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Geological Factors Affecting Methane in the Beckley Coalbed

UNITED STATES DEPARTMENT OF THE INTERIOR

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UNITED STATES DEPARTMENT OF THE INTERIOR
Thomas S. Kleppe, Secretary

BUREAU OF MINES
Thomas V. Falkie, Director

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GEOLOGICAL FACTORS AFFECTING METHANE IN THE BECKLEY COALBED[1]

by

J. T. Popp[2] and C. M. McCulloch[2]

ABSTRACT

This Bureau of Mines study reviews the geological factors that affect methane in the Beckley coalbed in southern West Virginia, including overburden, coalbed structure, type of and changes in lithology above and below the Beckley coalbed, and presence of fractures in the coal and rock adjacent to the Beckley. Depending on the depth, the Beckley coalbed emits from 216 to 520 ft^3 of methane per ton of coal mined, and the Bureau estimates that methane emission in a deep, extensively developed mine in this area may exceed 3,000 ft^3 per day per ton of coal mined.

Average face cleat and butt cleat trends in the Beckley coalbed measured underground are N 33° W and N 53° E, respectively. Close cleat spacing contributes to the friable nature of the Beckley and provides easy movement for methane and water. Because rider coals, splits, and carbonaceous shales may contribute methane to mine emissions, predictions of methane emission based on gas content of the Beckley coalbed alone may be conservative. Beckley coalbed reserves in the study area are 234 million tons. The gas content of the Beckley coalbed averages 407 ft^3/ton, and the coalbed gas reserves are 108 billion ft^3.

INTRODUCTION

The Bureau of Mines, in cooperation with five local coal companies, studied the effects of geology on methane in the Beckley coalbed. The study area includes portions of Fayette, Raleigh, and Wyoming Counties, in southern West Virginia, where five underground coal mines are presently working in the Beckley coalbed. The Beckley coalbed is being developed in the deeper parts of its basin of deposition; earlier development was hindered by irregular coal thickness and increasing methane emission with depth. Because the Beckley, a low-volatile metallurgical coal, is in large demand, three mines (Beckley, Beckley No. 1, and Maple Meadow) have opened in the last 4 years with another mine (Beckley-Lick Run) under construction. Initial desorption tests of coal

[1] This report contains portions of a Master's Thesis in Geology completed at Southern Illinois University, Carbondale, Ill.
[2] Geologist.

cores and mine methane emissions in the new mines indicate a high methane content, especially as mining deepens.

Because the structure and stratigraphy of the Beckley coalbed control the migration and retention of methane, geologic maps were constructed from core logs and mine data. These maps include the coalbed structure, coal thickness, overburden thickness, mined-out coal areas, and lithology above and below the Beckley. Surface joints were measured and are presented on a quadrangle basis. Cleat directions in the five mines were also measured, and the relation of the joints to the coal cleat is examined.

Finally, the amount of methane in the Beckley coalbed is estimated. The data collected indicate that the Beckley coalbed will probably be gassier than the Pocahontas No. 3 coalbed, especially as mining moves under 1,000 feet of overburden.

ACKNOWLEDGMENTS

The authors thank the following companies and their officials for their cooperation in collecting data: Beckley Coal Mining Co., Maple Meadow Mining Co., The New River Co., Ranger Fuel Corp., and Westmoreland Coal Co.

The authors also thank Dr. Russell Dutcher, Department of Geology, Southern Illinois University, Carbondale, Ill., for his suggestions regarding preparation of the manuscript.

HISTORICAL BACKGROUND

The first use of the Beckley coalbed coincided with settlement in the area where the Beckley crops out. Early settlements began in the Wyoming County area in the 1780's. As railroads extended from Virginia into West Virginia in the 1880's, mining increased.

Previous Work

Investigations concerning the Beckley coalbed are divided into two categories: Studies of carbonizing properties and blending qualities of the Beckley, and geological studies of problems related to coal deposition in southern West Virginia.

The first geologic references to the Beckley coalbed are by Campbell (8-9)[3] in 1898 and 1902 and White (72) in 1903, who published columnar sections of the Beckley and other New River sedimentary units. According to Hennen (34), the Beckley is the equivalent of the War Creek coalbed as reported by White (73).

Carbonizing properties were studied by Aresco (2-5), Fieldner (25-26), Davis (15), Reynolds (57), and others (7, 26, 55, 63, 66). In 1944, Headlee

[3]Underlined numbers in parentheses refer to items in the list of bibliography preceding the appendix.

(31) described both the petrography of the Beckley and the flow of methane through different coal types, while the physical properties and characteristics of the Beckley were described in 1955 (32). Estimates of recoverable reserves of the Beckley in several counties are made by Dowd (21) and Wallace (70-71).

Two different ideas on the geologic history of the area are reported in the literature. Gwinn (29) and Price (56) have published papers on the deposition, thickness, and irregular structures of the Beckley coal. Gwinn placed responsibility for the irregular coal thickness on deposition on an irregular surface. Working in Kentucky, Ohio, and Pennsylvania, Ferm (23-24) advanced the idea that the strata containing coals similar in age and stratigraphic position to the Beckley represent successive depositional environments relating to deltaic sedimentation. Galloway (28) and Robinson (58-59) have found a similar environment of deposition in the Fayette-Raleigh County area, working with the Beckley coalbed.

Origin of Methane in Coal

A fundamental understanding of the origin of methane in coalbeds is necessary to relate geology to methane movement. Because methane is a hazard to underground coal mining, a great deal of literature is devoted to the origin and movement of methane. A basic explanation of the origin of methane is discussed here; for a more complete discussion see Hass (30), Selden (62), Moore (48), and Venter (68).

Two theories for the origin of methane in coal are (1) that methane in coal originates in a source foreign to the bed, and (2) that methane is generated within the bed. The latter theory is preferred in this study.

Atmospheric gases absorbed by and occluded in peat and dissolved in swamp waters during the first stages of accumulation of plant material have been suggested as an outside source (16). Gases produced by the transformation of organic material during coalification and gases produced by radioactive disintegration of elements in the coal strata are an internal source. However, the most important process, volumetrically speaking, is by the transformation of organic materials into gases (16). In this process, methane is a product of anaerobic bacterial metabolism of cellulose, lignin, wax, and resins. This process takes place in three stages:

1. The cellulose ferments, forming mostly carbon dioxide, hydrogen, and methane. Because the vegetal matter is exposed either to water or air, most of the gas is released to the atmosphere.

2. This is followed by the slow decomposition of lignin. A sediment may have accumulated over the deposit to allow the presence of moisture, but not of air. Differential diffusion in this stage allows carbon dioxide to be absorbed by the water, and hydrogen is diffused through the sediment to the atmosphere while the coal retains the methane.

3. In the final stage, methane is prevented from escaping by burial and is trapped in the coal. With increasing pressure at depth and lack of complete impermeability, some methane escapes while some is contained within roof and floor rock (52). The result is a coal with high methane content relative to carbon dioxide, hydrogen, and other gases, characteristics of the internal source theory of methane generation. Gas samples taken from the Beckley coalbed by Bureau of Mines personnel contain more than 97 pct methane and less than 0.5 pct carbon dioxide, percentages that favor the internal source theory.

GEOLOGY OF THE BECKLEY COALBED

Lotz (43) has shown that the Beckley coalbed has a minable thickness and low mineral matter content for more than 600 square miles (fig. 1). Although original minable Beckley reserves were estimated at over 2 billion tons, recent exploration by mining companies shows the reserves to be more extensive. In the central part of its basin the Beckley coalbed ranges in thickness from 3 to 10 feet with local thickenings up to 22 feet. Headlee (31) describes the Beckley as soft, columnar, and multibedded. In hand specimens the Beckley

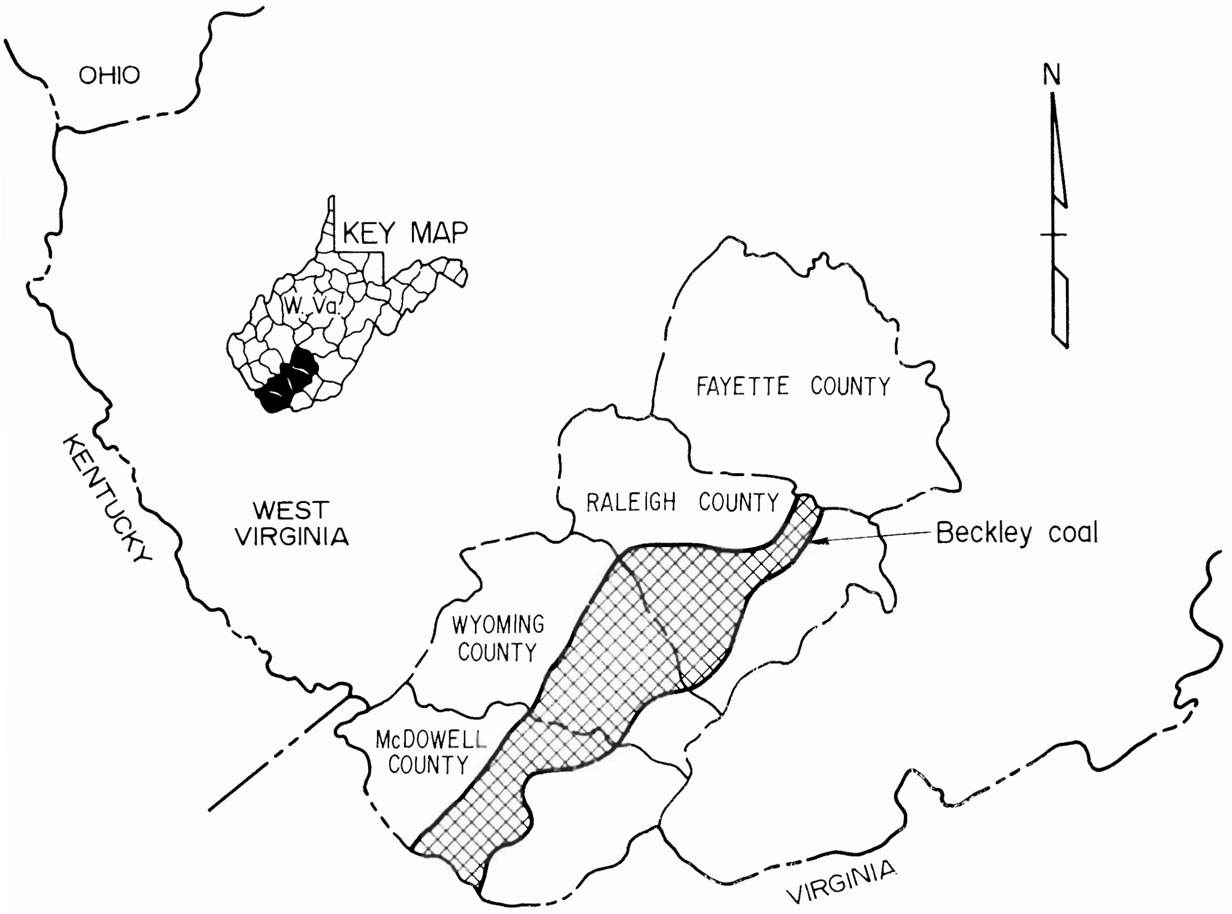

FIGURE 1. - Original minable extent of the Beckley coalbed.

