Kentucky Geological Survey
James C. Cobb, State Geologist and Director
University of Kentucky, Lexington

Geology of the Fire Clay Coal in Part of the Eastern Kentucky Coal Field

Stephen F. Greb, John K. Hiett, Gerald A. Weisenfluh, Robert E. Andrews, and Richard E. Sergeant

Report of Investigations 2

Series XII,1999

CONTENTS

Figures

Acknowledgments

We would like to thank the many people from the mining community who gave us access to their property, provided data, and shared their knowledge of the Fire Clay coal. Some of the data used in the study were collected under a grant from the U.S. Geological Survey, National Coal Resource Data System. We would also like to thank James C. Cobb, Donald R. Chesnut Jr., Garland R. Dever Jr., and David C. Harris for technical discussions and reviews; Margaret Luther Smath for editing; Terry Hounshell and Collie Rulo for redrafting many of the figures; and Shirley Davis Dawson for word processing.

For further information contact:
Manager, Office of Communications and Technology Transfer
Kentucky Geological Survey
228 Mining and Mineral Resources Building
University of Kentucky
Lexington, KY 40506-0107

ISSN 0075-5591

Mission Statement

The Kentucky Geological Survey at the University of Kentucky is a State-mandated organization whose mission is the collection, preservation, and dissemination of information about mineral and water resources and the geology of the Commonwealth. KGS has conducted research on the geology and mineral resources of Kentucky for more than 150 years, and has developed extensive public databases for oil and natural gas, coal, water, and industrial minerals that are used by thousands of citizens each year. The Survey's efforts have resulted in topographic and geologic map coverage for Kentucky that has not been matched by any other state in the Nation.

One of the major goals of the Kentucky Geological Survey is to make the results of basic and applied research easily accessible to the public. This is accomplished through the publication of both technical and nontechnical reports and maps, as well as providing information through open-file reports and public databases.

Geology of the Fire Clay Coal in Part of the Eastern Kentucky Coal Field

Stephen F. Greb[1], John K. Hiett[2], Gerald A. Weisenfluh[1], Robert E. Andrews[1], and Richard E. Sergeant[1]

ABSTRACT

Coal beds mined in Kentucky often are not laterally continuous in thickness, quality, or roof condition. Regional and local variation is common. Because thickness, quality, and roof conditions are the result of geologic processes that were active when the coal was deposited as a peat swamp, a better understanding of the relationships between geology and major coal resources can aid in identifying geologic trends, which can be extrapolated beyond areas of present mining. The focus of this study is on the Fire Clay (Hazard No. 4) coal, one of the leading producers in the Eastern Kentucky Coal Field with 20 million short tons of annual production. More than 3,800 thickness measurements, highwall and outcrop descriptions, borehole and geophysical-log descriptions, and proximate analyses from 97 localities were used in conjunction with previous palynologic and petrographic studies to investigate the geology of the Fire Clay coal in a 15-quadrangle area of the Eastern Kentucky Coal Field.

The Fire Clay coal is commonly separated into two distinct layers or benches by a flint-clay and shale parting called the “jackrock parting” by miners. Maps of coal benches above and below the parting show that the lower bench is limited in extent and variable in thickness. In contrast, the coal above the jackrock parting occurs across most of the study area and is characterized by rectangular patterns of coal thickness.

Multiple coal benches resulted from the accumulation of multiple peat deposits, each with different characteristics. The lower bench of the coal was deposited when a peat accumulated above an irregular topographic surface. Because the peat was being deposited at or below the water table, it was often flooded by sediment from lateral sources, resulting in moderate to locally high ash yields. This peat was drowned and then covered by volcanic ash, which formed the flint clay in the jackrock parting. The upper coal bench accumulated above the ash deposit, after irregularities in the topography had been filled. The relatively flat surface allowed the swamps to spread outward and dome upward above the water table in some areas. Doming of the peat resulted in areas of coal with generally low ash yields and sulfur contents. Sharp, angular changes in the upper coal bench are inferred to represent subtle fault influence on upper peat accumulation.

The upper peat was buried by a series of river channels, which were bounded by levees, flood plains, and elongate bays. Several of the rivers eroded through the Fire Clay peats, forming cutouts in the coal. These cutouts often follow orientations similar to the angular trends of coal thinning, suggesting a relationship that can be extended beyond the present limits of mining. Also, additional peat swamps accumulated above the levees and flood plains bounding the channels. Along the thinning margins of these deposits, the peats came near or merged with the top of the Fire Clay coal, resulting in local areas of increased coal thickness.

Rider coal benches exhibit high to moderate sulfur contents and ash yields, so that although they may increase coal thickness, total coal quality generally decreases where riders combine with the Fire Clay coal.

[1] Kentucky Geological Survey, University of Kentucky
[2] Center for Applied Energy Research, University of Kentucky

INTRODUCTION

The development of a coal mine is not without risks from problems such as decreased coal thickness, decreased coal quality, or poor roof conditions. These factors can reduce the productivity of a mine, and in some cases can cause the mine to be abandoned, which means a loss of capital and decreased resources. Coal thickness, quality, and roof strata are the result of geologic processes that were active during deposition of the peat that formed the coal and the sediment that buried the peat. Understanding lateral variation in these processes can aid in recognizing trends in coal thickness, coal quality, and roof conditions. Often, these trends can be extrapolated beyond present mining.

Purpose

The purpose of this investigation is to identify the relationships between geology and an important eastern Kentucky coal resource, the Fire Clay coal bed (also known as the Hazard No. 4 or Jackrock). Although major coal beds cover large areas in eastern Kentucky, they are mostly concealed from close observation by enclosing strata. Coals can be observed only in outcrops, roadcuts, mines, and drill holes. The important characteristics of a coal bed must often be inferred from geologic trends recorded at other locations and extrapolated into the areas where the coal is concealed. In this study, observations and measurements of coal thickness and enclosing rock strata were used to develop a model of the formation of the Fire Clay coal. This model can help predict important coal characteristics where the bed is not exposed.

Fire Clay Coal Project

This is one of a series of three publications concerning the Fire Clay coal. The first is a detailed analysis of the coal quality and trace elements in the Fire Clay coal in an eight-quadrangle area of the Eastern Kentucky Coal Field (Eble and others, 1999). This second publication is a summary of the geology of the Fire Clay coal, and especially deals with coal thickness and roof geology trends in a 15-quadrangle study area that includes the eight-quadrangle study area of the first report. The third is a study of the available Fire Clay coal resources in the same 15-quadrangle study area as the second report (Greb and others, 1999b). These three studies were coordinated in order to determine factors important to future coal development.

The large amount of data collected for this study is not possible or practical for all such studies, but allows for detailed, regional examination of subtle coal characteristics that might not be noticed with fewer data. The types of relationships found by analyzing this large database provide clues to trends in coal thickness, coal quality, and roof-rock associations that can be extrapolated beyond areas of present mining. These trends may be applicable to other eastern Kentucky coals in areas where fewer data are available.

Study Area

The study area is a 15-quadrangle area that covers parts of Breathitt, Knott, Letcher, Leslie, and Perry Counties in the Southwestern District of the Eastern Kentucky Coal Field (Fig. 1). It has a long history of mining, is still actively mined, and has numerous roadcut and abandoned highwall exposures where the coal and enclosing strata can be observed. The coal has been mined in the study area since 1911, and towns such as Hazard, Vicco (named for Virginia Iron, Coke, and Coal Company), and Hyden owe much of their growth to development of the seam. The town of Fourseam owes its name to the Hazard No. 4 coal. Production of the coal in the area of study accounts for 43 percent of all Fire Clay coal production, according to the Kentucky Department of Mines and Minerals. Therefore, the study area is representative of this important coal seam.

Regional Setting

The Fire Clay coal is Middle Pennsylvanian in age. Stratigraphically, it is located between the Kendrick Shale Member and the Magoffin Member, in the Hyden Formation of the Breathitt Group (previously the Breathitt Formation; see Chesnut, 1992) (Fig. 2). The Fire Clay coal contains a regionally extensive flint-clay and shale parting, locally known as the jackrock. The term "jackrock" stems from the use of jacks to support equipment above the flint clay during underground mining. The distinctive hard, brown to gray flint clay aids in correlation of this seam across the central Appalachian Basin. The Fire Clay is equivalent to the Wallins Creek coal of the Upper Cumberland District south of Pine Mountain, the Hernshaw coal of West Virginia, and the Windrock coal of Tennessee.

The Fire Clay is usually the largest or second largest producer of coal in eastern Kentucky, with annual production of approximately 20 million short tons (Mt). The coal is high-volatile A bituminous, generally low in ash content (mean, 10 percent), and generally low in sulfur content (mean, 1 percent). Regional resource analysis of the coal shows that it is continuous across most of the coal field, although it is unevenly distributed (Brant and others, 1983a–d). In general, the coal is thickest and most continuous to the southeast toward Pine Mountain, and thins northwestward as a series of elongate pods separated by areas of thin or absent coal (Fig. 3). This pattern is fairly typical of major coal beds in the Eastern Kentucky Coal Field (Cobb and Chesnut, 1989).

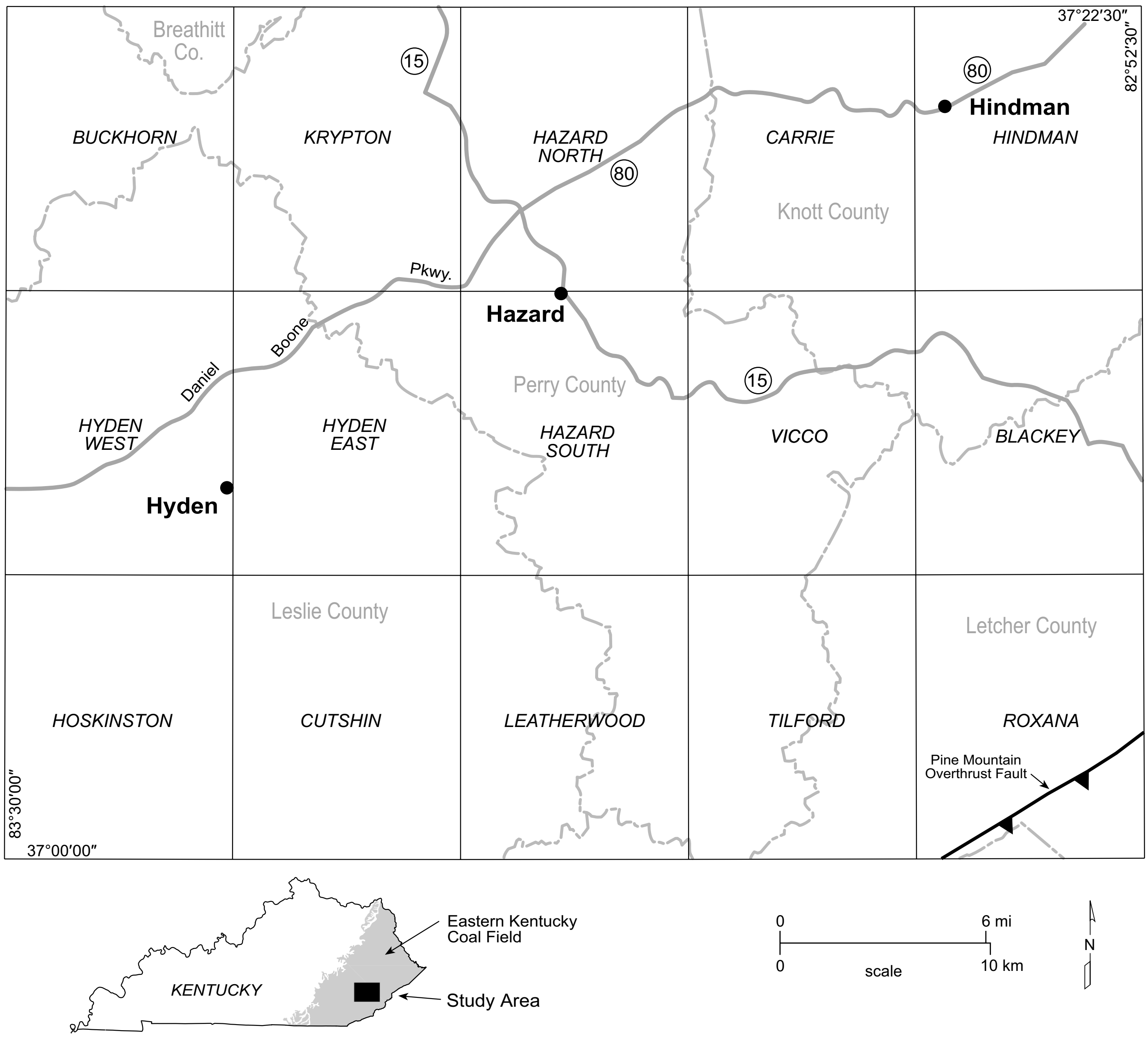

Figure 1. Location of the study area.

Previous Investigations

Resource Studies. Because the Fire Clay coal has a distinctive parting and is regionally widespread, it was mapped across the coal field during the U.S. Geological Survey–Kentucky Geological Survey Geologic Mapping Program (Puffett, 1964, 1965a, b; Seiders, 1964, 1965a, b; Danilchik and Lewis, 1965; Mixon, 1965; Prostka, 1965; Prostka and Seiders, 1968; Danilchik, 1976; Maughan, 1976; Waldrop, 1976; Ping, 1977; Lewis, 1978; Taylor, 1978). Because of its economic significance, it has also been the subject of numerous coal-resource studies for eastern Kentucky (Huddle and others, 1963; Huddle and Englund, 1966; Smith and Brant, 1980; Brant, 1983a, b; Brant and others, 1983a–d). The estimated original Fire Clay coal resource for the study area is 1.9 billion short tons (Bt) (Brant and others, 1983b). This estimate has recently been revised to 1.7 Bt, based on data collected for this study; not all of that resource is available for mining, however (Greb and others, 1999b).

Controls on Coal Thickness. Previous studies have interpreted the depositional environments of the Fire Clay coal and enclosing strata in order to understand regional variations in coal thickness and quality. Haney and others (1983) compared the regional geometry of the Fire Clay coal to structural maps of the coal field

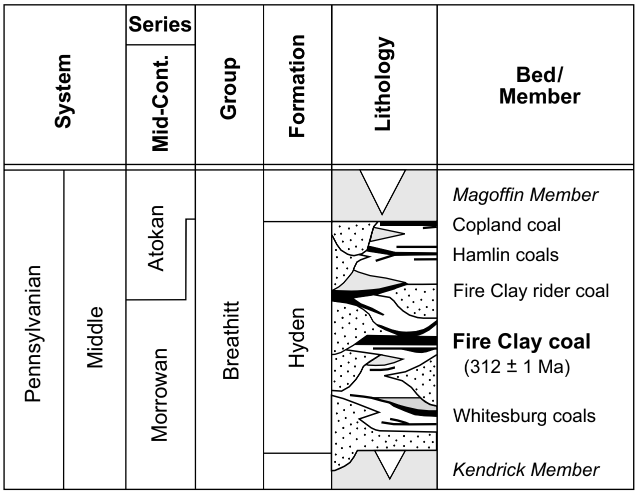

Figure 2. Stratigraphic position of the Fire Clay coal.

and inferred that coal distribution was controlled by the Eastern Kentucky Syncline, a broad downwarping of Pennsylvanian strata between Pine Mountain and the Irvine–Paint Creek Fault System (Fig. 3). They also noted that at least one elongate lobe of the Fire Clay coal was restricted to the downthrown margin of the Irvine–Paint Creek Fault.

Weisenfluh and Ferm (1991) noted rectangular patterns of Fire Clay coal thickness in mines in Harlan and Leslie Counties and also inferred structural controls on distribution of coal thickness. According to their interpretation, the peat that became the coal accumulated on upthrown fault blocks, while rivers carrying sediment truncated the peats and deposited sand on the downthrown margins of faults contemporaneously with peat accumulation. They also observed that rider coals commonly drape wedges of strata thought to have been deposited as crevasse splays, and that these crevasse splays are a common problem in underground mines. In other areas, some Fire Clay cutouts were not associated with lateral splitting, and therefore had post-depositional rather than contemporaneous origins (Andrews and others, 1994).

Fire Clay coal exposures in the study area have been described in several field-trip guidebooks (e.g., Horne and others, 1979; Cobb and others, 1981). Most guidebooks have noted scour fills and coarsening-upward strata above the coal, and have cited them as evidence that the original peat was a swamp on an exposed delta plain that was buried by sedimentation from interdistributary bays, distributary channels, and crevasse splays. Regionally, the elongate areas of thick coal shown in Figure 3 have been inferred to represent a well-drained swamp, bounded by areas of poorly drained swamps, salt marshes, and marine conditions, represented by thinner coal (Currens, 1981; Haney and others, 1983). Areas of poorly drained swamps, marshes, and marine influences generally are interpreted as resulting in thin coals of poor or more variable quality.

Multiple Swamp Origins. Recent analysis of the Fire Clay coal has shown that many depositional models were oversimplified, and that the coal is the result of peat accumulation in successive swamps (termed "mires"). Comparisons of data gathered from petrographic and palynologic studies of the coal with data from modern mires have shown that different layers of Fire Clay coal may have accumulated in different kinds of environments (Eble and others, 1999). Several studies (Eble and Grady, 1990; Andrews and others, 1994;

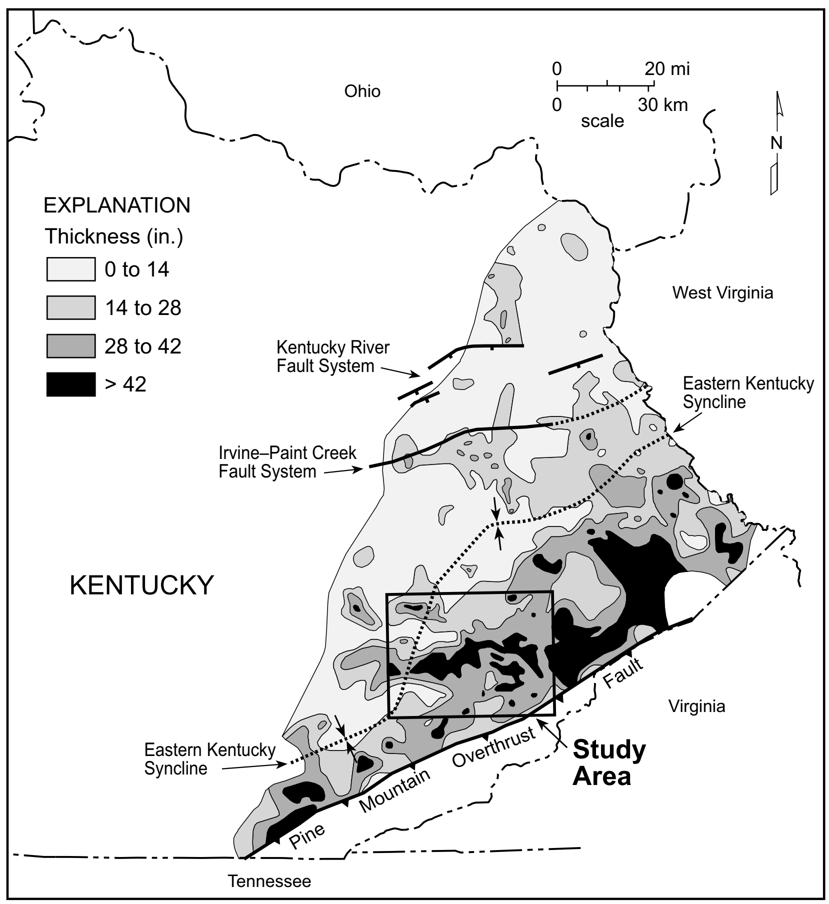

Figure 3. Thickness of the Fire Clay coal in the Eastern Kentucky Coal Field (after Brant, 1983a, b; Brant and others, 1983a–d). Locations of major structures after Haney and others (1983).

Eble and others, 1994) have shown that the coal below the jackrock parting was deposited as a planar mire; essentially, it was a type of peat that accumulated in low-lying areas, at or below the water table. Because topographic lows also attract sediments, the coal bench below the parting is generally high in ash yield and sulfur content.

In contrast, the coal bench above the parting has been interpreted as being deposited in one or more mires in which peat built up above the water table, resulting in domed mires. Because domed mires (also called ombrogenous mires) formed in topographically higher areas, inorganic sediments were prevented from washing into the peat. The process of peat accumulation in domed mires results in thick coal that is low in ash yield and sulfur content (Eble and others, 1989, 1994, 1999; Eble and Grady, 1990).

Jackrock Parting. Interpreting the coal as the result of successive mires was prompted by the obvious separation of the seam by the jackrock parting. The parting consists of flint clay and carbonaceous shale. The flint clay in the parting has been the subject of numerous investigations (Nelson, 1959; Seiders, 1965b; Huddle and Englund, 1966; Stevens, 1979; Chesnut, 1983; Lyons and others, 1992, 1994). The occurrence of sanidine phenocrysts, beta-quartz paramorphs, euhedral zircons, and iron-titanium minerals such as ilmenite and rutile indicates the parting was deposited as a volcanic ash fall that smothered the peat mire represented by the lower bench of Fire Clay coal (Bohor and Triplehorn, 1981; Chesnut, 1983; Lyons and others, 1992, 1994). Samples of sanidines from the flint-clay parting have been radiometrically dated across the coal field and in surrounding states (e.g., Hernshaw coal of West Virginia), and all tests indicate that the deposit is 311 million years old ± 1 million years (Lyons and others, 1992). This is the only radiometrically dated stratum in the upper Paleozoic rocks of the basin. As such, it is a natural datum for correlations because it represents a definitive time line. In addition, because modern ash falls tend to drape the existing topography on which they fall, an ancient ash fall should define the topography on which it was deposited—in this case, the peat mire represented by the lower bench of the Fire Clay coal. Therefore, the geometry and type of peat that formed the lower coal bench can be determined by using the flint clay as a datum.

DATA

Data used to study the Fire Clay coal in this study include (1) coal-thickness measurements from outcrop exposures, surface and underground mine pillars, and exploratory cores, (2) locations of rolls and cutouts derived from mine maps, and (3) information on roof-rock type and thickness derived from measured sections of surface-mine highwalls, descriptions of roofs in underground mines, surface outcrops, and geophysical logs from oil and gas wells. Data were obtained from both government and private sources. They were used to map total coal thickness and the thickness of individual benches. A comparison was made within and between benches of the coal to more accurately define components of thickness variability that might contribute to total coal-thickness variability.

