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Geology of the Lower Kittanning Coalbed and Related Mining and Methane Emission Problems in Cambria County, Pa.

UNITED STATES DEPARTMENT OF THE INTERIOR

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By A. T. Iannacchione and D. G. Puglio

UNITED STATES DEPARTMENT OF THE INTERIOR
Cecil D. Andrus, Secretary

BUREAU OF MINES
Roger A. Markle, Director

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GEOLOGY OF THE LOWER KITTANNING COALBED AND RELATED MINING AND METHANE EMISSION PROBLEMS IN CAMBRIA COUNTY, PA.

by

A. T. Iannacchione[1] and D. G. Puglio[1]

ABSTRACT

The Bureau of Mines established geologic factors affecting the mining of the Lower Kittanning coalbed to aid in coalbed minability studies and examined the occurrence of "wants" (places where coal is missing) and types of unstable roof rock strata. Trends established from mapping, including prediction of areas of high methane emissions, were extrapolated to unmined areas.

"Wants" in the coalbed are of two types: Erosional and depositional. Erosional features occur where north-south-trending sand-filled channels cut into the coalbed. Variations in depositional environments have caused the coalbed to "split" into several thinner units.

Slickensides, commonly indicative of unstable roof, are adjacent to and on the underside of sandstone channels; they were caused by differential compaction and by soft sediment sliding along the contact between the sandstone and adjacent shale. The frequency of unstable roof also increases where the interval between the Middle and Lower Kittanning coalbed is less than 30 feet. The zones of weakness at the contacts above and below the Middle Kittanning coalbed are the controlling factors for unstable roof in these strata.

Methane emissions from the coalbed are controlled primarily by depth, fracture permeability, and rank of coal. Local geologic factors are coalbed thickness, associated rock strata, structure, and proximity to outcrop.

INTRODUCTION

The Lower Kittanning coalbed in Cambria County, Pa., has a long mining history and is currently being explored to define deeper reserves. As these deeper reserves are explored, geologic factors that affect mining in unmined coal need to be examined to aid in mine planning. With the accumulation of large amounts of exploration drilling data over the last century, it is now possible to analyze geologic trends in actively mined areas and to project these trends into unmined areas. Delineation of "want" trends where the coal

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is missing and prediction of areas of high roof instability and high methane emissions are the main topics of concern in this Bureau of Mines study.

Cambria County is in west-central Pennsylvania (fig. 1). It lies near the eastern edge of the Allegheny Plateau Province and is near the northeastern edge of the Appalachian coalfield, which extends from southern New York to northern Alabama. Major towns, rivers, and the nine 7-1/2-minute topographic quadrangles that make up the study area are shown in figure 2.

In Cambria County the Lower Kittanning is a low- to medium-volatile bituminous coal which has been used for coke making and steam generation. It is generally very friable and ranges in thickness from 0 to 117 inches, averaging 36 to 60 inches. Overburden thickness ranges from zero at the outcrop to 1,100 feet. Mining is presently most active in the deepest synclines, where most of the remaining reserves lie under 600 feet of overburden.

When the Lower Kittanning coalbed was first mined, it was common practice to mine from outcrop into the surrounding hillsides, always staying above drainage. "Wants" and unstable roof were encountered, but methane gas was not the major problem that it is today. Little exploration coring was done, and coal was mined until thin coal, bad roof, or excessive water problems made it uneconomical to continue.

The methane problem increased as deeper coal reserves were mined, and the gas is now generally considered a major mining hazard of this area. In a recent survey, Irani (5)[2] compiled a list of the 35 counties in the United States with the highest gas emissions from active mines. Cambria County ranks ninth (methane emissions totaled 10.3 MMcfd in 1975) among those counties. This ranking is largely controlled by the Lower Kittanning coalbed because it accounts for the greatest amount of tonnage of the four coalbeds presently being mined in this county and also because it is stratigraphically the lowest minable coalbed in the local geologic section.

ACKNOWLEDGMENTS

The authors thank the following companies and their officials for their cooperation in collecting data: Barnes and Tucker Mining Co., Bethlehem Mining Co., Eastern Associated Coal Corp., and Clearfield Bituminous Coal Co.

The authors also thank Norman K. Flint, Department of Earth and Planetary Sciences, University of Pittsburgh, Pittsburgh, Pa., for his suggestions regarding preparation of the manuscript.

REGIONAL GEOLOGY

Cambria County lies physiographically within the Allegheny Mountains section of the Appalachian Plateau Province (fig. 3). The Allegheny Front, which forms the border between the Appalachian Plateau Province and the Valley

[2]Underlined numbers in parentheses refer to items in the list of references at the end of this report.

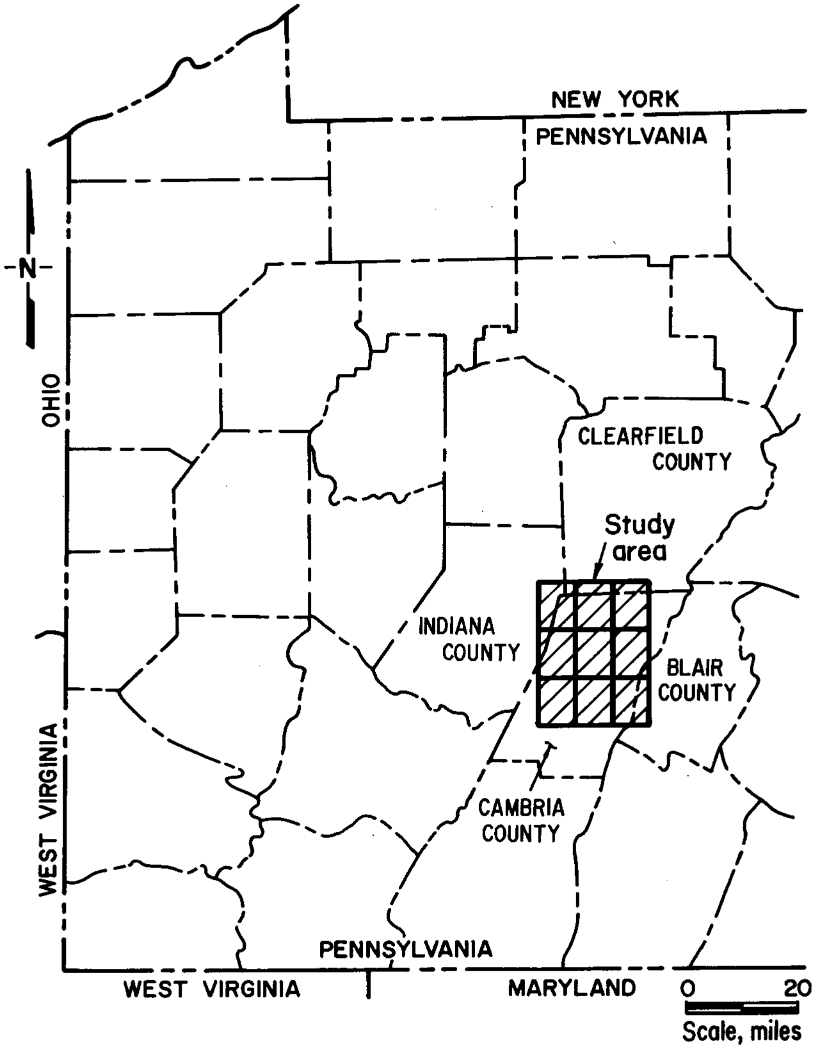


FIGURE 1. - Location of study area.

