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Geology and Stratigraphy of the Western Kentucky Coal Field

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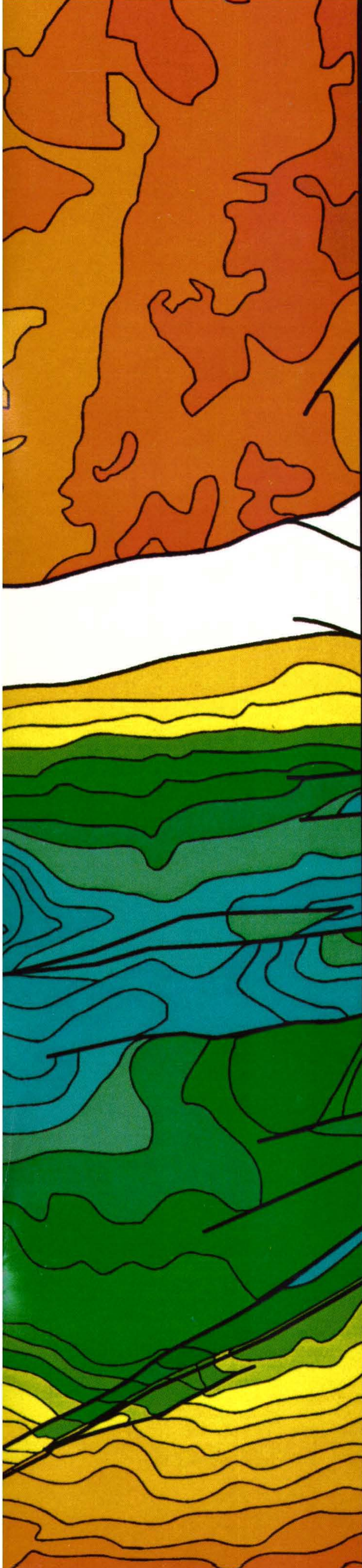
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A vertical geological cross-section on the left side of the cover. It shows various rock layers in shades of orange, yellow, green, and blue, with black lines representing geological structures like faults and folds. The top layer is orange, followed by a white layer, then yellow, green, and blue layers with complex folding. The bottom layer is orange with wavy lines.

GEOLOGY AND STRATIGRAPHY OF THE WESTERN KENTUCKY COAL FIELD

**Stephen F. Greb
David A. Williams
Allen D. Williamson**

**KENTUCKY GEOLOGICAL SURVEY
Donald C. Haney, State Geologist and Director
UNIVERSITY OF KENTUCKY, LEXINGTON**

**BULLETIN 2
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Front Cover Illustration

Color version of part of the structure map (Plate 1 of this report) on the base of the Springfield (W. Ky. No. 9) coal. Designed and prepared by R. C. Holladay and W. D. Harper.

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GEOLOGY AND STRATIGRAPHY OF THE WESTERN KENTUCKY COAL FIELD

**Stephen F. Greb, David A. Williams,
and Allen D. Williamson**

ABSTRACT

The Pennsylvanian rocks of the Western Kentucky Coal Field produce between 40 and 55 million tons of coal a year from as many as 45 coal seams; however, three seams produce more than 75 percent of the total. In addition, Pennsylvanian strata contain numerous oil and natural gas reservoirs, tar-sand reservoirs, and industrial minerals. Pennsylvanian sandstones are also some of the most important bedrock aquifers in the coal field. Because of the economic importance of the Pennsylvanian strata to the region and the Commonwealth as a whole, a better understanding of these rocks is needed. This description of the nomenclature of Pennsylvanian strata in the Western Kentucky Coal Field also provides information on their mineral resources and geology. New stratigraphic names, based on regional agreements among the state geological surveys of Kentucky, Illinois, and Indiana, are also presented.

INTRODUCTION

The Western Kentucky Coal Field is one of Kentucky's most important economic regions. This area is distinguished by its wealth of natural resources, particularly energy resources in the form of fossil fuels. An estimated 41 billion tons of bituminous coal was in the ground before mining began. During the decade of the 1980's, 429 million tons of coal were produced from the field. In 1990, 48 million tons were produced. This area has produced more than 2.2 billion tons of coal and millions of barrels of oil since coal mining and oil drilling began. Continued successful extraction and utilization of the resources in this area to a very large degree depend upon knowledge of the geology.

Purpose

This report summarizes the nomenclature and stratigraphy of the Pennsylvanian System in the Western Kentucky Coal Field. Two of the problems with the stratigraphy of this region have been the numerous coal seam miscorrelations, and the assignment of names from several different classification systems (e.g., Kentucky names, Illinois names, Indiana names, district names, etc.) to the same coal or rock layer. Specifically, the application of numeric names (e.g., No. 4 coal) has caused stratigraphic problems. These different nomenclature schemes have resulted from changes in methods geologists have used to interpret coal-bearing rocks and from correlations based on data that are too distant-

ly spaced. In this report the history of nomenclature for key beds in the coal field is summarized to clarify the stratigraphy of the Western Kentucky Coal Field, and, where pertinent, a discussion of the geology of key units is included.

During the preparation of this manuscript, the geological surveys of the states of Kentucky, Illinois, and Indiana formed a tri-state correlation committee to discuss the problems with stratigraphic correlation and nomenclature of the Pennsylvanian System of the Illinois Basin. One goal of this committee was the correlation of several key beds in the basin, and the adoption of common nomenclature for these key beds (Jacobson and others, 1985). Another goal was the adoption of a common formational nomenclature between the three states. Problems in correlating key beds and differences in the geology of the Pennsylvanian rocks between the three states have caused difficulties in developing a common stratigraphy. However, Illinois and Kentucky have agreed to a common nomenclature, and the effects of the new nomenclature as it pertains to Kentucky are discussed herein.

Coal-Mining Districts

The Western Kentucky Coal Field is divided into three coal-mining districts (Fig. 1). A discrete coal-bed nomenclature has evolved in each district. The Madisonville District is the largest district in area, and contains the bulk of the region's coal reserve, the thickest section

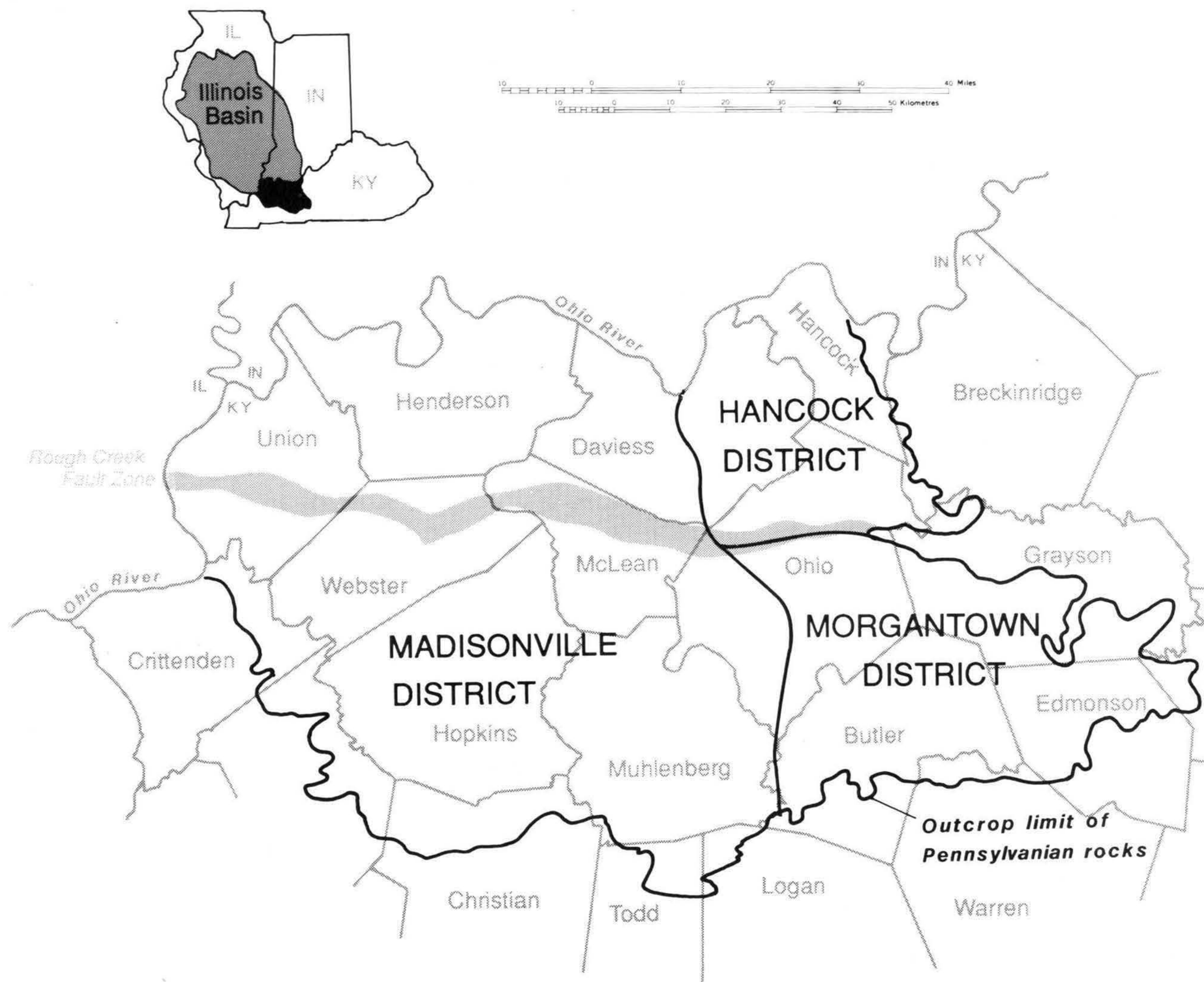


Figure 1. Mining districts of the Western Kentucky Coal Field and their location within the Illinois Basin.

of coal-bearing strata, and at one locality the only complete section of Pennsylvanian rocks in the Illinois Basin.

The boundary between the Madisonville District and the Morgantown and Hancock Districts is approximately the eastern cropline of the Davis coal bed (Fig. 1). The boundary between the Morgantown and Hancock Districts is the Rough Creek Fault System (Fig. 1). In both the Morgantown and Hancock Districts the upper part of the Pennsylvanian section, including the McLeansboro Group (previously called the Sturgis Formation) and the upper Carbondale Formation, is absent.

REGIONAL GEOLOGY

Post-Pennsylvanian Cover

The coal-bearing rocks of the Western Kentucky Coal Field are commonly covered by Quaternary sediments

and soil. In a single graben in Union County they may also be covered by Permian strata. In general, the topography of western Kentucky is subdued, and Pennsylvanian bedrock is covered with only a thin veneer of soil, but in secondary streams the Quaternary cover may be as much as 100 feet thick. Because most of the rocks in the region are covered, much of the information about Pennsylvanian strata must be derived from drilling records.

Lithology and Depositional Environments

The rocks of the western Kentucky coal-bearing sequence consist of conglomerates, medium- to fine-grained sandstones, siltstones, shales, coals, and limestones. Sandstones and siltstones make up between 50 and 80 percent of the coal-bearing sequence, while

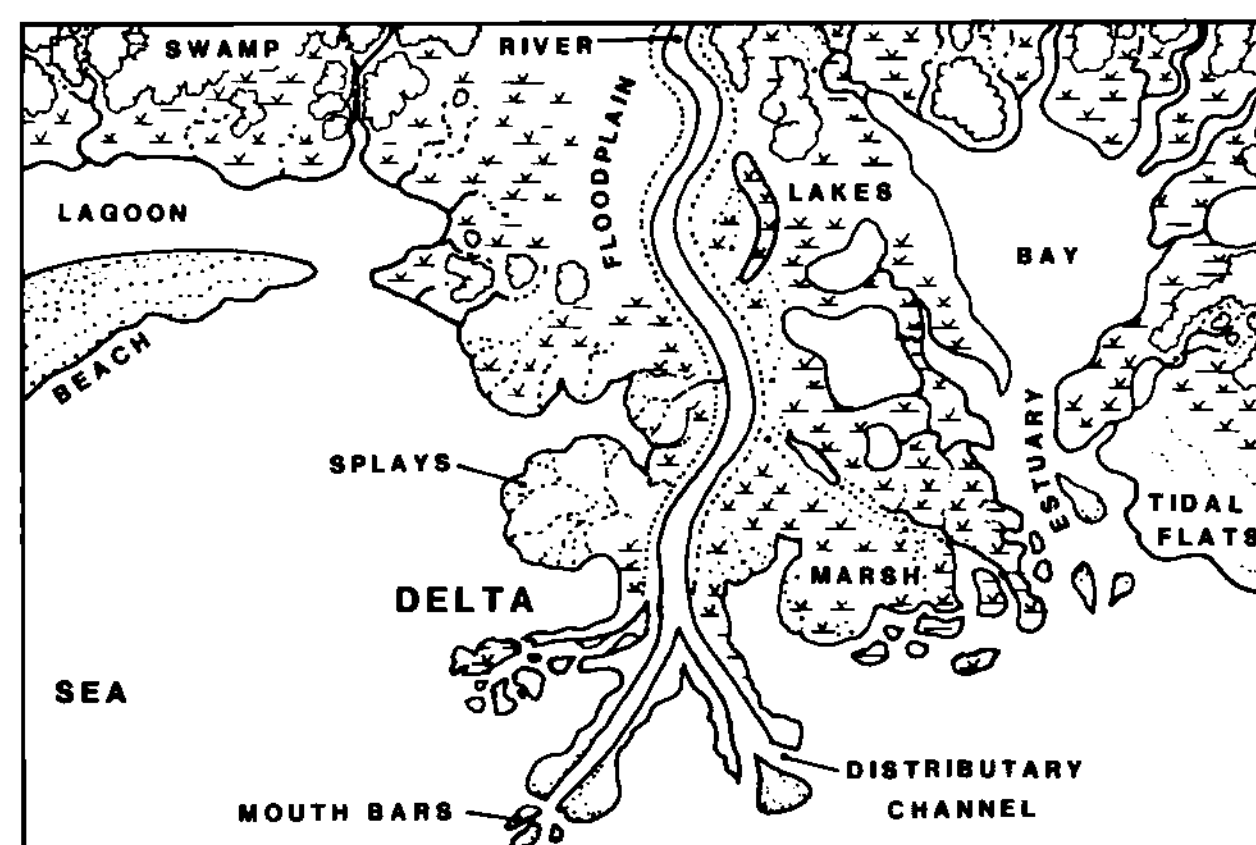
shales make up 20 to 40 percent. Limestones and coals account for 5 percent or less of the coal-bearing sequence, but are important for stratigraphic correlation (Cobb and others, 1985). Any attempt to correlate individual rock types or layers in a stratigraphic framework must consider the manner in which the rocks were originally deposited.

Pennsylvanian rocks in the Western Kentucky Coal Field were deposited at a time when Kentucky was close to the equator (Bambach and others, 1980), swamps covered large areas of the basin (White, 1931; Schopf, 1969; Wanless, 1975; Rice and others, 1979), and coastal/deltaic deposition was the main sedimentary process taking place. Coastal and deltaic areas are dynamic environments affected by fluvial energy, tidal energy, wave energy, rates of sediment supply, sea-level fluctuations, climate, rates of subsidence, and regional tectonic influences (Morgan, 1970; Wanless and others, 1970; Le Blanc, 1976; Miall, 1981; Coleman and Prior, 1982). The interplay of all these factors controls the manner in which sediments are transported and deposited.

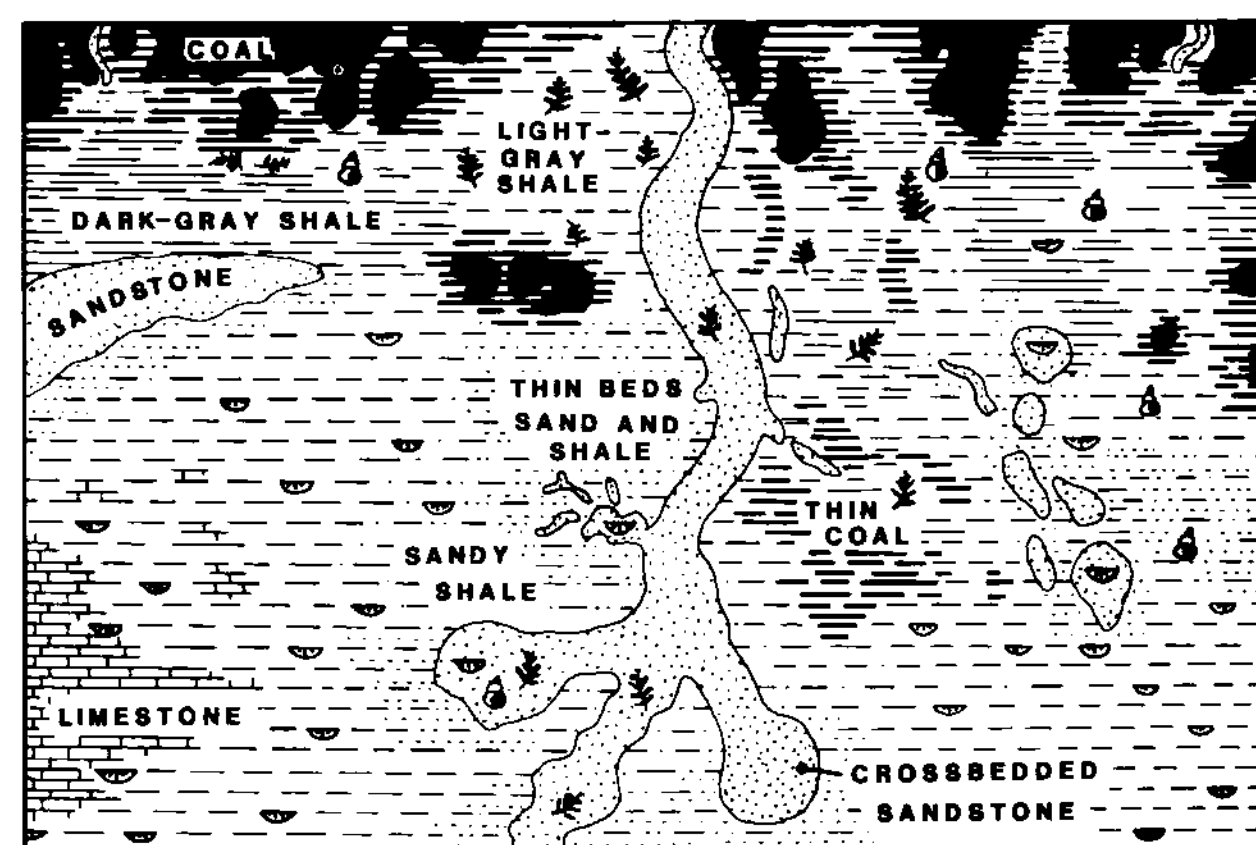
Common environments of deposition in coastal/deltaic settings include rivers, flood plains, splays, lakes, swamps, marshes, tidal channels, distributary channels, distributary mouth bars, lagoons, bays, beaches, and open-marine seaways (Fig. 2a). In general, coal is formed from peat accumulations in swamps and marshes (Fig. 2b); limestones are formed in marine bays, shallow open-marine seaways, and freshwater lakes (Fig. 2b); and detrital clastic rocks such as shale and sandstone are formed across most of the area (Fig. 2b), with sandstones being more common in the higher energy environments (i.e., river channels and distributary mouth bars) and shales being more common in lower energy environments (i.e., flood plains, lakes, and bays). Because these environments are dynamic and constantly shifting, the spatial distribution of rock types in the coal-bearing sequence of Pennsylvanian rocks in the Western Kentucky Coal Field is heterogeneous.

To correlate units, the spatial relationships of the environments from which the rocks were formed must be understood. For example, marine limestones are deposited in shallow seas and bays marginal to deltas (Fig. 2b). These environments are relatively stable and can extend for hundreds of miles. Hence, limestones are often a useful stratigraphic tool for correlating rock units over large areas. In contrast, sandstones deposited by ancient river channels may occur in narrow belts (Fig. 2b), which makes them less useful for regional stratigraphic correlations.

Correlation of a limestone bed across a region does not imply that the bed covered the entire region at a specific instant in time. As sea levels rise and fall, or as delta lobes are abandoned and subside, environments of deposition migrate laterally. Thus, as relative sea level rises, bay-fill shales are deposited over the marshes and swamps along the shores of the bay (Fig. 3). If the transgression continues, open-marine limestones may be deposited over the bay-fill shales that were previously deposited lateral to the marine limestones (Fig. 3). According to Walther's Law (1893-4), this lateral migration of depositional environments should be recorded in a vertical rock section as limestone over black shale over coal. The limestone may be preserved over a large area and correlated as the same bed, but it obviously was deposited over a wide span of time. This type of sequence is recorded many times in the Pennsylvanian rocks of the Western Kentucky Coal Field.



a.



b.

FOSSILS: PLANTS SNAILS SHELLS

Figure 2. Generalized diagrams of (a) environments of deposition that occur in coastal and deltaic areas, and (b) the types of rocks that can be deposited in each.

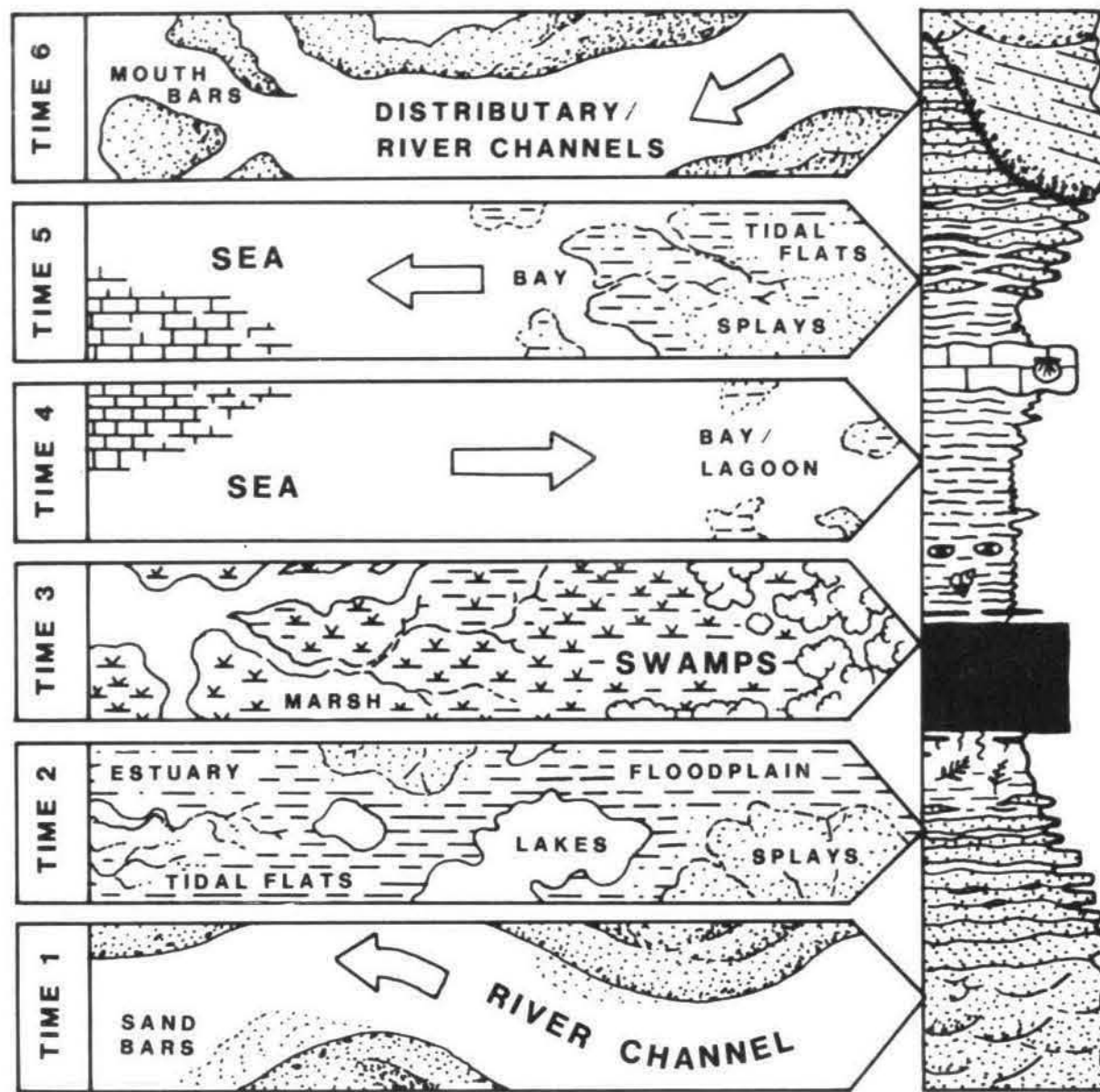


Figure 3. In a typical geologic section from the Western Kentucky Coal Field the relationships shown in Figure 2 can be illustrated as a series of time slices in which environments of deposition change with time.

Basin Tectonics

The Western Kentucky Coal Field is in the southern part of the Eastern Interior or Illinois Basin (Fig. 1). The basin developed through several phases of subsidence over a failed rift in the crust (an aulacogen) called the Reelfoot Rift that originated during the Precambrian or Cambrian (McGinnis, 1970; Ervin and McGinnis, 1975; Braile and others, 1986; Heidlauf and others, 1986; Trask and others, in press). Faulting in the coal field is largely related to zones of weakness along the margins of the buried rift (Fig. 4). The Rough Creek and Pennyrile Fault Systems are located along the approximate northern and southern margins, respectively, of an east-trending arm or branch of the Reelfoot Rift called the Rough Creek Graben (Soderberg and Keller, 1981; Hildenbrand and others, 1982). Major faults that have been mapped at the surface in the Western Kentucky Coal Field are shown in Figure 5. A cross section across the Western Kentucky Coal Field highlights the effects of these structures on the thickness and dip of Pennsylvanian rocks in the basin (Fig. 6). A structure map on the Springfield coal also illustrates the effects of the major structures on Pennsylvanian rocks (Plate 1). Subsidence and faulting related to these structures has controlled erosion and deposition within the coal field up to the present (Potter, 1978). Faulting causes significant offset of mineable coal seams throughout the coal field.

Moorman Syncline and Webster Syncline

The Moorman Syncline (Tradewater Trough, Webster Syncline, Central City Basin) approximately follows the basement trend of the Rough Creek Graben (Figs. 4–5). The syncline extends from the Ohio River in western Union County eastward across the Western Kentucky Coal Field to Grayson County, where it terminates against fault splinters of bounding faults and the flanks of the Cincinnati Arch (Fig. 5). The syncline is 125 miles long and 35 to 10 miles wide, and narrows and deepens to the west. It is asymmetrical, with a gently dipping southern limb and a steeply dipping northern limb. It is bordered on the north by the Rough Creek Fault System and on the south by the Pennyrile Fault System (Fig. 6). The deepest section, called the Webster Syncline by Mullins (1968), extends east-southeast through Union, Webster, and Hopkins Counties (Fig. 5, Plate 1). More than 2,000 feet of Pennsylvanian rocks have been preserved along the axis of the syncline, and 3,300 feet of Pennsylvanian rocks are preserved in one down-faulted block in Union County (Kehn and others, 1982).

The rocks on the southern flank of the Webster Syncline dip to the north at a rate in excess of 500 feet per mile in Union County and diminish to about 100 feet per mile in Hopkins County. Dip rates in excess of 1,000 feet per mile have been reported near Grove Center, Union County, on the northern flank of the syncline (Palmer, 1976).

Rough Creek Fault System

The Rough Creek Fault System enters Kentucky at Shawneetown on the Ohio River and extends east for about 100 miles into eastern Grayson County, where it dissipates into a series of bifurcating faults that arc to the southeast (Fig. 5). Strata within the fault system have been elevated as much as 3,300 feet in the eastern part of Union County, although vertical displacement across most of the fault system commonly is between 50 and 100 feet (Palmer, 1976; Smith and Palmer, 1981).

Tectonic activity occurred along the fault system during several geologic periods, resulting in a complex, greatly diversified fault zone, with normal, reverse, thrust, and strike-slip faulting occurring in different areas (Smith and Palmer, 1981; Stickney, 1988). The system has been described as (1) a low-angle thrust fault (Smith and Palmer, 1974), (2) a high-angle thrust fault (Weller, 1940; Rehn, 1968; Higgins, 1986), (3) a left-lateral shear fault (Clark and Royds, 1948; Heyl, 1972), and (4) a tensional fault with minor compressional features (Krause and others, 1979). The Rough Creek Fault System is characterized by high-angle, dip-slip faults with both reverse and normal offset (Nelson and Lumm, 1984).

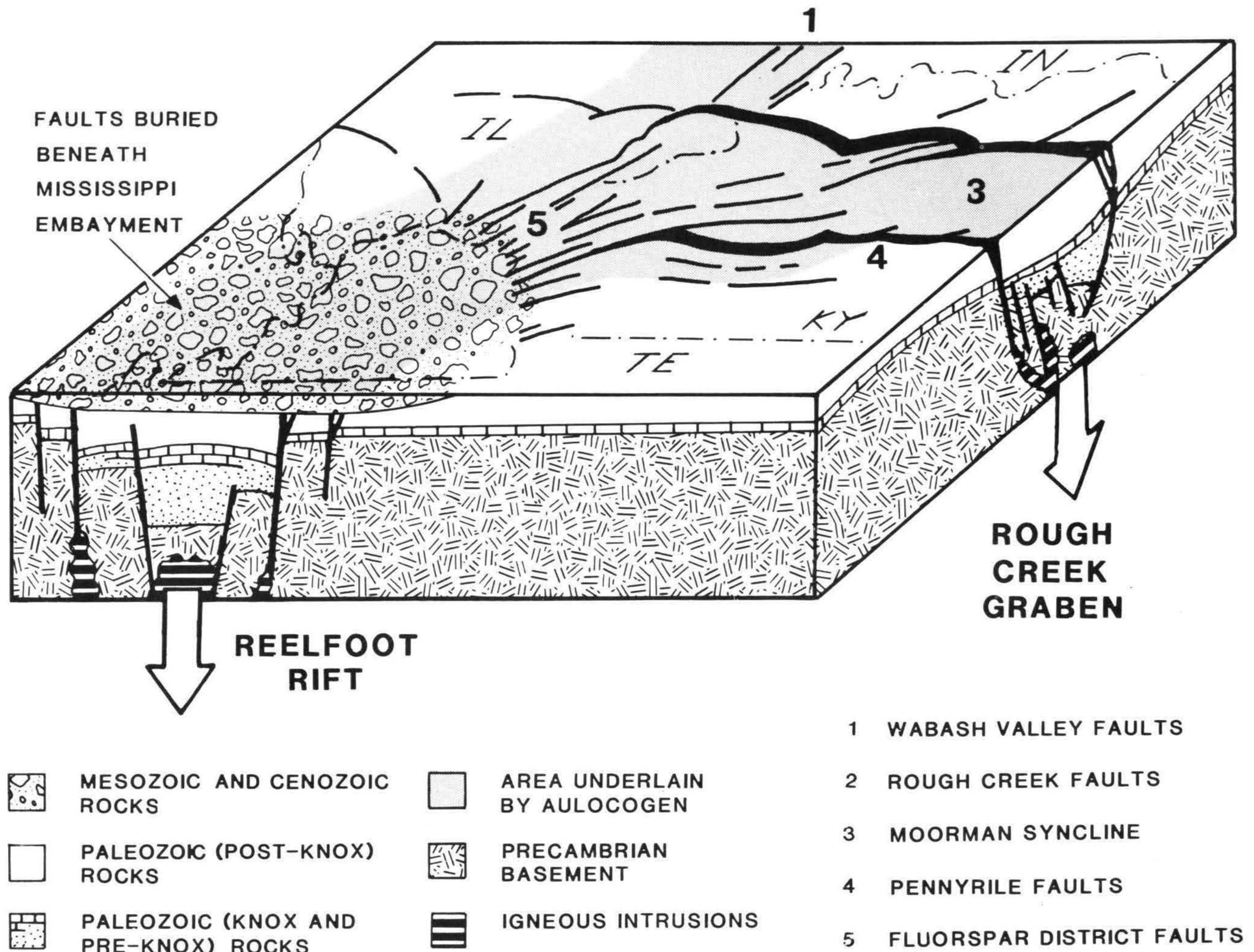


Figure 4. Block diagram of western Kentucky illustrating the relation between fault systems and basement rifts.

Most of the folding and faulting affecting Pennsylvanian rocks was post-Pennsylvanian and probably post-Paleozoic in age (McFarlan, 1943; Sutton, 1953; Nelson and Lumm, 1984), but there was also significant structural control of sub-Pennsylvanian paleovalleys (Greb, 1989b–c) and possibly some structural control of sedimentation in the Pennsylvanian strata (Mathis, 1983; Neuder, 1984; Rogers, 1985; Higgins, 1986; Greb, 1989a). Syn-depositional movement along structures during Pennsylvanian peat deposition could cause splitting, thickening, and thinning of coal seams. Post-depositional movement can cause offsets in coal-bed elevation, quality changes, and rank changes.

Central Faults

The Central Faults (Mullins, 1968) trend northeast from the Western Kentucky Fluorspar District in Caldwell County, across the syncline, and break up into a

complex series of fault slices against the Rough Creek Fault System in McLean County (Fig. 5). Although this belt is about 50 miles long, individual faults are seldom more than a few miles in length. Faults are high-angle normal faults with a maximum displacement of 600 feet. East of the Central Faults the Moorman Syncline broadens, shallows, and becomes more symmetrical than it is to the west (Plate 1).

Pennyrile Fault System

The Pennyrile Fault System approximately delineates the southern margin of the Moorman Syncline and the Western Kentucky Coal Field (Figs. 5–6). Faults trend predominantly east-northeast, with many bifurcating, and *en echelon* faults occur in arcuate bands generally less than 2 miles wide. Intersecting bands are gently convex toward the south. Faulting within bands is predominantly normal and down to the north, although

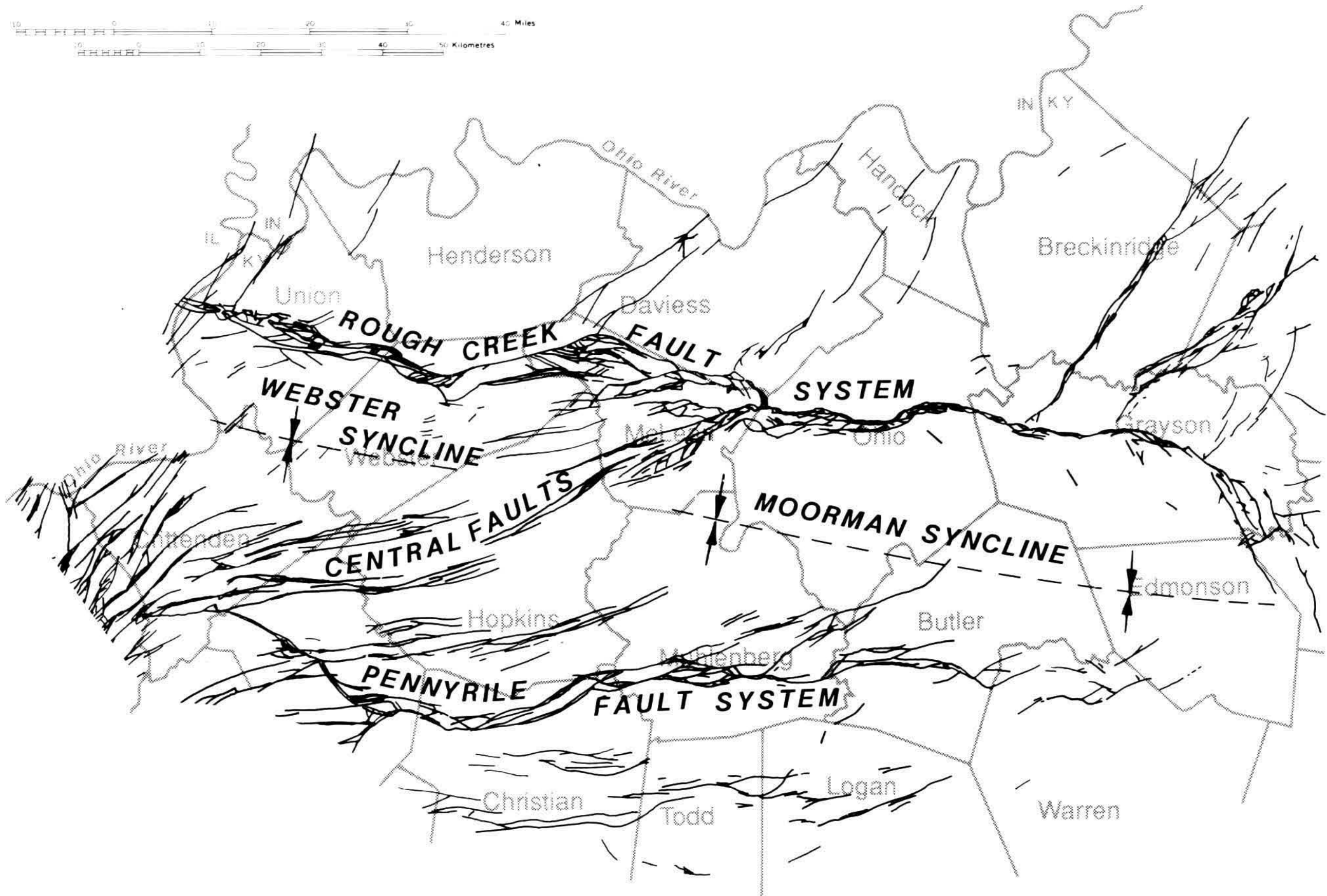


Figure 5. Structural features in the Western Kentucky Coal Field (modified from Cobb and others, 1985).

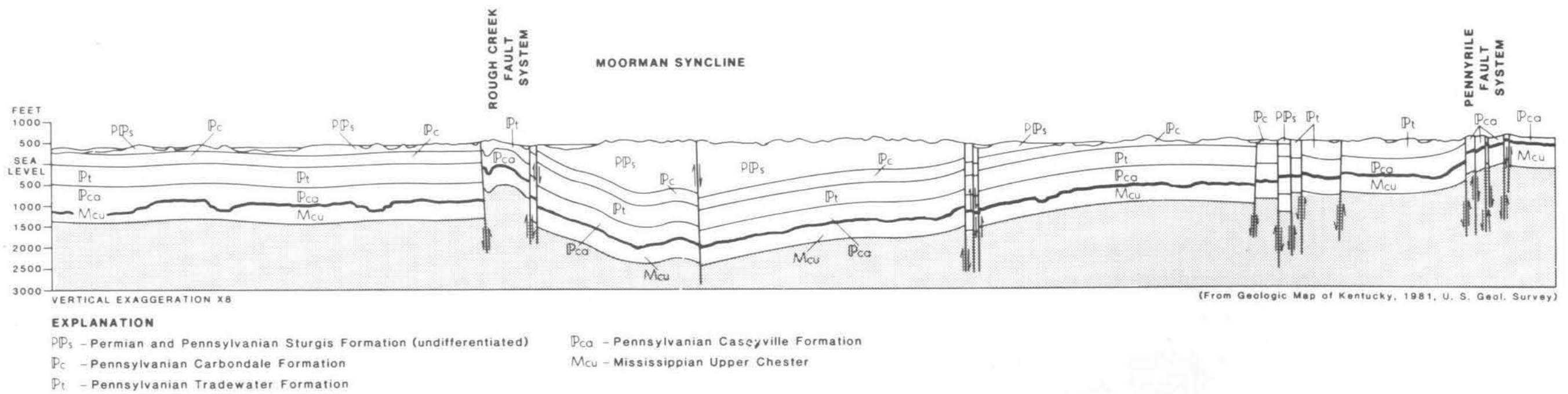


Figure 6. Cross section across the Western Kentucky Coal Field. The Sturgis Formation in this figure is equivalent to the newly defined McLeansboro Group (modified from Cobb and others, 1985).

small thrust faults may be present (Whaley and others, 1979; Lumm and others, 1991). In general, the fault system is narrowest and has the greatest displacement in its western part. Because of the downfaulting to the north, surface rocks south of the system are predominately of Mississippian age, and surface rocks north of the system are predominately of Pennsylvanian age.

Regional Trends in Coal Rank

The major structures of the Western Kentucky Coal Field have a direct influence on coal rank (Fig. 7) (Hower and others, 1982; Trinkle and others, 1983; Baynard and Hower, 1984; Hower and others, 1990). The average rank of coals in the Moorman Syncline is high-volatile C

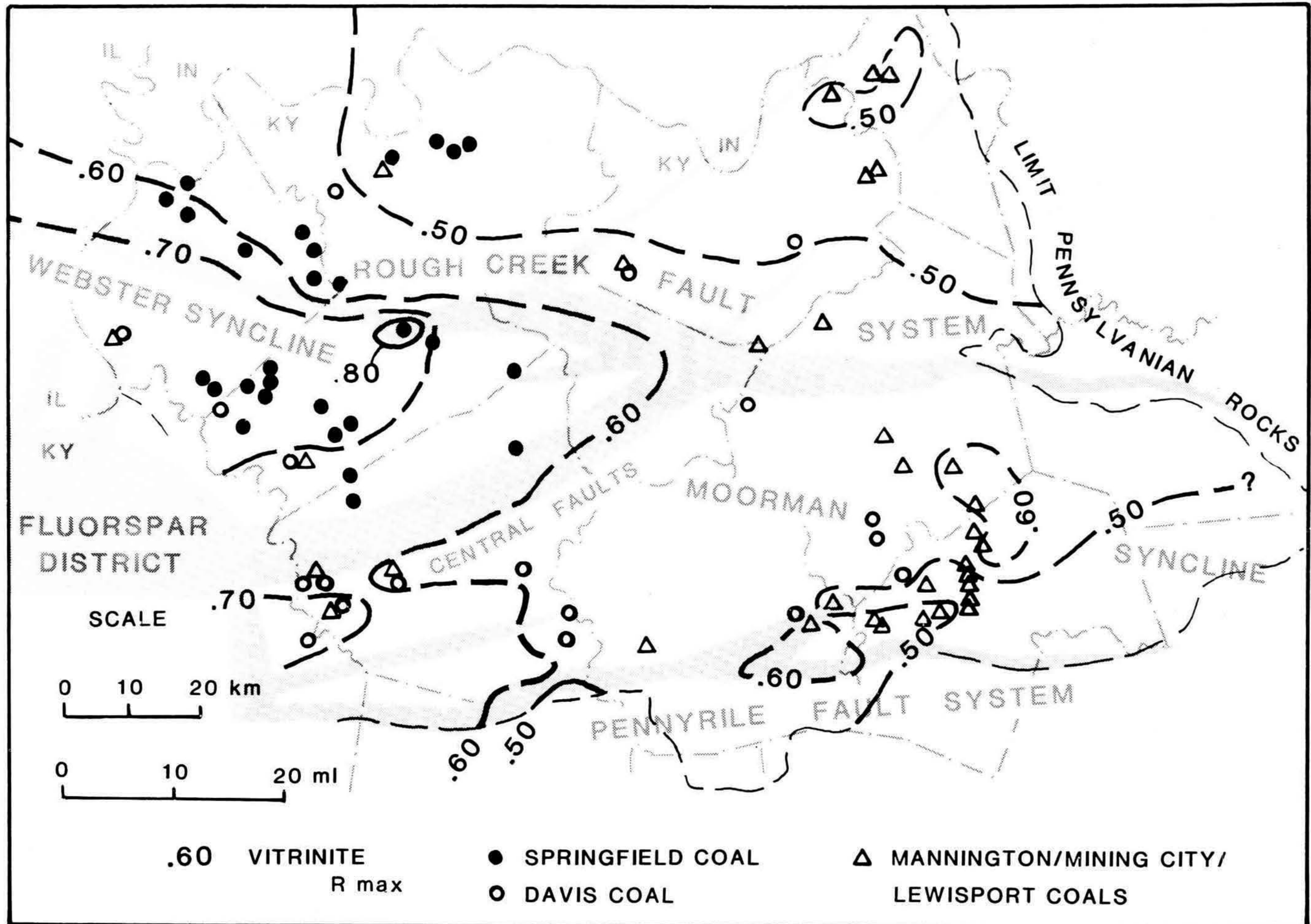


Figure 7. Isorank map of the Western Kentucky Coal Field showing the relation between structure and rank. (Data from Baynard and Hower, 1984; Hower and others, 1990.)

bituminous (0.47 to 0.59 percent R_{max}). However, coals in parts of the Pennyriple and Central Faults approach high-volatile B bituminous rank (0.60 to 0.62 percent R_{max}). West of the Central Faults, in the Webster Syncline (deepest part of the Western Kentucky Coal Field), rank is higher than in the Moorman Syncline: consistently high-volatile B bituminous (0.60 to 0.75 percent R_{max}). Within the Rough Creek Fault System on the northern border of the Webster Syncline, rank may increase to high-volatile A bituminous (0.75 to 0.85 percent R_{max}). High-volatile A bituminous coals in a graben of the Rough Creek Fault System near Cap Mauzy Lake in Union County are associated with sphalerite, chlorite, and twinned calcite (Hower and others, 1983), which indicate hydrothermal metamorphism of the coal within the fault zone. The Webster Syncline and western parts of the Rough Creek Fault System are adjacent to the Western Kentucky Fluorspar District. The fluorspar district is a known area of extensive hydrothermal metamorphism and may be responsible for higher rank in ad-

acent coal basins (Damberger, 1971, 1974; Hower and others, 1990). Hydrothermal metamorphism may also be responsible for the lack of a well-defined reflectance gradient in parts of the coal field. In several vitrinite-reflectance studies of cores in which several coals were measured, higher reflectance values were found in younger coals rather than older coals (Hower and others, 1990).

High-Sulfur Coals

The coal of the Western Kentucky Coal Field is characterized as high-sulfur coal. Although coal with medium to even low sulfur contents occurs in the coal field, the majority of the coal produced is high in sulfur content (Fig. 8). The average sulfur contents for the seven coal beds with the largest resources are all more than 3 percent (Cobb and others, 1982, 1985; Currens, 1986). Mined beds such as the Amos coal have a sulfur content of less than 1 percent, but they are the exception. Production of coal from this field in the decade from 1980 to

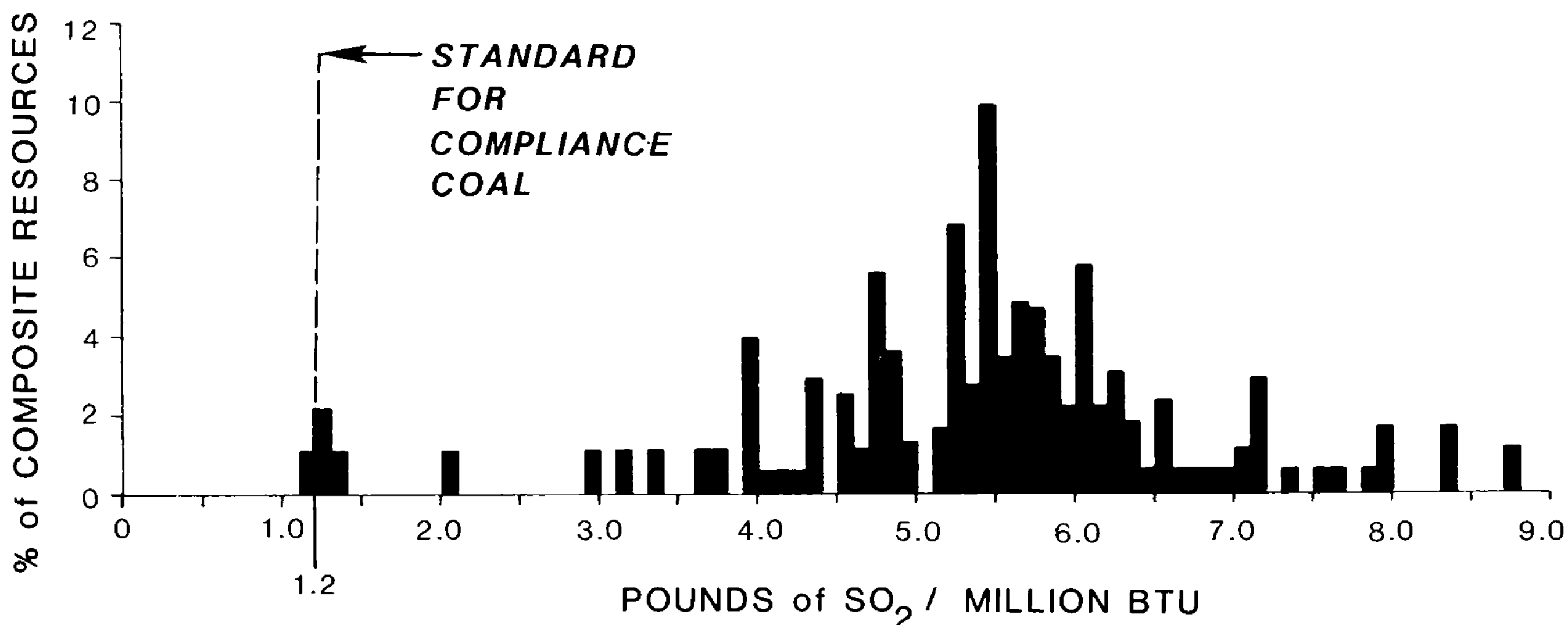


Figure 8. Distribution of major western Kentucky coal resources by potential sulfur dioxide emissions (from Cobb and others, 1982, Fig. 6, p. 16).