More than 3,800 thickness point data from the 15-quadrangle area were used in this study (Fig. 4). An additional 200 point data on the Fire Clay coal roof and floor, which did not indicate coal thickness, were also used. Previous resource studies were conducted with data density only a small fraction of the density of this one (e.g., Brant and others, 1983a–d).

Two types of data were collected for the study. Outcrop data were digitized to generate maps and measure areas. Point data, such as thickness measurements, were entered into databases for use in plotting thickness maps. The Fire Clay outcrop was digitized from stable Mylar geologic base maps of the 15 quadrangles

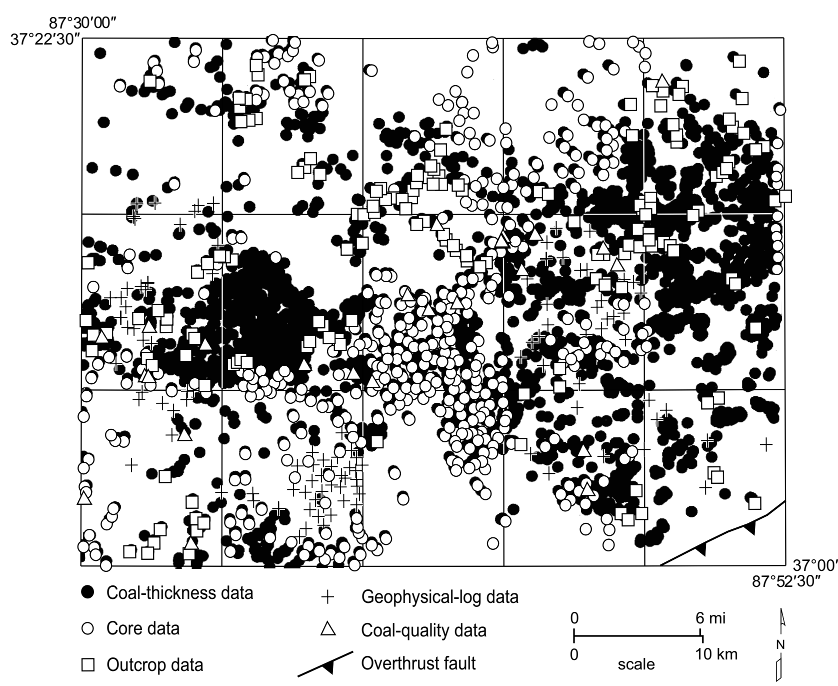

Figure 4. Locations of thickness data used in this study.

using the GSMAP software (version 7.2; Selner and Taylor, 1991). The inferred contacts of rolls, cutouts, and other areas of diminished coal thickness derived from notations on mine maps and interviews with mine personnel were also digitized.

Coal thicknesses were obtained from the Kentucky Coal Resources Information System (a database housed at the Kentucky Geological Survey), pillar measurements from mine maps, outcrop measurements along roads and mine highwalls, and from subsurface cores provided by mining companies. Coal-thickness data were divided into several fields in the database: total coal thickness; total parting thickness; thicknesses of the lower, upper, and rider coal benches; and thicknesses of partings in the lower and upper benches. The elevation at the base of the upper bench or top of the jackrock parting was also recorded.

In addition, cross sections were made parallel and perpendicular to the elongate pods of Fire Clay coal in the study area. These sections illustrate trends in roof rocks and coal thickness. The geologic trends of roof strata were mapped across the 15-quadrangle area using core data, outcrop exposures, and notations from mine maps. Exposures of roof strata above the coal were investigated to obtain details of the geology not possible from other sources.

Methods

Coal-thickness data were loaded into Geographical Resources Analysis Support System (GRASS), a geographic information system (GIS) developed primarily by the U.S. Army Corps of Engineers. GRASS is a raster-based GIS, which means that map data are rendered as matrices of equal-size grid cells (U.S. Army Corps of Engineers Construction and Engineering Research Laboratory, 1991). Maps stored in a GRASS database are oriented to the universal transverse Mercator coordinate system, based on the Clark 1866 spheroid. In order to use map information for calculations such as coal-resource tonnage (see Greb and others, 1999b), the original data (points, lines, or areas) were converted to raster data files. A grid-cell size of 10 m was chosen for resolution because the study covered a large region. A gridding algorithm was used to interpolate cell nodes between data points for thickness data. An algorithm called “s.surf.tps” was chosen because it uses a segmentation procedure that enhances the efficiency of mapping large data sets. Parameters are computed directly from the interpolation function so that the important relationships between these parameters are preserved (U.S. Army Corps of Engineers Construction and Engineering Research Laboratory, 1991).

Results

Structure

Figure 5 shows that the coal occurs lower than 900 ft above mean sea level (m.s.l.) in a broad area centered in the Krypton quadrangle, and rises to nearly 1,800 ft above m.s.l. along the flanks of Pine Mountain in the Roxana quadrangle. The rate of elevation change increases from northwest to southeast from less than 15 ft / mi to more than 50 ft / mi. The area of least elevation change corresponds to the axis of the Eastern Kentucky Syncline, a regionally extensive downwarping of strata that is a continuation of the Coalburg Syncline of West Virginia (Haney and others, 1983; Chesnut, 1992).

Total Coal Thickness

The Fire Clay coal is generally continuous across the study area. Based on data from 3,826 thickness points (Greb and others, 1999a), the coal ranges in thickness from 0 to 83 in., with a mean of 36.4 ± 10.6 in. and a mode of 36 in. The thickest coal occurs along an east–west trend through the middle row of quadrangles studied (Hyden West, Hyden East, Hazard South, Vicco, Blackey) (Fig. 6). In general, the coal is thickest to the east and thins westward from a line between the northwest corner of the Hindman quadrangle and the southeast corner of the Hoskinston quadrangle. At least two elongate pods of coal greater than 28 in. thick extend northwest from this line at an oblique angle. The coal is locally absent along the sharp, angular trends of coal thinning, and along a continuous cutout that trends through the middle row of quadrangles.

Total Parting Thickness

Figure 7 shows total parting thickness, which consists of partings in the upper coal bench, the jackrock parting, and partings in the lower coal bench. The total parting thickness varies from 0 to more than 90 in. across the study area, although of 1,917 measurements of parting thickness (Greb and others, 1999a), only 1 percent had thicknesses of more than 20 in., and 73 percent had total parting thicknesses of less than 5 in. (Fig. 7). In general, the thickest partings occur along the sharp trends of coal thinning (Fig. 6).

Thick partings also occur in the Leatherwood, Tilford, and Roxana quadrangles. This extra thickness is sometimes caused by the inclusion of additional partings between the upper bench of the Fire Clay coal and rider coals near the top of the Fire Clay coal. Where the rider is mined with the Fire Clay coal, intervening shales are added into the total parting. Adjacent to these areas, where the rider bench is not mined, the same shales occur, but because the rider is not mined, they are not counted as partings in the Fire Clay coal.

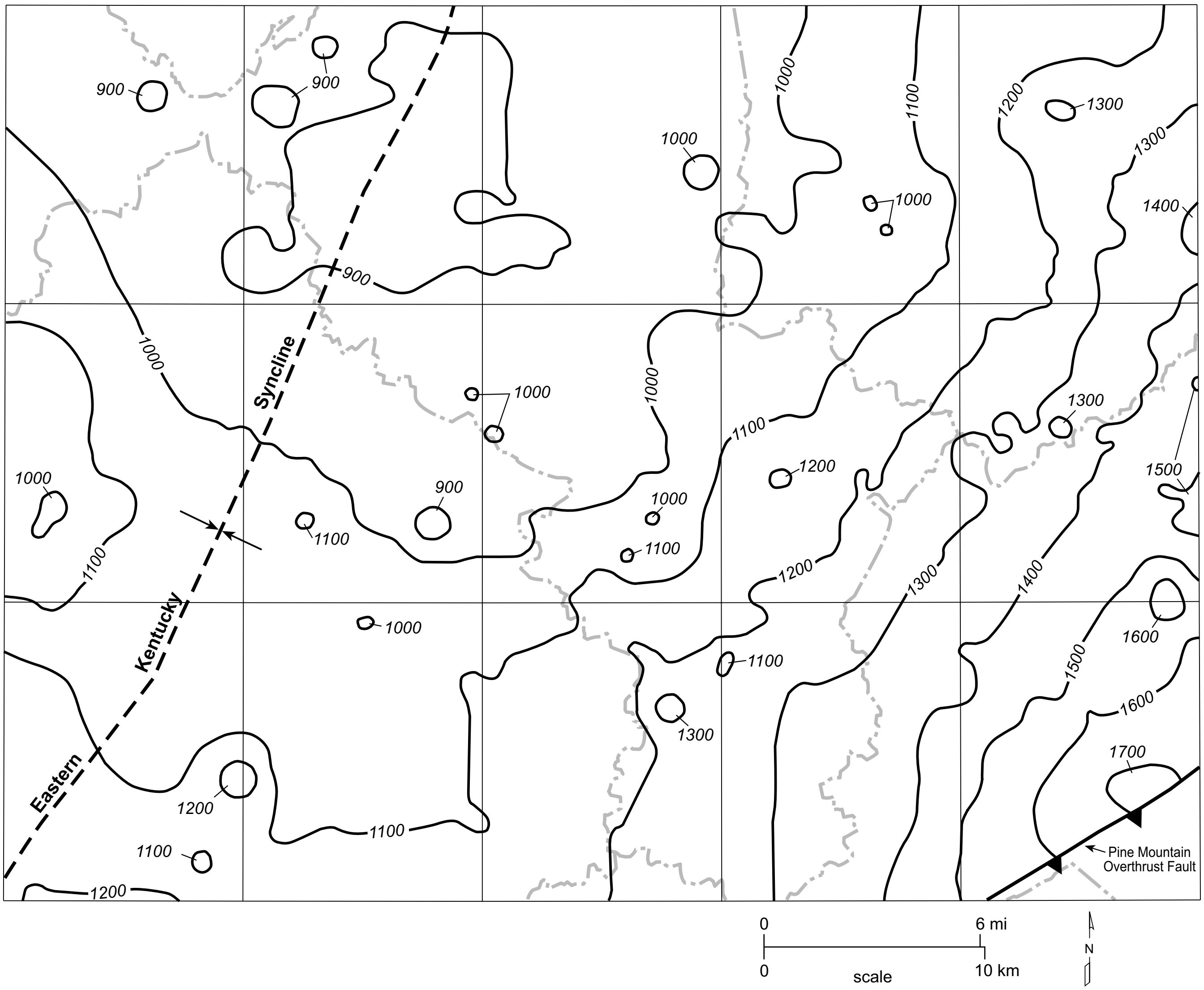

Figure 5. Structure on the base of the Fire Clay coal in the study area.

Lower-Bench Coal Thickness

Data from 1,550 locations (Greb and others, 1999a) show that the lower bench does not occur throughout the study area (Fig. 8). In general, the bench thickens to the east to a maximum of 37 in. in the Blackey quadrangle (Fig. 8). There are also numerous pockets of lower-bench coal as much as 24.5 in. thick in the Hazard South quadrangle (Fig. 8). The mean thickness of the lower bench is 8.0 ± 5.8 in. (Greb and others, 1999a), indicating significant variability. The lower coal bench occurs in a broadly sinuous pattern from the northeastern corner of the Roxana quadrangle westward toward the northwestern corner of the Buckhorn quadrangle (Fig. 8).

Lower-Bench Parting Thickness

Partings in the lower coal bench are common, and often not included in measurements of the coal. Thus, Figure 9 is a conservative estimate of parting distribution in the bench. Of 1,550 records in which partings were noted (Greb and others, 1999a), less than 1 percent of the partings were more than 5 in. thick. Sixty-five records with detailed analyses of the lower bench indicated a mean parting thickness of 4.31 ± 4.0 in., with a maximum of 15.0 in. along the southern edge of the sinuous trend of the lower coal bench in the Cutshin quadrangle. Partings are also common along the northeast–southwest trend of total coal thinning (compare to

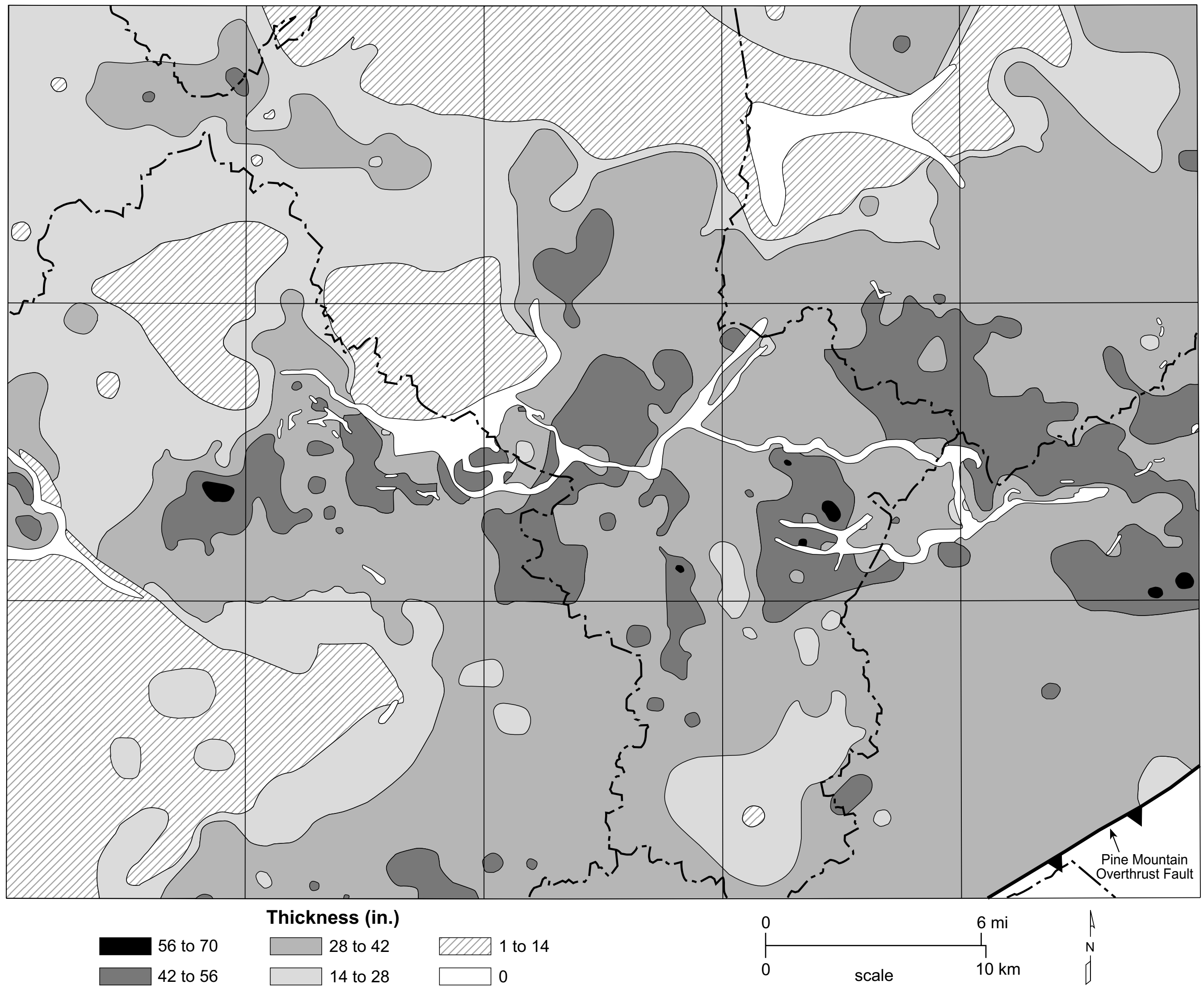

Figure 6. Total thickness of the Fire Clay coal in the study area.

Fig. 6), and in the outlier of the lower coal bench in the central part of the Tilford and Roxana quadrangles (Fig. 9). In the latter area, a leader coal splits and merges with the lower coal bench, resulting in thicker partings.

Jackrock Parting Thickness

The jackrock parting consists of all clastic material between the lower and upper bench of Fire Clay coal (Fig. 10). Generally, it consists of a gray silty shale or coaly shale overlain by the flint clay. Mean parting thickness in the study area, based on data from 1,446 locations (Greb and others, 1999a), is 4.2 ± 2.6 in. The flint-clay portion of the parting is laterally continuous. In any one mining area the thickness of the shale beneath the flint clay usually varies much more than the thickness of the flint clay itself. The flint clay is between 2 and 5 in. thick in the study area. Along the northern limit of the jackrock parting, the flint-clay portion of the parting is mainly restricted to the area where there is an underlying coal bench. Along the southern margin of the parting, the association of the flint clay and the lower coal bench is more variable; at several localities beyond the limit of the lower bench, the upper coal bench rests on the flint clay, and the flint clay occurs directly on seat rock, without there being a lower coal bench.

Upper-Bench Coal Thickness

Thickness patterns in the upper bench (Fig. 11) are similar to thickness patterns of the total coal (Fig. 6), because the upper bench comprises the bulk of the Fire

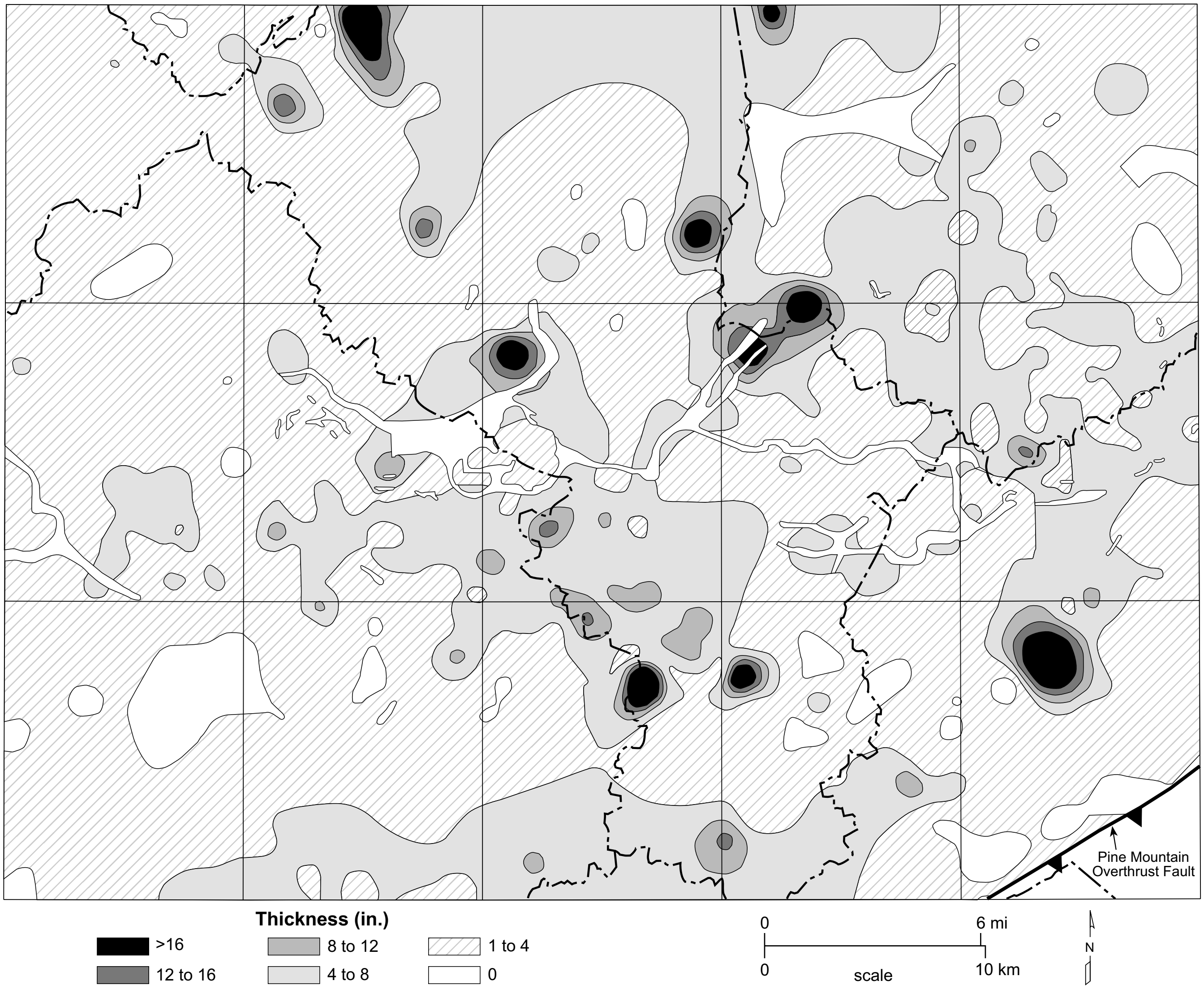

Figure 7. Total thickness of partings in the Fire Clay coal in the study area.

Clay coal across the study area. At many localities the upper coal bench is the only Fire Clay coal bench mined. Data from 2,212 locations (Greb and others, 1999a) indicate that the mean thickness of the upper coal bench is 29.4 ± 10.0 in., with a mode of 30.0 in. The maximum thickness of the bench is 68.0 in. The thickest coal occurs in the Hyden East and Hyden West quadrangles, and to the east in the Blackey quadrangle (Fig. 11). In contrast to the lower bench (Fig. 8), there are no widespread areas of absent upper bench coal. Instead, there are three distinct areas of thin coal that strike northwest–southeast along parallel trends. At least the northern edge of the coal in the Hyden East and Hyden West quadrangles changes rapidly northward from thick coal to carbonaceous shale. In other areas, the upper coal bench appears to thin by lateral cutout or gradual thinning. The three trends of northwest–southeast thinning terminate eastward along the northeast–southwest-oriented line of coal thinning shown on the total-coal-thickness map (Fig. 6). The upper coal bench is locally cut out along the northeast–southwest trend of thinning, along the cutout trend through the middle row of quadrangles, and along the southern margin of coal thinning in the Hyden East quadrangle. In many areas where the upper bench thins, data density decreases, but outcrops and the opinions of miners who have worked on the edge of these areas suggest rapid thinning and narrow cutouts are common. For the same reasons, local cutouts are possible in most of the areas where the coal is less than 28 in. thick.