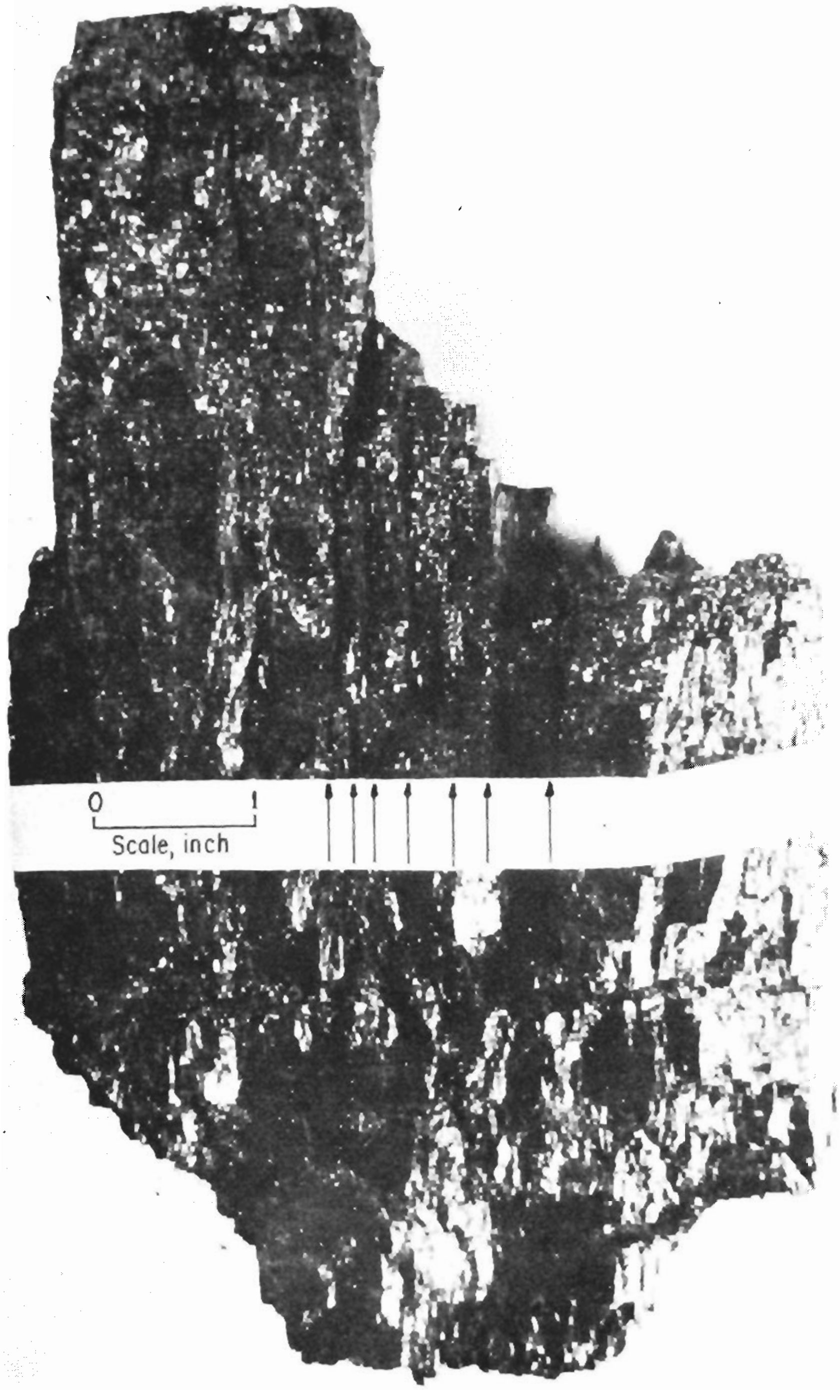

FIGURE 2. - Cleat spacing in a hand specimen of Beckley coal.

exhibits a cleat spacing as close as 1/8 inch.

Generalized Stratigraphy of the New River Formation

The study area (fig. 3) is west of the Allegheny Front and within the gently folded Appalachian Plateau. The New River Formation, the middle formation of the Pottsville Group, is characterized by orthoquartzites that are comparable in lateral continuity to the formation's coalbeds. The Sewell and Beckley are the principal economic coalbeds of this formation.

Hennen (34) describes the New River Formation as attaining a maximum thickness of 1,030 feet in Wyoming and McDowell Counties. Galloway (28) found that, within Raleigh County, the formation thinned 400 feet in a northwest direction. Within the study area the New River Formation varies in thickness for two reasons: (1) The formation generally thins to the north, and (2) minor transgressions, regressions, and erosion have locally thinned, thickened, or removed sections of the geologic column.

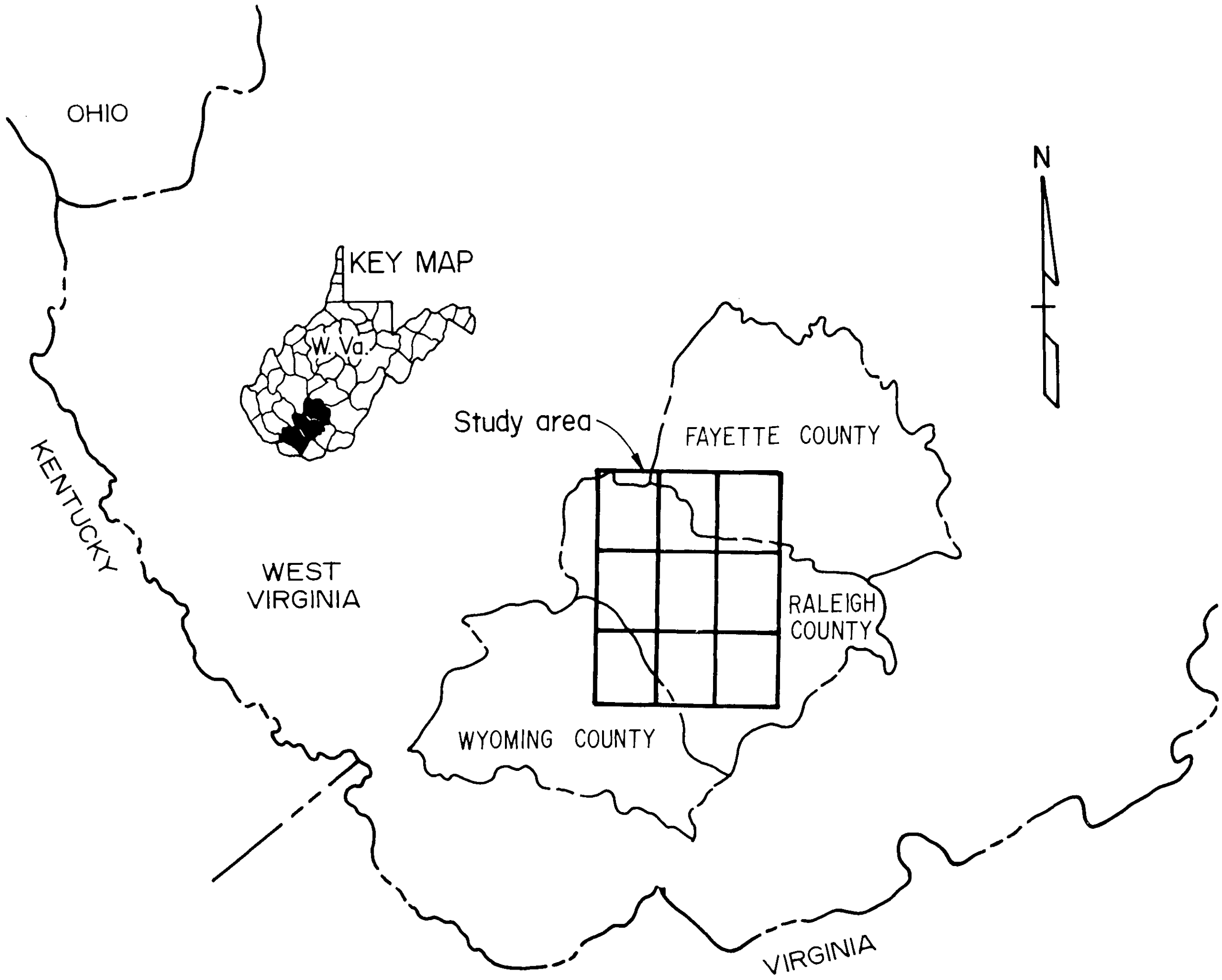

FIGURE 3. - Location of study area.

Figure 4 is a generalized stratigraphic column constructed from core hole descriptions of lithology between the Sewell and Fire Creek coalbeds. The more important stratigraphic markers include the Sewell coalbed, the Raleigh Sandstone, the Beckley coalbed, the Quinnimont Sandstone, and the Fire Creek coalbed. The core descriptions used are taken from characteristic core holes representing the different lithologies between the coalbeds from each mine property. The interval between the Sewell and Beckley coalbeds ranges from a section of sandstone to a section dominated by shale with several coals. Recognition of the Beckley in core hole descriptions is dependent on recognizing key beds and the intervals between these beds. The Sewell-Fire Creek interval is considered important here because of the confusion between the lower split of the Beckley and the Fire Creek.

