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KENTUCKY GEOLOGICAL SURVEY
Donald C. Haney, State Geologist and Director
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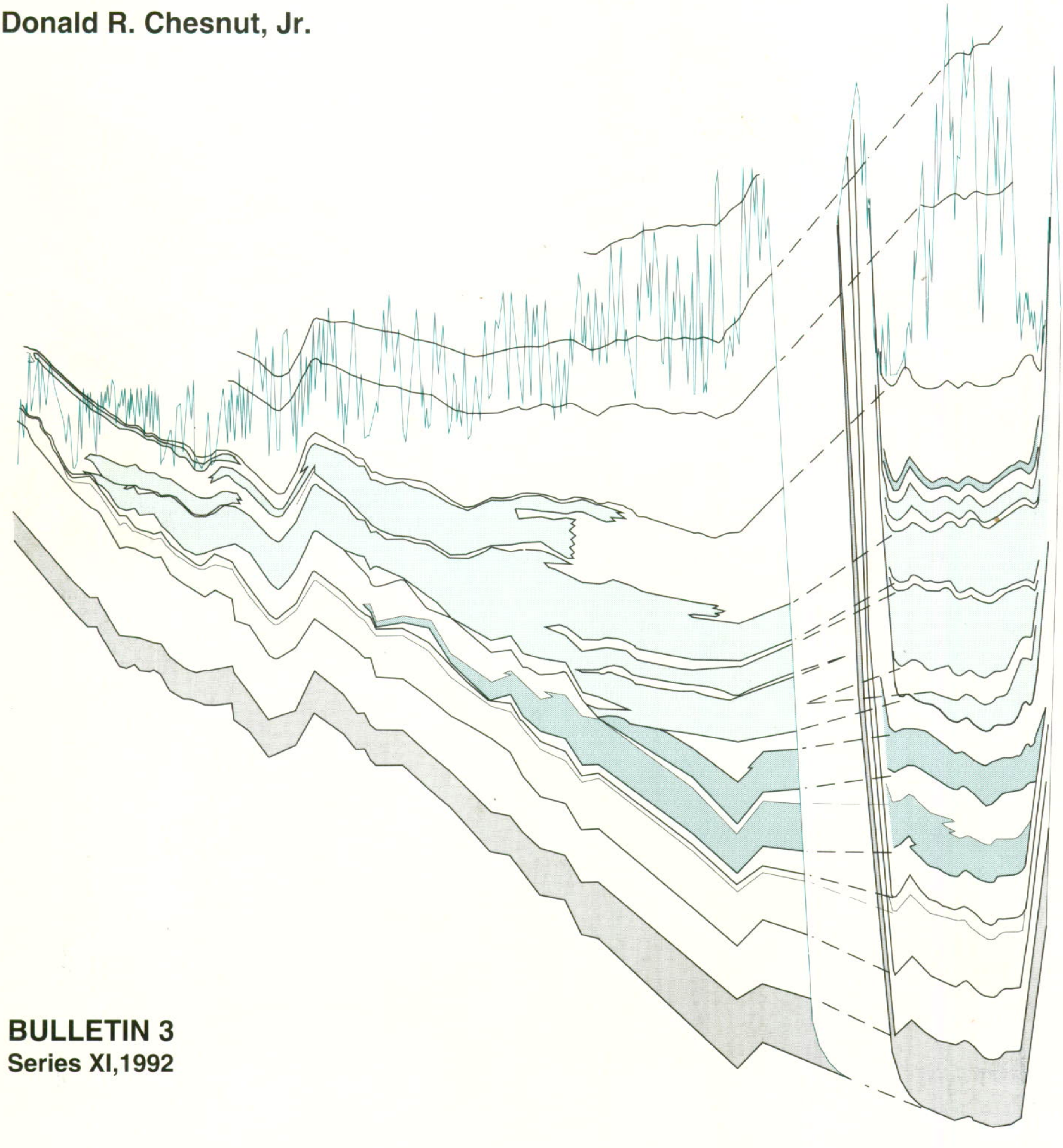
Stratigraphic and Structural Framework of the Carboniferous Rocks of the Central Appalachian Basin in Kentucky

Donald R. Chesnut, Jr.



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STRATIGRAPHIC AND STRUCTURAL FRAMEWORK OF CARBONIFEROUS ROCKS IN THE CENTRAL APPALACHIAN BASIN IN KENTUCKY

Donald R. Chesnut, Jr.

ABSTRACT

A series of seven cross sections across the Central Appalachian Basin in Kentucky, Tennessee, Virginia, West Virginia, and Ohio was constructed in order to determine a stratigraphic and structural framework of the Carboniferous rocks for the basin. Oil and gas well logs, coal-company core descriptions, measured sections, and mapping of surface geology were used to construct these sections. New surface and subsurface faults, folds, and flexures were identified.

New, formal and informal lithostratigraphic nomenclature was introduced to clarify the stratigraphic framework. Formalized nomenclatural changes are (1) elevating Breathitt Formation to Breathitt Group, (2) dropping the Lee Formation, (3) elevating four quartzose sandstone bodies (formerly members of the Lee Formation) to formation status (i.e., Warren Point, Sewanee, Bee Rock, and Corbin Sandstones), (4) including the Rockcastle Sandstone and Livingston Conglomerate of Kentucky as members of the Bee Rock Sandstone Formation, (5) formally replacing the Middlesboro, Chadwell, and White Rocks Members of the Lee Formation with the Sewanee-Warren Point Sandstones, (6) moving the Hensley and Dark Ridge Members of the Lee Formation to the Breathitt Group, and (7) subdividing the Breathitt into five formal (in Kentucky) and two informal (outside Kentucky) formations. The five formal formations are, in ascending order, the Grundy, Pikeville, Hyden, Four Corners, and Princess. The two informal formations, the Bottom Creek and Alvy Creek, occur largely in Virginia and West Virginia. In addition, the Pennington Group is subdivided into the Bluefield, Hinton, Princeton, and Bluestone Formations, which are projected informally into Kentucky from Virginia and West Virginia. The Paragon Formation, restricted to the western belt of outcrop in Kentucky (Ettensohn and others, 1984), is included in the Pennington Group and is largely equivalent to the Bluefield Formation throughout the rest of the basin. The Pinnacle Overlook Sandstone Member of the Lee Formation becomes the Pinnacle Overlook Sandstone of the Pennington Group.

The stratigraphic and structural framework developed in this study will be useful in assessing subsurface coal resources and coal-bed methane potential. Belts of quartzose sandstones (Corbin, Bee Rock, Sewanee, and Warren Point Sandstones) occur at the expense of the coal-bearing rocks of the Breathitt Group; therefore, the distribution of these quartzose sandstones determined in this study can be used to locate areas with greater subsurface resource potential. In addition, the structural framework can be used to explain the distribution of subsurface coal resources. More coal-bearing units are preserved from erosion in synclines and more are eroded at monoclines and anticlines. Basin subsidence also affected coal resources; little coal accumulated in northeastern Kentucky because of reduced subsidence, whereas a greater quantity of coal is present in southeastern Kentucky where greater subsidence occurred.

INTRODUCTION

The utilization of mineral resources is vitally important to the economy of the Central Appalachian Basin (Fig. 1). The Central Appalachian Basin produces more high-quality bituminous coal per year than any other region in the world (J. C. Cobb, Kentucky Geological Survey, 1987, personal commun.). Oil and gas also are major resources in the region. All of the coal and a large part of the oil and gas come from Carboniferous rocks. Moreover, limestone, glass sand, ceramic clay, and shale are other important mineral resources obtained from these Carboniferous rocks.

One of the most important future economic concerns in this basin is the location of subsurface coal resources, which are poorly known on a regional basis. Up to the present, most of the mined coal in this region has been from above drainage. As these shallow subsurface resources become depleted, more and more coal will have to be taken from deeper subsurface deposits. The identification, location, depth, and thickness of deep subsurface coals must be investigated if mining is to continue in the future. A stratigraphic and geometric framework of Carboniferous rocks in the Central Appalachian Basin will help in making these determinations. In addition, geologic studies of Carboniferous rocks involving local stratigraphy, sedimentology, depositional environments, and paleontology can be integrated regionally if such a framework is available.

The purpose of this study is to provide a descriptive stratigraphic and structural framework for Carboniferous rocks of eastern Kentucky and immediately adjacent states. The framework was developed by Chesnut (1988) using data made available from the mineral in-

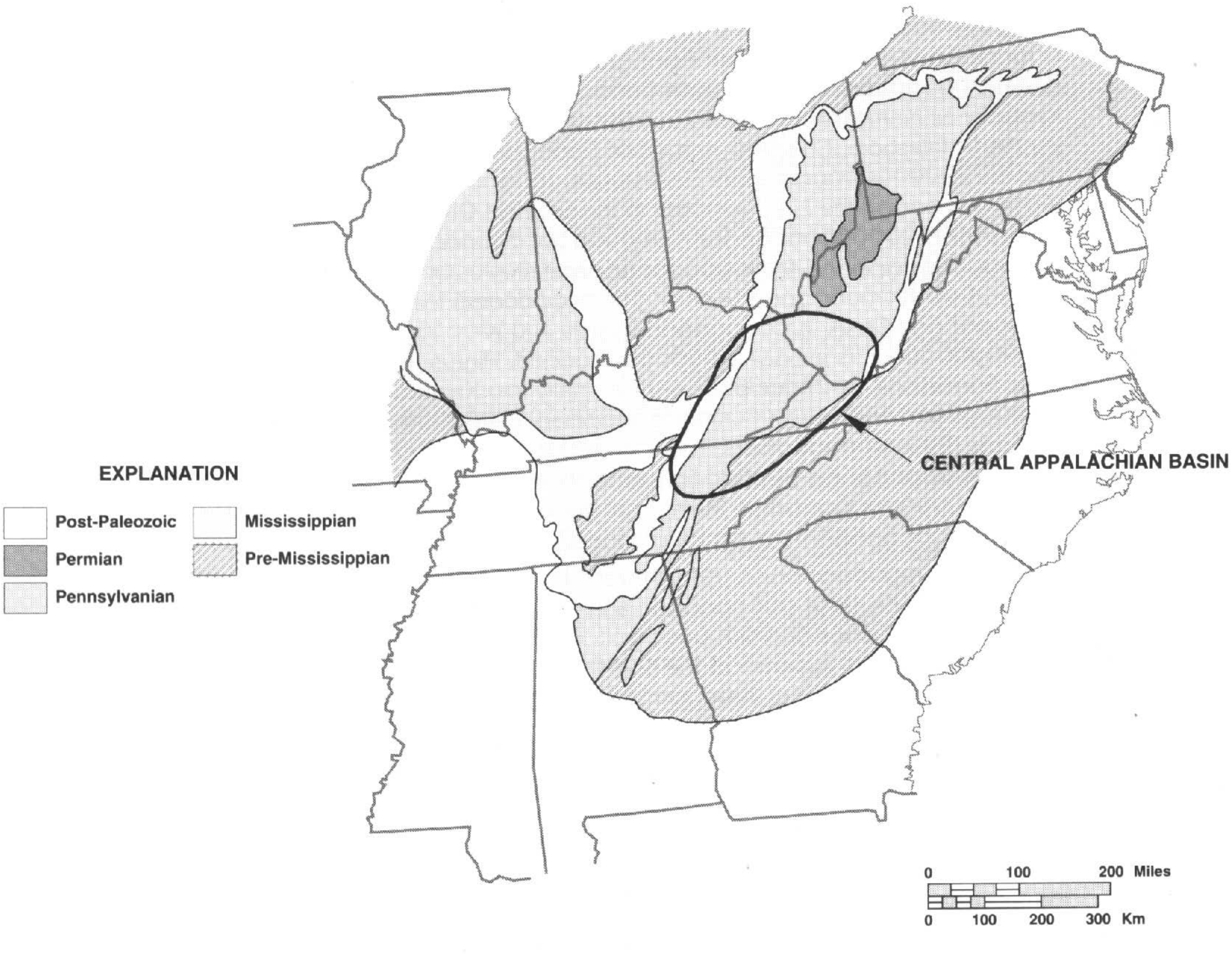

Figure 1. Location of the Central Appalachian Basin in the eastern United States.

dustry and state geological surveys. These data were used to construct a series of cross sections, both perpendicular and parallel to strike of the basin.

PROCEDURES

In order to show the lithostratigraphic and structural framework of the Central Appalachian Basin, a gridwork of detailed cross sections was constructed for the Carboniferous rocks (Fig. 2). The study area consisted of southernmost Ohio, southwestern West Virginia, eastern Kentucky, western Virginia, and part of northeastern Tennessee.

Subsurface data points, largely oil and gas logs, were selected at close to 1 mile (1.6 km) intervals. One cross section (Grundy dip section) has an average density of about one well per 1.4 miles (2.25 km). Average data spacing in remaining sections is less dense.

SYSTEM	LITHOSTRATIGRAPHIC UNITS: Kentucky	LITHOSTRATIGRAPHIC UNITS: West Virginia
Pennsylvanian	Conemaugh and Monongahela Formations	Monongahela Formation
		Conemaugh Formation
	Breathitt Formation	Charleston Sandstone
		Kanawha Formation
	Lee Formation	New River Formation
	not represented	Pocahontas Formation
Mississippian	Pennington and Paragon Formations	Pennington Group
	Slade Formation (Newman Limestone)	Greenbriar Limestone
	Warsaw & Salem Fms	
	Fort Payne Formation / Borden Formation	Maccrady Formation
	Sunbury Shale	Sunbury Shale
Devonian	Chattanooga Shale	Bedford Shale-Berea Sandstone
		Ohio Shale

Figure 2. Carboniferous lithostratigraphic units of the Central Appalachian Basin.

Approximately 3,000 borehole descriptions were collected from coal companies, land companies, government agencies, published literature, and engineering reports. Hundreds of oil and gas logs, available from the various state geological surveys and one private source, Dr. Richard Bergenback at the University of Tennessee-Chattanooga, were also used.

The most common type of geophysical log used in Pennsylvanian parts of the section was the gamma-ray log, which is useful in distinguishing between sandstone, siltstone, and shale, but not between sandstone and limestone or dolostone. Coarsening- and fining-upward sequences, quartz-rich sandstones, and argillaceous (or "dirty") sandstones can be distinguished on gamma-ray logs. Some marker beds, such as the Sunbury Shale, are also recognizable on gamma-ray logs.

Formation-density (gamma-density) logs also were used when available. Occasionally, casing did not go completely through the Pennsylvanian section, and a formation-density log was run through this part of the section. Coal beds and voids such as deep mines could therefore be recognized on density logs. Caliper logs also indicate the presence of voids, and they, in combination with density logs, can be used to distinguish between coals and voids. For a more detailed description of the use of geophysical logs in coal-bearing rocks, *see* Cobb and Smath (1981).

DESCRIPTIONS OF CROSS SECTIONS

Seven cross sections were constructed to determine the stratigraphic and structural framework of the Central Appalachian Basin (Fig. 3). Each section was named for a town along the line of section. Because of the scale used in these sections, only large lithostratigraphic units, rather than individual coals or sandstones, are shown.

Lithostratigraphic Units

Initial stratigraphic analysis of the cross sections generated in this investigation revealed that no existing stratigraphic nomenclature was useful for describing the Pennsylvanian rocks across the entire Central Appalachian Basin because they (1) were not based on regional key stratigraphic markers, (2) involved units too large or too small to be useful regionally, or (3) did not discriminate regionally important lithologic units. The nomenclature used by each state had limitations when applied to the rocks of adjacent states. In order to meaningfully describe and illustrate the Pennsylvanian strata on a regional scale, a new stratigraphic nomenclature was developed (*see* Plate 1). New stratigraphic nomenclature was presented to the Kentucky Strati-

Figure 3. Map of study area showing locations of cross sections.

graphic Nomenclature Committee. The Committee has accepted formalization of the stratigraphic units that occur in Kentucky and directed me to introduce them in this publication. Other units occurring largely outside Kentucky are left as informal. Only the dominant lithologies in each unit are described in the sections below. Informal units are designated as *formations* and *members* (lower case) and formal units are designated as *Formations* and *Members* (upper case).

Chattanooga Shale *(30–1,000 feet; 9–300 m)*

In this study, the Chattanooga Shale (Fig. 4, Plate 1) is divided into six members, in ascending order: the Rhinestreet Shale, Upper Olentangy Shale, Ohio Shale, Bedford Shale, Berea Sandstone, and Sunbury Shale. Where the members are too thin to differentiate, the Chattanooga Shale is undifferentiated on the cross sections.

The Chattanooga Shale is largely an Upper Devonian unit, although the Sunbury and perhaps part of the Berea Sandstone and Bedford Shale are Lower Mississippian units (Rice and others, 1979). Throughout most of the region the dominant lithology of the Chattanooga Shale is black, organic-rich shale (Rhinestreet, Ohio, and Sunbury Members). Black-shale members are separated by gray shales (Upper Olentangy and Bedford Members) and sandstone (Berea Member). In the eastern parts of the study area, the black shales progressively grade through interbedded gray and black shales into gray shales. The Chattanooga Shale is easily recognized on drillers' logs because of its distinctive color (black, dark brown, "coffee") and in gamma-ray logs by its high radioactivity.