1990 averaged 42 million tons of high-sulfur coal per year.

The Clean Air Act Amendments of 1990 mandate the reduction of sulfur dioxide emissions into the atmosphere, mainly from coal-burning power plants, by 10 million tons per year by the year 2000. The Western Kentucky Coal Field as well as the contiguous coal fields in Illinois and Indiana are principal targets of this new law because of the huge amounts of high-sulfur coal they produce for power plants. The law will be implemented in two phases. Phase I requires specific power plants, targeted by law, to reduce their emissions by 1995 to a level equal to the emissions that would be produced by meeting a 2.5 pounds of SO₂ (sulfur dioxide) per million Btu emissions rate while burning the average annual fuel consumed in the baseline years of 1985, 1986, and 1987. In Phase II, nearly all United States power plants must reduce their emissions to a rate of 1.2 pounds of SO₂ per million Btu based on their baseline fuel consumption (Cobb and Eble, 1992).

Virtually none of the coal beds of the Western Kentucky Coal Field can meet the new emission rates (Fig. 8). Predictions have been made that coal production from this field might decline in the near future as some power plants switch to low-sulfur coal. However, in the longer term, as power plants are equipped with sulfur-removing devices such as scrubbers, the demand for high-sulfur coal will again increase. The impact of clean-air legislation on production from this coal field will not be known until power plants decide on their strategies for compliance with SO₂ emission requirements. In the meantime, it is certain that a better understanding of

western Kentucky coal-bearing rocks is needed so that informed decisions can be made concerning the future development of energy resources in the region.

Coal Production

More than 35 coal beds have been named in western Kentucky. Most have been mined at some time. In the 1980's, 40 or more coal beds were mined in the coal field, and average annual production was around 50 million tons of coal. In Figure 9 the stratigraphic variation in coal-bed production is apparent. The Tradewater Formation may contain more than 20 mined coal beds, but because most Tradewater coals are patchy and discontinuous, they account for less than 10 percent of the total annual production. Although Tradewater coals do not account for a large percentage of the total production from the region, some are low sulfur and have better coal quality than overlying coals. The production of these low-sulfur coals may increase in the future.

The Carbondale Formation accounts for more than 80 percent of the coal field's total annual production, with nearly 60 percent from the Springfield (W. Ky. No. 9) coal alone. Carbondale coals are often regionally extensive; several coal beds are mined in Kentucky, Illinois, and Indiana. The Shelburn Formation (previously the lower part of the Sturgis Formation) also contains several regionally extensive coals, which account for around 10 percent of the coal field's annual production. Accurate production figures for the Shelburn Formation are difficult to determine because many multi-seam surface operations report the combined tonnage of the Baker (No. 13) and Paradise (No. 12) coals of the Shelburn Forma-

tion, with the Herrin (No. 11) coal of the Carbondale Formation.

Between 90 and 100 coal mines are active in the Western Kentucky Coal Field each year. Seventy-five percent of the mines are surface operations. The largest surface mines may produce more than 2.6 million tons of

coal annually. However, underground mining is increasing in importance because surface reserves are being depleted. Several underground mines in Union and Webster Counties produce more than 2 million tons of coal from the Springfield (W. Ky. No. 9) coal per year. A better understanding of coal-bed stratigraphy and deep coal resources of the coal field is needed because of the increasing importance of underground production.

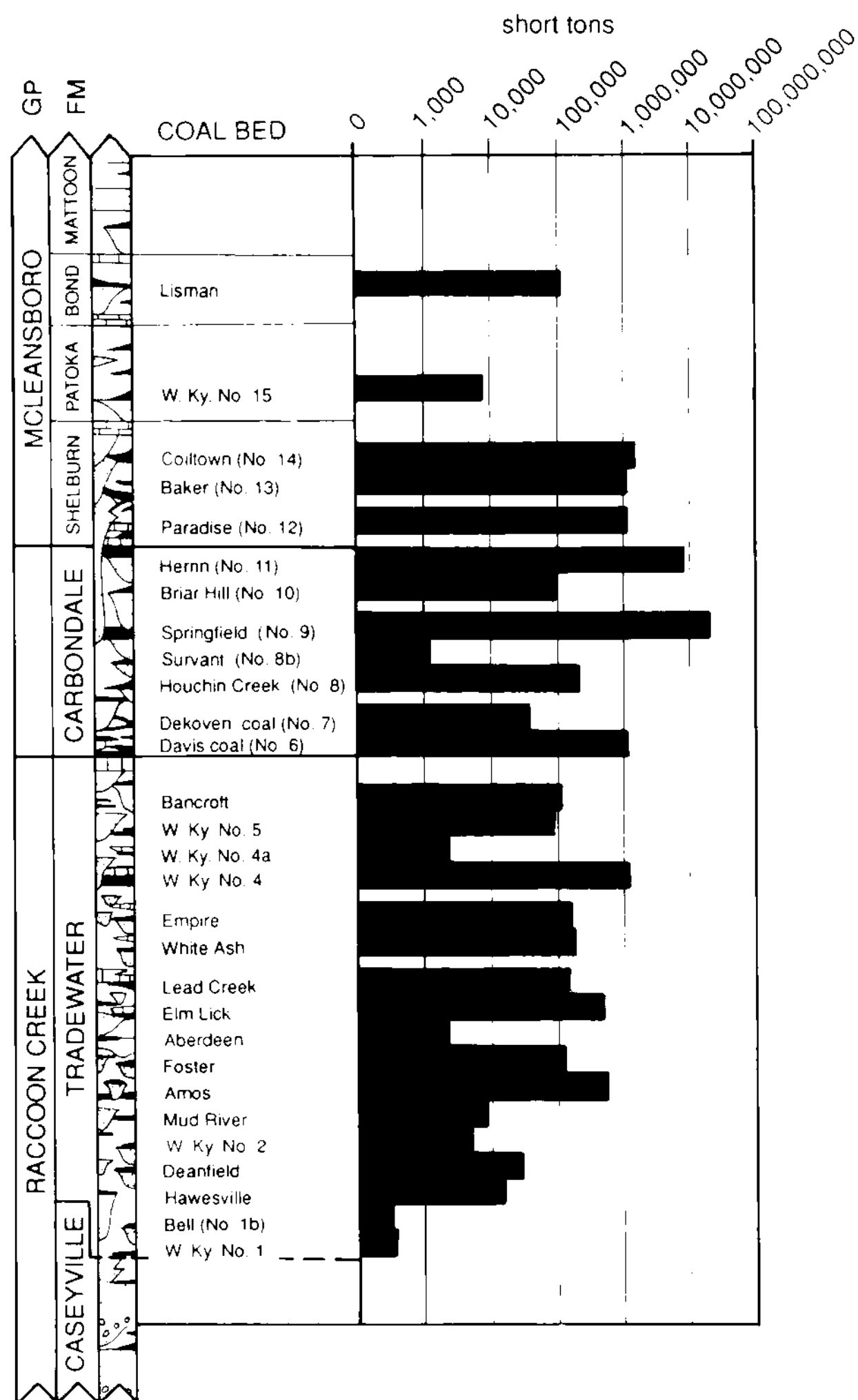


Figure 9. Average annual coal production in the Western Kentucky Coal Field for the years 1980 to 1990 by bed. Note that the horizontal scale is divided into increasingly larger tonnages in order to illustrate the smallest and largest values. Note also that the Amos includes all production reported as Amos and Jetson; the Lead Creek includes Lead Creek, Dunbar, and Cates; the Empire includes Empire, Empire 4, and Empire 6; the W. Ky. No. 4 includes No. 4, Mannington, Mining City, and Lewisport; and the Bancroft includes Bancroft and Bancroft No. 5. Also, because the No. 11 and No. 12 coals are often mined together, their tonnages may be different than those shown (data from Kentucky Department of Mines and Minerals).

PENNSYLVANIAN STRATIGRAPHY

Previous Work

The earliest report on the stratigraphy and geology of western Kentucky was included in William W. Mather's (1839) "Report on the Geological Reconnaissance of Kentucky." In this report, Mather mentioned several surface mines and local openings throughout the Ohio and Green River regions. Mather was one of the first to realize the importance of coal to the State's economy:

The economy of coal over wood, as wood is rapidly decreasing in quantity, and rising in value, must necessarily cause its substitution as a means of motive power for transport within a few years (p. 258).

He estimated that coal production in the Western Kentucky Coal Field would yield an annual income of \$1,200,000 if steamboats utilized the State's coal resource. He also realized that to maintain the economy of the region for the future, changes would have to be made in mining methods:

Mines and beds of minerals are of public utility, and when exhausted they cannot be renewed; hence it becomes a matter of moment, not only to the proprietor, but to the people, the State, and the Nation, that they should be wrought in such a manner as shall produce the greatest quantity and best quality of the materials, with the least waste and expenditure of labor, time and money (p. 258).

The First Report of the Geological Survey by David Dale Owen (1856) provided a more detailed reconnaissance of the coal field. In this and subsequent reports Owen (1856, 1857a–b, 1861) established the first regional stratigraphic framework for the Pennsylvanian System. Subsequent reports by Moore (1877a–b, 1878a–b) dealt with specific areas of the coal field.

Numerous reports on the geology, occurrence, and quality of coal beds in parts of the Western Kentucky Coal Field were published by the Kentucky Geological Survey between 1870 and 1930, including stratigraphic studies of several 15-minute quadrangles and counties (Crider, 1913, 1914a–b, 1915a–d; Gardner, 1912; Glenn, 1912a–b, 1922, 1923; Hutchinson, 1910, 1912; Lee, 1916). Parts of the previously mentioned studies were summarized in Miller's (1919) report on the geology of Kentucky.

Between 1935 and 1975 a number of significant contributions to the Pennsylvanian geology of the Illinois Basin (including western Kentucky) were made by H. R. Wanless and his colleagues. Among these contributions were the first regional description of key beds in the Illinois (Eastern Interior) Basin, correlations of key beds between different states, correlation of key beds between the Eastern Interior and Appalachian Basins, description of cyclic sedimentation patterns, and interpretations of the driving forces behind Pennsylvanian cyclic sedimentation (Wanless, 1931, 1939, 1947; Wanless and Weller, 1932; Wanless and Shepard, 1936). In subsequent reports, Wanless refined his interpretations of cyclic sedimentation and the climatic, tectonic, and eustatic implications of Pennsylvanian cyclothems in the Illinois Basin (Wanless, 1955, 1962, 1975; Wanless and others, 1963, 1970).

In 1943, A. C. McFarlan published "The Geology of Kentucky," which included a comparison of the different classification systems used for the Pennsylvanian System in the Western Kentucky Coal Field, lithologic descriptions of formations and significant intraformational units, cross sections and correlations of Pennsylvanian units, discussions of the regional geology and structure in western Kentucky, and specific descriptions and analyses of commercial coals in the region.

Between 1950 and 1965 a series of studies on oil pools was published by the Kentucky Geological Survey. Although most of these reports focused on oil production from Mississippian rocks, brief discussions of the Pennsylvanian System were also presented, as were descriptions of Pennsylvanian marker horizons on subsurface electric logs (Jacobsen, 1950; Walker and others, 1951; Bowen, 1952; Wood, 1955; Bauer, 1957; Rose, 1963). During this period, specific studies of coal resources were made by Mullins and others (1965).

Some of the most significant contributions to the understanding of the Pennsylvanian System in the Western Kentucky Coal Field were made between 1963 and 1978 during the U.S. Geological Survey-Kentucky Geological Survey Cooperative Mapping Program (Cressman and Noger, 1981). The project made Kentucky the only major state completely mapped geologically at the scale of 1:24,000; 707 7.5-minute-quadrangle maps were published. The Western Kentucky Coal Field is covered by 94 of these maps. Each map covers an area of approximately 60 square miles and contains a geologic map, a representative stratigraphic column with descriptions of the geologic units, and in many cases notes on the history of economic mineral development in the area.

Other significant contributions to the understanding of the Pennsylvanian System in the Western Kentucky Coal Field are discussed in this report as they relate to specific subjects.

History of Formation Nomenclature

The earliest classification of the Pennsylvanian System in western Kentucky by Owen (1856) subdivided the Pennsylvanian in ascending order into the Caseyville Conglomerate, the Lower Coal Measures, the Anvil Rock Sandstone, and the Upper Coal Measures (Fig. 10). Glenn (1912b) partitioned the section into the Caseyville, Tradewater, Dekoven, Mulford, Lisman, and Dixon Formations (Fig. 10). Except for the Dekoven and Mulford boundary, Glenn followed the stratigraphic practice of the time of placing formation boundaries at the top or base of prominent sandstone units thought to be regionally extensive. Subsequent work determined that many of these sandstone units are discontinuous and thus undesirable as formation boundaries. The use of the Caseyville and Tradewater Formations on the post-1960 geologic quadrangle maps of Kentucky (Cressman and Noger, 1981) and the state geologic map (McDowell and others, 1981) essentially follows Glenn's (1912b) definitions.

Lee (1916) modified Glenn's (1912b) classification by: (1) substituting the term "McLeansboro" for "Lisman," (2) substituting the term "Henshaw" for "Dixon," (3) combining the Dekoven and Mulford Formations into the Carbondale Formation, (4) moving the upper boundary of the Tradewater Formation from the base of the Sebree Sandstone down to the base of the Davis coal, and (5) moving the boundary between the Carbondale Formation (formerly Dekoven-Mulford) and McLeansboro Formation (formerly Lisman) down from the base of the Anvil Rock Sandstone to the top of the Herrin coal bed (Fig. 10). Glenn (1922) accepted the combination of the Dekoven and Mulford into the Carbondale, but rejected the terms "McLeansboro" and "Henshaw" for the earlier nomenclature of Lisman and Dixon. In doing so, he moved the boundaries back to the scour bases of the Sebree and Anvil Rock Sandstones, rather than the tops of regionally persistent coals.

Kehn (1964b) replaced the term "Dixon Formation" with the term "Henshaw Formation" (Fig. 10) because Dixon was already in use for a formation in Tennessee (Wilmarth, 1937). The Lisman and Henshaw Formations were subsequently merged into the Sturgis Formation because of difficulties in identifying the contact between the two formations (Kehn, 1973). The Sturgis Formation as defined by Kehn (1973) was used during the latter part of the U.S. Geological Survey-Kentucky Geo-

	Owen (1856)	Glenn (1912b)	Lee (1916)	Glenn (1922, 1923)	USGS/KGS Geologic Mapping Project		Ky.-Ill. Agreement (1991)			
					Kehn (1964b)	Kehn (1974a)				
Upper Coal Measures	Carthage Limestone	DIXON FM. Dixon Ss.	HENSHAW FM.	DIXON FM. Dixon Ss.	HENSHAW FM.	STURGIS FM.	MATTOON FM.	McCLEANSBORO GROUP		
			Geiger Lake coal	Geiger Lake coal	Geiger Lake coal		Livingston Ls.			
	LISMAN FM.	McCLEANSBORO FORMATION	LISMAN FM.	LISMAN FM.	LISMAN FM.		PATOKA FM.			
							West Franklin Ls.			
Anvil Rock Ss.	Anvil Rock Ss.	Anvil Rock Ss.	Anvil Rock Ss.	Anvil Rock Ss.	SHELBURN FM.	Providence Ls.				
Lower Coal Measures	No. 11 coal	MULFORD FM. No. 9 coal	No. 11 (Herrin) coal	CARBONDALE FORMATION	No. 11 (Herrin) coal	No. 11 (Herrin) coal	Herrin Coal	RACCOON CREEK GROUP		
	No. 9 coal		CARBONDALE FORMATION		CARBONDALE FORMATION	CARBONDALE FORMATION	CARBONDALE FORMATION			
	No. 5 coal	DEKOVEN FM. Sebree Ss.	(Davis) coal	Sebree Ss.	No. 6 (Davis) coal	No. 6 (Davis) coal	Davis coal			
		Tradewater section	TRADEWATER FORMATION	TRADEWATER FORMATION	TRADEWATER FORMATION	TRADEWATER FORMATION	TRADEWATER FORMATION			
	No. 1b coal						No. 1b (Bell) coal		No. 1b (Bell) coal	Bell coal
	No. 1a coal						No. 1a coal		No. 1a coal	Pounds Ss. equivalent
	Caseyville Conglomerate	top conglomerate Caseyville Conglomerate	top conglomerate Caseyville Sandstone	CASEYVILLE FORMATION	CASEYVILLE FORMATION	CASEYVILLE FORMATION	CASEYVILLE FORMATION			

Figure 10. The history of stratigraphic nomenclature for the Pennsylvanian rocks of the Western Kentucky Coal Field.

logical Survey Cooperative Mapping Program (Kehn, 1975a–b) and on the state geologic map (McDowell and others, 1981).

During the U.S. Geological Survey-Kentucky Geological Survey Cooperative Mapping Program, the boundaries of the Carbondale Formation were changed back to the definition of Lee (1916) (Fig. 10) so that the boundaries would be regionally persistent, relatively flat-lying coals rather than sandstones of variable thickness and extent (Palmer, 1966; Kehn, 1966a–b).

In 1990, the Kentucky and Illinois Geological Surveys reached a tentative agreement on a common Pennsylvanian nomenclature (Fig. 10). In summary, the changes to the Pennsylvanian nomenclature in Kentucky are: (1) adding the Caseyville and Tradewater Formation to the Raccoon Creek Group of Indiana (Wier, 1961), (2) adopting the McLeansboro Group (Kosanke and others, 1960) of Illinois and Indiana (Willman and others, 1975; Shaver and others, 1986) in favor of the Sturgis Formation of Kehn (1973), and (3) adopting various McLeansboro formations, including the Shelburn of Indiana (Cummings, 1922), the Patoka of Indiana (Wier, 1961), the Bond of Illinois (Kosanke and others, 1960), and the Mattoon of Illinois (Kosanke and others, 1960). Modifications to the Kentucky nomenclature are discussed in the sections to which they pertain.

RACCOON CREEK GROUP

The Lower Pennsylvanian section of the Illinois Basin is quite variable. It is understandable that the variable geology led to varied stratigraphic nomenclature in Illinois, Indiana, and Kentucky (Willman and others, 1975; Rice and others, 1979; Williams and others, 1982; Shaver and others, 1986). In order to promote cooperative basin-wide studies, the Kentucky and Illinois geological surveys adopted the term “Raccoon Creek Group,” presently used in Indiana, for the Pennsylvanian section beneath the Carbondale Formation (Fig. 11). The Raccoon Creek Group of Indiana (Wier, 1961) will be amended in Kentucky and Illinois to include the Caseyville and Tradewater Formations in Kentucky. The boundaries of the Caseyville and Tradewater will remain essentially the same in Kentucky. Adopting this term in Kentucky will be of benefit in those areas of the coal field in which the Caseyville and Tradewater cannot be differentiated.

CASEYVILLE FORMATION

Nomenclature History

The Caseyville Formation was named by Owen (1856) for a section of coarse-grained clastic rocks oc-

curing between the “coal measures” and the “sub-Carboniferous” limestone beds, near the town of Caseyville on the Ohio River in Union County, Kentucky. Although Owen did not use the term in a formational sense, he reported several widely separate Caseyville localities and apparently considered the unit to be extensive across the coal field.

Glenn (1912b) and Lee (1916) placed the upper limit of the formation at the top of the conglomeratic sandstone lying beneath the 1-a coal (Fig. 10). Later, the upper boundary was placed at the base of the Bell (1-b) coal, where present (Kehn, 1974a). Where the Caseyville Formation thins, or the coal is absent along the eastern margin of the basin, the Caseyville is largely indistinguishable from the overlying Tradewater Formation, and the two are commonly mapped together (Fig. 12).

The state geological surveys of Kentucky and Illinois defined the top of the Caseyville as the top of the Pounds Sandstone, after current usage in Illinois (Kosanke and others, 1960; Willman and others, 1975), or Bell (W. Ky. No. 1b) coal and equivalents where the Pounds is not identified (Fig. 11). Hence, the boundary will change little in Kentucky.

Formation Boundaries

The base of the Caseyville Formation in Kentucky is defined at the Mississippian-Pennsylvanian systemic boundary along the sub-Pennsylvanian unconformity (Fig. 13). The boundary may easily be distinguished both in the subsurface and at the surface where a conglomeratic Caseyville sandstone overlies a Mississippian limestone. However, where a Caseyville sandstone overlies a Mississippian sandstone or at Caseyville shale/Mississippian shale contacts (both common on the paleo-upland surface) the boundary may be more difficult to delineate (Bristol and Howard, 1971, 1974). In general, the boundary is defined at the uppermost recognizable Chesterian horizon. Chesterian carbonates have distinctive subsurface electric-log signatures and have been mapped across the basin. Where section is missing, the unconformity is inferred (Fig. 14a–c).

Although the unconformity is well established across most of the basin, investigations in the deepest part of the basin (southeastern Illinois) indicate that rocks generally considered to be Pennsylvanian in age contain conodonts that suggest the systemic boundary in the deepest part of the basin in Illinois may be conformable (Rexroad and Merrill, 1979, 1985). The unconformity is well established in Kentucky, but more work may be needed in the deeper parts of the Webster Syncline to determine if any continuous section exists.

INDIANA (Shaver and others, 1986; Jacobson and others, 1985)		ILLINOIS (Kosanke and others, 1960; Jacobson and others, 1985)		KENTUCKY (Williams and others, 1982; Jacobson and others, 1985)	KENTUCKY-ILLINOIS AGREEMENT			
Group	Formation	Group	Formation	Formation	Group	Formation		
McLEANSBORO	MATTOON <i>Millersville Ls.</i>	McLEANSBORO	MATTOON <i>Millersville Ls.</i>	STURGIS	McLEANSBORO	MATTOON		
	BOND <i>Shoal Creek/ Carthage Ls.</i>		BOND <i>Shoal Creek/ Carthage Ls.</i>			<i>Livingston Ls.</i>	BOND <i>Carthage Ls.</i>	
	PATOKA		MODESTO <i>Danville No. 7 Coal</i>			PATOKA		
	<i>W. Franklin Ls.</i> SHELburn <i>Danville (No. VII) Coal</i>					<i>W. Franklin Ls.</i> SHELburn <i>Providence Ls.</i>		
CARBONDALE	DUGGER <i>Springfield (No. V) Coal</i>	KEWANEE	CARBONDALE	<i>Herrin (No. 11) coal</i>	CARBONDALE	CARBONDALE		
	PETERSBURG <i>Survant (No. IV) Coal</i>			Colchester (No. 2) <i>Coal</i>			<i>Davis (No. 6) coal</i>	<i>Davis coal</i>
	LINTON			SPOON			TRADEWATER	TRADEWATER
<i>Seelyville (No. III) Coal</i> STAUNTON	Murray Bluff/ Bernadette Ss. ABBOTT <i>Bell (No. 1b) coal</i>	RACCOON CREEK	TRADEWATER					
<i>Minshall Coal</i> BRAZIL <i>Lower Block Coal</i>	McCORMICK			CASEYVILLE	CASEYVILLE			
MANSFIELD		Pounds Ss.	Bell coal <i>Pounds Ss.</i>			CASEYVILLE		

Figure 11. Pennsylvanian nomenclature for the Illinois Basin and revised stratigraphic nomenclature for Kentucky following agreements between Kentucky and Illinois Geological Surveys for the purpose of unifying the Pennsylvanian stratigraphy in the Illinois (Eastern Interior) Basin. Key beds italicized.

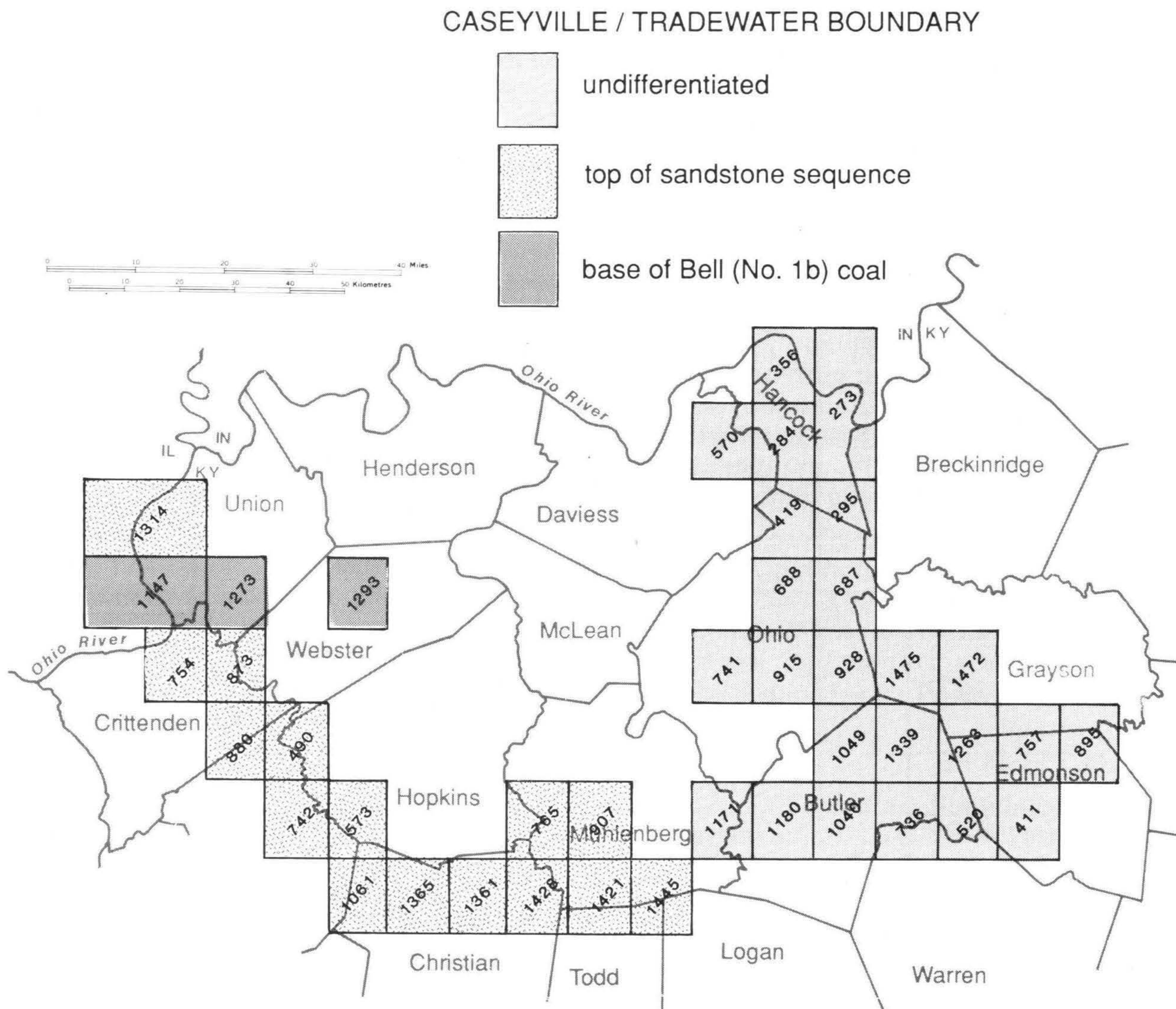


Figure 12. Manner in which the Caseyville/Tradewater boundary was mapped on geologic quadrangle maps (numbered) along the edge of the basin.

The upper boundary of the Caseyville Formation is placed at the base of the Bell coal in the western part of the coal field (Union County) and at the base of the Hawesville coal in the northeastern part of the coal field. But in the wide area between the limits of these two coals, the upper boundary is arbitrarily placed at the top of the uppermost, massive, quartzose, pebbly sandstone. This boundary may be difficult to discern in the subsurface across the southwestern and eastern margins of the coal field. In these areas the Hawesville and Bell coals are absent, and a thick, upper Caseyville sandstone is not developed (Fig. 14b). More subsurface work is needed in Kentucky to determine the equivalence of sandstone bodies near the top of the Caseyville and the base of the Tradewater.

Prior to the Tri-State Correlation Committee findings, the Caseyville of Illinois was part of the McCormick Group (Kosanke and others, 1960). In Indiana, the Caseyville terminology was not adopted and the Caseyville remains equivalent to the lower half of the Mansfield Formation (Fig. 11) (Kottowski, 1959; Shaver and others, 1986).

Thickness and Extent

The Caseyville Formation was deposited on an irregular surface of considerable relief, and its thickness is therefore highly variable (Figs. 13, 15). In major paleovalleys the thickness exceeds 300 feet. As much as an additional 300 feet of Caseyville was deposited above the paleovalleys on the paleo-upland surface in the

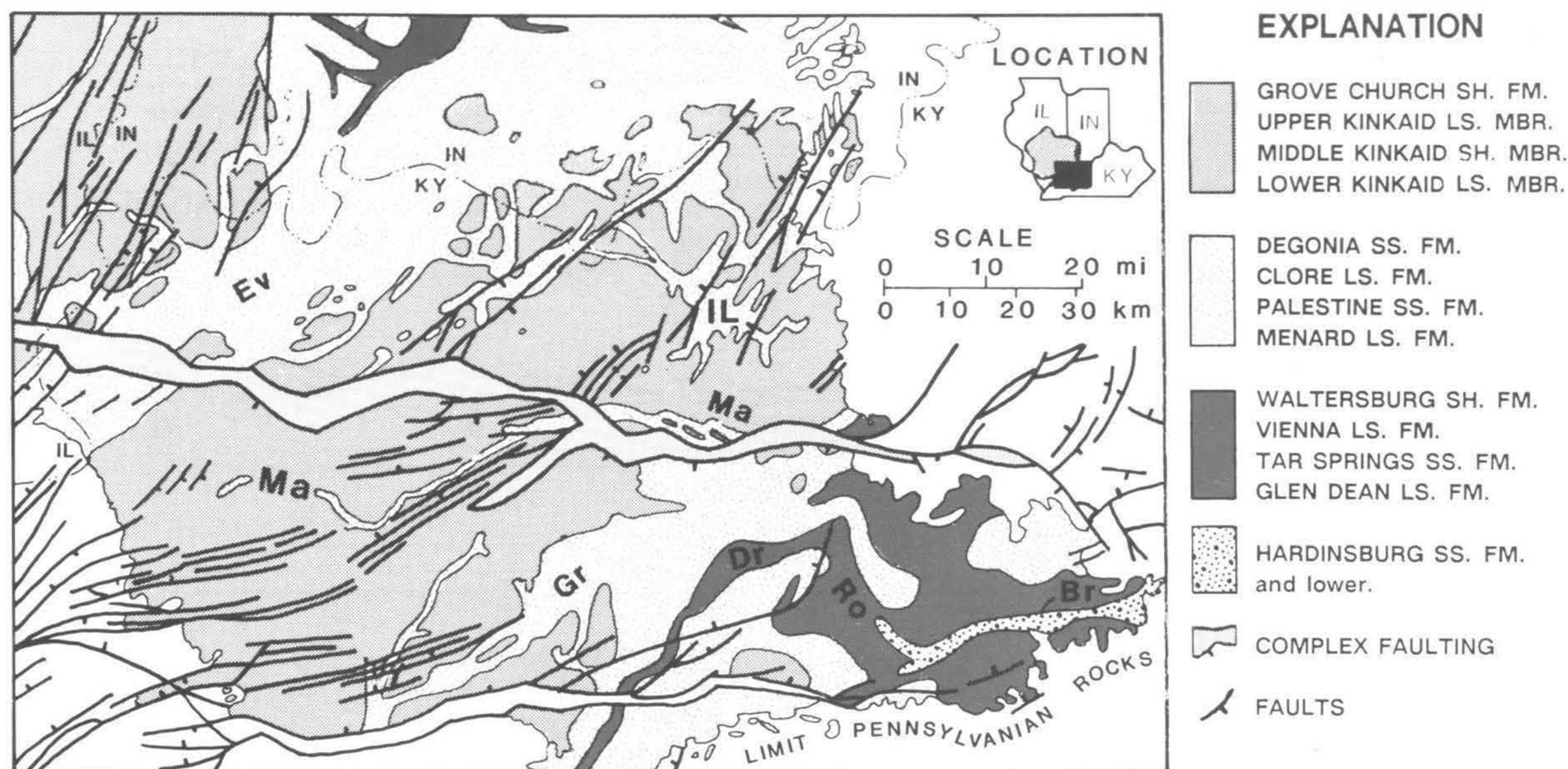


Figure 13. Paleogeologic map at the base of the Pennsylvanian rocks. Note the linear trends of the missing Mississippian rocks interpreted to be paleovalleys. Paleovalleys shown are the Evansville (Ev), Indian Lake (IL), Madisonville (Ma), Greenville (Gr), and Rochester (Ro); Rochester is the combined Brownsville (Br) and Drakesboro (Dr) paleovalleys (data from Droste and Keller, 1990; Greb, 1989b; Davis and others, 1974; Bristol and Howard, 1971).

western part of the coal field. The upper Caseyville thins to 100 feet in the eastern part of the coal field, reflecting the southwest-dipping paleoslope upon which the sediments were deposited and the influence of the Cincinnati Arch during Lower Pennsylvanian deposition (Fig. 15).

Lithology and Depositional Environments *Paleovalleys*

For many years the sub-Pennsylvanian paleovalleys have been considered to indicate the position of a regional unconformity between the Pennsylvanian and lower systems (Burroughs, 1923; Shiarella, 1933; Siever, 1951; Wanless, 1955; Rose, 1963; Potter and Desborough, 1965; Bristol and Howard, 1971, 1974; Davis and others, 1974; Greb, 1989b-c). This unconformity marks the division of the Kaskaskia and Absoraoka cratonic sequences (Sloss, 1963), and occurs between two global eustatic supercycles (Vail and others, 1977).

Four major paleovalleys and several secondary paleochannel systems have been mapped in the Western Kentucky Coal Field (Fig. 13) (Shawe and Gildersleeve, 1969; Bristol and Howard, 1971; Davis and others, 1974; Greb, 1989b-c). Valley fills are quite variable (Figs. 14a-c, 16a-b). Outcrops at Nolin Reservoir in the Rochester (combined Drakesboro and Brownsville) Paleovalley consist of two coarse-grained sandstones (Fig. 16a). The lower sandstone is conglomeratic with abundant quartz pebbles, and the upper sandstone exhibits large-scale accretionary or epsilon crossbedding and

finer upward (Sedimentation Seminar, 1978). In contrast, well records from the upper Madisonville Paleovalley in Ohio County indicate the presence of thin, basal sandstones overlain by thick shales (Fig. 16b).

The variation in channel fills is a reflection of the different types of stream deposition (anastomosing, braided, meandering, etc.), complicated by backfilling and estuarine sedimentation within the paleovalleys as base level rose (Sedimentation Seminar, 1978; Greb, 1989b). It may also reflect tectonic controls on valley formation and sedimentation along the sub-Pennsylvanian unconformity (Greb, 1989a-c).

Paleo-Uplands

When the valleys were filled, deltaic sedimentation was unconfined and became widespread (Sedimentation Seminar, 1978). The upper Caseyville sandstones are persistent over many of the valleys (Davis and others, 1974) and probably reflect this unconfined condition (Fig. 17). Fine-grained, burrowed Caseyville sandstones with fossil casts of trilobites, gastropods, ostracodes, and brachiopods attest to marginal marine conditions in the Caseyville sandstones on the paleo-upland surface (Whaley and others, 1979). Many of the paleovalleys may also contain partial marine fill, whether from valley backfilling, or from marine channeling after the valleys were filled. The complexity of the paleotopographic surface along the unconformity makes it important to determine whether strata are above a paleovalley

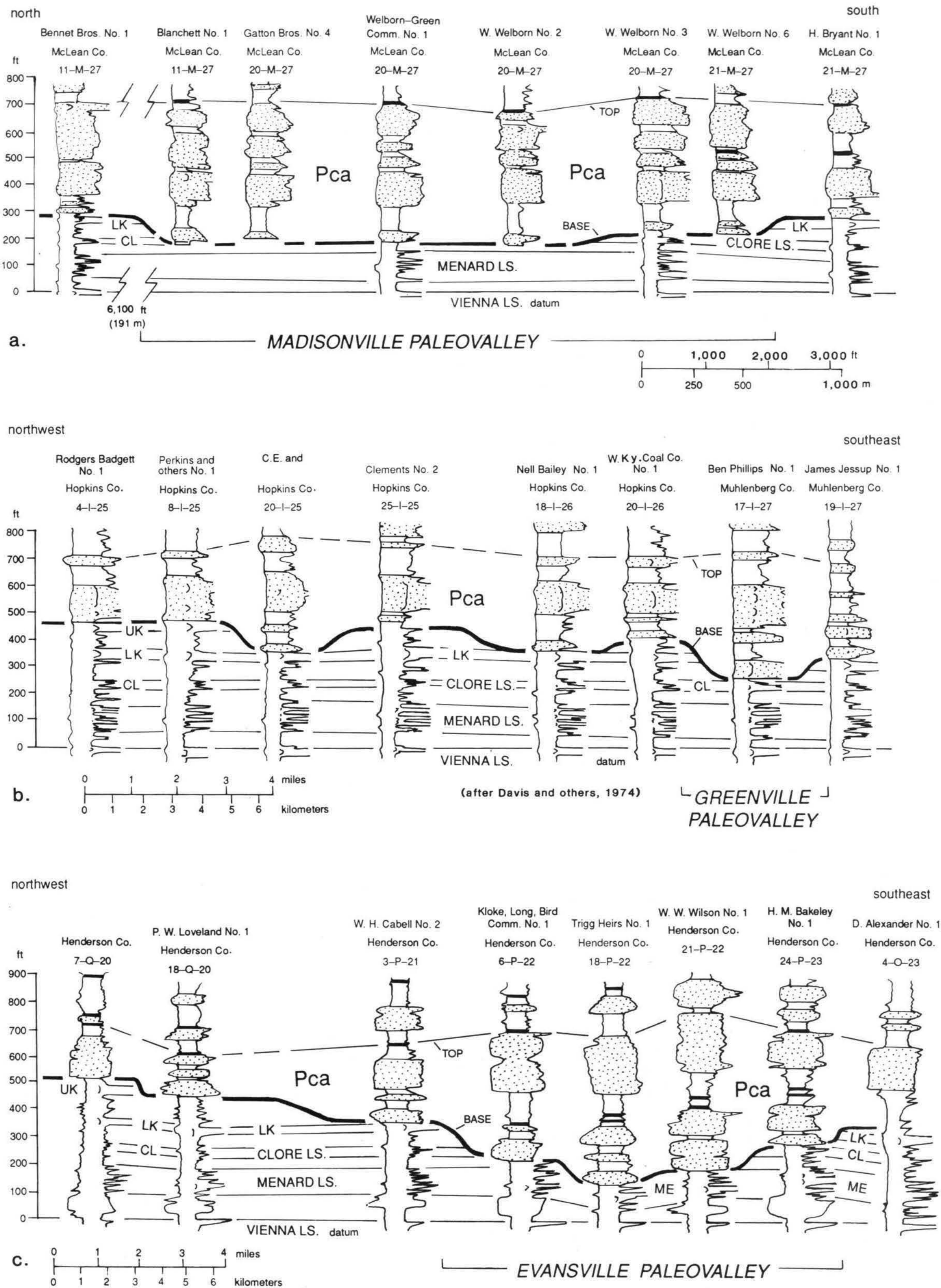


Figure 14. Three examples of western Kentucky paleovalleys from different parts of the coal field as indicated by downhole electric logs. Pennsylvanian sandstones are shown by dot pattern and possible coals are shown by thick black lines. Truncated Mississippian strata in these examples consist of the Upper Kinkaid (UK), Lower Kinkaid (LK), Clore (CL), and Menard (ME) limestones.

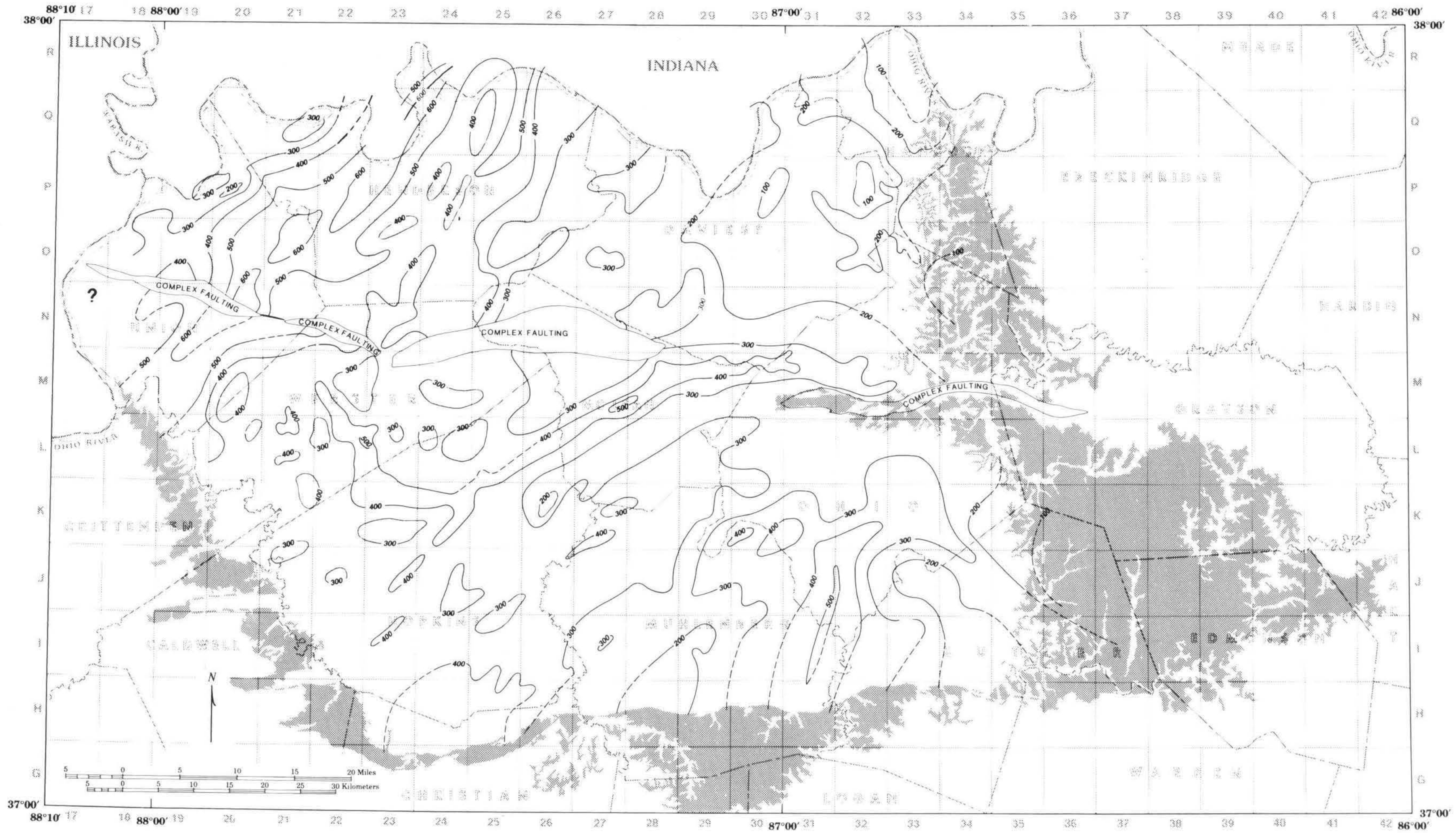


Figure 15. Isopach map of the Caseyville Formation. Outcrop area is shaded.

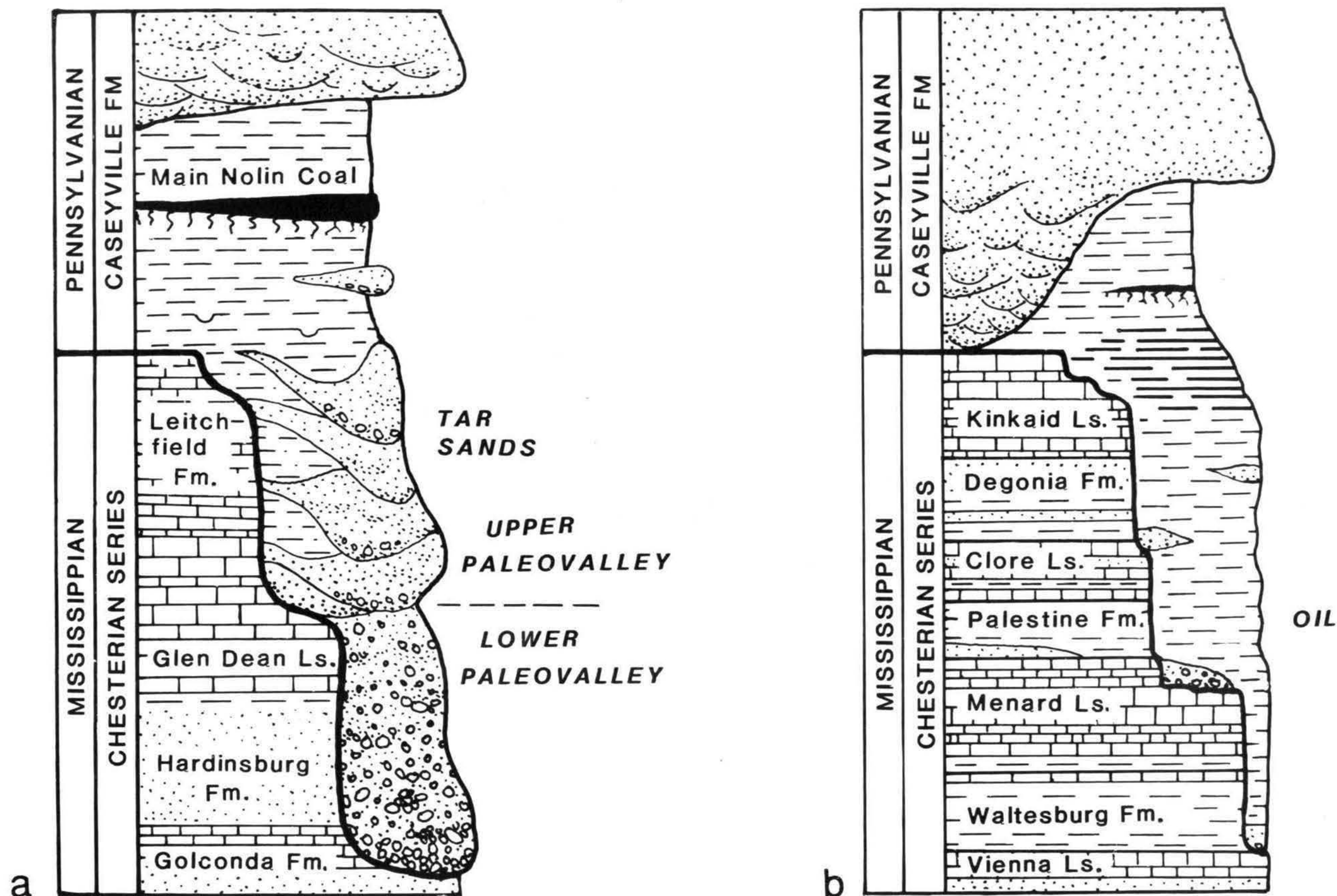


Figure 16. Comparison of Caseyville paleovalley fills. The Rochester Paleovalley (a) has a sandstone fill, and the Madisonville Paleovalley (b) is predominantly filled by shale. Both paleovalleys are economically important. Oil is produced from the Madisonville Paleovalley and tar sands have been mined from the Rochester Paleovalley.

or paleo-upland surface when interpreting Caseyville depositional history. On a paleo-upland surface, strata 5 meters above the unconformity may be stratigraphically equivalent to rocks more than 125 meters above the unconformity in a paleovalley.