The multibedded character of the Beckley is important in mining. In the Eccles No. 5 mine, for example, the Beckley coalbed is often found in three distinct coal units separated by two shale or slate bands. Dowd (21) noted that as much as 50 feet of strata may separate the three benches. An example

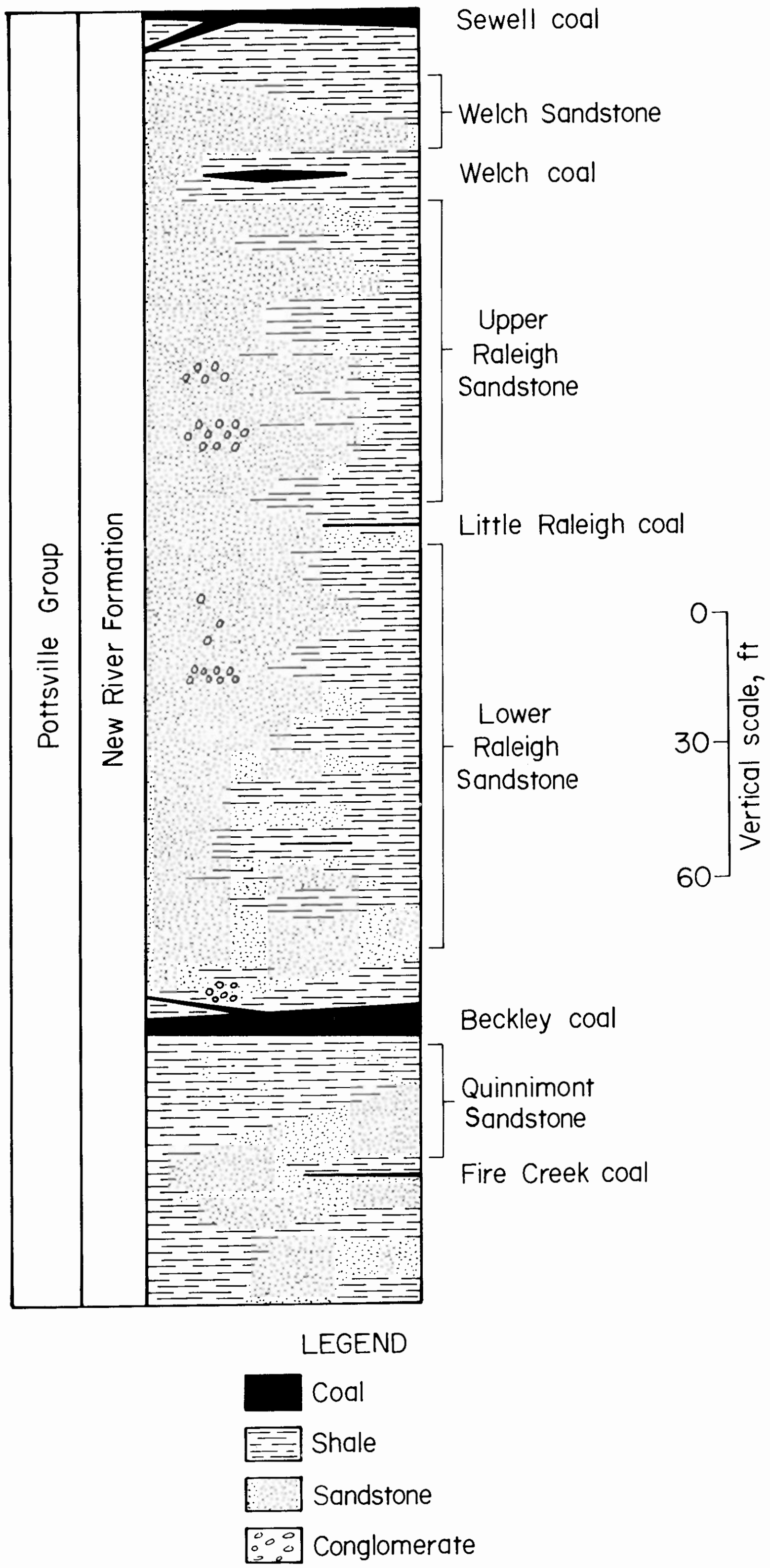

FIGURE 4. - Generalized stratigraphic column of the Sewell-Fire Creek interval.

FIGURE 5. - Split between the upper and lower Beckley coalbed near Slab Fork, W. Va.

of two coal benches separated by a split is shown in figure 5. If the bench being mined pinches out, the miners must tunnel through the split to mine the other bench. Because of the danger of roof falls and cave-ins, and because one bench is frequently unminable, benches are not usually mined simultaneously.

Regional and Local Structure

The Beckley coalbed lies in an area of southern West Virginia marked by gentle anticlines and synclines roughly parallel to the Allegheny Front. The sedimentary units are younger west of the Allegheny Front and dip to the northwest between 1° and 2° (90 to 180 feet per mile).

Figure 6 is a map of the data points used to prepare the maps in this report. It should be noted that the Beckley-Lick Run Mine has been included in figure 6 to show its proximity to the other mines even though it is still under construction. Because it is not open, the Beckley-Lick Run Mine is not included in the underground cleat surveys (fig. 8 and table 1), the mined-out areas (fig. 15), and the coal production and methane emission data (table 6). Figure 7 is a structure contour map of the study area drawn on the base of the Beckley coalbed. The map is drawn with a 40-foot contour interval to aid in the construction of an overburden isopach map from topographic maps with the same contour interval. It is similar to earlier mapping (34) and illustrates two structural features in the southwestern portion of the study area--the Pineville anticline and the Pineville syncline.

No structural faults were detected in the study area, although mining officials refer to areas within several mines as being "faulted-out." This refers to "want" areas where the coal thins or is not present, representing a sedimentary feature rather than a structural feature. (See appendix.)

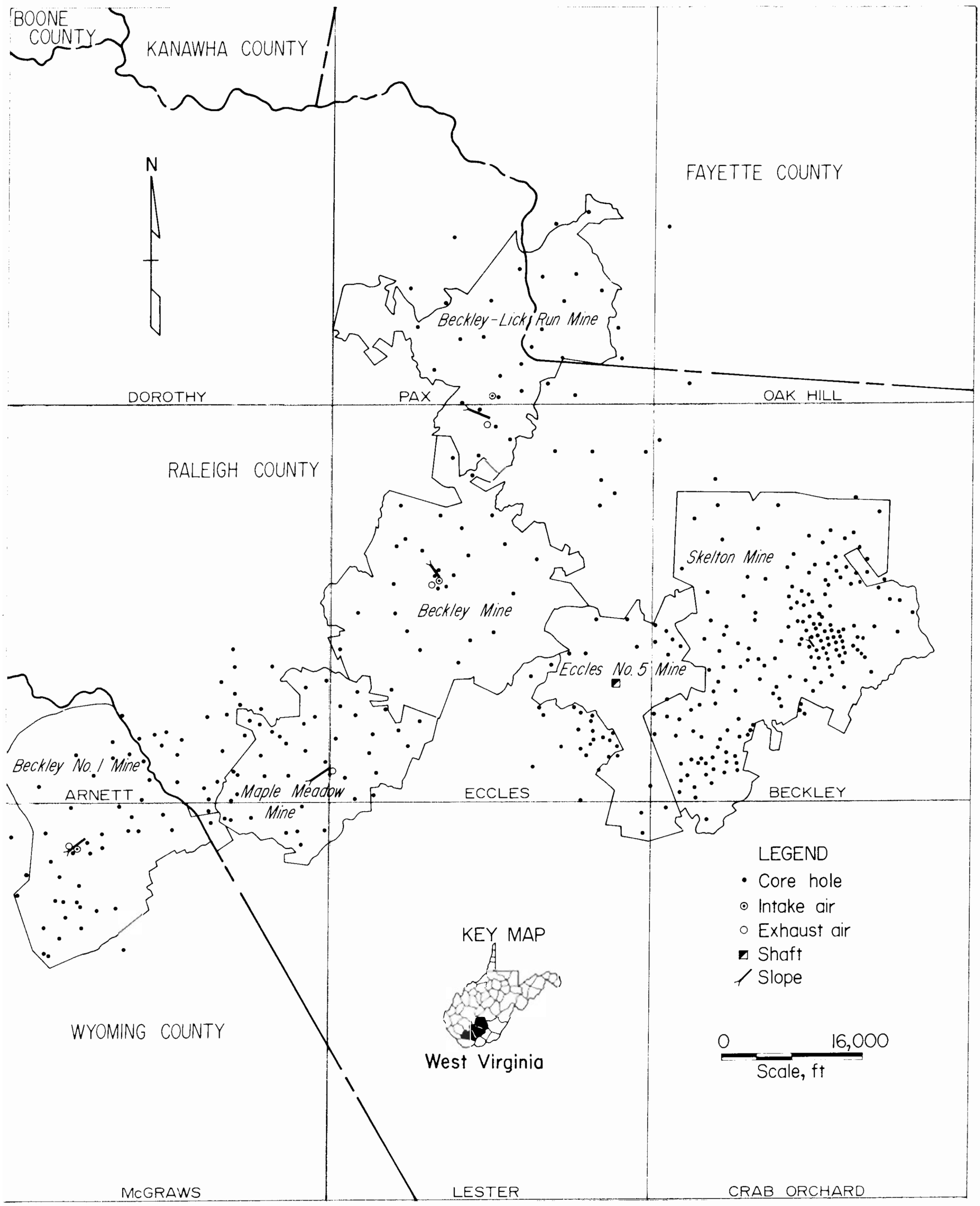

FIGURE 6. - Base map with data points and property outlines.

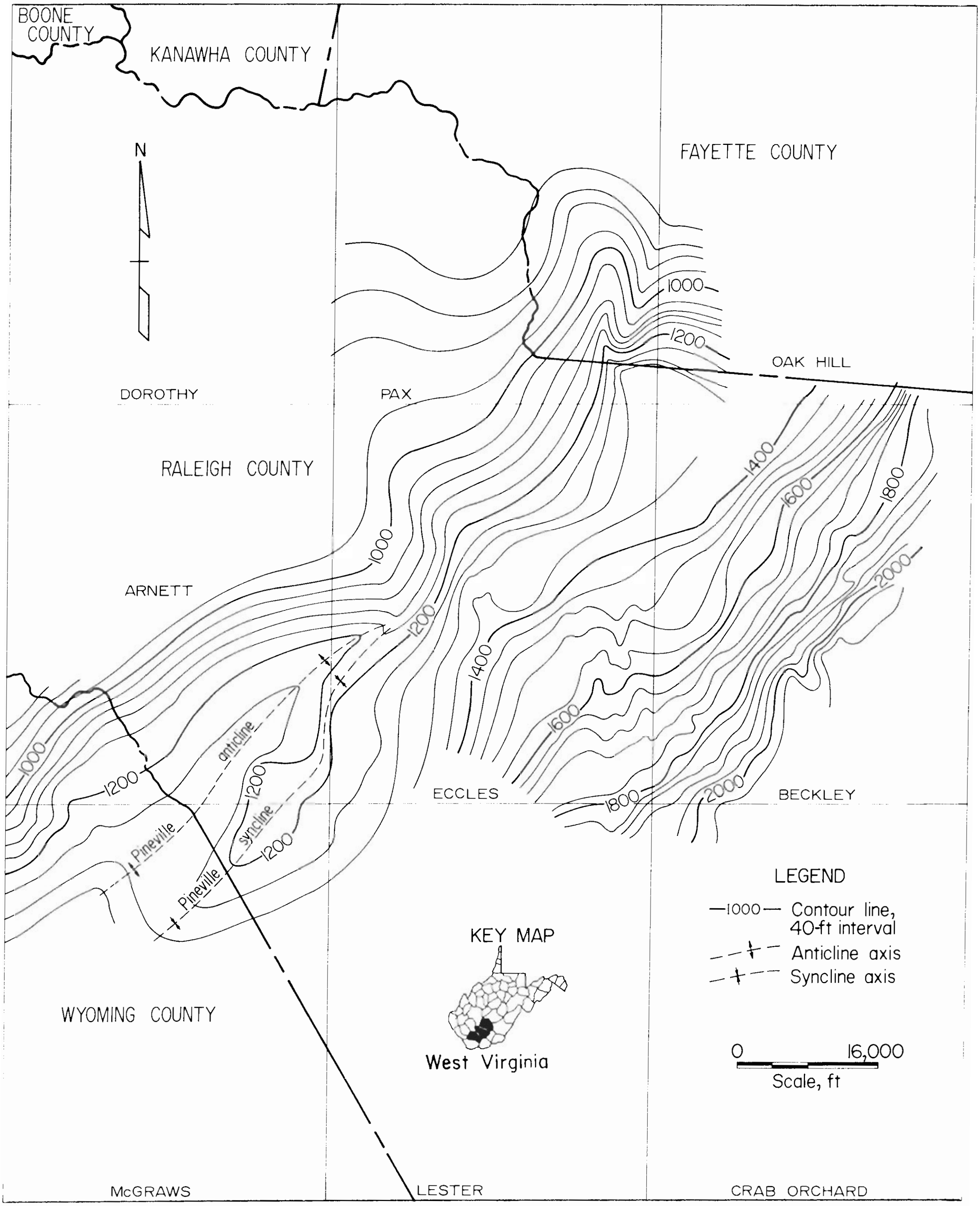

FIGURE 7. - Structure contour map of the base of the Beckley coalbed.