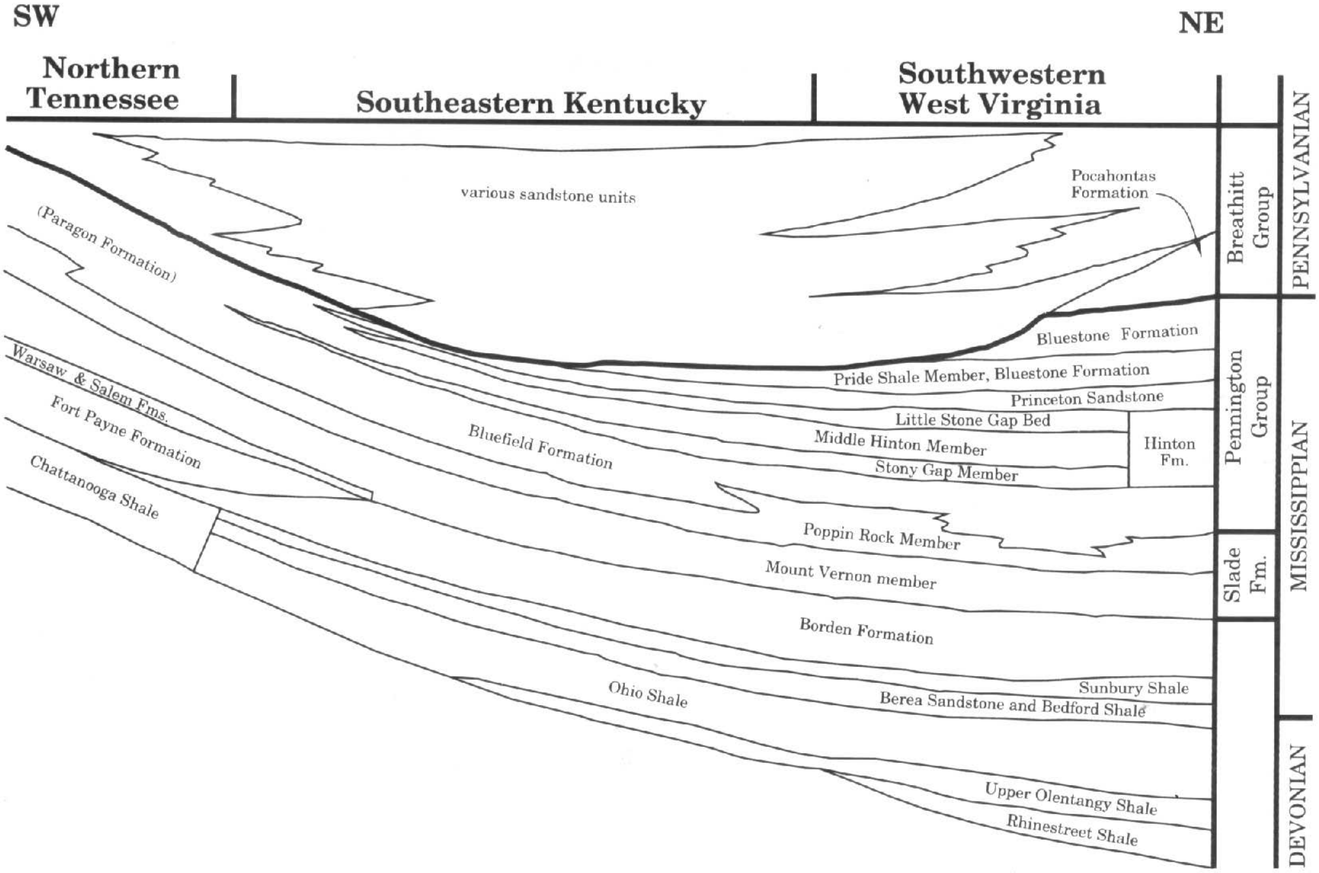

Figure 4. Stratigraphic framework of Mississippian rocks in the Central Appalachian Basin. Pennsylvanian and Devonian units are also shown.

The cross sections indicate that the Chattanooga is very thin in the extreme western part of the study area, but thickens to the east (Plates 2a–b, 3a). In the eastern part of the study area the members are easily recognized. In the western part, the members are not shown because they are too thin or the drillers' logs did not differentiate the members. However, geophysical logs indicate that in the western area the Chattanooga consists of the Sunbury, Berea-Bedford, and Ohio members.

The Rhinestreet is observed only in the eastern half of the Hazard strike section (Plate 2a), but because of a general increase in thickness of this part of the rock section, it probably occurs in the eastern quarter of the Pineville strike section (Plate 2b) and the southeastern half of the Grundy (Plate 3b) and Catlettsburg (Plate 4) dip sections where the deeper strata are not recorded on the sections. The Rhinestreet apparently thickens to the east (Plate 2a).

The upper Olentangy is recognized in the eastern part of the study area. It pinches out to the west and thickens to the east (Plates 2a–b, 3b, 4).

The Ohio Shale is dominantly a black shale in the western part of the study area. In the eastern part the black shale is interbedded with gray shales and in the extreme eastern part it is dominated by gray shales.

The Berea-Bedford interval can be recognized in the eastern and central part of the study area. In the extreme eastern part of the study area, where the interval of Ohio Shale is dominated by gray shale, the Berea-Bedford interval is not recognized because it also is composed of mainly gray shale. The Berea-Bedford interval thickens eastward, except for the extreme eastern part of the Pineville strike section, where, after thickening to the east, it starts to thin (Plate 2b).

The Sunbury Shale occurs throughout the study area; however, in the extreme western part of the study area the intervening Berea-Bedford interval pinches out to the west, and the Sunbury can only be recognized by its high-radioactivity gamma-ray signature in geophysical logs. The Sunbury thickens to the east except in the eastern third of the Hazard strike section, where it begins to thin toward the east near the Kentucky-West Virginia border (Plate 2a).

Borden Formation (0–700 feet; 0–200 m)

The Borden Formation (Fig. 4, Plate 1) is composed of gray, interbedded shales, siltstones, some sandstones, and a few limestones. Red and green shale, siltstones, and carbonates are present at the top of this interval in some areas.

The Borden Formation is absent in the extreme western part of the study area, where it is laterally replaced by the Fort Payne and part of the Salem-Warsaw Formations (Plates 2a–b, 3a, 5). The lateral change in lithology is ascribed to the Borden delta having been to the northeast and the basin-starved sediments of the Fort Payne to the southwest (Sedimentation Seminar, 1972). The Borden generally thickens eastward. Locally, the Borden appears to thin in the vicinity of the Warfield Anticline in the Catlettsburg section (Plate 4), and the Paint Creek Uplift in the Grundy section (Plate 3b), and to thicken north of the Rockcastle Uplift in the Booneville section (Plate 6).

Fort Payne Formation (0–250 feet; 0-75 m)

The Fort Payne Formation (Fig. 4, Plate 1) occurs above the Chattanooga Shale and below the Salem-Warsaw Formations in the southwestern part of the study area. In this study, the coeval dolomitic siltstones of the Muldraugh Member of the Borden Formation are considered to be a part of the Fort Payne Formation. The Fort Payne consists of limestones that are commonly cherty, biostromal, crinoidal, or siliceous; it also contains cherty dolostones and calcareous, cherty siltstones. The Fort Payne pinches out to the north and east, and is replaced laterally (*see* Borden Formation section) by the Borden Formation (Plates 2a–b, 3a, 5).

The Fort Payne Formation is only recognized in the southwestern part of the study area (Plates 2a–b, 3a, 5).

Salem and Warsaw Formations (0–300 feet; 0–90 m)

The Salem and Warsaw (Salem-Warsaw) Formations (Fig. 4, Plate 1) as used in this study are recognized as one unit composed of gray shales and fossiliferous, locally dolomitic limestones occurring between the Fort Payne Formation and the massive limestones of the Mount Vernon member of the Slade Formation (described below). Where the Fort Payne is absent, the shales of the Salem-Warsaw are indistinguishable from the underlying shales of the Borden Formation in subsurface logs. Where massive limestones dominate the Salem and Warsaw, they are included in the Mount Vernon member. The Salem and Warsaw Formations are only recognized from subsurface logs in the southwestern part of the study area (Plates 2a–b, 3a, 5). Data are insufficient to trace the northeasternmost contact of the Salem and Warsaw Formations with the Borden Formation.

Slade Formation (0–1,500 feet; 0–450 m)

The Slade Formation (Fig. 4, Plate 1) is a massive limestone sequence composed of two subunits recognized in this study, in ascending order: the Mount Vernon member (informal) and Poppin Rock Member (formal). Slade limestones previously were mapped along the Cumberland Escarpment as Newman Limestone (Ettensohn and others, 1984). Limestones along Pine Mountain in southeastern Kentucky are still designated as Newman Limestone.

MOUNT VERNON MEMBER (0–1,200 feet; 0–370 m)

The Mount Vernon member is composed of dominantly gray limestone and dolostone with a few thin shales. This member is named for exposures near Mount Vernon, Kentucky, in roadcuts along Interstate Highway 75 (Dever and others, 1979). The Mount Vernon member is easily recognized in drillers' logs as the "Big Lime" or as the thick limestone sequence above the Borden Formation. The strata informally designated as the Mount Vernon member in this study are divided into as many as eight formal members in the western belt of outcrop in east-central and northeastern Kentucky (Ettensohn and others, 1984). The scale of cross sections used here, and the difficulty in picking out some of these formal members in the subsurface, precludes using the members here.

In the northern part of the study area (Plates 3b, 4, 6), the Mount Vernon member thins progressively to the northwest. In the extreme northwestern part of the Catlettsburg and Grundy sections (Plates 3b, 4) the entire Slade Formation is locally absent, and isolated occurrences of Slade are present between lense-shaped bodies of the Corbin Sandstone. The upper part of the Mount Vernon is absent in the northwestern part of the Booneville dip section (Plate 4). The Poppin Rock is undifferentiated from the Mount Vernon member in the northwestern quarters of the Catlettsburg and Grundy sections (Plates 3b, 4), because the members were too thin to be noted on drillers' logs. The Mount Vernon member thickens to the northwest in the Lake City dip section (Plate 5), a trend opposite to that in the other dip sections, where the Mount Vernon thickens to the southeast. The Mount Vernon is thinner in the central parts of the Hazard, Pineville, and Harlan strike sections (Plates 2a–b, 3a) than in the northeastern and southwestern parts.

POPPIN ROCK MEMBER (0–250 feet; 0–75 m)

The Poppin Rock Member, a dark-gray limestone, is the uppermost member of the Slade Formation (Ettensohn and others, 1984). Drillers refer to the Poppin Rock as the "Little Lime." The Poppin Rock is commonly separated from the Mount Vernon member by sandstones and shales of the Hartselle Sandstone in Tennessee and south-central Kentucky, and by shales of the Maddox Branch Member of the Slade in northeastern and east-central Kentucky (Ettensohn and others, 1984). The Maddox Branch-Hartselle shales of Kentucky are known by the drillers' term "Pencil Cave" in the subsurface. Neither the Hartselle Sandstone nor the Maddox Branch Member are thick enough to delineate on the cross sections used in this report (Plates 2a–b, 3b, 4–6). The Maddox Branch-Hartselle shales should be carefully located because other shales occurring in the upper part of the Mount Vernon member can be misidentified as the Maddox Branch and, therefore, mistakenly used to separate the Poppin Rock and Mount Vernon members.

The Poppin Rock Member thickens to the south in Tennessee (Plates 2a–b) and to the southeast in Virginia and West Virginia (Plates 3b, 4). Some of this thickening is because limestone beds that interfinger with and laterally replace part of the overlying Pennington Group are included in the Poppin Rock (Bangor Limestone in Tennessee), especially to the south in Tennessee (Plates 2a–b).

The Poppin Rock is undifferentiated from the Mount Vernon member in the northern part of the study area (Plates 3b, 4) and the central part of the Harlan strike section (Plate 3a) because of the poor quality of the data. Elsewhere the Poppin Rock generally is easily recognized. The Poppin Rock is locally absent in the northwestern part of the study area, where the entire Slade Formation is locally truncated (Plates 3b, 4).

Pennington Group (0–2,500 feet; 0–760 m)

The Pennington Group (Fig. 4, Plate 1) is a heterogeneous unit composed of red, green, and gray shales, sandstone, limestone, and dolostone. Rarely, thin coals occur in all the formations of this group (Wilpolt and Marden, 1959). The red and green shales commonly distinguish the Pennington from the overlying gray clastic units and the gray shales and massive carbonates of the Slade Formation below. The Pennington Group, in ascending order, consists of the Bluefield Formation, Hinton Formation, Princeton Sandstone, and Bluestone Formation.

BLUEFIELD FORMATION (0–600 feet; 0–180 m)

This unit (Fig. 4, Plate 1) consists of calcareous gray shales interbedded with limestones, sandstones, dolostones, and some red and green shales. As used in this study, the Bluefield overlies the Poppin Rock Member of the Slade Formation, and may be partially equivalent to the Poppin Rock where the Poppin Rock is absent. The Bluefield is largely equivalent to the Paragon Formation. The Paragon Formation replaced the Pennington Formation recognized along the western belt of outcrop in Kentucky (Ettensohn and others, 1984).

HINTON FORMATION (0–850 feet; 0–260 m)

Red and green shales interbedded with limestones and sandstones constitute most of this unit (Fig. 4, Plate 1). The Hinton is separated from the underlying Bluefield by its basal member, the Stony Gap Sandstone, which varies from siliceous to calcareous sandstone, and in places is interbedded with shales. The sandstone is commonly called the "Maxon" or "Maxton Sand" by drillers, although other sandstone units in the Hinton and Pennington Group may be given the same designation by drillers. The Little Stone Gap Bed (Avis Limestone), an argillaceous limestone or calcareous shale, occurs near the top of the Hinton Formation. This limestone has been used as a stratigraphic marker by Wilpolt and Marden (1959) and Miller (1974). Some drillers in West Virginia have mistakenly called the Little Stone Gap Member the "Little Lime," but the "true" Little Lime (Poppin Rock) is much lower in the section. Red shales and siltstones in the Hinton are commonly called "Red Rock" by drillers. Where sandstones of the Hinton are quartz rich, gamma-ray signatures may be similar to those of the Pennsylvanian Warren Point, Sewanee, Bee Rock, and Corbin Sandstones.

PRINCETON SANDSTONE (0–400 feet; 0–120 m)

The Princeton Sandstone (Fig. 4, Plate 1) varies from a siliceous to calcareous sandstone, and in places is interbedded with shale. Where quartz rich, it commonly has a gamma-ray signature similar to younger quartzose sandstones previously assigned to the Lee Formation with which the Princeton may be confused. The Princeton Sandstone has been used as a stratigraphic marker by Wilpolt and Marden (1959) and Miller (1974). It is similar to the Stony Gap Sandstone Member of the Hinton Formation, but separates the underlying Hinton Formation from the Bluestone Formation above. The Princeton is commonly called the "Ravencliff," "Maxon," or "Maxton Sand" by drillers.

The Pinnacle Overlook Sandstone Member of the Lee Formation, mapped along parts of the Cumberland Overthrust Sheet, may be equivalent to the Princeton Sandstone. The Pinnacle Overlook Sandstone is herein removed from the Lee Formation and formally placed as a sandstone formation of the Pennington Group.

BLUESTONE FORMATION (0–600 feet; 0–180 m)

Red and green, and gray to dark-gray shales, siltstones, sandstones, minor calcareous beds, and thin coals compose this unit (Fig. 4, Plate 1). The Pride Shale Member, at the base of the Bluestone Formation, is a distinctive unit of dark-gray shale and siltstone. The gamma-ray signature of the Pride Shale has proven useful for correlation in Letcher and Pike Counties of Kentucky and in adjacent parts of Virginia. The unique signature is the result of a sequence of moderately radioactive shales that lacks the variability found in other Pennington units. The rest of the Bluestone is similar to the older Hinton Formation in lithology and lithologic variability. Red shales and siltstones in the Bluestone Formation also are referred to as "Red Rock" by drillers. The Bluestone is reported to be gradational with the overlying Pocahontas Formation in southwestern Virginia and southern West Virginia (Englund and others, 1979).

OCCURRENCE OF PENNINGTON GROUP

The Pennington Group thickens toward the southeast and is as much as 2,500 feet (762 meters) thick at the southeastern end of the Catlettsburg dip section (Plate 4); it thins to the northwest and is completely missing in several areas (Plates 3b, 4, 6).

Useful stratigraphic markers in the southeastern part of the study area include the Stony Gap Sandstone, Little Stone Gap Member, Princeton Sandstone, and Pride Shale Member. The Stony Gap Sandstone can be recognized in all the sections, but the other units are more difficult to recognize in other parts of the study area. The Stony Gap is less continuous and occurs as isolated lenses in the northern and western parts of the study area.

The Pennington Group may be conformable with the overlying Pocahontas Formation (described below) in the southeastern part of the study area, as suggested by Englund and others (1979). The Pocahontas and the marker units mentioned above are progressively truncated from the southeast to the northwest, and, to a lesser extent, to the southwest. The Bluestone Formation above the Pride Shale Member is absent in the Booneville and Lake City dip sections (Plates 5–6), and in the Pineville strike section (Plate 2b). Both the Princeton Sandstone and the Bluestone Formation appear to be absent in the Hazard strike section (Plate 2a). Where marker beds become progressively truncated down-section, the Pennington is overlain by Pennsylvanian quartzose sandstone formations (*see below*).

Pennsylvanian Quartzose Sandstone Formations

Several new sandstone formations occur in the lower part of the Breathitt Group (Fig. 5). These sandstone formations were previously recognized as members of the Lee Formation. However, the use of the term "Lee Formation" has led to much confusion in the past. With elevation of the sandstone members to formations, the use of Lee Formation is no longer needed, and it has been formally dropped as a formation in Kentucky. The new sandstone formations are dominantly thick bodies of quartzose sandstone and quartz-pebble conglomerate. The quartzose sandstone formations are separated by shales, coals, and sandstones of the intertonguing Breathitt Group. The Breathitt is composed of argillaceous, lithic sandstones, siltstones, shales, and coals. Most of the new sandstone formations differ from other sandstones of the Breathitt Group in that the new sandstones are generally quartz rich, may contain quartz pebbles, and are light in color. In addition, they are generally thicker and more massive, and many have a blocky, very low-radioactivity gamma-ray signature. The quartzose sandstones typically have scoured bases and may contain large-scale crossbeds. In the subsurface these sandstones commonly are called the "Salt" or "White-Hard Sands" by drillers. Other drillers' terms are less commonly used (*see* McFarlan, 1943, p. 297).

The quartzose sandstones occur in two forms: channel fills and large sandstone belts. Breathitt strata onlap the mid-Carboniferous unconformity surface (described in a later section) to the northwest. Several deep channels along the regional unconformity surface that are filled with quartzose sandstones have been mapped by Rice (1984). However, these sandstones are relatively localized bodies. The largest volume of quartzose sandstones occurs as four large, belt-shaped bodies (formations) within the lower part of the Breathitt Group. These belts trend southwest and average about 50 miles (80 km) in width. The belts, as much as 500 feet (150 m) thick, are composed of a number of sandstones, most of which are 65 to 100 feet (20–30 m) thick. Thicker bodies occur, but probably represent coalescing sandstone units.