Caseyville Reservoirs

The sandstones of the Caseyville Formation have historically been important reservoirs for tar sands, oil, natural gas, and water. Tar sands have been mined in Butler, Edmonson, and Grayson Counties (Fig. 16b) from the Kyrock and Bee Springs sandstones (Glick, 1963; Gildersleeve, 1965, 1968a; Shawe, 1966). They have a total in-place resource of between 300 and 550 million barrels (Noger, 1987).

At least 25 fields have produced oil from Caseyville reservoirs (Schwalb and others, 1971). Thin (3 to 6 m) sand bars at the base of the Madisonville Paleovalley (Fig. 16a) are believed to have produced several million barrels of oil from nine fields in Ohio and McLean Counties (Shiarella, 1933; Goudarzi and Smith, 1968a-b; Johnson and Smith, 1972b; Greb, 1988). Stratigraphic traps are formed in sand bars on the paleovalley floor (Shiarella, 1933; Sedimentation Seminar, 1978; Greb, 1988), as shown in the cross section across the Calhoun South Field in Figure 14a.

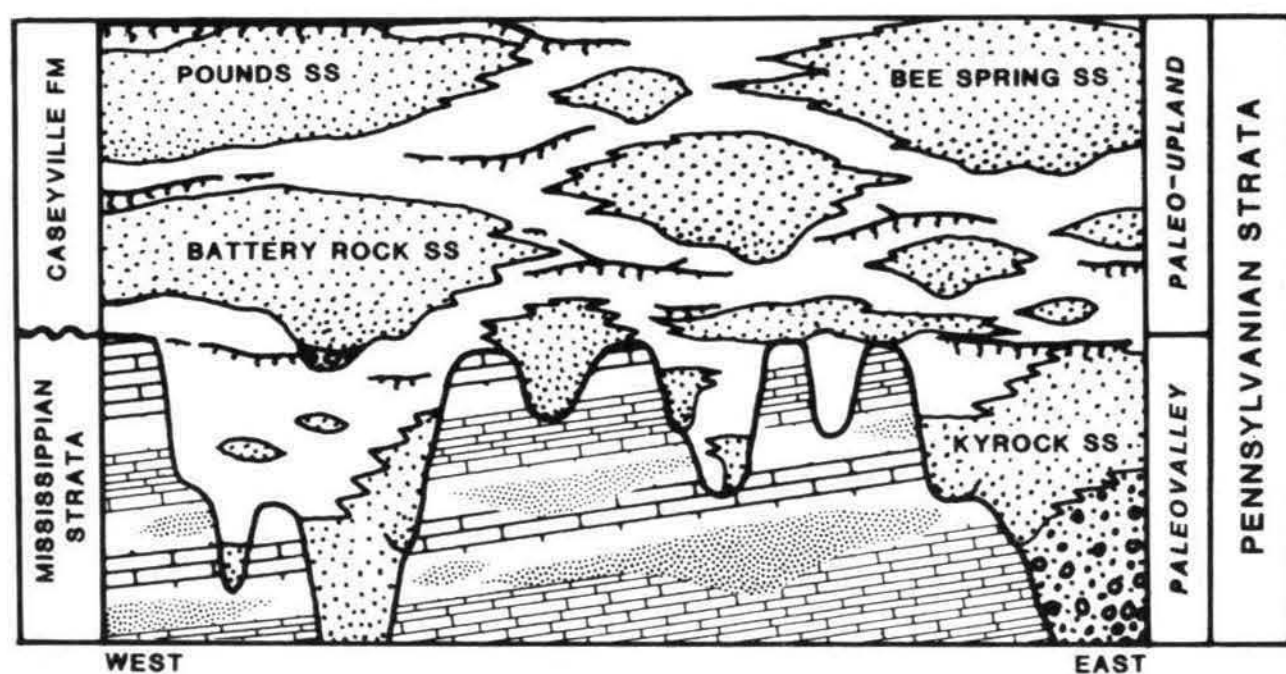


Figure 17. Generalized diagram of Caseyville sandstone distribution showing relation of paleovalleys, paleo-uplands, and named units. The Battery Rock and Pounds sandstones are Illinois terms that have received only limited acceptance in Kentucky.

Limited oil and gas production has also occurred in the upper parts of thick (less than 100 feet), lower Caseyville sands in the Grassy Pond Field of Henderson County; the Young Field of Union County; and possibly the Belton Field of Muhlenberg County (Schwalb and others, 1971; Hansen, 1972). Although some of these sands occur above paleovalleys, they do not appear to be part of the valley fill, but rather are spread across the paleo-upland surface.

In the subsurface, drillers often call middle and upper Caseyville reservoirs "Mansfield" sands. Mansfield sands have produced oil from shallow (less than 1,000 feet) reservoirs in the Bates Knob, Island, and Sebree Fields of McLean County; the Caney Mound, Grassy Pond, and Smith Fields of Henderson County; the Belton Pool of Muhlenberg County; and the Powells Lake Field and possibly the Boxville Field of Union County (Ingham, 1948; Schwalb and others, 1971; Hansen, 1972; Johnson and Norris, 1974; Hansen and Smith, 1978). The discovery well of the Morganfield South Field in Henderson County was a 14-foot-thick, probably middle Caseyville sandstone that produced 14 barrels of oil per day (bopd) (Wood, 1955). In the Powells Lake Field, production of 65 to 240 bopd came from an elongate, Mansfield sand, 0 to 35 feet thick and less than 1,500 feet wide (Ingham, 1948).

Natural gas was produced from a Mansfield sand in the Pratt Field of Webster County at 250,000 thousand cubic feet (mcf) (Fairer, 1973b). Gas has also been produced from upper Caseyville sandstones in the Southard Pool and wells in the vicinity of Carbondale in Hopkins County. Some of the wells in this area had a shut-in pressure of more than 300 pounds per inch (Palmer, 1967).

Aside from producing significant hydrocarbons, Caseyville paleovalley and paleo-upland sandstones are among the most important bedrock aquifers in the coal field (Maxwell and Devaul, 1962a–b; McGrain and others, 1970). Several studies have noted Caseyville sandstones as potential deep, fresh-water aquifers (Wilson and Van Couvering, 1965; Davis and others, 1974).

Also, the conglomeratic sandstones of the Caseyville Formation have been quarried for construction uses across the outcrop belt (Crider, 1914b; Miller, 1964; Amos, 1966; Kehn, 1966a; Gildersleeve, 1968b; McGrain and others, 1970; Trace, 1972; Hansen, 1973; Johnson and others, 1975).

Named Units of the Caseyville Formation in Kentucky

Although no formal nomenclature has been developed for Caseyville members in Kentucky, several terms have acquired acceptance in limited areas (Fig. 18).

Kyroock Sandstone

The Kyroock sandstone was named by McFarlan (1943) for Caseyville sandstone exposures near Kyroock in Edmonson County. In the Edmonson County area the Kyroock sandstone replaces nearly 200 feet (66 m) of Chesterian carbonates and clastics in the Rochester (Brownsville) Paleovalley (Figs. 13, 15, 16b, 17). The Kyroock can be traced on the surface from Edmonson County eastward into Hart, Green, Taylor, and Larue Counties (Sedimentation Seminar, 1978). The Kyroock sandstone is 0 to 150 feet (46 m) of coarse- to fine-grained, crossbedded, conglomeratic sandstone with quartz pebbles (Figs. 19–20). As a subsurface term it has been used to refer to the thick, massive conglomeratic sandstone facies of the lower Caseyville in several different paleovalleys, but it should not be considered continuous, since the paleovalleys are physically separated from each other. The term "Kyroock sandstone" should only be applied to the paleovalley fill of the Rochester (Brownsville) Paleovalley. Also, because of the apparent backfilling of paleovalleys, the basal, valley-filling sandstone of a paleovalley in the southwestern part of the basin may overlie the paleovalley fill and occur on the paleo-upland surface to the north and east (Greb, 1988).

Nolin Coal

In Butler, Edmonson, Grayson, and Warren Counties, several relatively thin, discontinuous coals occur on the paleo-upland surface and the Rochester (Brownsville) Paleovalley (Johnson and Smith, 1968; Mullins and others, 1963; Shawe, 1966, 1968). Subsidence of unconsolidated detritus on the paleo-upland surface and within the valley-fills may have created topographic lows that were colonized by peat-forming swamps. The most persistent of these coals is called the Nolin coal (Weller, 1927, p. 221) and is mapped on several geologic quadrangle maps (Shawe, 1966, 1968; Gildersleeve, 1968a, 1971). The Nolin was named for a coal 20 to 30 feet above the Chesterian surface and beneath a Caseyville sandstone called the Bee Spring sandstone (Fig. 18) in Edmonson and Grayson Counties (Owen, 1857b; Moore, 1877a; Crider, 1915c), where it may reach thicknesses of 36 inches (Gildersleeve, 1965). The Nolin appears to occur on the paleo-upland surface, with a thin-

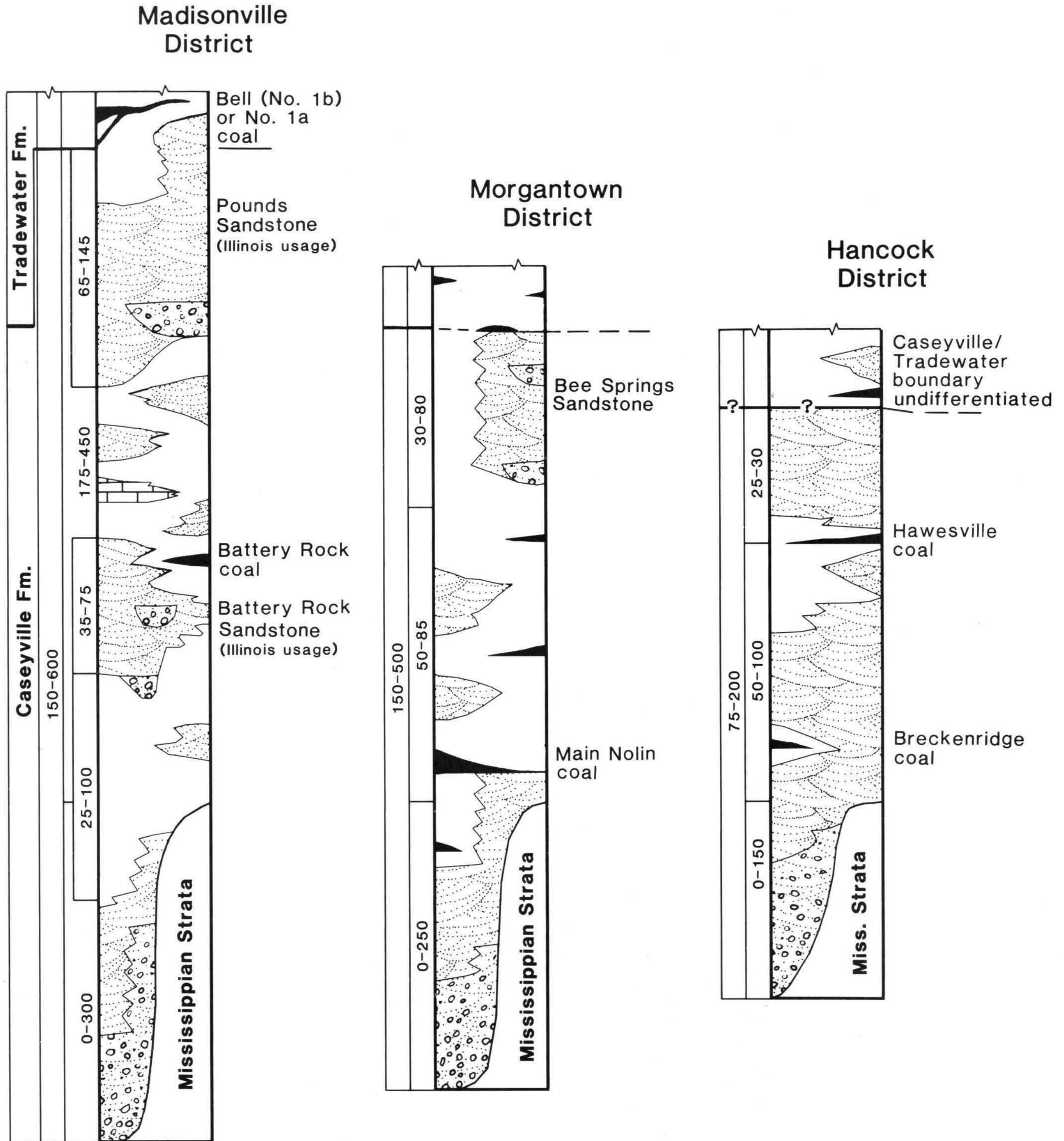


Figure 18. Representative geologic sections of the Caseyville Formation from the Madisonville, Morgantown, and Hancock Districts showing named units discussed in this report.

ner unnamed coal 20 to 30 feet below the Nolin in the Rochester Paleovalley fill (Gildersleeve, 1971). Thin coals near the tops of paleovalley fills have been noted in several parts of the coal field (Bergendahl, 1965; Trace

and Palmer, 1971). The Nolin coal reaches thicknesses of 48 inches and was strip mined in the vicinity of Bee Spring (Gildersleeve, 1968a). Spore assemblages from this coal suggest an age equivalence with the Gentry

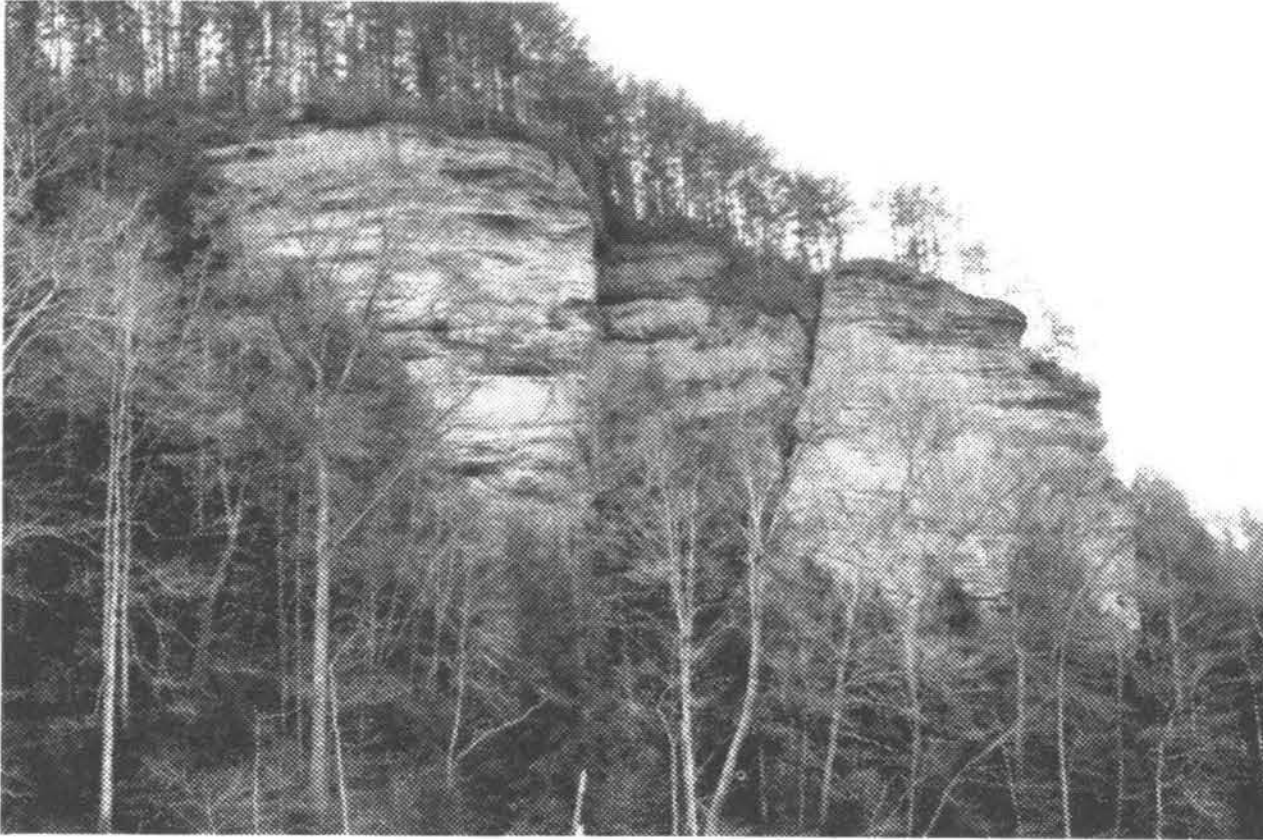


Figure 19. Caseyville sandstone cliff at Nolin Reservoir, Edmonson County (photo courtesy of Dr. P. E. Potter).

Coal of southern Illinois (Sedimentation Seminar, 1978). It may also be homotaxial with the Battery Rock coal of the Dekoven area.

Breckenridge Coal

Known occurrence of this coal is limited to one locality at Victoria crossroads in eastern Hancock County, where it occurs 10 to 25 feet above the Kinkaid Limestone (Mississippian) on a paleo-upland surface (Calvert, 1965). Originally, there was significant debate as to the stratigraphic position of the coal, with some placing the Breckenridge within the Mississippian System (Cridder, 1913). The coal was reported to be from 24 to 33 inches in thickness, but localized in extent. The Breckenridge coal is notable because it is the only major deposit of cannel coal in western Kentucky. In 1856, the Breckenridge cannel coal was locally distilled for oil (Miller, 1919).

Battery Rock Sandstone

The Battery Rock was named for a bluff on the Ohio River in Hardin County, Illinois (Cox, 1875). The term "Battery Rock" may be used for the lower Caseyville conglomeratic sandstone in Illinois, but in Kentucky the term is applied to a coal (Figs. 17–18).

The Battery Rock sandstone of the type area is fine to medium grained, often pebbly, moderately to well sorted, and massive to crossbedded. Several Battery Rock-type sandstone lenses exist in the Caseyville of Kentucky. One of these lenses may be the "3rd Pennsylvanian sand" of Avila (1968), which yielded significant oil in the Boxville Pool of Union County. Production has also occurred in thick lenticular "Mansfield sands" in the Powells Lake Oil Field of Union County (Ingham, 1948).

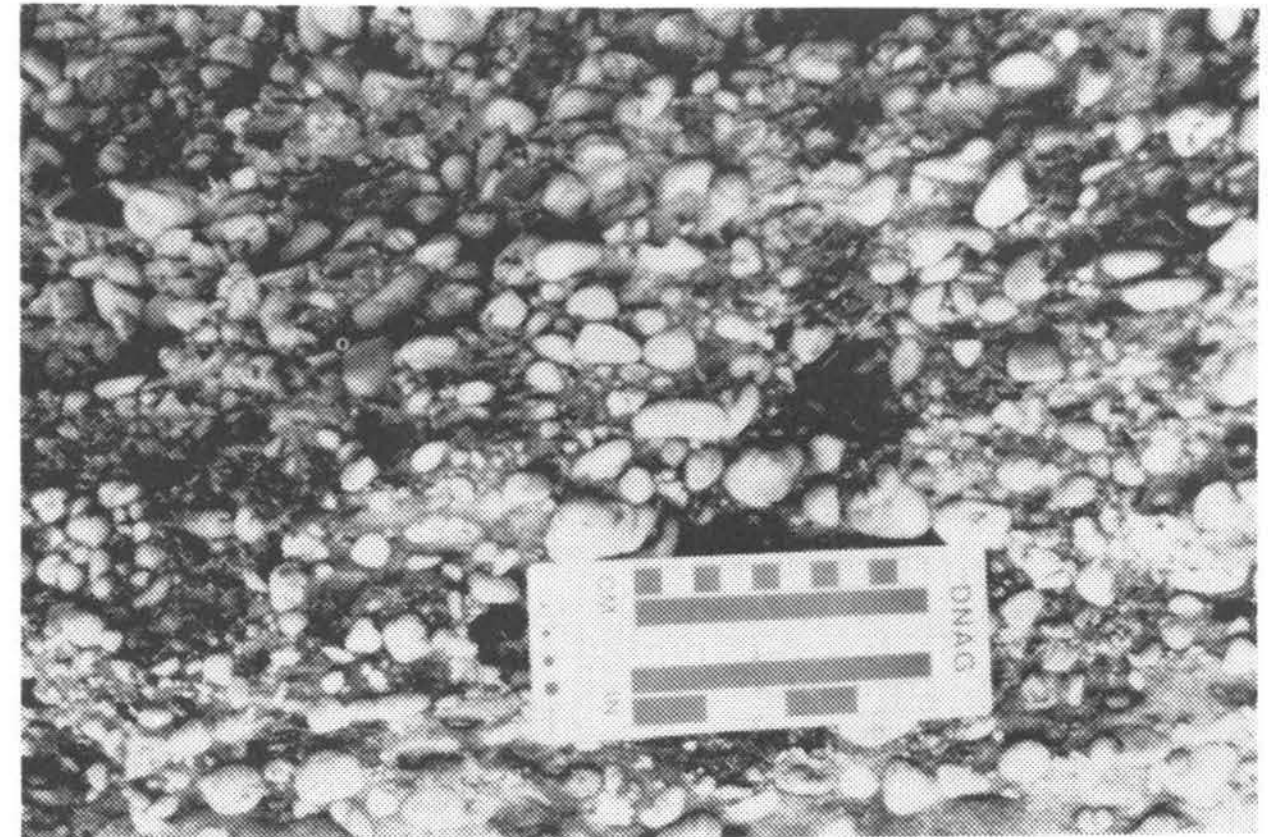


Figure 20. Characteristic Caseyville conglomerate from the paleovalley-fill sandstone at Nolin Reservoir, Edmonson County.

The lower Mansfield Formation of Indiana is equivalent to the Caseyville Formation. Davis and others (1974) mapped a series of disconnected sandstones called the "600-foot aquifer." As many as five separate sandstones have been recorded in the Caseyville (Kehn, 1974a), so that application of the term "Battery Rock" to the lower Caseyville sandstone is of limited stratigraphic use. Each of these sands may represent lobes of a Caseyville delta at various points in the basin (Fig. 21). Environments of deposition associated with any single lobe include the entire suite of deltaic environments from pro-delta marine shales to alluvial plain sandstones (Davis and others, 1974; Jacobson, 1987a).

Battery Rock Coal

This coal crops out south of Dekoven, Union County, Kentucky, in a bluff on the Ohio River, where it is 0 to 12 inches thick (Kehn, 1974a). It was mined on the Illinois side of the Ohio River opposite Caseyville, Kentucky (McFarlan, 1943). In Illinois the coal is limited to an area north of the river, where it is called the Gentry Coal Member (Kosanke and others, 1960), because the term "Battery Rock" was previously in use for a Caseyville sandstone unit (Fig. 18).

Bee Spring and Pounds Sandstones

The Bee Spring sandstone was named by Moore (1877a) for a sandstone that overlies the Nolin coal in Edmonson County (Figs. 17–18). As a surface term its use has been restricted to northern Edmonson and southern Grayson Counties, but in the subsurface it is occasionally used to denote a thick sandstone in the upper part of the Caseyville. Since the number of sandstones varies in any given Caseyville section, across-the-basin designation of a sand as "Bee Spring" is of limited stratigraphic value. The Bee Spring in Edmonson

County is the second thick sandstone in the Pennsylvanian section. In southern Illinois and the northern part of the Western Kentucky Coal Field, the second thick sandstone is called the Pounds Sandstone. Davis and others (1974) mapped a 700-foot aquifer that may also be the second thick sandstone in the Pennsylvanian section. Correlations of these Caseyville sandstones are difficult since they probably represent different but similar lobes of the Caseyville deltaic system as it migrated through time. More work is needed to correlate these sandstone lobes across the basin.

TRADEWATER FORMATION

Nomenclature History

The Tradewater Formation was informally defined by Glenn (1912b) for a series of outcrops between the Caseyville Conglomerate and the overlying Sebree Sandstone along the Tradewater River. Glenn (1912b) placed the lower boundary at the top of the Caseyville conglomerate (Fig. 10), but later workers noted the discontinuity

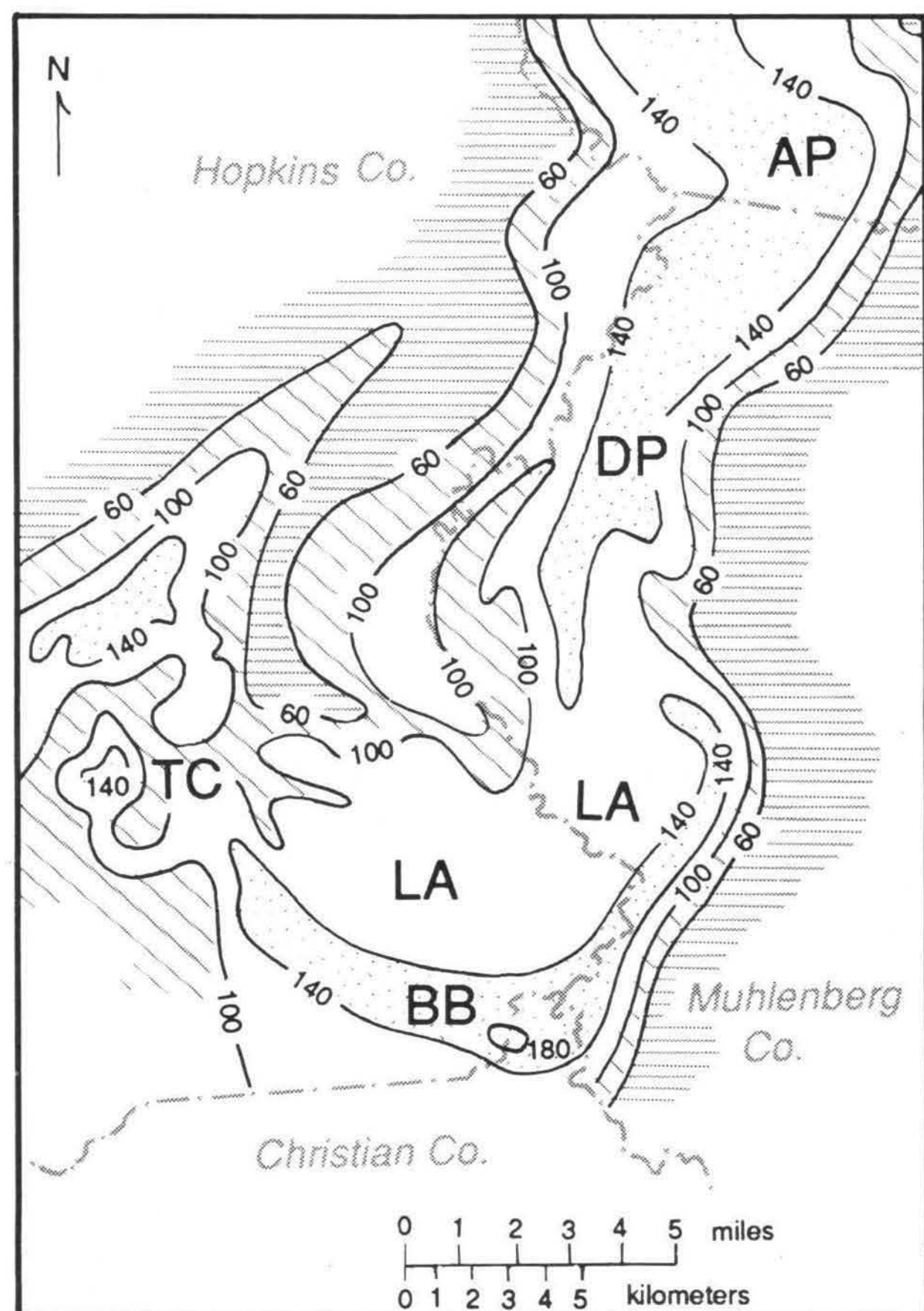


Figure 21. Isopach map of an upper Caseyville sandstone with interpretations of possible depositional environments. Beach bars = BB, lagoons = LA, tidal channels = TC, delta plains = DP, and alluvial plains = AP. (Modified from Davis and others, 1974.)

of these sandstone units and moved the boundary to the base of the Bell coal (W. Ky. No. 1-b), where present. Glenn (1912b) placed the top of the Tradewater Formation beneath the No. 5 coal (now Davis) so that the major economic coals would all be contained within the overlying Carbondale Formation (Fig. 10). Lee (1916) formalized Glenn's definition of the Tradewater and noted that the No. 5 of Glenn (1912b) was the No. 6 coal (Davis coal). The type section was designated in Union County (Lee, 1916). In 1990, the geological surveys of Illinois and Kentucky agreed to common use of the Tradewater Formation as defined by Lee (1916). Also, the Tradewater became a formation within the Raccoon Creek Group in Kentucky and Illinois.

Formation Boundaries

During the geologic quadrangle mapping of the 1970's (Cressman and Noger, 1981), the base of the Tradewater was placed at the top of the uppermost Caseyville pebbly sandstone; the base of the Bell (No. 1b) coal; the base of a thin lime that occurs directly beneath the Bell coal; or the base of the No. 1a coal (Fig. 22). In practice this boundary is arbitrary because of the similarity of upper Caseyville and lower Tradewater rocks. Field workers often make a distinction between quartz-rich, pebbly Caseyville sandstones and "dirtier" Tradewater sandstones that may contain appreciable amounts of mica. Sandstone petrography is not apparent on down-hole geophysical logs, and the placement of the lower boundary in areas where the upper Caseyville does not contain a thick, upper sandstone, can be difficult.

Because an upper pebbly sandstone and Bell coal could not be determined over a large part of the coal field, the two formations are mapped together on many geologic quadrangle maps (Fig. 12). The Raccoon Creek Group (Fig. 11) may be used for the combined Caseyville and Tradewater in Kentucky in areas where the two cannot be differentiated. More work is needed in the subsurface of Kentucky to determine the extent of the Pounds sandstone as a basal boundary.

The upper boundary of the Tradewater Formation was mapped at the base of the Davis coal bed where this bed is present in the western part of the coal field and on the top of the Yeargins Limestone in the eastern part of the coal field (Fig. 22).

Prior to the nomenclature agreement between Kentucky and Illinois in 1991, the Tradewater correlated with all of the Abbott Formation and the lower part of the Spoon Formation in Illinois (Willman and others, 1975). The Abbott was the upper part of the McCormick Group, and the Spoon was the lower part of the Kewanee Group (Willman and others, 1975) (Fig. 11). Tentatively, Illinois

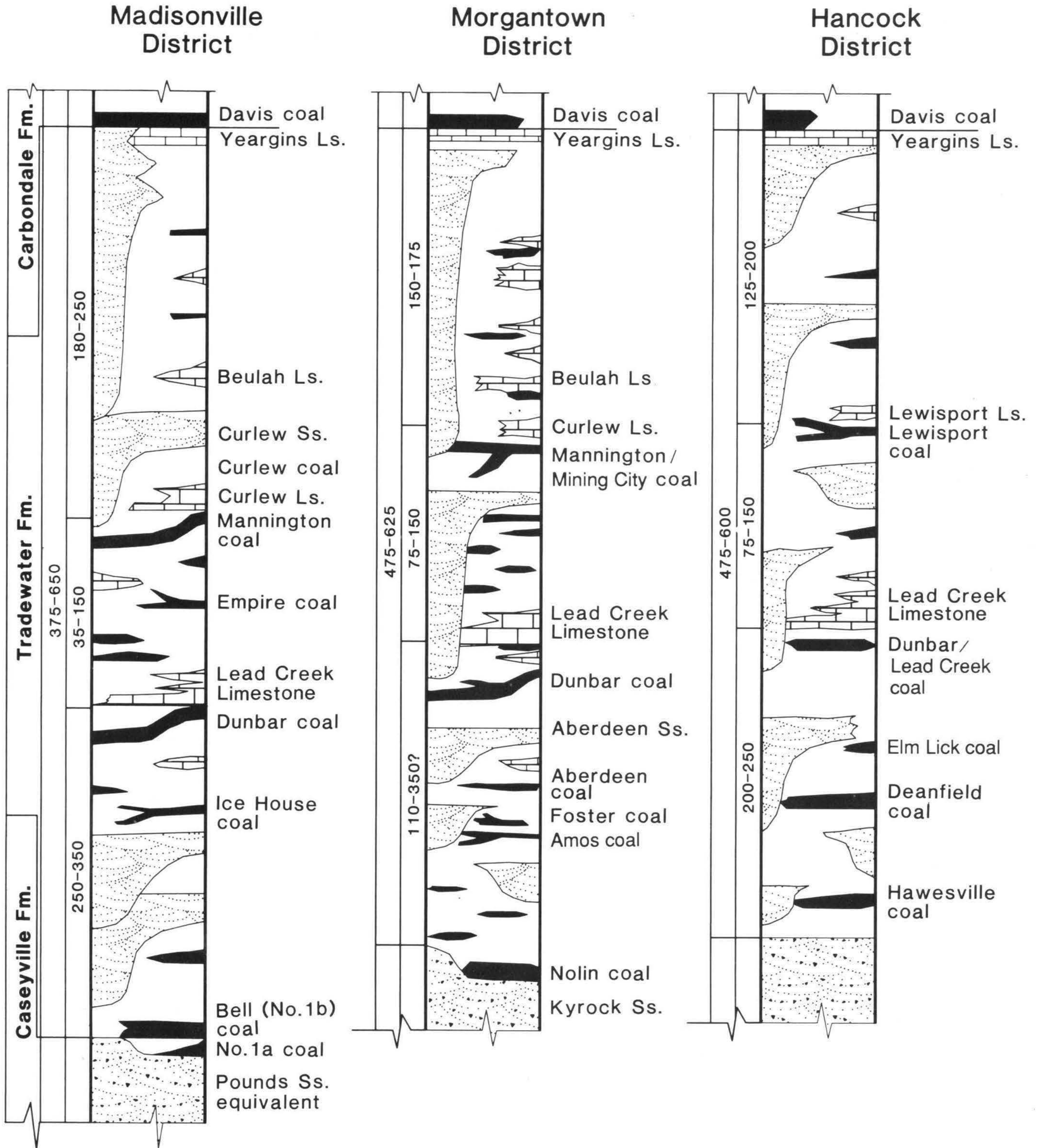


Figure 22. Representative geologic sections of the Tradewater Formation from the Madisonville, Morgantown, and Hancock Districts showing named units discussed in this report.

has adopted the Tradewater Formation as defined in Kentucky. In Indiana, the Tradewater Formation correlates with the upper part of the Mansfield Formation, all of the Brazil Formation and the lower part of the Staunton Formation, and all parts of the Raccoon Creek Group (Fig. 11) (Shaver and others, 1986).

Thickness and Extent

The Tradewater crops out along the eastern, southern, and southwestern rim of the Western Kentucky Coal Field. The thickness of the formation is much less variable than the Caseyville, ranging from a minimum of slightly less than 400 feet in northern Christian County to a maximum of more than 600 feet in at least five separate areas (Fig. 23). It is not difficult to visualize these areas of thick Tradewater as lobes of deltas, with depositional environments similar to those of the upper Caseyville sandstones (Fig. 21). A continued northeast–southwest strike in thickness trends is also apparent (Fig. 23).

Transitional Lithology

The rocks of the Tradewater Formation are lithologically transitional between the Caseyville and Carbondale Formations. Sandstones in the lower part of the Tradewater are quartzose and may contain scattered quartz pebbles similar to those in the underlying Caseyville sandstones (Lee, 1916). Caseyville sandstones tend to be orthoquartzitic, while Tradewater sandstones are subgraywackes with more feldspar, clay, and mica (Siever, 1957; Potter and Glass, 1958). However, the petrologic differences are time transgressive, with the orthoquartzites in Kentucky being older than the orthoquartzites to the north in Illinois. For example, the Finnie sandstone of the Tradewater is indistinguishable from lower Caseyville sandstones in Kentucky and southern Illinois, but is distinguishable in northern Illinois (Potter and Glass, 1958). The general rule for the petrographic change is that Caseyville sandstones are orthoquartzites, lower Tradewater sandstones are transitional, and sandstones above the middle of the Tradewater are subgraywackes (Potter and Glass, 1958). Upper Tradewater sandstones are indistinguishable from the sandstone units of the overlying Carbondale Formation.

Tradewater Formation sandstones were deposited in many different coastal and deltaic environments. The most common sandstones are lenticular, have basal lags, fine upward, and exhibit sedimentary structures indicative of fluvial origin. But many fine-grained, calcareous sandstones with planar to very low-angle bedding and scattered marine fossils indicate that marginal-marine and marine sandstones are also preserved (Whaley and others, 1979, 1980). Sandstones of the Tradewater

Formation are economically important. Hydrocarbons have been produced from several discontinuous Tradewater sandstone lenses in Henderson County (Bauer, 1957). More continuous sandstone bodies in the Tradewater Formation are important aquifers (Davis and others, 1974).

Limestone beds are common above coal beds in the Tradewater Formation. At least 20 discrete limestone beds are recognized in western Kentucky (Fig. 24). The limestones are generally less than 10 feet thick, tan to gray, argillaceous, and contain abundant and diverse assemblages of marine invertebrates, including fusili-nids, ostracodes, and conodonts, that can be useful as an aid to regional correlation.

The shale beds of the Tradewater Formation are uniformly medium to dark gray, often silty, and micaceous, with varying amounts of carbonaceous plant debris. Shales commonly occur in coarsening-upward packages 20 to 40 feet thick. Black to very dark-gray shale sometimes containing pyritic pectinid fossils is common at the base of the shales. Lighter gray silty shale with ironstone nodules is common in the middle and upper parts of the shales. These coarsening-upward packages were formed when brackish- to marine-water bays were filled (Graese and others, 1974; Whaley and others, 1979, 1980).

Named Units of the Tradewater Formation in Kentucky

The Tradewater Formation was originally defined in order to group the discontinuous coals and fine-grained rocks between the Caseyville and Carbondale Formations into a single unit. Therefore, numerous rock units have been named locally. Examples are the Truman Hill, Rocky Fork, and Waltham coals of Hancock County (McFarlan, 1943; Johnson and Smith, 1968), the Gidcomb and Cates coals of Butler County, the Millsite and Beda coals of Ohio and Edmonson Counties (Gardner, 1927; Weller and Wanless, 1939; McFarlan, 1943), and the Jesse Roberts and Cox coals of Hopkins and Christian Counties (Glenn, 1912a; Kehn and others, 1967). Other local units are discussed where they pertain to more widespread units. Although the Tradewater contains many locally restricted rock units, it also contains several regionally continuous units. The Tradewater contains two limestone members and several named coal and sandstone units (Fig. 22). Correlation of named coal beds in the Tradewater Formation is problematic in that many coals are defined by their positions above or below named limestone beds. Since many of the limestones are lithologically similar and have been miscorrelated, many of the coals have been miscorrelated as

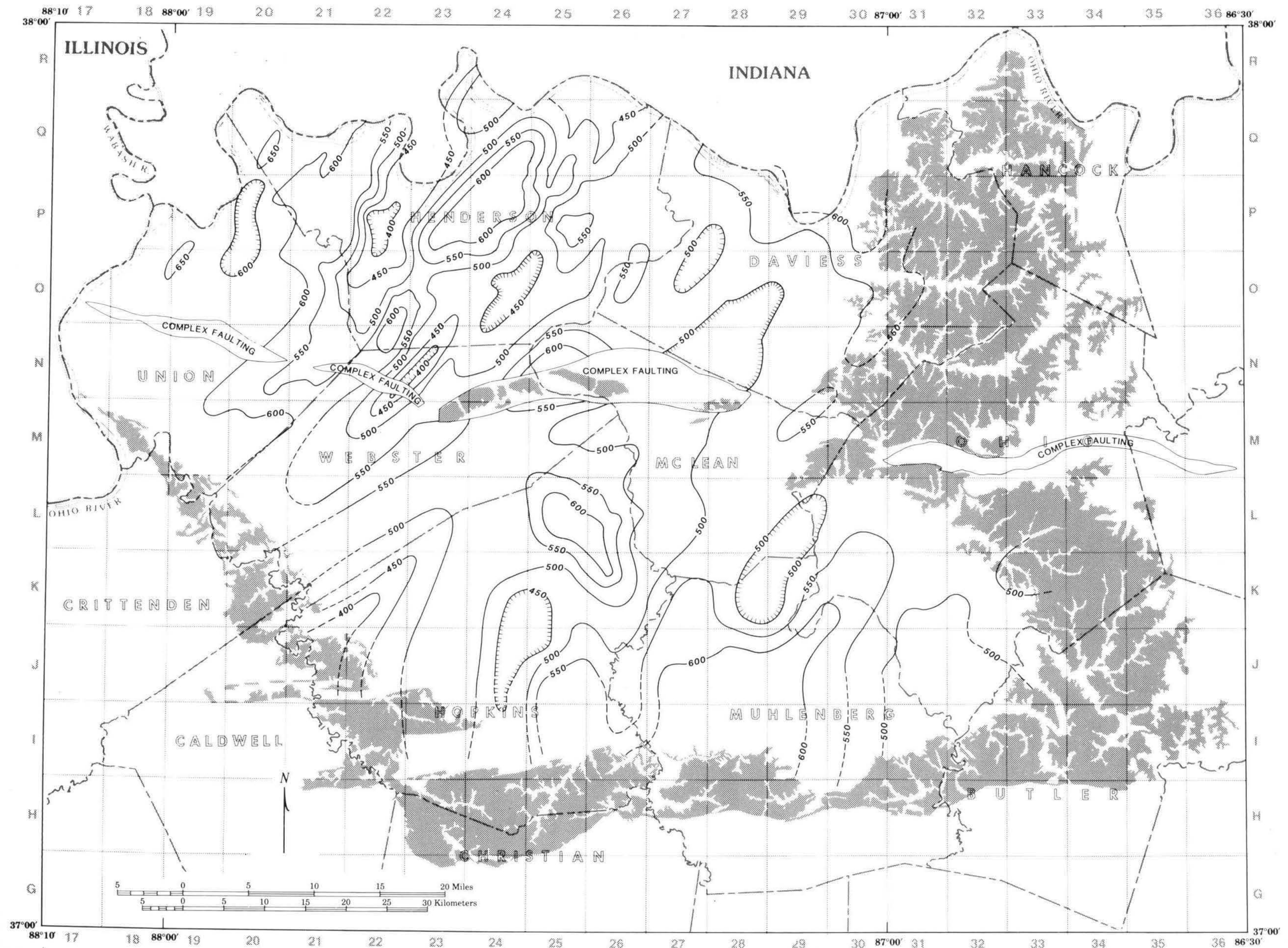


Figure 23. Isopach map of the Tradewater Formation. Outcrop area shaded. The approximate top of the formation occurs along the inner margin of the shaded area.

GEOLOGIC QUADRANGLE AREA

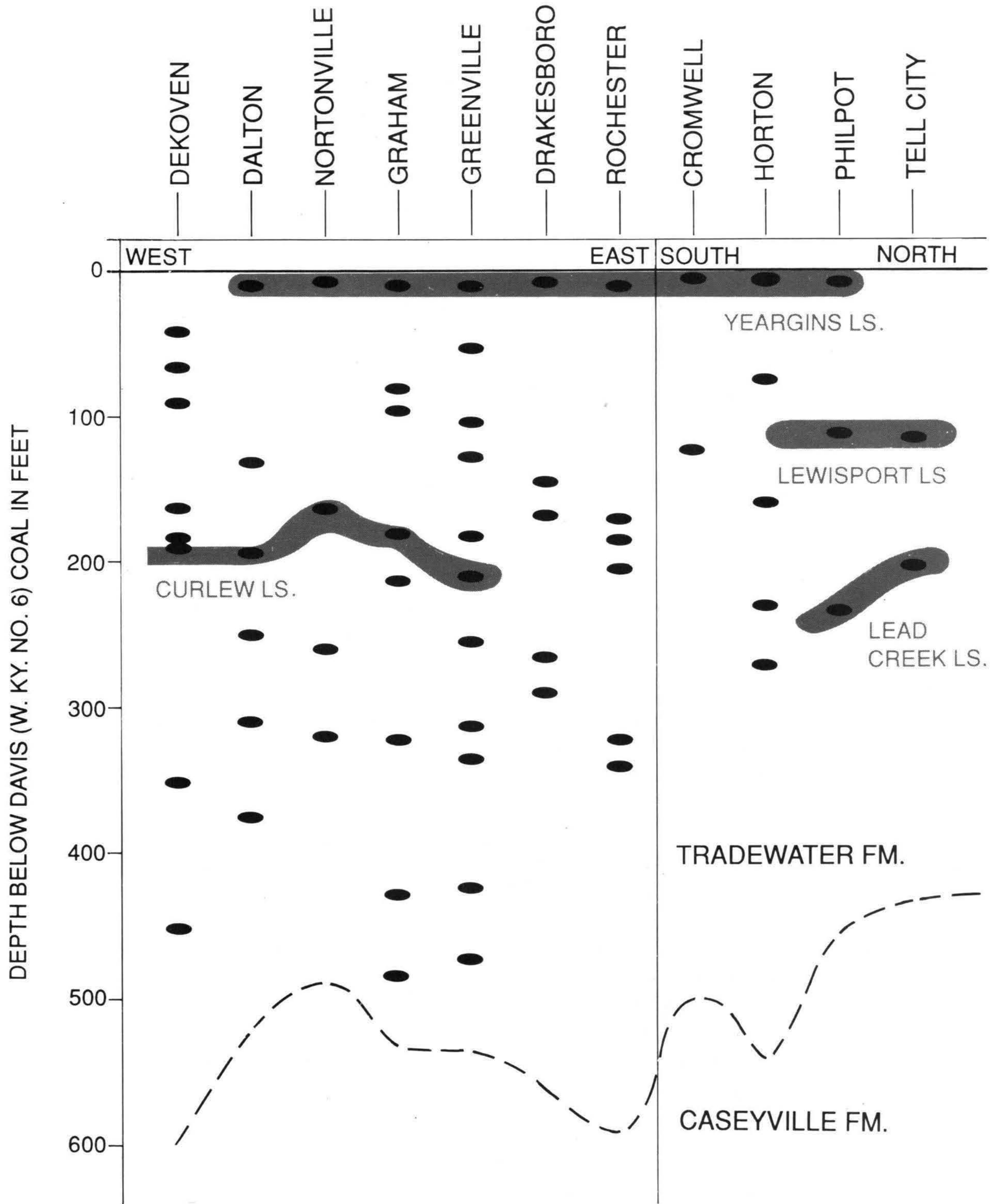


Figure 24. Stratigraphic position of Tradewater limestones (ovals) in selected 7.5-minute geologic quadrangle maps.

well. Some of these miscorrelations are discussed in the following sections.