FRACTURE TRENDS IN ROCK AND COAL

Sedimentary rocks including coalbeds are cut by fractures. Because fractures increase the permeability of rock and coal to fluid migration, the relationship of methane movement to fracture systems is examined below.

Cleat in Coal

The natural vertical fracture system in bituminous coalbeds is called cleat. Two cleat directions, the face cleat and butt cleat, are common to coal, with the face being more prominent than the butt. (See appendix.) Because coal tends to break along cleat, the orientation of the cleat has in the past controlled the direction of mining. With the advent of continuous-mining machines, the direction of mining is no longer solely determined by the direction in which coal most easily fractures. Cleat is important in the flow of methane and water into mines, and a direct permeability relationship has been formed between the amount of gas emitted and cleat direction (45).

Cleat directions were measured at locations throughout the five mines and plotted on rose diagrams (fig. 8). Directional trends for the cleat systems and their separations are listed in table 1.

TABLE 1. - Measured cleat directions in the Beckley coalbed

Mine	Face cleat	Butt cleat	Separation
Beckley.................	N 36° W	N 49° E	85°
Beckley No. 1...........	N 37° W	N 72° E	109°
Eccles No. 5............	N 34° W	N 52° E	86°
Maple Meadow............	N 25° W	N 60° E	95°
Skelton.................	N 28° W	N 47° E	74°

Joints in Rock

A fracture system along which there has been no movement is called jointing; such systems are common to most sedimentary rocks. Joints are nearly vertical and disrupt the physical continuity of the rock mass. (See appendix.) Jointing in surface strata is believed to indicate the direction of inherent weakness in the Beckley coalbed. Determination of the dominant joint directions in advance of mining permits the planning of entries and mine development in directions that reduce mining problems. In addition, the joint directions determine the spacing of holes for maximum gas flow from hydraulically stimulated vertical degasification holes.

Surface measurements of joints above the Beckley coalbed were made within the study area. An average of 113 joint readings were made per quadrangle with a minimum of 100 readings per quadrangle and no more than 10 at each outcrop. The directions were read on azimuth-type damped Brunton compasses and corrected for magnetic declination.

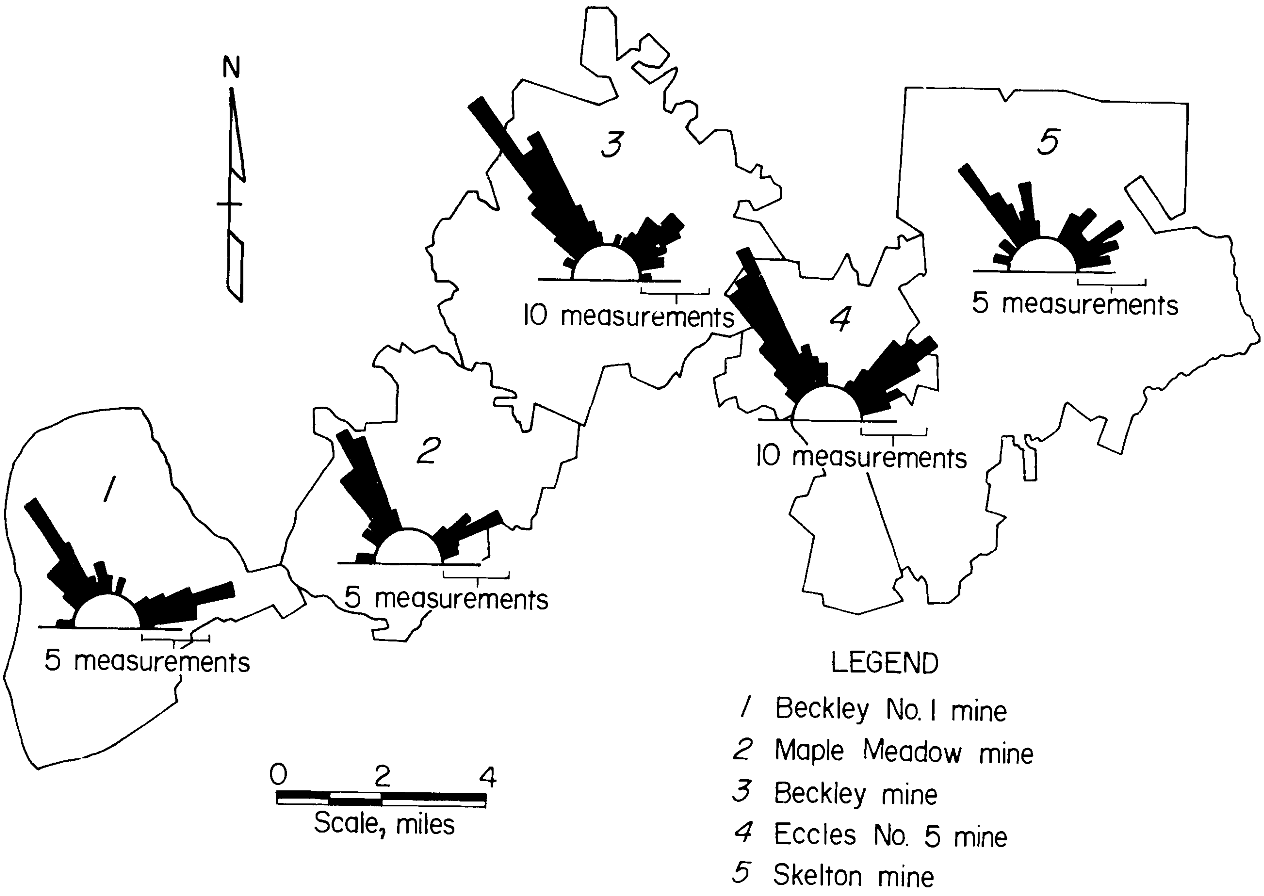

FIGURE 8. - Rose diagrams of subsurface cleat directions in the Beckley coalbed.

Rose diagrams were plotted to determine the major joint directions for each quadrangle and assembled for the study area (fig. 9). The directional trends for each quadrangle are listed in table 2.

TABLE 2. - Principal joint directions measured

Quadrangle	Joint	Directions	Separation
Arnett...........................	N 49° W	N 43° E	92°
	N 88° W	N 01° E	89°
Beckley..........................	N 34° W*	N 57° E*	93°
	N 63° W	N 25° E	88°
		N 71° E**	
		N 84° E**	
Crab Orchard.....................	N 82° W	N 22° E	104°
	N 62° W*	N 37° E*	99°
	N 40° W	N 65° E	105°
	N 38° W	N 65° E	103°
Dorothy..........................	N 09° W	N 73° E	82°
	N 46° W	N 50° E	96°
	N 58° W	N 28° E	86°
Eccles...........................	N 20° W*	N 72° E*	92°
	N 76° W	N 41° E	117°
Lester...........................	N 38° W	N 53° E	91°
McGraws..........................	N 51° W	N 41° E	92°
	N 39° W	N 51° E*	90°
Oak Hill.........................	N 42° W	N 52° E	94°
Pax..............................	N 16° W	N 74° E	90°

*Dominant trend.
**Trends that do not represent a fundamental system.

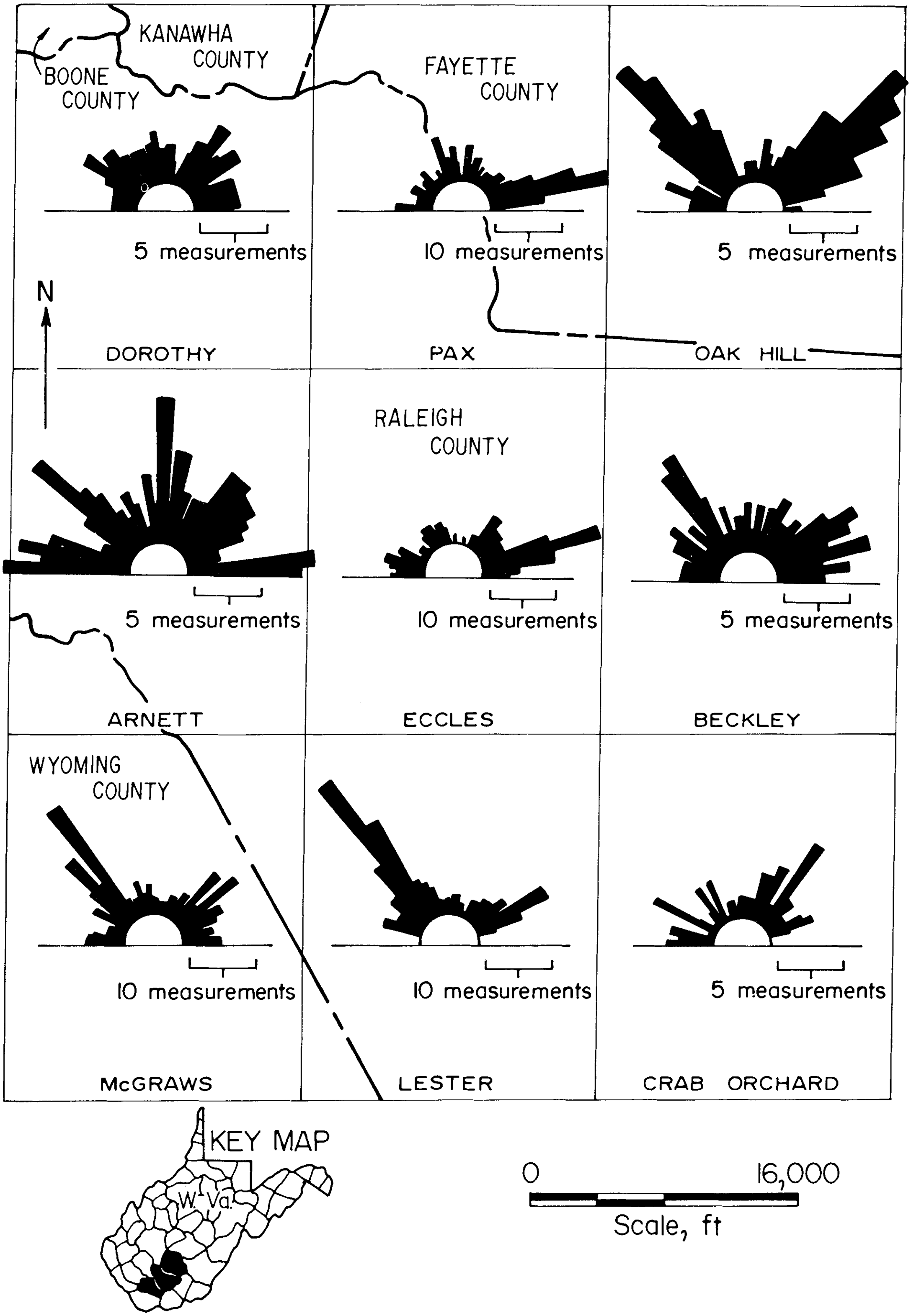

FIGURE 9. - Rose diagrams of surface joint measurements.