The various quartzose sandstone formations are separated from each other by shale, sandstone, and

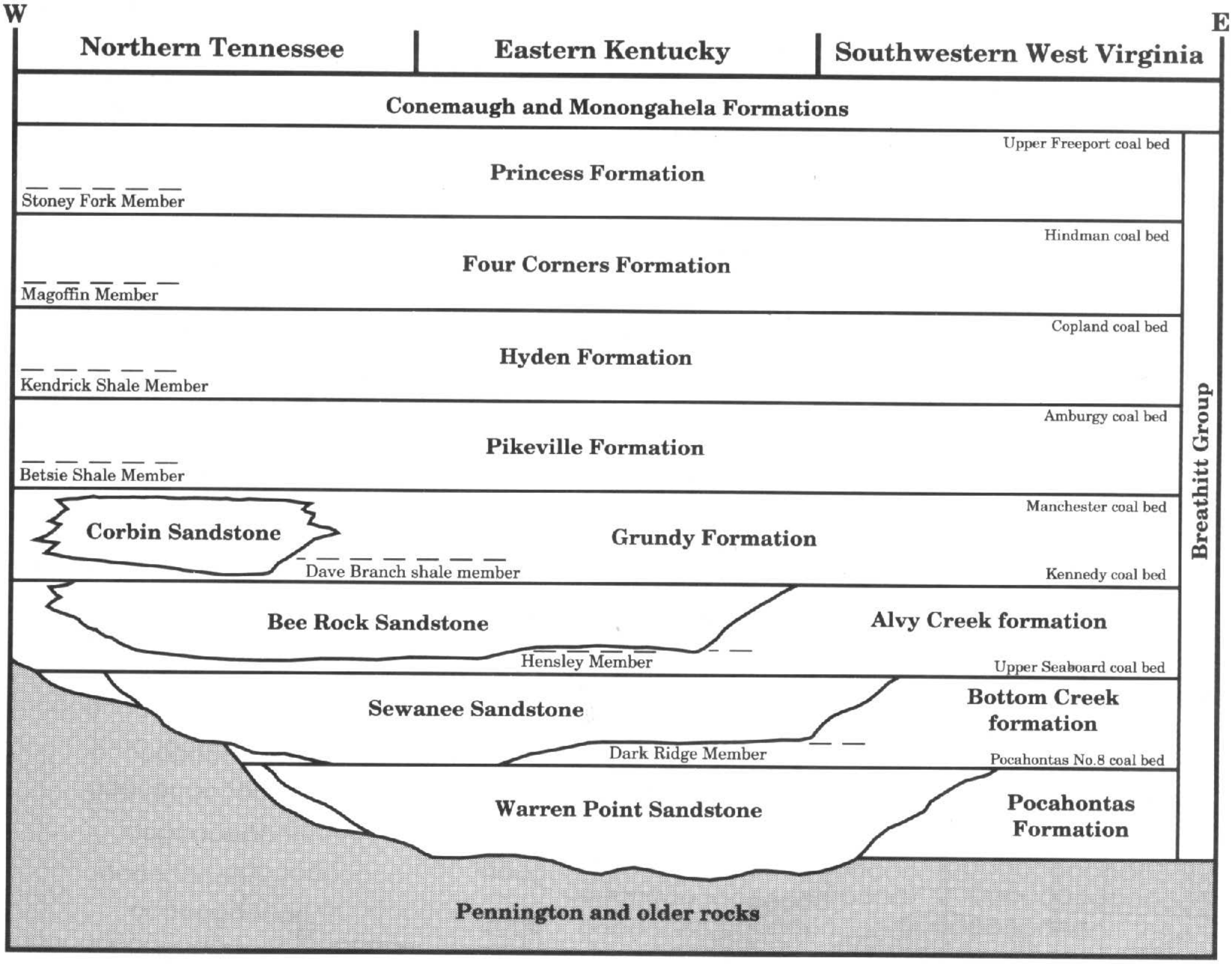

Figure 5. Stratigraphic framework of Pennsylvanian rocks in the Central Appalachian Basin.

coal units (described below) of the Breathitt Group. Otherwise these sandstone formations generally cannot be lithologically distinguished from each other. Several of the belt-shaped formations recognized in this study include, in ascending order: the Warren Point, Sewanee, Bee Rock, and Corbin Sandstones (Fig. 5). The formations are formal units in some states, but none are formal units across the basin. The sandstone formations are described in the following sections. Cross sections with a datum drawn on the top of these sandstones are shown in Plate 7a–g.

WARREN POINT SANDSTONE (0–500 feet; 0–150 m)

The Warren Point Sandstone of Tennessee (Nelson, 1925), herein formally designated a quartzose sandstone formation of the Breathitt Group, is restricted to the southern part of the study area. In this area the Warren Point Sandstone is stratigraphically the lowest quartzose sandstone formation of the Breathitt Group (Fig. 5). It is overlain by Breathitt lithologies, including shale, sandstone, and coal of the Bottom Creek formation (described below). In the south-central part of the study area in Kentucky, the Bottom Creek is thin or absent (Fig. 5, Plate 7a–c), and the Warren Point is overlain by similar sandstones of the Sewanee Sandstone. Where the Bottom Creek is absent, both sandstone formations are combined as the Warren Point-Sewanee Sandstones. The Warren Point-Sewanee Sandstones are equivalent to and formally replace the Middlesboro Member of the Lee Formation of Englund (1964) (Plate 1) on the Cumberland Overthrust Sheet (Pine Mountain Thrust Sheet). The Warren Point-Sewanee, Bee Rock, and laterally equivalent units (Plate 1) are mapped as the New River Formation (of Fontaine, 1874) in Virginia and West Virginia. The Warren Point was previously recognized only in Tennessee.

The White Rocks Sandstone and Chadwell members of the Lee Formation were thought by Englund and DeLaney (1966) to occur below the Middlesboro

Member (Fig. 6). However, reinterpretation of their sections (Fig. 7) indicates that the White Rocks and Chadwell are equivalent to the Warren Point; therefore, these sandstones are formally replaced by the Warren Point Sandstone. Until more stratigraphic details are available, the White Rocks and Chadwell should only be used as informal beds within the Warren Point.

The overall shape of the Warren Point in the study area is a belt, oriented northeast-southwest, with a lense-shaped cross section approximately 40 miles (64 km) in width (Figs. 5 and 8). Along its southeastern border, the Warren Point interfingers with the Bottom Creek formation of the Breathitt Group, but along the northwestern border, the sandstone pinches out (Plate 7a–d).

SEWANEE SANDSTONE (0–600 feet; 0–180 m)

The Sewanee Sandstone (or Conglomerate) of Tennessee (Safford, 1893) is herein designated a formal formation of the Breathitt Group. The Sewanee is rarely a true conglomerate, but commonly contains conglomeratic sandstones. The Sewanee (Fig. 5) is a quartzose sandstone occurring above the Bottom Creek formation and below the Alvy Creek formation (both described below). The Bottom Creek and Alvy Creek formations are composed of Breathitt lithologies including shale, sandstone, and coal. In parts of southeastern Kentucky and northeastern Tennessee the Bottom Creek formation is thin or absent, and the Sewanee overlies similar sandstones of the Warren Point Sandstone. Where the Bottom Creek is thin or absent,

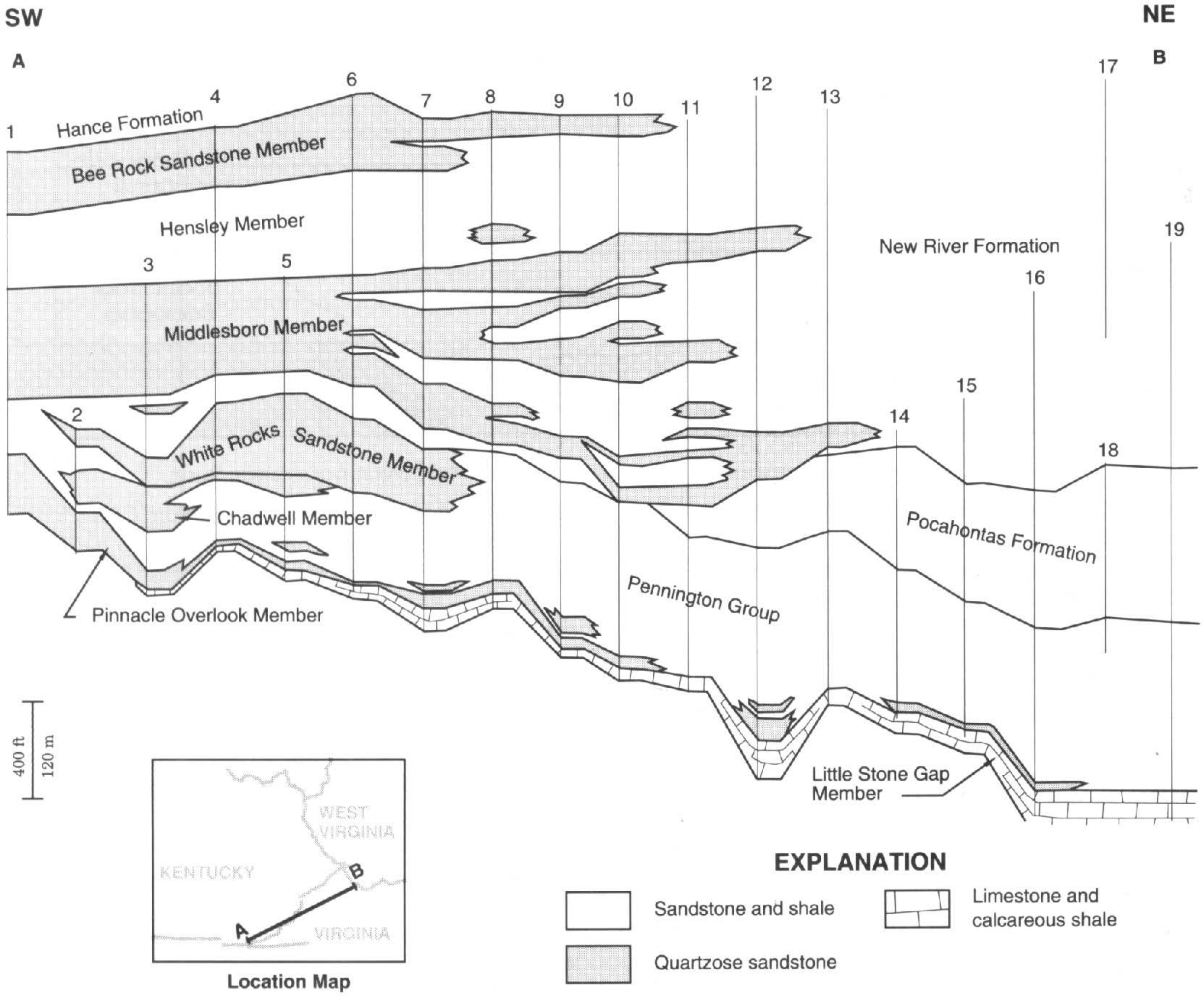

Figure 6. Cross section of mid-Carboniferous units along Cumberland Mountain. Redrawn from Englund and DeLaney (1966).

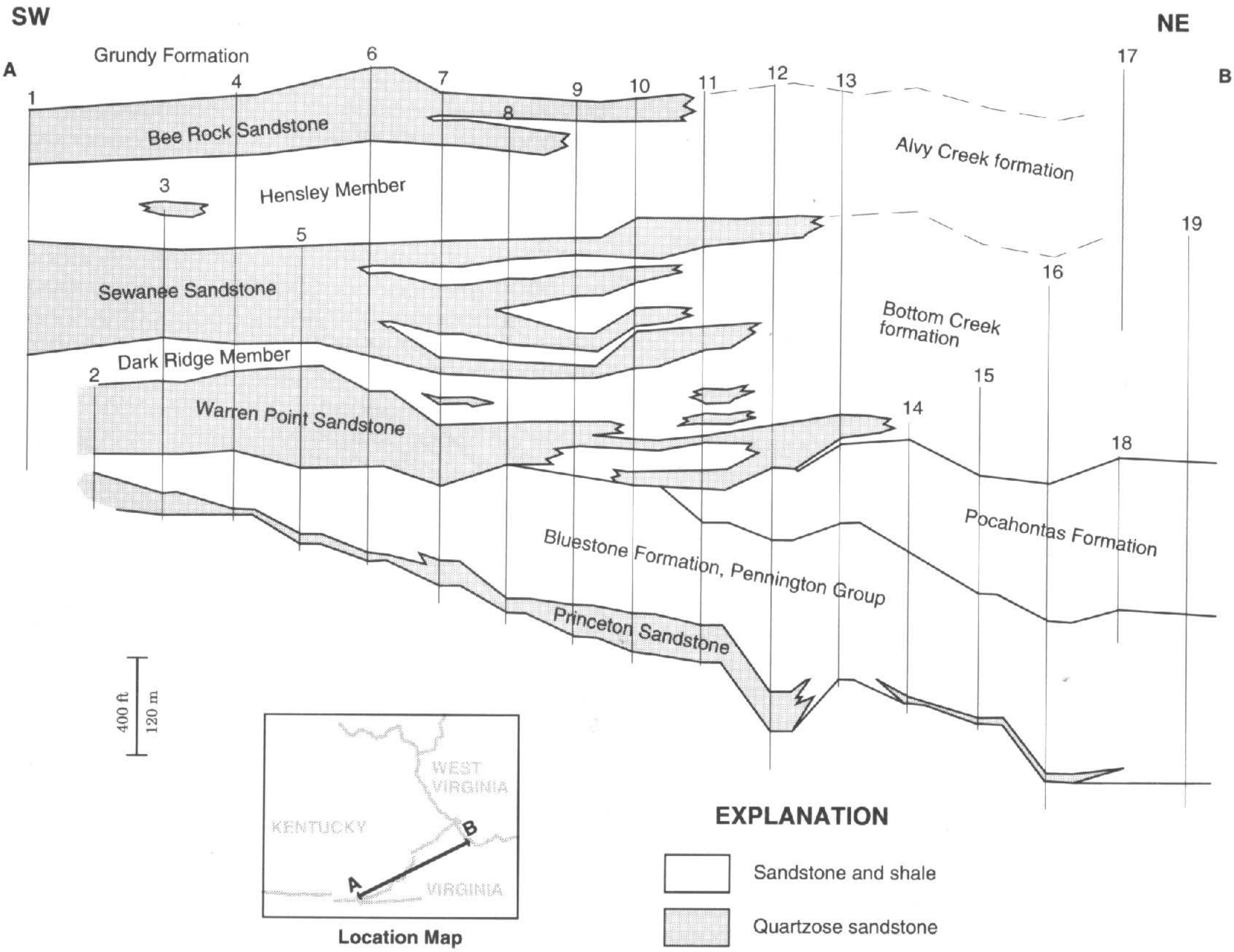

Figure 7. Reinterpretation of Englund and DeLaney's (1966) cross section (Fig. 6).

these sandstones are grouped together as the Warren Point-Sewanee Sandstones. The eastern occurrence of the Sewanee is equivalent to the middle quartzose sandstones of the New River Formation as mapped in Virginia and West Virginia (Plate 1). The Sewanee was previously mapped only in Tennessee.

The Sewanee Sandstone pinches out to the northwest. The northwestern extent is difficult to discern because overlying and underlying shale units become thin and discontinuous and the Sewanee comes in contact with similar sandstones of the Warren Point and Bee Rock in this direction (Plate 7a–d). The Sewanee also thins to the southeast, where the sandstone interbeds with and pinches out into the Bottom Creek and Alvy Creek formations of the Breathitt Group (Plate 7a–b, g). The Sewanee forms a belt, approximately 50 miles (80 km) wide, oriented northeast-southwest, parallel to the Warren Point belt, but located farther to the northwest (Fig. 9).