No. 1a Coal

Owen (1857b) reserved the number "1a" for a coal that was reported 40 to 70 feet below the 1b coal. Later, the 1a coal was described by Glenn (1912a) and Lee (1916) as a thin coal or "smut zone" occurring a few feet above the Caseyville conglomerate (Figs. 10, 22). During the geologic mapping of the 1960's and 1970's, the top of the Caseyville Formation was moved upward to the Bell coal, making the 1-a coal part of the Caseyville Formation. However, as a result of the Tri-State Correlation Committee's adoption of a basin-wide Pennsylvanian nomenclature, the No. 1a coal has been moved back into the Tradewater Formation. Also, the No. 1a coal could not be identified in the type area by later investigators and may in fact be a lower split of the Bell (No. 1b) coal of the Tradewater Formation (Kehn, 1974a).

Bell Coal ***(W. Ky. No. 1b)***

The Bell coal was named by Owen (1856) for mines near Caseyville in Union County, Kentucky, where it was mined for many years. It is 12 to 55 inches thick in the vicinity of Caseyville, and pinches out to the southeast. Near Dekoven the Bell coal is mapped as two benches separated by as much as 15 feet of shale (Kehn, 1974a). This occurrence may be the 1a and 1b coals. Eastward, thin, discontinuous coal beds occur that may be homotaxial to the Bell (W. Ky. No. 1b), but there are not enough data at the present time to confirm this correlation. The Bell has been correlated with the Hawesville coal of the Hancock Coal District (Fig. 22), the Reynoldsburg Coal of southeastern Illinois, and the St. Meinrad coal of southern Indiana (Peppers and Popp, 1979), as well as the Willis Coal of southern Illinois (Weller and Wanless, 1939). These coals may represent relatively contemporaneous swamps on different lobes of the Tradewater deltas, rather than a continuous peat deposit.

Hawesville Coal

The Hawesville coal was named by Owen (1856) for mines near Hawesville in Hancock County, where it is mapped on several geologic quadrangle maps (Spencer, 1963, 1964b; Bergendahl, 1965; Calvert, 1965). The coal occurs 80 feet above the top of the Caseyville conglomerate (Fig. 22), and is distributed in lenticular patches that are reported to reach thicknesses of 5 feet (Crider, 1913), although thicknesses of 3 feet or less are

more common (Spencer, 1964a–b; Bergendahl, 1965; Smith and Brant, 1980). Where the coal is thick it commonly contains a 6-inch-thick pyritic parting and may be cut out by sandstone (Spencer, 1963). The Hawesville coal was one of the most heavily mined deposits in western Kentucky before the Civil War (Crider, 1913). In recent years, (1980–1990) it has averaged less than 20,000 tons per year, according to the Kentucky Department of Mines and Minerals. A canneloid black shale in the roof above the coal was a common means of identification (McFarlan, 1943).

The Hawesville coal of the Hancock Reserve District was correlated with the Cannelton coal (St. Meinrad coal) in Indiana by Weller and Wanless (1939). The Cannelton is confined to depressions in the top of the Mansfield (a Caseyville equivalent). It is probable that coals like the Hawesville, Cannelton, and other minor coals in the lower Tradewater and upper Caseyville have patchy, lenticular distributions because of local subsidence in underlying Caseyville sediments. It is also probable that these coals were not continuous and were restricted both spatially and temporally to local depressions.

Deanfield Coal

In the Hancock District, the Deanfield coal occurs 50 feet above the Hawesville coal (Fig. 22). It is mapped in Hancock County, where it reaches thicknesses of 4 feet (Calvert, 1965; Johnson and Smith, 1968). Data from Smith and Brant (1980) suggest that the coal is thickest in the Owensboro Graben area of Ohio County. The Deanfield coal is at approximately the same stratigraphic level as the W. Ky. No. 2 coal (Fig. 22), although the two coals are not continuous. Smith and Brant (1980) reported that the Deanfield coal had an estimated remaining resource of 289,000 short tons. However, nearly 45,000 tons of coal a year were produced from the Deanfield coal between 1980 and 1990, according to the Kentucky Department of Mines and Minerals.

W. Ky. No. 2 Coal

The No. 2 coal bed of the Madisonville District is a thin, discontinuous bed that occurs 55 to 75 feet above the Bell coal in Union County (Fig. 22). The coal is thin and discontinuous and is only noted on a few of the quadrangles mapped during the U.S. Geological Survey-Kentucky Geological Survey Cooperative Mapping Program. It has a remaining resource of 48,465 short tons (Smith and Brant, 1980). The No. 2 coal is possibly equivalent to the Reynoldsburg coal of Illinois (Willman and others, 1975).

Finnie and Grindstaff Sandstones

The Finnie sandstone was named by Owen (1856) for a "massive ferruginous sandstone" occurring above the Bell coal and almost directly beneath the Ice House coal in Union County, Kentucky (Fig. 22). The Finnie is a 40- to 50-foot, cliff-forming sandstone at the type area near Dekoven. The unit can be traced for only a few miles southwestward along the outcrop (Glenn, 1922; Kehn, 1974a), and subsurface records indicate that it also pinches out to the northeast. The Finnie sandstone is generally fine to medium grained, with scattered lenses of coarse-grained sandstone containing quartz pebbles. It is similar in appearance to Caseyville sandstones and can easily be misidentified where the underlying Bell coal is not present.

The Grindstaff sandstone (Butts, 1925) occurs at the same stratigraphic level as the Finnie in southern Illinois (Peppers and Popp, 1979), and is recognized in part of Union County, Kentucky, although in some areas where two thick sands occur between the top of the Caseyville and No. 4 coals, the lower sand has been called Finnie and the upper sand has been called Grindstaff (i.e., Wood, 1955). It is a fine- to medium-grained sandstone with a lenticular geometry (Fraunfelder, 1979). Other sandstones at a similar stratigraphic level include an unnamed unit (above the Hawesville coal bed) in the Hancock District (Fig. 22), the Babylon sandstone of western Illinois (Willman and others, 1975), and the Delwood Sandstone of southern Illinois (Wanless, 1955). In many areas, these sandstones contain marine fossils (Siever, 1957) and thin, calcareous horizons or limestone (Fraunfelder, 1979), indicating marine influences during deposition.

Several sandstones at approximately the Finnie and Grindstaff stratigraphic level have produced hydrocarbons. A sandstone in the Cairo, Dixie, and Dixie West Fields of Henderson County produced both oil and natural gas from this interval. The sandstone was considered one of the largest oil-producing reservoirs in the Pennsylvanian strata of western Kentucky. In the Dixie West Field the reservoir was converted to gas storage with a total capacity of 7,114,500 mcf (Fairer, 1973a). A sandstone identified as the Finnie also produced oil in the eastern part of the Morganfield South Field in Union County (Wood, 1955).

In the Niagra, Euturpe, and Rangers North Field of eastern Henderson County, two thin sands at depths of 600 to 700 feet were significant producers in the area (Fig. 25). Individually the sands are 5 to 20 feet thick, but they may merge into a single sand body, called the "Niagra" sand by drillers, that is 20 to 40 feet thick.

W. Ky. No. 2 Coal to W. Ky. No. 4 Coal Interval Coals

As many as eight coals may occur between the No. 2 and No. 4 coals (Kehn, 1974a). The stratigraphic position of these coals is difficult to determine because of historical confusion in the numbering of coals and naming of limestones in this interval. Several of the coals are extensive enough to be mapped across several quadrangles and are discussed in the following sections.

Griffin/Knight No. 1, W. R. Walton Co.
16-0-25, Henderson Co.

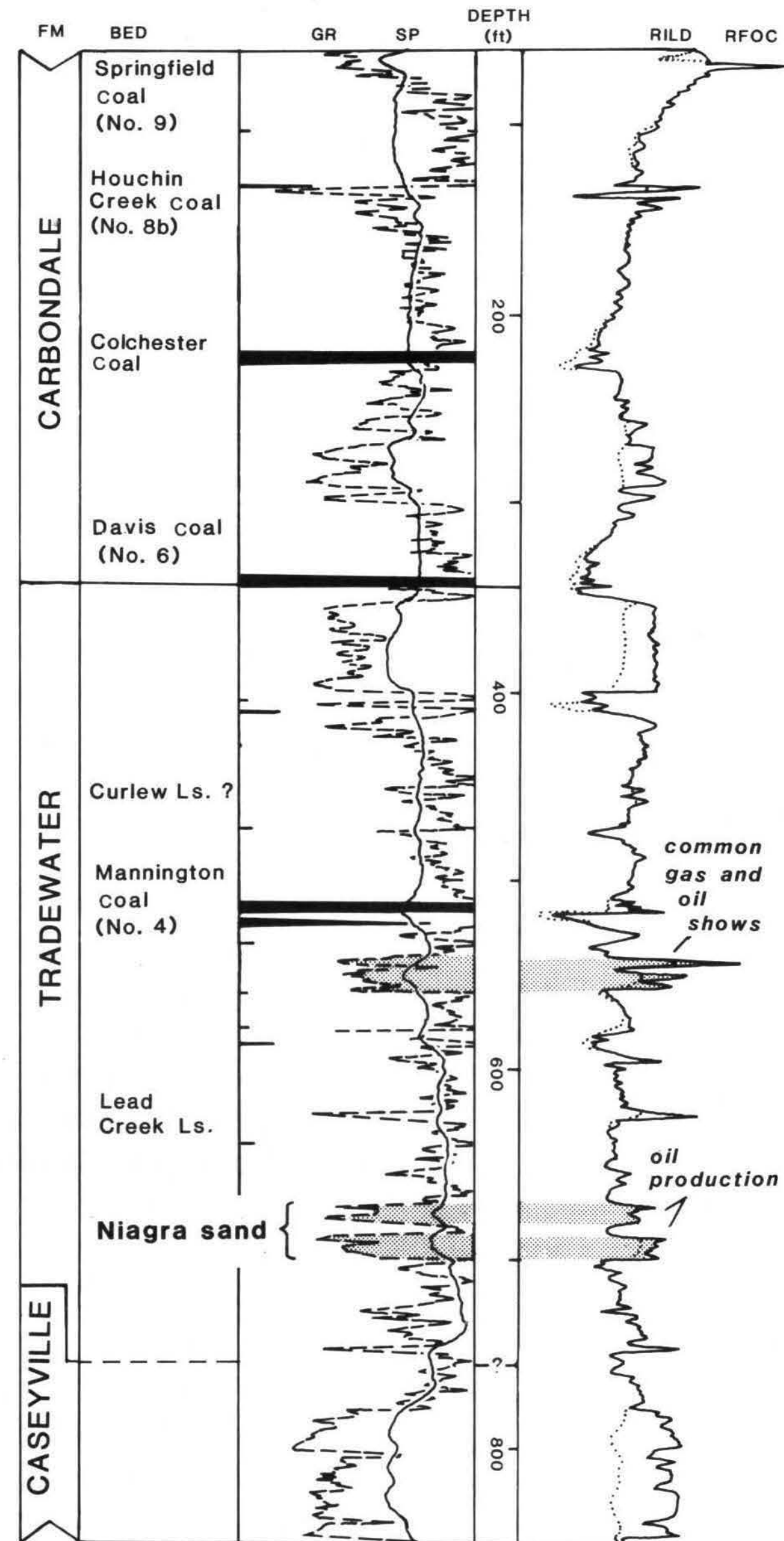


Figure 25. Dual-induction focused and gamma-ray log from the Niagra Consolidated Field showing Tradewater oil and gas sands (stippled) in eastern Henderson County.

Many are locally mined (Fig. 9). Other coals at this relative stratigraphic level are only local in extent. The Top-miller coal of Butler County and the James Mason coal of Hancock County are examples (McFarlan, 1943). A coal called the Mud River (Crider, 1915b) was mapped in parts of Muhlenberg County, where it reaches 40 inches in thickness and was reported to be deep mined prior to 1971 (Hansen, 1974). Since 1971, mining has primarily consisted of small surface operations. Another coal at a similar stratigraphic level is the Truman Hill coal. This coal occurs 45 to 70 feet above the Deanfield coal and was mapped in parts of Butler County (Johnson and Smith, 1968). A coal called Smith by Lee (1916) was reported to occur 275 feet above the Bell coal. For many years the Smith was considered a miscorrelation of the Bell coal, but Williams and others (1982) noted several distinctly separate coals above the Bell that could be the Smith coal. The Smith coal was considered older than the Dunbar (Lead Creek) coal of the Morgantown and Hancock Districts (Peppers and Popp, 1979).

Ice House Coal (W. Ky. No. 3)

This coal was named by Owen (1856) for a mine near an ice house in Union County south of Dekoven (Carter coordinate location 6-M-18, 3,000 FSL X 1,800 FWL). The coal was reported to be more than 2 feet thick at the mine, but is absent 0.5 mile north of the mine (Williams and others, 1982). Eastward, the coal is thin and split (Lee, 1916). The Ice House coal occurs approximately 20 feet above the Finnie sandstone and 400 feet below the Davis coal (Fig. 22).

Amos and Foster Coal Zone

The Amos coal (Fig. 26) was named for openings along Big Bull Creek in the Little Muddy Quadrangle (Crider, 1915c). The Foster was named by Crider (1915c) for a 30-inch seam mined above the Amos along Bull Creek. The Foster has been reported to be as much as 48 inches thick in Butler County (Gildersleeve, 1972a), where it is extensively mined. The Amos and Foster zone is extensive in the Morgantown District and may contain as many as four coals in an interval 40 feet thick (Fig. 27). In Butler County a bed locally called the Jetson coal, which occurs within the Amos and Foster interval, is mined. The coals are often cut out by 10- to 40-foot-thick, crossbedded sandstones. Both coals and intervening rock units exhibit patchy, heterogeneous distribution.

The Amos and Foster coal zone occurs 200 feet below the top of the Lead Creek Limestone in the Morgan-

town District (Fig. 22). The Amos is a low-sulfur (1.2 percent), low-ash (3.9 percent) coal, and is the most persistent of the four coals. The low percentage of sulfur and ash are inferred to have resulted from deposition in swamps protected from detrital influence, where peat accumulated under fresh-water conditions. The Foster has higher sulfur (2.7 percent) and ash (7.7 percent) contents, which are inferred to represent peat accumulation under brackish-water influences with intermittent detrital influx from adjacent distributary channels (Williams and others, 1990).

Mullins and others (1963) determined a resource of 26,790,000 tons in place for the Foster coal and 10,602,000 tons in place for the Amos and Gidcomb coals. Mullins and others (1963) considered the Amos and Gidcomb to be equivalent units. However, subsequent correlations have indicated that the Gidcomb is a separate coal occurring 20 to 50 feet below the Amos coal (Williams and others, 1990). The combined Amos and Foster remaining resource is considered to be less than 23,206,000 tons (Smith and Brant, 1980).

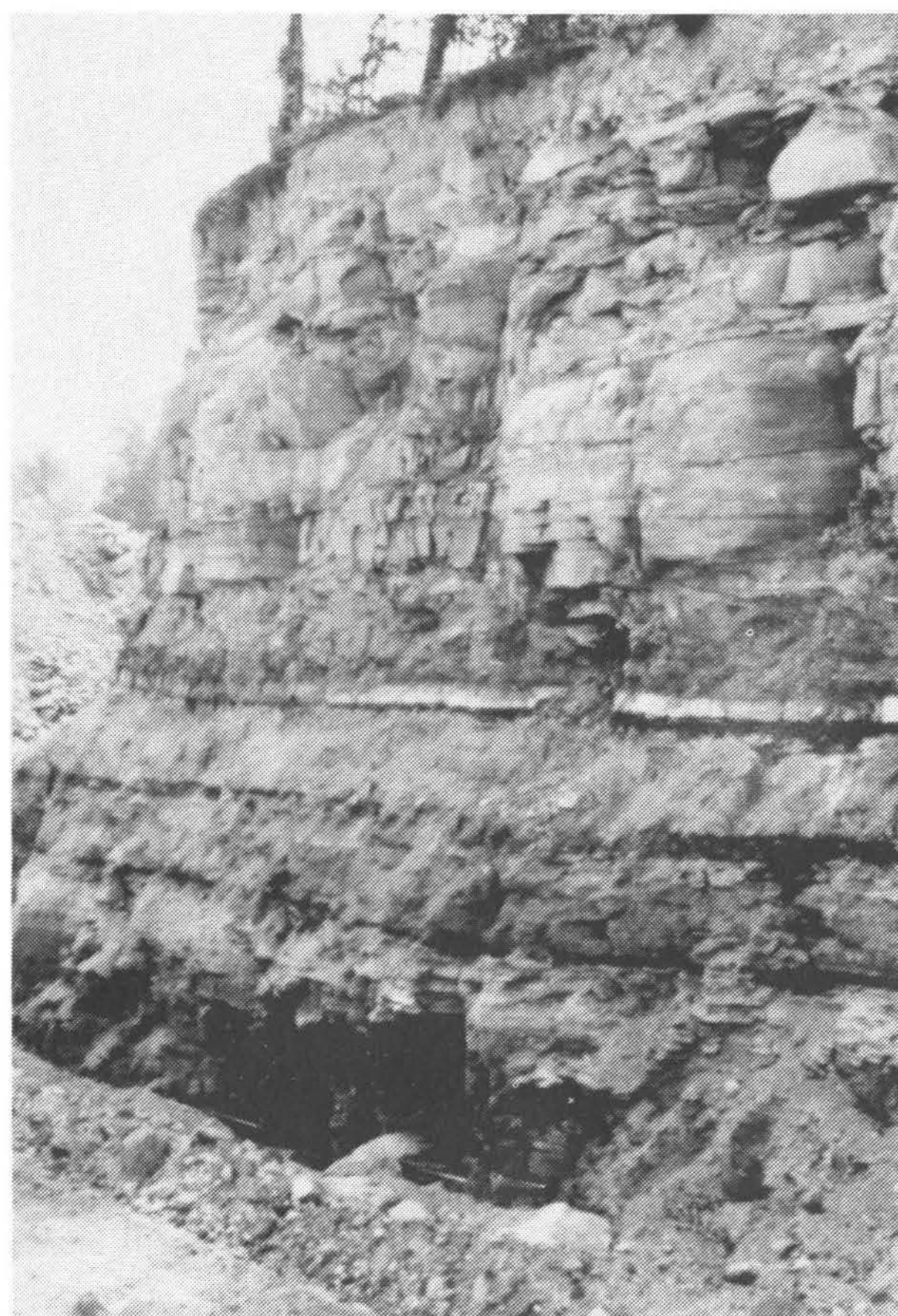


Figure 26. Amos coal strip bench from the Riverside Quadrangle, Butler County.

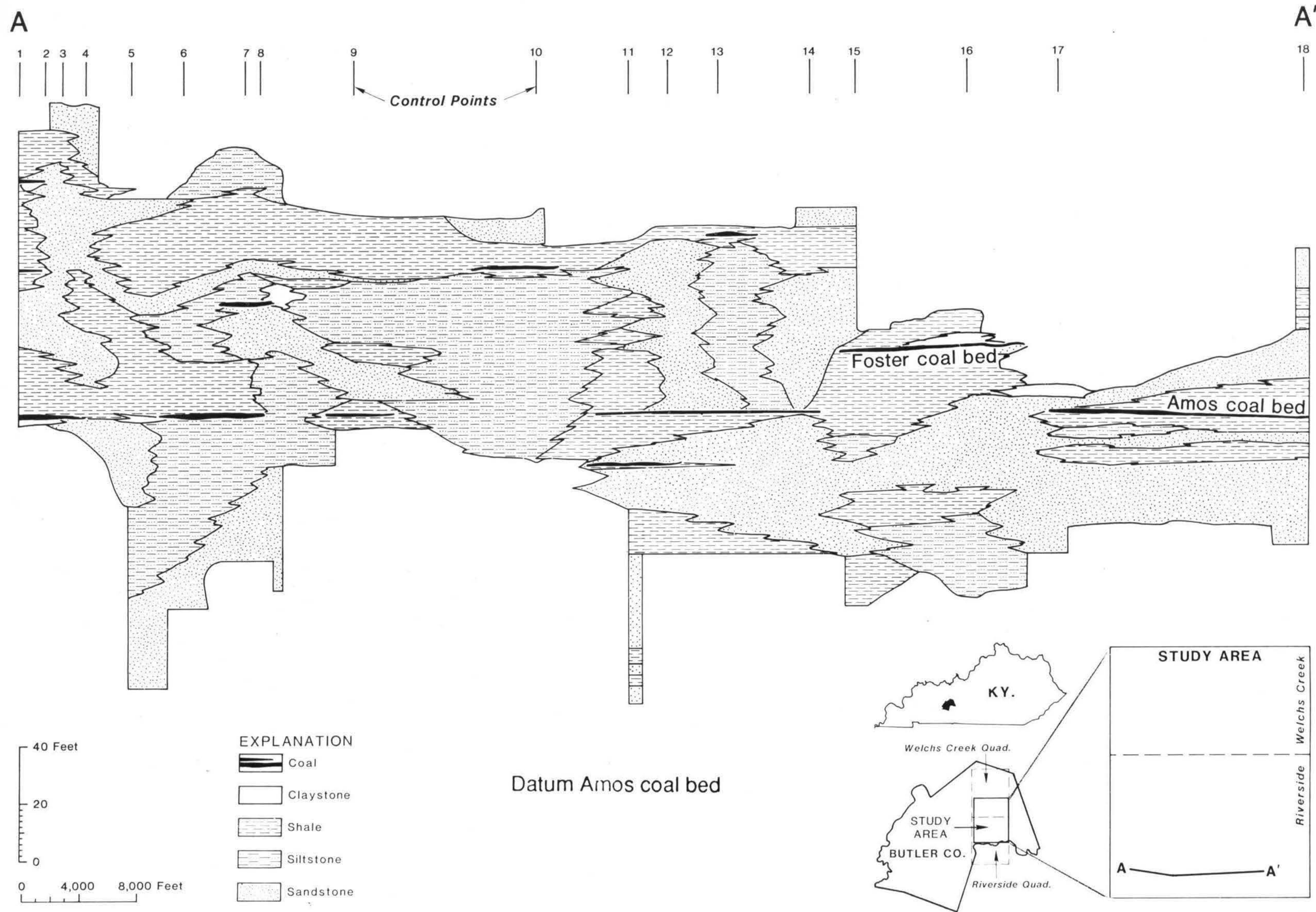


Figure 27. East-west cross section across part of Muhlenberg County showing the Amos and Foster coal beds (from Williams and others, 1990, Fig. 7, p. 10).

Aberdeen Coal and Sandstone

The Aberdeen coal (Fig. 22) was named for a coal 90 to 100 feet above the Foster coal in Butler County (Crid-er, 1915b). The coal is only mapped on a few geologic quadrangle maps in the Butler County area (Mullins and others, 1963; Shawe, 1968; Gildersleeve, 1972a). The Aberdeen coal is 0 to 30 inches thick and is overlain (and in some areas cut out) by the Aberdeen sandstone (Crid-er, 1915b; Shawe, 1968). The Aberdeen coal was corre-lated with the Dunbar and Elm Lick coals by Mullins and others (1963). However, the correlation of the Aberdeen to the Dunbar appears to be a mistake. Correlations of coals in the upper Tradewater are difficult because of the variation and subsequent miscorrelations of coals and limestones. More work is needed with closely spaced subsurface data to correlate the many seams of the Tradewater.

The Aberdeen sandstone (Crid-er, 1915b) extends from the Aberdeen coal upward to within a few feet of the Lead Creek Limestone (Fig. 22). At the type locality, the sandstone is composed of 100 feet of fine- to medium-grained sandstone with laminations of dark-gray shale. The Aberdeen sandstone may extend into the southern part of Ohio County. Confusion between the Lead Creek and Curlew Limestones has led to misapplication of the name Aberdeen to a sandstone that is actually below the Curlew Limestone in the Madisonville District.

Elm Lick Coal

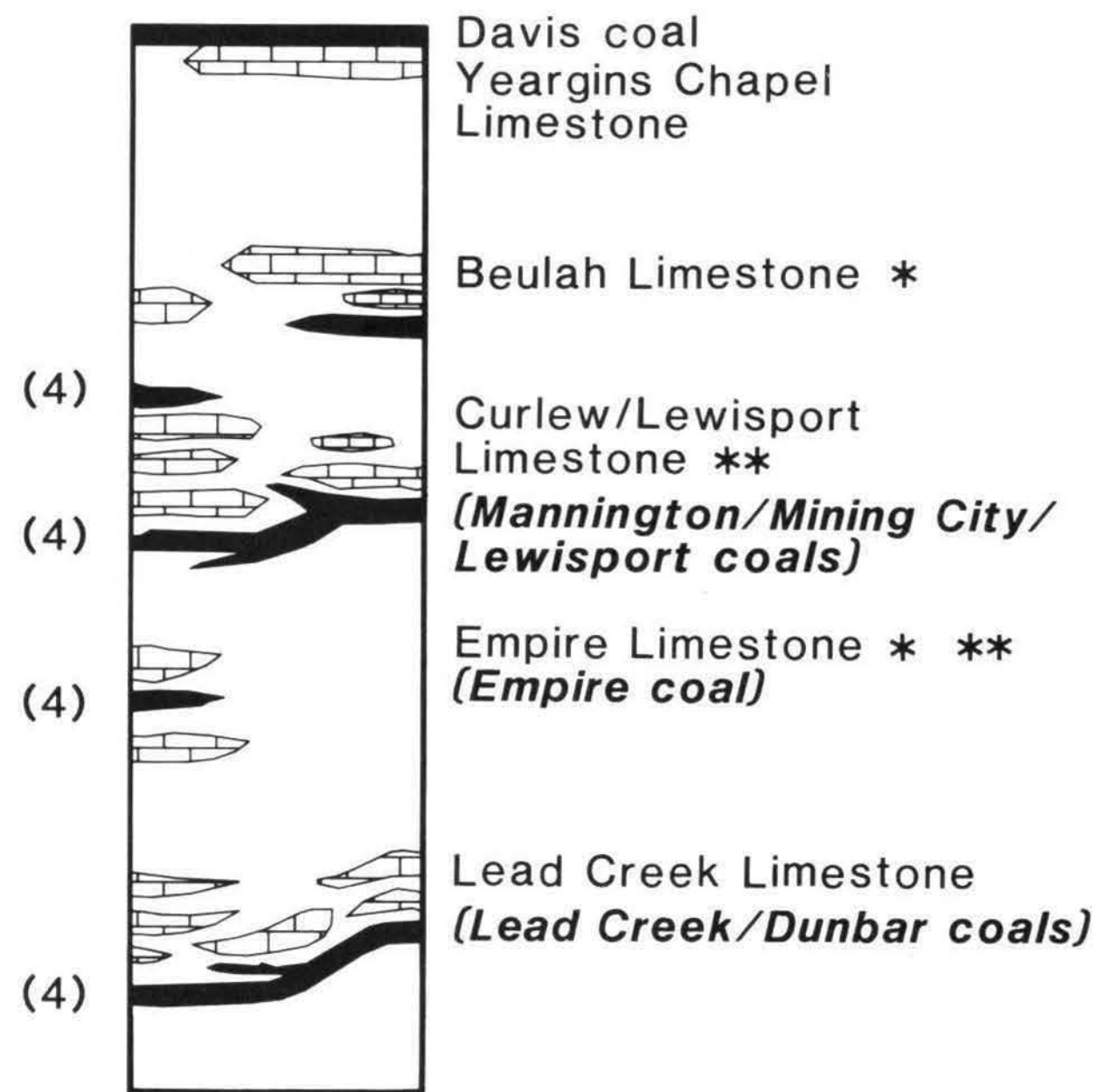
The Elm Lick was named by Norwood (1880) for mines along Elm Lick Creek near Hartford, Ohio County, Kentucky. The coal was extensively measured by Gard-ner (1927) in Ohio and Butler Counties. Gardner (1927) noted that the coal had a limited mineable extent and was quite variable in thickness. He also noted that the coal was overlain almost everywhere by a thick sand-stone correlated with the Aberdeen sandstone. If this sandstone is the Aberdeen sandstone, then the Elm Lick coal is equivalent to the Aberdeen coal of Butler County (Fig. 22). The Elm Lick and Aberdeen coals were appar-ently miscorrelated with the Dunbar coal by Mullins and others (1963). The Elm Lick probably only has a limited geographic extent, as originally suggested by Gardner (1927).

During the U.S. Geological Survey-Kentucky Geo-logical Survey Cooperative Mapping Program, the Elm Lick coal was only mapped on the Rosine and Horton geologic quadrangle maps in Ohio County (Johnson, 1971a-b). On the Horton Quadrangle it was thought to be a good enough stratigraphic marker to be used as a color break. The coal ranges from 0 to 3.5 feet in thick-ness, may contain partings up to 1.5 feet in thickness,

and is commonly truncated or cut out by a thick sand-stone (Johnson, 1971a-b). Thick Elm Lick coal (greater than 42 inches) occurs in a thin belt that extends from Hartford, Ohio County, southeast to the Ohio-Butler-Grayson county line (Smith and Brant, 1980).

Dunbar/Lead Creek Coal

The Dunbar coal (Fig. 22) was named for openings near Wards School in the Dunmor Quadrangle (Crid-er, 1915b). It was originally considered equivalent to the Mannington, Empire, and Dawson Springs coals (Crid-er, 1915b), although it subsequently was determined not to be equivalent. Miscorrelations resulted from the simi-larity of the Dunbar coal and limestone, Mining City coal and limestone, and W. Ky. No. 4 coal and Curlew lime-stone sequences (Fig. 28). In Hancock County, Peppers and Popp (1979) placed the Dunbar coal beneath the Lead Creek Limestone. Unpublished fusulinid studies by the U.S. Geological Survey of limestones in the Dun-bar interval indicate that the Dunbar is probably equiva-lent to the Lead Creek coal in the Hancock County Dis-trict and an unnamed coal beneath the limestone under the Empire coal in the Madisonville District (Williams and



- (4) Previously called No.4 coal in parts of the coal field
- * Miscorrelated in parts of the coal field as Lead Creek Limestone
- ** Miscorrelated in parts of the coal field as Curlew Limestone

Figure 28. Generalized geologic column through part of the Tradewater Formation showing the coals that have been called No. 4 based on miscorrelations of overlying lime-stones.

others, 1982). Hence, the coal mapped on geologic quadrangle maps as W. Ky. No. 4 in the eastern part of the coal field (Gildersleeve, 1972a–b; Moore, 1974) may actually be the Dunbar coal. Similar miscorrelations occurred across the coal field with coals mapped as No. 4 through No. 6 (Kehn and others, 1967).

The Lead Creek coal of Hancock County was named for a thin coal beneath the Lead Creek Limestone (Spencer, 1963, 1964a; Calvert, 1964). The coal is generally thin but may reach thicknesses in excess of 4 feet (Spencer, 1963). Because of the correlation of the Lead Creek and Dunbar coals based on unpublished studies of fusulinids in limestones and spores in coals, Williams and others (1982) used the term “Dunbar” for coals 20 to 40 feet below the Lead Creek Limestone across the coal field (Fig. 22). The coal reaches thicknesses of 44 inches in Butler and Warren Counties (Shawe, 1968). The Lead Creek and Dunbar coals commonly have sulfur values from 5 to 8 percent, and ash values from 11 to 18 percent. However, the Dunbar is locally a low-ash (3.5 to 4.3 percent), low-sulfur (0.8 to 1.8 percent) coal in northwestern Butler and southeastern Daviess Counties, similar to the Amos and Foster coals lower in the section (Hower and others, 1982).

Lead Creek Limestone Member

The Lead Creek Limestone Member was named by Crider (1913) for several discrete limestone beds occurring in a 30- to 40-foot interval, about 255 feet above the Caseyville conglomeratic sandstones in Hancock County (Figs. 22, 24). The interval may be as much as 350 feet above the base of the Tradewater Formation in Muhlenberg County (Williams and others, 1982). Chisolm (1931) described the Lead Creek Limestone as a 5- to 11-foot-thick bed occurring from a few inches to 15 feet above the Lead Creek coal. On U.S. Geological Survey geologic quadrangle maps published between 1960 and 1970, the term was restricted to the lowest limestone bed in the interval. The top of the Lead Creek Limestone is placed at the top of the uppermost limestone bed, 30 to 40 feet above the base of the member.

The Lead Creek is the oldest Pennsylvanian bed correlated in all three of the western Kentucky mining districts; thus it is an important stratigraphic marker (Fig. 22). Correlation of the member between districts is based on paleontological (Shaver and Smith, 1974; Douglas, 1979) and palynological evidence (Peppers and Popp, 1979). In the Morgantown District, the Lead Creek Limestone is correlated with a limestone above the Dunbar coal that was previously miscorrelated as the Curlew Limestone (Fig. 28) (Williams and others, 1982), and in the Madisonville District the Lead Creek is

correlated with an unnamed limestone 100 feet below the Curlew Limestone. In the northern part of the Madisonville District, a limestone unit 500 to 600 feet below the Springfield coal, called the “Tradewater Limestone,” may be correlative with the Lead Creek Limestone. Confusion between the numerous limestones in the upper Tradewater has caused a wide variety of coal correlations since many of the coals are named or numbered by their relative positions in relation to specific limestones (Mullins and others, 1963; Kehn and others, 1967; Kehn, 1974a; Williams and others, 1982).

The type section of the Lead Creek Limestone in Hancock County consists of 10 to 30 feet of gray shale and multiple gray, argillaceous limestones with abundant brachiopods and large crinoid stems, capped by a 2- to 4-foot bed of sparsely fossiliferous, dense to lithographic limestone. To the south in the Morgantown District, the Lead Creek Limestone consists of three limestone beds, each separated by 20 to 40 feet of gray shale. The limestone beds are generally 2 to 5 feet thick, light to dark gray, and contain well-preserved brachiopods and crinoids. At some localities the middle limestone bed is siliceous and weathers to a conspicuous, porous chert containing abundant fossil molds and casts. To the west in the Madisonville District, the Lead Creek Limestone thins to a single bed of brown to gray, argillaceous, fossiliferous limestone (Williams and others, 1982). The uppermost bed of the Lead Creek Limestone is considered to be equivalent to the Ferdinand Limestone of Indiana, and the lower Lead Creek Limestone is considered to be equivalent to the Fulda Limestone in Indiana (Douglas, 1979).

Lead Creek Limestone to W. Ky. No. 4 Coal Interval

Several discontinuous coals occur in the Tradewater Formation within 100 feet of the Lead Creek Limestone. These coals are not regionally mappable but have been historically important to local economies. The Adair coal occurs within 25 feet of the top of the Lead Creek Limestone (McFarlan, 1943). A coal at the same position above the limestone called the White Ash coal was mined in the Hancock District (Spencer, 1963; Calvert, 1966). Several mines operated in this coal during the 1980's with an average annual production of nearly 250,000 tons per year, according to the Kentucky Department of Mines and Minerals (Fig. 9). Also, the underclay of the White Ash coal and the underclay of an unnamed coal 17 feet below the White Ash (10 feet above the Lead Creek Limestone) have been extensively mined in the Maceo area of Hancock County for use in bricks and tiles. Coals called Persimmon Run and Ma-

son were historically mined within 45 feet of the top of the limestone (Crider, 1913; McFarlan, 1943). A coal 65 to 75 feet above the base of the Lead Creek Limestone called the Red Ash coal was mined in Hancock County (Spencer, 1963). All of these coals are locally extensive and generally thin, but may thicken to more than 4 feet (Crider, 1913; McFarlan, 1943; Spencer, 1963; Calvert, 1966). A thin coal mapped as W. Ky. No. 4a on several geologic quadrangle maps in the eastern part of the coal field was mapped above what was thought to be the Curlew Limestone. However, subsequent correlations have indicated that the "4a" (Gildersleeve, 1972b; Moore, 1974) is probably a coal above the Lead Creek rather than the Curlew Limestone.

Sandstones at approximately this interval have had numerous oil shows and limited production in the Morganfield and Uniontown Fields of Union County; the Euturpe, Niagra, Rangers Landing, and Sebree Fields of Henderson County; and the Delaware Field of Daviess County (Schwalb and others, 1971; Fairer, 1973b; Johnson, 1973a). Gas shows are also common in fields in Henderson County. The reservoir in eastern Henderson County is sometimes called the "Niagra sand" by drillers, although it should not be confused with the main Niagra sand in the Niagra Field, which occurs 225 to 250 feet beneath it (Fig. 25).

Empire Coal

The Empire coal was named for large mines near Empire in Christian County (Glenn, 1912a; Crider, 1915d), where it occurs 100 feet below the Mannington coal (Fig. 22). The No. 4 or Mannington coal was correlated with the Empire coal (Glenn, 1912a; Crider, 1915d; McFarlan, 1943), but the thick coal mined near the town of Empire is stratigraphically lower (20 to 60 feet) than the Mannington (Williams and others, 1982). Stratigraphic confusion may have resulted from a similar lithologic sequence of coal overlain by limestone (Fig. 28). The Empire coal is limited to an area in northern Christian County, where it reaches thicknesses of 48 inches (Kehn, 1977; Trace, 1977). Mines in this area were abandoned before 1950 (Kehn, 1977), although the coal is still mined in small amounts nearby (Fig. 9).

Mannington/Mining City/Lewisport Coal (W. Ky. No. 4)

These three coals were recently correlated by Williams and others (1982), although before 1982 a wide range of nomenclature and application of the number "4" were used to designate coals in the upper Tradewater Formation (Fig. 28) (Kehn and others, 1967; Kehn, 1974a). The correlation of Williams and others (1982)

makes this coal zone the oldest correlated between all three coal districts (Fig. 22). It is known as the Mannington coal (Crider, 1915d) in the Madisonville District, the Mining City coal (Crider, 1915b) in the Morgantown District, and the Lewisport coal (Moore, 1878a) in the Hancock District.

The Mining City coal (Crider, 1915b) was named for a coal beneath a hard limestone near Morgantown in Butler County. During the U.S. Geological Survey-Kentucky Geological Survey Cooperative Mapping Program, the Mining City coal was mapped in the Morgantown Quadrangle as the coal beneath an unnamed limestone 90 feet above the Curlew Limestone, and thus above the No. 4 coal (Gildersleeve, 1972b; Moore, 1974). However, the Curlew was confused in the Morgantown area with another coal and limestone sequence (Fig. 28). Williams and others (1982) constructed cross sections across the coal field from Union to Butler County that suggest that the Mining City coal occurs beneath the Curlew Limestone in Butler County (Fig. 22). Problems in correlation across the coal field have resulted from stratigraphic confusion among the Curlew, Lead Creek, and other limestones in the upper Tradewater, and the numerous coals that have been called No. 4 (Kehn and others, 1967; Kehn, 1974a; Williams and others, 1982). The Mining City coal reaches thicknesses of 54 inches in the type area in Butler County (Gildersleeve, 1972b).

The Lewisport coal is noted throughout the northeastern part of the coal field, where it is often mapped as the coal beneath the Lead Creek Limestone (Spencer, 1963, 1964a; Calvert, 1964, 1966). The Lewisport coal of the Lewisport (Spencer, 1964a) and Pellville (Spencer, 1963) Quadrangles differs slightly from the Lewisport of the Maceo Quadrangle because subsurface information derived from near the borders of the quadrangles after 1964 was not available when the Lewisport and Pellville Quadrangles were mapped (Calvert, 1966). The Lewisport in this area ranges from 0 to 4.5 feet in thickness and may be split by up to 5 feet of shale. Williams and others (1982) constructed cross sections from Daviess to Butler County in which the Lewisport of Daviess County was correlated with the Mining City coal (above a limestone called Lead Creek and below a limestone called Curlew). The coal beneath the Lead Creek Limestone in the Daviess County area was correlated with the Dunbar coal (Williams and others, 1982). The underclay of the Lewisport coal was historically mined for use in clay products in Daviess and Hancock Counties (Calvert, 1964; Spencer, 1964a).

The Mannington coal was named by Crider (1915d) for a coal beneath a thin, impure limestone near Mannington in the Nortonville Quadrangle. When the Norton-

ville Quadrangle was remapped during the U.S. Geological Survey-Kentucky Geological Survey Cooperative Mapping Program, the No. 4 coal was mapped beneath the Curlew Limestone and was correlated with the Mannington, Cates, Empire, and White Plains of Crider (1915d) by Palmer (1968). Thus, the Mannington was mapped as the No. 4 coal beneath the Curlew Limestone Member, following the use of the No. 4 by Kehn and others (1967). It has also been called the Belton and No. 6 coal in Muhlenberg County (Hansen, 1972). A 6-foot seam of Mannington coal was reported near the type section (Crider, 1915d), but the Mannington (and No. 4 as mapped on geologic quadrangle maps in the Madisonville District) is generally between 36 and 48 inches thick. The Mannington of Hopkins County was correlated with the Mining City of Butler County by Williams and others (1982).

As presently correlated, the Mannington, Mining City, and Lewisport coals are considered equivalent, occurring from 2 to 60 feet beneath the Curlew Limestone (Fig. 22). Bed sequences at this level may be similar to the typical Illinois cyclothem as described by Kosanke and others (1960), with two limestone beds and a fissile black shale above the coal (Fig. 29). However, the complete Illinois cyclothem is rarely preserved in the Trade-water Formation of Kentucky (Whaley and others, 1979). Although the Mannington/Mining City/Lewisport coals can be correlated across the coal field, the thickness of the coal is quite variable (Shepard, 1980; Baynard and Hower, 1984). Isolated patches of thick Mannington coal (Fig. 30) may have been caused by an undulating paleotopography. Rock sequences beneath the coal consist of thin (less than 20 feet), heterogeneous sandstone and shale, in contrast to the more persistent (and theoretically more stable) Davis coal above, which is underlain by thick (30 to 50 feet), more homogenous rock sequences (Baynard and Hower, 1984). Variability in thickness is accompanied by variability in sulfur values and maceral types that may also be related to varying degrees of marine inundation around the irregularly distributed Mannington peat swamps (Hower and others, 1982; Baynard and Hower, 1984).

The Mannington/Mining City/Lewisport coal is the fourth largest coal in the Western Kentucky Coal Field, with an estimated original resource of 6,585,894,000 short tons (Smith and Brant, 1980). Between 1980 and 1990 the combined production of No. 4 coals averaged approximately 1.5 million tons per year, according to the Kentucky Department of Mines and Minerals (Fig. 9). Coal analysis indicates a mean total sulfur value of 3.01 percent, ± 1.42 percent; mean Btu (daf) of 14,268, ± 449 ;

mean total moisture of 6.4 percent; and a mean ash value of 10.0 percent (Cobb and others, 1985). Although the Mannington has a reputation of being a relatively

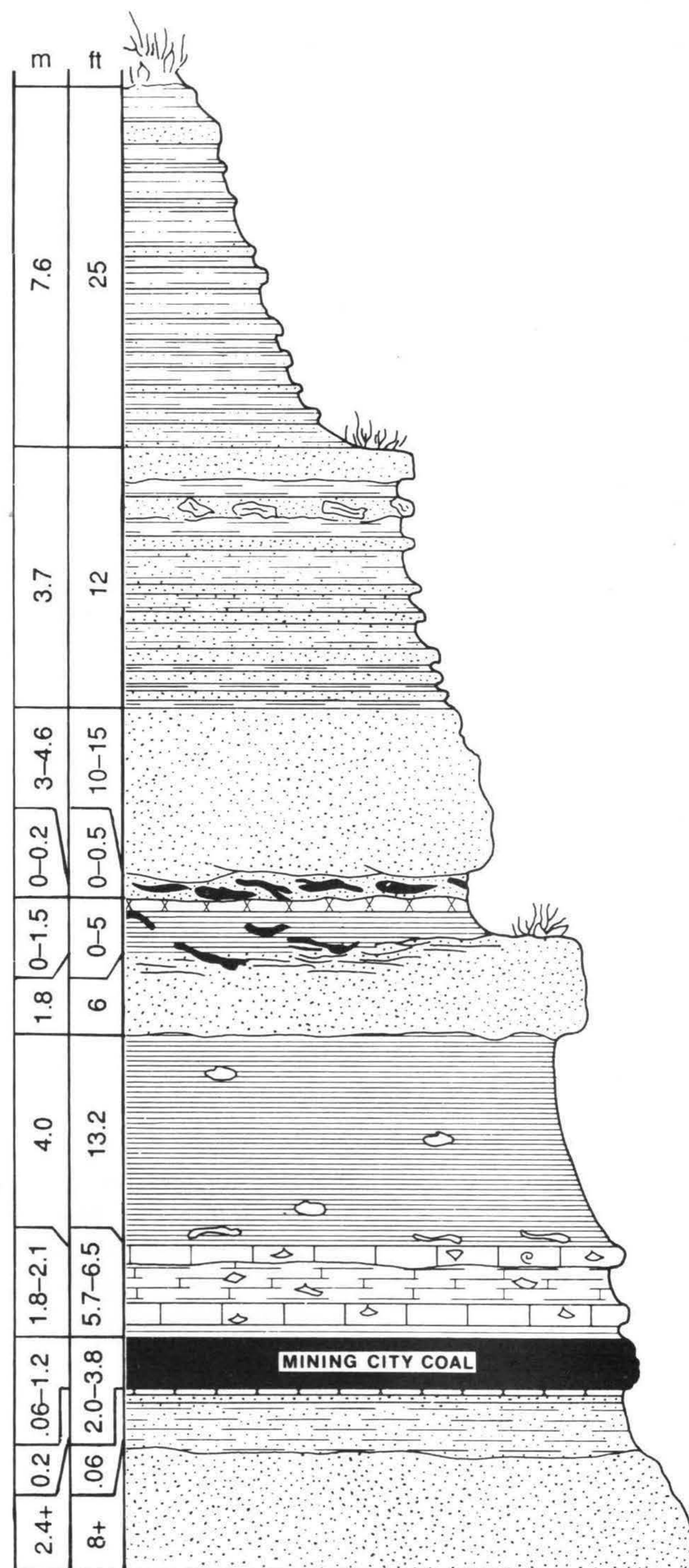


Figure 29. Geologic column of exposure at milepost 26 on the Green River Parkway showing the Mining City Coal and surrounding strata (modified from Whaley and others, 1979, Fig. 42).

low-sulfur coal, areas of low sulfur are discontinuous and probably controlled by original depositional environments (Hower and others, 1982).

Curlew Limestone Member

The Curlew Limestone Member was named by Owen (1856) for a limestone bed 175 feet below the top of the Tradewater Formation. The type section was established by Glenn (1922) at Indian Hill in western Union County where two limestone beds separated by 15 feet of shale were exposed. In a nearby ravine, a 60-foot interval with three limestone beds is exposed, and it is not clear if Glenn considered all three of the limestone beds as the "Curlew horizon." Later workers used the term to designate a single limestone bed that apparently is the lower limestone of the type section (Walker and others, 1951; Mullins and others, 1965; Kehn and others, 1967; Palmer, 1968; Kehn, 1974a). The upper limestone of Glenn (1922) was named the Beulah Limestone by Williams and others (1982).

The Curlew is 140 to 200 feet below the top of the Tradewater Formation (Figs. 22, 24). The Mannington (Mining City) coal occurs from 2 to 100 feet below the limestone. In some areas the "Curlew Sandstone" of Owen (1857b) replaces the limestone and Mannington coal. This sandstone was reported to contain bryozoan remains (Siever, 1957). Although the Curlew locally is cut out by the sandstone, it is persistent enough to be a

useful stratigraphic marker around the southern rim of the Madisonville District, where it is at or near the surface. In the subsurface, toward the center of the district, the limestone appears to be discontinuous.

The persistent limestone mapped in the Morgantown District as "Curlew" (Shawe, 1968; Gildersleeve, 1972b) is considered to be correlative with the Lead Creek Limestone that occurs lower in the section (Douglas, 1979). The actual correlative of the Curlew in the Morgantown District is a previously unnamed limestone and calcareous shale above the Mannington (Mining City) coal bed (Fig. 31). The Curlew Limestone is correlative with the Lewisport Limestone in the Hancock District (Williams and others, 1982). The type section of the Curlew Limestone contains fusulinids known from the Selville Limestone Member of the Tradewater (previously Spoon) Formation in Illinois and the Perth Limestone Member of the Staunton Formation in Indiana (Douglas, 1979). A unit named the "Curlew Limestone" of Illinois is younger than the type Curlew of Kentucky (Douglas, 1979).