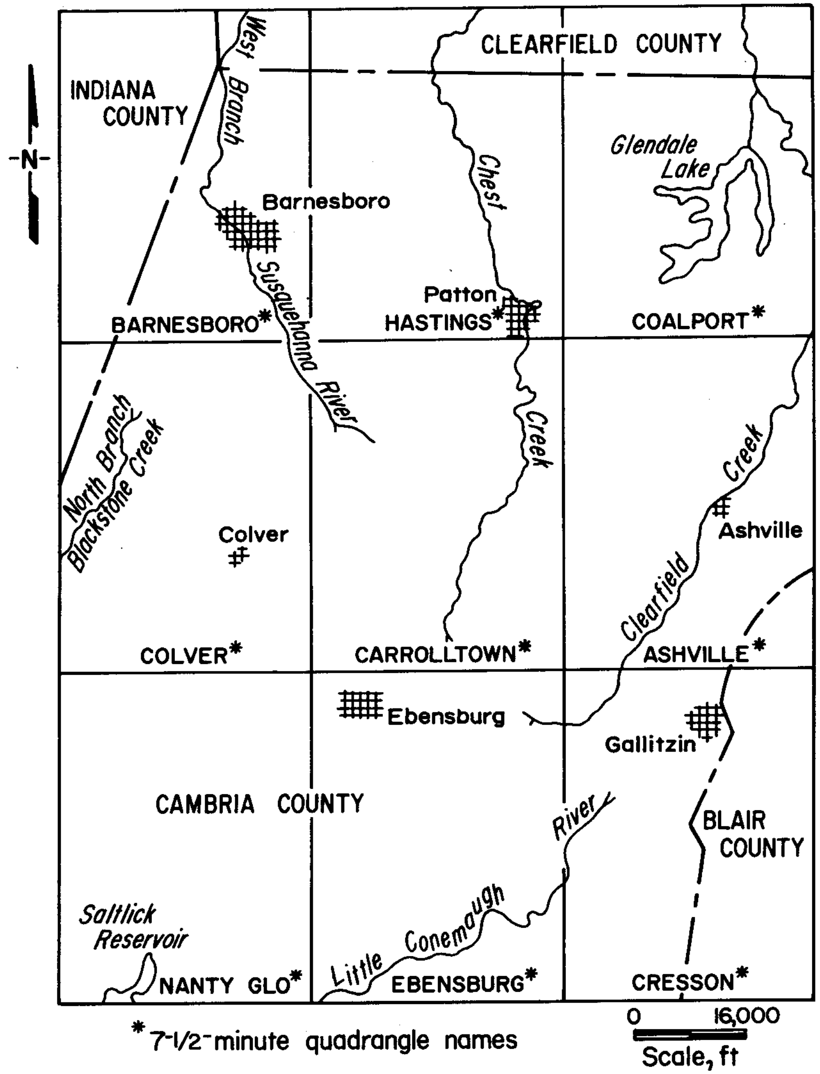


FIGURE 2. - Location of important geographic features of northern Cambria County, Pa.

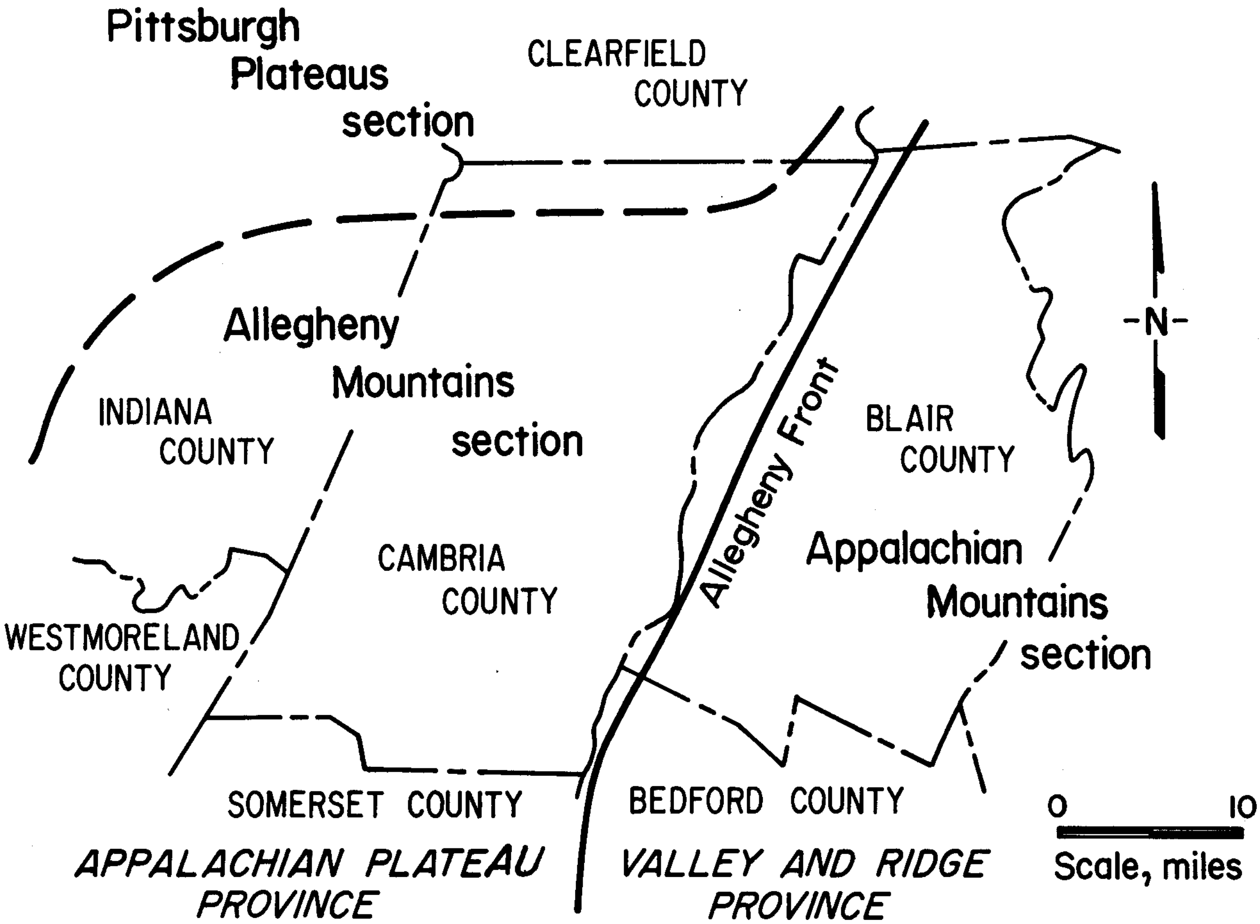


FIGURE 3. - Physiographic divisions in the area around Cambria County.

and Ridge Province, generally coincides with the eastern border of Cambria County. Directly west of the Allegheny Front, open folds having flank dips of 1° to 20° characterize the Allegheny Mountain Province.