BEE ROCK SANDSTONE (0–500 feet; 0–150 m)

The Bee Rock Sandstone (Fig. 5) is a thick sandstone sequence separated from the stratigraphically lower Sewanee by the intervening Alvy Creek formation (described below). Cross sections developed in this study indicate that the Bee Rock Sandstone (originally used by Stevenson, 1881, p. 230, and Campbell, 1893, p. 17, 36) includes sandstone units (Plate 1) originally mapped as the Rockcastle Sandstone or Rockcastle Conglomerate in Kentucky (first used by Campbell, 1898, p. 3) and Tennessee (used by Campbell, 1899, p. 3). The name "Bee Rock" has priority over "Rockcastle." The Rockcastle Sandstone and the Livingston Conglomerate, as mapped in Kentucky, are herein named formal members of the Bee Rock Formation. The Rockcastle of Tennessee in most places is equivalent to both the Rockcastle and an overlying unnamed sandstone member in Kentucky. To avoid confusion over the term Rockcastle, one must state either

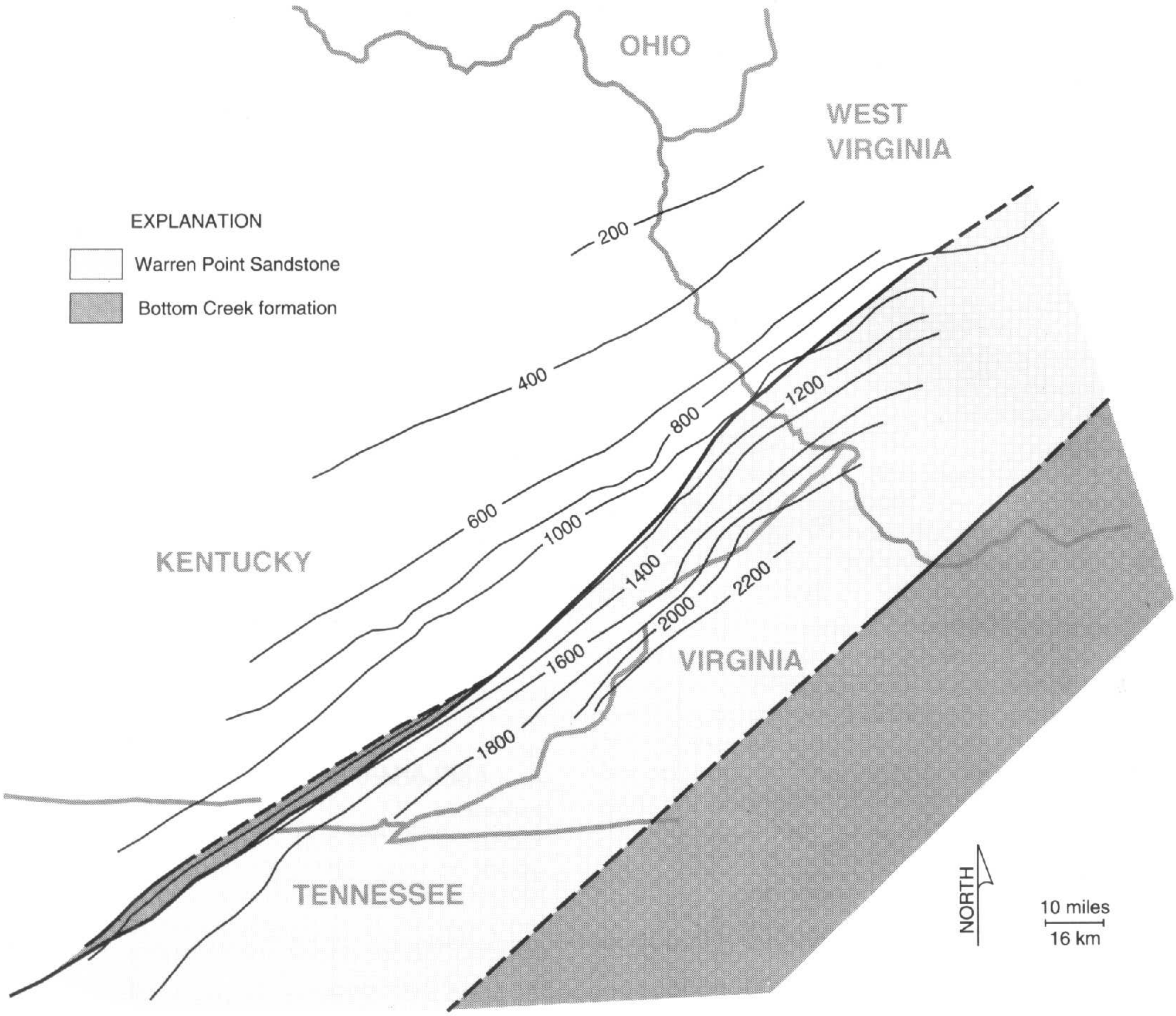

Figure 8. Distribution of Warren Point Sandstone and laterally equivalent lithologies of the Breathitt Group. The blank area northwest of these units represents the erosional surface underlain by Mississippian rocks exposed during Warren Point deposition. Contours indicate the depth to the unconformity at the base of the Betsie Shale; contour interval is 200 feet. Data points used in contouring have been restored to positions occupied prior to movement along the Pine Mountain Thrust Fault.

the "Rockcastle of Kentucky" or the "Rockcastle of Tennessee" when referring to these sandstones. The Bee Rock, as used here, also locally contains lenses (informal members) called the Naese (Ashley and Glenn, 1906), and "K" sandstones (Puffett, 1962) in Kentucky.

The upper part of the Bee Rock Sandstone interbeds with the overlying Grundy Formation in the southeastern part of the study area (Plate 7a, c, e–f). The top of the Bee Rock rises slightly stratigraphically to the northwest as a result of this interbedding.

The Bee Rock Sandstone thins and pinches out to the northwest (Plate 7a–c). The sandstone becomes difficult to discern in the northwestern parts of the study area because shale units overlying and underlying the Bee Rock are thin or absent, and the Bee Rock comes in contact with the similar Sewanee and Corbin Sandstones. The Bee Rock also thins to the southeast, where it interbeds with and pinches out into the Alvy Creek formation of the Breathitt Group (Plate 7a–b, g). The Bee Rock forms a northeast-southwest-trending

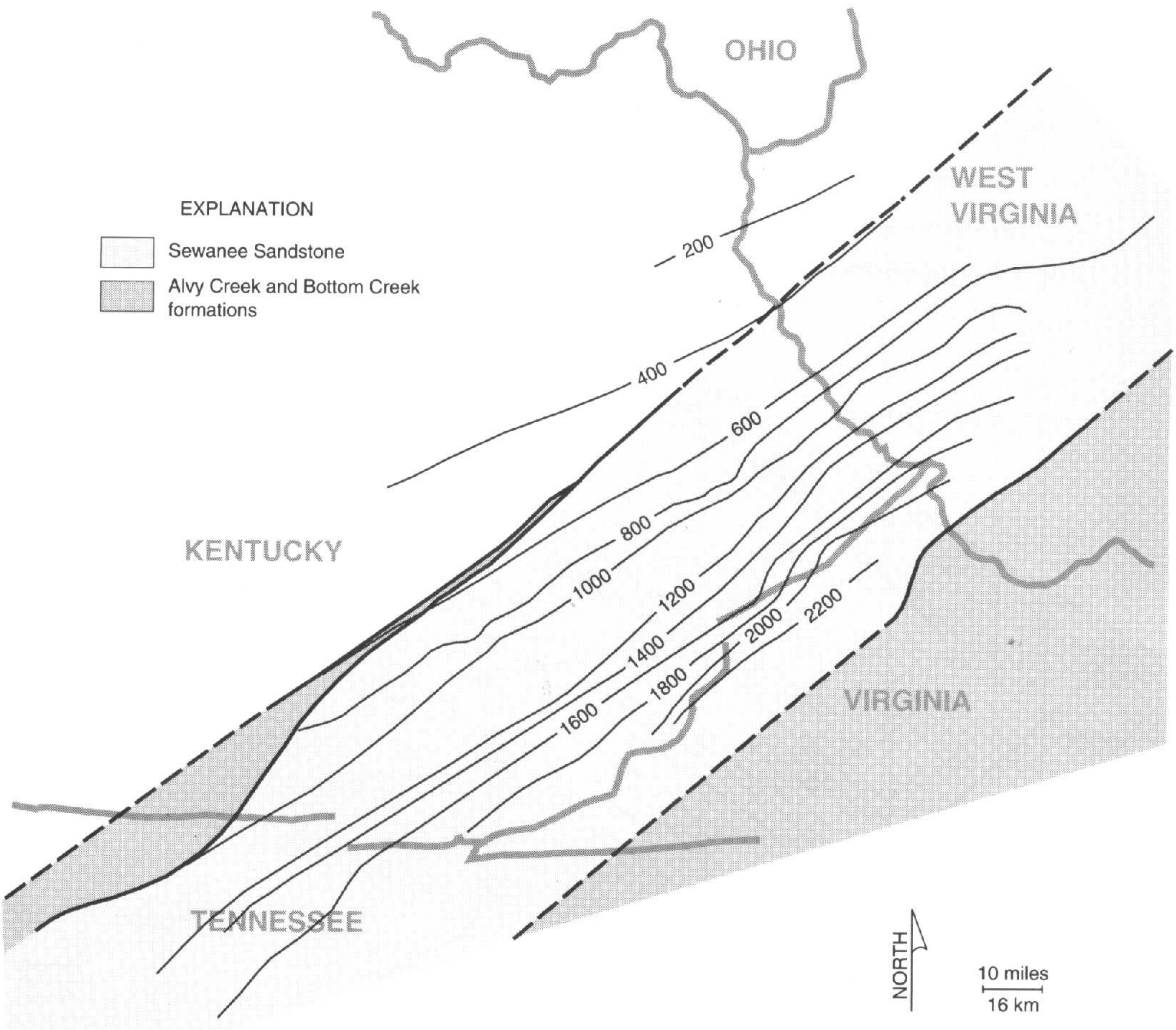

Figure 9. Distribution of Sewanee Sandstone and laterally equivalent lithologies of the Breathitt Group. The blank area northwest of these units represents the erosional surface underlain by Mississippian rocks exposed during Sewanee deposition. Contours indicate the depth to the unconformity at the base of the Betsie Shale; contour interval is 200 feet. Data points used in contouring have been restored to positions occupied prior to movement along the Pine Mountain Thrust Fault.

belt approximately 57 miles (91 km) in width (Fig. 10). The Bee Rock belt is located northwest of the Sewanee belt, but partially overlaps the Sewanee belt.

CORBIN SANDSTONE (0–350 feet; 0–105 m)

The Corbin Sandstone (Fig. 5), as used in this study, consists of a series of local sandstone bodies that interfinger laterally with the Grundy Formation (described below). The Corbin sandstone bodies are much smaller in extent than the Bee Rock, Sewanee, and Warren Point Sandstones, and are apparently restricted to the northern and northwestern part of the study area.

To the north, the Corbin Sandstone is difficult to discern from the underlying Bee Rock Sandstone because intervening shale units are thin or absent. In the northernmost part of the study area, the Corbin thins and becomes isolated lenses separated by remnants of the Slade Formation (Plates 4–5). The sandstones of the Corbin interbed with the Grundy Formation and pinch out to the southeast near the central part of the study area (Plate 7a–c, f–g).

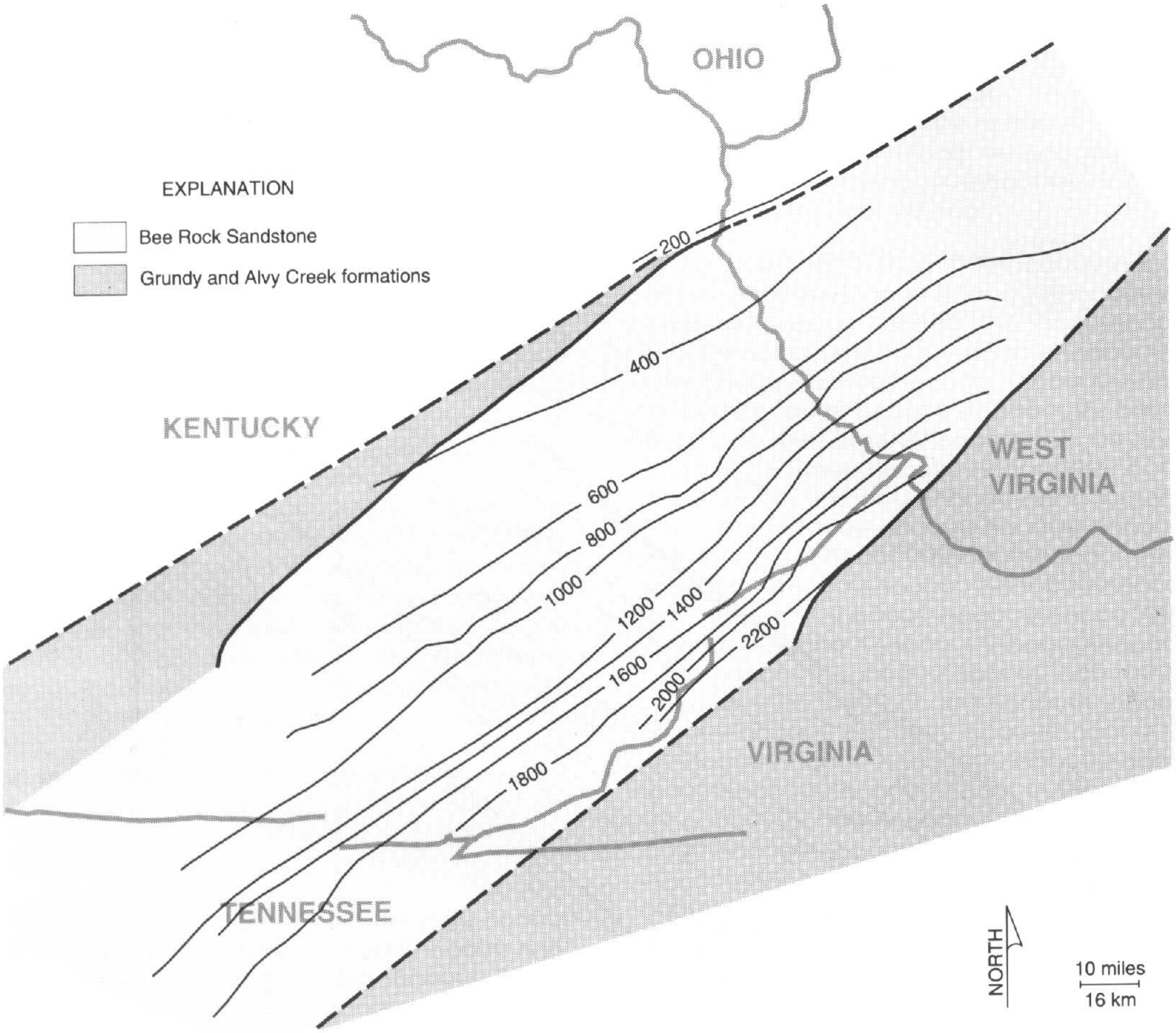

Figure 10. Distribution of Bee Rock Sandstone and laterally equivalent lithologies of the Breathitt Group. The blank area northwest of these units represents the erosional surface underlain by Mississippian rocks exposed during Bee Rock deposition. Contours indicate the depth to the unconformity at the base of the Betsie Shale; contour interval is 200 feet. Data points used in contouring have been restored to positions occupied prior to movement along the Pine Mountain Thrust Fault.

The Corbin Sandstone forms a belt, oriented northeast-southwest, approximately 40 miles (64 km) wide (Fig. 11). Most of the northwestern edge of the Corbin is absent because of erosion. The Corbin is also absent in the area of the Rockcastle or Rockcastle River Uplift (Fig. 11).

The Breathitt Group

The Breathitt Group (Fig. 5) is composed of shale, siltstone, argillaceous and lithic ("dirty") sandstone, coal, and some thin limestone; it also contains most of the coal in the Central Appalachian Basin. Because of vertical scale limitations, Breathitt coals and sandstones were not drawn on the cross sections; only larger stratigraphic units could be shown. This study determined that several widespread and easily identified marine units within the Breathitt, as well as the new quartzose sandstone formations, could be used to subdivide the Breathitt into formations approximately equal in thickness (Fig. 5). In this report the lower part of the Breathitt is subdivided into formations by the quartzose sandstone formations and by coal beds in areas where the sandstones are absent. The upper part of the Brea-

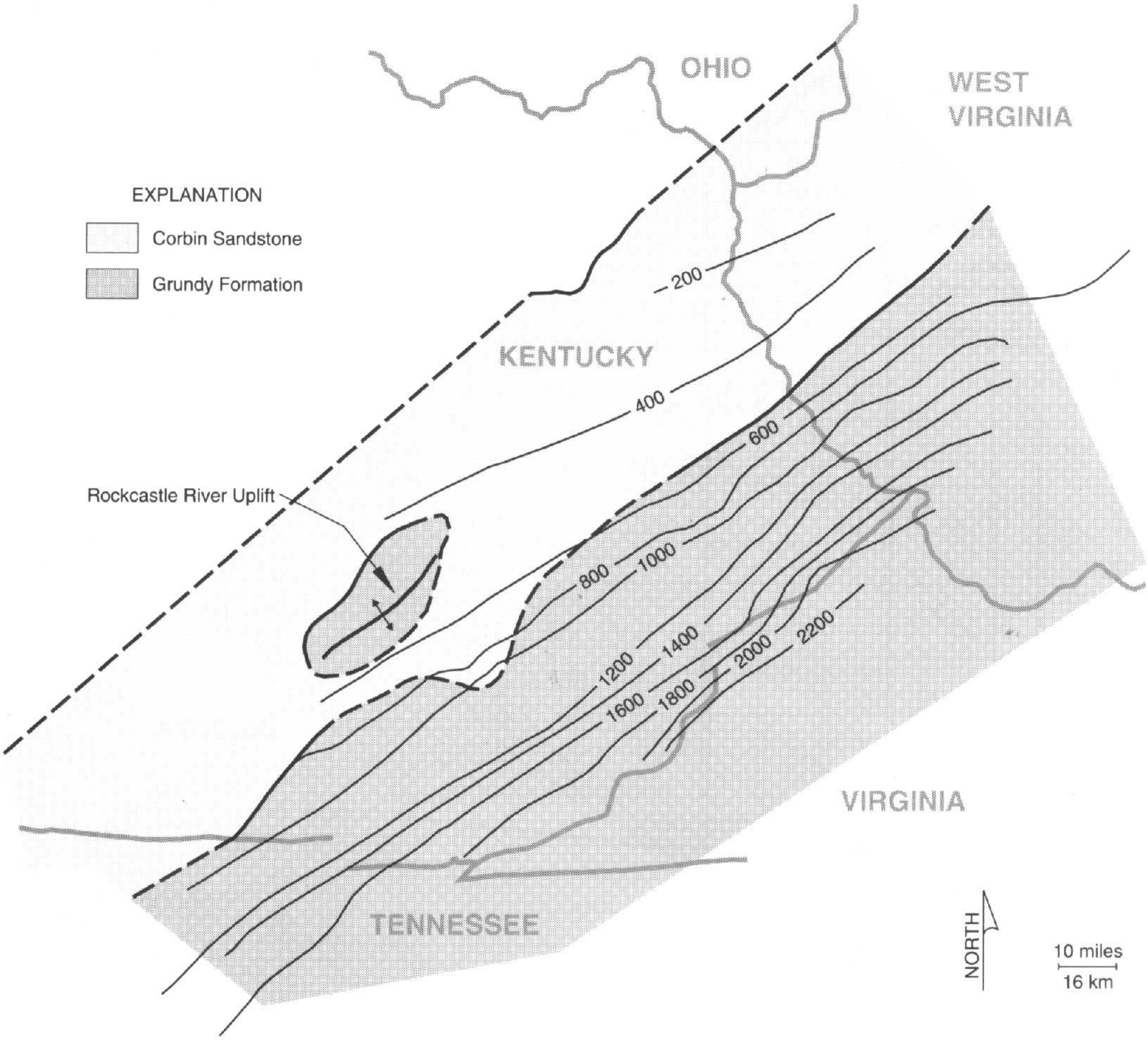

Figure 11. Distribution of Corbin Sandstone and laterally equivalent lithologies of the Breathitt Group. The blank area northwest of these units represents the erosional surface underlain by Mississippian rocks exposed during Corbin deposition. Details along the western outcrop belt are adapted from Rice (1984, Fig. 27). The axis of the Rockcastle River Uplift appears to coincide with a local absence of the Corbin. Contours indicate the depth to the unconformity at the base of the Betsie Shale; contour interval is 200 feet. Data points used in contouring have been restored to positions occupied prior to movement along the Pine Mountain Thrust Fault.

thitt is subdivided by the marine members. Because the Breathitt is subdivided into formations, the Breathitt Formation is herein formally elevated to group status.