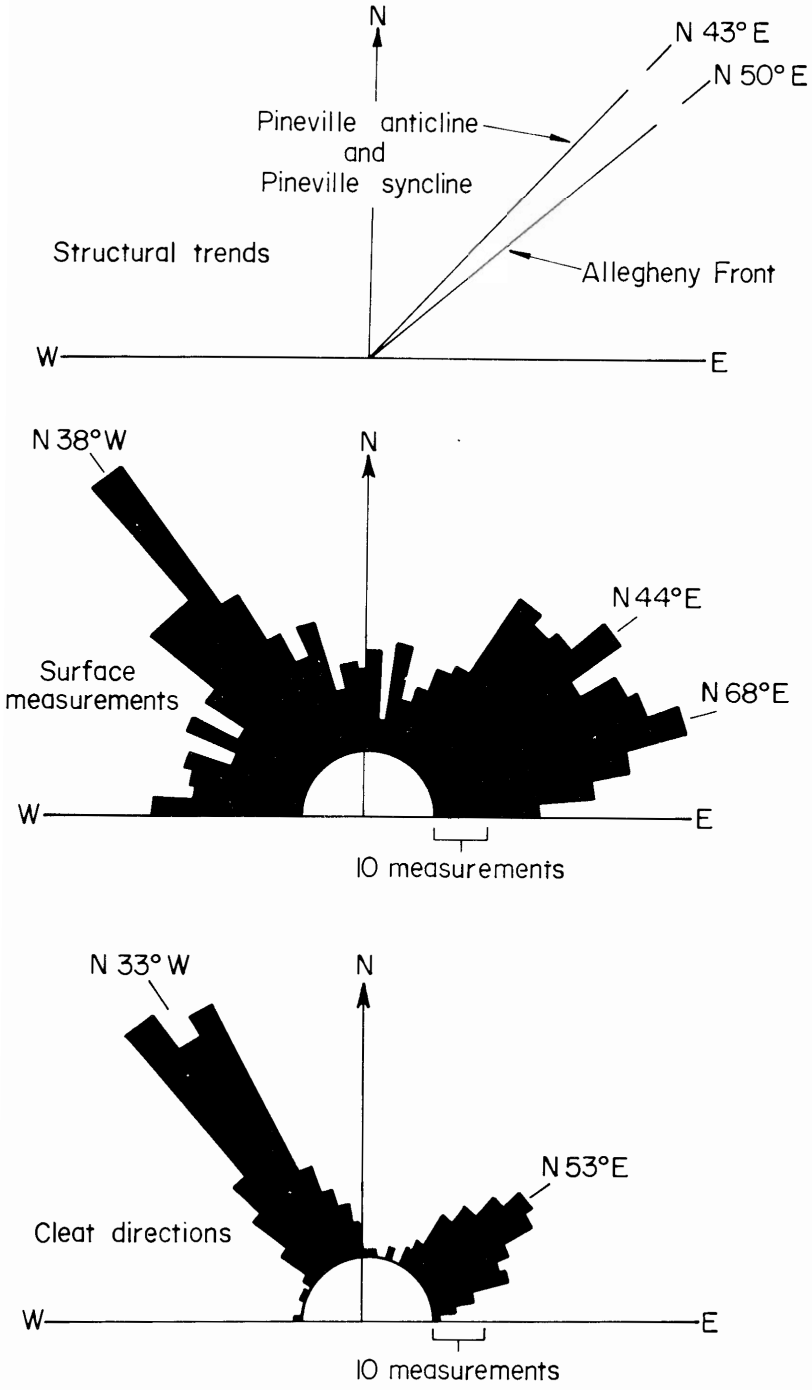

FIGURE 10. - Comparison of subsurface cleat directions, surface measurements, and structural trends.

Relationship of Cleat and Joints to Regional Structure

In figure 10 rose diagrams of all subsurface and surface measurements are compared with the regional structural trends. Combining cleat measurements from all mines into a single rose diagram highlights the fundamental cleat system; the face cleat is at N 33° W, and the butt cleat is at N 53° E with an 86° separation. When the 1,021 surface measurements for all nine quadrangles are combined, three trends are recognized: N 44° E (nonsystematic), N 68° E (nonsystematic), and N 38° W (systematic). These trends are assumed to represent a fundamental joint system as described by Nickelsen (50) with one systematic trend and two nonsystematic trends present.

The Pineville anticline and the Pineville syncline are seen in figure 7 and are nearly parallel with the Allegheny Front, which trends N 50° E, east of the study area. During folding, the systematic joints and face cleats formed parallel to the direction of greatest compression, while the nonsystematic joints and butt cleats formed parallel to the direction of least stress. This can be observed in figure 10 where the parallelism of the face cleats with the systematic joints, and of the butt cleats with the nonsystematic joints and structural trends, is evident. The relationship of fracture trends and fold axes to the structural front noted here is similar to that developed in earlier work (45, 51, 69).

In the Eccles No. 5 mine there is a correlation of cleat directions (face cleat N 34° W, butt cleat N 52° E) to surface joint measurements (N 32° W, N 48° E) above the mine. This correlation supports a study in which coal cleat orientation in the Pittsburgh coalbed was estimated using surface joint measurements (19).

GEOLOGIC FACTORS AFFECTING METHANE EMISSION

Methane is intimately associated with coal. Research has shown that methane is contained under pressure in equilibrium with its surroundings until coal is mined, faulted, or intercepted by drilling, and that methane moves once its environmental equilibrium is upset (11-12, 14, 18). This research shows that methane and its movement in the coalbed environment are related to geology. The geologic factors affecting methane emission in the Beckley coalbed considered here are lithologic variations above and below the Beckley coalbed, overburden thickness above the Beckley coalbed, thickness of the Beckley coalbed, structure of the Beckley coalbed, and cleat orientation in underground mines.

Lithologic Variations Above and Below the Beckley Coalbed

Methane emission from Beckley coalbed mines is not only from coal, but also from adjacent strata. The presence of porous and permeable sandstone above and/or below the Beckley may allow methane to enter the mine atmosphere from external sources such as rider coals, splits, and carbonaceous shales. Panel diagrams illustrate lateral and vertical changes in lithology above and below the Beckley and possible external sources of methane.

The panel diagrams were constructed using nearly 80 core holes and drillers' logs selected from some 250 logs available and represent the regional stratigraphic trends. The lithologic descriptions are very general and represent only coal, sandstone, and shale. Because of rapid lateral changes in lithology above and below the Beckley, panel interpretations from data locations more than 1 mile apart are less reliable than data located within one-half mile; an optimum core hole spacing might be 2,000 feet with more holes in areas of low coal. The panel diagrams of the roof strata are drawn from the base of the Beckley coalbed, while the panel diagrams of the floor strata are drawn from the top of the coalbed; both diagrams are terminated at a lithologic contact whenever possible.

According to Krebs (42), the strata below the Beckley coalbed consist of a lenticular sandstone with a dark gray, lenticular shale beneath, underlain by the Fire Creek coalbed. Any or all of these units may be absent. Carbonaceous shales in the floor, formed from organic-rich muds, may be a source of methane (64), especially if the shale is permeable. In the mines surveyed, the floor lithology ranged from a black shale to a sandy shale; in the Maple Meadow and Beckley mines methane was being emitted from a black shale.

Figure 11 shows the strata below the Beckley. Because exploration cores are not usually drilled very far below the coal, fewer data points are available than in the construction of geologic maps on the strata above the coalbed.

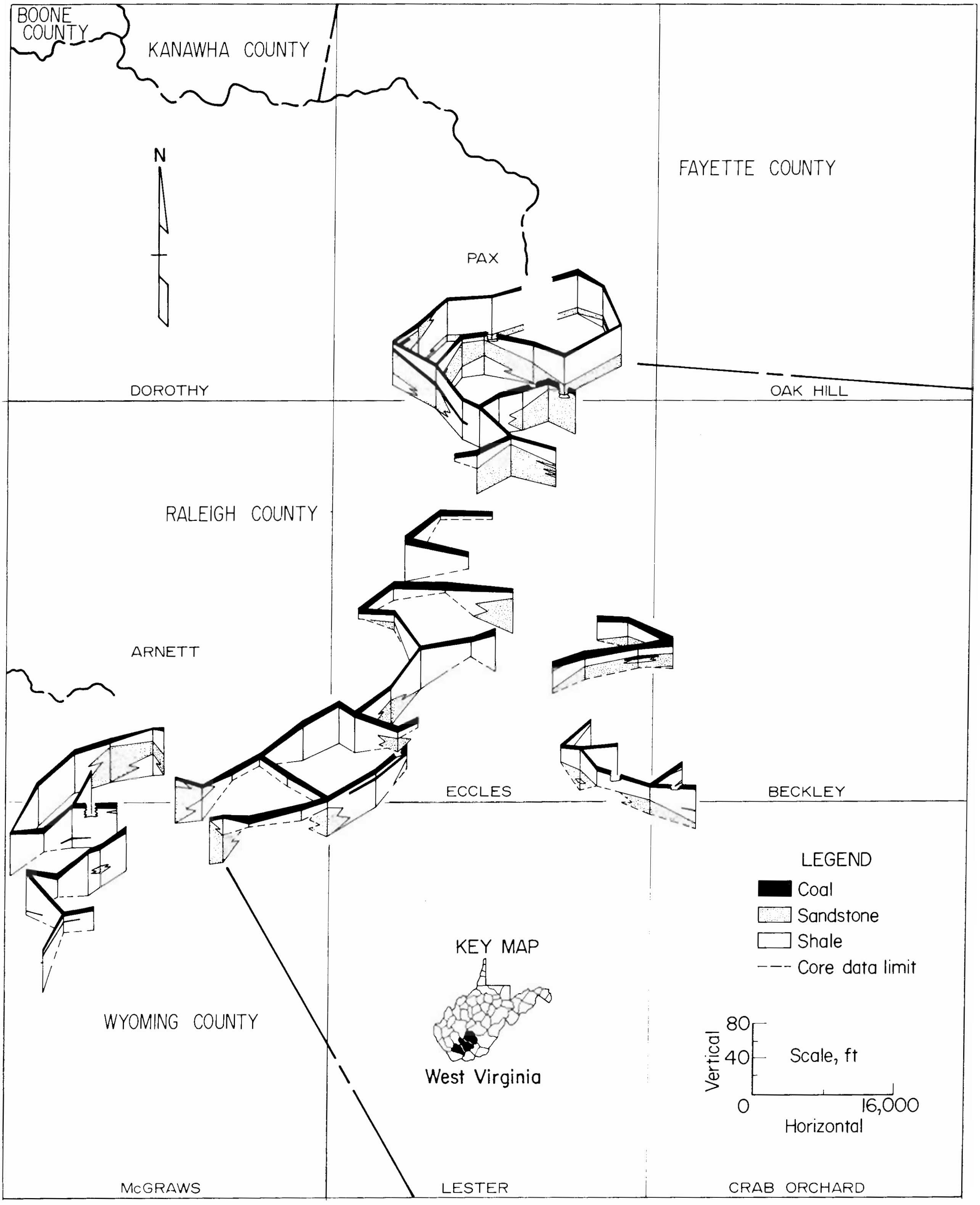

FIGURE 11. - Panel diagram of the strata below the Beckley coalbed.