Predominantly Pennsylvanian sediments are exposed in the Allegheny Mountain section. A generalized geologic column of exposed rocks in the Allegheny Mountain section is shown in figure 4.

The Allegheny Group (the group containing the Lower Kittanning coalbed) includes all rocks from the base of the Brookville coal to the top of the Upper Freeport coal. The Allegheny Group, comprised of the Clarion, Kittanning, and Freeport Formations, is composed of sandstone, shale, limestone, claystone, and coalbeds (4).

The local geologic setting directly reflects the regional geology. The stratigraphic section of interest is the Kittanning Formation, which includes the Lower Kittanning coalbed. The formation varies in thickness within the area of investigation in two ways: (1) It shows a regional thinning to the northwest, and (2) localized channel scour-and-fill phenomena have thinned,

System	Rock unit
Pennsylvanian	Monongahela Group Conemaugh Group Allegheny Group Pottsville Group
Mississippian	Mauch Chunk Formation Loyalhanna Formation Pocono Formation
Devonian	Catskill Formation Jennings Formation

FIGURE 4. - Generalized stratigraphic column of exposed rocks in the Allegheny Mountain section of Appalachian Plateau Province.

thickened, or removed sections of the geologic column. The formation has a maximum thickness of 130 feet and a minimum thickness of 85 feet.

Figure 5 is a generalized stratigraphic column describing the lithology from the Lower Kittanning to the Upper Kittanning coalbed (the Kittanning Formation). The more important stratigraphic markers include the Lower, Middle, and Upper Kittanning coalbeds and their underclays, the Lower and Upper Worthington Sandstone, and the Johnstown Limestone. In any particular location one or more of the members may be absent.

Recognition of a coalbed is partially dependent on recognizing key rock units. The Lower Kittanning coal group is recognized as lying between the Kittanning Sandstone and the overlying Lower Worthington Sandstone. We chose to refer to the horizon containing the Lower Kittanning coalbed as part of the Lower Kittanning coal group, owing to the inconsistent character of the interval. The lower coalbed as a rule is the thicker, more persistent coal. For this reason local usage refers to the lower coalbed in the Lower Kittanning coal group as the Lower Kittanning coalbed, and to the upper coalbed as the Lower Kittanning "rider" coal.

Another stratigraphic problem in this interval is distinguishing the Lower Kittanning "rider" coal from the Middle Kittanning coal group where the Lower Worthington Sandstone is missing. The lowest member of the Middle Kittanning coal group has a thick underclay, whereas the Lower Kittanning "rider" coalbed generally has none. In correlating the Middle Kittanning coal group throughout the area, the first coalbed above the Lower Kittanning coalbed with a well-developed underclay is considered the Middle Kittanning. It has been suggested by Spieker (16) in his studies of the Cretaceous of Utah and by Weller (20) in his studies of the Pennsylvanian of Illinois that coalbeds representing a regression of the sea have sharp lower contacts of sandstone, siltstone, or shale, whereas transgression of the sea produces varying thickness of claystone beneath a coal.

Local structures include folds, faults, joints, and cleats in the coal. The folds, joints, and cleats generally appear to have a genetic relationship with the Allegheny Front, based on the fact that the fold axes, nonsystematic joints, and butt cleats are parallel to the trend of the Allegheny Front, while the systematic joints and face cleats are perpendicular to it.

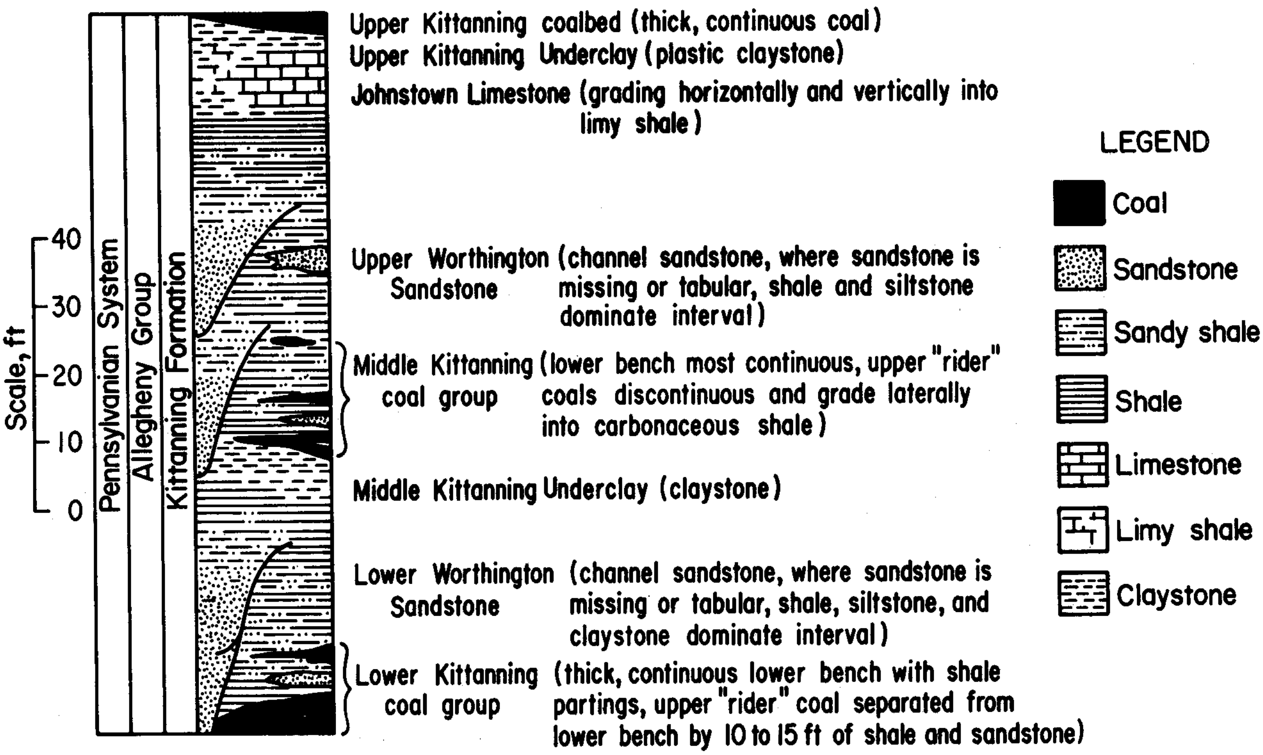


FIGURE 5. - Generalized stratigraphic column of the Kittanning Formation.

No faults were described in this area by earlier geologists; however, the present writers observed several faults with a maximum of 5 feet of vertical displacement in the Barnes and Tucker No. 20 mine.

GEOLOGY OF THE LOWER KITTANNING COALBED

The Lower Kittanning coalbed is the highest grade, most persistent, and economically the most important coalbed in Cambria County. Its thickness ranges from zero to as much as 8 feet. Generally, the coal is clean and bright, occurring as a single bench with few partings; in some localities clay partings separate the coal into two benches (fig. 6).

Stratigraphy

Recognition of the Kittanning Formation in the field was accomplished through the use of key rock units. Waage (19) identified key rock units as the Lower Kittanning coal group, Lower Worthington Sandstone, Middle Kittanning coal group, Upper Worthington Sandstone, Johnstown Limestone, and Upper Kittanning coal group.