The Breathitt Group above the level of the Pocahontas Formation unconformably overlaps underlying strata to the northwest (Fig. 5). This unconformity is Early Pennsylvanian (it is commonly, but mistakenly called the Mississippian-Pennsylvanian unconformity), and it originates between the Pocahontas and Bottom Creek formations (Chesnut, 1983, 1988). The unconformity is described in another section. The Breathitt formations are described below, in ascending order.

POCAHONTAS FORMATION (0–700 feet; 0–200 m)

This unit (Fig. 12) is composed of interbedded sandstone, siltstone, shale, and coal; it occurs only in Virginia and West Virginia, where it contains most of the Pocahontas coals (Englund and others, 1979). The Pocahontas Formation, as used here, is equivalent to the

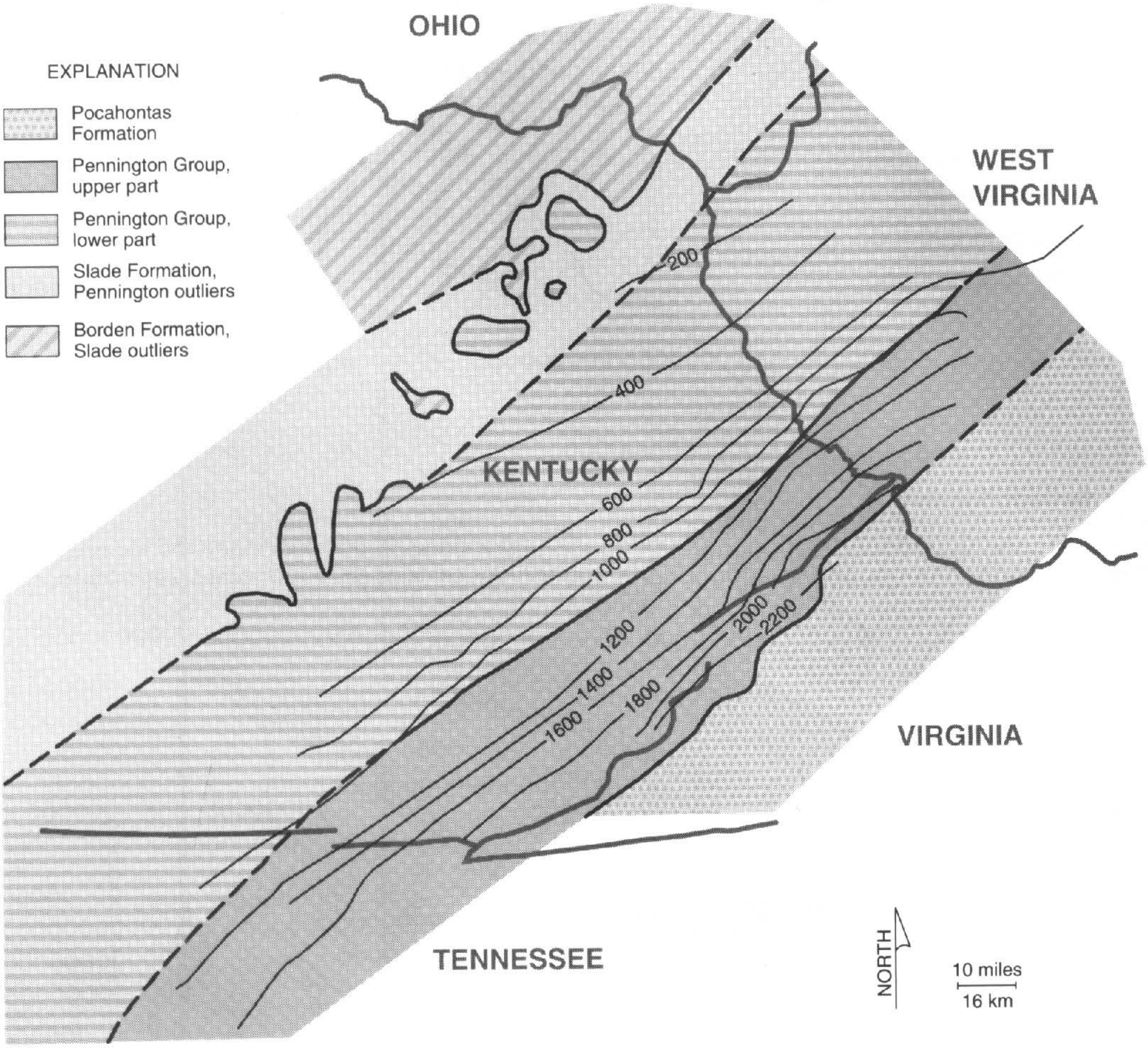

Figure 12. Subcrop geology below the Early Pennsylvanian unconformity. Interpretations are based on cross sections in this study, as well as information from Rice (1984, Fig. 4) for the western outcrop belt and from Miller (1974, Fig. 17) for Virginia. Contours indicate the depth to the unconformity at the base of the Betsie Shale; contour interval is 200 feet. Data points used in contouring have been restored to positions occupied prior to movement along the Pine Mountain Thrust Fault.

Pocahontas Formation as mapped in Virginia and West Virginia (Fig. 2). Since Pocahontas lithologies are identical to Breathitt Group lithologies, the Pocahontas Formation is included as a unit of the Breathitt Group in this study. The Pocahontas Formation was reported by Englund and others (1979) to intertongue with the underlying Bluestone Formation of the Pennington Group. Similarly, in the extreme southeastern part of the study area (Plate 7a–b), the upper part of the Pocahontas appears to be conformable with the overlying Bottom Creek formation (described below). Elsewhere, to the north and west in parts of Virginia and southern West Virginia, the Pocahontas is overlain by the Warren Point Sandstone and is progressively truncated to the northwest (Fig. 5) (Miller, 1974, Fig. 47). This truncation is part of the Early Pennsylvanian unconformity discussed previously.

BOTTOM CREEK FORMATION (0–1,000 feet; 0–300 m)

The informal Bottom Creek formation (Fig. 5) is composed of typical non-quartzose Breathitt lithologies (interbedded argillaceous and lithic sandstone, siltstone, shale, and coal), and has its maximum development in West Virginia and Virginia. It is named for outcrops near Bottom Creek in the Keystone Quadrangle, West Virginia.

The Bottom Creek formation is separated from similar lithologies of the underlying Pocahontas Formation by the Warren Point Sandstone, and where the Warren Point is absent, by the Pocahontas No. 8 coal. The Bottom Creek formation is separated from similar lithologies of the overlying Alvy Creek formation by the Sewanee Sandstone, and where the Sewanee is absent, by the Upper Seaboard coal in West Virginia and Virginia. Northwest of its occurrence in Virginia and West Virginia, the Bottom Creek formation is interbedded with and progressively replaced by the Warren Point-Sewanee Sandstones (Plate 7a–b, g).

The New River Formation of Virginia (Fig. 2) contains both quartzose sandstones and more typical Breathitt lithologies. This study indicates that the informal Bottom Creek in Virginia and West Virginia is equivalent to the Breathitt lithologies only in the lower half of the New River Formation. This study also indicates that the Bottom Creek is equivalent to the Signal Point Shale and the lower part of the Fentress Shale of Tennessee (Plate 1).

In Kentucky the Bottom Creek is largely absent except along Cumberland Mountain where the partly marine Dark Ridge Member occurs (Chesnut, 1991a). The Dark Ridge Member, mapped along parts of Cumberland Mountain, was considered a member of the Lee Formation (Rice and others, 1979) although it was composed of shale, siltstone, lithic sandstones, and coal typical of the Breathitt non-quartzose coal-bearing rocks. Regional studies indicate that where the overlying Sewanee Sandstone and underlying Warren Point Sandstone pinch out (i.e., Virginia and West Virginia) the Dark Ridge Member is laterally equivalent to a thick sequence of Breathitt-type lithologies of the Bottom Creek formation. The Dark Ridge Member is herein formally removed from the Lee Formation and placed in the Breathitt Group as a member of the Bottom Creek formation.

ALVY CREEK FORMATION (0–850 feet; 0–260 m)

The Alvy Creek formation (Fig. 5) is composed of typical Breathitt lithologies and is named for outcrops near Alvy Creek in Big A Mountain Quadrangle, Virginia (Miller and Meissner, 1977). This formation is separated from the underlying Bottom Creek formation by the Sewanee Sandstone. In parts of Virginia and West Virginia where the Sewanee pinches out, the base of the Alvy Creek is placed at the base of the Upper Seaboard coal bed. The top of the Alvy Creek is placed at the base of the overlying Bee Rock Sandstone, and where the Bee Rock pinches out in parts of Virginia and West Virginia the top is placed at the base of the Kennedy coal bed. Northwest of its thickest occurrence in Virginia and West Virginia, the Alvy Creek formation is interbedded with and progressively grades into the Bee Rock and Sewanee Sandstones.

The New River Formation of West Virginia consists of typical Breathitt lithologies as well as quartzose sandstones. This study indicates that the Alvy Creek is equivalent to the non-quartzose coal-bearing lithologies in the upper half of the New River Formation (Plate 1).

In the south-central part of the study area, the Alvy Creek is much reduced in thickness and is equivalent to part of the Hensley Member of the Cumberland Overthrust Sheet (Plate 1). The Hensley Member, mapped along Pine and Cumberland Mountains in Kentucky, contains shales, siltstones, sandstones, and coal beds typical of the Breathitt. However, in Kentucky, it is situated between the underlying massive Sewanee (upper Middlesboro Member) and overlying Bee Rock Sandstones and, therefore, was called a member of the Lee Formation. Regional studies show that both of the sandstone members pinch out in the subsurface, and the Hensley is laterally equivalent to the larger package of coal-bearing rocks of the Alvy Creek formation in Virginia and West Virginia. Herein, the non-quartzose coal-bearing strata of the Hensley Member of the Lee Formation is transferred as a member to the Alvy Creek formation. Any quartzose sandstone locally mapped as part of the Hensley Member should be considered as part of the adjacent Sewanee or Bee Rock Sandstones or as unnamed units within the Hensley.

Subsurface studies also show that the Hensley Member is equivalent to the strata between the Paragon (Pennington) Formation and the Rockcastle Sandstone Member of the Bee Rock Sandstone along the western belt of outcrop (in Laurel, McCreary, Pulaski, and Wayne Counties, Kentucky). These strata were previously mapped as part of the "lower tongue of the Breathitt Formation," but are herein called the Hensley Member. In Tennessee, the Alvy Creek is equivalent to the Fentress Member (Plate 1).

GRUNDY FORMATION (0–950 feet; 0–290 m)

The Grundy Formation (Fig. 5) is an important coal-bearing unit of the Breathitt Group and may contribute significant deep subsurface coal resources. Its lower boundary is marked by the top of the underlying Bee Rock Sandstone and at the Kennedy coal bed where the Bee Rock is absent in the southeastern part of the study area (Virginia and West Virginia). The Grundy also interbeds with the Bee Rock Sandstone, causing the lower part of the Grundy to be stepped and stratigraphically lower to the southeast, as reflected in the dip sections (Plate 7a–c). The upper boundary of the Grundy is at the base of the Betsie Shale Member of the Pikeville Formation (described below). The Betsie Shale is the most extensive shale marker horizon in the coal field.

The Grundy Formation is formally named here for Grundy, Virginia, where these rocks crop out and the coal beds are mined. At Grundy the lateral equivalent of the Bee Rock is mapped as the McClure Sandstone Member of the Norton Formation (*see* Taylor, 1989). The lateral equivalent of the Betsie Shale was not mapped there, but occurs above the Clintwood and Addington coal zone of the Wise Formation, which were mapped. The Grundy Formation at Grundy, Virginia, contains the Kennedy through Addington coal beds.

The reference section for Kentucky is Diamond Drill Hole No. 7, drilled by the U.S. Geological Survey in the Elkhorn City Quadrangle in southern Pike County, Kentucky. The core description records strata from the Upper Elkhorn No. 3 coal zone (in the Pikeville Formation) down to the top of the Bee Rock Sandstone. A geologic description of the section represented by the Grundy Formation is in Appendix 1. The coal beds found in the Grundy are the Banner through the Clintwood (=Manchester) coal zones.

The Grundy is the most extensive of all the Breathitt formations. The Grundy Formation contains the Corbin Sandstone along the western part of the study area. The Gladeville Sandstone (Plate 1), a marker bed used extensively in Virginia and parts of West Virginia (Miller, 1974; Mitchell and others, 1982), occurs in the upper third of the Grundy Formation in the southeastern part of Kentucky, southern West Virginia, and Virginia.

The correlation of major coals of the Grundy and overlying formations of the Breathitt Group is shown in Plate 8. For local coal bed nomenclature in eastern Kentucky, *see* Rice and Smith (1980). The coal-bed names shown in Plate 8 for West Virginia, Virginia, and Tennessee are those used in subsurface records obtained for this study, and are not necessarily the correct correlations used throughout these states. Internal correlation problems within these states became apparent during construction of the cross sections. For instance, West Virginia renamed its coal beds based on a stratotype in central West Virginia (Englund and others, 1979). Unfortunately, the coals (and other strata) in the western tier of counties in West Virginia had been miscorrelated with the West Virginia stratotype along the Kanawha Valley (this study; Rice and others, 1987). The West Virginia Geological and Economic Survey is presently correcting these correlation problems. Resolution of detailed coal-correlation problems was not attempted in this paper.

PIKEVILLE FORMATION (<1,100 feet; <340 m)

The Pikeville Formation is composed of the coal-bearing strata occurring above the Grundy and below the Hyden Formations (Fig. 5). The base of the Pikeville is marked as the base of the Betsie Shale Member, and its upper boundary is marked at the base of the Kendrick Shale Member, both of which are widespread marine marker beds (Chesnut, 1991a).

The Pikeville Formation is formally named for coal-bearing rocks that are exposed near Pikeville, Kentucky. The well-known "Model City" roadcut in Pikeville includes most of the new formation (Chesnut and Cobb, 1989). The reference section for the Pikeville Formation is U.S. Geological Survey Diamond Drill Hole No. 1 from the Dorton Quadrangle (just south of Pikeville). A geologic description of the Pikeville Formation in this core is given in Appendix 2. The coal beds of the Pikeville Formation are the Pond Creek (=Lower Elkhorn) through the Williamson.

The Pikeville is the lowermost formation of the Breathitt Group that does not contain a formally named quartzose sandstone formation. Coal-bed correlation problems in adjacent states are discussed in the Grundy Formation section. The Pikeville Formation thickens to the southeast, as do the other Breathitt formations (Plates 3b, 6).

HYDEN FORMATION (<850 feet; <260 m)

The Hyden Formation consists of important coal-bearing rocks situated between the underlying Pikeville Formation and the overlying Four Corners Formation. The base of the Hyden is marked as the base of the Kendrick Shale Member, and the top is placed at the top of the Taylor/Copland coal bed and the base of the Magoffin Member. The Kendrick and Magoffin Members are marine strata commonly mapped on the U.S. Geological Survey 7.5-minute geologic quadrangle maps in eastern Kentucky.

The Hyden Formation is named for exposures in the vicinity of Hyden, Leslie County, Kentucky. The reference section is the Daniel Boone Project, Redbird Series No. R-9 core drilled in the Creekville Quadrangle by the Kentucky Geological Survey (Cobb and others, 1983). The Hyden Formation portion of this core description is given in Appendix 3. The coals of the Hyden range from the Whitesburg through Copland coal zones and include the Fire Clay coal, which contains a distinctive tonstein (flint clay) parting of volcanic origin.

Although the Hyden Formation is found throughout the study area, it thins to the north (Plates 3b, 6) and is difficult to differentiate from adjacent units in northeastern Kentucky because all the units are thin or absent, and data are sparse. Coal-bed correlation problems in adjacent states are discussed in the Grundy Formation section.

FOUR CORNERS FORMATION (<900 feet; <275 m)

The Four Corners Formation consists of coal-bearing strata between the Hyden Formation and the Princess Formation (Fig. 5). The base of the Magoffin Member, a widely mapped marine marker bed, represents the base of the Four Corners, and the top is marked at the top of the Hindman coal bed and the base of the marine Stoney Fork Member of the overlying Princess Formation.

The Four Corners Formation is named for a series of four roadcuts arranged around the intersection of the Daniel Boone Parkway, Kentucky Highway 80, and Kentucky Highway 15 near Hazard, Perry County, Kentucky. The roadcuts have been described in several field trip guidebooks (Cobb and others, 1981; Chesnut and others, 1986; Cobb and Chesnut, 1989). The Four Corners, probably the most important formation for coal resources that have been mined, contains the Haddix, Hazard, Hazard No. 7, Hazard No. 8 (Francis), and Hindman (Hazard No. 9) coal zones. The reference section for the Four Corners Formation is part of the U.S. Geological Survey Diamond Drill Hole No. 11 from Vicco Quadrangle (Perry County), southeast of the Four Corners roadcut locality. The reference section is described in Appendix 4.

The Four Corners Formation thins to the north and is difficult to distinguish from adjacent units in northeastern Kentucky because of a lack of adequate data (Plate 3b). This formation is present in Tennessee but is poorly known because of sporadic exposures and uncertainty about the position of the Magoffin and Stoney Fork Members. The Four Corners is present in all the cross sections, but is more restricted in occurrence because of erosion than the underlying Breathitt formations.