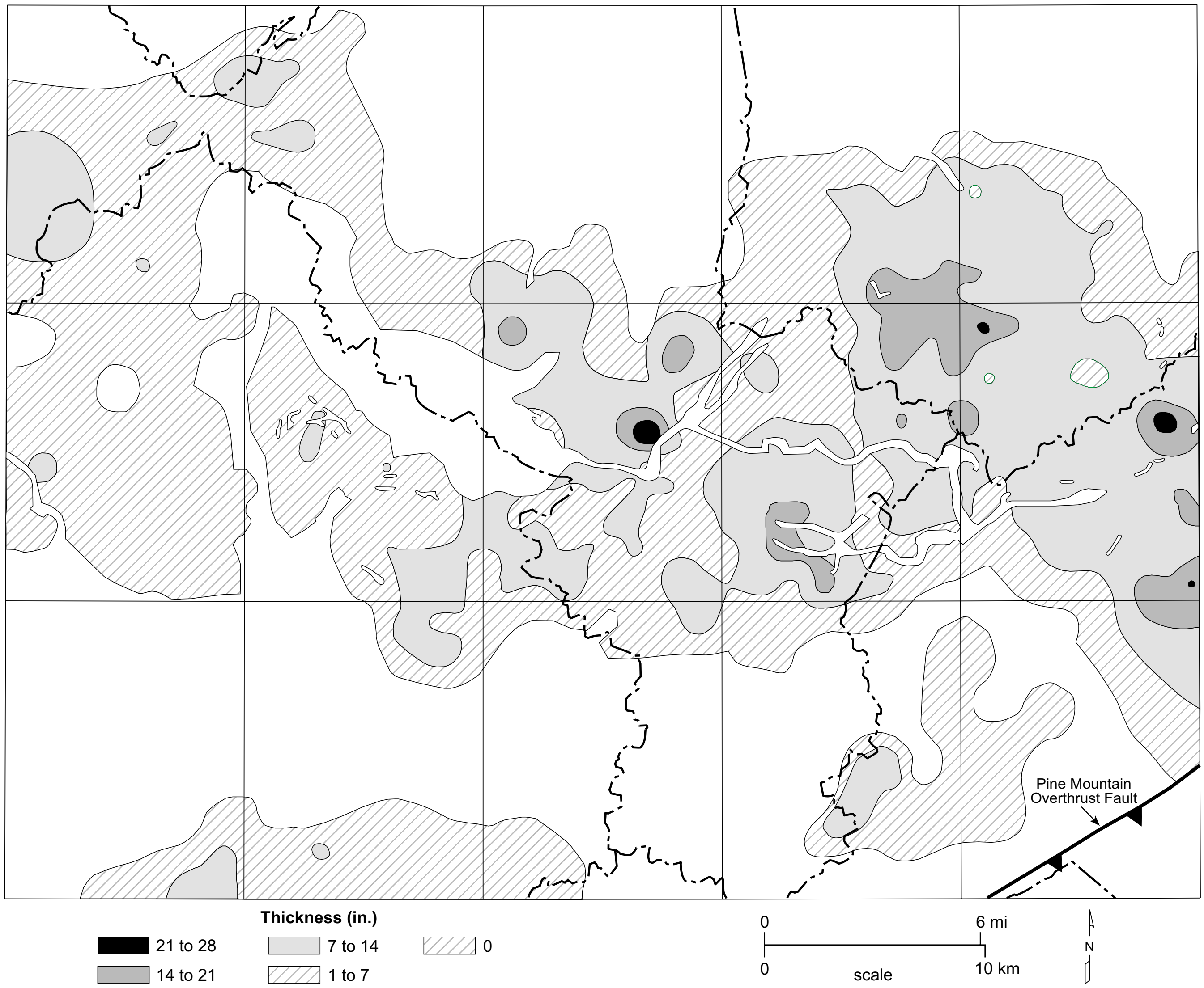

Figure 8. Thickness of the lower bench of the Fire Clay coal in the study area. The lower bench is defined as the coal beneath the jackrock parting.

Upper-Bench Parting Thickness

Figure 12 shows that the upper bench of the Fire Clay coal is mostly free of partings. Of 1,394 measurements (Greb and others, 1999a), only 106 denoted partings in the upper bench, and most partings occurred toward the top of the bench where the coal split, or where rider benches merged with the upper coal bench. Maximum parting thickness was 36 in., and was actually a parting between a rider coal and the top of the Fire Clay coal rather than a true parting in the upper coal bench itself. Partings are common along the northern edge of the study area (Fig. 12) where the upper coal bench thins (Fig. 11). Partings are also common in the northern part of the Hyden East and Hazard North quadrangles (Fig. 12), where the bench splits into one of the northwest–southeast-oriented, rectangular areas of thin coal (Fig. 11), and in the Leatherwood quadrangle (Fig. 12) along the northeast–southwest trend of coal thinning, where the bench appears to split toward the rectangular area of thin coal to the west (Fig. 11).

Rider-Bench Coal Thickness

Coal riders occurring within 12 in. of the top of the upper bench were mapped (Fig. 13), since in most cases they cannot be left in the roof of an underground mine and are mined with the rest of the seam. Rider coals merge or nearly merge with the top of the main bench in several areas. These rider benches are not usually

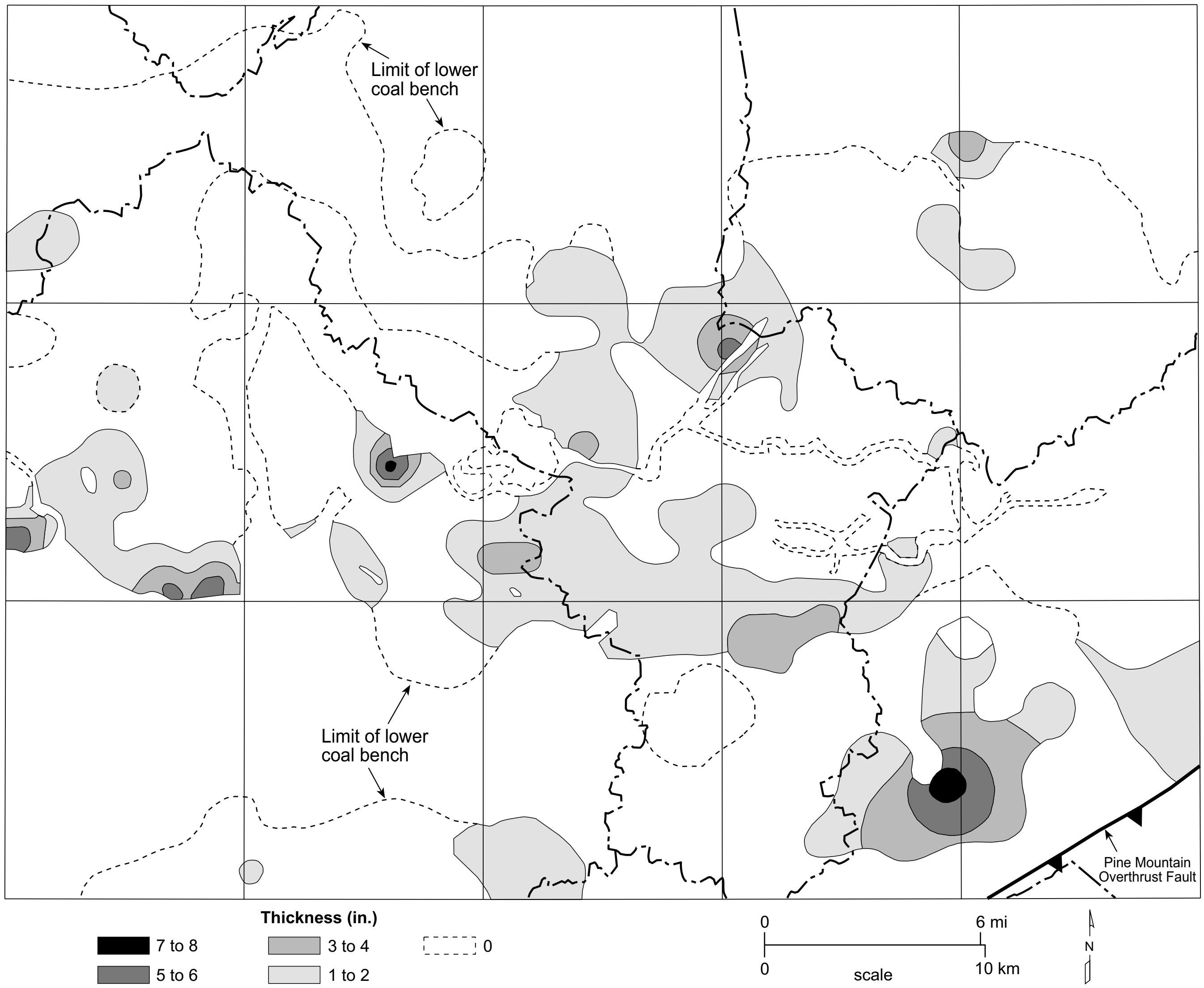

Figure 9. Total parting thickness in the lower bench of the Fire Clay coal in the study area.

mapped as the Fire Clay rider coal; rather, they represent local rider coals between the Fire Clay and the Fire Clay rider.

Sulfur Content

Figure 14 is a plot of total sulfur contents for the Fire Clay, as determined from 116 proximate analyses (Greb and others, 1999a), including the 28 analyses of Eble and others (1999). The Fire Clay coal generally contains 0.8 to 1.2 percent sulfur, with a mean of 1.0 ± 0.2 percent in areas where the coal is mined. Areas of greater than 1.2 percent sulfur occur in the Hoskinston quadrangle and near the northeast–southwest trend of total coal thinning in the Hyden East quadrangle (Fig. 6). Proprietary data from mines indicate that local areas of higher sulfur content occur at greater frequency than indicated in Figure 14, and should be expected where the coal thins. Detailed analysis of sulfur contents sampled vertically through the coal at 28 locations in the study area by Eble and others (1994, 1999) indicates that the upper bench generally is lower in sulfur than the lower bench. The areas of lowest sulfur content shown in Figure 14 correspond to areas where the upper coal bench is thick (Fig. 11).

Ash Yield

Proximate analyses from 66 locations (Greb and others, 1999a) show that the ash yield of the Fire Clay coal varies from 34.0 to 3.2 percent across the study area, with a mean of 11.4 ± 6.9 percent (Fig. 15). The increase

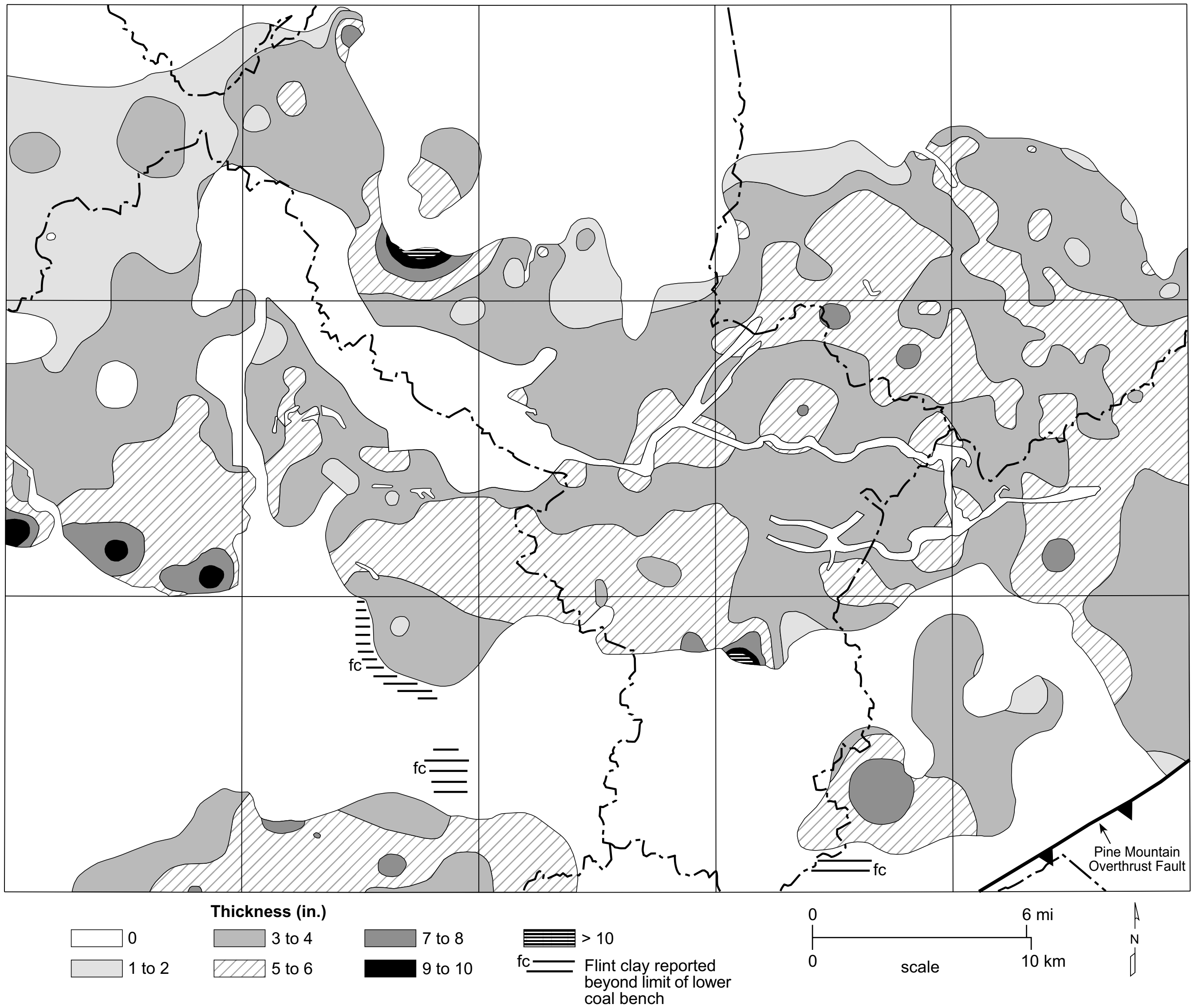

Figure 10. Thickness of the jackrock parting in the study area.

in ash toward the Hoskinston quadrangle is similar to the trend in sulfur content (Fig. 14). Areas of locally increased ash yield also correspond to areas of splitting along the northeast–southwest trend of total coal thinning (Fig. 6). Ash-yield data were not available for several quadrangles (Greb and others, 1999a); therefore, projected ash trends are tentative. This is especially true for areas of thinning coal in the top row of quadrangles (Buckhorn, Krypton, Hazard North, Carrie, Hindman), where low ash yields are projected. Outcrop exposures of thinning coal in the top row of quadrangles show that the coal locally contains abundant partings, which would increase ash yield. As with sulfur, ash yield can vary more locally than regionally. Eble and others (1999) provided a detailed investigation of the vertical ash distribution within coal benches for eight of the quadrangles in the study area. Their analysis indicates that the upper bench is generally lower in ash yield than the lower bench.

Btu

Btu values of Fire Clay coal from 74 locations across the study area (Greb and others, 1999a) range from 8,865 to 14,464 Btu (Fig. 16). Mean Btu value for the coal in the study area is 12,824 ± 1,117 Btu, with a mode of 12,500 Btu. Where the coal is mined, it usually exceeds 12,000 Btu. Heating values above 13,500 Btu were found locally in the Hyden West, Hyden East, Hazard South, and Tilford quadrangles. Several of these high-Btu areas are also areas of thick coal (Fig. 6). As with sulfur

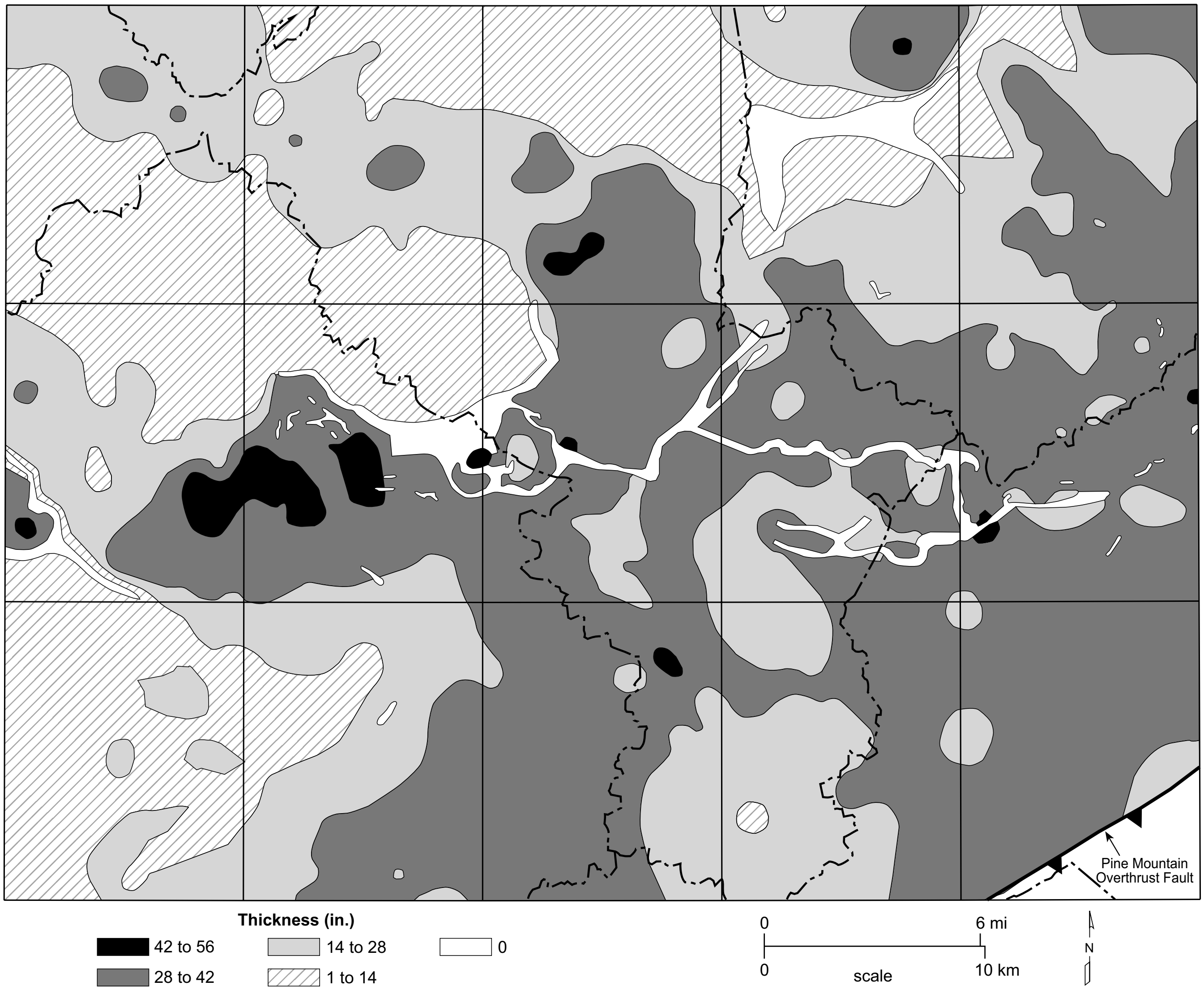

Figure 11. Thickness of the upper bench of the Fire Clay coal in the study area. The upper bench is defined as the coal above the jackrock parting.

contents and ash yields, Btu values were not available for many areas, but generally heating values decrease into the area of thin coal in the Hoskinston quadrangle (Fig. 16). Btu value also decreases markedly along the northeast–southwest trend of coal thinning from the Hindman to the Hoskinston quadrangle. Btu values probably decrease in many of the areas of thinner coal, especially where the upper bench thins, because the upper bench tends to have higher Btu values (Eble and others, 1999).

Cross Sections

Several cross sections were made through the study area to illustrate changes in the strata between the uppermost coal in the Whitesburg coal zone and the lowermost coal in the Hamlin coal zone, in order to determine if thickness changes in the Fire Clay coal might be caused by changes in the enclosing strata. The datum for the sections is the top of the jackrock parting, or the base of the upper coal bench where the jackrock is missing. Section A–A'' (Fig. 17) trends east–west through the axis of thickest coal, and sections B–B', C–C', and D–D' (Figs. 18–20) each trend north–south from the eastern to western parts of the study area.

Two coals can be correlated with confidence across the cross sections: the Fire Clay and the lowest coal in the Hamlin coal zone. The Fire Clay coal has a distinctive jackrock parting throughout much of the area. The lowest Hamlin coal is overlain by a thick (greater than

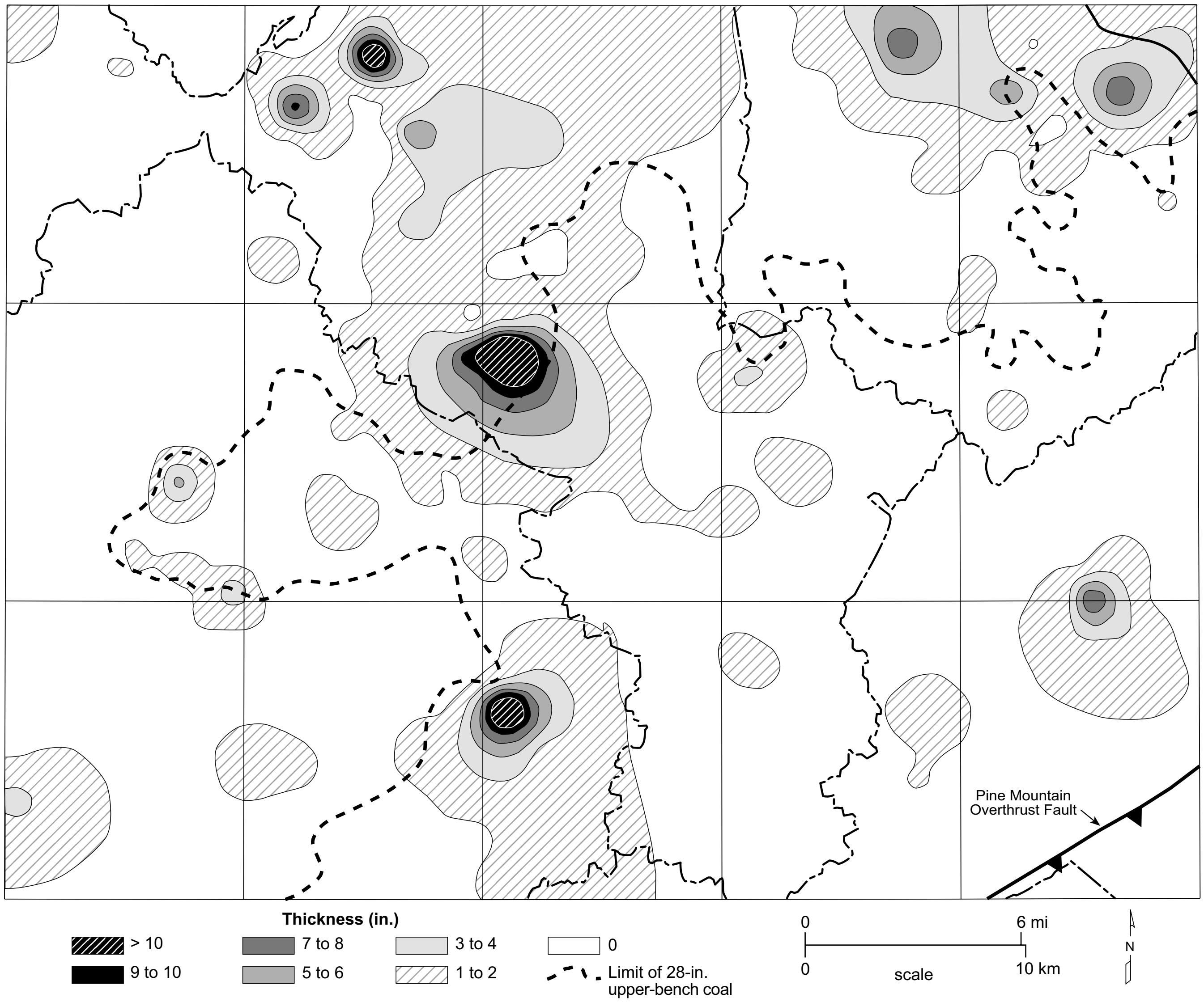

Figure 12. Total parting thickness in the upper bench of the Fire Clay coal in the study area.