FIGURE 6. - Clay parting in the Lower Kittanning coalbed.

Figure 7 is a panel diagram showing a three-dimensional view of lithologic facies in the Kittanning Formation. Several key rock units are recognized in every section; however, no one section contains all key units identified by Waage (19).

The Lower Kittanning coalbed is very persistent (fig. 7) even though it may be split by as many as three visible partings. Immediately below the Lower Kittanning coalbed and overlying the Kittanning Sandstone and shale members of the Clarion Formation is the Lower Kittanning Underclay.

The strata immediately overlying the Lower Kittanning coalbed generally consist of dark gray and gray shale, some siltstone, and thin tabular sandstone. Abundant siderite nodules in layers parallel to the bedding occur in the siltstone and shale.

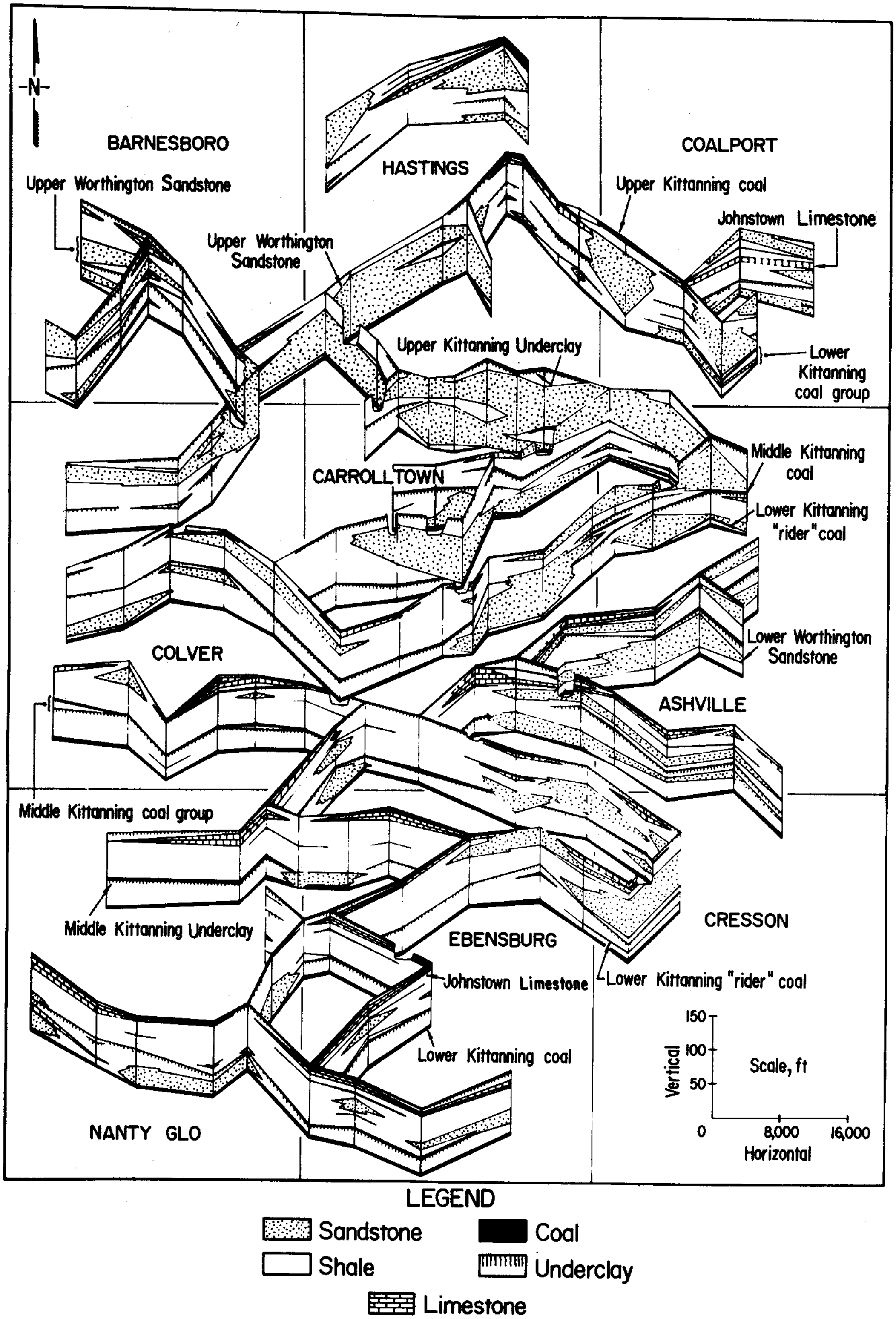


FIGURE 7. - Panel diagram of the interval from the bottom of the Lower Kittanning coalbed to the top of the Upper Kittanning coalbed.

The "rider" coal, or its stratigraphic equivalent, is observed in most sections where the Lower Worthington Sandstone is not well developed. This can be seen in the northwestern Cresson, south-central Colver, and east-central Hastings quadrangles of figure 7. This condition, as Williams (21) suggested, indicates that the "rider" coal was once present over most of the area, but was cut out by channel erosion.

The Lower Worthington Sandstone occupies the interval between the Lower and Middle Kittanning coal groups. A good exposure can be found along Chest Creek in an abandoned strip mine 2 miles north of Patton, Pa. Where the sandstone is not developed, shales, which grade horizontally and vertically into sandy to silty gray shales, commonly occupy the section.

The Lower Worthington Sandstone is found in the western Ebensburg, eastern Carrolltown, western Ashville, southern Coalport, and southern Hastings quadrangles (fig. 7). In the southern Hastings and northeastern Carrolltown quadrangles the Upper and Lower Worthington Sandstones are combined to form one thick sandstone unit. Recognition of the Lower Worthington Sandstone is also accomplished by the construction of a percent sandstone map (fig. 8) of the interval between the Lower Kittanning coalbed and the lowest coal in the Middle Kittanning coal group.

The percent sandstone map shows the Lower Worthington Sandstone to be a linear body with sharp lateral boundaries. The geometry of the sandstone bodies is generally troughlike. These features were produced by high-energy streams eroding into semilithified to lithified sediments. Periodically, with sediment overload of streams and channel abandonment, sands, shales, and clay filled in channel cuts. Therefore, undersides of the ancient stream channels represent disconformable surfaces.

The Middle Kittanning coal group lies from 20 to 60 feet above the Lower Kittanning coalbed (fig. 9). This interval tends to be thin where the section is composed mainly of shale, as in northern Nanty Glo, southern Colver, western Carrolltown, and western and southern Ebensburg quadrangles, and thick where the Lower Worthington Sandstone is present in the section as in eastern Carrolltown, Coalport, and Ashville quadrangles (fig. 7). Trends of this interval were projected where the Middle Kittanning coal group is eroded. The coals of this group are erratic in thickness, splitting into as many as three benches of coal in some places.

The Upper Worthington Sandstone overlies the Middle Kittanning coal group. In some places the sandstone extends downward through the strata of this coal group, thereby replacing them. This can be seen in portions of southern Hastings, northern Carrolltown, and southwestern Coalport quadrangles (fig. 7). Where channel-type sandstone is not present, the interval contains shale, siltstone, and thin tabular bodies of sandstone. Variations in the thickness and lithologic character of the interval occur over very short lateral distances.