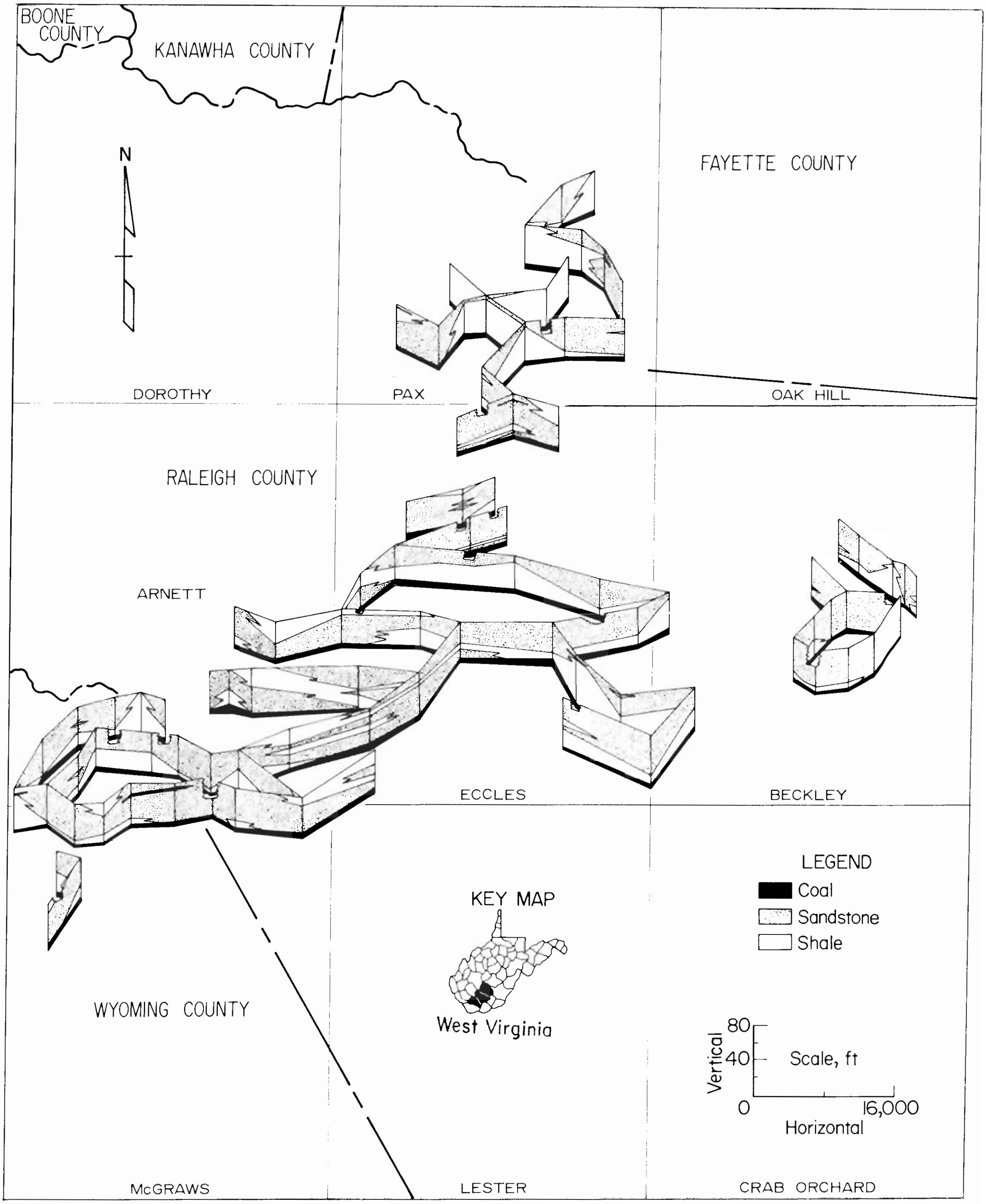

FIGURE 12. - Panel diagram of the strata above the Beckley coalbed.

Generally, the floor strata in the mines consist of shale. The panel diagrams do not describe the shale types, nor do they show the presence of a coal directly underlying the portions of the two mines having floor emissions. However, methane emission from the shale floor implies either that the shales are carbonaceous and the source of the methane, or that the methane has migrated to the floor of the mine from the Beckley coalbed or from a coalbed below. Figure 11 shows coal beneath the Beckley coalbed in the McGraws quadrangle and along the Pax-Eccles quadrangle boundary. The proximity and areal extent of these lower coals indicate an additional potential source of methane for the mines being developed in those areas; namely, the Beckley No. 1 mine and the Beckley-Lick Run mine.

Krebs (42) described the presence of a dark gray shale, rider coal, and sandstone above the Beckley in the study area. Both the shale and sandstone are described as lenticular, and the shale and coal may both be absent. In general the mines surveyed have a dark shale or draw slate roof; the shale is usually thin bedded and grades into sandy shale or thin-bedded sandstone. Core descriptions bear out the rapid changes in lithology and also denote the presence of a discontinuous rider coal above the Beckley.

Rapid changes in roof lithology and the presence of a rider coal are illustrated in figure 12. In the Pax quadrangle, the roof lithology changes from predominantly shale to sandstone, with a discontinuous rider present at two data points. Along the Eccles-Arnett quadrangle border the roof becomes a succession of thin shales and sandstones. Near the Raleigh-Wyoming line in the McGraws quadrangle a continuous coal (about 1-1/2 miles long) appears in the roof strata. This coal is separated from the Beckley by 25 to 30 feet of sandstone.

In figure 12, the absence of a split or rider coal may be a function of widespread data points and does not necessarily mean that a split or rider coal is not present in the field. Poor roof conditions, due to alternating thin-bedded shales and sandstone, subject overlying splits to a release in confining pressure. This can result in additional methane emission.

Overburden Thickness Above the Beckley Coalbed

A widely accepted rule of thumb for coal is that the deeper the coalbed, the more gaseous it is. If the methane in a coalbed is in equilibrium, equal volumes of methane would be expected per unit volume of coal throughout the coalbed. When the equilibrium is disrupted by outcrop or mining, methane is emitted. Where the disequilibrium is large, as may be caused by mining under increased overburden, methane emission rates may increase substantially.

An isopach of the overburden above the Beckley coalbed is shown in figure 13. A 400-foot contour interval is used because of the difficulty in reading a smaller scale on a map of this size.

In the study area, overburden thickness ranged from zero at outcrop in the Beckley quadrangle to greater than 2,200 feet in the Pax quadrangle. In general, the overburden increases to the northwest, corresponding to the

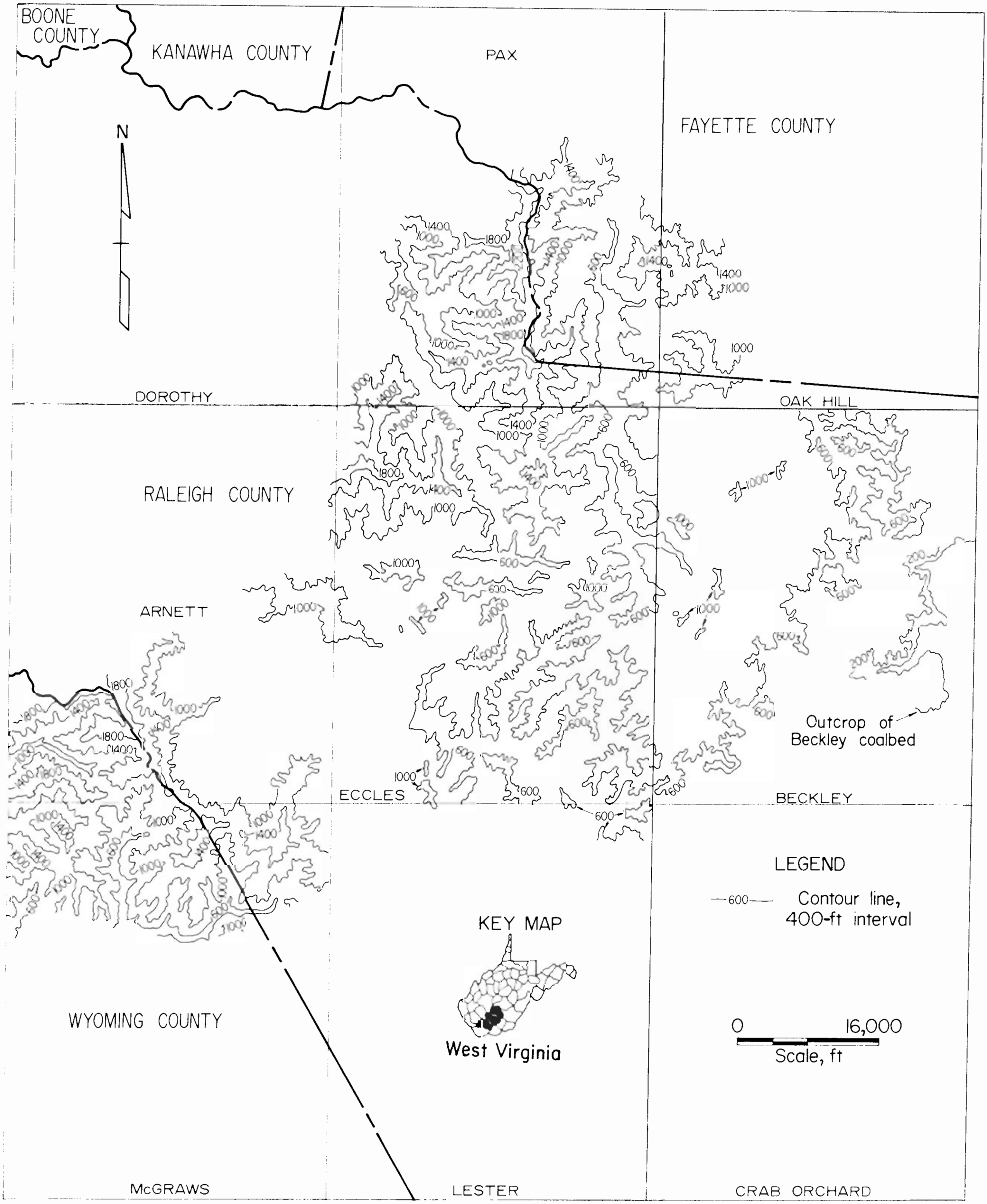

FIGURE 13. - Isopach map of the overburden above the Beckley coalbed.