PRINCESS FORMATION (<500 feet; <150 m)

The Princess Formation (Fig. 5) is the uppermost formation of the Breathitt Group; it overlies the Four Corners Formation and is overlain by the Conemaugh Formation (not of the Breathitt Group). The base of the Princess Formation is marked by the base of the Stoney Fork Member (of the Princess Formation), and the upper boundary is marked at the Princess No. 9 coal bed.

The Princess Formation is named for the Princess coals and the Princess Coal Resource District in northeastern Kentucky (Boyd, Carter, Greenup, Lawrence, and part of Lewis Counties). The lower part of the Princess Formation is widespread in the hilltops in the other districts of eastern Kentucky where the Stoney Fork Member is widely recognized. The reference section for the lower half of the Princess Formation (from the Stoney Fork through the Skyline coal zone) is U.S. Geological Survey Diamond Drill Hole No. 5 from Hazard South Quadrangle, Perry County, Kentucky (*see* Appendix 5).

Although the Stoney Fork Member is widespread across most of eastern Kentucky, it has not been identified in the Princess District (it may be equivalent to the marine "Main Block ore"). In the Princess District the base of the Princess Formation is placed at the top of the Princess No. 4 coal, which is equivalent to the Hindman coal at the top of the Four Corners Formation (Rice and Smith, 1980). The reference section for the upper part of the Princess Formation in the Princess District is Kentucky Geological Survey Diamond Drill Hole No. R-2 (*see* Appendix 6). These two reference sections are tied together at the Skyline and Princess No. 5 coal zones, which are equivalent (Rice and Smith, 1980).

The Princess Formation thins to the north and is difficult to distinguish from adjacent units because of a lack of identifiable stratigraphic markers. In the central and southern parts of the study area (Plates 2a–b, 3b, 4, 6), the Princess is found on hilltops, and its upper contact is absent. However, in the northern part of the study area (Plates 3b, 4), complete sections of the Princess are found in the Allegheny Synclinorium (Parkersburg Syncline).

Conemaugh and Monongahela Formations (<600 feet; <180 m)

The Conemaugh and Monongahela Formations (Fig. 5) occur only in the northern part of the study area. Elsewhere, they apparently have been removed by modern erosion. These coal-bearing units are not part of the Breathitt Group as used in this study. The Conemaugh consists of red (and some green) shales and siltstones, gray shales, sandstones, few coals, and some marine shales, siltstones, and limestones. The overlying Monongahela is similar in lithology to the Breathitt Group (i.e., fewer red beds, better developed coals compared to the Conemaugh). The base of the Conemaugh Formation has been defined as the top of the Upper Freeport coal (Rice and Smith, 1980). The base of the Monongahela Formation in West Virginia is placed at the base of the Pittsburgh coal (Englund and others, 1979). However, the Pittsburgh is not readily found in northern Kentucky, and there the Conemaugh and Monongahela Formations are mapped together (Plate 3b). These two formations are Late Pennsylvanian in age (Englund and others, 1979).

The Conemaugh-Monongahela Formations were recorded only in the Allegheny Synclinorium (Parkersburg Syncline) in the northern part of the study area. Because of the lack of detailed core descriptions in the area of the Catlettsburg dip section (Plate 4), the base of this interval is placed at the level of the lowermost reported red beds. The nature of drillers' logs and insufficient data density prevent adequate identification of the Breathitt Group and Conemaugh-Monongahela Formations in this section. The base of the Conemaugh-Monongahela Formations in the Grundy section (Plate 3b) was determined from published geologic quadrangle maps (Carlson, 1971; Brown, 1977; Pillmore and Connor, 1978) from the Allegheny Synclinorium area because of insufficient subsurface data.

Regional Unconformity

The widely accepted model of Ferm and Cavaroc (1969) for the Carboniferous of the Appalachian Basin holds that the largely terrestrial, coal-bearing rocks called "Pennsylvanian" prograded over the "Mississippian" marine rocks. Ferm and Cavaroc considered the Mississippian and Pennsylvanian rocks to represent laterally equivalent facies, partially coeval, separated by transitional facies composed of beach-barrier bar sandstones and lagoonal shales. Subsequent studies, however, do not support this model (e.g., Ettensohn, 1980; Chesnut, 1988).

A regional unconformity surface separates the Mississippian and Pennsylvanian rocks across most of the basin. The unconformity is evident from both surface and subsurface analysis. At the surface it is marked by such features as scours, channels, pedogenic flint clays, iron ore, and paleokarst. In addition, regional cross sections reveal sequential truncation of lowermost Pennsylvanian and Mississippian rocks from the center of the basin toward the Cincinnati Arch (Fig. 12). Pennsylvanian strata overlying the unconformity onlap older units to the northwest (Fig. 13). Moreover, paleontological data support separate ages for the Mississippian and Pennsylvanian rocks throughout the basin (Chesnut, 1988, p. 154–168).

The unconformity occurs within Lower Pennsylvanian rocks near the center of the Carboniferous Appalachian Basin (Plates 3a–b, 4). Where the lowermost Pennsylvanian rocks are entirely removed by erosion, the unconformity is an apparent "Mississippian-Pennsylvanian" unconformity (Plates 2a–b, 3a–b, 4–6). In the deepest parts of the basin (parts of Virginia and southern West Virginia), the unconformity cannot be identified (Plates 3b, 4), and the contact may become conformable, as previously suggested by Englund and others (1979). However, the possibility of a conformable sequence appears restricted to the deepest part of the basin. The amount of missing section along the unconformity increases toward the edge of the basin, where Early Pennsylvanian sandstones directly overlie the Early Mississippian Borden Formation in Ohio and northeastern Kentucky (Plates 3b, 4). The unconformity would more properly be called the "Early Pennsylvanian unconformity."

Structural Framework

The structural framework of the Central Appalachian Basin includes large-scale structures that are evident in structure-contour maps and in the cross sections (Plates 2a–b, 3a–b, 4–6). Structural features in the study area, shown on Figure 14, were compiled from maps prepared by Stearns (1954), Woodward (1961), Huddle and others (1963), Miller (1974), Ettensohn (1975), and Arkle and others (1979).

Figure 15 is a structure-contour map on the Fire Clay coal of the Hyden Formation (Breathitt Group) in Kentucky. The Fire Clay coal was chosen as a structural datum because of numerous data points and its stratigraphic position near the middle of the most productive part of the Breathitt Group. Because the Fire Clay coal occurs near the surface throughout most of this area, the map also reflects the general trends of the surface geologic structure. Only structures encountered in the cross sections are described in following sections. Tectonic analyses of the structural features are given in Chesnut (1988, 1991b).

Folds

The most obvious feature on the Fire Clay structure map (Fig. 15) is a complex synclinal structure oriented generally northeast-southwest. This structure actually consists of two previously recognized synclines (Fig. 14), the Allegheny Synclinorium and the Eastern Kentucky Syncline (Huddle and others, 1963). The Allegheny Synclinorium is located in northeastern Kentucky and northwestern West Virginia: i.e., the northeastern part of the structure-contour map (Fig. 15) and the northwestern thirds of the Catlettsburg (Plate 4)

Figure 13. Supercrop geology above the Early Pennsylvanian unconformity, based on cross sections in this study. Data are plotted on a palinspastic base map that shows positions of Pennsylvanian units prior to movement along the Pine Mountain Thrust Fault.

and Grundy (Plate 3b) cross sections. In West Virginia (Fig. 14), the northeast-trending Allegheny Synclinorium is known as the Parkersburg Syncline (Arkle and others, 1979).

The Eastern Kentucky Syncline occurs in the central part of the study area (Figs. 14–15). The Eastern Kentucky Syncline, which is equivalent to the Coalburg Syncline of West Virginia, is recognized in the central parts of the Catlettsburg, Grundy, and Booneville dip sections (Plates 3b, 4–6) and in the central parts of the strike sections (Plates 2a–b, 3a). The Allegheny Synclinorium and the Eastern Kentucky Syncline are separated by the Irvine-Paint Creek, Johnson Creek, Warfield, and Walbridge Faults, the Paint Creek Uplift, and the Paintsville-Warfield Anticline (Plate 3b, Fig. 14). Carboniferous strata do not thicken in the Eastern Kentucky Syncline (Plates 2a–b, 3a, Fig. 14), whereas Middle and Late Pennsylvanian strata thicken in the Allegheny Synclinorium (Sergeant, 1979). These thickness trends indicate that the Allegheny Synclinorium was active during the Carboniferous, while the Eastern Kentucky Syncline was not. The difference in thickness trends also suggests that the synclines were not genetically related features.

Northwest of the Allegheny Synclinorium and the Eastern Kentucky Syncline, the outcrops consist of the

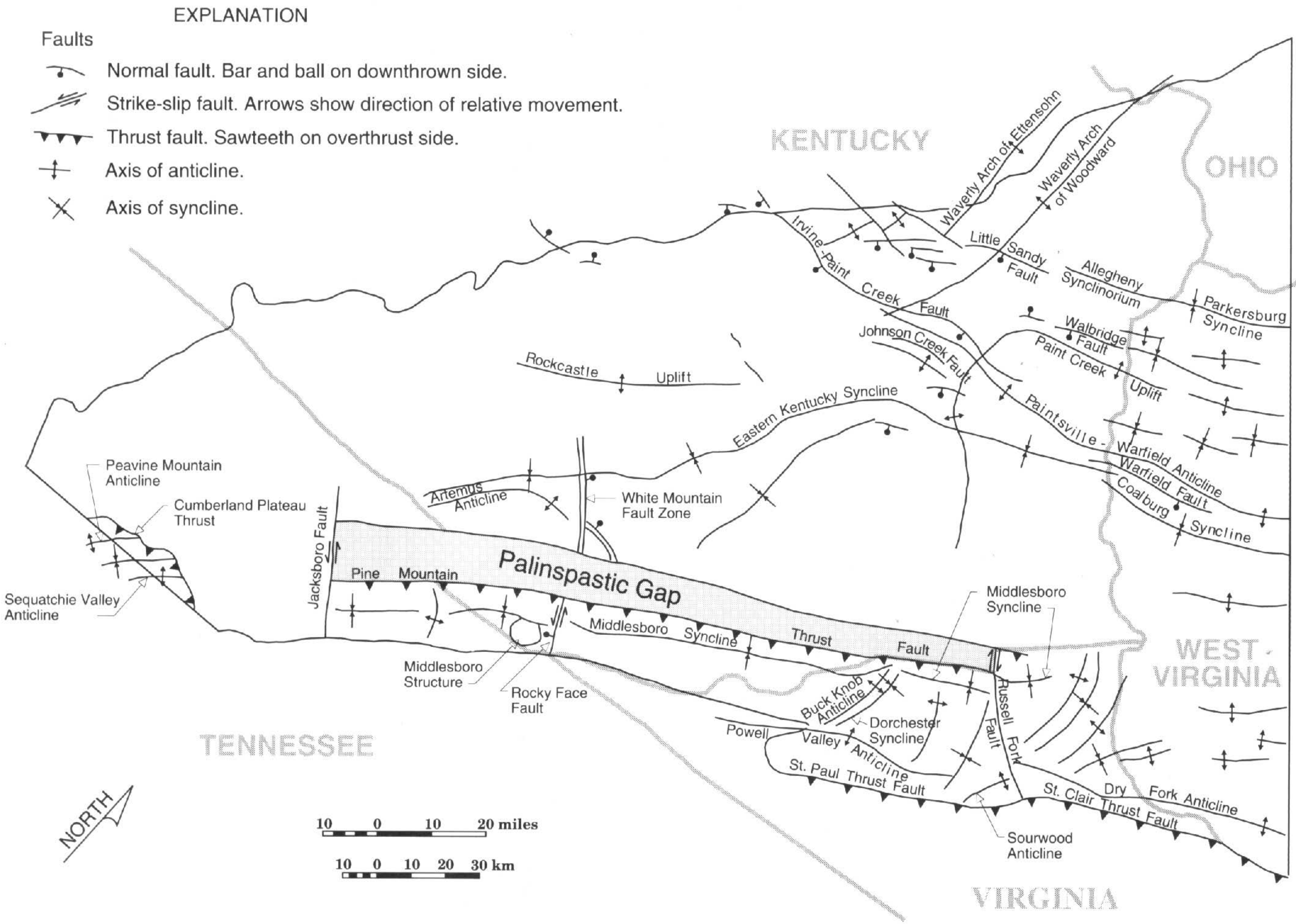

Figure 14. Near–surface structural features of part of the Central Appalachian Basin, compiled from maps prepared by Stearns (1954), Woodward (1961), Huddle and others (1963), Miller (1974), Ettensohn (1975), and Arkle and others (1979). Base map has been reconstructed to show original position of Pine Mountain Thrust Fault.

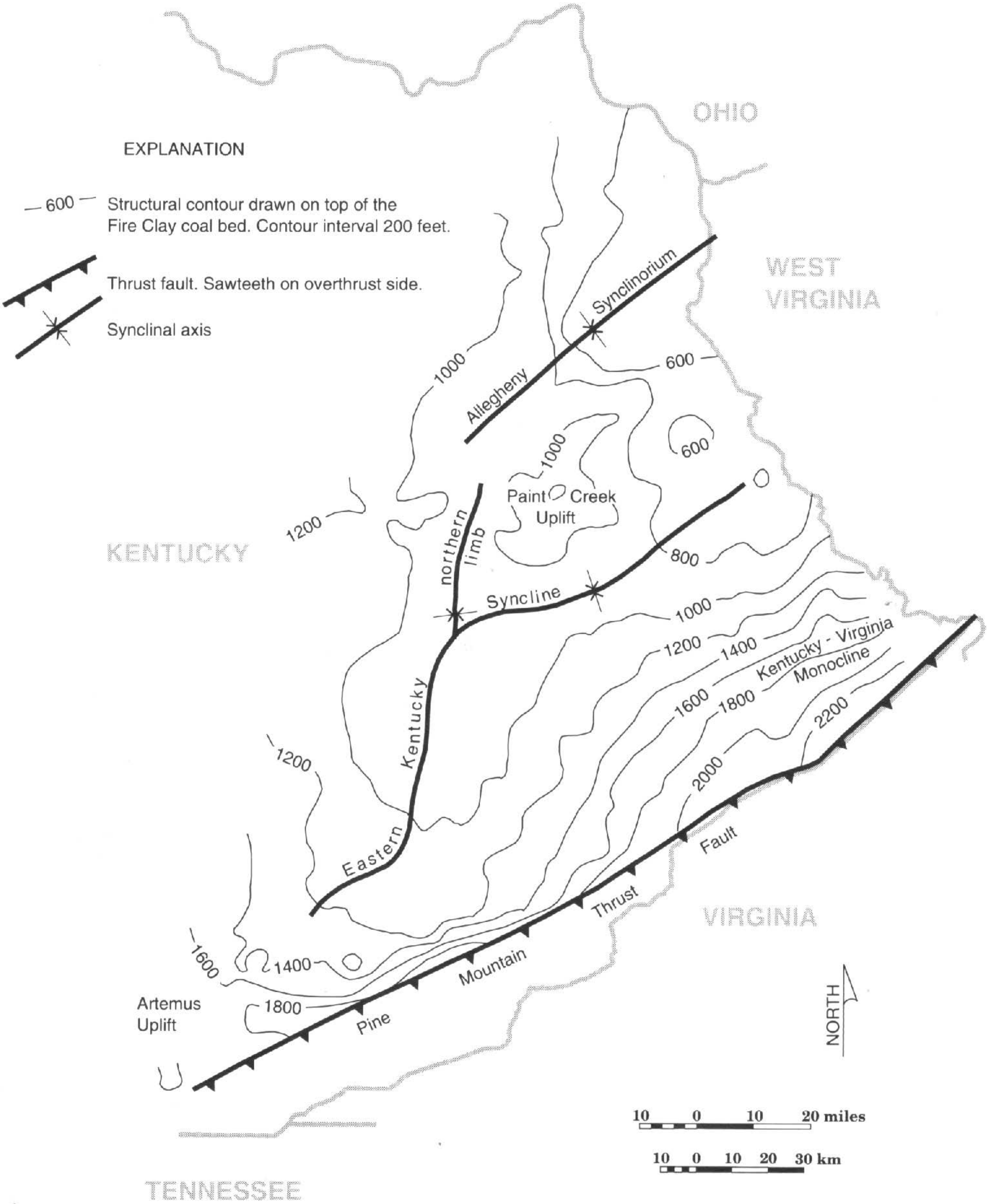

Figure 15. Computer-generated structure map on the Fire Clay coal bed of the Hyden Formation (Breathitt Group). Structure contours produced by Richard Sergeant (Kentucky Geological Survey) from approximately 2,000 data points.

east- or southeast-dipping beds of the southeastern limb of the Cincinnati Arch (Fig. 15). This feature is more easily recognized in the northwestern parts of the dip cross sections (Plates 3b, 4–6); the sections are based on data farther to the northwest than data used for the structure-contour map.

The Middlesboro Syncline, located between Cumberland Mountain and Pine Mountain, and between the Jacksboro and Russell Fork Faults in the southern part of the study area, was formed by movement of the Pine Mountain Thrust Fault (Englund, 1968). This northeast-southwest-striking syncline is encountered in the southeastern part of the Booneville dip section (Plate 6). The central part of the Harlan strike section (Plate 3a) is located along the axis of this syncline.

Many smaller synclinal and anticlinal features were encountered in the cross sections. In the Catlettsburg dip section (Plate 4), the Warfield Anticline occurs in the central part of the section, and the Coalburg Syncline is just south of the anticline. An unnamed anticline and syncline occur in the southern quarter of the Catlettsburg dip section. In the Grundy dip section (Plate 3b), the Paint Creek Uplift is located just south of the Walbridge Fault, whereas an unnamed anticline in eastern Kentucky, close to the Virginia border, may be equivalent to the Belfry Anticline of Hower and Pollock (1988). The large, but weakly developed anticlinal feature east of the Eastern Kentucky Syncline shown in the Hazard strike section (Plate 2a) is also part of the Paint Creek Uplift. The Rockcastle River Uplift (anticline) is present in the northern part of the Booneville dip section (Plate 6). Additional analysis indicates that the Rockcastle River Uplift is probably the surface expression of a deeper (normal?) fault and not a shallow, blind-thrust anticline.