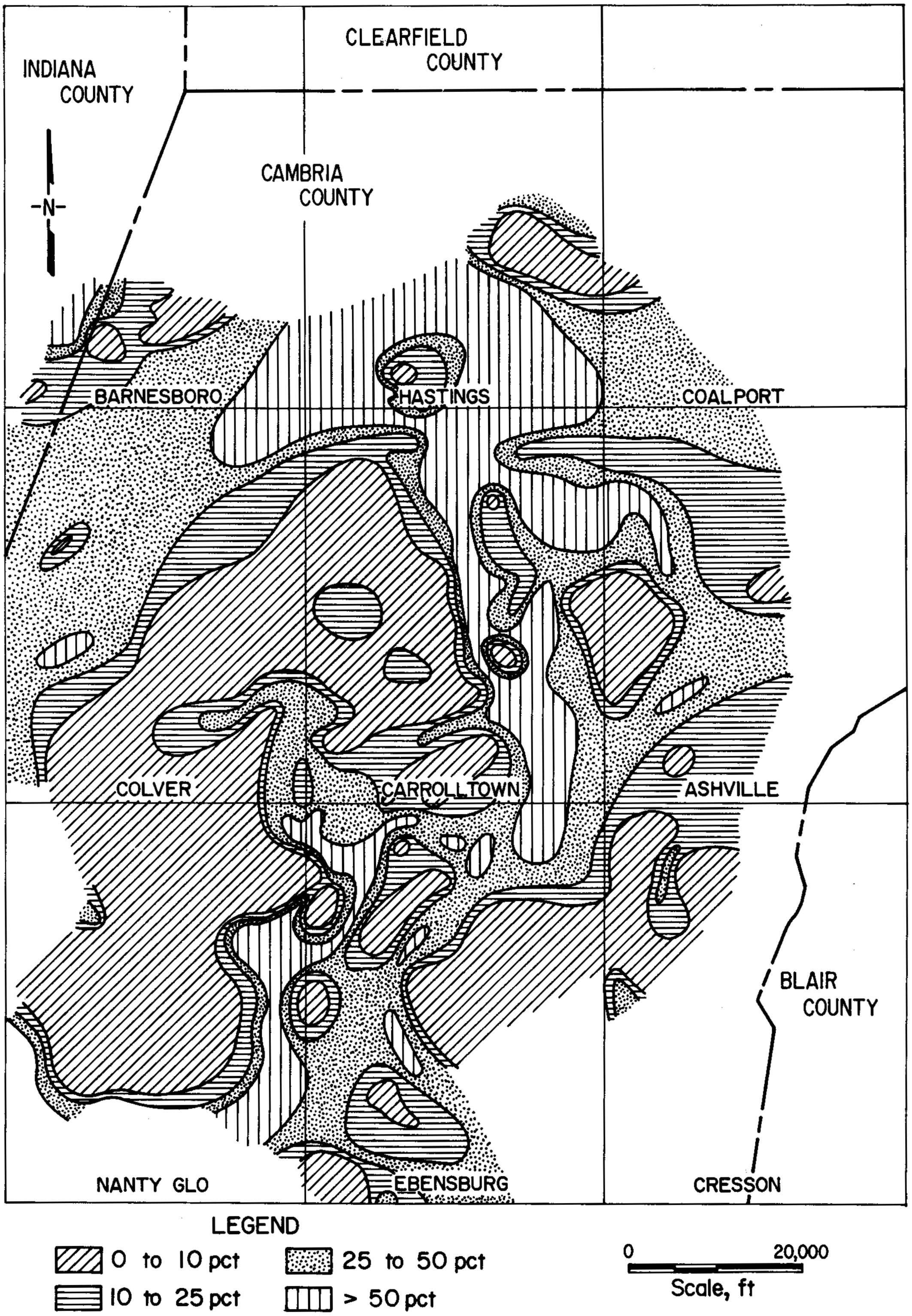


FIGURE 8. - Percent sandstone map of the interval from the top of the Lower Kittanning coalbed to the bottom of the Middle Kittanning coal group.

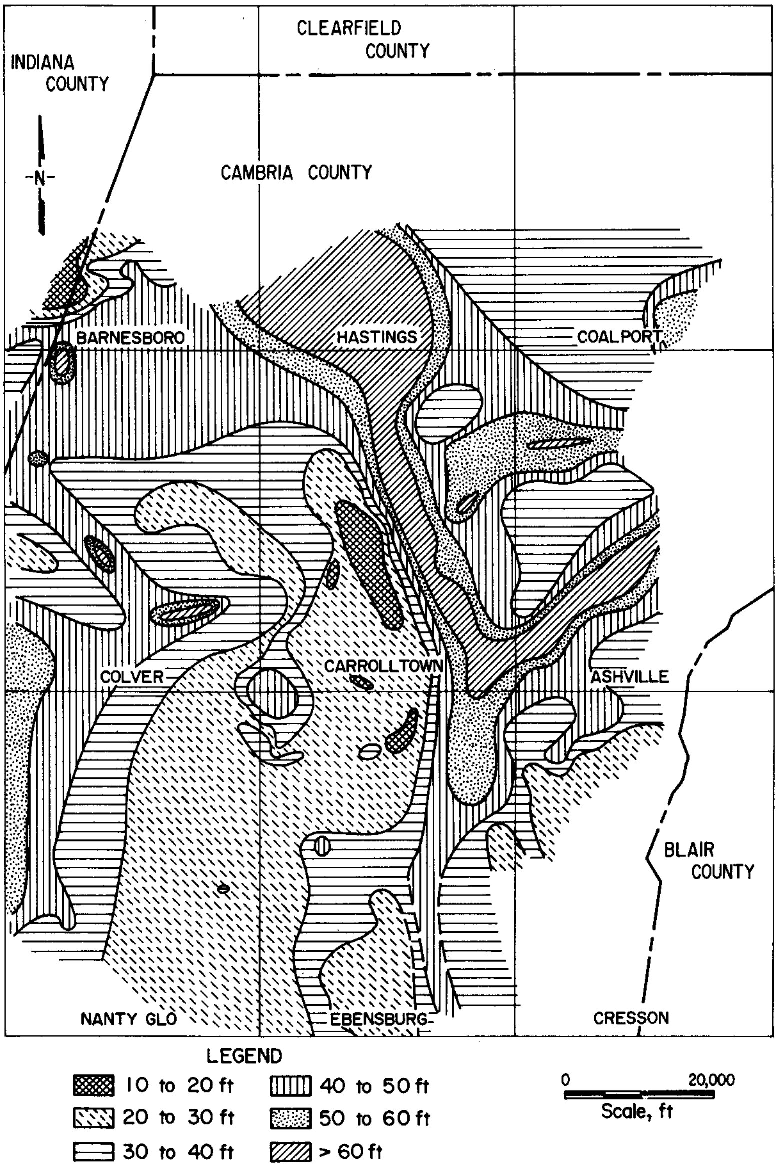


FIGURE 9. - Isopach map of the interval from the top of the Lower Kittanning coalbed to the bottom of the Middle Kittanning coal group.