Curlew Limestone to Yeargins Chapel Limestone Interval

This interval ranges from 140 to 250 feet in thickness. It is generally composed of shale with thin coals, carbonaceous shales, and limestones. In Union County a thin (less than 24 inches) coal occurs just above the Curlew Limestone and is called the Curlew coal (Owen, 1857b). It has also been called the No. 4 coal (Kehn, 1974a), although No. 4 has been applied to many coals in the upper Tradewater. A thin coal 40 feet above the Curlew was mapped as No. 4a on several geologic quadrangle maps in the southeastern part of the coal field (Gildersleeve, 1972b; Moore, 1974), but the Curlew appears to have been miscorrelated with the Lead Creek Limestone in the area where the No. 4a is mapped; therefore, a coal numbered "4a" would actually occur higher in the section (Fig. 31).

As many as 10 coal beds and four limestone beds have been reported in this interval (Kehn, 1971). Most of these beds are regionally discontinuous, but some are persistent throughout a single coal district. The No. 5 coal is mentioned in several reports on the coal field (Owen, 1856, 1857b; Glenn, 1912a; Lee, 1916; Kehn and others, 1967), but because it is thin and discontinuous it was only mapped in a small part of Hopkins County during the U.S. Geological Survey-Kentucky Geological Survey Cooperative Mapping Program (Palmer, 1968). At about the same stratigraphic interval as the No. 5 coal (100 feet above the No. 4 coal), Kehn (1971) mapped the Bancroft coal in parts of Muhlenberg County. Two coals were noted between 80 and 100 feet above the No. 4

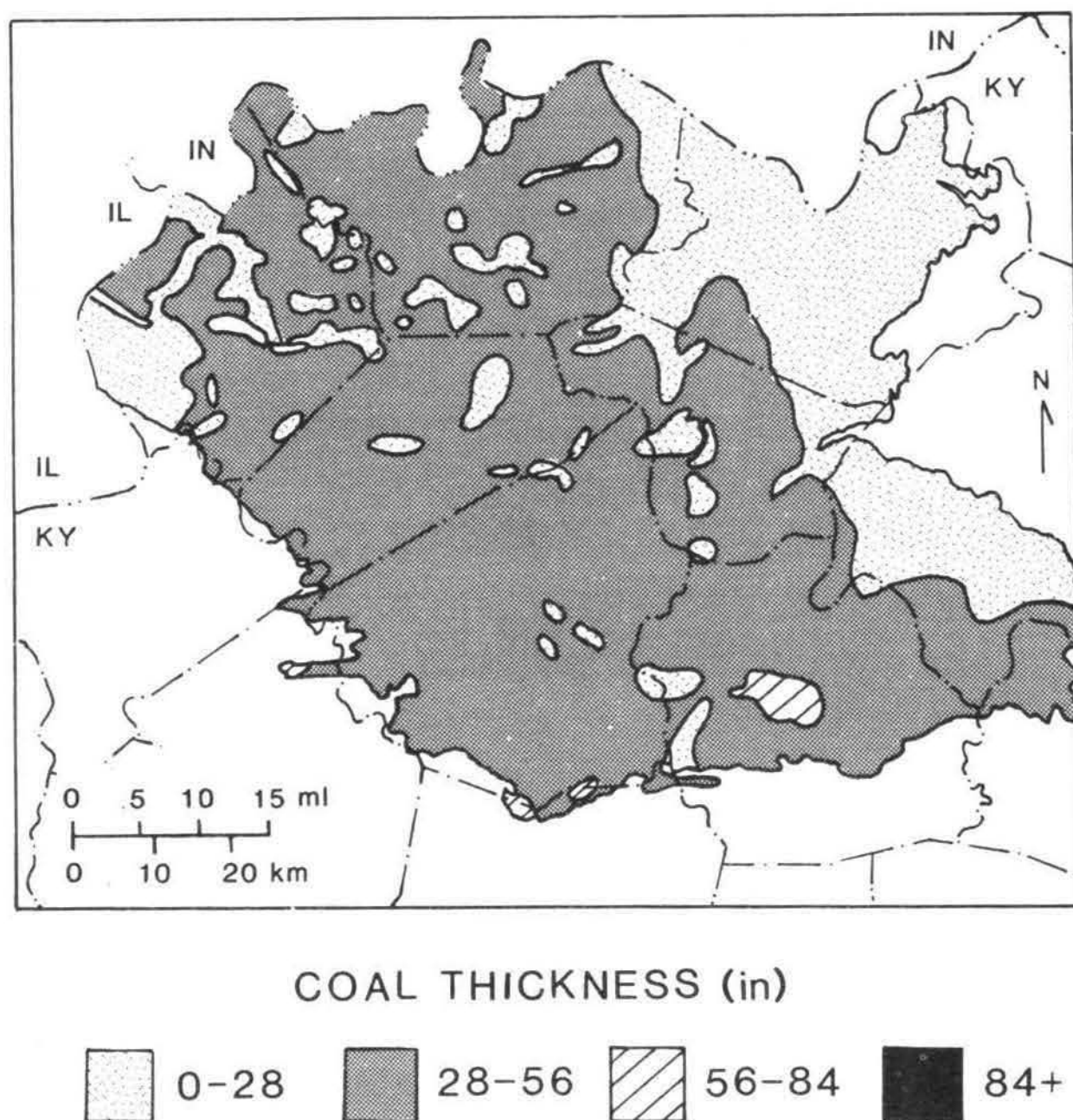


Figure 30. Isopach map of the Mannington/Mining City/Lewisport (W. Ky. No. 4) coal (modified from Smith and Brant, 1980).

coal in parts of Muhlenberg County, so the Bancroft may be distinctly separate from the No. 5 coal.

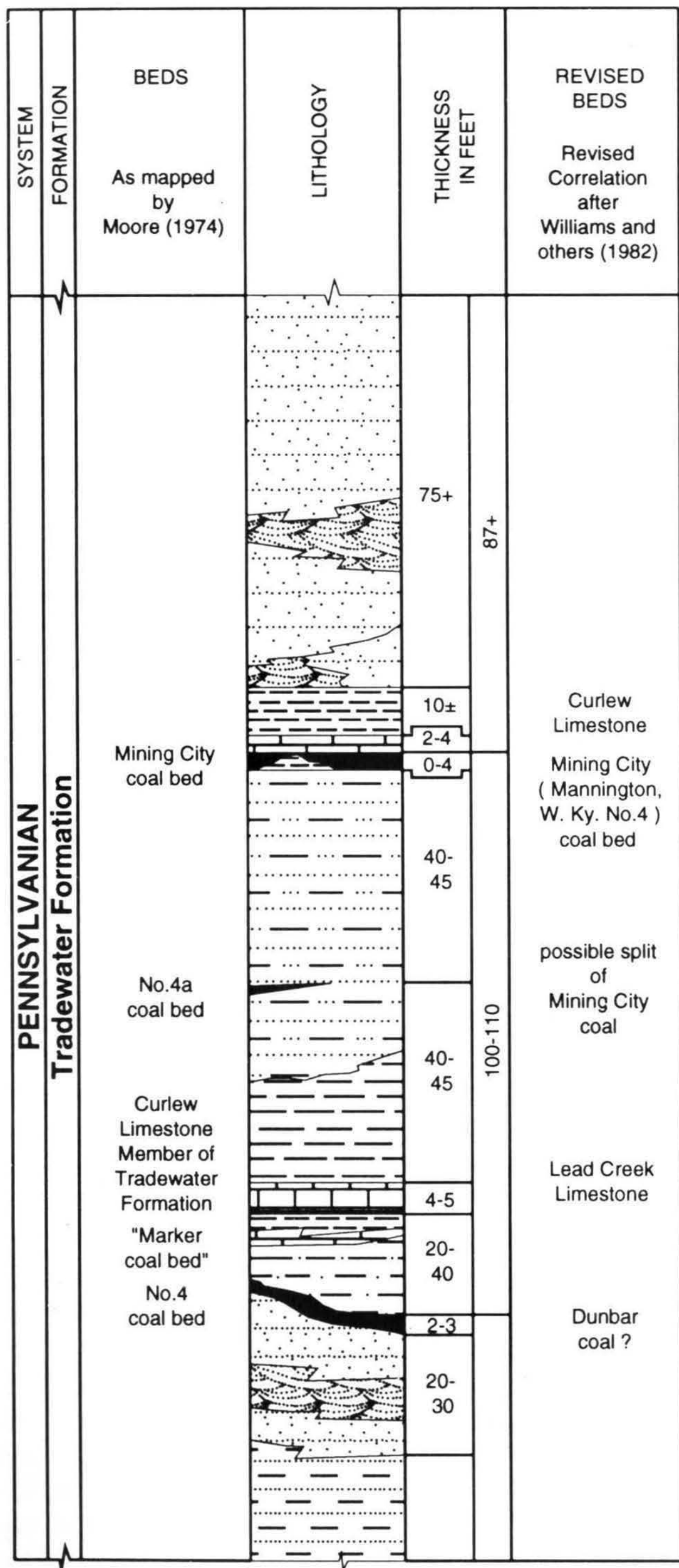


Figure 31. Example of a possible miscorrelation of limestones and coals in the South Hill Quadrangle (Moore, 1974), in which the Lead Creek Limestone was miscorrelated as the Curlew Limestone.

Two sandstone units, one near the top of the interval, the other in the lower part of the interval, occur over wide areas of the three districts (Fig. 22). These sandstones are generally less than 20 feet thick, but in the western part of the Madisonville District they occupy all of the Curlew to Davis interval. The lower sandstone is called the Curlew (Owen, 1856) and may truncate the underlying Curlew Limestone and Mannington coal. The upper sandstone may be correlative with the Granger Sandstone of Illinois (Kosanke and others, 1960). More work is needed in the limits of these rock bodies in the Curlew to Yeargins Chapel interval.

Sandstones near the top of the Tradewater in the Mount Carmel and Central City Fields of Muhlenberg County have produced numerous, shallow (less than 550 feet), low-yield gas wells (Jillson, 1931; Schwalb and others, 1971; Palmer, 1972). Some shut-in wells exhibited open flows of between 983,000 and 1,000,000 cubic feet per day. A sandstone at this interval near Richland in Daviess County is also a local aquifer for domestic well and oil-field waterflooding (Davis and others, 1974).

Yeargins Chapel Limestone Member

The Yeargins Chapel Limestone is named for outcrops near Yeargins Chapel in Muhlenberg County (Whaley and others, 1979). It occurs a few inches to a few feet beneath the Davis coal bed (at the base of the Carbondale Formation) and is persistent in the eastern part of the Western Kentucky Coal Field, where it is colloquially identified as the "No. 6 limestone" (Douglas, 1979). In the eastern part of the coal field where the Davis coal bed is absent, the upper boundary of the Tradewater Formation is placed at the top of this limestone (Figs. 22, 24).

The Yeargins Chapel is a relatively pure, fine-grained, medium-gray, 5- to 15-foot-thick limestone. It may be cherty and is moderately fossiliferous. It becomes increasingly argillaceous to the west and grades into a claystone seat rock with limestone nodules in the Madisonville District.

CARBONDALE FORMATION

Nomenclature History

The Carbondale Formation was named for exposures in the vicinity of Carbondale, Illinois (Lines, 1912; Shaw and Savage, 1912), and the term was introduced into Kentucky by Lee (1916). Glenn (1923) placed the lower boundary of the Carbondale at the base of the Seebree sandstone and the upper boundary at the base of the Anvil Rock sandstone (Fig. 10). However, both of

these units have very irregular thicknesses and make poor boundaries.

During the U.S. Geological Survey-Kentucky Geological Survey Cooperative Mapping Program of the 1960's and 1970's, the boundaries of the Carbondale were changed to coals that were believed to have more uniform distribution (Fig. 10). The lower boundary of the Carbondale was moved to the base of the Davis coal bed, and the upper boundary was moved to the top of the Herrin coal bed (Williams and others, 1982).

The term "Carbondale" was the only stratigraphic name common to all three states in the basin, but the term was defined differently in all three states (Fig. 11). The base of the Carbondale in Illinois was placed at the base of the Colchester Coal (Kosanke and others, 1960). In Indiana the Carbondale had group status and contained the Linton, Petersburg, and Dugger Formations (Shaver and others, 1986). The base of the Carbondale in Indiana was formerly placed at the top of the Seelyville coal (a Davis equivalent). The top of the Carbondale in Indiana and Illinois was placed at the top of the Danville coal (Willman and others, 1975; Shaver and others, 1986).

In 1990, Illinois and Kentucky agreed to the same boundaries for the Carbondale. Kentucky changed the top of the Carbondale from the top of the Herrin to the base of the Providence Limestone (Fig. 11). Since the Providence often rests directly on the Herrin coal, this difference is not significant, and does not affect the accuracy of the geologic quadrangle maps.

Formation Boundaries

The lower Carbondale Formation boundary is placed at the base of the Davis coal in the Madisonville District, except where the coal is absent in the eastern part of the district (Fig. 32). There the boundary is placed at the top of the Yeargins Limestone, which underlies the Davis (Fig. 32). The upper boundary is drawn at the base of the Providence Limestone, or where the limestone is absent at the top of the Herrin coal (Fig. 32). In Indiana, the upper contact of the Carbondale is placed at the Danville coal (above the Herrin) (Fig. 11).

Thickness and Extent

The Carbondale is present throughout most of the Madisonville Coal District, along the western edge of the Morgantown District, and in a few scattered outliers along the western edge of the Hancock District (Fig. 33). The formation is more than 400 feet thick in the western part of the coal field (Johnson and others, 1975), maintains a fairly consistent thickness over most of the basin,

and exhibits rapid thinning on the eastern flanks of the basin to a minimum of 195 feet (Gildersleeve, 1975). This geometry suggests that the Carbondale was deposited over a level, topographic surface. The broad area of uniform Carbondale thickness also suggests subsidence over a large part of the basin relative to a hingeline on the eastern margin of the basin, where the formation rapidly thins (Fig. 33). The many local, elongate variations in thickness were probably caused by

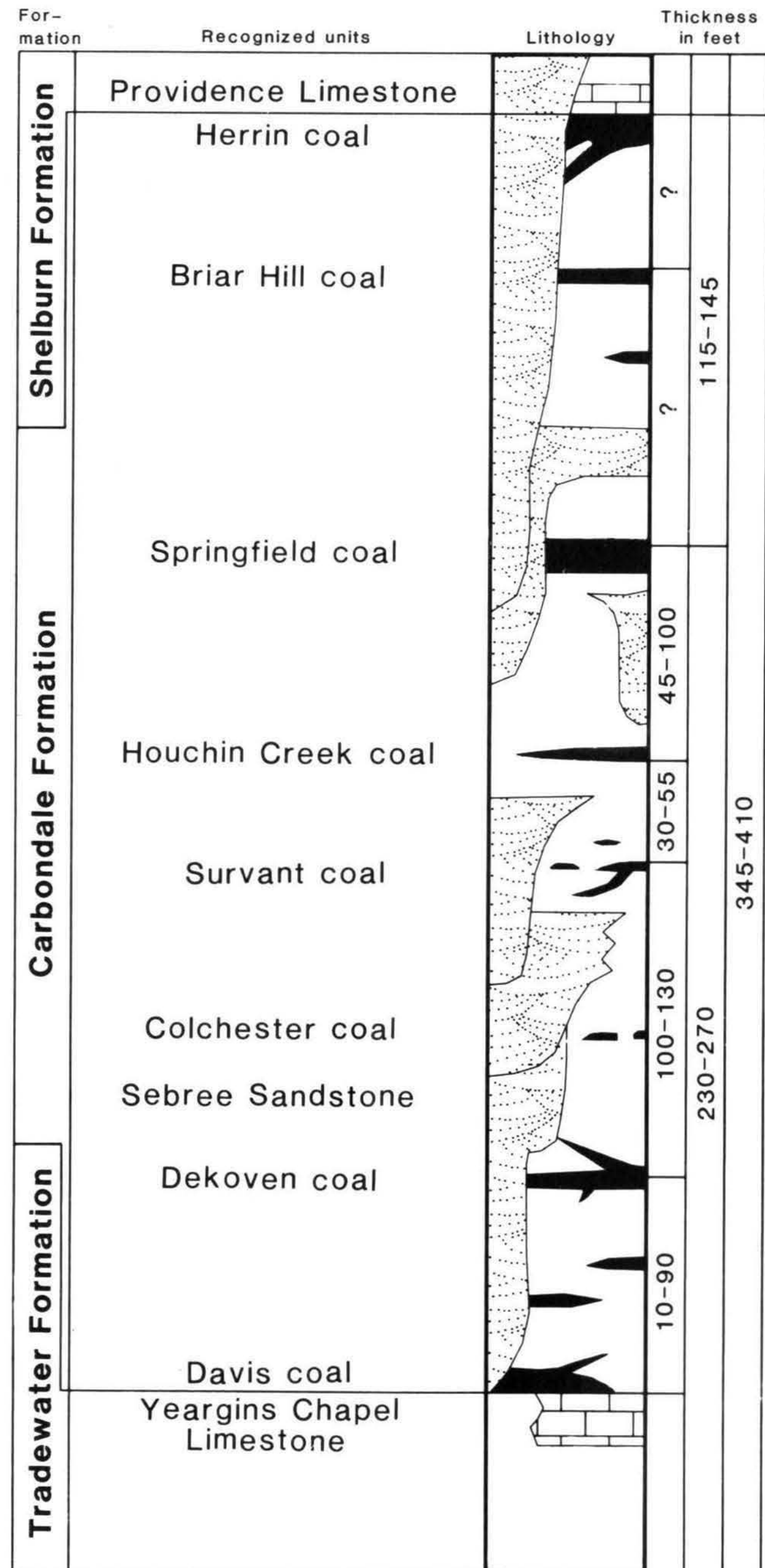


Figure 32. Generalized geologic column of the Carbondale Formation in the Madisonville District showing rock units discussed in the text.

narrow accumulations of sandstones within the Carbondale section that did not compact as much as lateral shales.

Cyclic Sequences

The rocks of the Carbondale in Kentucky can be subdivided into recurring, coarsening-upward sequences, each beginning with a coal and ending with the next higher persistent coal (Fig. 34). Subdivisions of cycles can be based on marine strata, coals, and scoured contacts at bases of channel sandstones (Moore, 1964). In general, the rocks are finer grained and darker at the base and become coarser grained and lighter upward. These repetitive sequences are similar to the classic cyclothems of Weller (1930) and Wanless and Weller (1932). The classic Midcontinent cyclothem consists of sequential marine strata and non-marine deltaic complexes (Wanless and Shepard, 1936; Wanless and others, 1969, 1970; Wanless, 1975).

Cyclothem origin has been attributed to both eustatic and tectonic controls. In the Kansas coal fields, cyclothems are dominated by marine facies with periodicities approximating Milankovitch orbital cycles, suggesting eustatic control (Ross and Ross, 1985; Heckel, 1986). In contrast, Appalachian Basin coal-bearing sequences are dominated by non-marine facies that were the product of superimposed eustatic and tectonic cycles (Chesnut, 1988). Quinlan and Beaumont (1984) suggested the sedimentation cycles were caused by migrating stresses along the continental margins. Klein and Willard (1989) proposed that the Illinois and western Kentucky cyclothems (containing approximately equal amounts of marine and terrestrial facies) were attributed to the remarkable coincidence of supercontinent development, concomitant glaciation in the southern hemisphere resulting in eustatic sea-level change, and associated episodic thrust loading and foreland basin subsidence on progressively more rigid crust.

Each of the cycles records sedimentation during a period of relative regression and transgression. During times of maximum regression, the coals were rapidly covered by shales (Figs. 34–35). Shales are fissile, dark gray to black, and may contain pyrite nodules, ironstone concretions, and marine fossils such as fish remains, conodonts, inarticulate brachiopods, and pectinoid pelecypods. Some of these shales have been used as stratigraphic markers because of their regional extent (Wanless and Weller, 1932; Weller, 1930). The shales become more calcareous upward, grading into thin limestone beds. Marine limestone beds mark maximum transgression. In western Kentucky, the marine limestone facies of the Illinois cyclothem is not common, but

may occur as thin lenses of argillaceous limestone or concretions grading laterally into fossiliferous shale (Fig. 35).

Following maximum transgression, prodelta muds (shales) were deposited as each deltaic complex prograded to the west and southwest (Wanless and others, 1969; Wanless, 1975). Upward, shales are lighter colored with macerated plant debris on bedding planes and common interlaminated siltstone and sandstone (Fig. 35). Siltstone beds are generally light to medium gray, micaceous, and ripple bedded. Locally, thick sandstone beds disrupt these sequences, causing abrupt vertical and lateral variations (Fig. 35).

Carbondale sandstone beds occur in two dominant facies: channel and interchannel (Hopkins, 1958; Beard and Williamson, 1979). In a single sequence, the interchannel facies occurs above dark-gray shales and siltstones, and beneath thin limestones and coals. These sandstones are light to medium gray (generally weathering to tan), fine to medium grained, thin bedded with abundant muscovite and interstitial clay, and generally exhibit a sheet-form geometry.

The channel-fill sandstone facies is less abundant than the interchannel facies. It consists of light-gray (weathering tan to brown), medium- to coarse-grained, thick-bedded sandstone, with less muscovite and interstitial clay than the interchannel facies. Channel-fill sandstones are commonly lenticular in cross section, crossbedded, and exhibit conglomerate lags of ironstone, lithic pebbles, and detrital coal. The lower contact of the channel-fill facies is generally sharp; the upper contact commonly is gradational (Harvey, 1956; Wanless, 1975; Beard and Williamson, 1979).

Coals may cap both of the sandstone facies. The coals are commonly banded with numerous thin fusain and claystone partings, and have medium to high sulfur contents. Rooted claystone is common just beneath the coals that cap each sequence. Claystones may contain nodules of nonfossiliferous limestone or dolomite.

Differences in sandstone or limestone content, overall thickness, and the occurrence of highly radioactive bituminous shale are some of the variations that provide each cyclic unit in the Carbondale a distinctive aspect, both aerially and stratigraphically (Wanless, 1955, 1975; Kosanke and others, 1960; Baird and Shabica, 1980; Trask, 1987). These differences also cause significant correlation problems. Cyclothems were used as mapping units in western Illinois and in parts of the Midcontinent region, but their use in mapping failed to gain acceptance in western Kentucky.

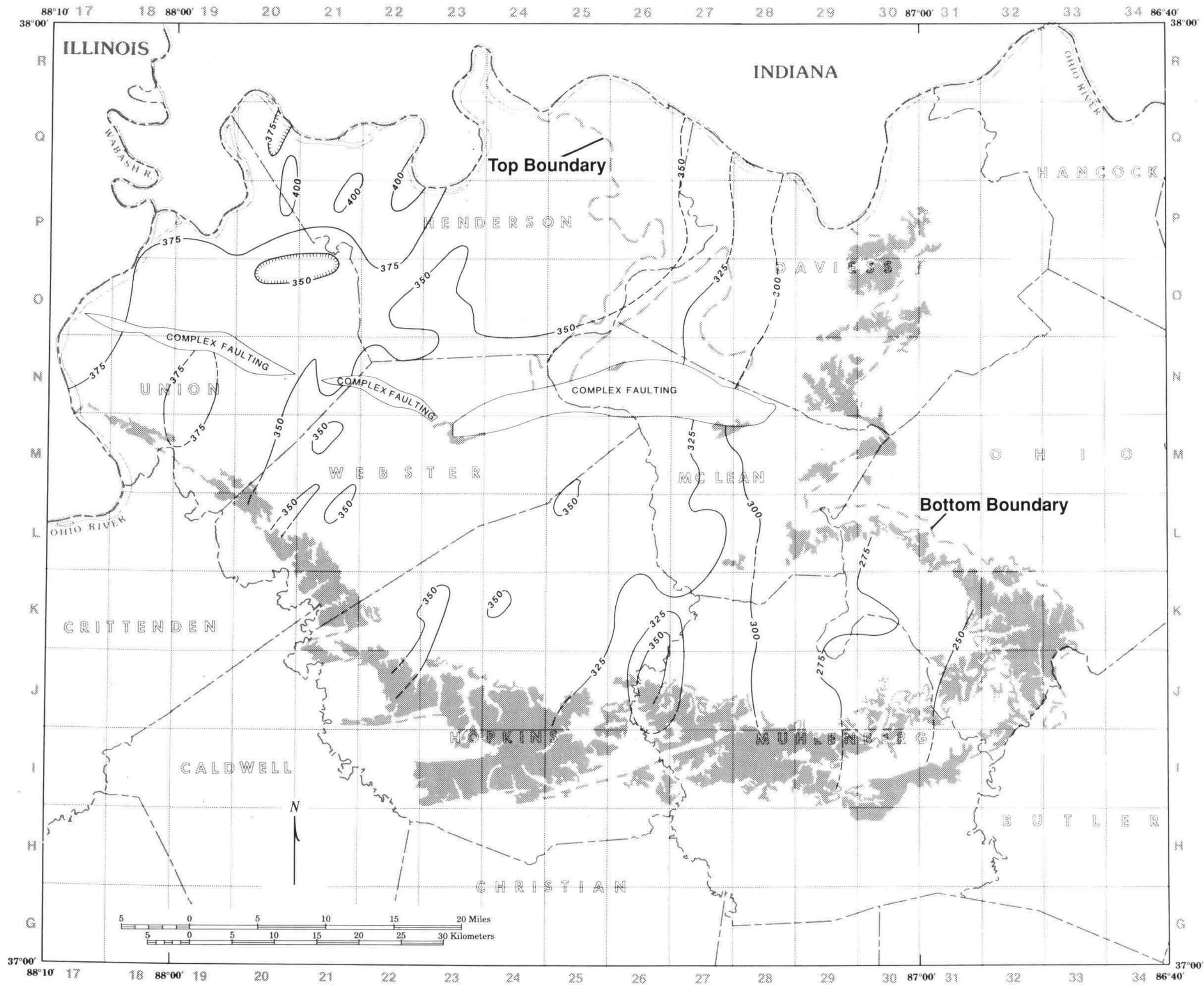


Figure 33. Isopach map of the Carbondale Formation. Outcrop area shaded. Top of formation shown by gray dashed line in the northern part of the coal field where the top of the formation is a significant distance from the outcrop margin.

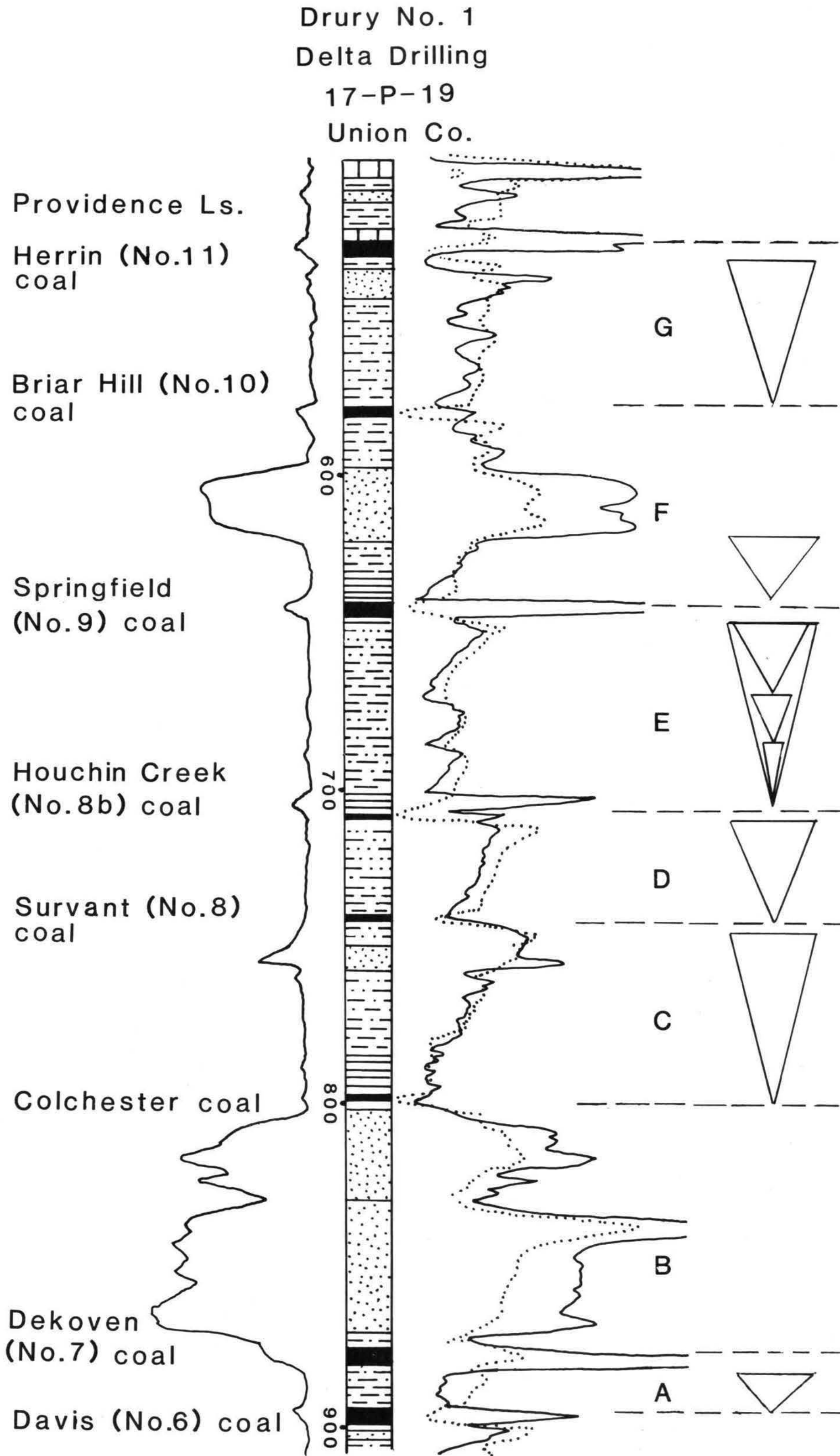


Figure 34. Example core and electric log through the Carbondale Formation showing the typical pattern of coarsening-upward packages bounded by coals (triangles). Seven coal-bound intervals (labeled A through G) are widespread in the Carbondale. Thick sandstones may disrupt the normal coarsening-upward signatures, as in interval B.

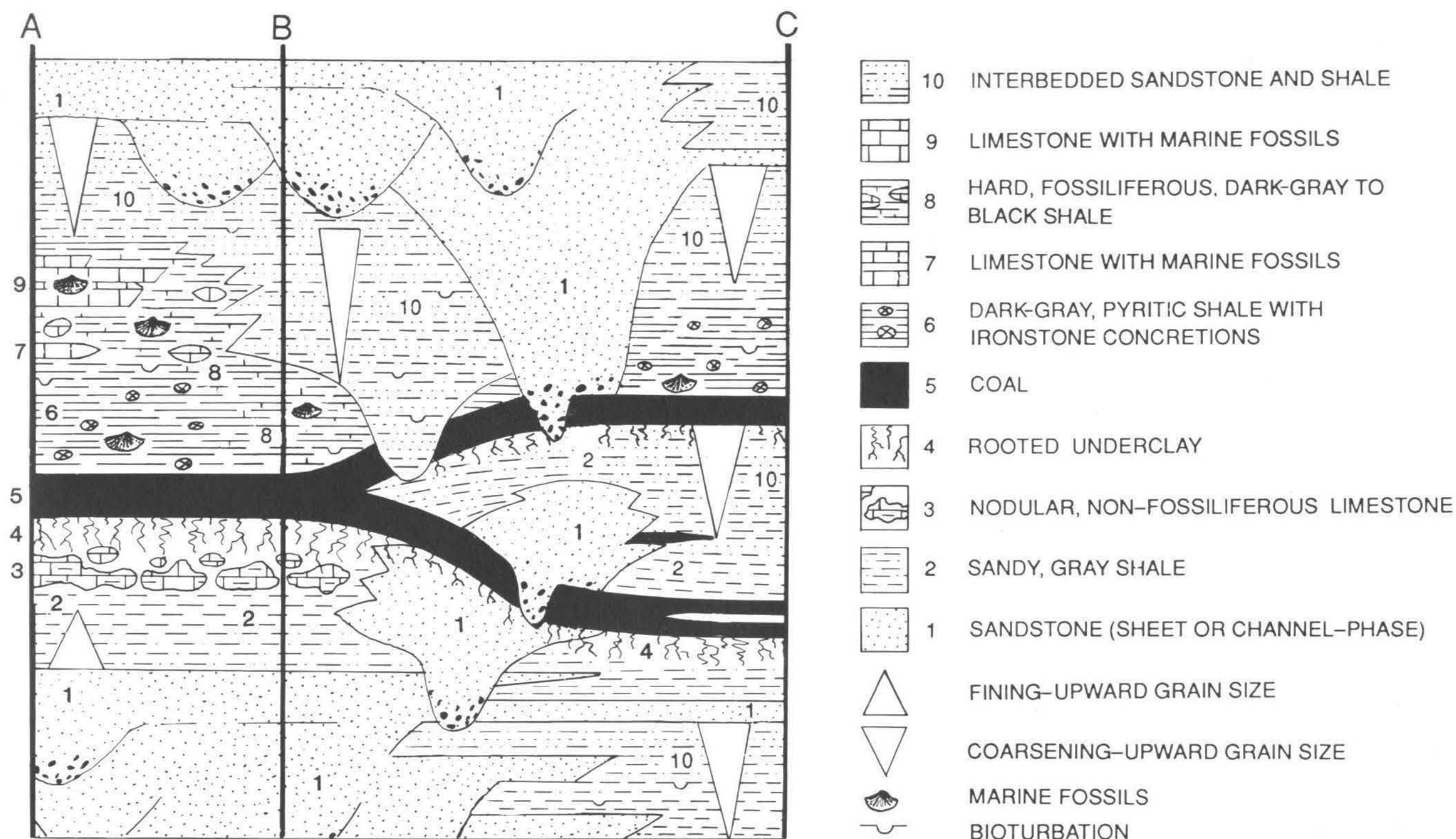


Figure 35. Generalized diagram of the cyclothem concept. The classic Illinois cyclothem (A) of Kosanke and others (1960) consists of 10 lithologic units. Kosanke and others noted that the limestone parts of the Illinois cyclothem do not commonly continue into Kentucky (B). However, lateral variability in each cyclothem can be considerable, as shown on the right side of the diagram. Many Kentucky cyclothem consist of simple coarsening-upward sequences capped by coals (C).

Named Units of the Carbondale Formation in Kentucky

Although the Carbondale comprises less than one-quarter of the total Pennsylvanian System section, it contains more than two-thirds of the total coal resources. Three coal beds (Table 1) make up most of the Carbondale resource. In ascending order, these beds are the Davis coal, the Springfield coal, and the Herrin coal (Smith and Brant, 1980; Cobb and others, 1985).

Other named coals and sandstones in the Carbondale Formation are shown in Figure 32.

Davis Coal (W. Ky. No. 6)

The Davis coal was named for a mine (Carter coordinate section 8-M-18) approximately 3 miles west of Sturgis in Union County (Lee, 1916). This bed was identified as the "No. 5 seam" or "Four-Foot seam" by Owen

Table 1.—Average Quality Characteristics of the Three Primary Coals in the Carbondale Formation.

AVERAGES OF ANALYTICAL RESULTS

COAL BED	BTU	ASH	TOTAL MOISTURE	VM	FC	S	NUMBER OF SAMPLES
HERRIN (W. KY. NO. 11)	12,000	9.7	6.4	38.9	45.1	4.0	34
SPRINGFIELD (W. KY. NO. 9)	11,700	10.5	8.3	36.4	44.9	3.3	56
DAVIS (W. KY. NO. 6)	12,300	8.2	6.4	37.2	48.1	2.9	24

(1856). It was later called the No. 6 seam by Lee (1916) and Glenn (1922). Unfortunately, the Mannington coal in southern Hopkins County, the Dunbar coal in Butler County, and several other coal beds at various localities in western Kentucky also have been referred to as "No. 6" by miners (Kehn and others, 1967; Kehn, 1974a). Thus, the numerical designation was stratigraphically confusing.

Although the Davis is widespread throughout the coal field, it has been intensively mined only in the southern part of Union County. An interval of relatively thick coal, possibly of mineable thickness, extends across the northern part of Union and Henderson Counties and into the western edge of Daviess County (Fig. 36). The Davis thins southeastward and generally is thin and inconspicuous along the cropline in southern Muhlenberg, eastern Ohio, and southern Daviess Counties (Fig. 36).

The coal is similar in appearance and composition to other coal beds of the Carbondale Formation, and commonly is overlain by a carbonaceous shale that may contain calcareous and pyritized marine fossils. In the western part of the coal field there is little to distinguish the Davis from other Carbondale coal beds, and it is identified almost solely on the basis of stratigraphic position. In the eastern part of the coal field the Davis is generally thin and recognized by its position just above the Yeargins Chapel Limestone (Fig. 32). These differing stratigraphic relationships can lead to local miscorrelations between the coal mapped as Davis and the overlying Dekoven (W. Ky. No. 7) coal (Fig. 37). Also, the interval

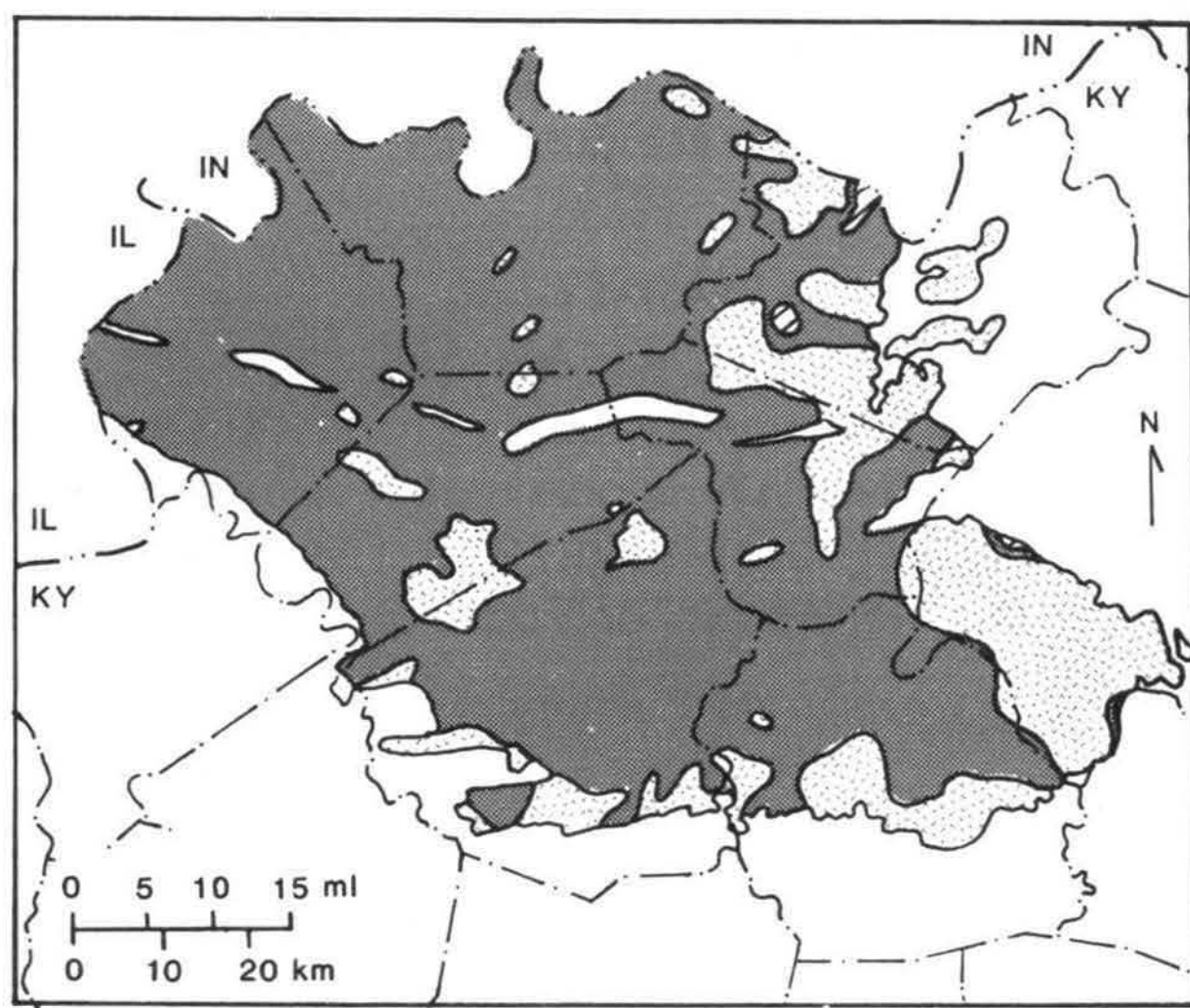


Figure 36. Isopach map of the Davis (W. Ky. No. 6) coal (modified from Smith and Brant, 1980).

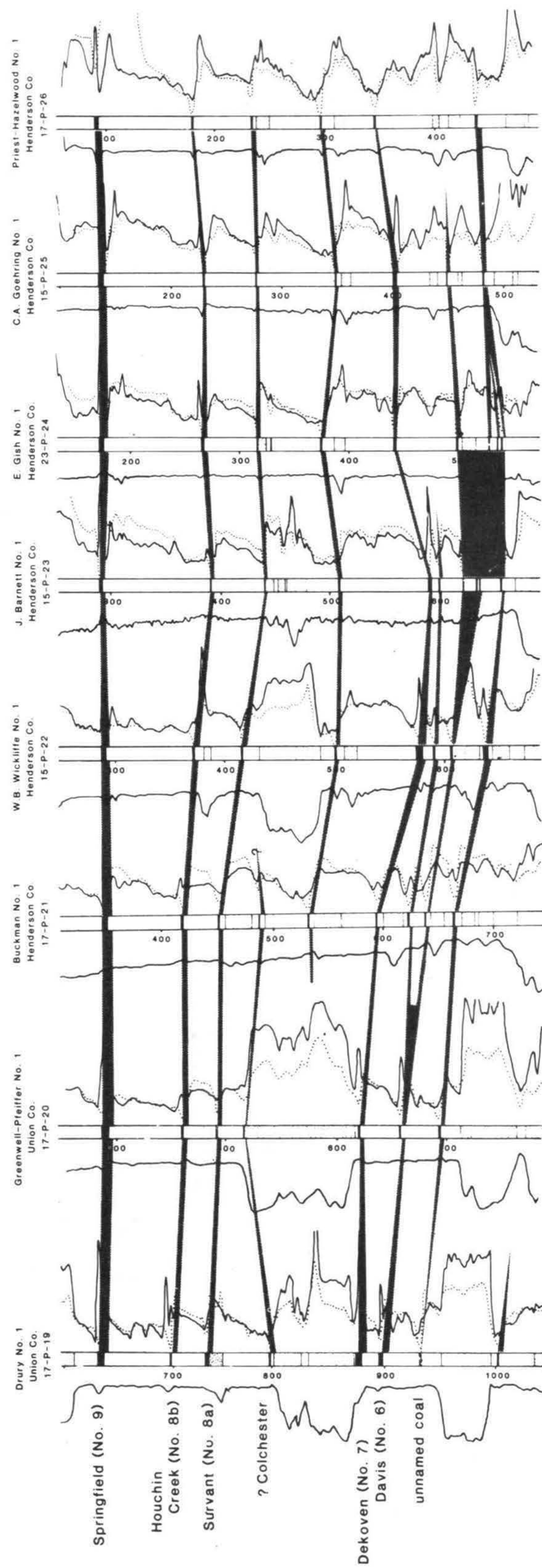


Figure 37. Cross section of the Davis (W. Ky. No. 6) through Springfield (W. Ky. No. 9) coal interval highlighting potential correlation problems between Davis and Dekoven (W. Ky. No. 7) coals in parts of Henderson and Union Counties.

between the Davis and the Dekoven ranges from as little as 10 feet near Dekoven to as much as 90 feet in the vicinity of Providence (Kehn, 1974a). These thickness variations are usually caused by the presence or absence of thick sandstones, and can add to the correlation problems.

The Davis coal was traced across the Ohio River into southeastern Illinois by Butts (1925) and has been correlated with the Wiley Coal of western Illinois (Willman and others, 1975). It is considered the equivalent of the Seelyville coal in Indiana (Jacobson, 1987b).

The Davis coal exhibits uniformity in coal quality and maceral composition across much of the basin. Stratigraphically it is the oldest coal to exhibit regional uniformity in the Western Kentucky Coal Field. In general, coals in the Carbondale Formation all exhibit similar uniformity, in contrast to underlying Tradewater Formation and overlying McLeansboro Group (previously Sturgis Formation) coals (Hower and others, 1982). The Davis coal ranks third among western Kentucky coals with an estimated resource of 7,482,922,000 short tons (Smith and Brant, 1980). It commonly ranks fourth or fifth in terms of annual production, with an average production between 1980 and 1990 of 1,400,000 tons per year, according to the Kentucky Department of Mines and Minerals. Coal analysis indicates mean sulfur values of 2.9 percent, mean ash of 8.2 percent, mean Btu of 12,320, and mean total moisture of 6.4 percent (Cobb and others, 1985).

Dekoven Coal ***(W. Ky. No. 7)***

The Dekoven coal was first identified as the "Three Foot seam," "Little seam," or "6th seam" by Owen (1857b). In the ensuing years the bed became known by miners as the "No. 7 coal" (Kehn, 1974a). The bed was first named "Dekoven" by Lee (1916) and then was correlated with the No. 7 by Glenn (1922). On geologic quadrangle maps the coal is noted as the "No. 7." However, to avoid the confusion of differing numerical designations between states, Kentucky readopted the name "Dekoven" (Williams and others, 1982). The name was derived from a mine at Dekoven in Union County (Lee, 1916). Although the exact site of the original mine is not known, a slope into this coal bed is still accessible in the highwall of an abandoned strip mine in the underlying Davis coal (Carter coordinate location 5-M-18, 300 FSL X 2,250 FWL). The Dekoven has been traced in Kentucky, Indiana, and Illinois (Jacobson, 1987b).

The Dekoven is 3 feet thick in western Union County, but thins southeastward along the outcrop. In the south-

ern and eastern parts of the Madisonville District the coal, although discontinuous, is thick enough to mine. Records of exploratory test wells indicate that the Dekoven is thin or absent beneath much of the Madisonville District, although a thick coal bed that may be correlative with the Dekoven has been encountered in drill holes along the northern edge of the district.

The lateral extent of the Dekoven coal in western Kentucky away from the type area is controversial. Smith (1967) reported that the coal generally mapped as No. 7 throughout the Madisonville District was actually the next higher coal in the section ("S" or "Schulztown" coal of Smith, 1967, and correlative with the Colchester No. 2 Coal of Illinois) and that the Dekoven (No. 7) coal of the type area near Dekoven (Glenn, 1922) pinches out in eastern Union County (Fig. 38). Other workers, relying primarily on outcrops and shallow coal-exploration tests, considered the "No. 7" coal of Hopkins and Muhlenberg Counties to be persistent and the discontinuous coal to be a bed between the "No. 7" and the Davis (No. 6) below (Kehn, 1968, 1971). The Dekoven may also be miscorrelated as the underlying Davis coal locally because of thickness variations and multiple splits in the coals (Fig. 37). In Union County the interval between the Davis and Dekoven may be as little as 10 feet (Kehn, 1974a). Detailed cross sections of the interval in controversial areas will be needed to define the continuity of these coal beds.

Sebree Sandstone

The Sebree sandstone of Glenn (1912a) occurs between the Dekoven and Colchester coal beds (Figs. 32, 37). In parts of the coal field where the Dekoven is absent, this sandstone occupies the position of the coal bed, and in some areas the sandstone extends almost from the Colchester down to the Davis coal. Individual sandstone pods may be as much as 75 feet thick, although average thicknesses are between 20 and 40 feet. In Daviess, Henderson, McLean, and Webster Counties, the sandstones are broadly lenticular in nature, with the thickest parts along linear, channel-belt trends (Glenn, 1922; Wanless, 1939; Potter, 1962).