20 ft), widespread, coarsening-upward sequence, 40 to 60 ft above the Fire Clay coal. In many areas, two distinct zones of Whitesburg coals, an upper and lower, can also be correlated, but splitting and cutouts often make correlation difficult. Correlation of the coal mined as Fire Clay rider is also tentative, because numerous coals may occur from 1 to 40 ft above the Fire Clay coal.

Section A–A"

Cross section A–A" (Fig. 17) was drawn along the axis of thick coal from the Hyden West quadrangle to the Blackey quadrangle. In the western half of the cross section, the roof geology consists of a series of sandstones and wedges of sandstones and sandy shales, some capped by coal riders. Areas of thick (greater than 15 ft) sandstone are generally broad, and extend for 2 to 4 mi across the top of the coal. Thick, coarse- to medium-grained, usually crossbedded sandstones are flanked by wedges of shaly sandstone, interbedded sandstone and shale, and shale. Wedges of strata between thick sandstones are often truncated by thinner (less than 15 ft thick) and narrower (less than 250 ft wide), crossbedded to ripple-bedded sandstones. Several of the wedges are capped by thin (less than 1 ft thick) coals that occur within 3 ft of the upper bench of the Fire Clay coal.

Another association shown on Figure 17 is that the lower bench of the coal is thickest where it is underlain by shale. Where a thick sandstone (greater than 20 ft) occurs between the uppermost coal in the Whitesburg

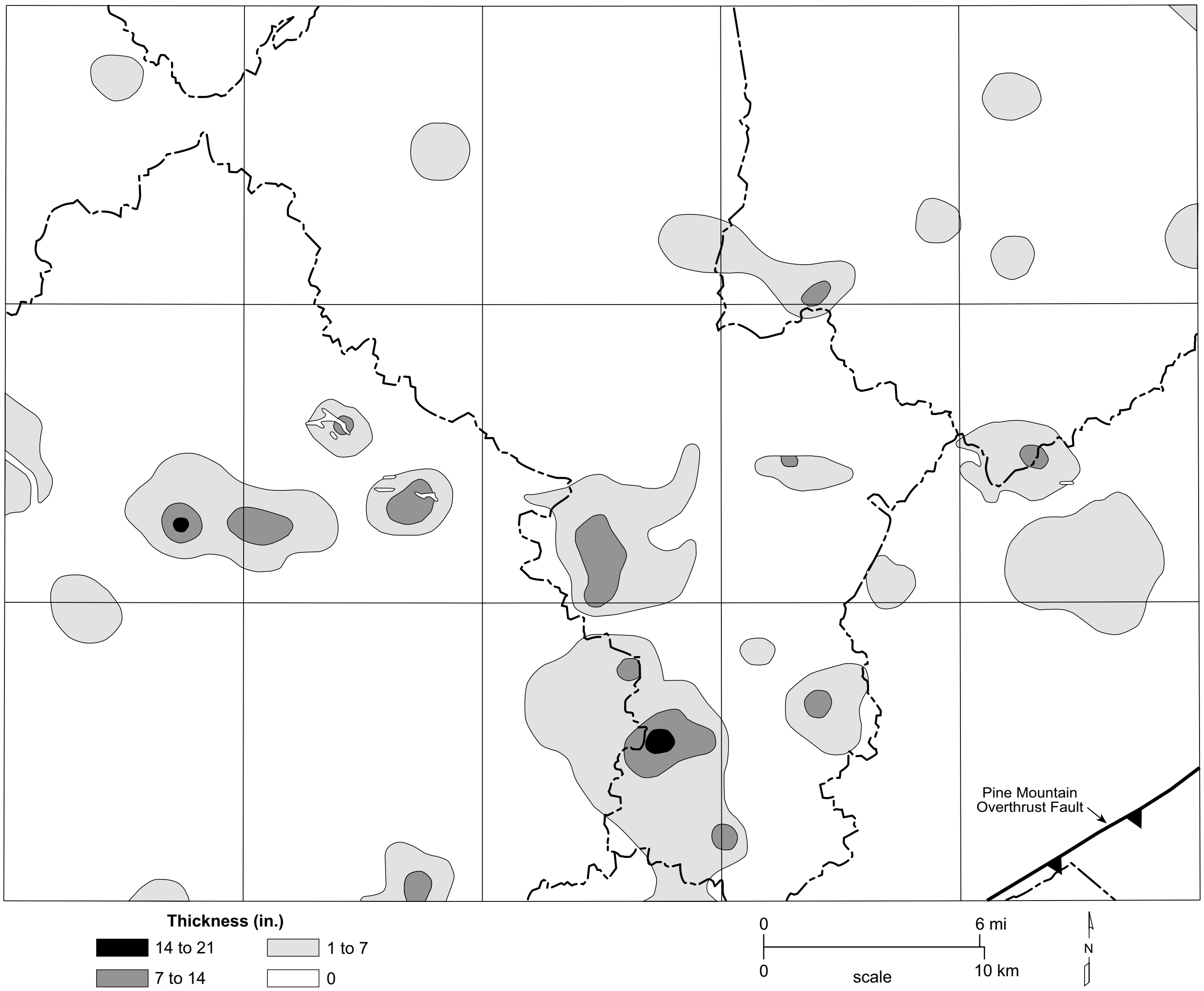

Figure 13. Thickness of rider coals that come within 12 in. of the top of the upper bench of the Fire Clay coal in the study area.

coal zone and Fire Clay coals, the lower bench of the Fire Clay is thin or absent.

Section B–B'

Cross section B–B' (Fig. 18) extends from the northern edge of the Buckhorn quadrangle to the southwest corner of the Hoskinston quadrangle. This section has the most widely spaced data, because it crosses several areas with few exposures. The Fire Clay coal is more than 24 in. thick only in the south-central part of the Hyden West quadrangle and in the north-central Buckhorn quadrangle in this section. In both areas, the lower bench of the coal occurs only locally, and thins or is absent where the coal is underlain by a thick sandstone. The upper bench of the coal is more than 48 in. thick only in small areas, and rapidly thins and splits laterally.

The Fire Clay rider coal, as mapped on geologic quadrangle maps (Puffett, 1964, 1965a, b; Seiders, 1964, 1965a, b; Danilchik and Lewis, 1965; Mixon, 1965; Prostka, 1965; Prostka and Seiders, 1968; Danilchik, 1976; Maughan, 1976; Waldrop, 1976; Ping, 1977; Lewis, 1978; Taylor, 1978), occurs between 2 and 30 ft above the Fire Clay along the line of section B–B'. In general, the rider is at a higher elevation where a sandstone occurs between it and the Fire Clay coal. The rider is mined in the northern part of the Hyden West quadrangle, and the southwestern margin of the Hoskinston quadrangle. In both areas, the rider is thick where the Fire Clay coal is thin. In much of the Hoskinston quadrangle, the Fire Clay rider is thicker than the Fire Clay coal, and was used as a datum where the Fire Clay coal is missing (Fig. 18). Both coals split where they come within 10 ft

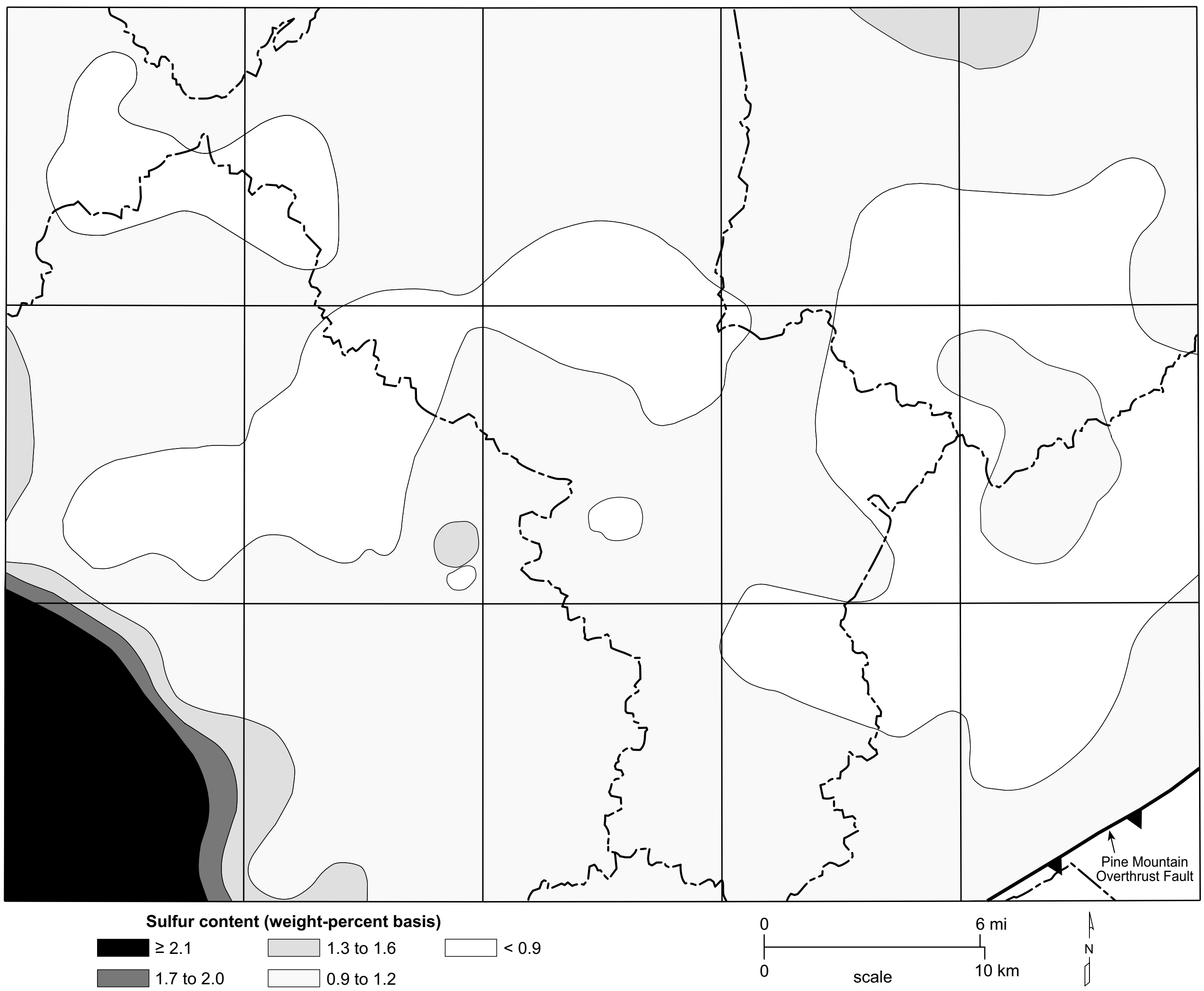

Figure 14. Sulfur contents of the Fire Clay coal in the study area.

of each other in the Hyden West quadrangle (Fig. 18). According to miners, areas where the rider is within 10 ft of the Fire Clay coal have been associated with adverse roof conditions. Also, in the Hoskinston quadrangle and southern Buckhorn quadrangle, many of the coals between the Kendrick Shale Member and the Magoffin Member are thin or absent. Because the coals are thin and data are widely spaced, correlations of individual beds are problematic.

Section C–C'

Section C–C' (Fig. 19) extends from the northern limit of mining in the Hazard North quadrangle, through the Hazard South and Leatherwood quadrangles, into the northern part of the Bledsoe quadrangle. North of the section there are few subsurface data, but the northern limit of mining is marked by rapid thinning of the coal beneath a thick, crossbedded sandstone, and possibly splitting toward the sandstone, so the coal is probably thin or absent to the north (Fig. 19).

In general, this section is very similar to section A–A"(Fig. 17), with wide (2 to 6 mi) areas of thick (40 to 60 ft) sandstone and no Fire Clay rider, separated by areas of thinner sandstones, sandy shales, and shales with multiple rider coals. Coal riders drape wedge-shaped lenses of sandy shale and sandstone near the border between the Hazard North and Hazard South quadrangles, the border between the Hazard South and Leatherwood quadrangles, and in the Bledsoe quadrangle (Fig. 19). In the latter two areas, the riders come

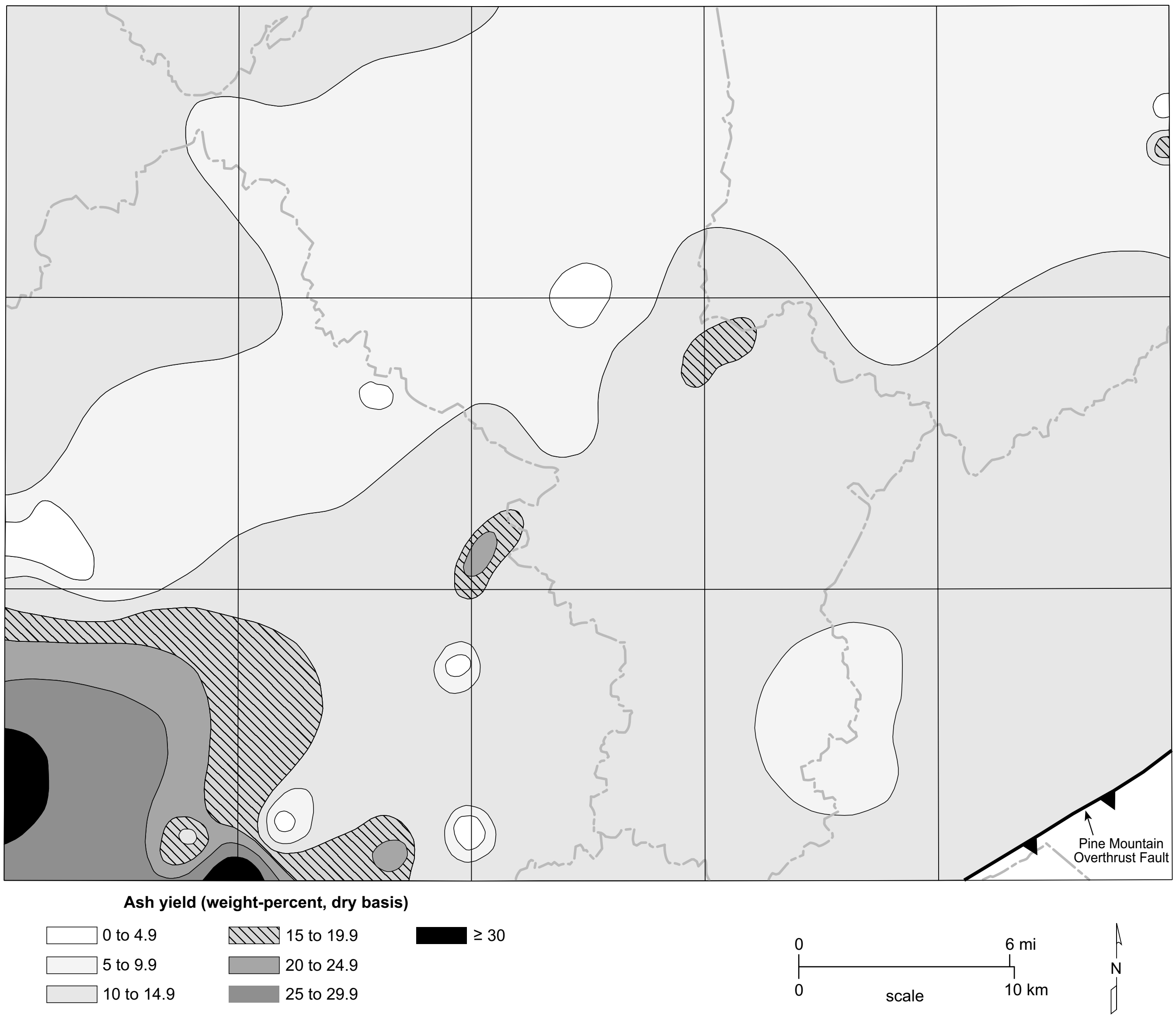

Figure 15. Ash yields of the Fire Clay coal in the study area.

close to or merge with the top of the Fire Clay coal, resulting in locally thick coal.

In the northern part of the Hazard South quadrangle, drillers' logs were used to supplement exploratory core data, because there are no borehole records for the area where mining has taken place. The coal has been mined out, but outcrops around three sides of the area suggest a relatively uniform coal thickness with a thick, sandstone top. The southern part of the Leatherwood quadrangle was another area where data were widely spaced. Inferences of a thick sandstone roof in the area are based on conversations with local mining company personnel, the rising elevation of the Fire Clay rider on either side of the area, and the elevation of the lowest coal in the Hamlin coal zone rising toward this area.

Section D–D'

Section D–D' (Fig. 20) is the easternmost section and extends from north of the Hindman quadrangle to the Pine Mountain Fault in the Roxana quadrangle. In contrast to the two previous north–south sections, the Fire Clay coal is much more continuous in this section. As in the two previous sections, the lower bench is restricted to a much smaller area than the upper bench. North of the town of Hindman, the lower bench may split toward a broad sandstone cutout near the border between the Vest and Hindman quadrangles. More than 80 ft of sandstone occurs between the lowest coal in the Hamlin coal zone and the Whitesburg coal zone, where the Fire Clay coal is cut out. The lower bench of the Fire Clay

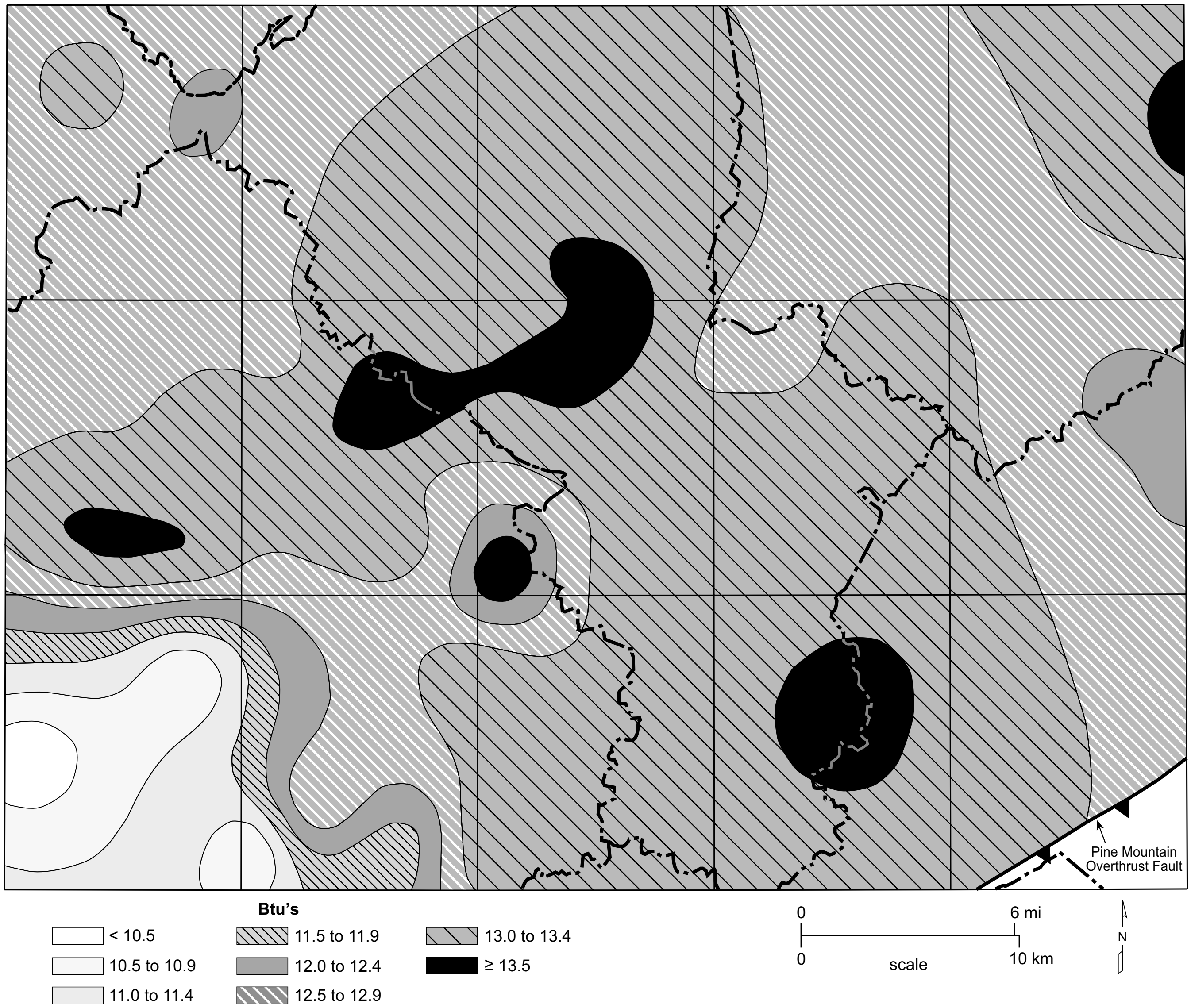

Figure 16. Btu values in the Fire Clay coal in the study area.

coal similarly splits toward the cutout on the northern margin of the sandstone in the Vest quadrangle. The upper bench may also split toward the cutout, although in most areas it thins beneath the sandstone.

As in the previous sections, thick (20 to 55 ft) sandstones occur in broad belts (8 to 10 mi) above the coal. These belts are separated by narrow areas (2 to 6 mi) of interbedded sandstone and shale. Coal riders are common in these shalier areas. Both of the coals mapped as Fire Clay rider and the lowest coal in the Hamlin coal zone tend to occur at lower elevations between the thick sandstones.