The Johnstown Limestone typically rests on shale and grades laterally into limy shale. This limestone has proven to be very persistent, being especially thick in the southern half of the study area (fig. 7). It is a dark-gray, fine-grained, yellowish-weathering, argillaceous limestone which breaks with a smooth, concoidal fracture. Generally, the limestone occurs as a lenticular body; however, it may occur as nodules within thicker sections of the Upper Kittanning Claystone.

The interval above the Johnstown Limestone is occupied by the Upper Kittanning Underclay, or the Upper Kittanning coal group, as in the northern Ebensburg quadrangle (fig. 7). This underclay has commercial value as a refractory clay in the northeastern Carrolltown quadrangle.

Resting on top of the Upper Kittanning Underclay and/or Johnstown Limestone is the Upper Kittanning coal (fig. 7). It is generally a thick, continuous coalbed lying approximately 110 feet above the top of the Lower Kittanning coalbed.

Structure

The most pronounced fold in the area (fig. 10) is the Nittany arch, the northwest limb of which crosses the southeastern corner of the study area in Blair and Cambria Counties. The northwestern limb of this arch forms a cuesta-like feature which has been named the Allegheny Front. Ten miles to the west of this structure lies the Laurel Hill anticline. This fold plunges to the northeast and is flanked to the east by the Ebensburg anticline and the west by the Nolo anticline. The narrow Bradley and Wilmore synclines lie en echelon to one another between the Laurel Hill anticline and the Allegheny Front. The

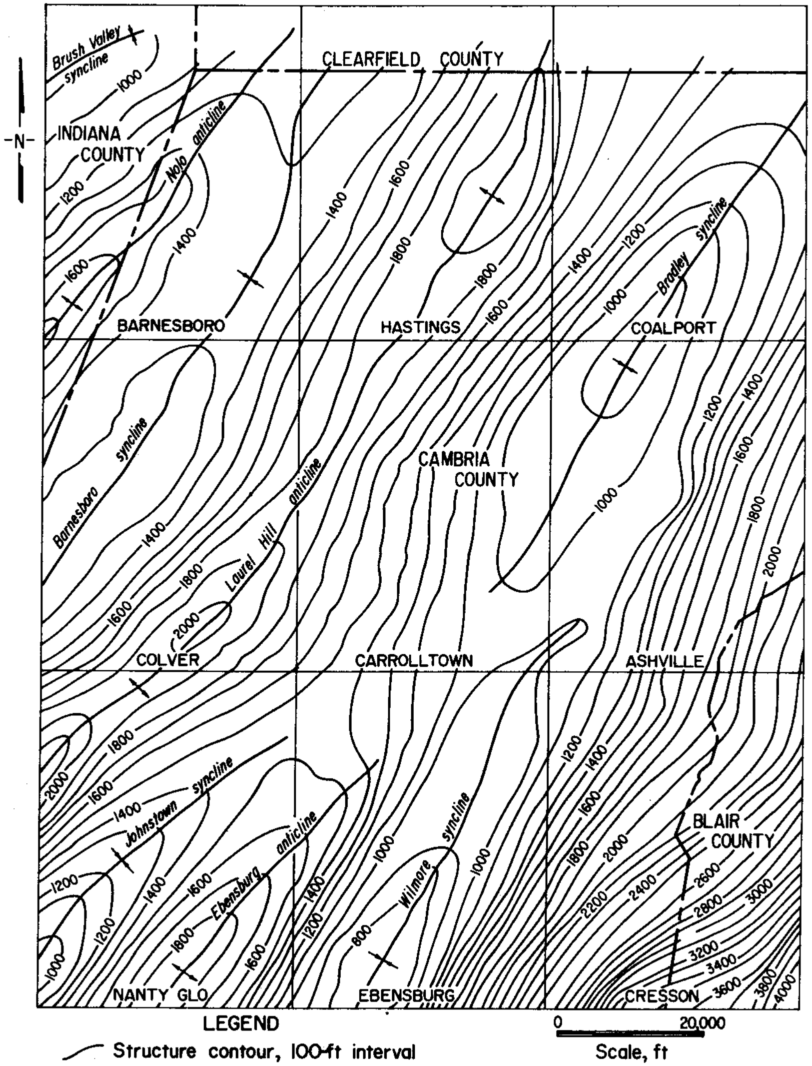


FIGURE 10. - Structure contours on the base of the Lower Kittanning coalbed.

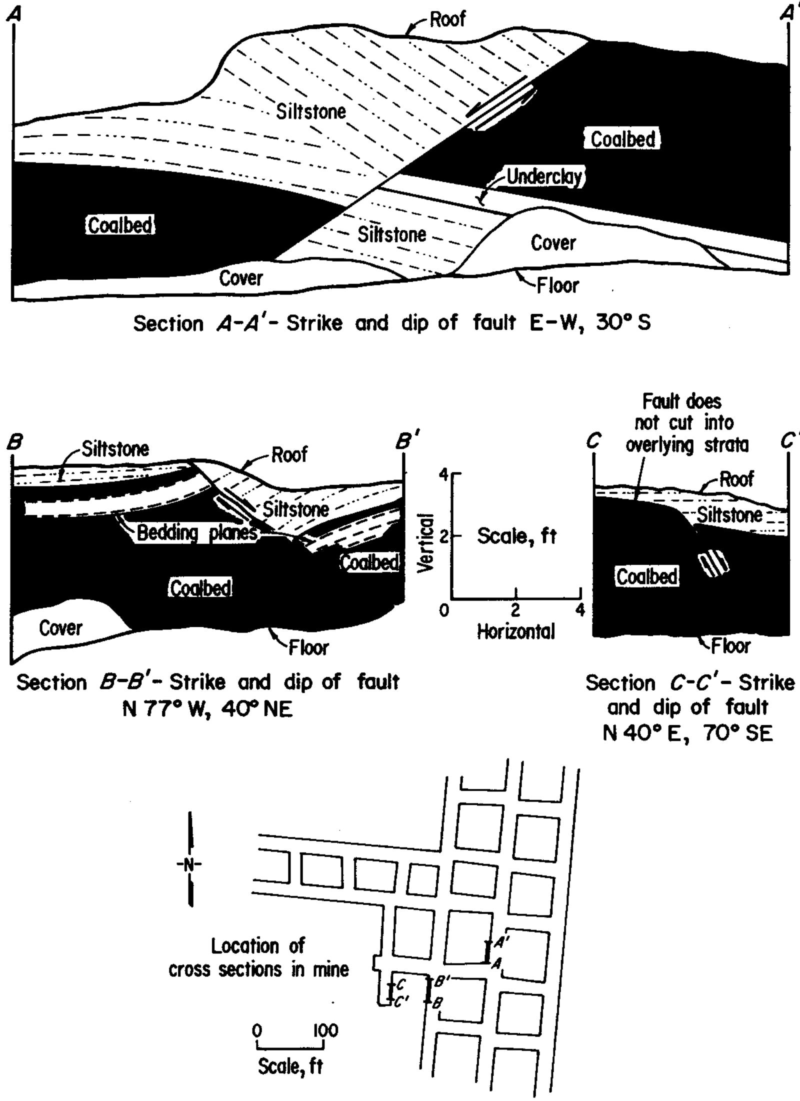


FIGURE 11. - Location and cross-sectional view of three displacement faults encountered in the Barnes and Tucker No. 20 mine.

spoon-shaped Johnstown syncline plunges to the southwest in the southwestern portion of the area, while the broader Barnesboro syncline parallels the western boundary of Cambria County.