In the central part of the Pineville strike section (Plate 2b), an unnamed, steeply dipping anticline is located just southwest of the White Mountain-Dorton Branch Fault Zone. This anticline may be an extension of the Artemus anticline (Fig. 14). A similar anticline is located just southwest of the Rocky Face Fault in the central part of the Harlan strike section (Plate 3a). The anticline in the Harlan section is also near the Middlesboro cryptoexplosive structure, a probable meteor-impact structure mapped by Englund and others (1964).

In the northeastern part of the Harlan strike section, two closely related anticlines southwest of the Russell Fork Fault are evident. The easternmost and best developed is the Buck Knob Anticline (Miller, 1974, p. 14); the other is unnamed. Other small "anticlines" and "synclines" occurring between the Jacksboro and Russell Fork Faults may only appear to be structures; they may be caused by the zig-zag traverse of the section along the Middlesboro Syncline, and not be true structures. True anticlines and synclines could be masked by these apparent structures.

Monocline

The northwest-dipping beds of a previously unnamed monocline southeast of the Eastern Kentucky Syncline are shown on the structure-contour map (Fig. 15). The monocline occurs in the southeastern parts of the Catlettsburg and Grundy dip sections (Plates 3b, 4). The monocline is herein designated the Kentucky-Virginia Monocline.

In the area of the Kentucky-Virginia Monocline, an interesting structural relationship between older and younger rocks occurs. The Pennsylvanian strata dip to the northwest, as shown by the structure-contour map on the Fire Clay coal bed (Fig. 15), but the Mississippian and older strata dip to the southeast; the trend of the overlying strata apparently reverses. In the southern half of the Catlettsburg dip section (Plate 4), the Slade Formation and lower units are nearly horizontal or dip to the southeast, whereas the units above the Slade dip to the northwest. In the Grundy section (Plate 3b), surface rocks in the southern half of the section dip to the northwest, and subsurface units below the Pennsylvanian formations dip to the southeast, away from the Cincinnati Arch. In the Booneville dip section (Plate 6), the Sewanee, Bee Rock, and Corbin Sandstones and overlying rocks are nearly horizontal north of the Pine Mountain Fault, whereas rocks below the quartzose sandstones dip to the southeast. In the Lake City section (Plate 5), the subsurface rocks dip away from the Cincinnati Arch toward the southeast. Surface rocks, however, are nearly horizontal in the Pikeville and Hyden Formations, and rocks above the Hyden dip to the northwest.

The southeastern dip of the older beds is part of a regional trend of beds dipping from the Cincinnati Arch toward the Appalachian Basin. The change in dip direction from older to younger strata may have been caused by a combination of two processes: partial uplift of basinal strata, and regional erosion followed by a shift in the position of the basin. When a basin subsides more along its axis than its margin, the strata deposited in the basin will have divergent dip from bottom to top (i.e., the strata in the central part of the section will be horizontal, while overlying strata will dip in a direction opposite that of the underlying strata).

Structural subsidence and subsequent uplift may explain the divergences in dip in the study area, but another process may play a part as well. Most of the Carboniferous rocks gradually change in dip up-section, from southeast to horizontal. A more abrupt change in dip can be recognized between Pennsylvanian and subjacent Mississippian strata in each of the dip cross sections (Plates 3b, 4–6). Although the differences in dip observed in an outcrop may be too subtle to detect, differences in dip can be discerned in regional cross sections with large vertical exaggeration. This change in dip, which occurs at the Early Pennsylvanian unconformity, is caused by a shift of the depositional basin prior to and following Early Pennsylvanian erosion. Subsidence in the center of the basin, relative to the flanks, caused dipping toward the axis. Uplift of the basin caused an increase in dip toward the flanks and led to erosion and the Early Pennsylvanian unconformity. Dips above the unconformity differ from those below because (1) they were not affected by the uplift that preceded erosion, and (2) the basin depocenter may have shifted following the development of the unconformity.

Faults

The Pine Mountain Thrust Fault (Fig. 14) is located in the southern part of the study area. The thrust fault is encountered in the southeastern end of the Booneville dip section (Plate 6) and in the central part of the Harlan strike section (Plate 3a). The Middlesboro Syncline, a feature associated with the Pine Mountain Thrust Fault and represented in the Booneville dip section, is discussed above. The Harlan section is more complex than the other sections because it traverses the full length of the Cumberland Overthrust Sheet (Pine Mountain Thrust Sheet). In the southwestern part of the Harlan section, the southwestern limit of the thrust sheet is the Jacksboro Fault, which apparently is a lateral ramp with left-lateral displacement. The lateral displacement along the Jacksboro Fault is reported to be about 11 miles (17.7 km) (Wentworth, 1921; Englund, 1968).

Farther east in the central part of the Harlan section (Plate 3a), the Rocky Face Fault (Fig. 14) occurs in the thrust sheet. This fault is upthrown to the northeast. The Rocky Face Fault and the anticline just to the southwest are reminiscent of similar structures just north of Pine Mountain (Pineville strike section, Plate 2b) and are probably related to the other structures. In the northeastern part of the Harlan strike section, the northeastern end of the Pine Mountain Thrust Sheet is marked by the Russell Fork Fault. The lateral displacement along the Russell Fork Fault is reported to be about 4 miles (6.4 km) (Wentworth, 1921; Englund, 1968; Miller, 1974).

In the thrust sheet, the base of the Pine Mountain Thrust Fault occurs in the Chattanooga Shale (Plates 3a, 6). Slickensides and gas blowouts (over-pressured gas) are reported in the shale in this region. In the Chattanooga, they are associated with fractures or slip surfaces, and in the thrust sheet, they indicate the presence of the thrust fault (Brandon C. Nuttall, Kentucky Geological Survey, personal commun., 1986).

Many other faults were also recorded in the cross sections. The Walbridge Fault (Fig. 14), a normal fault with the downthrown block to the south, traverses the northeastern part of the Grundy dip section (Plate 3b). In the southeasternmost part of the Lake City section (Plate 5) at Walden Ridge, the rocks dip abruptly to the northwest. This ridge marks the Eastern Cumberland Escarpment and the eastern belt of outcrop of Carboniferous rocks. A thrust fault is mapped at this ridge on the Lake City geologic quadrangle map (Swingle, 1960). Unmapped thrust faults in the Breathitt Group northwest of Walden Ridge may explain difficulties in correlation of strata in this area.

In the Pineville section (Plate 2b), several faults were recognized. Faults such as the Lick Ridge and the Little Peavine Thrust Faults, and the Fox Creek, Otter Creek, Yellow Creek, and other lateral faults were mapped in the southwestern end of the study area (Fig. 14) (Stearns, 1954). These closely associated faults are illustrated collectively in the Pineville section. The westernmost block may contain several repeated sections of Pennsylvanian sandstones. Correlations in this study were not extended west of these faults.

In the southwestern third of the Pineville strike section (Plate 2b), the Terry Creek Fault is present in the Pioneer Quadrangle (Englund, 1968). The southern part of the scissor fault is upthrown to the northeast, whereas the northern part is upthrown to the southwest. In the area of the cross section, the upthrown side is to the southwest, and very little displacement occurs across this fault in this section.

In the central part of the Pineville strike section (Plate 2b), a steeply dipping anticline and associated fault zone just east of the anticline are recognized. This anticline and fault zone are part of the White Mountain-Dorton Branch Fault Zone (Fig. 14). Similar and probably related to the anticline and faults of the White Mountain-Dorton Branch Fault Zone are the Rocky Face Fault and associated anticline located in the central part of the Harlan strike section (Plate 3a).

A new structural feature disclosed in these cross sections is herein designated the subsurface Dorton-Hellier Fault. It occurs in the subsurface between Dorton and Hellier Quadrangles on the Pineville strike section (Plate 2b). Additional analysis indicates that this subsurface fault may coincide with the north-northeast-trending Belfry Anticline of Hower and Pollock (1988) in Pike County, Kentucky. The fault is noted in the northeastern part of the cross section and offsets the Pride Shale Member (Pennington Group) and older strata. The Warren Point Sandstone is largely restricted to the downthrown side of the fault. The Bee Rock and Sewanee Sandstones overlie the fault, but do not appear to thicken on the downthrown side. Therefore, faulting could have occurred following deposition of the Pride Shale (Late Mississippian) and prior to or during the deposition of the Warren Point Sandstone (Early Pennsylvanian).

POTENTIAL FOR SUBSURFACE COAL RESOURCES

The stratigraphic and structural framework developed in this study can be helpful in determining the potential for subsurface coal resources. Although the quartzose sandstone formations (Warren Point, Sewanee, Bee Rock, and Corbin) contain some coal beds, they are discontinuous and local in extent. The quartzose sandstone formations largely occur at the expense of the coal-bearing rocks of the Breathitt Group. Where the quartzose sandstone belts have been mapped in this study, reduced resources can be expected. For example, coal-resource potential is probably greater in the Grundy Formation in areas where the Corbin sandstone belt does not exist (Plates 3b, 4–6). In the Eastern Kentucky Coal Field most of the coal resources occur above the level of the Bee Rock Sandstone-Alvy Creek Formation because little of the coal-bearing lithologies exist at or below this level. However, in parts of Virginia and West Virginia, where the quartzose sandstones pinch out (Plates 3a–b, 4), the Alvy Creek and underlying Breathitt formations contain abundant coal resources.

This structural framework is also useful in explaining subsurface resource potential. For instance, more Breathitt formations (coal-bearing) are preserved in the subsurface along the axis of the Eastern Kentucky Syncline than in surrounding areas (Plate 2a–b). In addition, uplift along the margin of the syncline eroded more coal-bearing strata than in adjacent areas. For example, uplift represented by the Kentucky-Virginia Monocline in eastern Kentucky and western Virginia has caused progressively deeper truncation by erosion to the southeast (in the area of the monocline), thereby reducing the amount of preserved coal-bearing rocks to the southeast (Plates 3b, 6).

Basinal structures that were active contemporaneous with the deposition of Pennsylvanian rocks also affected coal resources. For example, subsurface coal resources in northeastern Kentucky are limited because basin subsidence appears to have been reduced during Early and Middle Pennsylvanian time compared to the rest of the study area, as evidenced by the thinning of section shown in Plate 3b. Only very thin deposits of coal-bearing rocks accumulated in these areas. Conversely, subsidence was greater toward the axis of the basin in the southeastern part of the study area, and coal-bearing formations are thicker in that direction.

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ANR Coal Co.

ARMM Coal Co.

Appollo [*sic*] Fuels

Belfry Coal

Benham Coal, Inc.

Dr. Richard Bergenback

Blackwood Land Co., Inc.

Blue Diamond Coal Co.

Mr. Eugene Boston

CSX Mineral Development, Inc.

Cardinal Resources, Inc.

Cargill-Johnson Coal Co.*

Citation Coal Co.

Clinchfield Coal Co.

Consolidation Coal Co.

Cumberland Mountain Coal Co.

*Acquired during a previous study.

Diamond Coal Co.*
Diamond Shamrock Coal Co.
The Elkhorn Coal Corp.
Enterprise Coal Co.*
Mr. Wayne Frankie
Gatliff Coal Co.
Glamorgan Coal Corp.
Greenwood Land and Mining Co.*
Ikerd-Bandy Co., Inc.
Ingram Coal
Interstate Coal Co., Inc.
Island Creek Coal Co.
Kentland Elkorn
Kentucky Berwind Land Co.
Kentucky Carbon Corp.
Kentucky Prince Coal Corp.
Kentucky River Coal Corp.
King Coal Co.
Koppers Co., Inc.
Manalapan Mining Co.
Mapco Coals, Inc.
Middle States Coal Co.
Mr. Robert Miser
Mountain Coals, Inc.
National Mines Corp.
Penn-Virginia Resources Corp.
Pickands-Mathers Co.
Pikeville Coal Co.
Plastics Universal*
Powell Mountain Coal Co.
R. B. Coal Co.
R. J. F. Coal Co.
Richland Coal Co.
River Processing, Inc.*
Royal Land Company (Old Ben Coal Co.)
Ruby Coal Co.
Sandy Fork Mining Co.
Sierra Coal Co.
Southeast Coal Co.
The Stearns Co.
Straight Creek Resources
Taywood Mining, Inc.
Triple Elkhorn Mining Co., Inc.
United Coal Co.
United States Steel Mining Co.
Utah International, Inc.
VICC Land Company
WesCo Engineering
Mr. Gerald Yahne

I hope I have not inadvertently omitted any companies, though this is a possibility. If I have, I offer my apologies.

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APPENDIX 1:
Reference Section for the Grundy Formation

Diamond Drill Hole No. 7, Elkhorn City Quadrangle, Carter coordinate location 23-K-87, 725 FEL X 4,400 FSL, Elev. 2,120 ft., T.D. 1,390, Drilled 9/24/62–10/24/62, Logged by C. L. Rice and W. F. Outerbridge. Only a portion of the core description is recorded below.

Depth to Bottom (ft.)	*Thickness of Unit (ft.)*	*Description*
Betsie Shale Member (part)		
500.0	40.8	Sandstone, fine- to very fine-grained, interbedded with siltstone; some slumping, some ripple marks.
611.8	111.8	Siltstone, sandy in part, well-bedded, with abundant siderite lenses.
617.3	5.5	Claystone, becoming darker downward.
620.2	2.9	Claystone, grading to coal.
Grundy Formation		
622.6	2.4	**Clintwood coal.**
691.0	68.4	Sandstone, fine- to medium-grained; siderite-pebble conglomerate at base.
695.0	4.0	Claystone, with siderite pebbles; laminated; grades into roof clay.
695.5	0.5	**Eagle "A" coal.**
697.0	1.5	Seatrock, carbonaceous, silty.
700.7	3.7	Siltstone, sandy, with some black shale nodules with pyrite borders.
712.0	11.3	Sandstone, very fine- to fine-grained, laminated with siltstone, well sorted, quartzitic.
722.5	10.5	Siltstone, interlaminated with very fine-grained sandstone; siderite lenses throughout; ripple marked.
724.5	2.0	**Eagle coal.**
736.3	11.8	Sandstone, fine- to medium-grained.
748.5	12.2	Siltstone, with claystone and sandstone; some ripple marks; very sandy at base.
755.5	7.0	Clay, very coaly at base.
757.5	2.0	**Blair(?) coal.**
761.6	4.1	Claystone and siltstone.
788.2	26.6	Sandstone, very fine- to medium-grained, with siltstone; crossbedded.
796.7	8.5	Siltstone, with many siderite nodules.
818.8	22.1	Sandstone, very fine- to coarse-grained (at base).
835.8	17.0	Siltstone and claystone, some very fine-grained sandstone, many sideritic layers; becomes roof clay of coal.
841.1	14.1	**Glamorgan coal**, with partings.
845.0	3.9	Seatrock, clayey and sandy.
904.8	59.8	Sandstone, fine- to medium-grained; shale pebbles and siderite pebbles in lowest 15 feet; lower half is weakly calcareous.
950.2	45.4	Siltstone, very dark- to medium-dark-gray, with some sideritic material.

Depth to Bottom (ft.)	*Thickness of Unit (ft.)*	*Description*
951.7	1.5	Claystone, with streaks of very fine-grained sandstone, slight greenish tinge.
964.0	12.3	Sandstone, fine- to very fine-grained, calcareous, crossbedded.
1,010.7	46.7	Siltstone, interbedded with fine-grained sandstone containing lenses of siderite irregularly spaced throughout.
1,013.3	2.6	**Hagy coal**, with minor splits.
1,015.3	2.0	Seatrock, sandy.
1,050.0	34.7	Sandstone, fine-grained, wispy, some massive, silty.
1,063.0	13.0	Siltstone to claystone.
1,109.0	46.0	Sandstone, silty, carbonaceous, with thin, discontinuous lenses of siderite; crossbedded.
1,113.5	4.5	Claystone, some silt, grading to roof clay of coal.
1,116.1	2.6	**Splashdam coal**, with splits.
1,118.1	2.0	Claystone, seatrock.
1,170.2	52.1	Sandstone, medium-grained, poorly sorted, with wisps of coal trash throughout.
1,191.8	21.6	Shale and siltstone, dark-gray, some fine-grained sandstone, fossiliferous, pyritic.
1,194.6	2.8	**Upper Banner(?)** seatrock, siliceous, silty.
1,199.6	5.0	Sandstone and shale, fine- to very fine-grained, microcrossbedded.
1,238.6	39.0	Shale, calcareous siltstone, well-bedded, wisps of sandstone.
1,270.0	31.4	Sandstone, silty, fine- to coarse-grained, very dark-gray; some lenses very calcareous.
1,354.5	84.5	Shale, silty claystone, pyritic; some laminated sandstone; fossiliferous in bottom 15 feet.
1,356.3	1.8	**Banner coal**, some shale.
1,366.3	10.0	Siltstone, clayey; some very fine-grained sandstone in upper part.
Bee Rock Sandstone Formation (part)		
1,373.1	6.8	Sandstone, fine- to very fine-grained, rounded, crossbedded, some laminae of shale; sandstone appears to be quartzitic; sugary in texture.

APPENDIX 2: Reference Section for the Pikeville Formation

Diamond Drill Hole No. 1, Dorton Quadrangle, Carter coordinate location 12-J-84, 650 FSL X 2,900 FEL, Elev. 2,836 ft., T.D. 1,704, Drilled 6/27/62–7/31/62, Logged by C. L. Rice and E. C. Jenkins. Only a portion of the core description is recorded below.