Roof-Rock Descriptions

The lithologic units shown in the cross sections are sandstone, interbedded sandstone and shale, coal, gray shale, and dark-gray to black shales. These units are described below from surface exposures.

Sandstone

The most common roof rocks in the study area are medium-grained, crossbedded sandstones, generally 12 to 30 ft in thickness (Figs. 17–20). Sandstones are coarse to fine grained and tend to fine upward. Most have sharp scour bases with common lags of coal spar and siderite cobbles (Figs. 21a–b). Lateral accretion surfaces are common in surface exposures (Fig. 21c). Although many borehole records do not include bedding descriptions, exposures of sandstones that are greater than 10 ft thick along the cross sections are crossbedded.

Crossbedded sandstones generally form a good roof in mines where they are encountered, although rapid pinch-outs and unexpected cutouts have led to mines being closed along the cutout and the thinning trends noted previously.

Interbedded Sandstone and Shale

Between areas of thick, crossbedded sandstone, the rocks above the Fire Clay coal are dominated by interbedded sandstones and shales (Figs. 17–20), termed "heterolithic strata." Some borehole records have described individual layers of sandstone and sandy shale, but usually heterolithic units are amalgamated into units of sandy shale or shale with sandstone interbeds. Exposures of these intervals along the line of cross sections show that many of the units designated in borehole descriptions as sandy shale are laterally variable in sandstone and shale composition. Figure 22 is a representation of a highwall in the Roxana quadrangle along cross section D–D', which changes laterally from sandstone to shale. The lateral extent of any individual sandstone bed in these types of roofs is difficult or impossible to predict from cores, because sandstones may be less than 200 ft wide. Where the sandstones are flat bedded, fine grained, relatively extensive, and with no coal riders within 10 ft of the roof, they provide a good roof. Sandstone and shale beds with a high degree of lateral variability have had roof-support problems.

Sandstones within heterolithic intervals vary from fine to medium grained, and from massive to crossbedded, and generally are less than 10 ft thick. Lenticular sandstones usually grade laterally into wedge-form or sheet-form, finer grained, ripple- to flat-laminated sandstones (Figs. 23a–b). Sheet-sandstone beds are separated by gray sandy shales, often with thin interbeds of ripple- to even-bedded sandstone. In several mines, sandstone beds are less than an inch thick and are separated by thin shale laminae, forming sequences of what miners call "stackrock" (Fig. 23c). Numerous roof falls have occurred in stackrock roofs above the Fire Clay coal.

Shale-dominated heterolithic intervals usually consist of sandy shales, commonly coarsening upward into fine-grained, ripple-bedded, sheet sandstones. Coarsening-upward sequences generally contain disseminated plant-fossil debris and may be capped by coals (Fig. 23d). At one location in the Krypton quadrangle, thin-bedded to laminated sandstones and shales are intensely bioturbated in the roof above the Fire Clay coal (Fig. 23e), but in most areas interbedded sandstones and shales were not bioturbated. Bioturbation is common beneath the Fire Clay coal in the sandstones and shales above the Whitesburg coal zone, and above the Fire Clay rider coal.

Areas of interbedded sandstone and shale above the Fire Clay coal commonly contain fossil tree stumps (Fig. 23g). Underground, these stumps are known as "kettlebottoms," and are a mining hazard (Fig. 23f). Interviews with miners who had worked in older Perry County mines indicate that kettlebottoms are a common problem above the Fire Clay coal.

Coal Riders

Numerous coal riders, and in some cases the coal mapped as the Fire Clay rider, occur within 10 ft of the Fire Clay coal locally. In most areas, the first rider coal caps a 10- to 20-ft-thick, crossbedded sandstone above the Fire Clay coal (Fig. 24a). In areas marginal to the sandstones, riders may be lower in elevation and occur near the top of the Fire Clay coal (Fig. 24b). Coal riders commonly drape lenticular and wedge-form units of sandstone and shale (Figs. 17–20). They are rarely continuous for more than a mile, and are commonly truncated by sandstones, or pinch out into carbonaceous shales.

Where coal riders merge with the top of the Fire Clay coal, the riders are mined along with the main coal (as shown in Figure 24b). Figure 25 is a cross section from the Leatherwood quadrangle along the line of section C–C', showing the merging of rider coals with the top of the coal. Examination of numerous areas showed that where the Fire Clay coal is more than 50 in. thick, it often merges with a rider coal. Unfortunately, these areas are relatively small in extent, and often associated with an increase in sulfur content and ash yield (Eble and others, 1999).

Gray Shale

In many borehole records, the roof of the Fire Clay coal is described as shale or gray shale. Shale roofs appear to be more common toward the east. In most exposures, gray silty shale is evenly laminated and coarsens upward or is overlain by interbedded sandstones and shales. Disseminated plant fossils are common in the shale, especially where the shale is in contact with the coal. In situ fossil tree stumps occur locally. Thick (greater than 3 m) shale roofs are uncommon, but form good roofs. Where the shale is thin and contains plant fossils, it is usually removed as "draw slate" (shale above the coal that collapses during or shortly after removal of the coal) during mining. Gray shales tend to be laterally truncated by sandstones or grade into interbedded sandstone and shale. Adverse roof conditions can oc-

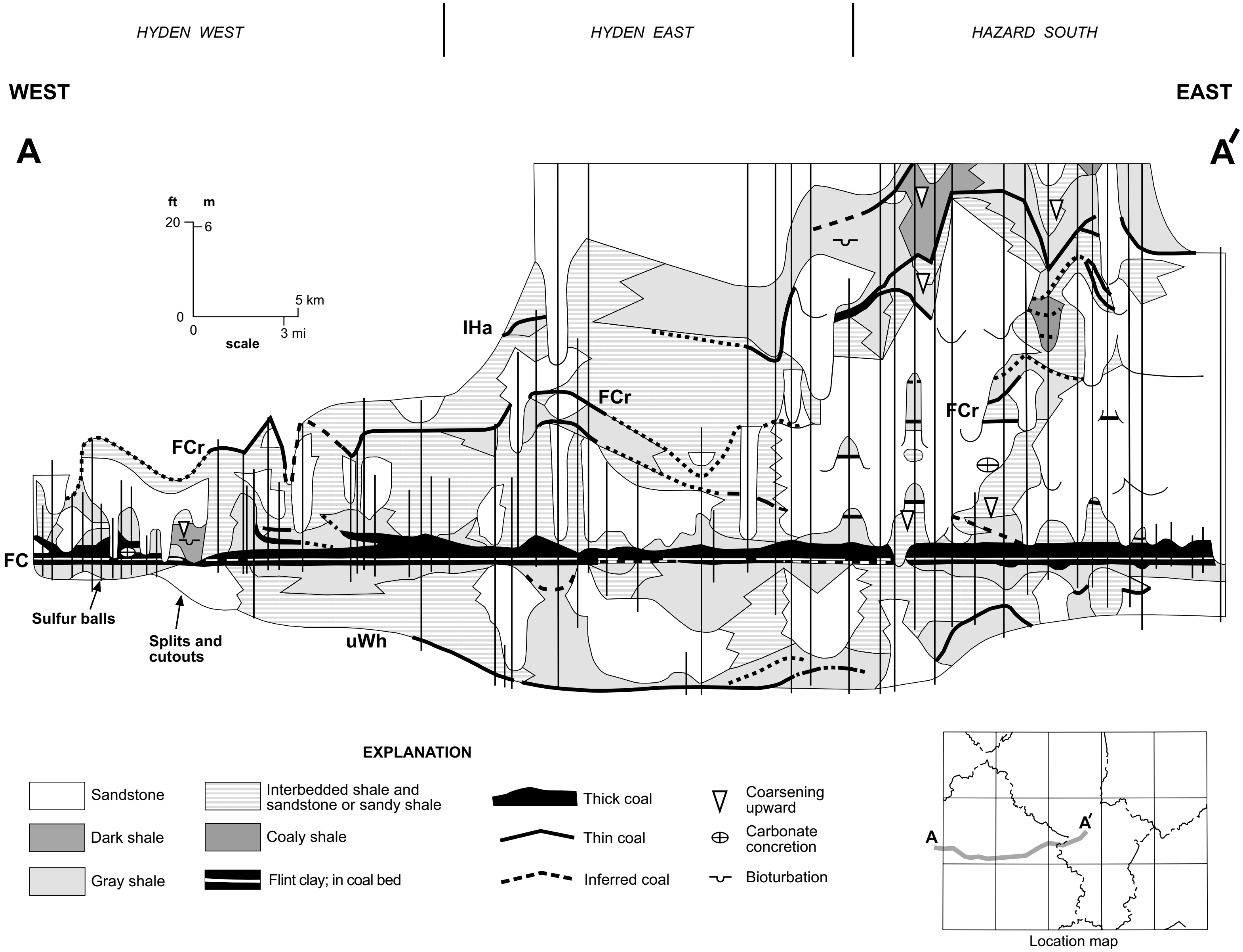

Figure 17. (a). Cross section A–A'.

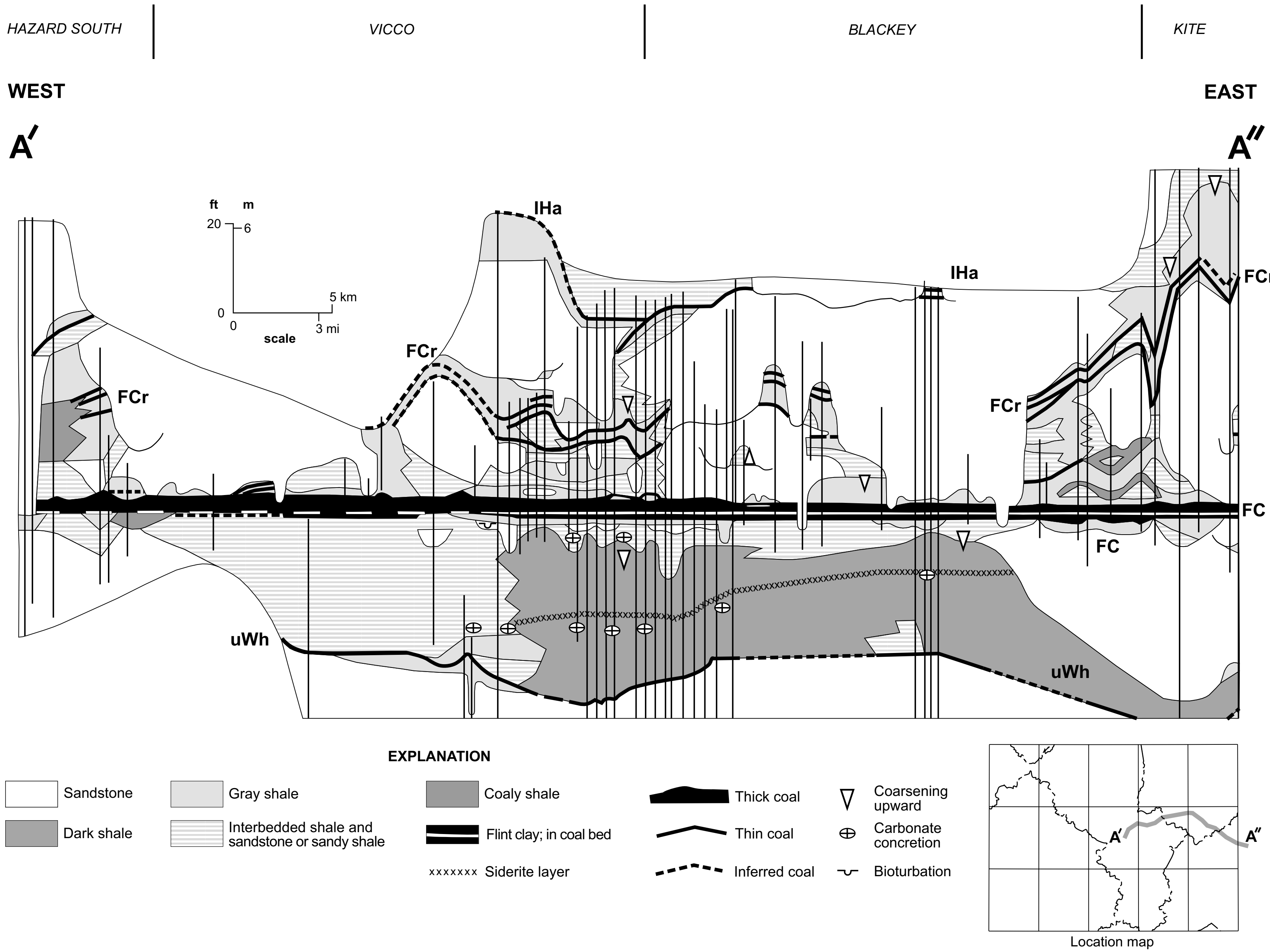

Figure 17. (b) Cross section A'–A".

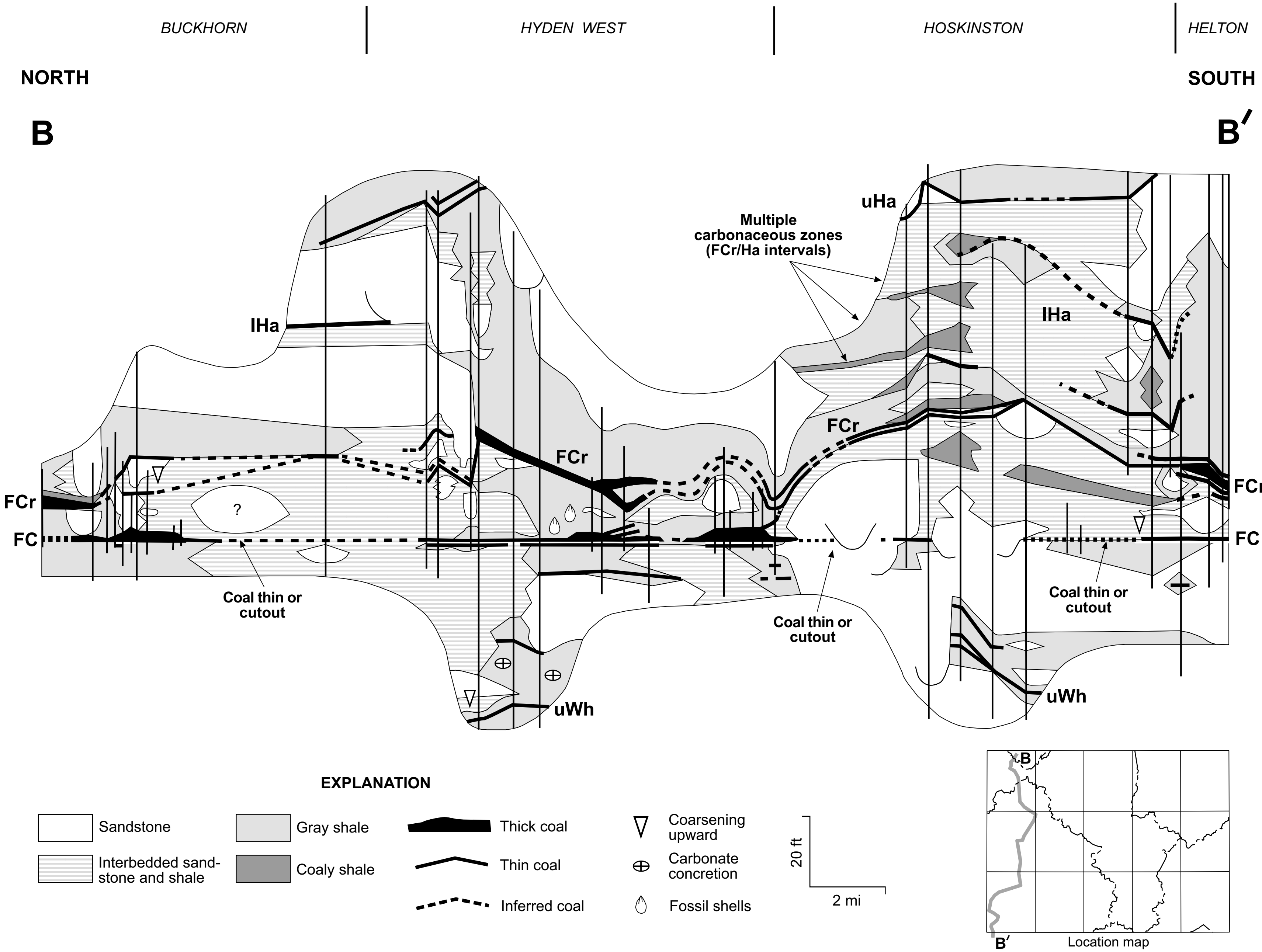

Figure 18. Cross section B–B'.

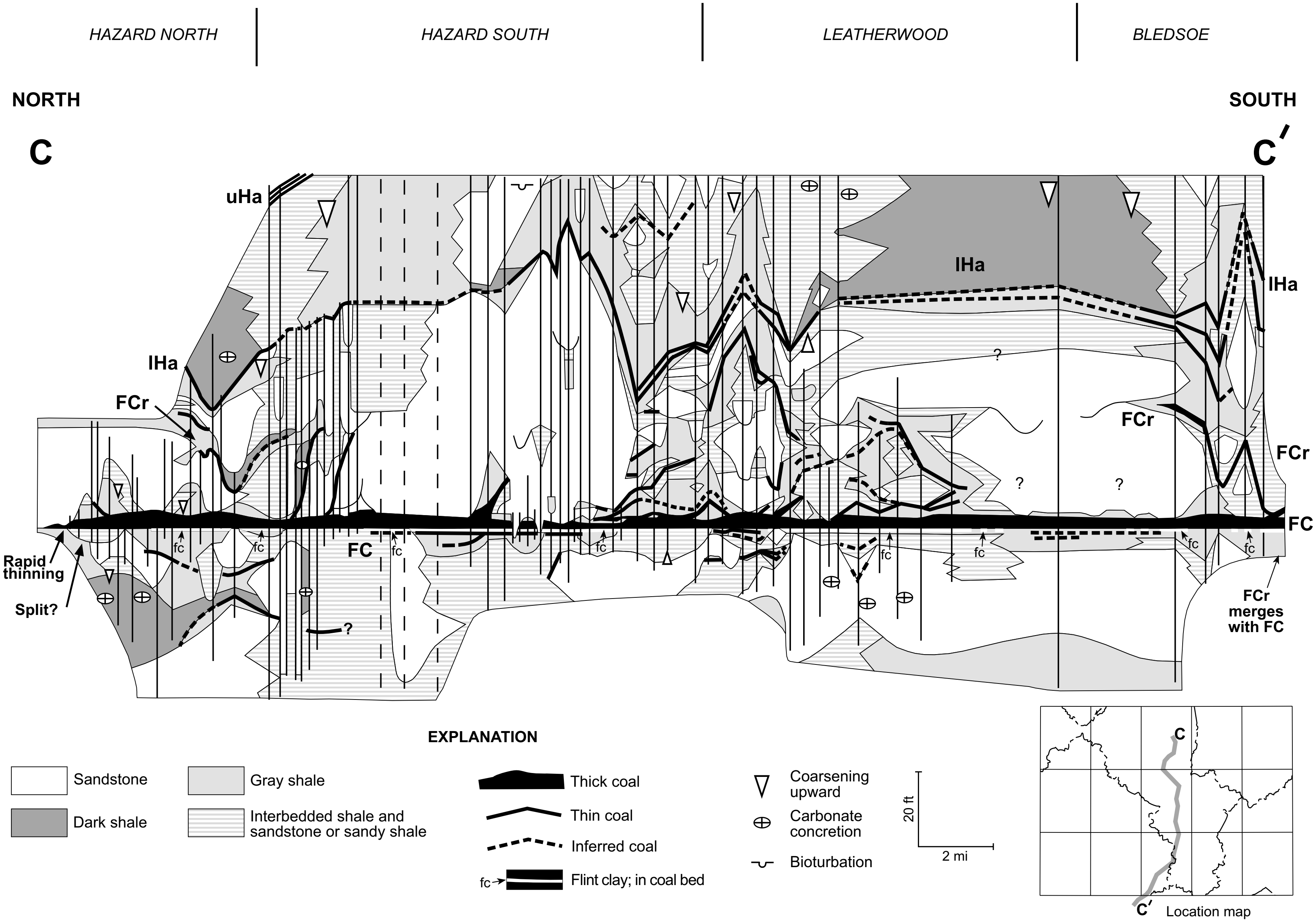

Figure 19. Cross section C–C'.

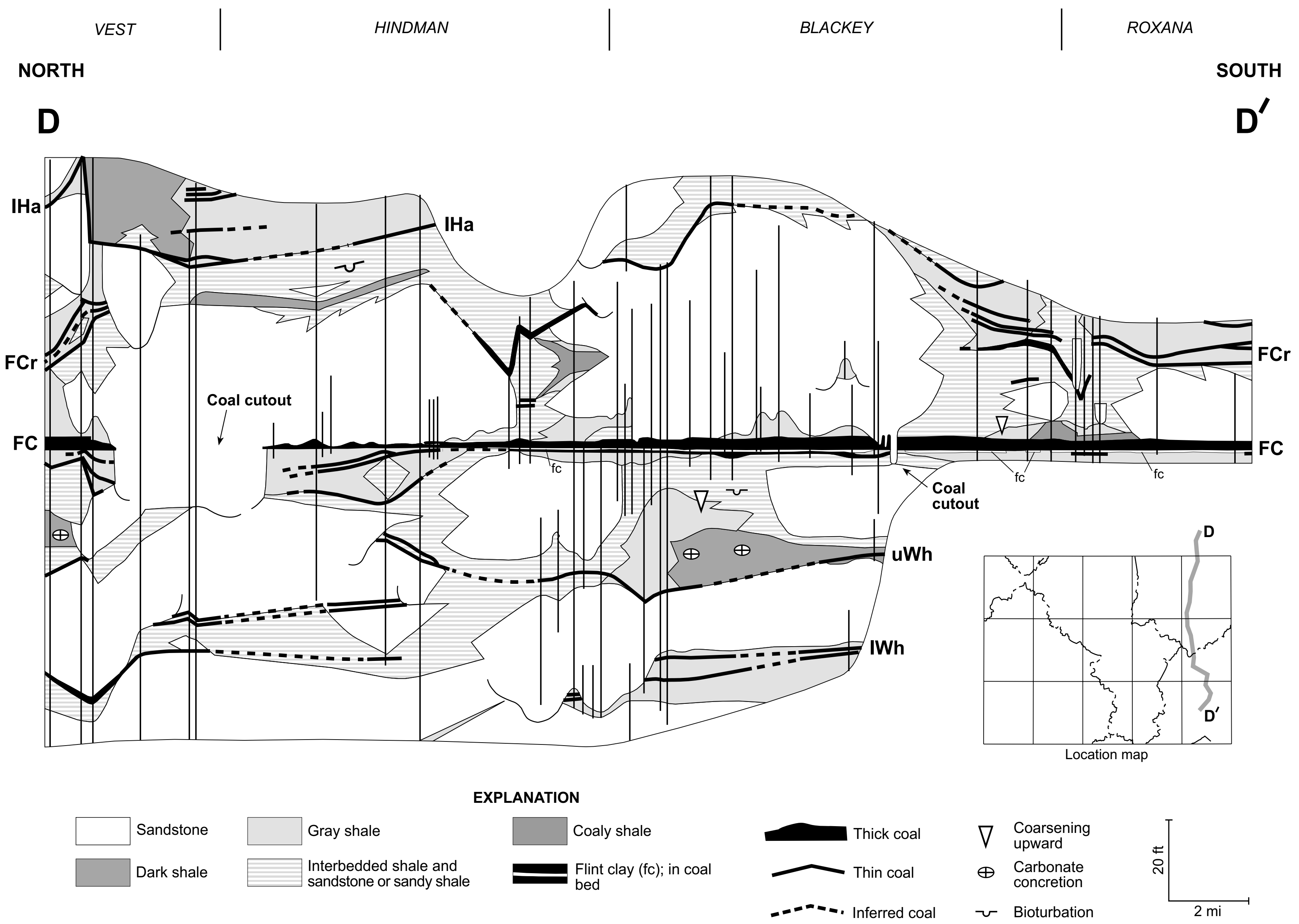

Figure 20. Cross section D–D'.