The structure map shows distinctive changes in the fold along a northwest-southeast belt from the southeast corner to the northwest corner of the study area. Generally, greater amplitudes and closer spacing of folds occur to the south of this diagonal. A structural culmination along the Barnesboro syncline and a saddle in the Laurel Hill anticline occur along this belt. The Johnstown syncline and Ebensburg anticline die out directly to the south of the belt, and the Wilmore and Bradley synclines occur en echelon directly along the belt. Finally, the amplitude of the Nittany arch increases to the southwest. Perhaps the differing degrees of compressional forces exerted on either side of this belt are associated with a deep strike-slip fault, a byproduct of the bending in the Allegheny Front in central Pennsylvania.

No major faulting was recognized in the study area, but several minor displacement faults in the Barnes and Tucker No. 20 mine (fig. 11) were observed along the eastern flank of the Laurel Hill anticline. Upon first observation, the faults appeared to be interconnected and of tectonic origin, based on the presence of highly polished, slickensided fault planes, but closer observation shows the initial observation to be in error. First, the strike and dip of all three faults are different (EW 30° S, N 77° W, 40° NE, and N 40° SE). Second, the fault plane flattens out directly into the bedding plane above the coalbed (C-C', fig. 11). Finally, the bedding shows reverse drag along the fault plane (B-B', fig. 11). All of these features probably result from soft-sediment slumping and are not necessarily due to tectonic forces. Williams (22) described similar features in the interval above the Lower Kittanning coalbed in Clearfield County. He referred to them as rotational slumps, indicating that their origin is connected with slumping of semilithified blocks of sediment into paleotopographic low areas.

Joint directions measured in mine roofs, strip mine highwalls, and widespread outcrops within each of the nine quadrangles were plotted on rose diagrams and are illustrated in figure 12. Joint traces are widely spaced and show many inconsistent orientations.

Cleat measurements were taken in deep mines, in strip mines, and at different coal outcrops (fig. 13), using the method devised by Diamond (3). The mean face cleat, the principal cleat perpendicular to structural trends, ranges in direction from N 82° W to N 54° W. Mean butt cleat directions range from N 10° E to N 45° E and parallel the structural trends in the area. The face cleats were probably formed as extension fractures during structural deformation, and the butt cleats as released fractures during erosion and uplift (14).

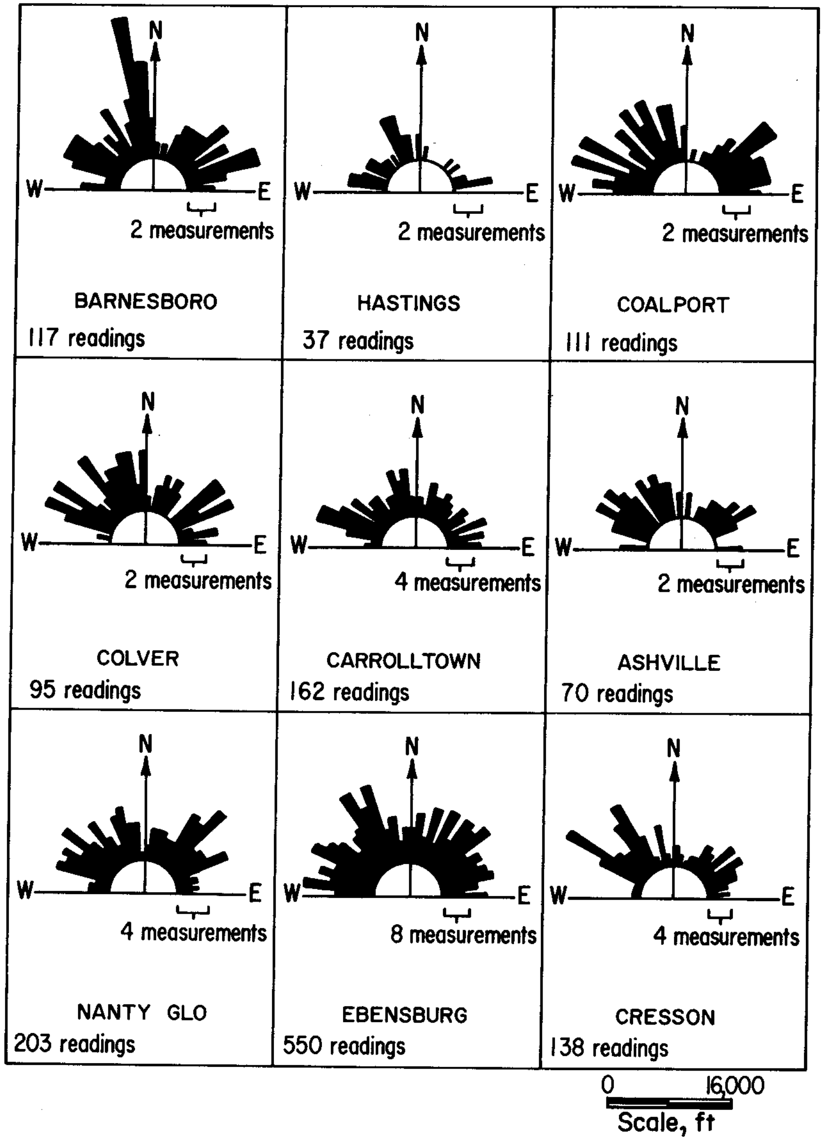


FIGURE 12. - Rose diagrams of bedrock joints of each of the nine quadrangles of the study area.