Depth to Bottom (ft.)	*Thickness of Unit (ft.)*	*Description*
Kendrick Shale Member of Hyden Formation (part)		
851.8	38.3	Shale, silty, to siltstone with thin lenses of very fine-grained sandstone; lower part fossiliferous, dark-gray to medium-dark-gray.
Pikeville Formation		
852.1	0.3	**Williamson coal.**
868.25	16.65	Shale, grading down to sandstone in two or three sets.
914.5	45.75	Sandstone, light-gray to medium-light-gray, very fine-grained to fine-grained; upper 6 feet very calcareous.
917.5	3.0	Claystone, underclay with no coal; disconformable upper surface; sandy in lower parts.
931.5	14.0	Sandstone, fine-grained, crossbedded; grain size increased downward; weakly calcareous throughout.
933.9	2.4	Shale, medium-dark-gray, interlaminated with claystone, siltstone, and very fine-grained sandstone.
936.4	2.5	**Upper Elkhorn No. 3 rider coal**; includes coal, bony coal, and carbonaceous shale.
940.75	4.35	Shale: very silty underclay with plant remains; lower part interlaminated with sandstone.
955.6	14.85	Sandstone, medium- to fine-grained; finer at top; poorly indurated.
956.0	0.4	Shale.
958.65	2.65	**Upper Elkhorn No. 3 coal.**
959.1	0.45	Underclay, dark-gray, silty, with much coaly material and plant fragments.
960.8	1.7	Shale, medium-dark-gray to medium-gray, banded, interlaminated with claystone, siltstone, and very fine-grained sandstone.
962.9	2.1	Sandstone, very fine-grained, microcrossbedded.
966.8	3.9	Shale, dark-gray to medium-gray, interlaminated with siltstone and very fine-grained sandstone; lenses of siderite throughout with concentration at the bottom of the unit; animal borings.
982.35	15.55	Sandstone, very fine-grained; animal borings in upper part; siderite pebbles and one granite pebble found; lower part calcareous.
988.3	5.95	Sandstone and shale; sandstone very fine-grained; some microcrossbedded sandstone lenses; irregular bedding; worm borings(?).
995.1	6.8	Shale, grayish-black to dark-gray to medium-dark-gray; silty claystone to carbonaceous shale; siderite bands and nodules.
995.9	0.8	**Upper Elkhorn No. 3 coal** (leader?).

Depth to Bottom (ft.)	*Thickness of Unit (ft.)*	*Description*
1,006.00	10.1	Sandstone and siltstone; upper part seatrock; very fine-grained to silty at bottom of unit; siderite nodules common.
1,060.05	54.05	Sandstone, very fine- to medium-grained; gradational to unit above; crossbedded.
1,062.55	2.5	Shale, medium-dark-gray; silty claystone with few bands of siderite; carbonaceous.
1,063.25	0.7	**Upper Elkhorn No. 2 coal** (upper bed).
1,068.3	5.05	Seatrock, silty, grading down into very fine-grained sandstone.
1,071.0	2.7	Sandstone, very fine- to fine-grained, with coaly laminae.
1,079.0	8.0	Shale and claystone; shale sandy to silty.
1,081.2	2.2	**Upper Elkhorn No. 2 coal** (main bed).
1,084.0	2.8	Seatrock, sandy.
1,086.8	2.8	Shale, silty claystone grading down to siltstone and sandstone.
1,091.3	4.5	Sandstone, fine- to very fine-grained, crossbedded.
1,100.1	8.8	Shale, medium-dark-gray to medium-gray, interlaminated with sandstone, siltstone, and silty claystone.
1,100.3	0.2	**Upper Elkhorn No. 2** (lower bed).
1,102.9	2.6	Seatrock, claystone grading down to sandstone, rooted.
1,160.3	57.4	Sandstone, fine- to coarse-grained, crossbedded, weakly calcareous.
1,168.15	7.05	Sandstone, very fine-grained, grading down to claystone, with plant impressions, few siderite bands.
1,172.95	4.8	**Upper Elkhorn No. 1 coal.**
1,181.0	8.05	Seatrock, bony coal to sandstone.
1,196.3	15.3	Sandstone, fine- to very fine-grained, crossbedded.
1,203.1	6.8	Shale, dark-gray to medium-dark-gray, interlaminated with sandstone and siltstone.
1,205.6	2.5	Sandstone, fine-grained, microcrossbedded.
1,207.1	1.5	Shale, dark-gray to medium-dark-gray.
1,228.0	20.9	Sandstone, fine- to medium-grained, crossbedded, weakly calcareous.
1,232.2	4.2	Coal (lost in drilling) and seatrock; claystone grades down to siltstone.
1,279.1	46.9	Sandstone, coarse- to fine-grained, crossbedded, weakly calcareous.
1,314.1	35.0	Shale, dark-gray to medium-dark-gray, claystone to silty claystone, with few interbeds of siltstone or sandstone; limestone concretion near base.
1,316.1	2.0	Shale, black, carbonaceous, silty, with *Lingula.*
1,316.4	0.3	**Pond Creek coal zone** (rider coal).
1,318.5	2.1	Claystone, underclay, with coaly material and siderite nodules.
1,323.7	5.2	Sandstone, fine- to very fine-grained, crossbedded.
1,324.0	0.3	Bony roof shale, grayish-black to dark-gray, silty.
1,325.0	1.0	**Pond Creek coal zone** (rider coal).

Depth to Bottom (ft.)	*Thickness of Unit (ft.)*	*Description*
1,339.34	14.34	Claystone and mudstone; upper part underclay; with siderite nodules and beds.
1,352.95	13.64	Shale and claystone; shale silty; darker near base, carbonaceous, with thin coal streaks near base.
1,355.98	3.0	**Pond Creek coal** (main bed).
1,358.5	2.52	Claystone and shale, carbonaceous; coal laminae near top; siderite nodules and beds in bottom half; bedding indistinct.
1,365.39	6.89	Sandstone and shale, interbedded; shale, medium-dark-gray; sandstone, fine- and very fine-grained, crossbedded.
1,366.73	1.34	**Pond Creek coal zone** (leader bed).
1,392.9	29.27	Sandstone and shale, interbedded, with minor coal.
1,426.03	33.44	Sandstone, with fining-upward grain size from very coarse to medium.
Betsie Shale Member of the Pikeville Formation		
1,431.16	5.13	Sandstone, fine- to very fine-grained, very uniform; bedding planes not distinguishable.
1,537.71	106.55	Sandstone, siltstone, and shale, interbedded; with calcareous zones.
1,558.57	20.83	Shale, silty, very uniform, dark-gray to grayish-black; few siderite bands and nodules.
Grundy Formation		
1,559.34	0.77	**Clintwood(?) coal**; bony at top.
1,561.55	2.21	Claystone, sandy near base, with abundant plant fragments.

APPENDIX 3: Reference Section for the Hyden Formation

Daniel Boone Series Drill Hole R-9, Creekville Quadrangle, Carter coordinate location 21-G-71, 4,515 FEL X 5,410 FSL, Elev. 1,556 ft., T.D. 1987.7 ft. Only a portion of the core description is recorded below.

Depth to Bottom (ft.)	*Thickness of Unit (ft.)*	*Description*
Magoffin Member of Four Corners Formation (part)		
112.5	1.1	Siltstone, with limestone nodules, abundant marine fossils.
113.7	1.2	Shale, dark-gray, with abundant rippled sandstone laminae.
Hyden Formation		
143.6	29.9	Sandstone with some shale; sandstone rippled; shale sandy; conglomeratic at base.
159.6	16.0	Shale with some sandstone; sandstone laminae; burrowed; siderite nodules.
177.0	17.1	Sandstone with some shale, fine-grained; upper part burrowed; shale interbeds near middle; conglomeratic zones in lower half.
178.7	1.7	**Hamlin(?) coal.**
196.7	18.0	Shale and siltstone, rooted in upper part; burrowed; some sandstone laminae; siderite bands.
201.0	4.3	Sandstone, fine-grained, rooted, rippled, with siderite bands, some shale laminae.
209.9	8.9	Shale with some sandstone, fine-grained, burrowed, with siderite bands.
238.1	28.2	Shale with sandstone and siltstone; rooted at several levels; coal stringers; *Stigmaria* in upper part.
277.2	39.1	Sandstone, fine- to medium-grained, with shale laminae; crossbedded; sparse coal bands.
284.3	7.1	Shale, dark-gray to black, with sandstone laminae, sparse coal stringers; rooted; *Stigmaria* in upper part.
296.6	12.3	Shale and sandstone, interbedded; some thin coal stringers, siderite bands; gradational lower contact.
308.8	12.2	Shale with some siltstone, black to gray, silty, rooted throughout, siderite nodules.
324.3	15.5	Siltstone and shale, interbedded; lower part with burrows and *Lingula*.
324.4	0.1	**Fire Clay or Whitesburg coal.**
326.0	1.6	Shale, black and underclay, gray, rooted.
328.7	2.7	Siltstone, rooted.
364.4	35.7	Sandstone, fine- to medium-grained, with shale laminae; rippled and crossbedded; sharp lower contact; sparse coal clasts.
365.6	1.2	Shale, carbonaceous in part; rare coal bands.
365.7	0.1	**Whitesburg coal** (upper bed).
369.1	3.4	Shale, silty, rooted.
377.2	8.1	Siltstone with sandstone and shale; sandstone at top, shale at bottom; rippled, with siderite bands, sparse coal stringers.

Depth to Bottom (ft.)	*Thickness of Unit (ft.)*	*Description*
378.2	1.0	**Whitesburg coal** (lower bed).
379.5	1.3	Underclay, rooted.
383.3	3.8	Shale, carbonaceous in part; with sandstone laminae; rooted; siderite nodules.
417.4	34.1	Sandstone, fine-grained; calcareous in part; rippled to crossbedded; abundant coal clasts; some siderite pebbles; irregular lower contact.
Kendrick Shale Member of the Hyden Formation		
459.1	41.7	Shale with siltstone and sandstone, burrowed, with siderite nodules, coal clasts, some rooting.
Pikeville Formation		
459.5	0.4	**Amburgy coal**, and bone coal.
460.5	1.0	Shale, clayey, rooted.

APPENDIX 4:
Reference Section for the Four Corners Formation

U.S. Geological Survey Diamond Drill Hole No. 11, Vicco Quadrangle, Carter coordinate location 4–H–78, 4,500 FWL X 3,050 FNL, Elev. 2,170 ft., T.D. 1,700 ft., Drilled 12/31/62–2/7/63, Logged by C. L. Rice and V. Trent. Only a portion of the core description is recorded below.

Depth to Bottom (ft.)	*Thickness of Unit (ft.)*	*Description*
Stoney Fork Member of the Princess Formation (part)		
194.3	39.8	Shale, silty, with sandstone laminae, siderite concretions, marine invertebrate fossils.
Four Corners Formation		
201.5	7.2	**Hindman (Hazard No. 9) coal.**
203.0	1.5	Seatrock, silty clay to siltstone, *Stigmaria.*
253.0	50.0	Sandstone, fine– to medium–grained, coal spar and plant material.
262.0	9.0	Sandstone and shale, interbedded; sandier toward top.
271.3	9.3	Bulan shale, silty, sideritic, with marine invertebrate fossils.
271.5	0.2	**Hazard No. 8$^1/_2$ coal.**
273.5	2.0	Siltstone with *Stigmaria.*
285.0	11.5	Sandstone, fine– to medium–grained, coarsening–downward.
287.0	2.0	Siltstone, fossiliferous (invertebrates?).
346.5	59.5	Sandstone, fine– to medium–grained; lower part with few shale pebbles and slightly calcareous.
346.8	0.3	Claystone.
347.8	1.0	**Hazard No. 8 coal** (upper bed).
355.4	7.6	Claystone with coaly stringers, grading down to fossiliferous (invertebrates?), silty claystone.
355.5	0.1	Coal stringer.
360.6	5.1	Claystone, silty; coaly near base.
364.3	3.7	**Hazard No. 8 coal** and shale interbedded.
374.2	9.9	Siltstone and sandstone, interbedded, with coaly material.
443.2	9.0	Sandstone, medium– to very fine–grained, with scattered shale and siderite pebbles and coal spar.
446.0	2.8	**Hazard No. 7 coal.**
446.8	0.8	Underclay with coaly material.
467.3	20.5	Sandstone and siltstone, interbedded, with thin shale partings; calcareous, sideritic, with coaly material, possible shell material, burrows (Cowcreek shale?).
467.95	0.65	**Hazard rider coal** and underclay parting; parting 0.3 feet thick.
470.5	2.55	Underclay, upper part silty; plant remains, sideritic.
481.1	10.6	Sandstone and siltstone, interlaminated, calcareous, plant fossils.
481.5	0.4	**Hazard coal** (an upper bed).

Depth to Bottom (ft.)	*Thickness of Unit (ft.)*	*Description*
516.2	34.7	Claystone, shale, and siltstone, interbedded; carbonaceous, locally limy, with coaly plant remains.
516.9	0.7	**Hazard coal** (thin main bed?).
518.9	2.0	Seatrock, claystone.
611.8	92.9	Sandstone, fine– to medium–grained, grades down to locally coarse–grained; few interbeds of siltstone or silty claystone; plant and coal debris.
614.3	2.5	Claystone and siltstone, coaly plant material.
616.0	1.7	**Haddix(?) coal** with shale partings.
618.0	2.0	Underclay, coaly.
Magoffin Member of the Four Corners Formation		
681.4	63.4	Sandstone and siltstone, interbedded,w ith scattered shale partings; locally crossbedded; worm burrows(?), siderite.
745.0	63.6	Siltstone, sandy in part, sandstone laminae, calcareous, locally graded bedding, limy zones.
779.4	34.4	Siltstone, with abundant marine invertebrate fossils, calcareous, sideritic, plant material.
Hyden Formation		
780.6	1.2	**Copland coal** with 0.5–foot black–shale parting.
782.6	2.0	Seatrock, siltstone.

APPENDIX 5:
Reference Section for the Lower Part of the Princess Formation

U.S. Geological Survey Diamond Drill Hole No. 5, Hazard South Quadrangle, Carter coordinate location 20–I–76, 560 FWL X 2,440 FNL, Elev. 1,990 ft., T.D. 495 ft., Drilled 10/16/62–11/6/62, Logged by W. F. Outerbridge and W. P. Puffett. Only a portion of the core description is recorded below.

Depth to Bottom (ft.)	*Thickness of Unit (ft.)*	*Description*
Princess Formation (lower part)		
71.65	60.85	Sandstone, medium– to coarse–grained, with siderite nodules, some coaly debris.
73.95	2.3	**Skyline coal** (middle bed).
76.3	2.35	Siltstone and clay, rooted.
101.8	25.5	Sandstone, fine– to medium–grained, crossbedded, with some claystone beds and coal debris.
102.8	1.0	**Skyline coal** (lower bed).
105.0	2.2	Siltstone, fire clay, grading to fine sandstone, *Stigmaria*.
141.35	36.35	Sandstone, fine– to medium–grained, becoming coarser downward; massive to thin bedded, locally crossbedded.
147.0	5.65	Shale, silty, grading downward to claystone, shale, siderite; becoming more carbonaceous downward.
147.5	0.5	**Skyline coal** (lower bed).
149.6	2.1	Underclay, claystone, swells.
150.1	0.5	**Skyline coal** (lower bed).
153.0	2.9	Claystone, underclay, very carbonaceous, with *Stigmaria*.
195.0	42.0	Sandstone, very fine– to medium–grained, locally rooted, crossbedded, with coal debris.
195.3	0.3	Clay, plastic.
197.0	1.7	Sandstone, medium–grained, with coal debris.
197.8	0.8	Clay, plastic.
265.6	67.8	Sandstone, fine– to medium–grained, some crossbedding, some laminae of sandy siltstone, locally abundant coal debris, sharp basal contact.
266.1	0.5	Shale, silty, coaly plant debris and impressions.
267.5	1.4	Siltstone, calcareous; many irregular laminae of mudstone.
274.5	7.0	Sandstone, fine– to medium–grained; shale pebbles in places.
274.6	0.1	Coal.
277.6	3.0	Sandstone and claystone, interbedded, with coaly laminae.
312.3	34.7	Sandstone, fine– to medium–grained; upper part contains thin beds and laminae of siltstone and silty shale.
313.2	0.9	Conglomerate, medium– to coarse–grained sandstone matrix with sideritic claystone pebbles and coaly debris.

Depth to Bottom (ft.)	*Thickness of Unit (ft.)*	*Description*
Stoney Fork Member of the Princess Formation		
331.0	17.8	Sandstone, fine– to medium–grained, interbeds of claystone and siltstone.
338.7	7.7	Shale, locally silty.
345.5	6.8	Claystone, thinly laminated, with siderite nodules, *Lingula* at base.
Four Corners Formation		
350.9	5.4	**Hindman (Hazard No. 9) coal.**
353.0	2.1	Siltstone and claystone, underclay; locally grades to sandstone; silicic; rootlets locally disrupt bedding.

APPENDIX 6:
Reference Section for the Upper Part of the Princess Formation

Kentucky Geological Survey Diamond Drill Hole No. R–2, Burnaugh Quadrangle, Carter coordinate location 6–V–84, 3,850 FSL X 4,100 FEL, Elev. 675 ft., T.D. 705.7 ft., Drilled 10/11/77–10/24/77, strata identified and described by Richard Sergeant (1979). Only a portion of the core description is recorded below.

Depth to Bottom (ft.)	*Thickness of Unit (ft.)*	*Description*
Conemaugh Formation (lower part)		
274	9.6	Siltstone, medium–dark–gray at top, maroon and yellow mottling toward base; calcareous stringers.
Princess Formation (upper part)		
284	10	Shale, calcareous near top; contains sand stringers, clay, and siderite (**Princess No. 9** horizon).
364	80	Sandstone, shaly near middle, rippled, crossbedded, coaly.
366	2	Shale and limestone; limestone dense and silty.
442	76	Sandstone, rippled, crossbedded, shaly.
449	7	Clay shale, rooted, sideritic.
454	5	Clay, rooted, in part semiflint or silty (**Princess No. 7** horizon).
466	12	Sandstone, with thin beds of shale, rippled.
486	20	Shale and silty shale with thin sandstone beds.
488	2	**Princess No. 6(?)** (upper bed?).
502	14	Shale, partly sandy, clayey, carbonaceous.
505	3	**Princess No. 6 coal,** with shale parting.
508	3	Underclay, rooted, and siltstone.
523	15	Sandstone, with coal spars; lower part shaly.
526	3	**Princess No. 5b coal** with two shale partings.
542	16	Shale and sandy shale, siderite bands.
546	4	Clay and coal; coal 4 inches; underclay rooted, flint to semiflint.
600	54	Shale and silty shale, partly sandy, clayey, sideritic, carbonaceous.
601	1	**Princess No. 5 coal.**
604	3	Shale, carbonaceous, coaly.