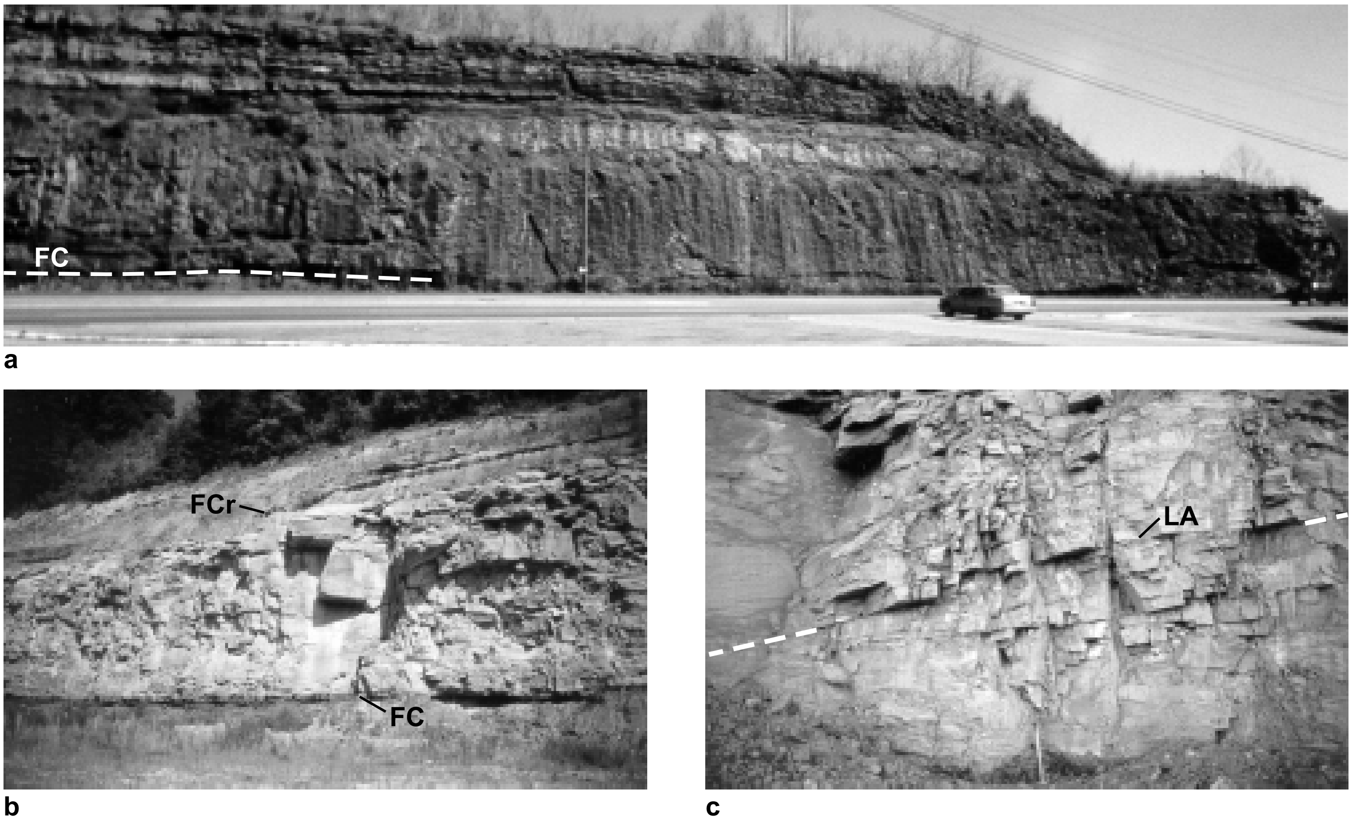

Figure 21. (a) Sandstone channel near Hazard, with sharp scour base. (b) Sandstone in box cut near Hindman. Fire Clay coal (FC) thins beneath the scour at the base of the sandstone. FCr=Fire Clay rider. (c) Lateral accretion (LA) surfaces in sandstone above coal near Roxana.

cur where thin shale is overlain by scour-based sandstone or where shale is laterally truncated by sandstone.

Dark-Gray Shale

Dark-gray shales are evenly laminated and often contain carbonate concretions (Fig. 26a). They tend to be harder and less fissile than gray shales. In the Hyden West quadrangle, dark-gray shales in the roof above the Fire Clay coal contain brachiopod and gastropod fossils. Dark-gray to black shales are relatively uncommon above the Fire Clay coal, although they are common above the uppermost coal in the Whitesburg coal zone,

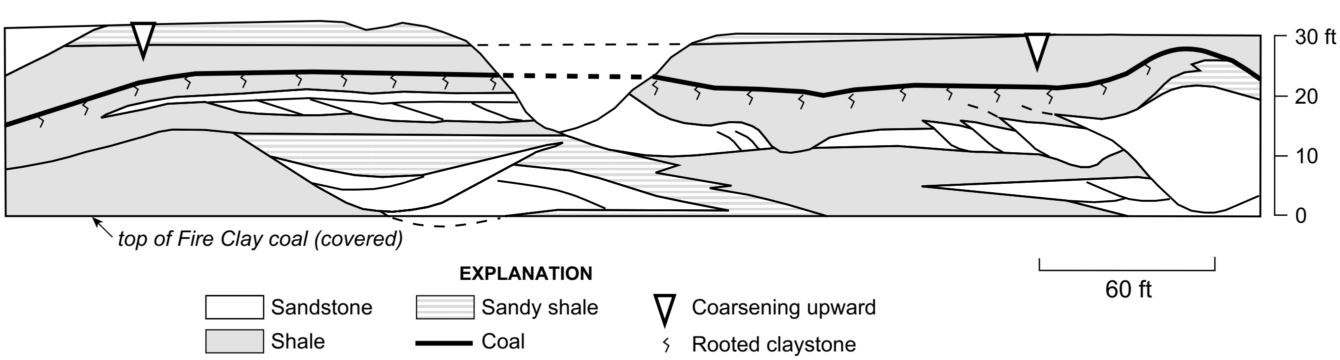

Figure 22. Geologic section from surface-mine highwalls in the northern Roxana quadrangle shows lateral variability of sandstones and shales in the roof above the Fire Clay coal.

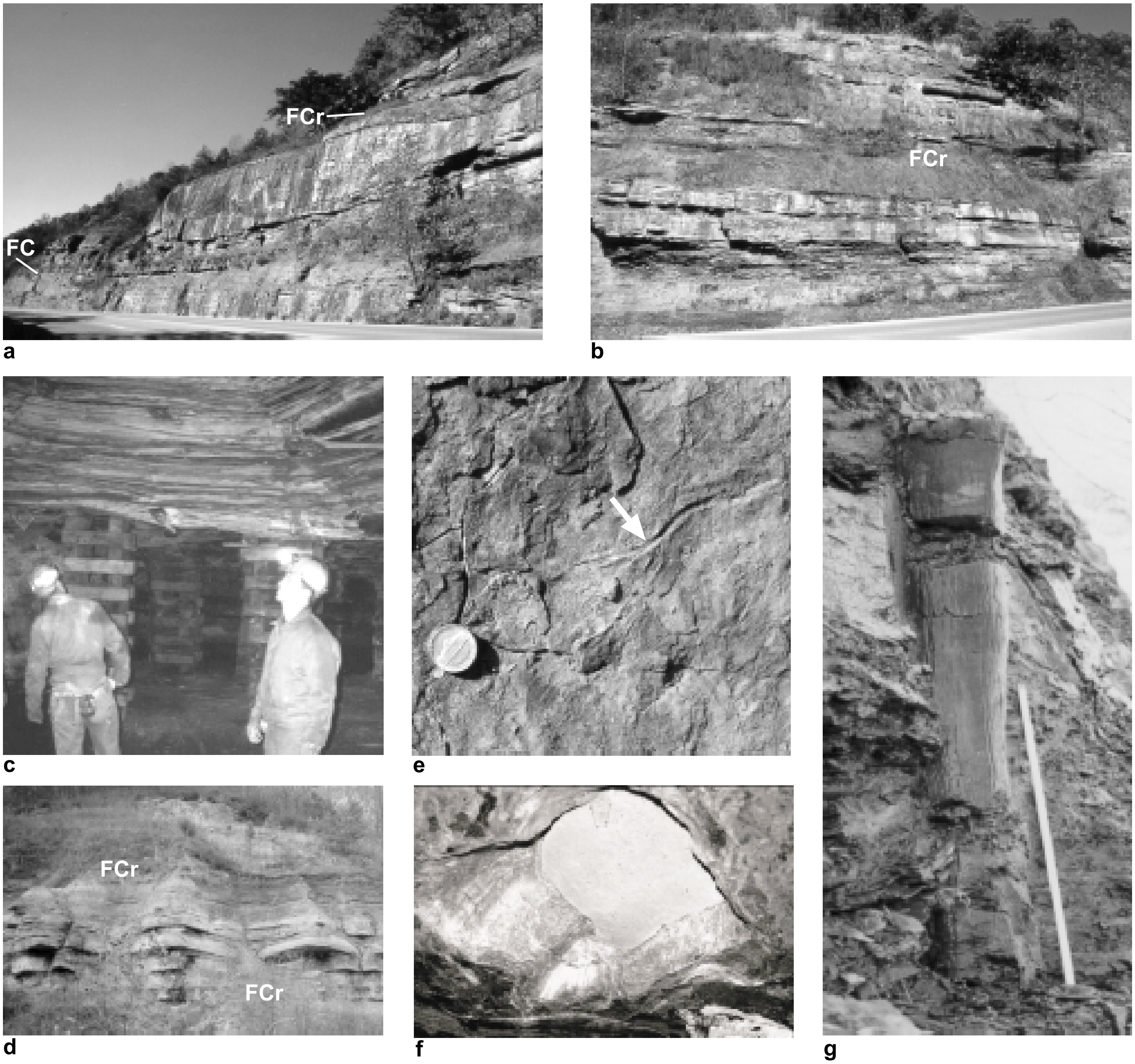

Figure 23. Interbedded sandstone and shale. (a) Lenticular sandstone along Kentucky Highway 15 near Carr Fork Lake in the Vicco quadrangle, which grades laterally into (b) thinner bedded, sheet sandstones. (c) “Stackrock” roof fall in a Fire Clay coal mine. (d) Coarsening-upward sequence showing thickening-upward sandstone beds, capped by Fire Clay rider coal. From the western Hindman quadrangle. (e) Bioturbated sandstone laminae. From the Krypton quadrangle. (f) Fossil tree stump in heterolithic strata above the Fire Clay coal along Kentucky Highway 15 in Hazard, Ky. (g) Kettlebottom in roof of Fire Clay mine in the Cutshin quadrangle.

the Fire Clay rider coal, and the lowermost coal in the Hamlin coal zone (Figs. 17–20). In one mine in the Cutshin quadrangle in which the Fire Clay coal rests on a dark-gray shale, concretions in the floor of the coal have caused haulage problems (Fig. 26b).

Lateral Associations of Rock Types

Figure 27 is a generalized map of the types of rocks within 10 ft of the top of the Fire Clay coal in the study area. Thick sandstones in the roof are generally more

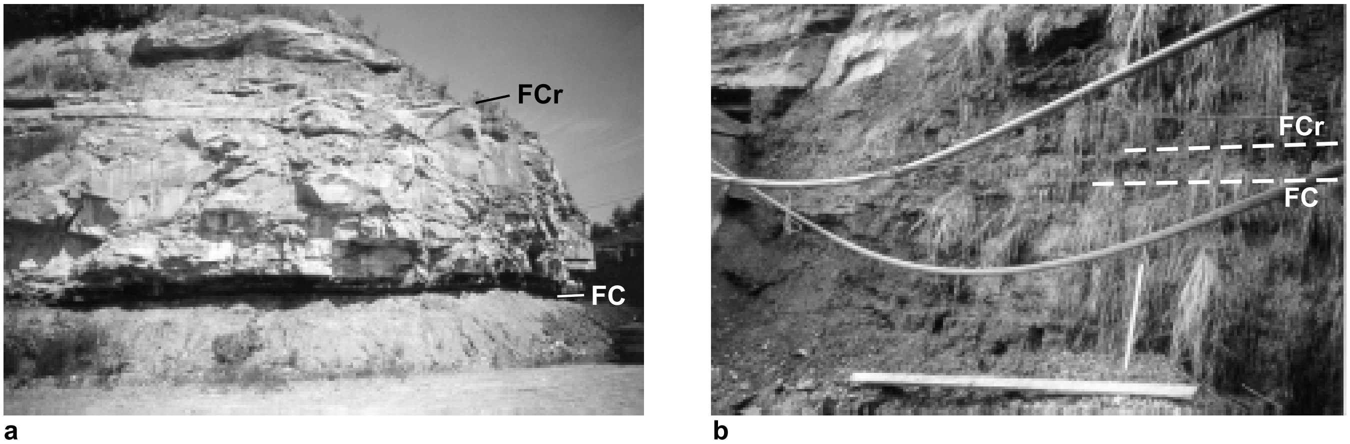

Figure 24. (a) Rider coal (FCr) above sandstone in the Hindman quadrangle. FC=Fire Clay coal. (b) Rider coal (FCr) merged with Fire Clay coal (FC) in the Hazard South quadrangle.

widespread to the west and southwest; they thin eastward and northeastward as narrower belts. Sandstones generally follow northwest–southeast and northeast–southwest orientations, similar to the thickness trends in the Fire Clay coal (Fig. 6). Even the cutout trend that occurs through the middle tier of quadrangles has angular changes in orientation that parallel the sharp changes in coal thickness shown in Figures 6 and 11.

Numerous mines stopped production along the sharp cutout trend through the middle row of quadrangles in the study area. In at least two mines, roof falls resulted from rotated bedding along the cutout margin. Figure 28a is a cross section across an entry through the central cutout trend. Bedding is locally rotated to vertical within the cutouts (Fig. 28b). Also, the Fire Clay coal may be thrust above itself, resulting in greater-than-average coal thickness along the cutout trend (Greb and Weisenfluh, 1996). Numerous occurrences of slickensided roofs and rotated beds have been reported along the central cutout trend in the Hyden East, Hazard South, Vicco, and Blackey quadrangles, as well as in other areas (Fig. 28c).

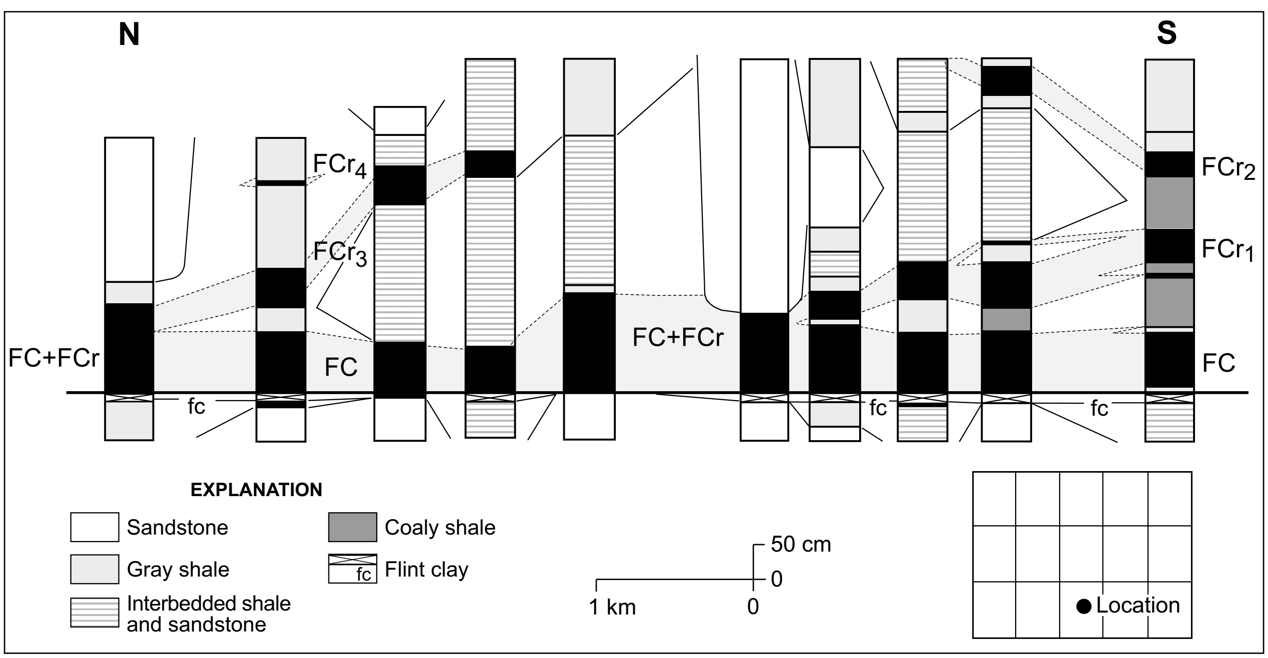

Figure 25. Cross section from borehole data showing merging of rider coals with the Fire Clay coal around lenticular sandstones and shale wedges in the Leatherwood quadrangle.

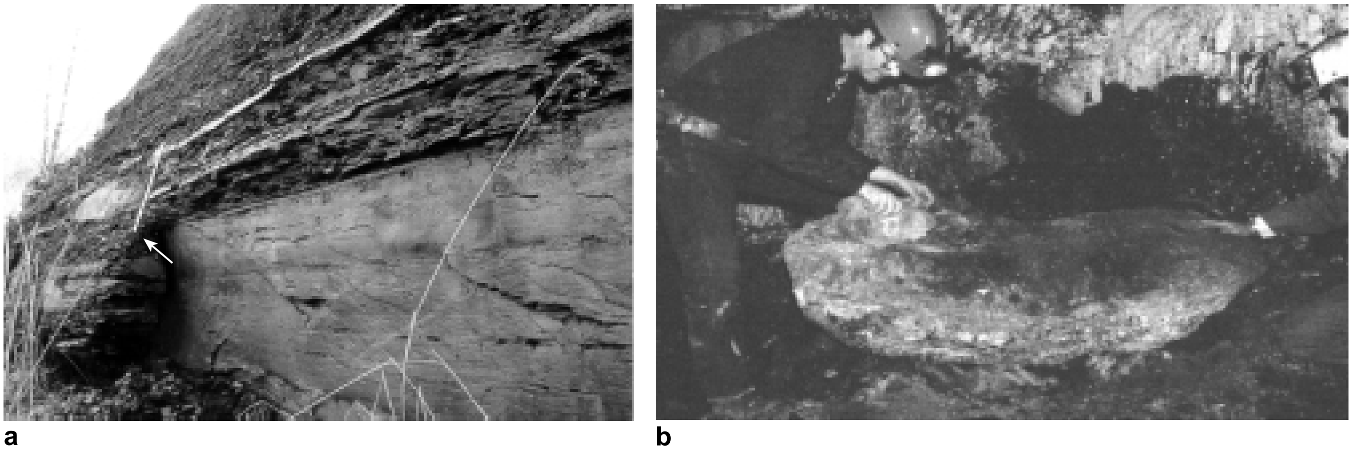

Figure 26. Dark-gray shales. (a) Dark-shale roof with concretions above the Fire Clay coal along Kentucky Highway 15 in Hazard. (b) Concretions in the floor of a Fire Clay underground mine in the Cutshin quadrangle.

To the west, sharp cutouts also flank the limits of mining. Roof rocks in these areas generally consist of crossbedded sandstone cutting through sandy shale or gray shale. In the Hyden West and Krypton quadrangles, sandstones may also cut through dark, fossiliferous shales. Locally, sulfur balls are reported in the coal adjacent to or beneath the sandstones and dark shales. No sulfur-bearing concretions were found during this study, but notations on mine maps for the Hyden West quadrangle (Fig. 29) and reports from miners from western Perry County indicate that they are common.

Figures 17 through 20 and Figure 27 show a repetitive lateral association of rock types from thick, crossbedded sandstone, to interbedded sandstone and shale, to shale. This transition is well documented above adits at a roadcut along Kentucky Highway 15 near Hazard (Fig. 30). Crossbedded, coarse- to medium-grained sandstones with sharp lower contacts, basal coal and fossil-log lags, and common lateral accretion surfaces occur above the coal for a distance of several miles. The sandstone is flanked by moderately dipping (5 to 20º), interbedded, fine-grained sandstones and sandy shales, with abundant rooting and common in situ fossil tree stumps. The fine-grained sandstones and sandy shales are flanked by even-bedded dark shale with carbonate concretions. On the north end of the roadcut the dark shale is truncated by a narrow, crossbedded sandstone, which is flanked by interbedded sheet sandstones and shales. This type of transition appears to be common throughout the study area.

INTERPRETATIONS

Depositional History

The Fire Clay coal represents the accumulation of peat in a succession of mires, each with its own characteristics. Understanding how the stacking of those different swamps contributes to the characteristics of the coal as a whole is important for identifying meaningful trends in coal thickness and quality. Likewise, understanding the processes involved in the burial of the original peat can aid in identifying trends in roof rocks. Similar trends in peats and roof rocks suggest that controls were not limited to the peat alone, and therefore may be applicable to the Fire Clay coal in other areas, as well as to other coal beds.