Beckley's increasing depth relative to mean sea level in that direction. The average overburden and range of overburden thickness for each mine are given in table 3.

TABLE 3. - Overburden thickness above Beckley coalbed mines

Mine	Overburden variation, ft	Av overburden, ft
Beckley-Lick Run.......	600-2,360	1,139
Beckley................	520-1,680	827
Beckley No. 1..........	480-2,240	1,117
Eccles No. 5...........	550-1,400	669
Maple Meadow...........	600-1,720	865
Skelton................	0-1,100	647

No accurate data are available to compare methane emission in each mine from areas of lesser and greater overburden. Officials in both the Skelton and Eccles No. 5 mines have noted increased emission when mining under deeper cover. Within the five-mine area emission rates generally increase as overburden increases. A remote monitoring system now being installed in the Beckley mine by the Bureau of Mines may yield information on methane emission from areas with varying overburden (35).

Thickness of the Beckley Coalbed

An isopach map (fig. 14) with a 36-inch contour interval was drawn of the Beckley coalbed. The map was constructed utilizing core holes, drillers' logs, and mine maps, and depicts total coalbed thickness (coal and partings). The thickness is variable, ranging from 0 to more than 108 inches. There are several possible explanations for the variation: (1) The coal may have been deposited on an irregular surface, (2) the coal may have compacted differentially with overlying sediments, and (3) the coal may have undergone erosion both during deposition and after burial. Examples of the latter theory may be seen in the southeast corner of Eccles quadrangle and in the southwest corner of Beckley quadrangle in figure 15. In these locations, areas of want are outlined by what appear to be channels, and roughly correspond to low-coal areas in figure 14.

Large areas of low coal (less than 36 inches) appear in figure 13. Several researchers relate the Beckley coalbed's accumulation and thickness to the coalbed's environment of deposition (27, 58-59). In this theory thick coal is associated with topographic lows, while thin coal is associated with topographic highs. The low and high areas correspond with "hills" and "valleys" of a paleotopography, and are similar to the coal thickness trends of the Eccles No. 5 and Skelton mines. In portions of the Arnett, Eccles, and McGraws quadrangles one thick coal accumulation compares with the "valley" of the Pineville syncline.

The coal isopach map is used to calculate original coal reserves and methane reserves. Coal reserve calculations are based on coal seam thickness rather than on clean coal thickness, since it is felt that both coal and

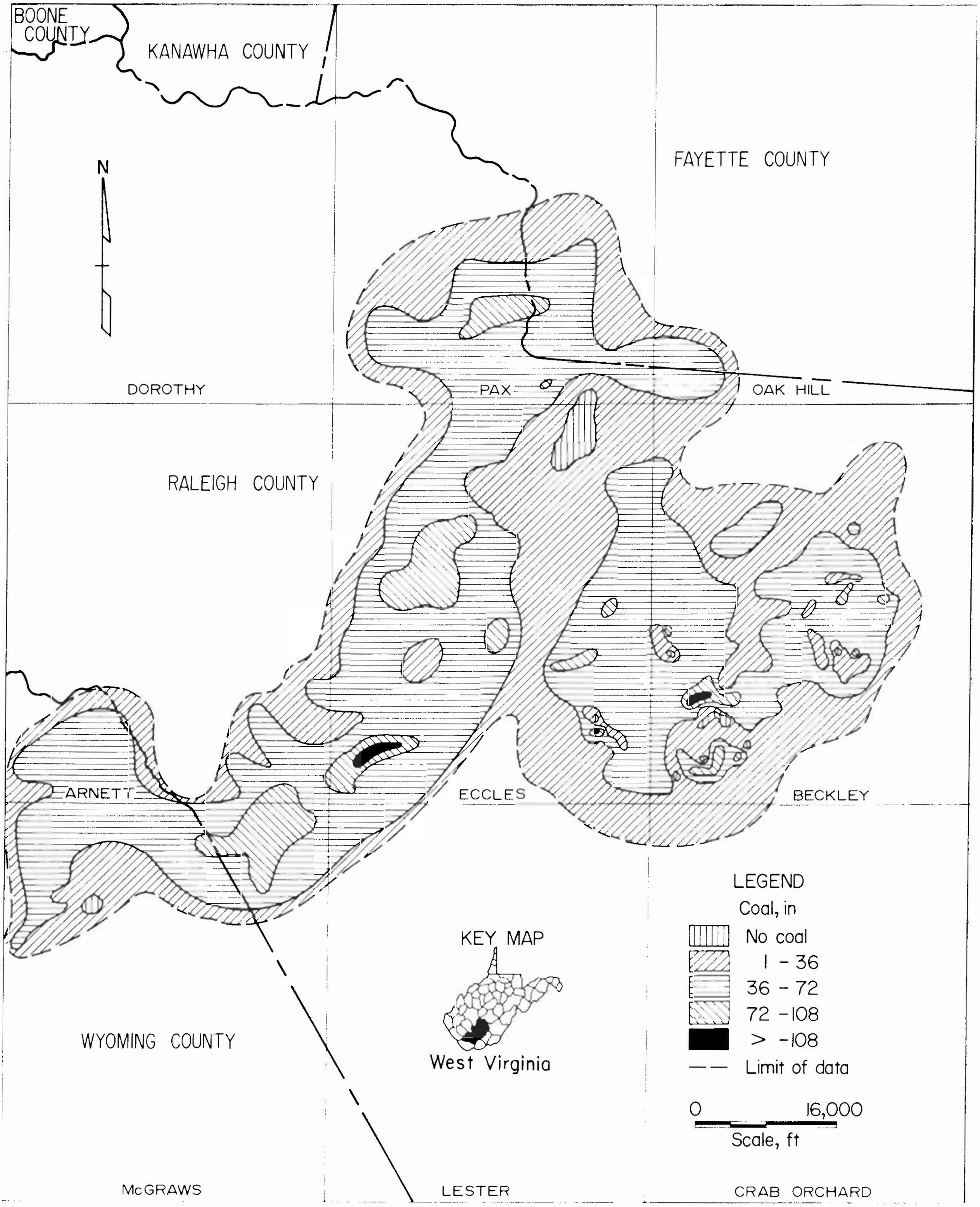

FIGURE 14. - Isopach map of the Beckley coalbed.

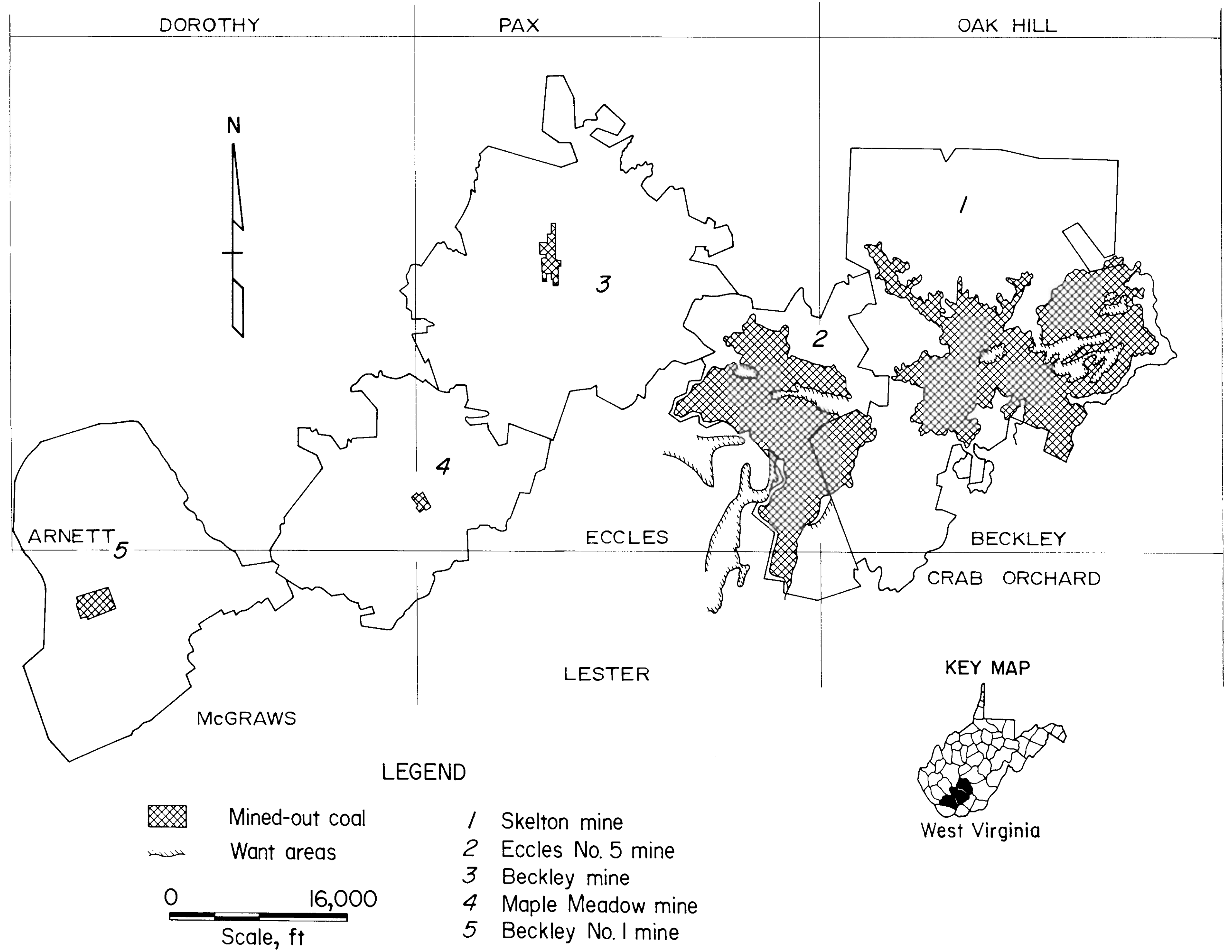

FIGURE 15. - Mined-out areas and wants in the Beckley coalbed.

partings will emit methane into the mines. In table 4, the original reserves of the Beckley coalbed for each mine have been calculated. The original coal reserves were about 279 million tons. Subtracting the amount mined to date, the total reserves at present are about 234 million tons.