The sandstone has been used for building stone near Sebree (Hansen, 1975) and was a possible oil reservoir in the Morganfield South Field of Union County (Wood, 1955; Schwalb and others, 1971; Johnson and others, 1975).

The Sebree sandstone has been correlated with the Palzo (Williams and others, 1982), Isabel, and Browning Sandstones of Illinois (Wanless, 1939, 1955). Wanless's (1939) definition and stratigraphic position of the Sebree sandstone have been generally accepted, although Hansen (1975) reported that the Sebree at the type sec-

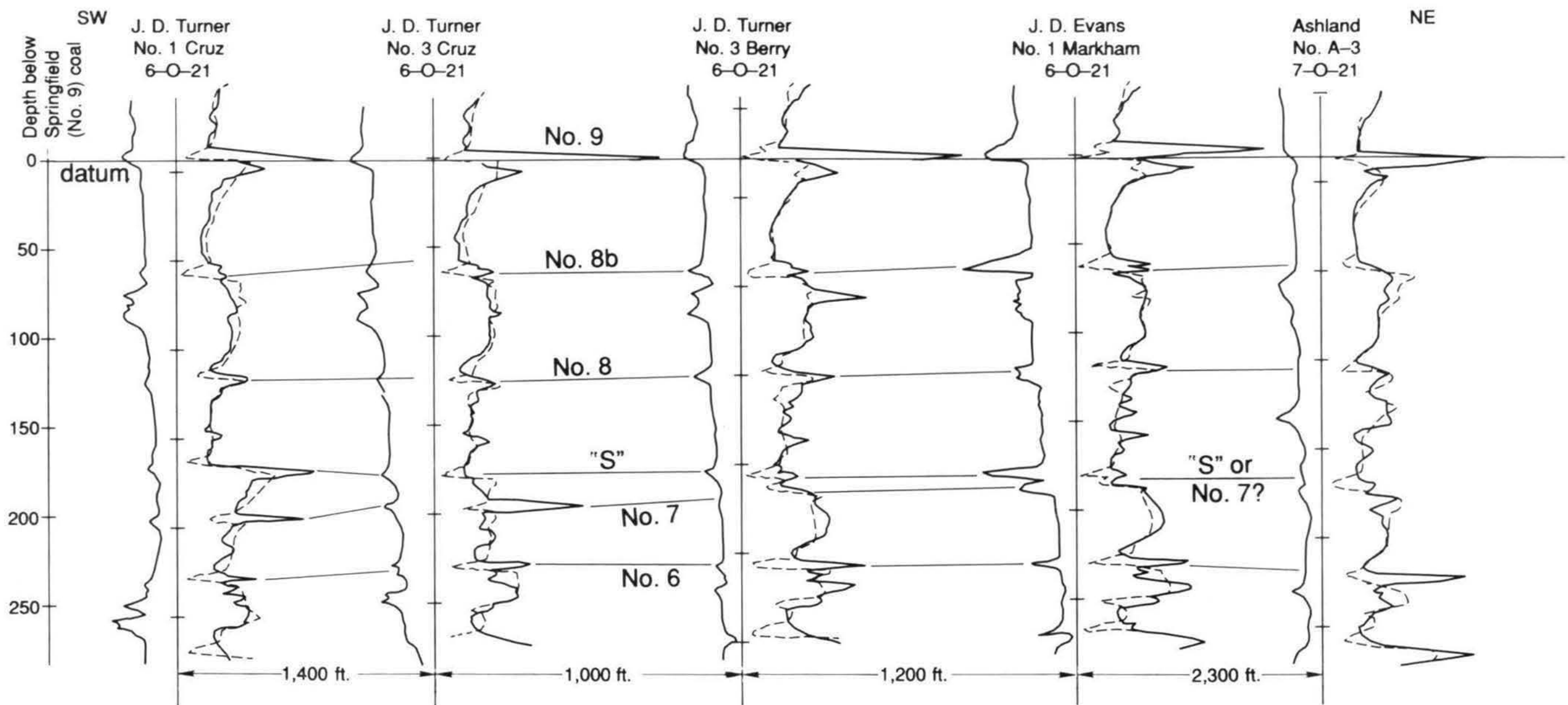


Figure 38. Cross section of the Davis (W. Ky. No. 6) through Springfield (W. Ky. No. 9) coal interval in Union County. Smith (1967) considered the "S" coal bed to be continuous and the Dekoven (W. Ky. No. 7) coal bed to be discontinuous, while other mappers (e.g., Kehn, 1966b) considered the Dekoven to be the continuous coal.

tion is approximately 300 feet below the Sebree as described by Wanless (1939). This controversy once again points out the difficulty in correlating sandstone bodies without closely spaced data.

Colchester Coal

The Colchester coal (Fig. 32) was named by Worthen (1866) for a mine in Madison County, Illinois. It is a relatively thin, persistent unit that is widely used in Illinois and Indiana as a stratigraphic marker because the coal is overlain by a thick, black, radioactive shale that gives it a distinctive geophysical-log signature. In the subsurface the Colchester has been traced directly from southwestern Indiana into northwestern Kentucky by use of geophysical logs (Jacobson and others, 1985) and cores (Williams and others, 1982). The Colchester was directly correlated with the Schultztown coal in Ohio County (Weller and Wanless, 1939), which is equivalent to a coal mapped as the "S" coal by Smith (1967). It was also correlated with the No. 8 coal (Survant coal) in the same county (Gildersleeve, 1975). Further study will be necessary for the resolution of these correlations.

Colchester Coal to Survant Coal Interval

The 40- to 70-foot interval between the Colchester coal and the Survant (W. Ky. No. 8) coal generally is composed of shale and siltstone (Fig. 38). Locally, the interval is dominated by 50 feet of fine- to medium-grained sandstone that may replace the underlying Colchester

coal. In some areas this sandstone thickens upward and coalesces with another sandstone above the Survant coal (Fig. 37). As much as 100 feet of fine-grained sandstone may occur in this interval. These sandstones may correlate with the Pleasantview Sandstone of Illinois (Wanless, 1939, 1955; Harvey, 1956). The Pleasantview Sandstone has been shown to have a distinct channel-form geometry that can be traced for more than 30 miles (Wanless, 1955). In northern Illinois, one of the Pleasantview Sandstone channels was interpreted to represent a tidal channel (Rusnak, 1957). Tidal, distributary, crevasse, and fluvial channels probably occur within this channel system at different points in the basin.

Sandstones beneath the No. 8b coal have produced small amounts of gas and oil at shallow depths (400 feet) in the Sacramento Field of McLean County (Schwalb and others, 1971; Hansen, 1976b).

Survant Coal (W. Ky. No. 8)

The Well or Water coal was designated as the No. 8 coal by Owen (1857b). Lee (1916) called Owen's No. 8 coal the Upper Well coal. Glenn (1923) noted an additional coal between the No. 9 and No. 7 in Webster County and mapped No. 8a and 8b coals. The 8b of Glenn was apparently equivalent to the No. 8 of Owen (Kehn, 1974a). Wanless (1939) correlated the No. 8 of Kentucky to the Colchester of Illinois, but spores from the No. 8 indicated that it was significantly younger than

the Colchester. Coals labeled No. 8 in Kentucky have also been correlated with the Schultztown coal (Wanless, personal communication *in* Gildersleeve, 1975).

Because of the obvious confusion resulting from the "No. 8" designation, and because the term "Well coal" had been used for other coals, the No. 8 coal was renamed the Survant coal in Kentucky (Jacobson and others, 1985). The W. Ky. No. 8 was correlated with the Survant coal in Indiana (Walker and others, 1951). The Survant was named for an exposure near Survant in Pike County, Indiana (Fuller and Ashley, 1902).

The No. 8/Survant (Figs. 32, 37) is one of the least persistent Carbondale coal beds, and is usually less than 36 inches in thickness (Kehn, 1974a–b; Hansen, 1975; Palmer, 1976). It is often cut out by overlying channel sandstones and is absent in the southern and eastern parts of the Madisonville District (Kehn, 1966a). The coal commonly occurs in two benches separated by as much as 10 feet of shale and siltstone. Like the other Carbondale coals, it often occurs above a coarsening-upward sequence (Figs. 34, 37–38). The interval between the Survant and Houchin Creek coals is a 20- to 50-foot-thick coarsening-upward sequence, except where the entire interval is composed of thick sandstone.

Houchin Creek Coal ***(W. Ky. No. 8b)***

This bed was called the "Well coal" by Owen (1856), Western Kentucky 8b by Glenn (1912a), and locally Ruff coal (Williams and others, 1982). The W. Ky. No. 8b was correlated with the Houchin Creek coal of Indiana (Walker and others, 1951). The Houchin Creek was named after exposures in Pike County, Indiana (Fuller and Ashley, 1902). Because "Well coal" was used to describe other coal beds, and "8b" was stratigraphically confusing (as are many numerical designations), the coal bed was renamed the Houchin Creek in Kentucky (Jacobson and others, 1985). The Houchin Creek (Fig. 32) is thin, but persistent throughout most of western Kentucky (Figs. 37–38). It consists of less than 2 feet of impure coal overlain by a bituminous shale that ranges from 2 to 6 feet in thickness. The Houchin Creek coal was correlated with the Summum (No. 4) Coal of Illinois (Willman and others, 1975). The 8b was not mapped in some quadrangles (Kehn, 1966a).

Houchin Creek Coal to ***Springfield Coal Interval***

The interval between the Houchin Creek and the Springfield coal ranges in thickness from 45 to 90 feet

and generally is composed of gray shale coarsening upward into a fine-grained sandstone (Figs. 34, 37–38). A thin sand in the Williams Field of Webster and Union Counties has produced oil from several wells at depths of 40 feet beneath the Springfield (No. 9) coal (Schwalb and others, 1971; Kehn, 1975a).

In parts of Hopkins County (Kehn, 1963), a thin limestone occurs within 20 feet of the base of the Springfield coal that was called the Hanover Limestone by Wanless (1939). Wanless (1957) considered the limestone to be one of the most extensive Pennsylvanian carbonates in the Midcontinent, correlating it with the Blackjack Limestone of Missouri, Kansas, and Oklahoma. The limestone and underlying dark shale were used to correlate the Houchin Creek and equivalents throughout the Illinois Basin (Weller and Wanless, 1939). However, the limestone was not considered distinctive enough to map at the surface during the U.S. Geological Survey-Kentucky Geological Survey Cooperative Mapping Program, and did not become part of the Kentucky stratigraphic nomenclature. Sandstone channels also occur in this interval that can cut out underlying coals (Fairer and others, 1975).

Springfield Coal ***(W. Ky. No. 9)***

The Springfield coal (Fig. 32) was named for mines in the vicinity of Springfield, Illinois (Shawe and Savage, 1913). In Kentucky, the coal was originally named Mulford for a mine near Dekoven, Kentucky (Owen, 1856). The coal has been called the No. 9 coal in western Kentucky, Coal V in Indiana, Summit Coal in Missouri, and the Harrisburg or No. 5 Coal in Illinois (Wanless, 1955); however, the currently accepted stratigraphic name is Springfield coal (Jacobson and others, 1985). The Springfield coal was one of the principal mapping units during the U.S. Geological Survey-Kentucky Geological Survey Cooperative Mapping Program. In quadrangles in which most of the Carbondale is preserved, the Springfield coal is used as a color-break horizon (i.e., Goudarzi, 1969; Hansen, 1972). It is also the most common structural contour horizon (Plate 1) on geologic quadrangle maps in the Madisonville District (i.e., Franklin, 1965; Palmer, 1976).

The Springfield coal has been mapped in Illinois, Kentucky, and Indiana. Currently, the geological surveys of these three states are compiling data on the Springfield into a common data base. The goal of the project is to develop basin-wide maps of the Springfield coal (Damberger and Tri-State Coal Study Group, 1989).

In western Kentucky the Springfield coal is present only in the Madisonville District. In the southern and

western parts of the district, within the Moorman Syncline, the coal ranges from 5 to 6 feet in thickness, but thins to slightly less than 4 feet toward the east and northeast of the Rough Creek Fault System (Fig. 39). This pattern is different from the pattern of Davis coal thickness, which also thins significantly to the south (Fig. 36), illustrating the shifting positions of the ancient Carboniferous swamps in each of the cyclic sequences, and possibly the different effects of tectonic structures during peat deposition.

A 6- to 24-inch-thick bituminous shale overlies the coal over much of its extent (Fig. 40). The high resistivity of the coal compared to the reverse peaks of the black shale and the underclay make it easy to identify in the subsurface (Figs. 34, 37–38). The distinctive black shale above the Springfield coal, and sometimes the coal itself, may be cut out by sandstone paleochannels (Fig. 41) (Williams, 1984). Trends of missing Springfield coal are mapped on several geologic quadrangle maps in Henderson and Webster Counties (Fairer, 1973a–b; Johnson, 1973a–c).

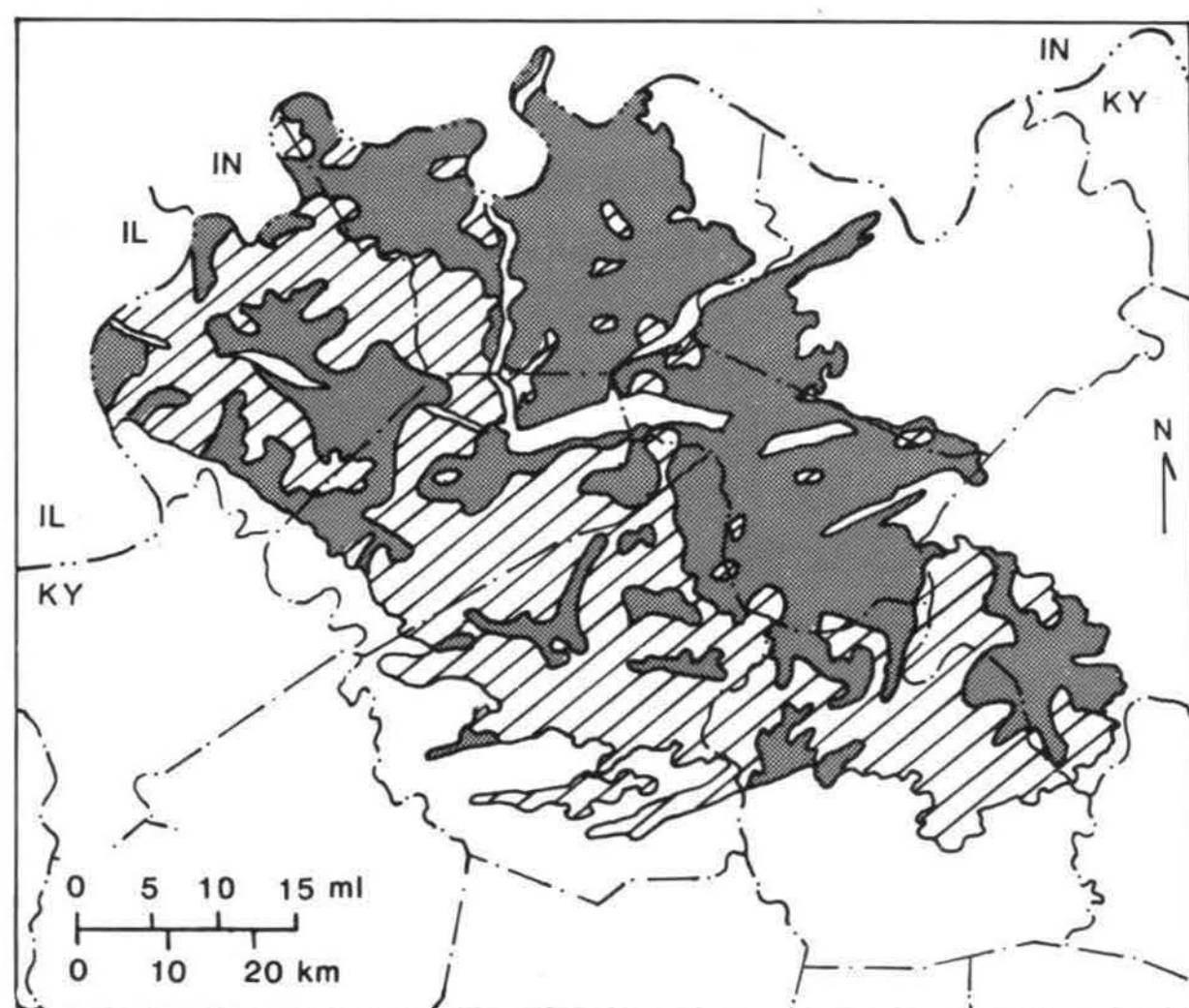
The Springfield coal is estimated to have the largest resource in the Western Kentucky Coal Field, with an original resource of 10,264,653,000 short tons and a remaining resource of 9,382,424,000 short tons (Smith and Brant, 1980). Since 1980, the Springfield coal has had an average reported annual production of more than

30 million tons, accounting for nearly 60 percent of the total production in the coal field, according to the Kentucky Department of Mines and Minerals. The coal has a mean total sulfur value of 4.12 percent, ± 0.65 percent; mean Btu (daf) of 14,414, ± 222 ; mean ash content of 10.5 percent; and mean total moisture content of 8.3 percent (Cobb and others, 1982, 1985).

Petrographically and chemically, the coal exhibits regional uniformity (Hower and Wild, 1982), although previous workers noted a general, northwesterly increasing trend (from Kentucky into Illinois) in the percentage of mineral matter, pyrite, and ash, and a trend of increasing pyritic sulfur toward the center of the basin from the margins (Ward, 1977). The largest increases in rank and chlorine content occur in the deepest part of the coal field, in the Webster Syncline of Union County, where hydrothermal metamorphism has affected coal properties (Hower and others, 1990). Local effects on coal quality may also occur in the Springfield coal. In southern Illinois, the Springfield coal (like many other Pennsylvanian coals) has sulfur values as low as 0.66 percent where a gray, silty shale occurs in the roof between the black shale and the top of the coal (Hopkins, 1968). Similar local effects of roof geology on Springfield sulfur content have been noted in western Kentucky.

Springfield Coal to Briar Hill Coal Interval

The interval between the Springfield and Briar Hill coals ranges from as little as 35 feet in Henderson County to as much as 75 feet in eastern Muhlenberg County. In many areas, the interval consists of a coarsening-upward sequence from carbonaceous shale at the base to sandstone at the top (Figs. 34, 37–38). Commonly the basal dark shale is separated from the Spring-



COAL THICKNESS (in)



Figure 39. Isopach map of the Springfield (W. Ky. No. 9) coal (modified from Smith and Brant, 1980).



Figure 40. Springfield coal exposed on the Western Kentucky Parkway near milepost 32. The coal is 1.5 m (4.9 feet) thick and is overlain by a high-resistivity, bony shale (B) with pelecypod and brachiopod fossils; a dark-gray, silty shale (SH); and a thick sandstone (SS).

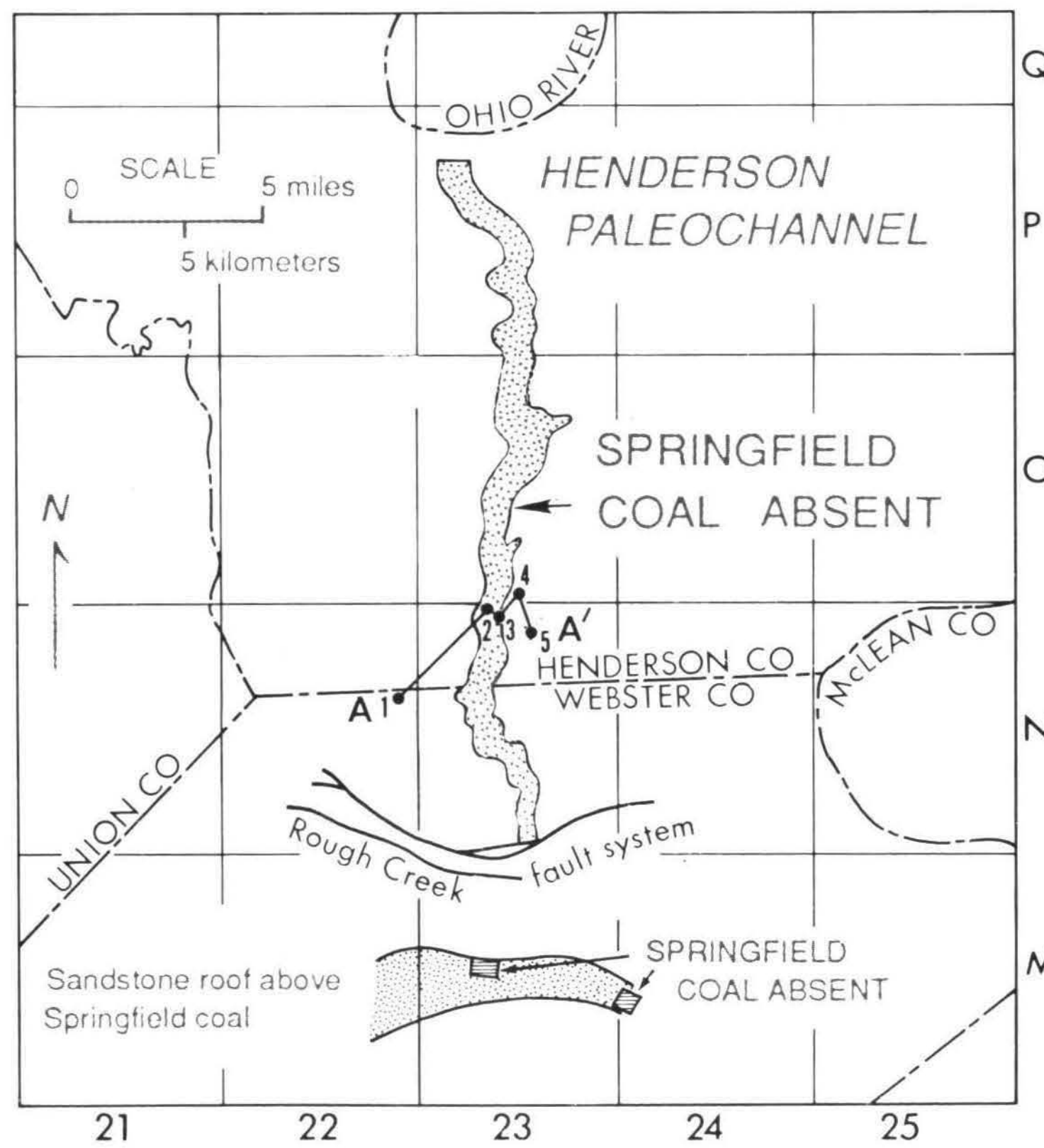
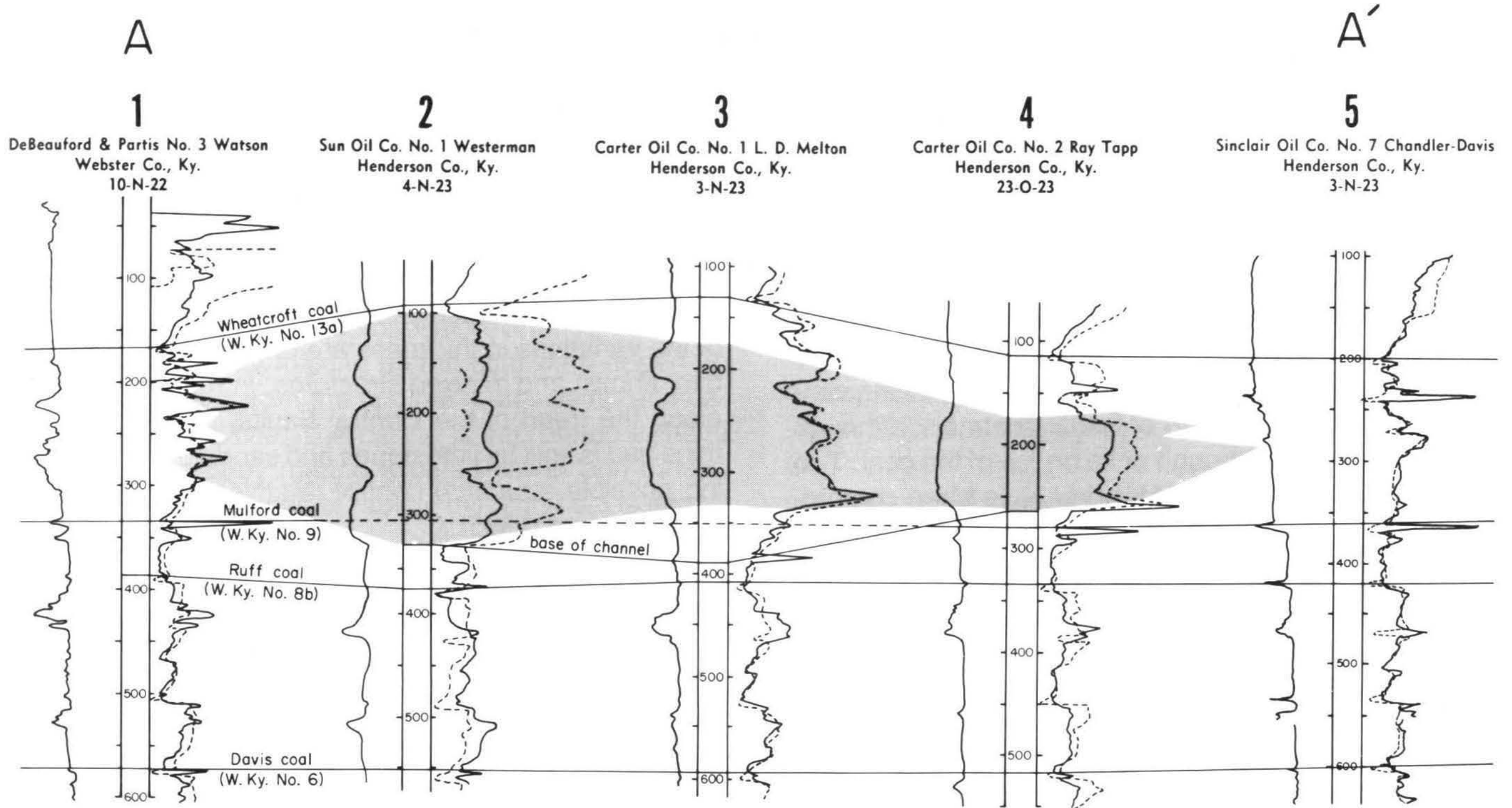


Figure 41. Cross section through the Henderson channel showing cut-out of the Springfield coal (top), and map of the Henderson Paleochannel (bottom) (after Beard and Williamson, 1979, Figs. 3 and 5).

field coal by a few inches of dark-gray claystone containing pyritized and sideritized concretions with abundant plant fossils and marine brachiopods and mollusks, called "Penniwinkle rock" by coal miners (McFarlan, 1943; Kehn, 1964a–b).

At some localities most of the interval between the Springfield and Briar Hill coals is composed of medium- to coarse-grained, crossbedded sandstones (Johnson, 1973a–c; Hansen, 1975; Greb, 1989b), informally called the Lower Vermillionville sandstone (Fig. 40). The coal may be split adjacent to the channels, suggesting contemporaneous deposition of fluvial channels, although most channels cut through or lie on top of the coal. Two paleochannel systems, inferred to have been contemporaneous with peat accumulation, have been mapped just north of the Western Kentucky Coal Field in southern Illinois and Indiana (Eggert, 1982).

In western Kentucky, several paleochannels truncate the Springfield coal. These channels apparently formed after accumulation of the coal. The Henderson Paleochannel of Beard and Williamson (1979) is as much as 3,000 feet wide and can be traced for more than 20 miles in the subsurface through Henderson and the northern part of Webster Counties (Fig. 41).

Briar Hill Coal **(W. Ky. No. 10)**

This bed was first reported by Owen (1857b) as Coal No. 10 in a mine near Dekoven, Kentucky, but was later changed to Briar Hill for a hill near Dekoven (Glenn, 1912a). The Briar Hill (Fig. 32) is as much as 4 feet thick, but the coal is discontinuous and irregular away from the type area. A thin, discontinuous coal in the underlying interval between the Springfield and Briar Hill may have been confused with the Briar Hill coal locally.

The Briar Hill is persistent through southeastern Illinois (Willman and others, 1975), where it is called the 5a Coal, and in Indiana, where it is correlative with the Bucktown coal (Shaver and others, 1986).

The interval between the Briar Hill and Herrin coal is similar to intervals between Carbondale coals discussed previously. An apparent channel sandstone between the Briar Hill and overlying Herrin coal is informally called the Upper Vermillionville sandstone.

Herrin Coal **(W. Ky. No. 11)**

The Herrin coal was named for mines in the vicinity of Herrin, Williamson County, Illinois (Shaw and Savage, 1912). In Kentucky, it was designated the "Eleventh coal" by Owen (1856), and less formally as the "No. 11

coal" by miners. For the sake of uniformity in nomenclature, the name "Herrin" was adopted for this bed throughout the Illinois Basin (Fig. 11) (Jacobson and others, 1985). The Herrin coal is most persistent in the southern part of the Madisonville District, where it is as much as 124 inches thick (Fig. 42). In the northern part of the district it is thin or absent. Thickness trends of the Herrin coal are very similar to those of the Springfield coal (Fig. 39), indicating similar basinal controls. Some of the variations in thickness are related to subsidence over known and inferred structures. In narrow grabens along the trend of the Central Faults, the Herrin coal thins and is split by limestones and sandstones, indicating possible structural control (Mathis, 1983; Neuder, 1984; Rogers, 1985).

The coal contains a distinctive parting of carbonaceous claystone called the "blue band" that is considered coextensive with the coal (Fig. 43). This claystone and a thin, black, carbonaceous and pyritic claystone occurring between the Herrin and the overlying Providence Limestone Member of the newly designated Shelburn Formation of the McLeansboro Group (previously Sturgis Formation) are distinctive marker beds for the Herrin coal. The blue band may have been deposited by a basin-wide flooding event (Nelson, 1983). The blue band and other partings and splits thicken along a trend where the coal is cut out in southern Illinois called the Walshville Channel. The thickening is associated with an in-

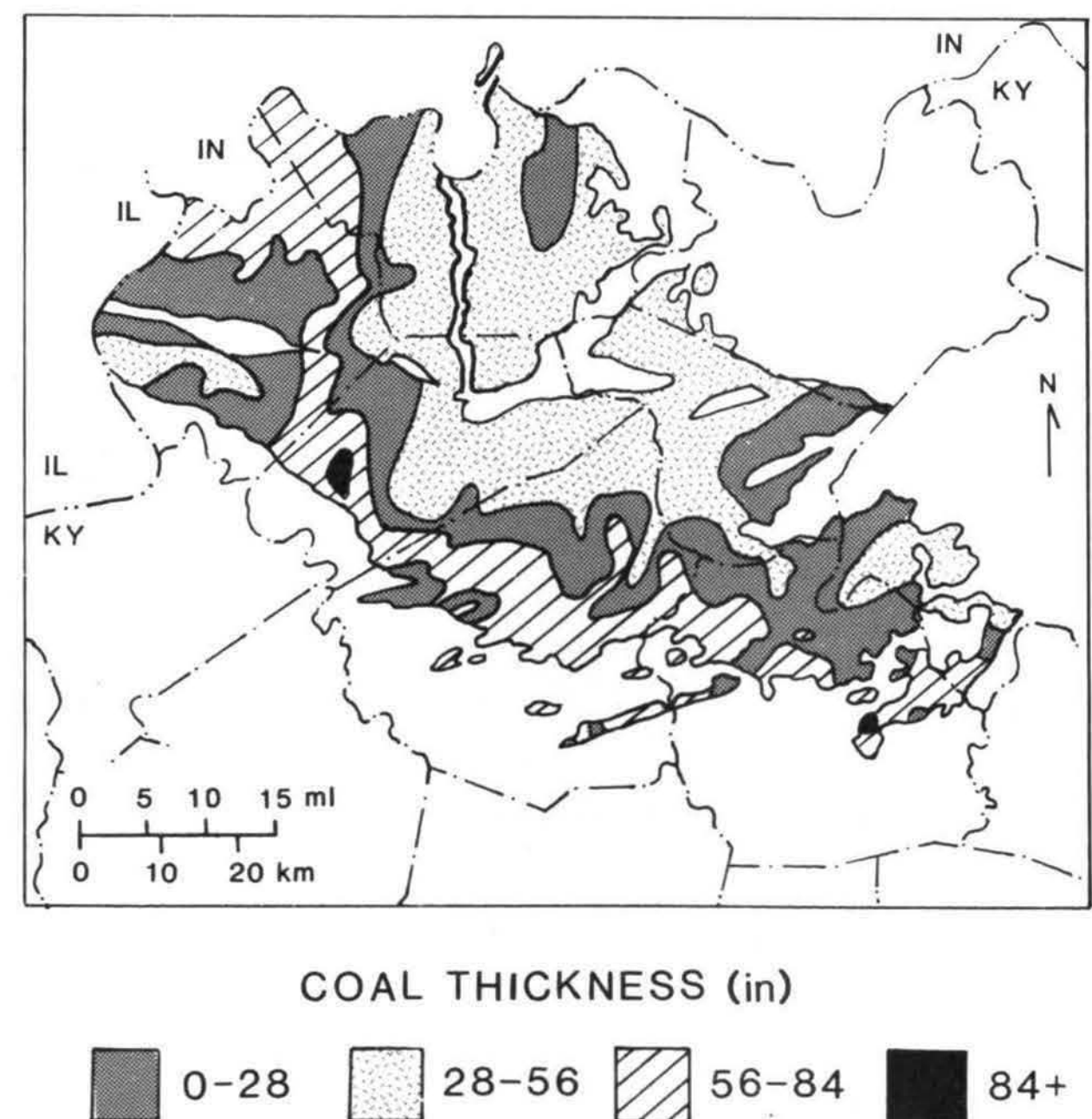


Figure 42. Isopach map of the Herrin (W. Ky. No. 11) coal (modified from Smith and Brant, 1980).

crease in ash content and petrographic changes in the coal (Nelson, 1983).

In several places around the coal field the Herrin coal deviates from its normal, bright-banded appearance and may be canneloid or brecciated. These localities have been interpreted to represent the edges of the original Herrin peat swamp (Hower and others, 1987). In Hopkins County the coal thins abruptly, is brecciated, and is cemented by calcite. Microscopic evidence indicates that the fragments making up the coal were ripped up and transported from the original peat swamp and cemented with calcite. The calcite is interpreted to have come from nearby marine waters (Hower and others, 1987). Locating areas of rapidly thinning coal is important in defining the limits of the Herrin coal for reserve estimation.

In Illinois the Herrin is the most economically important coal. In Indiana it is less persistent and of less economic importance. It was the first coal correlated across the Midcontinent on the basis of spores and was correlated with the Mystic coal of Iowa and the Lexington coal of Missouri (Schopf, 1938). In the Western Kentucky Coal Field the Herrin coal is second in economic importance only to the Springfield (Fig. 9), and has been mined extensively in the southern part of the Madisonville District. Resource estimates of the coal in Kentucky are complicated because the No. 11 and No. 12 have often been mined together, resulting in combined totals for both seams. The original resource of the two coals is estimated at 9,620,361,000 short tons, with 8,366,246,000 short tons remaining (Smith and Brant, 1980). Since 1980, coal production from the Herrin coal has averaged 9.6 million tons per year, but this figure may include some production from the Paradise (W. Ky. No. 12) coal, according to the Kentucky Department of Mines and Minerals (Fig. 9). Coal analysis of the Herrin in Kentucky

indicates a mean total sulfur value of 3.98 percent, ± 0.51 percent; mean Btu (daf) of 14,484, ± 132 ; mean ash content of 24.15; and mean total moisture content of 6.4 percent (Cobb and others, 1982, 1985).

Petrographically and chemically, the Herrin coal exhibits regional uniformity (Hower and Wild, 1981), although in areas of Illinois, low-sulfur Herrin coal is associated with a roof of silty gray shale called the Energy Shale, which acted as a buffer or seal against the black, sulfur-bearing shales (Anna Shale) and limestone (Brereton Limestone) that overlie the coal (Allgaier and Hopkins, 1975; Nelson, 1983).

McLEANSBORO GROUP (FORMERLY STURGIS FORMATION)

Nomenclature History

The strata above the Herrin coal have been assigned to many different stratigraphic units since they were originally described in the late 1800's (Fig. 10). Owen (1856) called the interval above the Anvil Rock Sandstone the Upper Coal Measures. Glenn (1912b) used the base of the Anvil Rock to define the base of a formation called the Lisman Formation, and the interval above the Dixon Sandstone was called the Dixon Formation (Fig. 10). The boundaries of the upper formation were accepted by Lee (1916), but renamed the Henshaw Formation because of the previous use of the term "Dixon Formation" in Tennessee. Also, the term "Lisman" was changed to McLeansboro Formation, which was the name of the same interval in Indiana and Illinois (Fig. 11). Glenn (1922, 1923) disregarded the use of the term "McLeansboro" and continued using Lisman and Dixon.

During the early years of the U.S. Geological Survey-Kentucky Geological Survey Cooperative Mapping Program the term "Lisman" was redefined to include the strata from the top of the Herrin (No. 11) coal to the base of the Dixon sandstone, but the term "Dixon Formation" as introduced by Glenn (1912b) was substituted for the term "Henshaw Formation" as used by Lee (1916). Hence, geologic quadrangle maps in the coal field made prior to 1973 use the Lisman and Henshaw Formation nomenclature for the strata above the Carbondale (i.e., Kehn, 1964b, 1966a; Franklin, 1965; Hansen, 1976b).

During the latter years of the U.S. Geological Survey-Kentucky Geological Survey Cooperative Mapping Program, Kehn (1973) proposed that the Lisman and Henshaw Formations be combined into one formation, the Sturgis Formation, because (1) the Dixon Sandstone (Glenn, 1912a-b) was not a persistent unit, and (2) the Lisman and Henshaw Formations were lithologically indistinguishable. Several geologic mappers had in fact mapped the Lisman and Henshaw together as undiffer-

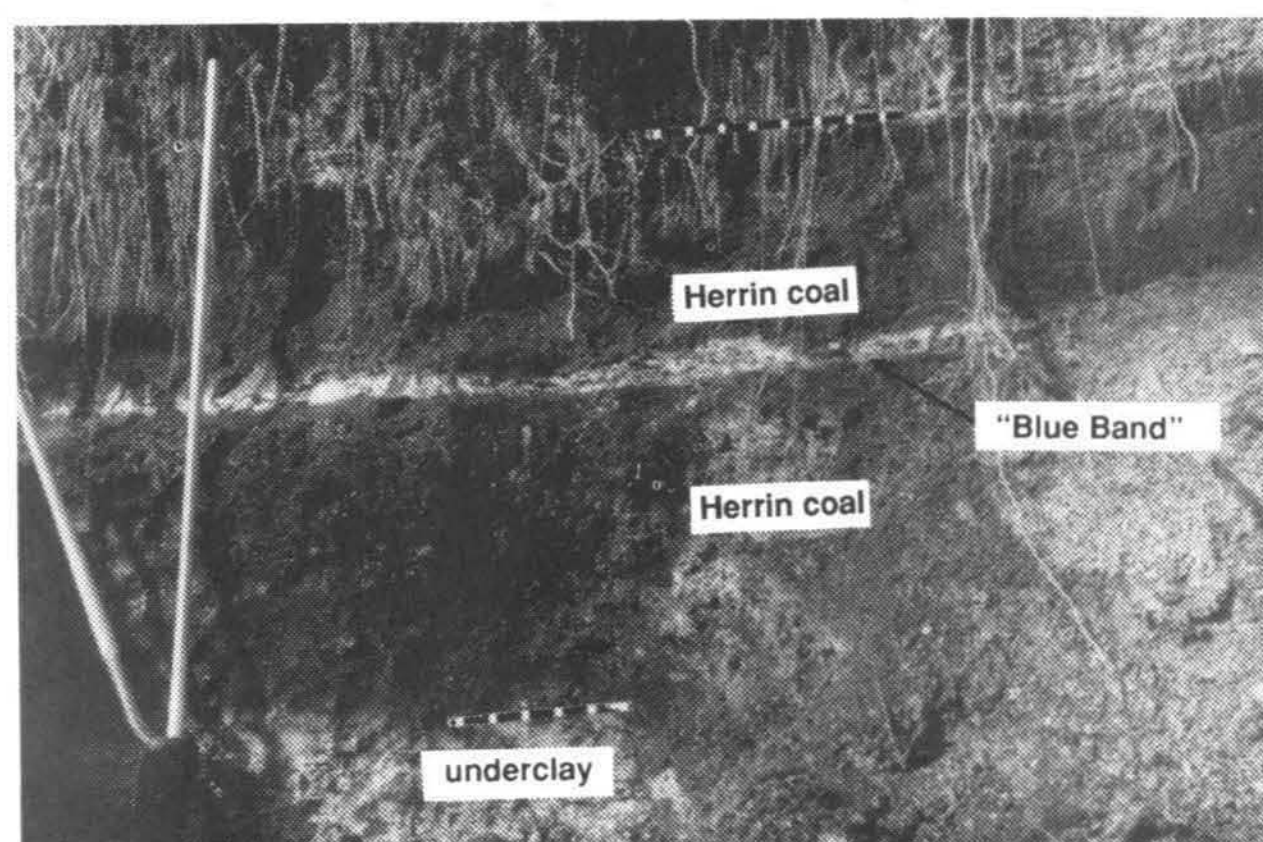


Figure 43. The Herrin coal, showing the characteristic blue-band parting (from Smith and others, 1969, Fig. 21, p. 37).

entiated strata. Because this interval of Pennsylvanian strata is largely concealed by colluvium at the surface, the type section was designated as a composite section of two diamond-drill cores located about 3 miles northeast of Sturgis in Union County, and a nearby stratigraphic test hole (Kehn, 1973). The Sturgis Formation was used as a mapping unit for geologic quadrangle maps made after 1973 (i.e., Johnson and Norris, 1974; Kehn, 1974a–b, 1975a–b; Hansen, 1976a–b), and the Kentucky state geologic map (McDowell and others, 1981).

As a result of discussions between the Indiana, Illinois, and Kentucky Geological Surveys, the term "Sturgis" was dropped for the term "McLeansboro Group." Also, Kentucky will adopt four formations within the group (Figs. 11, 44): the Shelburn (Wier, 1961), the Patoka (Wier, 1961), the Bond (Kosanke and others, 1960), and the Mattoon (Kosanke and others, 1960). These changes do not greatly affect the geologic quadrangle maps of Kentucky, because those maps using the Sturgis terminology also plot the West Franklin (Madisonville) and Carthage Limestones, which are the limits of the lower formations in the McLeansboro Group (i.e., Johnson and others, 1975). Also, geologic quadrangle maps in which the Sturgis was divided into different colors are based on the three limestone boundaries (i.e., Johnson and Norris, 1974, 1976; Kehn, 1974a, 1975a–b; Fairer and others, 1975; Hansen, 1976a–b).

Group Boundaries

The Sturgis Formation of Kehn (1973) accounted for about two-thirds of the vertical succession of Pennsylvanian rocks in western Kentucky. All of the 2,650 feet of strata above the Herrin coal was assigned to the Sturgis Formation (Kehn, 1973). However, fossil evidence in cores indicated that only the lower 2,039 feet was Pennsylvanian in age. The overlying 611 feet of strata formerly included in the Sturgis was assigned to the Permian Mauzy Formation (Kehn and others, 1982). Hence, the top of the Sturgis Formation was placed at the Mauzy Formation. Lithologically, the Mauzy differed from the Sturgis by having a larger percentage of calcareous beds. Limestone and calcareous shale constitute about 33 percent of the Mauzy Formation (Kehn and others, 1982), while the Sturgis Formation contained less than 20 percent calcareous beds.

One of the major benefits of Kentucky adopting the McLeansboro Group and associated formations in place of the Sturgis is that the new nomenclature divides the section into mappable units of workable thickness, rather than a single unit more than 2,000 feet thick. However, since the Kentucky section is the only complete Pennsyl-

vanian section in the basin, the upper boundary of the McLeansboro Group is revised to the base of the Permian section (Figs. 11, 44). Also, the base is revised in Kentucky and Illinois to the base of the Providence Limestone (Fig. 11). The use of a limestone as the base of the group, rather than a coal, as was previously used for the McLeansboro Group in Illinois (Kosanke and others, 1960; Willman and others, 1975), keeps the use of basin-wide carbonates as formation boundaries consistent throughout the McLeansboro Group, and compromises with the use of the top of the Herrin coal/base of the Providence Limestone as the top of the Carbondale Formation in Kentucky.

Thickness and Extent

The McLeansboro Group (previously Sturgis Formation) outcrops in Union, Webster, Hopkins, Muhlenberg, McLean, southeastern Ohio, and western Daviess Counties (Fig. 45). South of the continuous outcrop the McLeansboro is preserved in a few outliers and east-northeast-trending grabens. The group thickens into the Webster Syncline in Union and Webster Counties.

Much of the McLeansboro has been removed by post-Pennsylvanian erosion; therefore, an isopach map of the group is not provided here. Only in Union County is a complete sequence of this strata preserved (Fig. 45). At one locality the group is 2,039 feet thick (Kehn and others, 1982), and at another site the maximum thickness was recorded as 2,650 feet, although some Permian beds may have been included in the interval (Palmer, 1976). It is probable that a similar thickness of McLeansboro Group sediments originally was deposited across a large part of western Kentucky, but was subsequently eroded. Damberger (1971) estimated that the Herrin coal (W. Ky. No. 11) was buried by more than 3,000 feet of sediments in southeastern Illinois, which agrees closely with the more than 2,650 feet of McLeansboro (Sturgis) strata reported by Palmer (1976).

Continued Cyclicity

The lithology of the McLeansboro Group is similar to the Carbondale Formation, with detrital and marine rocks occurring in repetitive sequences. Sandstone units of the McLeansboro are commonly calcareous and burrowed. Many of the shales are also burrowed and contain marine invertebrate fossils. Carbonaceous shales associated with coals are present, but lack the high radioactive content characteristic of their counterparts in the Carbondale Formation. Limestone units in the McLeansboro are generally thicker and more persistent than those of the Carbondale or Tradewater Formations. Although only three McLeansboro Group lime-

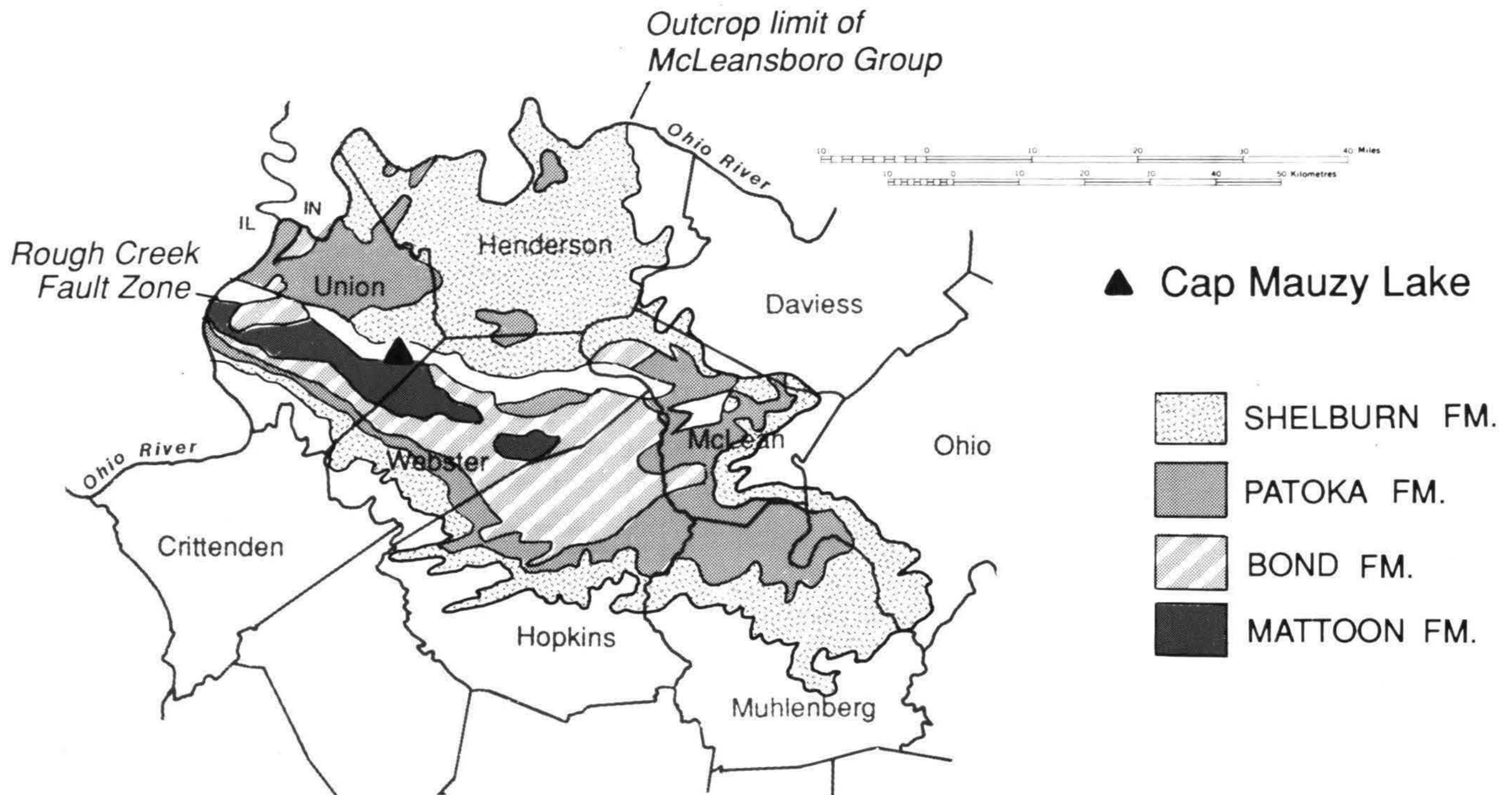


Figure 45. Surface outcrop limits of the McLeansboro Group, and approximate limits of the Shelburn, Patoka, Bond, and Mattoon Formations.

stone units are named, many limestone beds occur (Fig. 46).