Lower Coal Bench. Petrographic, palynologic, and geochemical analyses of the lower coal bench indicate that it formed from a peat that filled depressions in the paleotopography, essentially at or below the water table. This is called a planar mire (Eble and Grady, 1990; Eble and others, 1994, 1999). This interpretation is supported by the results of this study. Figures 17 through 20 indicate that the lower coal bench thickens and splits where it is underlain by shales, and pinches out where it is underlain by sandstones. Because shales are more easily compacted than sandstones, the shaly areas would probably have formed topographic depressions, which subsequently filled with peat and occasional sediment. Using the jackrock parting as a datum helps to illustrate this topography-filling geometry. Because the thickness of the flint clay within the parting does not vary significantly, it makes an excellent horizontal datum.

The lower coal bench locally splits or grades into a carbonaceous shale toward the broad cutout along the northern limit of the coal (Figs. 8, 20). In all areas where the cutout could be observed, it consisted of crossbedded sandstones. Splitting indicates that the depositional system that formed the sandstones was active during peat accumulation; thus, the northern limit of the lower

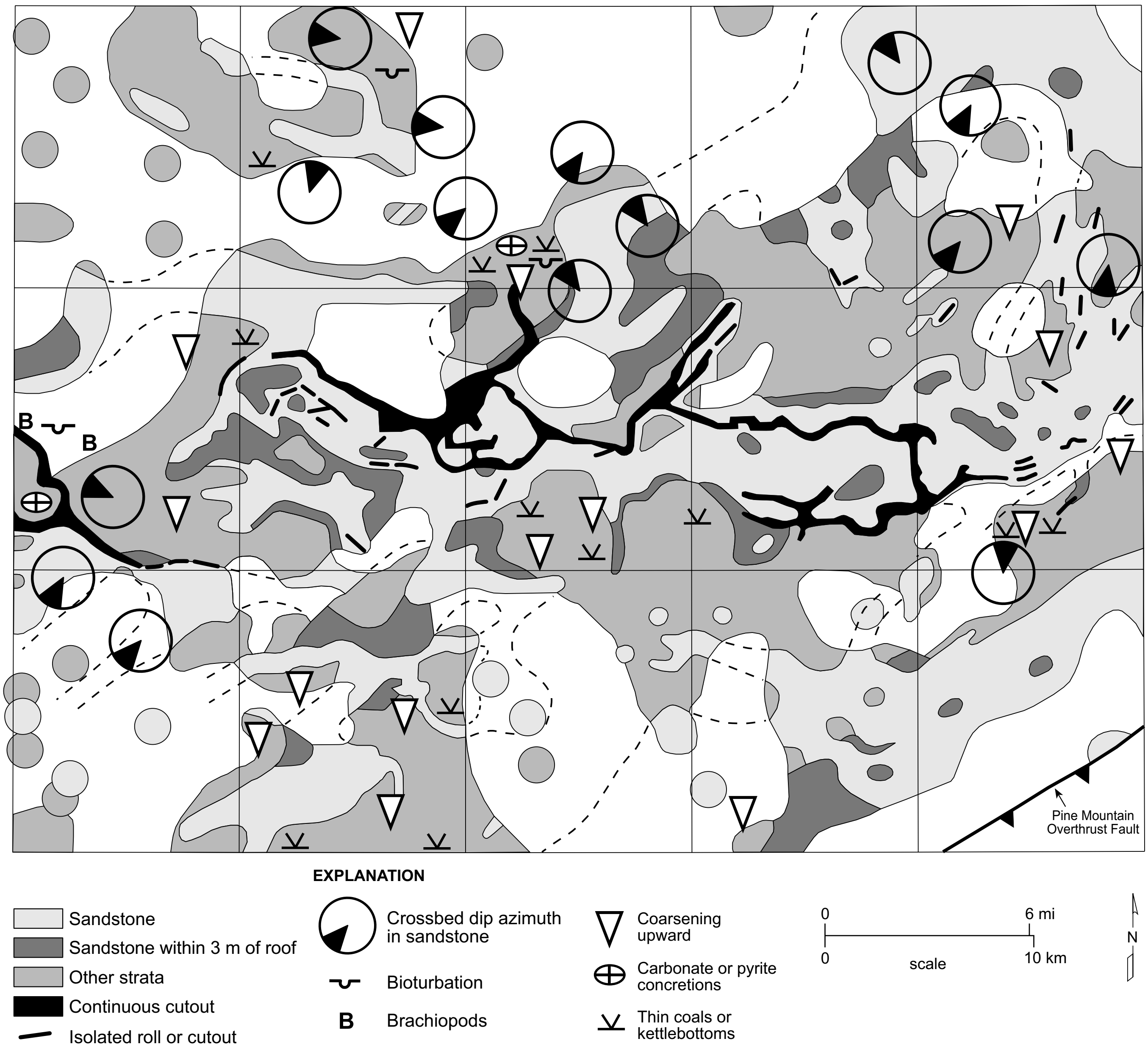

Figure 27. Roof geology of the Fire Clay coal showing rock types within 10 ft of the top of the coal.

coal bench probably represents the limit of the original mire. Likewise, increasing partings along the southern margin of the lower coal bench indicate a clastic source to the south during accumulation of the lower coal bench.

Jackrock Parting. The lower, planar mire has been inferred to have been catastrophically buried by a volcanic ash fall, which is preserved as the flint-clay parting (Chesnut, 1983; Lyons and others, 1992, 1994; Eble and others, 1994). The flint clay often does not rest directly on the lower bench, however, but on several inches of shale or shale and bone coal. Increasing ash content upward in the lower bench suggests that it was drowned prior to accumulation of the flint clay, and hence prior to the ash fall. Also, no stumps or coal protrudes from the lower bench into the upper bench, as would be expected if the main part of the mire were buried by ash. The lack of stumps suggests that there were no standing trees when the volcanic eruption occurred. The flint layer contains abundant carbonaceous material and coaly streaks, which are inferred to represent low-lying

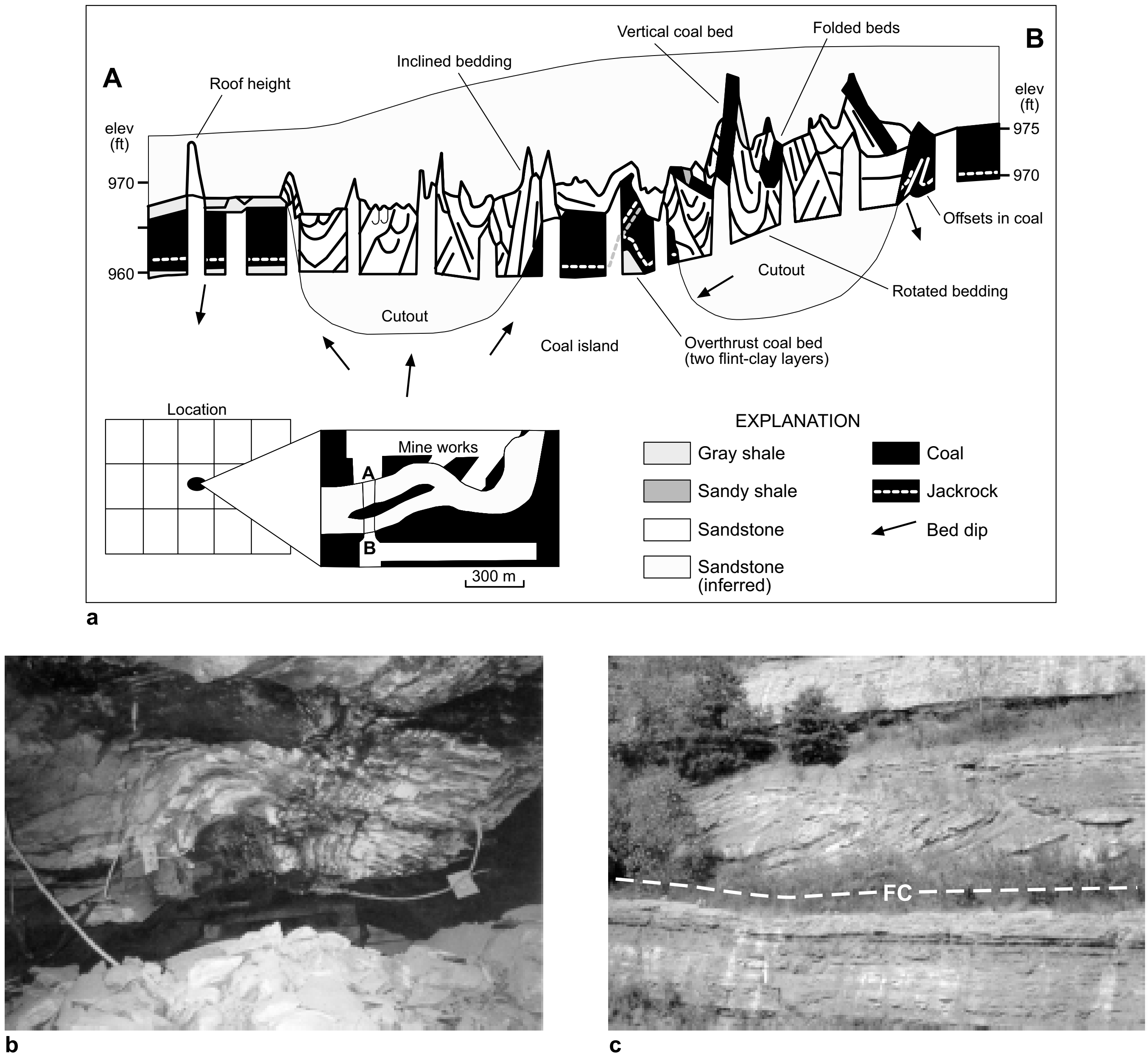

Figure 28. (a) Section through roof in an underground coal mine in which entries cross through a cutout channel with slumped bedding. From the Hazard South quadrangle. (b) Deformed roof rock in paleoslump. (c) Rotated bedding in paleoslump above Fire Clay coal (FC) along Kentucky Highway 15 near Buckhorn Lake.

vegetation and toppled trees. The lack of local lateral thickness variation in the flint clay shows that the ash was deposited on a relatively flat surface, without the irregularity of standing trees, which would be expected in a mire. The widespread, relatively regular distribution of the flint clay also argues for deposition in shallow water (rather than on an exposed surface where wind and rain would probably have caused local erosion and thickness variability), further suggesting that the lower mire was drowned prior to the ash falls. Because the ash is regularly distributed, current energy was nonexistent, so deposition probably occurred in a very shallow, relatively stagnant lake or bay. This body of water is inferred to have formed from a rise in the ground-water table. The net result of drowning and ash fall was an increase in the ash content of the lower coal bench, and an increase in the concentration of certain volcanic trace elements in the upper coal bench (Hower and others, 1994).

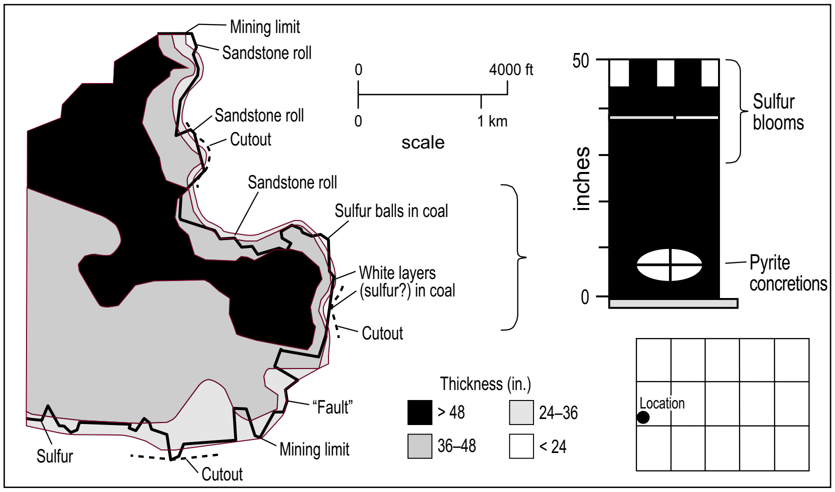

Figure 29. Fire Clay coal cutouts in the southwest corner of the Hyden West quadrangle showing locations of reported concretions and sulfur-bearing partings. "Faults" on mine maps appear to be sandstone and shale cutouts rather than tectonic fault displacement of the bed.

The ash falls caused ponding and the accumulation of muds prior to renewed peat accumulation. Studies of ash falls in Cretaceous coals of the western United States show that the ash increased the pH of the water in the peat mire, causing an increase in inertinite just below the ash layer. These Cretaceous ash layers also appear to have created semi-impermeable layers that caused local ponding of water. Crowley and others (1994) inferred that an increase in fern spore assemblages just above these western U.S. ash partings indicates that ferns were well suited to the wet substrates produced by ponding. A similar situation appears to have occurred in the Fire Clay coal. Eble and Grady (1990) noted an increase in fern spores (on average, 20 to 25 percent) within and just above the jackrock parting. Although ferns in the Cretaceous were different from the tree ferns of the Pennsylvanian Age, the vertical change in spore assemblages and the fact that inertinites also commonly increase beneath the jackrock

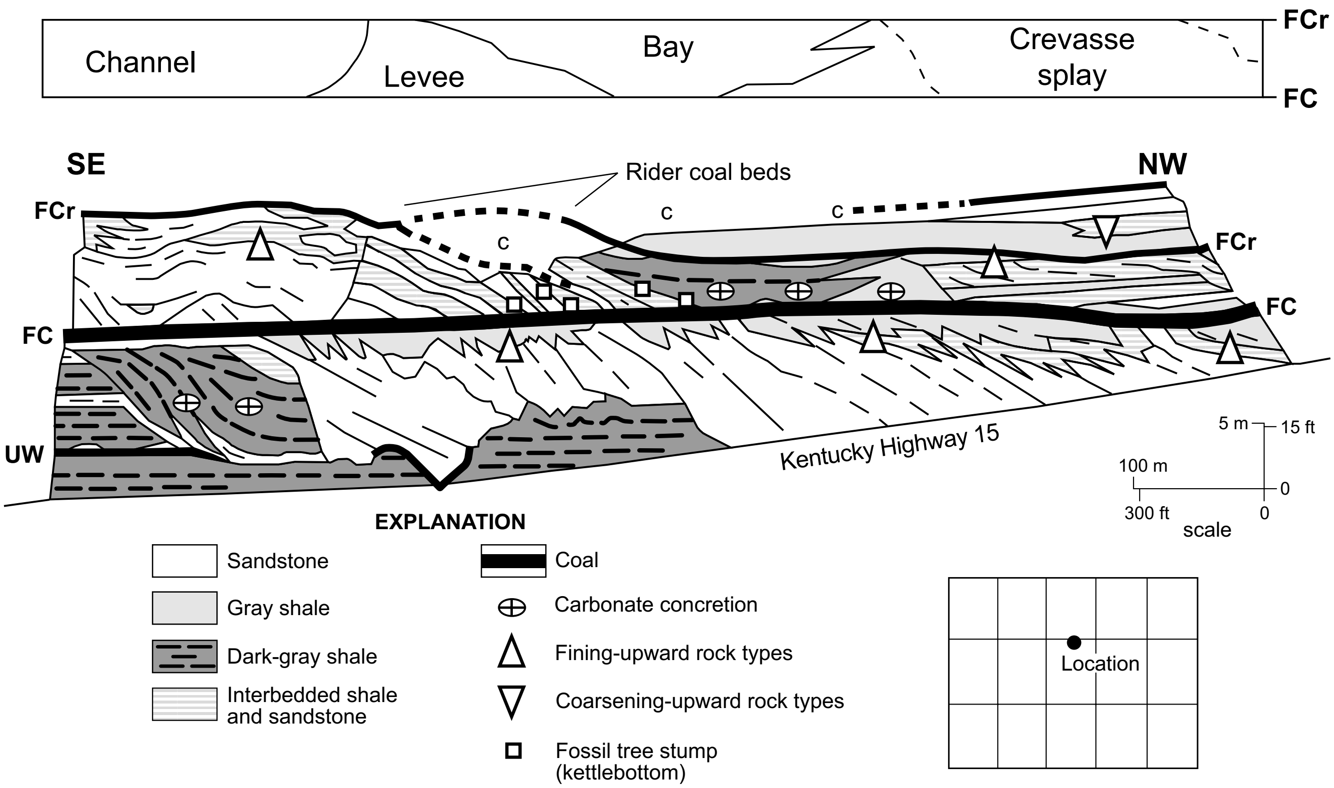

Figure 30. Roof-rock associations derived from photomosaic taken along Kentucky Highway 15 near Hazard. This type of lateral transition was found throughout the study area.

parting in the Fire Clay coal may justify the comparison. In addition to these similarities, cannel coals sometimes occur at the base of the upper bench of the Fire Clay, further supporting the idea of local ponding above the ash fall. Eble and Grady (1990) also noted an increase in cordaites within and just above the flint-clay parting, and suggested that this type of tree may have been well suited to the mineral-rich soil formed by the ash fall.

Upper Coal Bench. Petrographic and palynologic studies of the upper coal bench show that it began as a ground-water-fed (planar) peat, similar to but more widespread and uniform in character than the lower-bench peat. With time, the peat domed above the ground-water table across parts of the study area (Eble and Grady, 1990; Eble and others, 1999). When peats rise above the ground-water table, making them topographically higher than the surrounding area, they are less likely to be affected by clastic sedimentation from streams and other sources. This results in low ash yields and generally low sulfur contents. A domed-peat interpretation is supported for the upper coal bench by the regional extent of the relatively parting-free upper bench (more than 1,400 km^2).

Not only was the upper bench formed in a different type of swamp than the lower bench, it also accumulated under different regional controls. The lower coal bench accumulated along a rather sinuous trend (Fig. 8), probably related to compaction of underlying channel and interchannel deposits. The upper bench coal exhibits a different pattern. The crudely rectangular pattern of coal thickness (Fig. 11) is not the type of pattern commonly formed from compaction around underlying rock types. Rather, the rectangular pattern suggests structural controls.

The angular thickness trends shown in Figure 11 are interpreted as faults (Fig. 31). The main fault is a northeast–southwest-oriented structure striking from the northwest corner of the Hindman quadrangle to the southeast corner of the Hoskinston quadrangle. This feature is subtle and would be difficult to delineate without the data density used in this investigation. East of the fault, peat accumulated to its greatest thicknesses. Because the basin axis is toward the southeast, the fault is inferred to be down to the southeast. Coal thickens on the downthrown margin of the fault. Most coals and their enclosing strata thicken toward the basin axis.

West of the fault, the peat was affected by a series of northwest–southeast-oriented fault blocks, resulting in a series of northwest-oriented, elongate trends in coal thickness (Figs. 6, 11). Similar, but smaller-scale structural controls have been inferred for the Fire Clay coal (also the bench above the flint-clay parting) south of the study area (Weisenfluh and Ferm, 1991).

The identification of rectangular thickness patterns in the Fire Clay coal in different parts of the Eastern Kentucky Coal Field suggests that structural controls were widespread. By subtly controlling topography or ground-water flow, the faults may have controlled the areas in which the upper-bench peat was able to dome. Not all of the upper bench was a domed swamp. Lateral variation in coal quality in the upper bench reflects changes from domed conditions where the upper bench is thick, to planar conditions where the coal is thin. If thickness was fault-controlled, then the areas of domed and therefore low-sulfur peats were also fault-controlled.

Post-Coal Deposition. The upper-bench peat was buried by a west-flowing drainage system. At least one channel system can be traced across four quadrangles (Fig. 27). The angular changes in the sandstone channel mapped through the middle row of quadrangles suggest that channel location was controlled by the same fractures or faults that controlled the thickness of the upper peat. The channel appears to make a southwest change in course where it crosses the main northeast–southwest-oriented structure in the Hazard South quadrangle (Fig. 31). Lateral accretion surfaces (Fig. 21c) and a lack of bioturbation in or bidirectional paleocurrent data for the channel fills examined in outcrop suggest that the channels were part of a broad, meandering, fluvial drainage system. Channels flowed to the west and northwest in belts 2 to 6 mi wide.

Figure 30 illustrates environments of deposition that were common between fluvial channels during burial of the upper-bench peat. Channel sandstones truncate interbedded sandstones and shales, which dip away from the channel and are interpreted as the channel's levee (Fig. 30). Fossil tree trunks (Fig. 23g) on the dipping beds were formed by lycopod trees that grew on the levees. The levee deposit thins laterally into a dark-gray shale (Figs. 26a, 30), which was deposited in a quiet-water bay or estuary. Similar shales with carbonate concretions (Fig. 26a) are common in the western part of the study area (Fig. 27); this is toward the inferred paleocoastline. Rare bioturbation in interbedded sandstones and shales (Fig. 23e) marginal to some dark shales above the coal supports at least local brackish-water sedimentation in the Krypton quadrangle. Brackish water along the southwestern margin of the upper-bench peat and in the embayments marked by the elongate areas of thin coal west of the main northeast–southwest-oriented fault (Fig. 31) may have contributed to the higher sulfur contents (Fig. 14), higher ash yields (Fig. 15), lower Btu values (Fig. 16), in-seam concretions (Fig. 29), and possible westward splitting of the upper coal bench.