TABLE 4. - Estimated coal reserves of the Beckley coalbed, million tons

Mine	Total coal	Mined-out coal	Remaining coal
Beckley-Lick Run........	56	-	56
Beckley.................	67	0.8	66
Beckley No. 1...........	41	.1	40
Eccles No. 5............	31	25.3	6
Maple Meadow............	46	.1	46
Skelton.................	38	18.8	19
Total.............	279	45.1	234

Structure of the Beckley Coalbed

While figure 6 illustrates the general structure of the Beckley coalbed, geologic factors may contribute locally to methane emission. The slope entry of the Maple Meadow mine is located in the axis of the Pineville syncline. In this mine very high emission rates occur during operation of the continuous miner. It seems probable that water, saturating and filling cleat spaces, prevents or slows natural degasification. While the miner is operating, coal is crushed, allowing rapid emission of methane trapped in the cleat by water. When the miner is not operating, emission decreases rapidly. The continued collection of water in the mine reflects a continuous recharge of water along the axis of the syncline.

A degasfication program utilizing vertical boreholes and hydraulic stimulation is under study for the area surrounding the slope of the Beckley-Lick Run mine. Emission may be hampered by water moving structurally downdip from virgin coal to the degasification holes. A preliminary well has been drilled and stimulated. Water, as well as methane, is being produced (table 5). Daily emission is less than originally expected. One reason may be improper well completion. Unless water relief wells are placed structurally updip from the degasification holes, or until the coal has dewatered itself, methane drainage may not be complete.

TABLE 5. - Methane emission and water production from a vertical borehole in the Beckley coalbed

Date	Methane emission, ft^3		Water production, bbl	
	Daily	Cumulative	Daily	Cumulative
Aug. 12, 1975........	10,296	3,768,400	10.5	3,838

NOTE.--Emission and production figures are averages of 240 daily measurements prior to August 1975.

A degasification program utilizing two horizontal boreholes was operated for 55 days in the Beckley mine in 1973. During the test nearly 4 million ft^3 of methane and over 33,000 bbl of water were produced. Emission apparently was not hampered by water in the coalbed (60).

All mines in the Beckley coalbed have encountered want areas where there is low coal due to "rolling" or "faulting" of the roof and/or floor (fig. 15). In either case, the coal thins with respect to the floor or roof. The transition zones between thin coal and thick coal often show slickensiding in the roof and coal, perhaps due to differential sediment compaction. However, not all slickensides occur under these conditions. In the Beckley mine slickensiding has also been observed where structural folding has thinned the coal. If the formation of want areas was initiated by geological factors, a detailed structure map and slickenside survey in each mine will be useful in detecting trends for the want areas. A knowledge of underground structure may forestall drilling horizontal degasification boreholes into roof rolls and want areas.

MOVEMENT OF METHANE IN THE COAL ENVIRONMENT

The movement of methane from coal and adjacent strata has been described by earlier researchers (10-11, 16, 33, 41, 44, 46, 52-54). A brief summary of methane movement is given.

Methane movement from coal may be described in two ways: (1) Diffusion of methane through the micropore structure of coal according to Fick's law, and (2) movement along secondary avenues or interconnecting fractures in the coalbed according to Darcy's law (11). The methane flow rates are related directly to the concentration of methane and the pressure gradient. Movement, then, is a function of porosity and permeability.

Methane movement from adjacent strata also contributes to mine emissions. Emission from roof strata has been associated with roof falls and sand channels (44), while emission from floor strata in Beckley mines is associated with black shales. Methane generated in organic-rich muds (33) can become trapped during shale formation just as methane is trapped during coal formation.

Methane movement in the coalbed environment is also dependent on depth. Because gas at greater depths is under higher pressure, the emission rate is dependent on depth, coal production rate, and nature of the coalbed and surrounding strata (16, 37). Several mathematical models predict methane and water movement in the coalbed environment while taking into account coalbed properties and fluid functions (53-54).

Two methods were used to estimate the methane content and emission potential for the mines operating in the Beckley coalbed. The first was to examine the methane emission records from the mines in the study area. The results are summarized in table 6.

TABLE 6. - Coal production and methane emission data for Beckley coalbed mines

Mine[1]	Age[2]	Production, tons/day		Methane emission, ft^3/day	Coal thickness, inches	Depth at tipple, feet
		Capacity	Actual			
Beckley............	29 mo	6,000	3,000	2,000,000	36-84	618
Beckley No. 1.......	24 mo	[3]4,000	[3]100	557,000	36-42	675
Eccles No. 5........	70 yr	2,200	1,700	474,000	36-66	530
Maple Meadow........	16 mo	[3]5,400	100	278,000	30-96	750
Skelton............	70 yr	1,800	700	151,000	36-60	[4]400

[1]All mines use continuous-mining machines with a room-and-pillar mining plan.
[2]As of August 1975.
[3]The mine is still in development.
[4]Represents approximate depth to coal at tipple; miners enter the mine through a portal where the Beckley crops out.

The second method (41, 46) estimates the methane content of a virgin coalbed based on the volume of methane desorbed from coal samples obtained from core drilling. This direct method gives the volume of methane per ton of virgin coal, which can be converted to methane emission per ton of coal mined per day (table 7).

TABLE 7. - Gas content of virgin Beckley coal and estimated emission rates

Drill hole No.	Depth, ft	Gas content of Beckley coal, cm^3/g	Gas content of Beckley coal, ft^3/ton	Estimated rate of emission, ft^3/ton mined
215..................	1,005	13.1	419	3,100
212..................	875	14.1	453	3,100
223..................	830	15.4	492	3,350
224..................	740	13.7	439	3,000
Average.........	862	14.1	451	3,140

Knowing the daily methane emission and/or amount of coalbed gas, coal production, and original coal reserves, the original methane reserves may be estimated. Knowing the structure, coal thickness, overburden thickness, and environmental settings, the methane reserves in virgin areas can be estimated from the methane volume per ton of coal (table 8).

Recent studies (22, 27) have shown that commercial-quality gas from vertical boreholes can be obtained from coalbeds in advance of mining. The four new mine properties in the Beckley coalbed have over 100 billion ft^3 of methane in their coal reserves. Degasification in advance of mining would reduce mining hazards and costs as well as supplement energy demands.

TABLE 8. - Estimated present gas reserves in the Beckley coalbed

Mine	Gas content, ft^3/ton	Original coal, 10^6 tons	Remaining coal, 10^6 tons	Gas reserves, 10^9 ft^3
Beckley.........	520	67	66	34
Beckley-Lick Run	[1]446	56	56	25
Beckley No. 1...	520	41	41	21
Eccles No. 5....	238	31	6	1
Maple Meadow....	500	46	46	23
Skelton.........	216	38	19	4
Average and totals....	407	279	234	108

[1]Represents gas content determined by the direct method in virgin coal. Kissell (41) estimates that a well-established deep mine with this content will liberate approximately 3,050 ft^3 of methane per ton coal per day.

SUMMARY

This study showed that at least four geology-related factors affect methane in the Beckley coalbed. The factors are as follows:

1. Lithologic variations above and below the Beckley may add to methane emissions. Carbonaceous shales and coal splits occur below the Beckley in areas where floor emissions are present. Panel diagrams constructed from core logs indicate substantial coal splits above and below the Beckley in other mines. Therefore, predictions of methane emission during mining based on the "direct method" may be conservative.

2. The theory that methane emission increases as depth increases holds in the Beckley coalbed. Methane emissions increase from just over 200 ft^3/ton in older, shallow mines to over 500 ft^3/ton in newer, deeper mines. Methane emissions are expected to increase to the northwest of present mining, corresponding to the increase in overburden. Present new mines will operate as deep as 2,300 feet and can expect higher emissions at these depths.

3. Areas of greater coal thickness can expect higher emissions because of greater volumes of coal mined and more rib exposure. The irregular thickness and distribution of coal reflect the depositional environment of the original coal swamp. Want areas or "faults" represent erosion or nondeposition of carbonaceous material in the original swamp. The presence of wants disrupts mining, and may also hinder attempts to degasify the coal.

4. The structure of the Beckley coalbed in the study area is characterized by a gentle dip to the northwest with two gentle folds in the southwest. Water moving downdip through the coalbed hampers degasification both in mines and in drill holes. The irregular structure of the Beckley may inhibit attempts to degasify mines by horizontal drill holes. The nearness of the Beckley to the Allegheny Front contributed to the coal cleat orientation. The average cleat directions are N 33° W for the face cleat and N 53° E for the butt cleat. Mine entries and horizontal boreholes perpendicular to these directions can expect greater emission than those at an angle because they

will intercept the greatest number of cleats. Water movement is also expected to be strongest in these directions.

The average methane emission for mines in the study area is about 400 ft^3 per day per ton. Samples of the Beckley near the future Beckley-Lick Run mine contain an average of 446 ft^3/ton of virgin coal as determined by the direct method. Using a Bureau correlation, this is the equivalent of 3,050 ft^3 per day per ton of coal mined for a well-developed deep mine. Because the Beckley, Beckley No. 1, and Maple Meadow mines are not fully developed, methane emission per ton of coal will continue to increase as development is reached.

In the study area the estimated coal reserves are 234 million tons, of which 209 million tons is in mines less than 3 years old. Because the average methane content of the Beckley is over 400 ft^3/ton, 108 billion ft^3 of commercial-quality methane is still trapped in the Beckley coalbed.

It is hoped that the techniques and results of this investigation can be used by geologists and mining engineers responsible for mining coal safely and quickly in the Beckley coalbed.

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APPENDIX.--NOMENCLATURE

Cleat.--Systems of joints, cleavage planes, or planes of weakness found in coal seams. The more pronounced joints are called face cleats and are normally parallel to the line or direction of regional folding. It is common for a set of joints, which are approximately parallel cracks or fissures a few inches apart, to also occur; known as butt cleats, these are not as well developed as the face cleats and are usually nearly at right angles to them.

Fault.--In coal mining, a sudden thinning or disappearance of a coal seam. Also known as a want or pinchout.

Friability.--A criterion of the ease with which a coal may be broken into smaller pieces.

Fundamental joint system.--The smallest unit of jointing in regions where both systematic and nonsystematic joints occur. Systematic joints are usually planar or broadly curved surfaces occurring in sets which continue across other intersect joint sets; they are perpendicular to the upper and lower boundaries of rock units in which they occur. Nonsystematic joints are curved fractures that meet but do not cross other systematic or nonsystematic joints; they commonly terminate against bedding planes.

Joint.--A fracture or parting that cuts through and abruptly interrupts the physical continuity of a rock mass; it is generally more or less vertical or transverse to bedding along which no appreciable movement has occurred.

Slickenside.--A polished and sometimes striated surface on the walls of a vein, or on interior joints of the vein material or rock masses. Produced by rubbing during faulting, on the sides of fissures, or on bedding planes.

Want.--A localized disappearance of a coal seam, for reasons other than faulting (for example, washouts, squeeze, rolls), or a portion of a coal seam in which the coal has been washed away and its place filled with clay or sand.

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