Smith and Smith (1967) described seven specific lithologic groupings in the McLeansboro (Sturgis): (1) black shale, generally fissile and commonly bearing inarticulate brachiopods, conodonts, and fish remains; (2) fossiliferous limestone, shale, generally containing abundant massive fossils; (3) sandstone and siltstone; (4) gray shale, typically silty or containing thin siltstone laminations; (5) claystone, including sediments composed dominantly of clay-sized particles that are not laminated (includes underclay); (6) unfossiliferous limestone occurring as beds, nodules, or pellets (normally associated with claystone), commonly referred to as underclay limestone, in some cases containing structures that may be algal in origin; and (7) fossiliferous limestone in which the only identified fossils are ostracodes and *Spirorbis* and which are generally regarded as being of freshwater origin (Fig. 47).

The *Spirorbis*-bearing limestone is the only unit of the seven groupings that does not also occur in the Carbondale Formation. It is most common in the upper part of the McLeansboro Group.

The cyclic nature of these facies is similar to the cyclothems of the underlying Carbondale Formation. Sea-level curves for the Midcontinent (Heckel, 1986) suggest

that at least 55 cycles of marine inundation and withdrawal occurred during the time of McLeansboro (Sturgis) deposition. Major cycles with estimated periods of 235 to 400 X 10³ years extended across much of the Midcontinent area, while minor cycles with periods of 120 to 40 X 10³ years were documented only in lower shelf areas. The periodicity of these cycles corresponds to Milankovitch cycles for the Pleistocene ice ages, and supports interpretations of glacial control of eustatic changes during the Pennsylvanian, as suggested earlier by Wanless and Shepard (1936). Eustatic cycles were probably superposed with tectonic cycles resulting from episodic thrust faulting during the Alleghenian-Hercynian Orogeny (Klein and Willard, 1989).

SHELBURN FORMATION

Nomenclature History

The Shelburn Formation was named for exposures near Shelburn, Indiana, between Indiana Coal VII and the Merom Sandstone (Cummings, 1922). Wier (1961) redefined the Shelburn as the section between the top of the Danville coal and the top of the West Franklin Limestone. Kentucky and Illinois redefined the base of the Shelburn as the base of the Providence Limestone (Figs. 11, 44). Since the Shelburn is a new formation in Kentucky, thickness and lithologic trends have not yet been determined. Future work will need to concentrate

on the distribution of this unit in the Western Kentucky Coal Field.

Named Units of the Shelburn Formation in Kentucky

Several rock units that were previously part of the lower Sturgis Formation are now included in the Shel-

burn Formation. In general, the lithologies are similar to the underlying Carbondale Formation.

Providence Limestone Member

The Providence Limestone was originally called the Jolly limestone by Hutchinson (1912). It was named Providence by Glenn (1922) for outcrops in the vicinity of Providence in Webster County. He described the unit as generally consisting of 5 to 8 feet of blue, argillaceous, fossiliferous limestone restricted to the interval between the No. 11 and No. 12 coals. Later workers adopted the term and boundaries until 1973 when the No. 12 coal of Glenn (1922) at Providence was discovered to be the No. 13 coal in reality (Kehn, 1973). The Providence subsequently was redefined to include all limestone beds (Fig. 48) from the top of the Herrin coal (W. Ky. No. 11) to the base of the Baker coal (W. Ky. No. 13), an interval that includes as many as four discrete coals and five distinct limestones (Shaver and others, 1970). Hence, geologic quadrangle maps of western Kentucky published by the U.S. Geological Survey prior to 1973 (in the southeastern part of the Madisonville District) use the old limits, while post-1973 maps (northwestern part of the Madisonville District) use the larger interval. Most of the geologic maps published between 1965 and 1975 show the Providence as consisting of upper and lower limestones, each up to 5 feet thick, separated by an interval of less than 30 feet.

The lower limestone is separated from the Herrin coal by only a few inches, making it the most easily distinguished bed of the Providence Limestone Member (Fig. 49). It is medium to dark gray, argillaceous, and micritic,

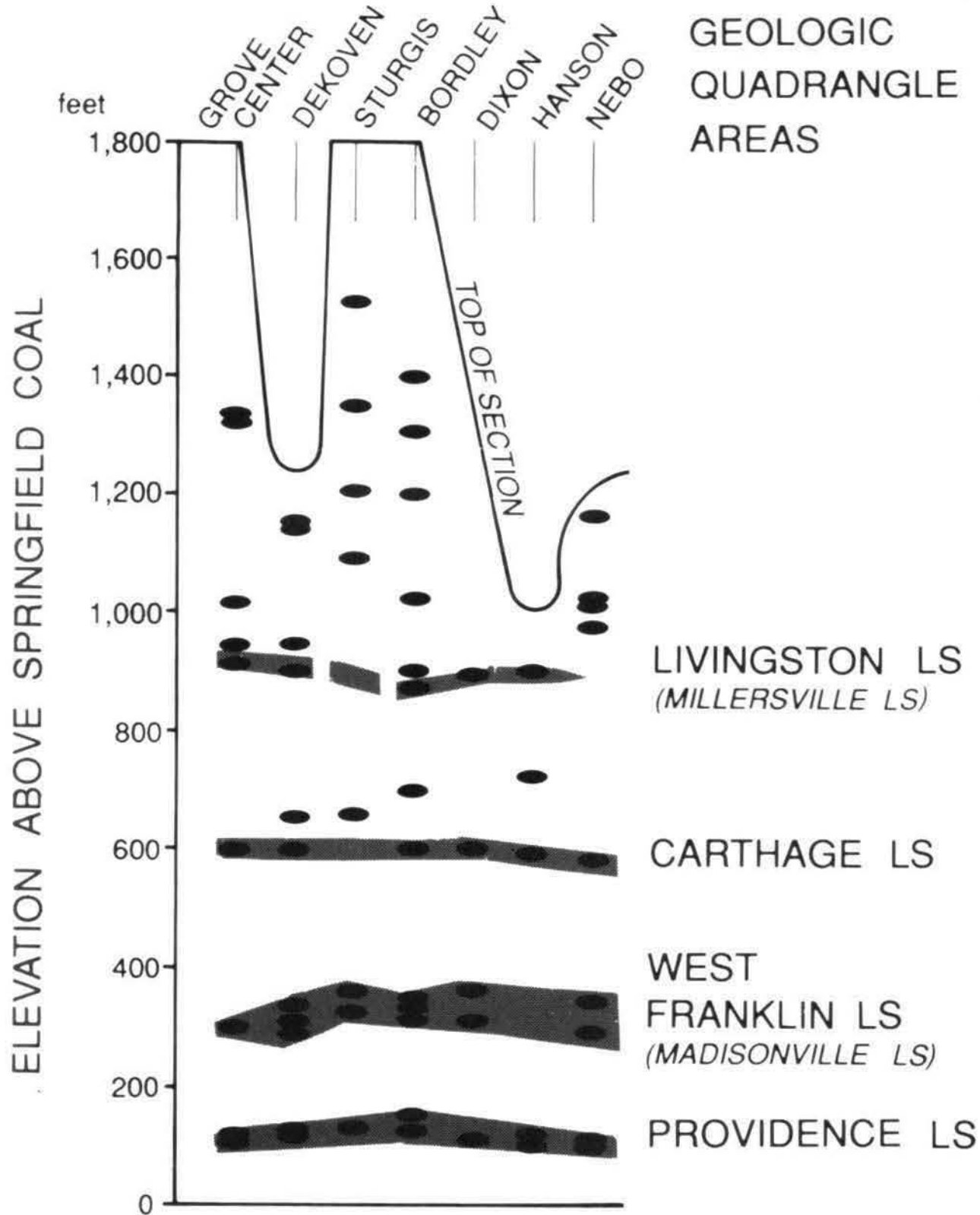


Figure 46. Stratigraphic position of McLeansboro Group limestones (ovals) on selected 7.5-minute geologic quadrangle maps.

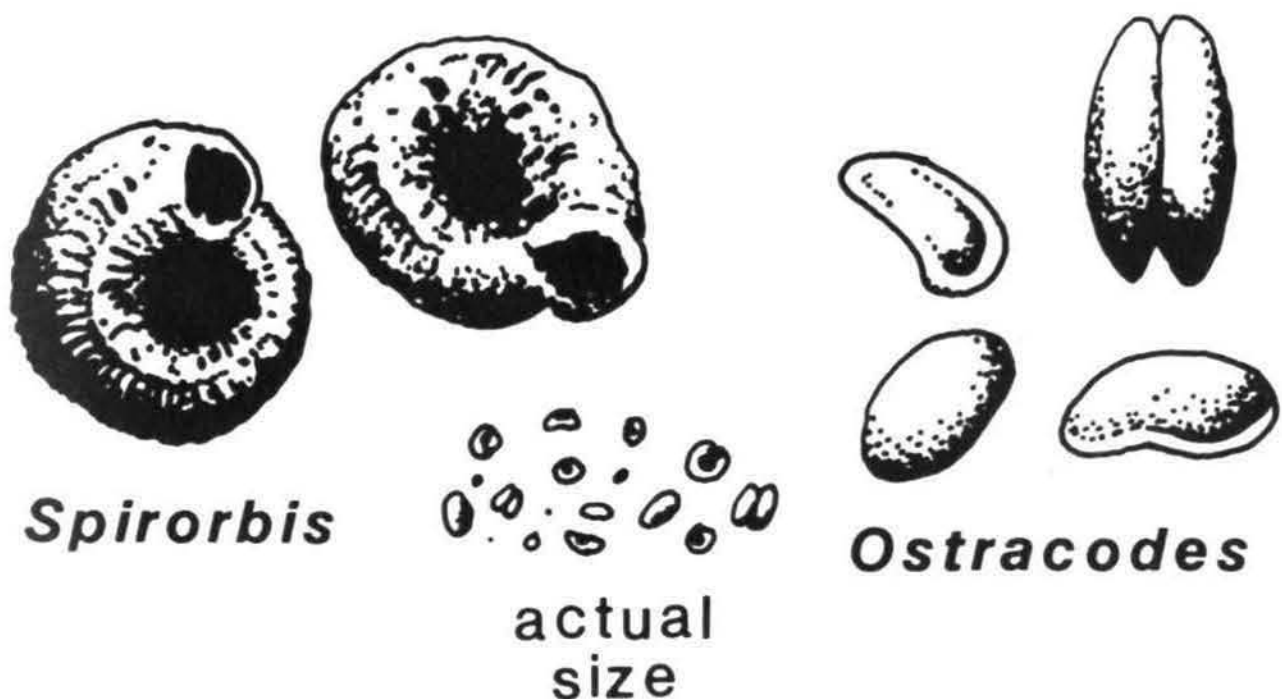


Figure 47. *Spirorbis* and ostracodes common in fossiliferous limestones of the McLeansboro Group. From an abandoned surface mine in the Coiltown Quadrangle, Hopkins County.

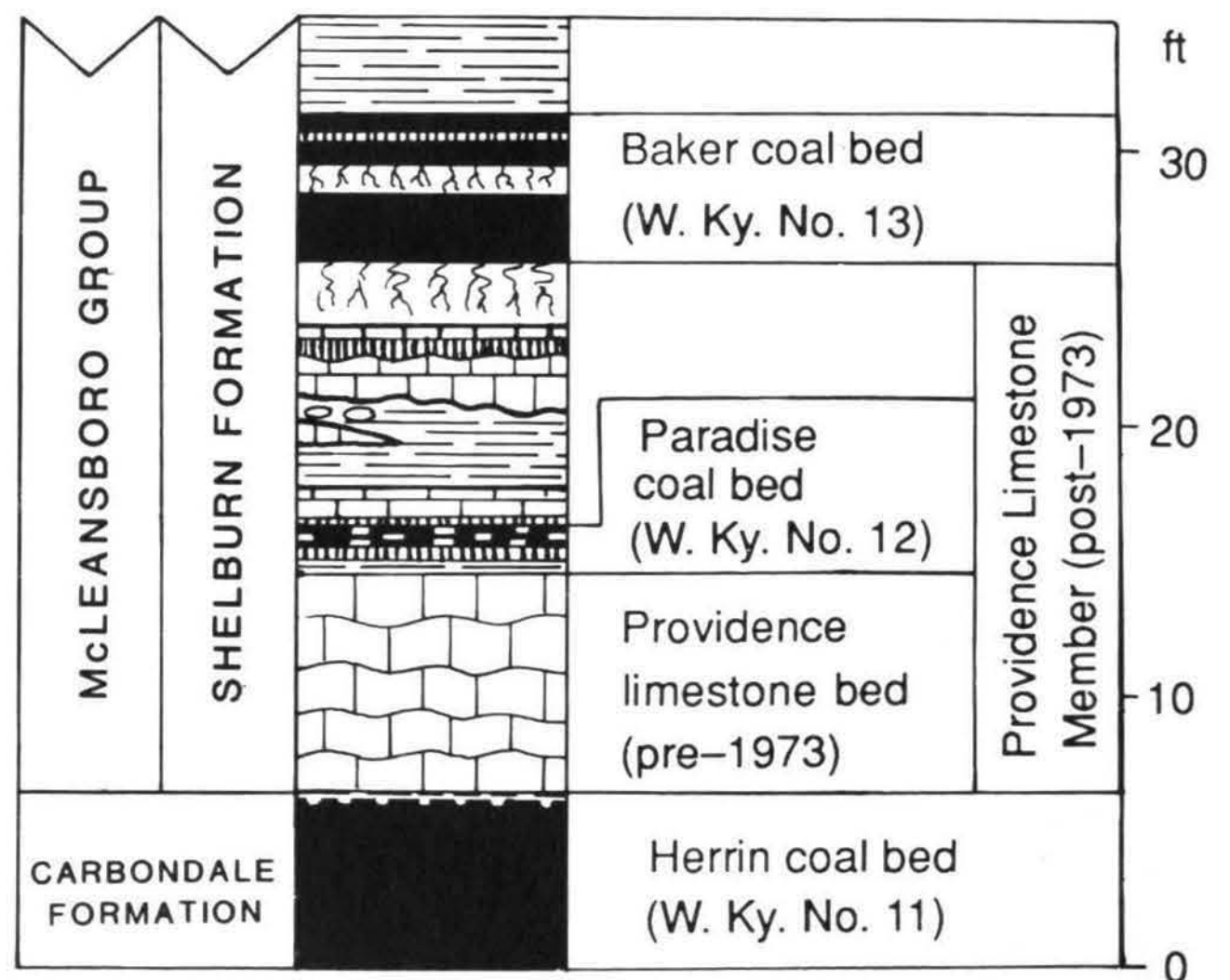


Figure 48. Geologic column based on exposures in an abandoned surface mine near Providence, in the Nebo Quadrangle, showing the Providence Limestone interval (after Smith and others, 1969, Fig. 29, p. 48).

with an abundant and diverse marine fauna. The lower limestone is the most widespread carbonate unit of the Providence, and is correlated with the Brereton Limestone of southern Illinois and the lower bench of the Providence Limestone of Indiana (Shaver and others, 1970).

The upper limestone is less persistent than the lower limestone and generally is composed of 2 to 5 feet of light-gray to light-brown, micritic limestone. At a few localities in Union and Webster Counties the upper limestone may be as much as 20 feet thick. The upper limestone is separated from the lower limestone by a few inches to as much as 20 feet of light- to dark-gray shale and claystone. This interval also contains the Paradise coal (W. Ky. No. 12) where it is present (Fig. 50).

At one time the Providence Limestone was quarried in Ohio and Daviess Counties for use as flux in furnaces (Owen, 1857b; Fairer and Norris, 1972; Kehn, 1974b). Also, a thin sand in the Dyson Creek Field of Union County (Kehn, 1975b) that may be in the Providence Limestone Member has produced up to 35 bopd from several shallow wells (930 to 945 feet).

Paradise Coal ***(W. Ky. No. 12)***

The No. 12 coal was first designated by Owen (1857b). Although a formal type section was not given, Owen measured the No. 12 coal in the Green River Valley of Muhlenberg County. Later, the No. 12 coal was measured throughout the central part of the coal field from Webster to Ohio County (Hutchinson, 1910, 1912; Glenn, 1912a, 1923). Because of the many stratigraphic problems caused by numbering the coals, Williamson and Whaley (1979) named the No. 12 coal the Paradise

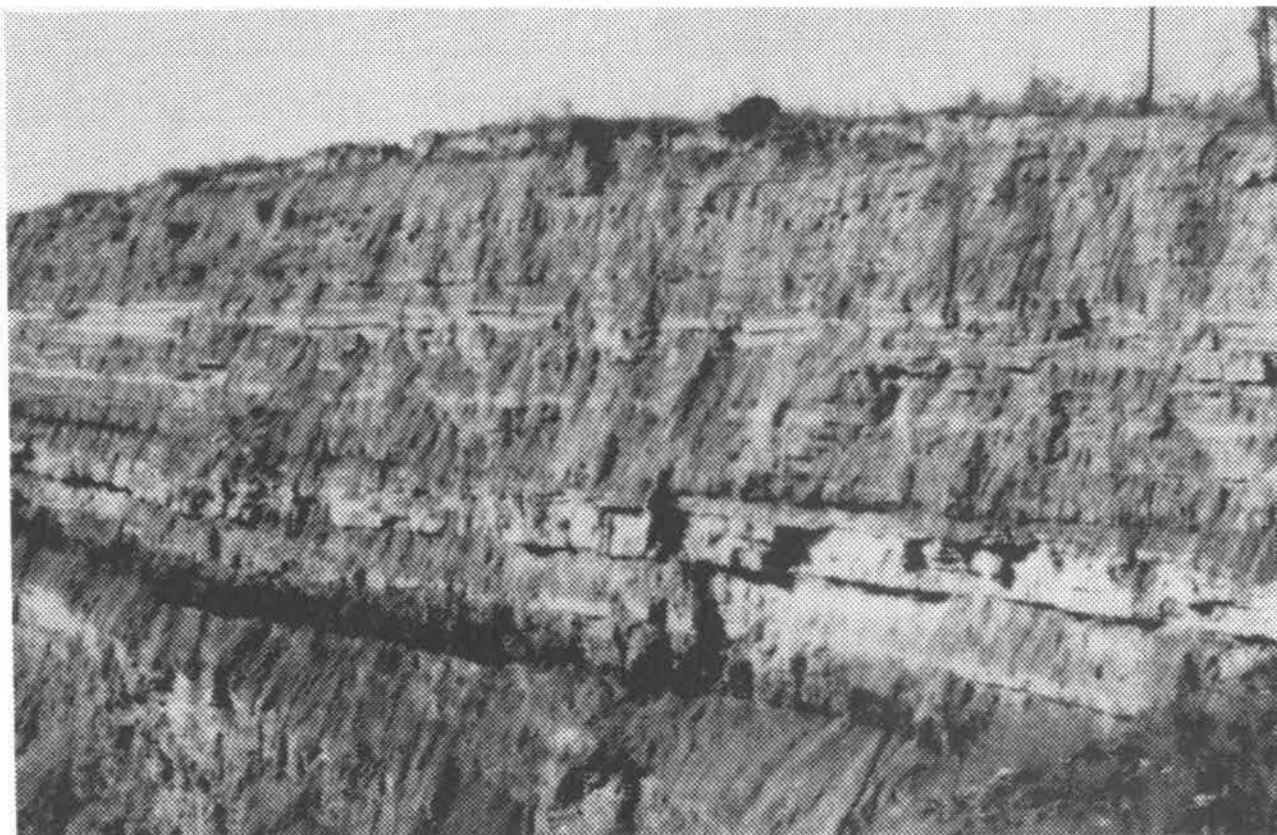


Figure 49. Herrin through Baker coal interval showing the Paradise (W. Ky. No. 12) coal between two benches of the Providence Limestone in a highwall of the Homestead Mine, Muhlenberg County.

coal, after mining in the vicinity of Paradise in Muhlenberg County.

In the southern and eastern parts of the Madisonville District the underclay of the Paradise coal rests on the top of a lower bench of the Providence Limestone. But in the western part of the district the Paradise coal is treated as a bed within the Providence Limestone Member because the Providence was defined as all of the limestones between the No. 11 and No. 13 coals (Figs. 48–50).

The Paradise coal exhibits thickness trends similar to the underlying Herrin (W. Ky. No. 11) coal of the Carbondale Formation, with the coal thickening into the Moorman Syncline in Hopkins and Muhlenberg Counties (Fig. 51). To the north and west of these thick areas the coal thins and grades into an inconspicuous black, coaly claystone distinguishable only because of its position between the upper and lower Providence limestones. The Paradise apparently is correlative with the Jamestown Coal of Illinois (occurring between the Bankston Fork and Brereton Limestones), and the Hymera Coal (VI) Member of Indiana (Willman and others, 1975; Phillips and others, 1980).

The Paradise is a high-ash, high-sulfur coal complexly interrelated to the surrounding Providence Limestone Member. It often contains numerous partings with marine fossils (Austin, 1979; Utgaard, 1979; Hower and others, 1987). Using the partings as chronostratigraphic horizons, Austin (1979) interpreted the widespread partings to be responses to marine transgressions, with the thickest coal forming on the highest paleotopography. Paleotopography was controlled in some areas by syndepositional subsidence over grabens. In grabens along the Central Fault trend, thick Paradise coal occurs on horsts, while thin, split coal and limestone occur in the grabens (Neuder, 1984; Rogers, 1985). Because many of the partings outside of the grabens are regionally persistent, because of intertonguing marine roof strata, because of a lack of rooting, and because of several petrographic anomalies, Austin (1979) proposed that the No. 12 coal was formed in floating peat mats rather than typical coastal plain analogs. However, significant evidence of rooting in areas outside of Austin's study area indicate *in situ* peat swamp development rather than deposition from floating peat mats (Utgaard, 1979).

Because the Paradise coal is often mined with the Herrin coal, and the amount of production from each is reported as combined or is assigned to the Herrin coal, it is difficult to determine accurate resource estimates for the Paradise coal. The combined original resource is estimated at 9,620,361,000 short tons, with 8,366,246,000 short tons remaining (Smith and Brant, 1980). Since

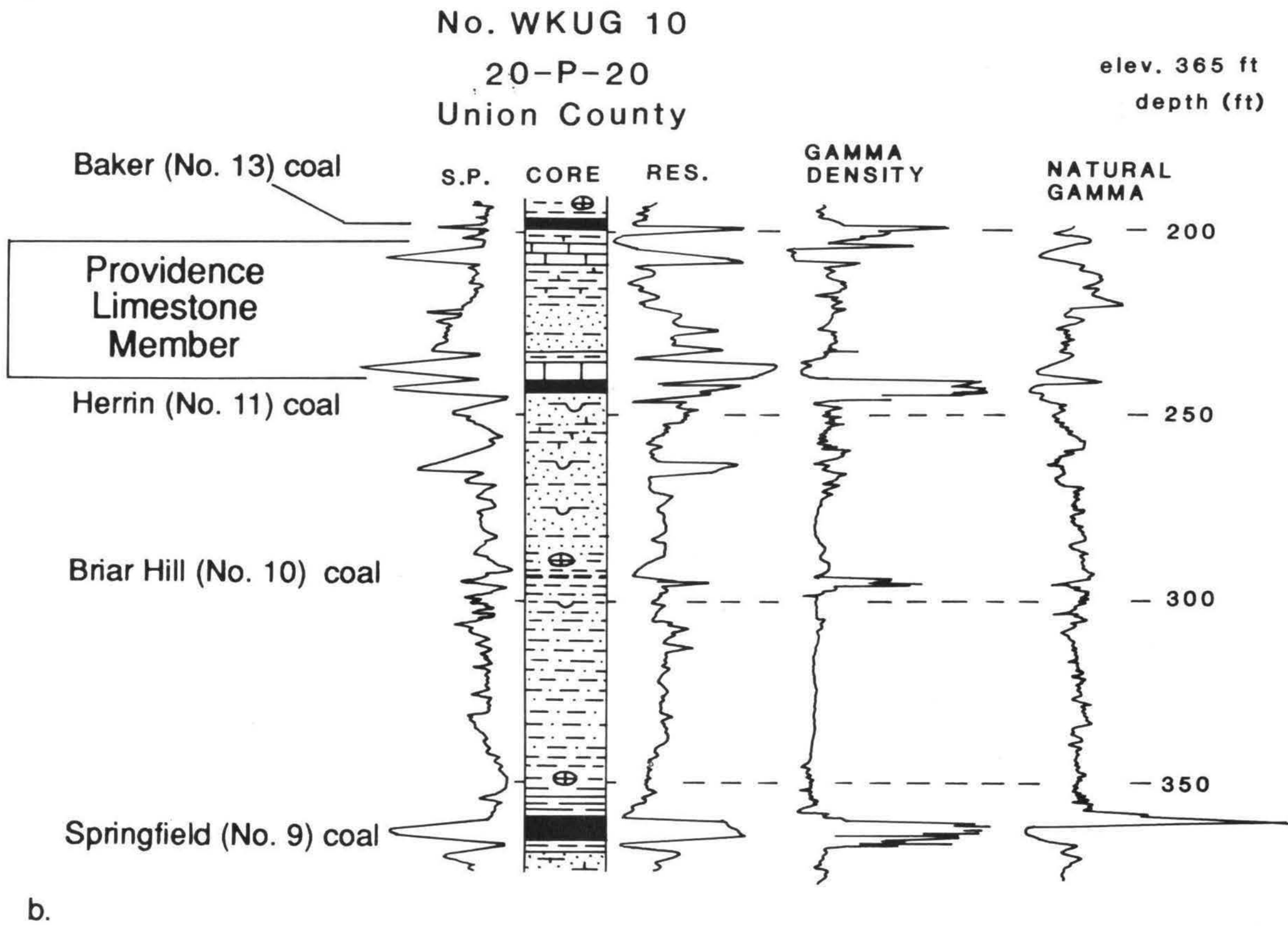
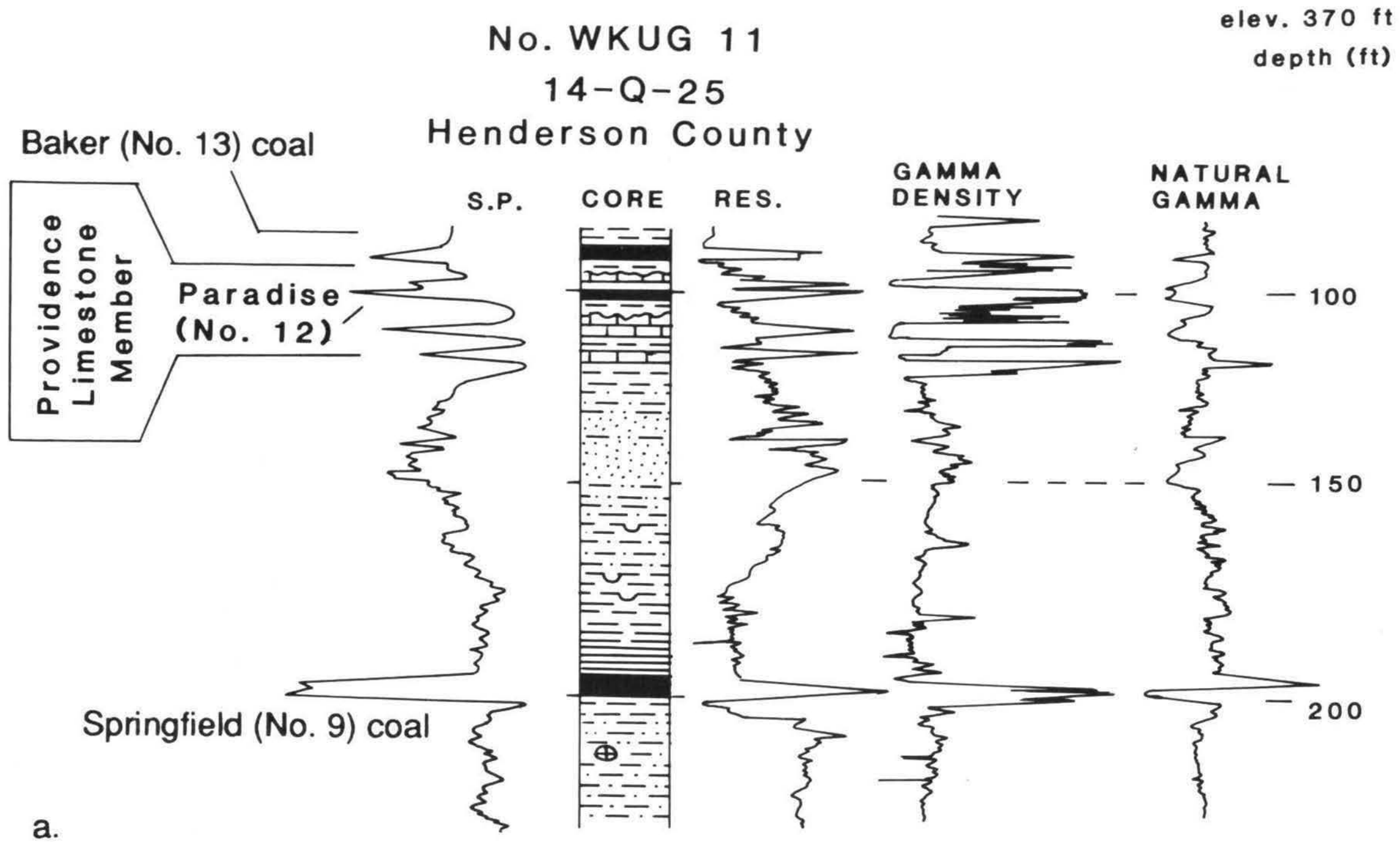


Figure 50. Downhole log examples of the Providence Limestone Member with (a) and without (b) the intervening Paradise (W. Ky. No. 12) coal.

1980, the Paradise has had a reported average annual production of 1.2 million tons, according to the Kentucky Department of Mines and Minerals. Analysis of the Paradise coal in Kentucky indicates a mean total sulfur content of 2.0 percent, mean Btu (daf) of 10,666, mean ash content of 9.7 percent, and mean total moisture content of 8.2 percent (Cobb and others, 1985).

Anvil Rock Sandstone

The Anvil Rock Sandstone was named for a large anvil-shaped block of sandstone along a bluff 1.5 miles west of Dekoven in Union County (Owen, 1856). At the type locality the sandstone rests disconformably on the Herrin coal and extends upward almost to the base of the Coiltown coal (Fig. 44). The sandstone is present north of the type section (Hopkins, 1958; Potter and Simon, 1961), but pinches out to the east along the outcrop (Kehn, 1973). It has also been called the Copperas Creek sandstone in Kentucky (Wanless, 1956).

The Anvil Rock is generally considered to be composed of a sheet sand facies deposited throughout much of western Kentucky, and a channel facies occupying a dendritic paleovalley pattern incised into the upper part of the Carbondale Formation (Hopkins, 1958; Potter and Simon, 1961). Anvil Rock channels in Kentucky may be incised more than 100 feet into underlying Carbondale strata (Kehn, 1974a; Beard and Williamson, 1979). Smaller channel sandstones that are not called Anvil Rock but occur at the same stratigraphic interval and

truncate underlying Carbondale strata are known in several parts of the coal field (Goudarzi, 1969; Hansen, 1972; Palmer, 1972; Fairer and others, 1975). The top of the unit in Kentucky generally is placed below the horizon of the Baker coal (Harvey, 1956), but in some areas the sandstone is coeval with the Baker coal (Fig. 52), which indicates that the coal developed on flood plains of the Anvil Rock channel system. The term "Anvil Rock" has been informally used for thick sequences of sandstones in the interval between the Wheatcroft and Springfield coal. Caution should be used in interpreting these "Anvil Rock" sandstones as a single unit in this interval since several sandstones could be stacked on top of each other, creating areas of apparently thick "Anvil Rock" sandstone.

The channel-sandstone facies actually is composed of numerous channels in a dendritic system that has been mapped extensively in Illinois (Hopkins, 1958; Potter and Simon, 1961; Andersen, 1961; Damberger and others, 1980; Nelson, 1983). More instances of coal cut-outs from the Anvil Rock are known than for any other Pennsylvanian sandstone in southern Illinois, but this frequency may be a reflection of the amount of mining in the Herrin coal rather than the size of the channel system (Potter and Simon, 1961). The main Anvil Rock channel in southern Illinois is several miles wide and has an overall meandering pattern. Many smaller channels or splays spread out from the major channel and affect mining (Hopkins, 1958; Potter and Simon, 1961; Damberger and others, 1980; Nelson, 1983).

The channel facies is composed of coarse- to fine-grained, conglomeratic, crossbedded sandstone whose bedding may thin upward and whose grain size may fine upward. Quartz pebbles are rare above the Caseyville Formation, but occur in the Anvil Rock. The upper channel facies of the Anvil Rock Sandstone are laterally continuous with the sheet-sandstone facies (Hopkins, 1958; Potter and Simon, 1961; Wetendorf, 1967; Palmer and others, 1979; Utgaard, 1979).

The sheet-sandstone facies of the Anvil Rock is both thinner and more extensive than the channel facies. It generally is less than 30 feet thick and overlies the Providence Limestone Member. The sheet sandstone exhibits planar and trough crossbedding, current-ripple and oscillation-ripple laminations, and may contain numerous shale partings, abundant plant fossils, burrows, and rare bivalves. Bedding commonly thickens upward (Hopkins, 1958; Palmer and others, 1979; Utgaard, 1979).

The channel-sand facies is interpreted to have been deposited in fluvial, distributary, tidal, and other coastal-plain channels during the construction of a lobate delta,

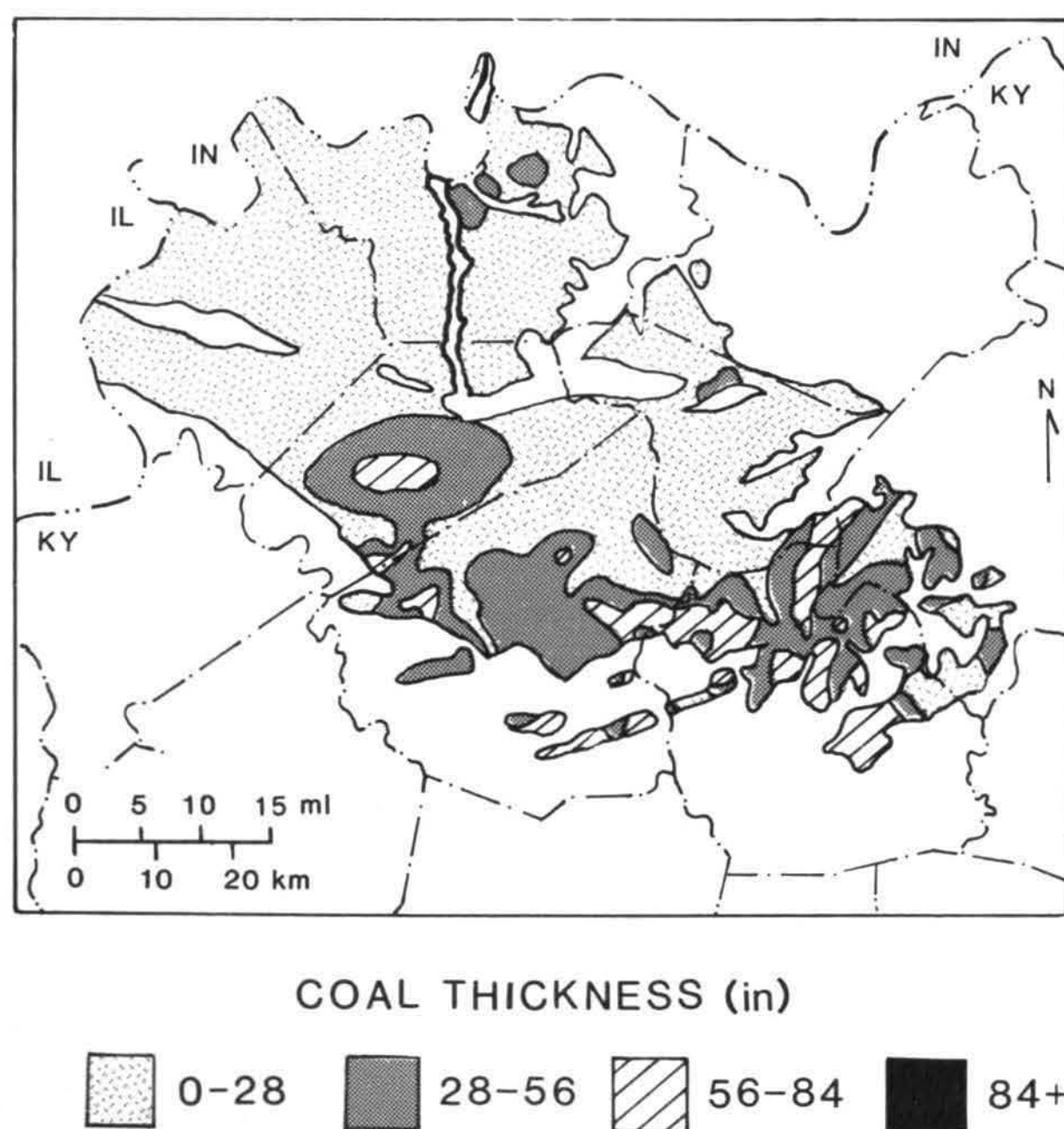


Figure 51. Isopach map of the Paradise (W. Ky. No. 12) coal (modified from Smith and Brant, 1980).

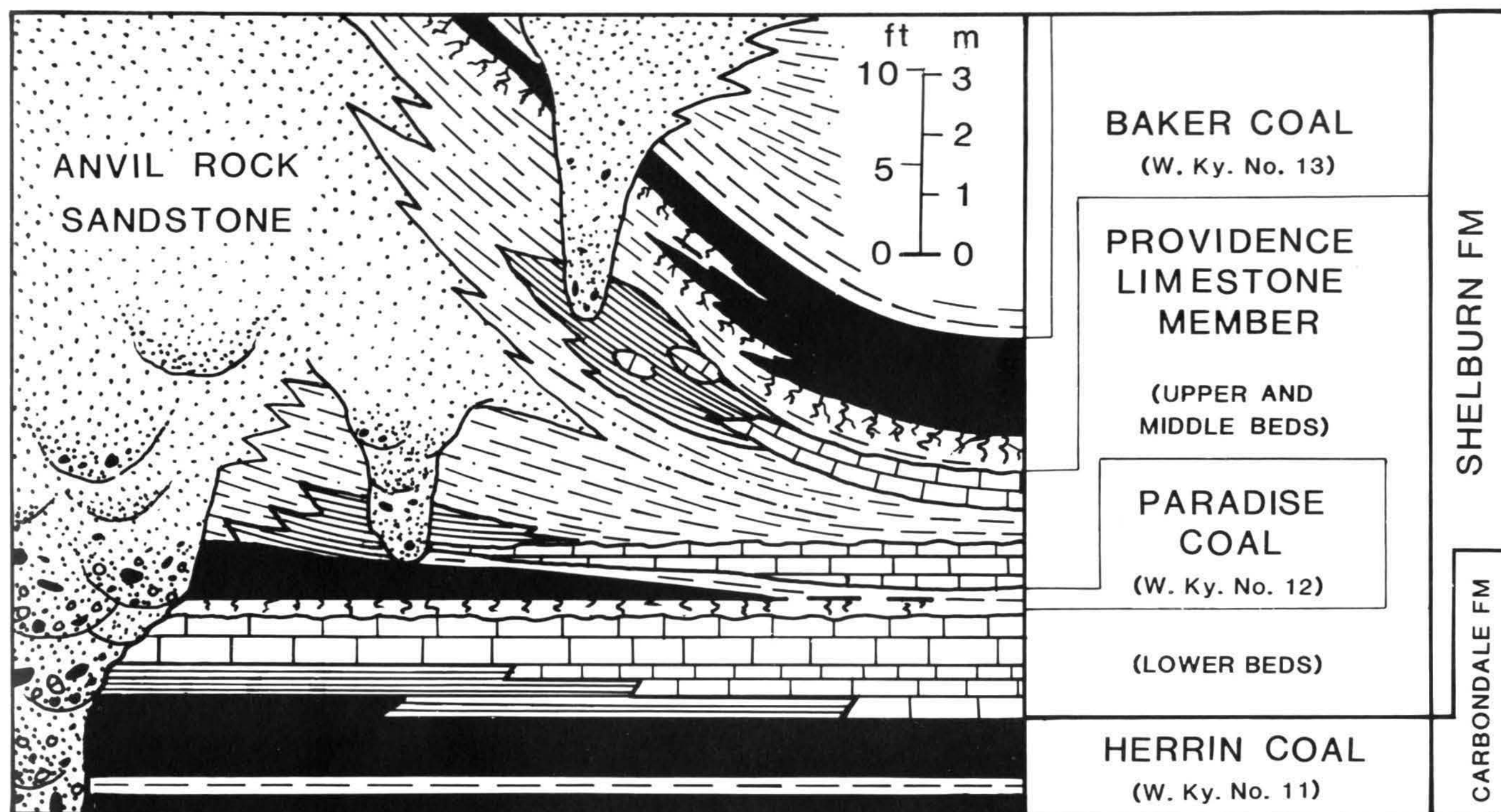


Figure 52. Generalized diagram of the Anvil Rock sandstone and lateral strata.

while the sheet-sand facies was deposited by crevasse splays and overbank flooding (Wetendorf, 1967; Utgaard, 1969). Minor sheet sands associated with the Anvil Rock may also have been deposited in tidal flats and shallow-marine bars along the margins of the distributaries (Palmer and others, 1979).

The Anvil Rock sandstone is one of the most important bedrock aquifers in the coal field. It and the Caseyville sandstones are the only Pennsylvanian aquifers that produce more than 100 gallons per minute (gpm), although the Anvil Rock generally produces less than 20 gpm (Maxwell, 1954; Maxwell and Devaul, 1962a–b). Porosity, vertical and horizontal permeability, and hydraulic conductivity are greatest in the thicker, channel-sand facies and decrease in the thinner, sheet-sand facies (Fickel, 1990).

The Anvil Rock is not a significant hydrocarbon producer in the coal field, although shows may have been reported in the Wagner Church Pool of Webster County (Schwalb and others, 1971) and the Williams Field of Webster County (Kehn, 1975b).

Baker Coal ***(W. Ky. No. 13)***

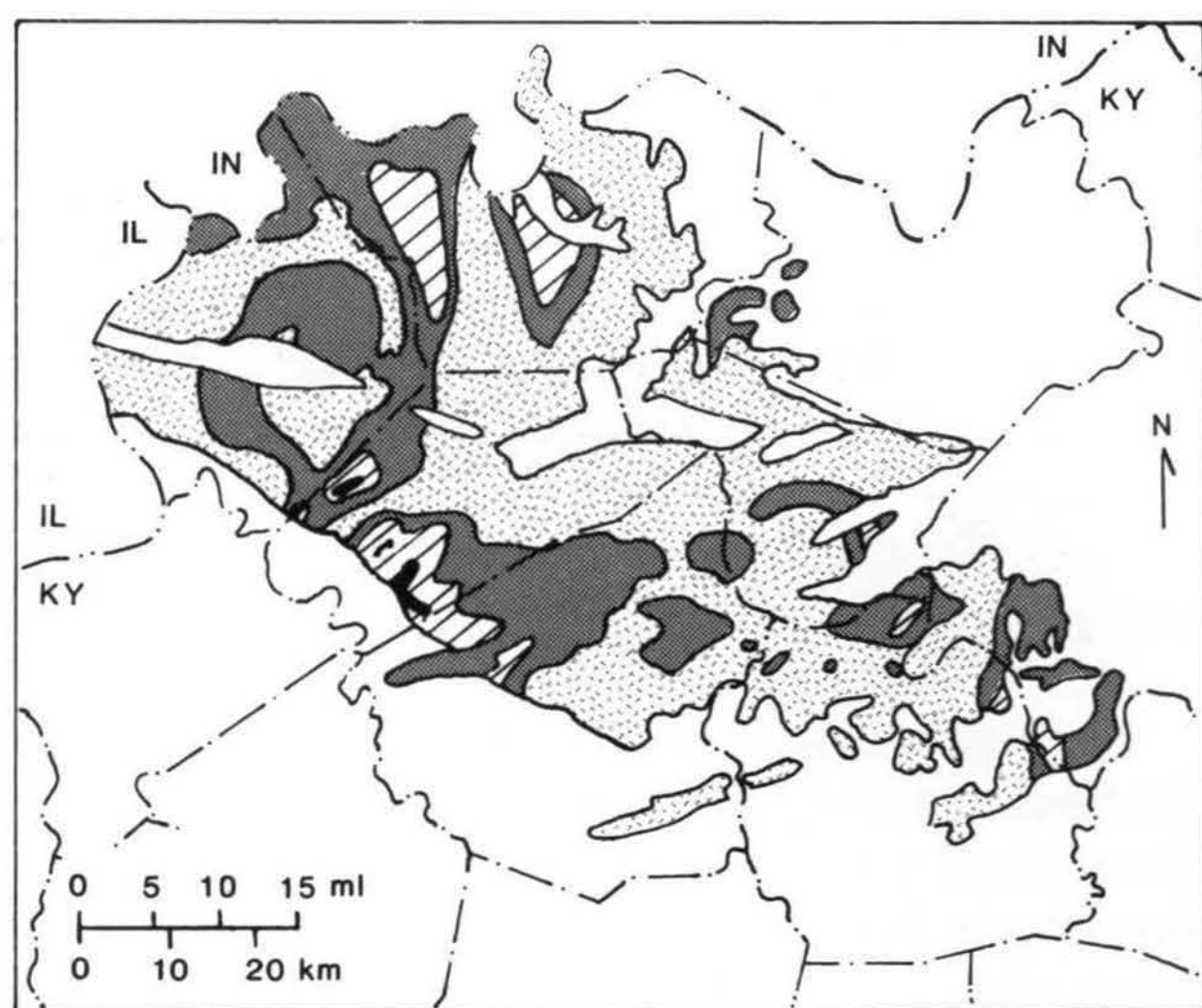
The No. 13 coal was originally designated by Owen (1857b). The coal was named “Baker” by Glenn (1912a–b) for a mine east of Sturgis in Webster County. Glenn

also identified this coal bed numerically as W. Ky. No. 12, and it may be known locally as No. 12 (Kehn, 1966b). However, another coal bed was found between the Baker and the Herrin (W. Ky. No. 11) in Hopkins and Muhlenberg Counties. Consequently, the Baker was renumbered No. 13 (Mullins and others, 1965), although the Baker had previously been correlated with the No. 13 coal by McFarlan (1943) based on measured sections by Weller and Wanless (1939). The Baker also was known locally in Union and Webster Counties as No. 14 (Glenn, 1922; Kehn, 1966b), which led to further confusion since a No. 14 coal occurs 50 feet higher in the McLeansboro Group (Sturgis Formation) in Hopkins, Muhlenberg, and Ohio Counties. The Baker is correlative with the Allenby Coal of Illinois and the Lower Millersburg coal of Indiana (Phillips and others, 1980).