Figure 30 shows dark-gray shales grading laterally and being partly truncated by even-bedded sandstones

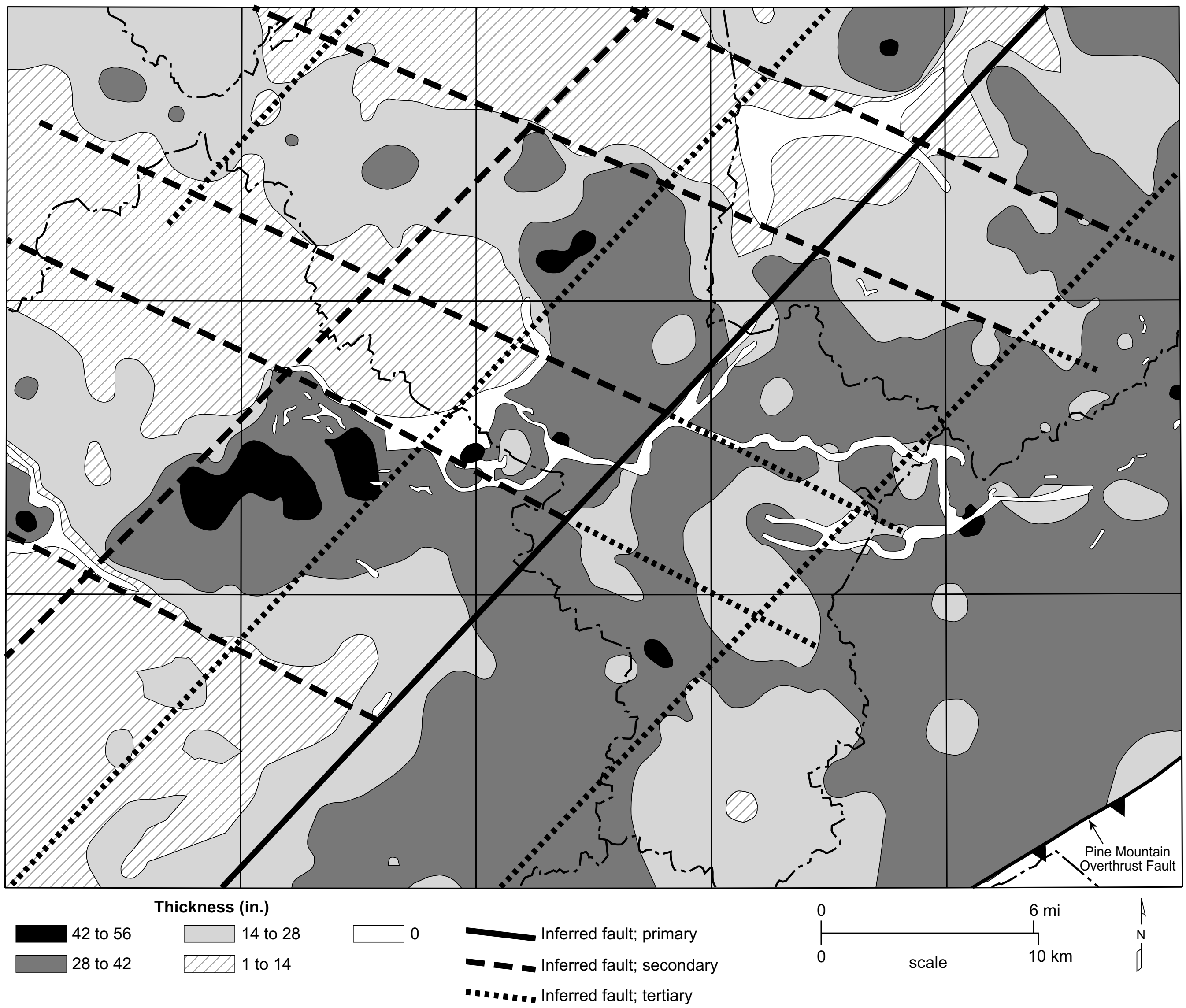

Figure 31. Total Fire Clay coal thickness showing central cutout trend and inferred position of faults.

and shales and a smaller sandstone channel. The small channel and lateral sheet sands were deposited in a crevasse splay, which probably emptied into the embayment through a breach in the levee. These crevasse-splay deposits (Figs. 22, 23a–b) are common in the narrow belts of heterolithic strata between the broad meandering channels (Figs. 27, 30). Where they interfinger with sandy gray shale or rooted sandstones and shales, the splay deposits represent infilling of flood plains rather than bays or estuaries. Flood-plain deposition appears to have been more common in the western part of the study area.

As the fluvial channels aggraded, peats accumulated on levees, splays, and flood plains, forming thin, often discontinuous coal riders. Numerous riders in areas between the sandstone belts (Figs. 17–20, 25, 30) indicate repeated periods of flooding followed by peat accumulation. The coal mapped as the Fire Clay rider appears to drape a 15- to 20-ft-thick channel system (Figs. 17–20), and may laterally cap splays and levees, as shown in Figure 30. Numerous riders and the discontinuous character of many of the rider coals indicate that the Fire Clay rider probably accumulated as a number of disconnected swamps, however.

Conceptual Ideas

During the course of this investigation, interviews with mining personnel suggested that coal quality should improve as the coal thinned, and that the jackrock parting would rise and fall in the coal. From a geological perspective, the flint-clay parting in the Fire Clay coal was deposited in a volcanic ash fall, and should be a relatively flat surface. When the flint clay is used as a datum, its position in the seam is a function of thickness variation in the lower coal bench. Where the parting occurs in the middle of the coal, the lower bench is thick. Where the parting is in the floor of the coal, the lower bench is absent. This concept of bench variability is critical to understanding lateral quality variation in the coal. Historically, the Fire Clay coal was most extensively mined where it consisted of two thick benches of coal with the jackrock in the middle or lower middle part of the coal. As development spread beyond the limits of the lower bench, the total seam height thinned and coal quality improved. This change in quality resulted from the loss of the lower bench, which has higher sulfur contents and ash yields than the upper bench (Eble and others, 1999). Near the limits of the upper bench, however, along the angular trends noted in Figure 31, thinning is often associated with decreasing coal quality, because the upper bench splits or grades into a carbonaceous shale. Hence, thinning resulting from a loss of the lower bench may be associated with increasing quality, but thinning of the upper bench is often also associated with decreasing quality. Understanding the juxtaposition of coal benches is important in potential mining areas.

To complicate matters further, adding coal rider benches to the upper bench can also decrease the overall quality of the Fire Clay coal. In many of the areas where the Fire Clay coal is more than 50 in. thick, a rider coal can be traced laterally to the area of thick coal (Figs. 24b, 25). Because the coal in these areas actually represents the merging of multiple coal benches, which were formed as different peats, the quality often differs from adjacent thinner areas (Eble and others, 1999). As when the lower bench is included, including a rider bench will lead to thicker, but poorer quality, coal.

Summary

Because eastern Kentucky coal beds such as the Fire Clay can be observed only in outcrops, roadcuts, mines, and drill holes, important characteristics of the coal must be inferred from geologic trends and extrapolated into the areas where the coal is concealed. In this study, detailed mapping of the Fire Clay coal in a 15-quadrangle region of the Eastern Kentucky Coal Field has identified regional trends in geology, coal thickness, and coal quality.

The first trend is caused by multiple benches of coal merging to form a single mineable bed. Each of the benches that make up the coal bed have distinct thickness and quality trends. The relative character of each bench contributes to the character of the whole coal at any one location. The bench of coal beneath the jackrock parting is not as widespread as the bench above the jackrock. Local rider benches that merge with the upper bench are also limited in extent. The extent of the benches is significant, because the lower coal bench and rider benches generally have higher ash yields and sulfur contents than the upper coal bench. Although they increase total coal thickness, the lower and rider coal benches often decrease total coal quality. Where practical, poor-quality lower and rider coal benches could be left in the ground or separated during mining to improve the quality of the mined product.

Differences in the characteristics of benches in a coal seam are not unique to the Fire Clay coal. Detailed descriptions of coal beds and partings can aid in identifying benches in other coals. By analyzing coals at bench scale, differences in coal-bench characteristics can be used to develop a better understanding of lateral and vertical variations in coal thickness and quality and especially to extrapolate the characteristics into unmined areas.

The second trend found in this study is the series of sharp, angular changes in the thickness of the upper coal bench, which is inferred to represent subtle faults. Even if these angular changes are formed by some other mechanism, they still appear to mark changes in coal thickness and quality that can be projected beyond the areas in which the Fire Clay coal is presently mined. Trends in roof-rock geology may also be related to these structures. If these subtle, linear changes in thickness are caused by faults, then these faults may affect other coals along the same trends. This is a powerful tool for future coal exploration.

References Cited

Andrews, W.M., Jr., Hower, J.C., and Hiett, J.K., 1994, Lithologic and geochemical investigations of the Fire Clay coal bed, southeastern Kentucky, in the vicinity of sandstone washouts: International Journal of Coal Geology, v. 26, p. 95–115.

Bohor, B.F., and Triplehorn, D.M., 1981, Volcanic origin of the flint clay parting in the Hazard No. 4 (Fire Clay) coal bed of the Breathitt Formation in eastern Kentucky, *in* Cobb, J.C., Chesnut, D.R., Hester, N.C., and Hower, J.C., Coal and coal-bearing rocks of eastern Kentucky (guidebook and road log for Geological Society of America field trip no. 14): Kentucky Geological Survey, ser. 11, p. 49–54.

Brant, R.A., 1983a, Coal resources of the Princess District, Kentucky: University of Kentucky Institute for Mining and Minerals Research, Energy Resource Series, 61 p.

Brant, R.A., 1983b, Coal resources of the Southwestern District, Kentucky: University of Kentucky Institute for Mining and Minerals Research, Energy Resource Series, 89 p.

Brant, R.A., Chesnut, D.R., Frankie, W.T., and Portig, E.R., 1983a, Coal resources of the Big Sandy District, Kentucky: University of Kentucky Institute for Mining and Minerals Research, Energy Resource Series, 47 p.

Brant, R.A., Chesnut, D.R., Frankie, W.T., and Portig, E.R., 1983b, Coal resources of the Hazard District, Kentucky: University of Kentucky Institute for Mining and Minerals Research, Energy Resource Series, 49 p.

Brant, R.A., Chesnut, D.R., Frankie, W.T., and Portig, E.R., 1983c, Coal resources of the Licking River District, Kentucky: University of Kentucky Institute for Mining and Minerals Research, Energy Resource Series, 57 p.

Brant, R.A., Chesnut, D.R., Frankie, W.T., and Smath, R.A., 1983d, Coal resources of the Upper Cumberland District, Kentucky: University of Kentucky Institute for Mining and Minerals Research, Energy Resource Series, 41 p.

Chesnut, D.R., Jr., 1983, Source of volcanic ash deposit (flint clay) in the Fire Clay coal of the Appalachian Basin: Compte Rendu, Dixième Congrès International de Stratigraphie et de Géologie du Carbonifère, v. 1, p. 145–154.

Chesnut, D.R., Jr., 1992, Stratigraphic and structural framework of the Carboniferous rocks of the central Appalachian Basin in Kentucky: Kentucky Geological Survey, ser. 11, Bulletin 3, 42 p.

Cobb, J.C., and Chesnut, D.R., Jr., 1989, Resource perspectives of coal in eastern Kentucky, *in* Cecil, C.B., Cobb, J.C., Chesnut, D.R., Jr., Damberger, H., and Englund, K.J., eds., Carboniferous geology of the eastern United States: 28th International Geological Congress, American Geophysical Union, Field Trip Guidebook T143, p. 64–68.

Cobb, J.C., Chesnut, D.R., Hester, N.C., and Hower, J.C., 1981, Coal and coal-bearing rocks of eastern Kentucky (Guidebook and road log for Coal Division of Geological Society of America field trip no. 14): Kentucky Geological Survey, ser. 11, 169 p.

Crowley, S.S., Dufek, D.A., Stanton, R.W., and Ryer, T.A., 1994, The effects of volcanic ash disturbances on a peat-forming environment—Environmental disruption and taphonomic consequences: Palaios, v. 9, p. 158–174.

Currens, J.C., 1981, Quality characteristics of the Upper Elkhorn No. 3 and Fire Clay coal beds, *in* Cobb, J.C., Chesnut, D.R., Hester, N.C., and Hower, J.C., eds., Coal and coal-bearing rocks of eastern Kentucky (Guidebook and road log for Coal Division of Geological Society of America field trip no. 14): Kentucky Geological Survey, ser. 11, p. 94–105.

Danilchik, W., 1976, Geologic map of the Hindman quadrangle, southeastern Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1308, scale 1:24,000.

Danilchik, W., and Lewis, R.Q., Sr., 1965, Geologic map of the Buckhorn quadrangle, southeastern Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1449, scale 1:24,000.

Eble, C.F., and Grady, W.C., 1990, Paleoecological interpretation of a Middle Pennsylvanian coal bed in the central Appalachian Basin, U.S.A.: International Journal of Coal Geology, v. 16, p. 2255–2286.

Eble, C.F., Grady, W.C., and Gillespie, W.H., 1989, Palynology, petrography, and paleoecology of the Hernshaw–Fire Clay coal bed in the central Appalachian Basin, *in* Cecil, C.B., and Eble, C., eds., Carboniferous geology of the eastern United States: 28th International Geological Congress, American Geophysical Union, Field Trip Guidebook T352, p. 133–142.

Eble, C.F., Hower, J.C., and Andrews, W.M., Jr., 1994, Paleoecology of the Fire Clay coal bed in a portion of the Eastern Kentucky Coal Field: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 106, p. 287–305.

Eble, C.F., Hower, J.C., and Andrews, W.M., Jr., 1999, Compositional variations in the Fire Clay coal bed of eastern Kentucky—Geochemistry, petrography, palynology, and paleoecology: Kentucky Geological Survey, ser. 11, Report of Investigations 14, 18 p.

Greb, S.F., Hiett, J.K., Weisenfluh, G.A., Andrews, R.E., and Sergeant, R.E., 1999a, Maps to accompany "Geology of the Fire Clay Coal in Part of the Eastern Kentucky Coal Field": Kentucky Geological Survey, Open-File Report OF-99-02, 15 plates.

Greb, S.F., and Weisenfluh, G.A., 1996, Paleoslumps in coal-bearing strata of the Breathitt Group (Pennsylvanian), Eastern Kentucky Coal Field, U.S.A.: International Journal of Coal Geology, v. 31, p. 115–134.

Greb, S.F., Weisenfluh, G.A., Andrews, R.E., Hiett, J.K., and Sergeant, R.E., 1999b, Available resources of the Fire Clay coal bed in part of the Eastern Kentucky Coal Field: Kentucky Geological Survey, ser. 11, Report of Investigations.

Haney, D.C., Cobb, J.C., Chesnut, D.R., Jr., and Currens, J.C., 1983, Structural controls on environments of deposition, coal quality, and resources in the Appalachian Basin in Kentucky: Compte Rendu, Dixième Congrès International de Stratigraphie et de Géologie du Carbonifère, v. 1, p. 69–78.

Horne, J.C., Ferm, J.C., and Milici, R.C., 1979, Field guide, *in* Ferm, J.C., and Horne, J.C., eds., Carboniferous depositional environments in the Appalachian region: Columbia, S.C., University of South Carolina, Department of Geology, p. 620–752.

Hower, J.C., Andrews, W.M., Jr., Wild, G.D., Eble, C.F., Dulong, F.T., and Salter, T.L., 1994, Quality of the Fire Clay coal bed, southeastern Kentucky: Journal of Coal Quality, v. 13, p. 13–26.

Huddle, J.W., Lyons, E.J., Smith, H.L., and Ferm, J.C., 1963, Coal resources of eastern Kentucky: U.S. Geological Survey Bulletin 1120, 247 p.

Huddle, J.W., and Englund, K.J., 1966, Geology and coal reserves of the Kermit and Varney area, Kentucky: U.S. Geological Survey Professional Paper 507, 83 p.

Lewis, R.Q., Sr., 1978, Geologic map of the Hyden West quadrangle, Leslie and Perry Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1468, scale 1:24,000.

Lyons, P.C., Outerbridge, W.F., Triplehorn, D.M., Evans, H.T., Jr., Congdon, R.D., Capiro, M., Hess, J.C., and Nash, W.P., 1992, An Appalachian isochron—A kaolinized Carboniferous air-fall volcanic-ash deposit (tonstein): Geological Society of America Bulletin, v. 104, p. 1515–1527.

Lyons, P.C., Spears, D.A., Outerbridge, W.F., Congdon, R.D., and Evans, H.T., Jr., 1994, Euramerican tonsteins—Overview, magmatic origin, and depositional-tectonic implications: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 106, p. 113–134.

Maughan, E.K., 1976, Geologic map of the Roxana quadrangle, Letcher and Harlan Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1299, scale 1:24,000.

Mixon, R.B., 1965, Geology of the Krypton quadrangle, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-389, scale 1:24,000.

Nelson, B.W., 1959, New bentonite zone from the Pennsylvanian of southwestern Virginia: Geological Society of America Bulletin, v. 70, p. 1651.

Ping, R.G., 1977, Geologic map of the Cutshin quadrangle, Leslie County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1424, scale 1:24,000.

Prostka, H.J., 1965, Geology of the Hyden East quadrangle, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-423, scale 1:24,000.

Prostka, H.J., and Seiders, V.M., 1968, Geologic map of the Leatherwood quadrangle, southeastern Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-723, scale 1:24,000.

Puffett, W.P., 1964, Geology of the Hazard South quadrangle, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-343, scale 1:24,000.

Puffett, W.P., 1965a, Geologic map of the Tilford quadrangle, southeastern Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-451, scale 1:24,000.

Puffett, W.P., 1965b, Geology of the Vicco quadrangle, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-418, scale 1:24,000.

Seiders, V.M., 1964, Geology of the Hazard North quadrangle, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-344, scale 1:24,000.

Seiders, V.M., 1965a, Geology of the Carrie quadrangle, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-422, scale 1:24,000.

Seiders, V.M., 1965b, Volcanic origin of flint clay in the Fire Clay coal bed, Breathitt Formation, eastern Kentucky: U.S. Geological Survey Professional Paper 525-D, p. D-52–D-54.

Selner, G.I., and Taylor, R.B., 1991, GSMAP7 system, version 7.52—Graphics programs and related utility programs for the IBM PC and compatible microcomputers to assist in compilation and publication of geologic maps and illustrations using geodetic and cartesian coordinates: U.S. Geological Survey Open-File Report 91-1, 151 p.

Smith, G.E., and Brant, R.A., 1980, Western Kentucky coal resources: University of Kentucky Institute for Mining and Minerals Research, Energy Resource Series, 148 p.

Stevens, S.S., 1979, Petrogenesis of a tonstein in the Appalachian bituminous basin: Richmond, Eastern Kentucky University, master’s thesis, 83 p.

Taylor, A.R., 1978, Geologic map of the Hoskinston quadrangle, Leslie County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1456, scale 1:24,000.

U.S. Army Corps of Engineers Construction and Engineering Research Laboratory, 1991, GRASS reference manual: U.S. Army Corps of Engineers Construction and Engineering Research Laboratory, 513 p.

Waldrop, H.A., 1976, Geologic map of the Blackey quadrangle, Letcher and Knott Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1322, scale 1:24,000.

Weisenfluh, G.A., and Ferm, J.C., 1991, Roof control in the Fire Clay coal group, southeastern Kentucky: Journal of Coal Quality, v. 10, p. 67–74.

Selected Coal Publications Available from the Kentucky Geological Survey

KGS Bulletin 2 (ser. 11): Geology and stratigraphy of the Western Kentucky Coal Field, by S.F. Greb and others, 1992, 77 p. **$8.00**

KGS Bulletin 3 (ser. 11): Stratigraphic and structural framework of the Carboniferous rocks of the central Appalachian Basin in Kentucky, by D.R. Chesnut Jr., 1992, 42 p., 8 plates. **$12.00**

KGS Information Circular 23 (ser. 10): Coal production in Kentucky, 1790–1975, by J.C. Currens and G.E. Smith, 1977, 66 p. **$2.50**

KGS Information Circular 8 (ser. 11): Stratigraphic framework of coal-bearing rocks in the Western Kentucky Coal Field, by D.A. Williams and others, 1982, 201 p. **$15.00**

KGS Information Circular 12 (ser. 11): Geologic descriptions and coal analyses for 1982 coal drilling in the Daniel Boone National Forest, eastern Kentucky, by R.R. Bergeron and others, 1983, 243 p. **$12.00**

KGS Information Circular 13 (ser. 11): General coal reflectance and rank study of the Eastern Kentucky Coal Field, by D.A. Williams, 1984, 47 p. **$3.75**

KGS Information Circulars 18–23 (ser. 11): Analyses of coal samples from the Princess, Hazard, Big Sandy, Southwestern, Upper Cumberland, and Licking River Districts. **Consult KGS "List of Publications" for prices.**

KGS Information Circular 29 (ser. 11): Predicting the impact of changes in the EPA compliance standard for sulfur emissions on the coal resources of eastern Kentucky, by J.C. Cobb and others, 1989, 9 p. **$2.50**

KGS Information Circular 38 (ser. 11): Sulfur in Kentucky coal and the Clean Air Act Amendments of 1990, by J.C. Cobb and C.F. Eble, 1992, 14 p. **$2.00**

KGS Information Circulars 42, 43, 47 (ser. 11): Available coal resources of the Booneville, Handshoe, and Salyersville South 7.5-minute quadrangles. **Consult KGS "List of Publications" for prices.**

KGS Information Circular 48 (ser. 11): Trace elements in coal: The next challenge, by C.F. Eble and J.C. Cobb, 1994, 4 p. **$1.00**

KGS Information Circular 59 (ser. 11): Kentucky's coal industry: Historical trends and future opportunities, by G.A. Weisenfluh and others, 1998, 9 p. **$5.00**

KGS Map and Chart Series 20 (ser. 11): Total coal thickness of the Lower Elkhorn coal in eastern Kentucky, by E.E. Thacker and others, 1998, 1 sheet. **$10.00**

KGS Report of Investigations 6 (ser. 10): Pennsylvanian cross sections in western Kentucky—Coals of the lower Carbondale Formation, part 1, by G.E. Smith, 1967, 14 p. **$1.50**

KGS Report of Investigations 5 (ser. 11): Amos and Foster coals: Low-ash and low-sulfur coals of western Kentucky, by D.A. Williams and others, 1990, 34 p. **$5.00**

KGS Report of Investigations 14 (ser. 11): Compositional variations in the Fire Clay coal bed of eastern Kentucky: Geochemistry, petrography, palynology, and paleoecology, by C.F. Eble and others, 1999, 18 p. **$6.50**

KGS Reprint 7 (ser. 11): Coal in Kentucky, by R.A. Brant and N.C. Hester, 1980, 11 p. **$1.00**

KGS Reprint 20 (ser. 11): Kentucky coal, by J.C. Cobb and others, 1985, 20 p. **$2.50**

KGS Reprint 36 (ser. 11): Determination of fluorine in coal and coal fly ash by proton-induced gamma-ray emission analysis, by A.S. Wong and others, 1993, 7 p. **$1.00**

KGS Special Publication 21 (ser. 11): Impact of hazardous air pollutants on mineral producers and coal-burning plants in the Ohio Valley, 1995, 25 p. **$3.00**

UK Institute for Mining and Mineral Resources publications: Coal resources of the Big Sandy, Hazard, Licking River, Princess, Southwestern, and Upper Cumberland Districts. **Consult KGS "List of Publications" for prices.**

USGS Miscellaneous Field Studies Map MF-2275: Revised correlation chart of coal beds, coal zones, and key stratigraphic units, Pennsylvanian rocks of eastern Kentucky, by C.L. Rice and J.K. Hiett, 1994, 1 sheet. **$3.00**

For information on obtaining copies of this publication and other Kentucky Geological Survey maps and publications, call:
Publication Sales Office
(606) 257-3896
View the KGS World Wide Web site at www.uky.edu/kgs