The Baker coal bed occurs from 10 to 50 feet above the base of the McLeansboro Group (previously Sturgis Formation). It is one of the three coals (in addition to the Herrin and Paradise) that provided the incentive for much of the large-scale strip mining in the coal field. Although the Baker is the least widespread of the three coals, it is the thickest and has the best quality. The coal was reported to be 6 feet 7 inches thick in Union County (Johnson and Norris, 1976), and thicknesses in excess of 100 inches have been reported throughout Webster County (Kehn, 1966b, 1975a; Franklin, 1969).

The Baker occurs in a definite, if uneven, pattern in the western part of the Madisonville District (Fig. 53). The coal is thickest in belts subparallel to the Anvil Rock channels and contains claystone partings that thicken toward the channel. On some geologic quadrangle maps the coal is not mapped (e.g., Johnson, 1973a). On others, the No. 13 coal is mapped as a zone containing two or three coals split by as much as 35 feet of shale and sandstone (Fairer and others, 1975; Johnson and Norris, 1976). In some areas the upper bench is the thickest coal (Kehn, 1974a; Johnson and Norris, 1976), and in others the lower split is thicker (Johnson, 1973b-c; Kehn, 1975a; Hansen, 1976b). The lower split may contain abundant partings. In parts of Henderson County a thin limestone may occur (Johnson, 1973b-c). The coal generally is overlain by a gray silty shale containing well-preserved, carbonized plant impressions and kettlebottoms (Glenn, 1922) or fine-grained sheet sandstones (Fig. 54). The geometry of the Baker coal and associated beds may suggest deposition on a flood plain of the Anvil Rock channel system.

The Baker coal in Henderson, Union, and Webster Counties occurs in an interval 10 to 30 feet above the base of the McLeansboro and displays a linear thickness trend, while the Baker in Hopkins, Muhlenberg, and Ohio Counties occurs 30 to 50 feet above the base of the McLeansboro and appears to form patchy lenses (Fig. 53). The differences between the two areas, coupled with the inability to trace the coal throughout the district, has compelled some investigators to suggest that the



COAL THICKNESS (in)



Figure 53. Isopach map of the Baker (W. Ky. No. 13) coal (modified from Smith and Brant, 1980).

Baker of the western part of the Madisonville District may not be coeval with the Baker of the eastern part (Franklin, 1969).

Miners have reported that the Baker coal is thickest where the underlying Paradise is thin or absent. At many localities in Ohio, Muhlenberg, and Hopkins Counties the coal is absent because the interval is occupied by sandstone. Unlike the relationship between the Anvil Rock channels and the Baker coal in the Madisonville District, the depositional relationship between this sandstone and the coal is unclear. At some of the localities the coal and sandstone appear to be coeval and at other sites the sandstone is clearly younger.

The Baker coal has an estimated original resource of 3,206,071,000 short tons, with 3,120,660 short tons remaining (Smith and Brant, 1980). Since 1980 the Baker coal has had an average annual production of more than 1 million tons per year, according to the Kentucky Department of Mines and Minerals. Limited analysis of the Baker coal in Kentucky indicates a mean total sulfur value of 3.5 percent, mean Btu (daf) of 10,140, mean ash content of 15.3 percent, and mean total moisture content of 6.3 percent (Cobb and others, 1985).

Wheatcroft Coal

The Wheatcroft coal is informally named for a coal 10 to 30 feet above the Baker coal (Fig. 44) in abandoned strip mines near Wheatcroft, Webster County. The coal is not mapped on any geologic quadrangle maps, and is only noteworthy because it may be an equivalent of the Danville Coal of Illinois and Indiana (Phillips and others, 1980). In Kentucky, several thin (less than 28 inches) coals have been noted in this interval (Kehn, 1975a).



Figure 54. Baker (W. Ky. No. 13) coal and overlying Central City sandstone along Kentucky Highway 62. The sandstone appears to have cut through the overlying Wheatcroft coal to the top of the Baker coal.

Wheatcroft Coal to Coiltown Coal Interval

In the eastern part of the Madisonville District a thick sandstone occurs in the lower part of the McLeansboro Group (previously Sturgis Formation) between the Providence Limestone and the West Franklin Limestone Members (Fig. 44). The lower boundary generally occurs just above the Baker coal (W. Ky. No. 13) (Fig. 54), but the sandstone may occupy the entire 150-foot interval between the Providence and West Franklin Limestone Members. The sandstone was informally named the Central City sandstone for outcrops near Central City in Muhlenberg County (Whaley and others, 1979). Geophysical logs indicate that the unit extends northeastward into the Moorman Syncline. Thick sandstones in this interval are also known in the western parts of the coal field (Amos, 1970), and may be related to a large channel network.

The lower 20 to 30 feet of the sandstone near Central City is medium to coarse grained. The basal few feet are conglomeratic with siderite nodules and rock clasts up to 6 inches in diameter. The Central City sandstone is one of the few non-Caseyville units that contains large detrital quartz pebbles near its base. The upper part of the unit is similar to other crossbedded sandstones in the Carbondale Formation and McLeansboro Group.

Coiltown Coal (W. Ky. No. 14)

The No. 14 coal was named by Owen (1857b) and given the same numerical designation by Hutchinson (1912). It was correlated with several local Kentucky coals, including the Nortonville, Nebo (Glenn, 1912a), and Franklin (Crider, 1914b) coals. Kehn (1974a) indicated that the No. 14 of Owen (1857b) was actually part of the No. 15 coal zone, but that the No. 14 of Hutchinson (1912) was the No. 14 coal. The coal was informally called the Coiltown by Williamson and Whaley (1979) after exposures in Hopkins County.

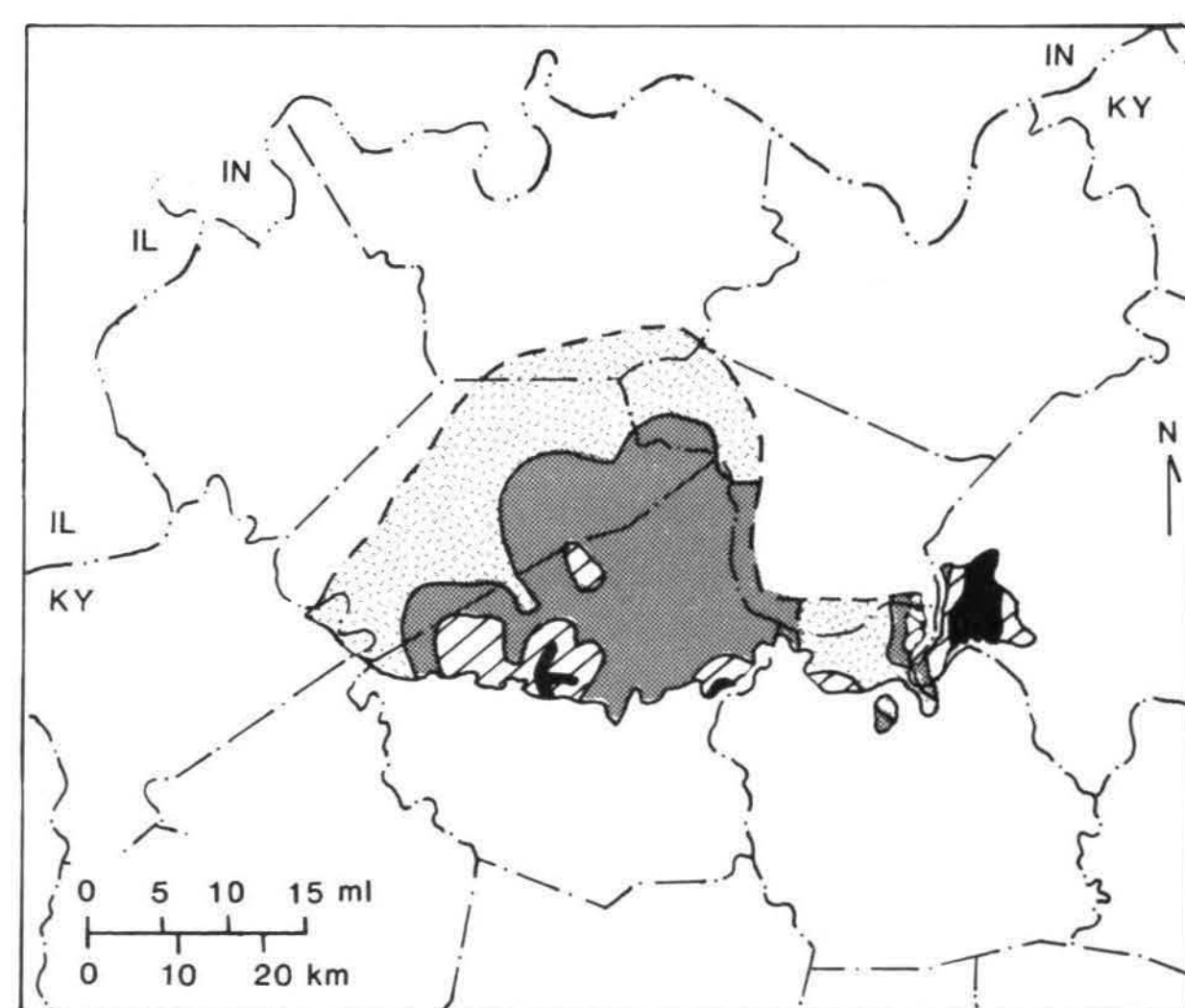
The coal occurs 100 to 150 feet above the base of the McLeansboro Group (Fig. 44). It is not persistent in western Kentucky, but where present this coal tends to be one of the thicker beds in the Madisonville District (Fig. 55). In Muhlenberg County, where the No. 14 coal is called the Green River seam, the coal is 7 feet thick with partings (Palmer, 1969). In eastern Hopkins County a coal thickness of 151 inches was reported, making the Coiltown the thickest coal bed in western Kentucky. Where the Coiltown is thick it often contains abundant partings (up to 12 inches thick), and may be cut out by thick sandstones (Palmer, 1972). Where the coal is thin it can easily be miscorrelated with several thin coals that

occur between the Wheatcroft coal and West Franklin Limestone (Kehn, 1975a).

The Coiltown coal has an estimated original resource of 1,281,648 short tons, with 1,242,932 short tons remaining (Smith and Brant, 1980). In recent years, the Coiltown coal (W. Ky. No. 14) has been one of the top producing seams in the coal field, averaging more than 2.5 million tons annually during the 1980's, according to the Kentucky Department of Mines and Minerals. Analysis of the Coiltown coal indicates a mean total sulfur content of 3.2 percent, mean Btu(daf) of 10,850, mean ash content of 8.7 percent, and mean total moisture content of 9.0 percent (Cobb and others, 1985).

West Franklin Limestone Member (Madisonville Limestone)

The West Franklin Limestone Member is a persistent and easily recognized unit throughout the Illinois Basin. It was first mentioned by Owen (1839) and later described by Lesquereaux (1862). The limestone was named for the town of West Franklin in Posey County, Indiana (Collett, 1884). In Kentucky, Norwood (1878) used the term "Madisonville" to identify a similar limestone unit in Hopkins County, Kentucky. Wanless (1939) and McFarlan (1943) correlated the Madisonville Limestone of Kentucky with the West Franklin of Indiana, but the Madisonville was retained as the name of the limestone in Kentucky. The term "Madisonville" was used for this limestone throughout the U.S. Geological Survey-Ken-



COAL THICKNESS (in)



Figure 55. Isopach map of the Coiltown (W. Ky. No. 14) coal (modified from Smith and Brant, 1980).

tucky Geological Survey Cooperative Mapping Program, and the Madisonville Limestone is used as a marker horizon on almost every geologic quadrangle map in which it occurs. Because the West Franklin and Madisonville are equivalent, and because the term "West Franklin" has precedence in the Illinois Basin, Jacobson and others (1985) recommended that West Franklin be used throughout the basin (Fig. 11).

The West Franklin attains a maximum thickness of 50 feet in Kentucky and consists of as many as four limestone beds. Although named a limestone, the West Franklin Member also contains claystone, shale, sandstone, and coal (Fig. 56). The limestone generally is light gray to brown and crystalline. The shale is medium to dark gray, and the sandstone is fine grained and silty. The claystone is predominantly light to medium gray, but a 2- to 4-foot-thick bed of mottled brick red-green-brown claystone occurs in the lower half of the member.

Clay beds in and below the limestone were once mined for tiles near Madisonville (Hutchison, 1912; Kehn, 1964a). The limestone itself has been mined for use in many areas as local building stone and road metal (Crider, 1914; Kehn, 1964a; Johnson and Smith, 1972a; Johnson, 1973d, c; Johnson and Norris, 1974).

The limestone may be cut out in parts of Webster and Union Counties by a thick, crossbedded sandstone. Andersen (1961) correlated this sandstone with the Trivoli Paleovalley Complex of Illinois, but the Trivoli Sandstone was not extended into Kentucky as a formal term during the U.S. Geological Survey-Kentucky Geological Survey Cooperative Mapping Program in the areas where Andersen noted a thick sandstone interval (Fairer and others, 1975; Hansen, 1975).

The W. Ky. No. 14a coal occurs between the second and third limestone beds of the member. It is thin (less than 18 inches) and usually gradational with dark marine shales (Wanless, 1939; Kehn, 1963; Franklin, 1969, 1973; Palmer, 1969, 1972).

As a subsurface unit, the West Franklin is generally recognized as a single limestone bed, 3 to 10 feet thick. On electric logs the West Franklin (Madisonville) is usually identified as the middle limestone bed where there are three limestone beds, and the lower limestone where there are two beds. In Indiana the uppermost bed was used to define the top of the Shelburn Formation (Wier, 1961; Shaver and others, 1986), and the top of the uppermost bed was the boundary accepted by the Tri-State Correlation Committee.

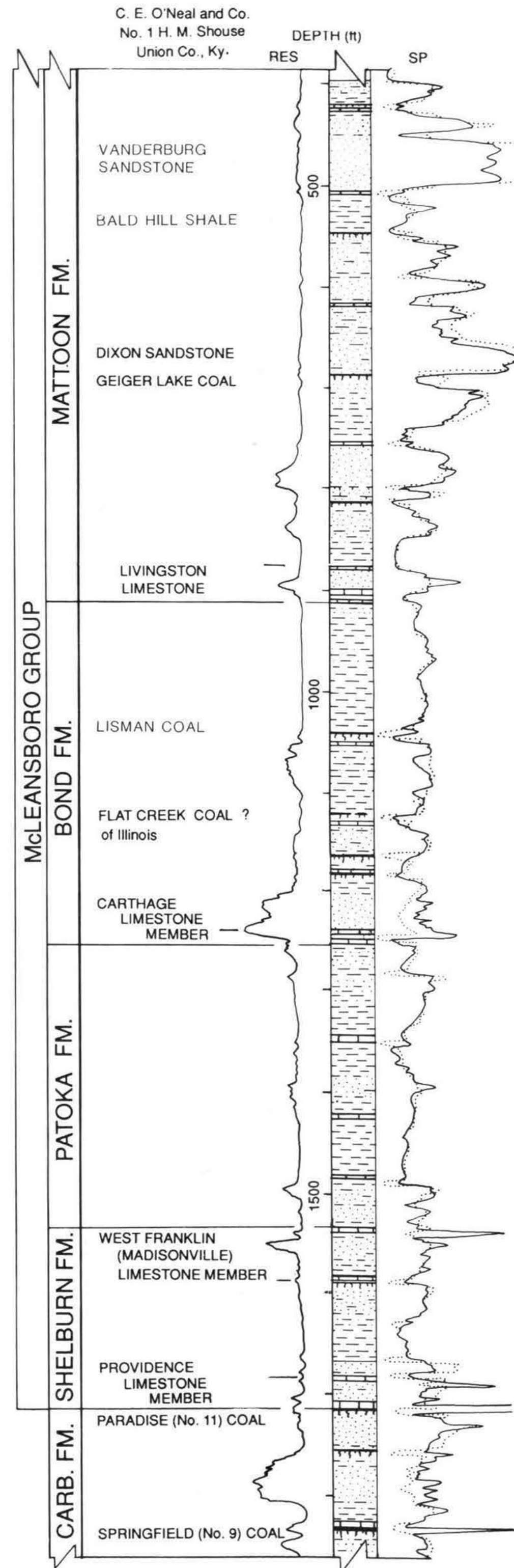


Figure 56. Core description and sample electric log for part of the McLeansboro Group in Union County, Kentucky, highlighting named units of the Bond and Mattoon Formations (modified from Smith and Smith, 1967).

PATOKA FORMATION

Nomenclature History and Formation Boundaries

The Patoka Formation was named by Wier (1961) for outcrops in Indiana. The Tri-State Correlation Committee agreed to adopt the Patoka across the basin. The original boundaries of the formation were also agreed upon. Hence, the Patoka in Kentucky is defined as the interval between the top of the West Franklin Limestone and the base of the Carthage Limestone (Figs. 11, 44, 56). Since the formation nomenclature has only recently been adopted into Kentucky, it has not been mapped. Future work will need to concentrate on delineating thickness and lithologic trends of the Patoka in Kentucky so that basin-wide trends can be determined.

Named Units of the Patoka Formation in Kentucky

The newly defined Patoka Formation in Kentucky consists of 300 feet of shale, siltstone, and fine-grained sandstone present only in the deeper parts of the Moorman Syncline and a graben in northwestern Union County. The Patoka interval in Kentucky is best known from drill-hole records. Coals and sandstones are generally thin and discontinuous, but a few are persistent enough to have been named (Fig. 44).

W. Ky. No. 15 Coal

The W. Ky. No. 15 coal was named by Owen (1857b) for a coal noted in borings near Uniontown, Kentucky. The coal was only 6 inches thick, and was overlain and underlain by soft shale and limestone. Franklin (1969) and Kehn (1974a) recorrelated the coal and considered Owen's (1857b) No. 14 to be equivalent to the No. 15 coal. The No. 15 of Owen (1857b) was considered equivalent to the No. 15a of Hutchinson (1912) by Franklin (1969) in Webster County. Hutchinson mapped many coals in a coal zone ranging from No. 15a through No. 15e. The No. 15 of Owen (1857b) is mapped as a discontinuous unnamed bed by Kehn (1974a). The numerical designation No. 15 has been used locally in the coal field for coals stratigraphically as high as the Lisman coal in the Bond Formation (Franklin, 1969).

On many geologic quadrangle maps the No. 15 coal is mapped as a coal zone containing as many as four distinct coals (Franklin, 1969; Kehn, 1975a). The coal is generally less than 36 inches thick where it occurs as a single bench (Palmer, 1972; Fairer, 1975; Hansen, 1976a–b). Where multiple coals occur in a No. 15 coal zone, individual coals are usually much thinner (Franklin, 1969; Kehn, 1975a). The No. 15 coal is truncated by

a thick sandstone channel more than 130 feet thick in the eastern part of the coal field (Goudarzi, 1969). Smith and Smith (1967) correlated the W. Ky. No. 15 with the Chapel (No. 8) Coal Member of the Modesto Formation in Illinois. The Modesto Formation is now called the Patoka Formation.

W. Ky. No. 16 Coal

The W. Ky. No. 16 coal was named by Owen (1857b) for an 8-inch-thick coal and rash noted in borings near Uniontown, Kentucky. The coal was underlain by a 2-foot-thick, sandy limestone and overlain by a 26-foot-thick coarsening-upward sandstone. The coal is correlated on geologic quadrangle maps by its position as the second coal beneath the Carthage Limestone. The coal is generally thin (less than 18 inches) and may occur in a zone of thin, sporadic coals (Franklin, 1969; Kehn, 1974a, 1975a; Palmer, 1976).

W. Ky. No. 17

The W. Ky. No. 17 coal was named by Owen (1857b) for an 8-inch-thick coal noted in borings near Uniontown, Kentucky. The coal occurred at the top of the coarsening-upward sequence above the No. 16 coal, and was capped by the Carthage Limestone. Like the No. 16 coal, the No. 17 coal is usually thin (less than 24 inches) and sporadic (Kehn, 1974a, 1975a; Palmer, 1976). Smith and Smith (1967) correlated the W. Ky. No. 17 with the New Haven Coal Member of the Modesto Formation in Illinois.

BOND FORMATION

Nomenclature History and Formation Boundaries

The Bond Formation was named in Illinois for the strata from the base of the Shoal Creek Limestone to the top of the Millersville Limestone (Kosanke and others, 1960). This interval was first considered equivalent to part of the Lisman Formation (Glenn, 1922), and then part of the Sturgis Formation (Kehn, 1973) in Kentucky. Stratigraphic correlations across the basin determined that the Shoal Creek Limestone of Illinois was equivalent to the Carthage Limestone of Kentucky (Smith and Smith, 1967), and the Millersville Limestone was equivalent to the Livingston Limestone in Illinois and Indiana (Kosanke and others, 1960). The terms "Carthage" and "Livingston" were adopted by the Tri-State Correlation Committee for use throughout the basin because of the precedence of each term (Jacobson and others, 1985). As a further result of tri-state cooperation, the Bond Formation was accepted as a basin-wide term.

The Bond Formation in Kentucky replaces the part of the Sturgis Formation (Kehn, 1973) from the base of the

Carthage Limestone to the top of the Livingston Limestone. The Livingston Limestone is widely mapped in Illinois and Indiana, but has not been mapped in Kentucky. Limited subsurface data indicate that it is discontinuous in Kentucky. Further work will be needed to delineate the extent of the Livingston and equivalents in Kentucky.

Named Units of the Bond Formation in Kentucky

Because the Bond Formation in Kentucky occurs only over a very limited area, it has few named units (Fig. 44). The only useful unit is the Carthage Limestone Member, which is a distinctive subsurface marker horizon. Thin coals above the Carthage Limestone in Kentucky (Fig. 56) were correlated with the Flat Creek and Witt Coals of Illinois by Smith and Smith (1967), but these names have not been used in other Kentucky reports and are not described here.

Carthage Limestone Member

The Carthage Limestone Member occurs 450 to 500 feet above the base of the McLeansboro Group (Fig. 44). The Carthage is a regionally persistent unit, although it is preserved well only in the deeper parts of the Moorman Syncline and a graben adjacent to the Ohio River in Union County. The Carthage was named by Owen (1856) for exposures on the bank of the Ohio River about 1 mile south of Uniontown; the exposures have since been covered by the pool behind dam No. 49. One mile southwest of the flooded type section the Carthage crops out in the river bluff. At that locality (Carter coordinate location 16-P-19, 2,750 FSL X 2,300 FEL, Union County, Kentucky), 7 feet of light-gray, crystalline, fossiliferous limestone is exposed. Drill-hole records indicate that the Carthage ranges in thickness from 1 foot to 15 feet, and at some localities it is split into two beds. The distinctive resistivity signature of the Carthage on geophysical logs penetrating this interval makes it the most useful and reliable stratigraphic unit above the West Franklin (Madisonville) Limestone Member (Figs. 56–57).

Mt. Carmel Sandstone

The Carthage Limestone is overlain by thick sandstones that buttress a series of low hills between southern Union County and central Hopkins County. In the subsurface the sandstone fines upward (Fig. 56). In southern Illinois, the sandstone unit directly above the Carthage Limestone Member is called the Mt. Carmel Sandstone (Andersen, 1961). This terminology has not been extended into Kentucky, although thick sandstones are noted in this interval.

W. Ky. No. 18 Coal

The W. Ky. No. 18 coal was the youngest coal named by Owen (1857b) in a series of subsurface borings near Uniontown, Kentucky. The coal occurred 50 feet above the Carthage Limestone and was 8 inches thick (Owen, 1857b). The coal is mapped on several geologic quadrangle maps in Webster and Union Counties, where it is generally less than 24 inches thick (Franklin, 1969; Kehn, 1974a, 1975a; Fairer and others, 1975), although locally it may reach thicknesses of 48 inches (Franklin, 1965). It may also be mapped as a zone of multiple coals (Fairer and others, 1975). As many as three thin, unnamed coals may occur between the Lisman coal and the Carthage Limestone (Hansen, 1976b).

Lisman Coal

The Lisman coal was named by Glenn (1923) for a thin coal 130 feet below the Geiger Lake coal and nearly 600 feet above the West Franklin (Madisonville) Limestone (Figs. 45, 56–57). The Lisman appears to be persistent throughout the deeper parts of the Moorman Syncline (Franklin, 1969; Kehn, 1974a, 1975a; Hansen, 1976b), and was mined in the hills north of Madisonville, Kentucky. In recent years the Lisman coal was the uppermost mined coal bed in the coal field, with an average annual production during the 1980's of 122 thousand tons, according to the Kentucky Department of Mines and Minerals.

The Lisman is generally thin (less than 24 inches), but reaches thicknesses in excess of 40 inches in Webster and Hopkins Counties (Franklin, 1969; Fairer and others, 1975). The Lisman has been called the No. 15, No. 15L, No. 15 Stray, Balls Hill coal, and Lower Otter Creek coal (Franklin, 1969). In the subsurface near Sturgis, Kentucky, a thin coal at the same stratigraphic interval as the Lisman was correlated with the Witt Coal of Illinois (Smith and Smith, 1967). Palynological studies of the Lisman (Lower Otter Creek) coal indicate that the peat that formed the coal was deposited during a period of climatic drying or lowering of the paleo-water table (Helfrich and Hower, 1989).

Livingston Limestone

The Livingston Limestone was named by Worthen (1875) for outcrops in Clark County, Illinois. It was accepted as a member of the Bond Formation in Illinois by Kosanke and others (1960), and in Indiana by Wier (1961). The Livingston was tentatively accepted as the lower boundary of the Mattoon Formation when the McLeansboro Group and associated formations were adopted into Kentucky. However, since the Livingston was not previously used as a marker horizon in Ken-

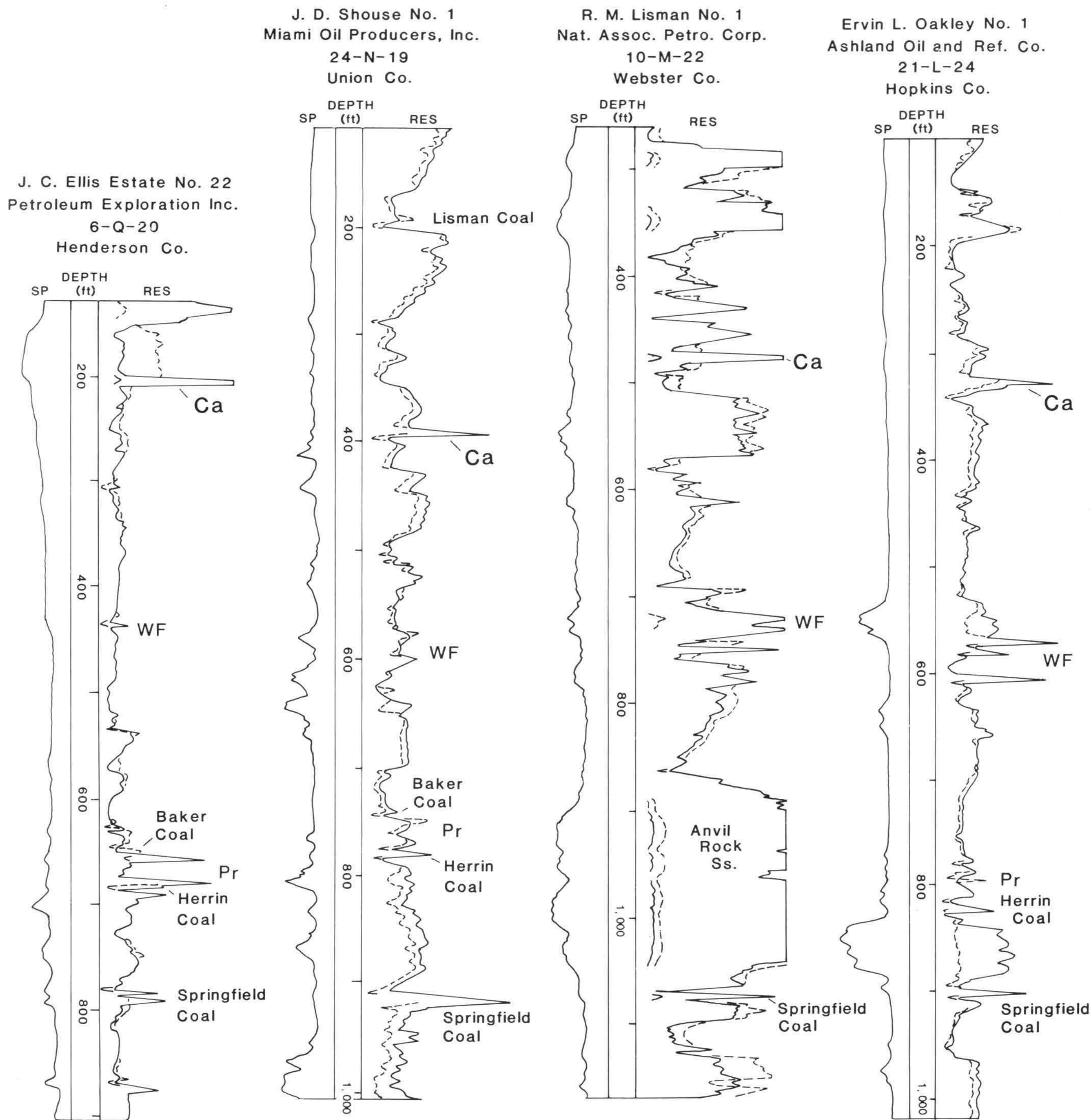


Figure 57. Representative downhole electric logs of part of the McLeansboro Group highlighting the characteristic signature of the Carthage Limestone in different parts of the coal field and showing the position of the Carthage relative to other significant marker beds.

tucky, future work will be needed to determine its extent and usefulness as a formation boundary. Smith and Smith (1967) identified the Millersville (Livingston) limestone 200 feet beneath the Geiger Lake coal (Fig. 56). Several geologic quadrangle maps in Union and Web-

ster Counties indicate limestones beneath the Geiger Lake coal that might be equivalent to the Livingston. Until the Livingston is mapped in Kentucky, the best approximation of the Mattoon Formation boundary is the Geiger Lake coal. The Geiger Lake coal is used as a marker bed

on geologic quadrangle maps that contain this interval of strata, and the Livingston horizon can be interpreted as occurring between 175 and 225 feet beneath the Geiger Lake coal.

Smith and Smith (1967) correlated the Livingston (Millersville) between several core holes in Union County, Kentucky. In these cores the Livingston consisted of a 37-foot-thick zone defined by three limestone benches. The upper bench consisted of 11 inches of fossiliferous limestone, separated from the middle bench by 25 feet of fine-grained, laminated sandstone, laminated siltstone, and shale. The middle bench consisted of a 3-foot-thick, sandy, fossiliferous (crinoidal) limestone separated from the lower bench by 7 feet of silty shale. The lower bench consisted of a thin carbonate conglomerate 332 feet above the Carthage Limestone (Smith and Smith, 1967).

MATTOON FORMATION Nomenclature History and Formation Boundaries

The Mattoon Formation was named by Kosanke and others (1960) in Illinois. The Mattoon was equivalent to the Henshaw and upper Lisman Formations in Kentucky (Kehn, 1964b), and then the middle part of the Sturgis Formation of Kehn (1973). At the recommendation of the Tri-State Correlation Committee, the Mattoon was extended into Kentucky. The base of the Mattoon Formation remains the top of the Livingston (Millersville) Limestone, as originally defined (Kosanke and others, 1960). However, because Permian rocks are known in Kentucky (Kehn, 1973), the top of the formation is revised to the erosion limit of Pennsylvanian rocks above the Livingston in Illinois and Indiana, or the base of the Mauzy Formation in Kentucky (Fig. 11).

The Mattoon is lithologically different from the underlying Bond Formation in that it contains a greater percentage of sandstone. Also, limestones of the Mattoon Formation are dominated by ostracodes and *Spirorbis* fossils (Fig. 47) rather than the abundant brachiopods, crinoids, and other marine fossils that characterize limestones lower in the section (Smith and Smith, 1967).

Named Units of the Mattoon Formation in Kentucky

Because the rocks in the Mattoon interval are restricted to a small area in Kentucky, it has few recognized named units (Fig. 44). Smith and Smith (1967) and Kehn (1973) described cores through the Mattoon interval from Union County, Kentucky. Several thin coals and limestones from these cores may correlate with named

units in Illinois, but more work will be needed on the paleontology and palynology of the thin carbonates and coals of the Mattoon interval in Kentucky before correlations can be made. On many geologic quadrangle maps where the Mattoon strata are mapped, coals are unnamed and uncorrelated above the Lisman coal. More than nine coals have been documented above the Lisman coal (Franklin, 1969; Fairer and others, 1975; Kehn, 1975a); most of the coals are less than 24 inches thick. The only consistently thick coal in this interval is the Geiger Lake coal.

Geiger Lake Coal

The Geiger Lake coal was originally called the Geigers Lake coal for openings on the Kentucky side of the Ohio River across from Shawneetown (Glenn, 1912a). It was considered the equivalent of the Dixon and Callender coals of Kentucky because of the stratigraphic position of these coals beneath a cliff-forming sandstone. The coal was mapped as the Geiger Lake coal (rather than Geigers) by Lee (1916) and Glenn (1923). The Geiger Lake coal (Fig. 44) was mapped on several geologic quadrangle maps in Union County (Franklin, 1969; Kehn, 1975a; Hansen, 1976b) and was the marker for a color break in the upper McLeansboro (Sturgis) on other maps (Kehn, 1974a; Palmer, 1976).

The Geiger Lake coal occurs approximately 550 feet above the Carthage Limestone (190 feet above the Livingston Limestone) and appears to be persistent in the subsurface (Fig. 56). It has been mined only in the vicinity of Henshaw in Union County (Kehn, 1974a). The Geiger Lake coal was reported to be 49 inches thick with partings near the type section at Geiger Lake (Glenn, 1912a), although core holes in other parts of Union County exhibit thicknesses less than 14 inches (Smith and Smith, 1967; Kehn, 1973). A split coal (11- and 19-inch benches) 117 feet below the Geiger Lake coal in Union County is overlain by a sandstone similar to the Geiger Lake coal and could easily be miscorrelated. The Geiger Lake is generally considered to be a coal below the Dixon sandstone (Glenn, 1923; Franklin, 1969), but some geologic quadrangle maps place the Geiger Lake above the Dixon sandstone (Hansen, 1975; Kehn, 1975a).

Dixon Sandstone

The Dixon sandstone of Glenn (1912a, 1923) was named for a sandstone that rested directly on the Geiger Lake coal (Figs. 44, 56). However, the Dixon sandstone was mapped on the Dixon geologic quadrangle map as a sandstone beneath the Geiger Lake coal (Hansen, 1976a). This correlation may cause stratigraphic confusion in pre-1973 literature since the base of the Dixon

sandstone was the base of the Henshaw Formation (Lee, 1916; Glenn, 1922), and this formation was widely mapped. Kehn (1973) noted the inconsistency in the use of the Dixon sandstone as a formation boundary, and combined the Lisman and Henshaw strata into the Sturgis Formation. The sandstone is massive to cross-bedded, medium to coarse grained, and ranges in thickness from 15 to 60 feet in Union and Webster Counties (Lee, 1916; Glenn, 1922; Smith and Smith, 1967). Sandstones of similar thickness and texture (also positioned above thin coals) are common in this interval, and can easily be miscorrelated (Glenn, 1922; Smith and Smith, 1967).

Dixon Sandstone to Vanderburg Sandstone Interval

The Dixon sandstone is overlain by a gray shale called the Dixon shale (Glenn, 1912a, 1922, 1923). Locally, a thin coal called the Polly coal may occur 40 feet above the Dixon (Glenn, 1912a, 1923; McFarlan, 1943). As many as three thin coals may occur within the same interval (Franklin, 1969). The Bald Hill shale was named for 60 to 125 feet of gray-green shale beneath the Vanderburg Sandstone in Webster County (Glenn, 1912a). These thick, shaly sequences are quite variable and of limited stratigraphic use.

Vanderburg Sandstone and Mt. Gilead Sandstone

The Vanderburg and Mt. Gilead Sandstones were named by Glenn (1912a). The Vanderburg was delineated as a sandstone 200 feet above the base of the Dixon sandstone (Figs. 44, 56). The Mt. Gilead Sandstone was the youngest unit named by Glenn (1922), and delineated 350 feet above the base of the Dixon sandstone in Webster County. The two sandstones are separated by a thick coarsening-upward sequence in Webster County called the Mt. Gilead shale (Glenn, 1912a). Several thick sandstones (30 and 75 feet) occur in the interval 100 to 450 feet above the base of the Dixon sandstone (Smith and Smith, 1967) that are similar to the two named units of Glenn (1922). The lack of detailed correlations in this part of the coal field makes applying these terms of limited use, stratigraphically.

Sulfur Springs Coal

The Sulfur Springs has the distinction of being the youngest coal bed in the Illinois Basin. The coal occurs about 1,300 feet above the Carthage Limestone (1,080 feet above the Livingston Limestone). The coal was named by Kehn (1975a-b), although it had been described previously by him in 1973. Three small under-

ground mines locally mined this seam (Kehn, 1975a). The coal occurs about 200 feet below the base of the Mauzy Formation at the type locality of the formation near Cap Mauzy Lake in Union County (Fig. 58) (Kehn and others, 1982). It is interpreted to be approximately equivalent or slightly younger than the Pittsburgh coal bed of the Northern Appalachian Basin (R. A. Peppers, personal communication, *in* Kehn and others, 1982).

Upper Boundary of the McLeansboro Group and Pennsylvanian System

The uppermost Pennsylvanian has been removed by erosion in western Kentucky except in a small graben in Union County where Pennsylvanian strata are overlain by the Mauzy Formation of Permian age (Fig. 58). The precise systemic boundary has not been determined. In fact, the top of the McLeansboro Group (previously Sturgis Formation) may intergrade with the Mauzy Formation across the systemic boundary (Kehn and others, 1982). For convenience, the Pennsylvanian/Permian boundary is placed at the proposed contact between the McLeansboro Group (Sturgis Formation) and Mauzy Formation. The contact between the two is somewhat arbitrary, and is placed at the base of a limestone sequence in the uppermost 340 feet of strata cored at the GIL-30 locality (Fig. 58) (Kehn and others, 1982). This contact was picked on the basis of (1) a lithologic change in which the percentage of limestone appeared to increase above the proposed contact, and (2) its location approximately midway between the Sulfur Springs coal, which contains Upper Pennsylvanian spores, and a limestone that contains fossils of Early Permian age (Douglas, 1979).

MAUZY FORMATION

(PENNSYLVANIAN(?) AND PERMIAN)

The Mauzy Formation was named for approximately 400 feet of rocks recovered from a core hole located in Union County (Kehn and others, 1982). The strata consists of interbedded shale, siltstone, limestone, and claystone, which are distinguishable from the underlying Mattoon Formation of the McLeansboro Group (Sturgis Formation) by an appreciably larger percentage of limestone (Fig. 58). These limestone beds typically occur in 3- to 6-foot beds composed of light-gray to tan, very fine-grained, nodular limestone with green and pink interstitial clay. The Mauzy generally is unfossiliferous, although one limestone bed yielded the Permian fusulinid *Triticites*, from which overlying parts of the formation were given a Permian age (Douglas, 1979). This section is the sole verified occurrence of Permian beds in the Illinois Basin. The age of unfossiliferous Mauzy strata beneath the *Triticites* zone has not been determined, so the

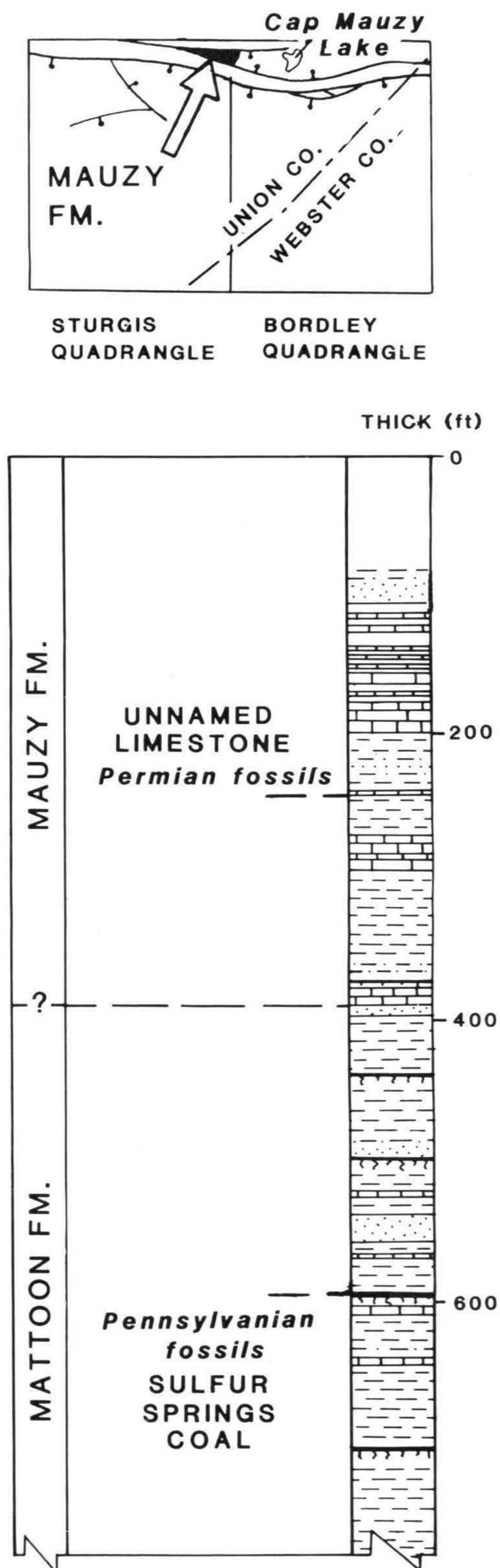


Figure 58. Delineation of the top of the Mattoon Formation (and McLeansboro Group) near Cap Mauzy Lake, Union County, where the Mauzy Formation occurs (modified from Kehn and others, 1982).

lower part of the Mauzy Formation may be Late Pennsylvanian in age. For convenience, the systemic boundary is placed at the base of the formation (Kehn and others, 1982).

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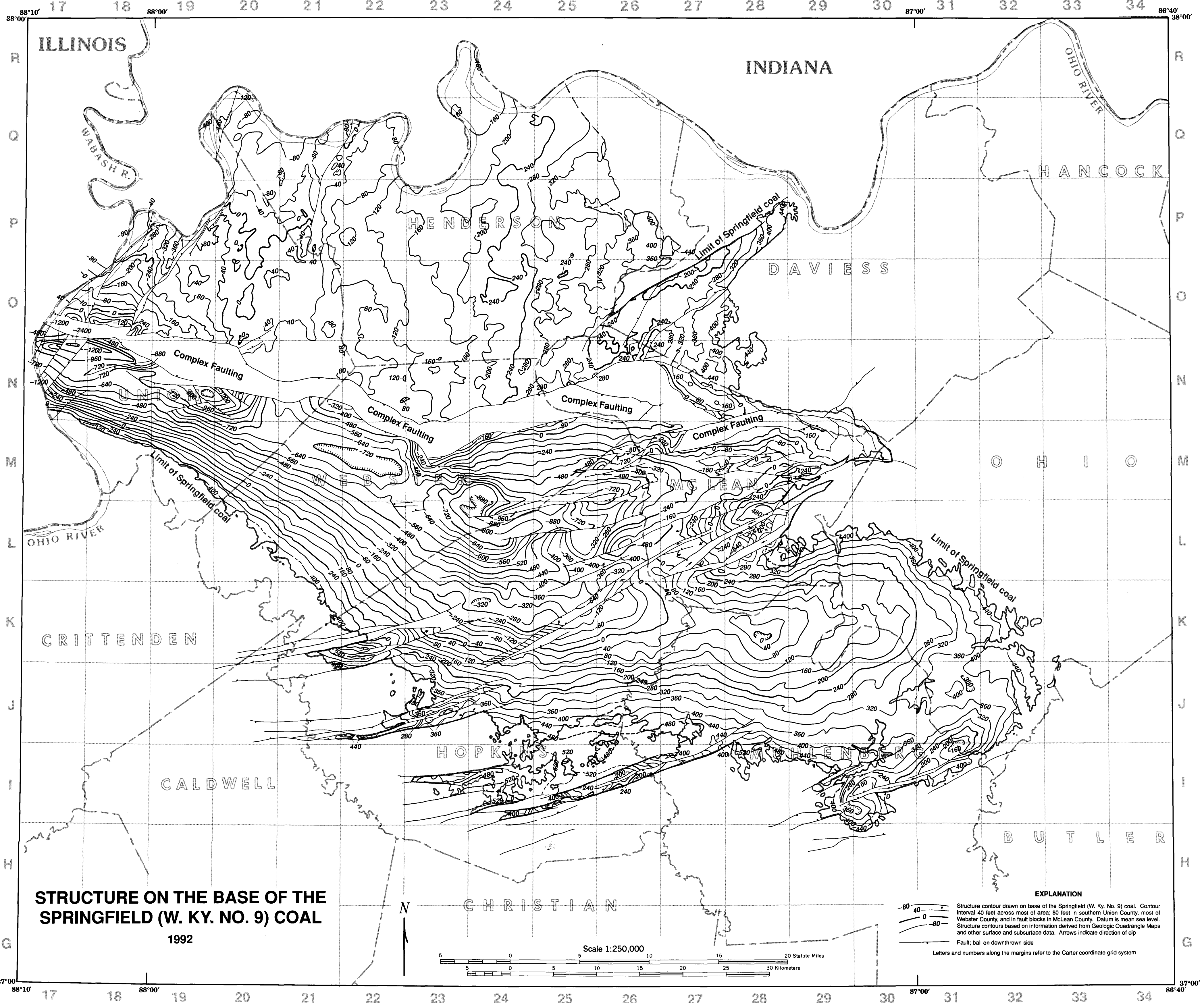
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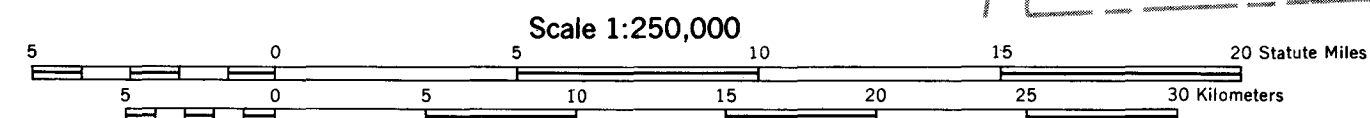
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**STRUCTURE ON THE BASE OF THE
 SPRINGFIELD (W. KY. NO. 9) COAL**
 1992



EXPLANATION

Structure contour drawn on base of the Springfield (W. Ky. No. 9) coal. Contour interval 40 feet across most of area; 80 feet in southern Union County, most of Webster County, and in fault blocks in McLean County. Datum is mean sea level. Structure contours based on information derived from Geologic Quadrangle Maps and other surface and subsurface data. Arrows indicate direction of dip.

Fault; ball on downthrown side

Letters and numbers along the margins refer to the Carter coordinate grid system