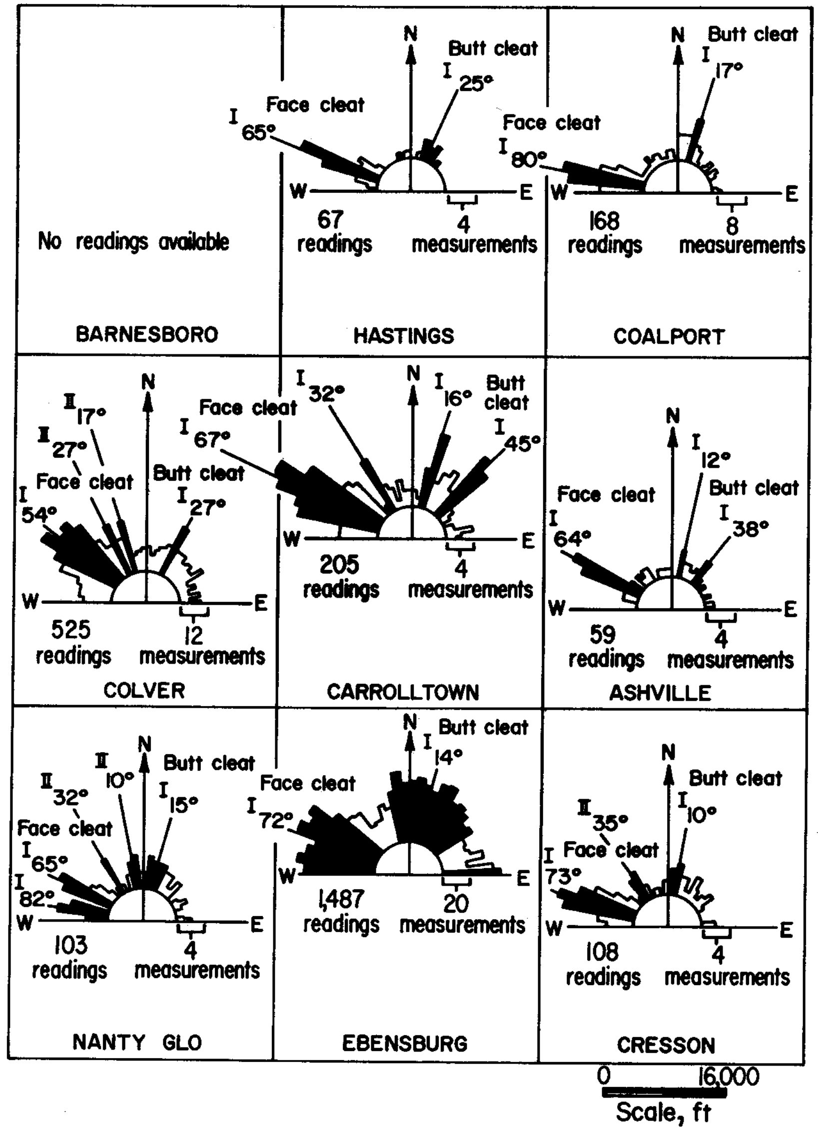


FIGURE 13. - Rose diagrams of cleat orientations in eight of the nine 7-1/2-minute quadrangles.

MINING PROBLEMS RELATED TO GEOLOGY OF THE LOWER KITTANNING COALBED

Certain geologic factors control the conditions that lead to problems in mining the Lower Kittanning coalbed. These factors are associated with the sedimentary environment of deposition and the diagenesis of these sediments into their present lithified state. Two principal geologic factors affecting mining are "wants" and the nature of roof-rock strata. Some preliminary work was done on the geology of the Lower Kittanning coalbed (10), but this study is more detailed and of broader scope.

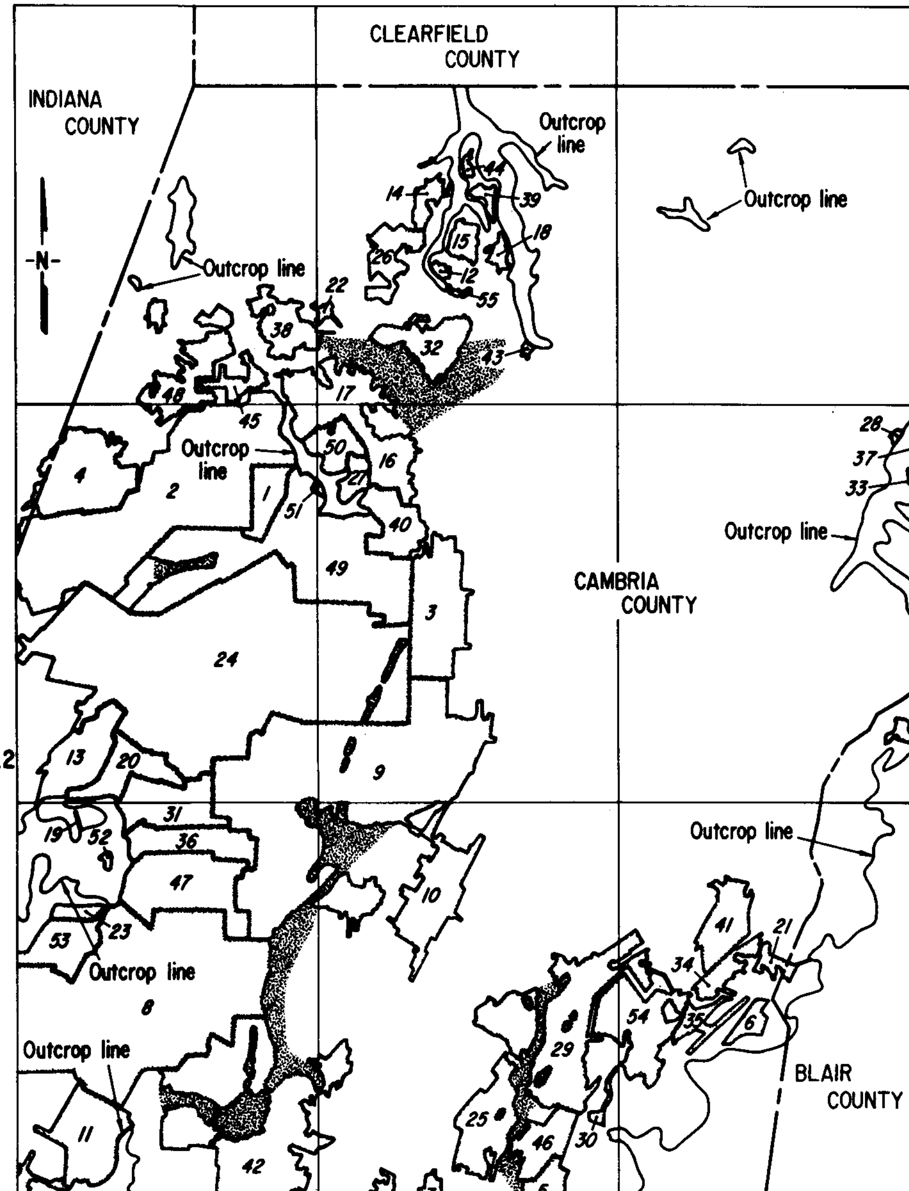
Occurrence of "Wants"

The term "wants" refers to the localized thinning or disappearance of coal. The two types of "wants" encountered are erosional and depositional in origin. The depositional and postdepositional environments in the coal-forming swamp were the controlling factors in the distribution and frequency of these "wants." The mechanism for their formation follows: Local removal of an incipient coalbed takes place when streams erode channels into underlying sediments. These channels are the sites of both erosion and deposition of sediments. The coarser grains settle out of suspension and may eventually fill the channel; the clay- and silt-size sediments are generally deposited in low-energy environments as overbank deposits in interdistributory bays or as delta-front deposits. It is possible, however, for a channel to be filled with silt and clay.

The type of "want" encountered must be determined before potential "wants" in unmined areas can be delineated. Figure 14 shows all the mines that have worked the Lower Kittanning coalbed in the area studied. Four major "want" areas can be identified from the mine maps; however, all are inaccessible for inmine inspection.

The first "want" area is encountered in three mines (15, 17, and 32, fig. 14); this Y-shaped "want" is between 3,000 to 5,000 feet in width. The second "want" area extends over a 12-mile, north-south direction in parts of mines 8, 9, 10, 24, and 42 (fig. 14); it meanders slightly with widths ranging from 100 to 3,000 feet. A third, north-south-trending "want" area occurs in mines 25, 29, and 46 (fig. 14); the northern extent of this "want" is not defined. Finally, a fourth small isolated "want" area is encountered in mine 49 (fig. 14).

It has already been shown that the Lower Worthington Sandstone is located stratigraphically between the Middle and Lower Kittanning coal groups. Figure 15 shows the thickness and trends of the linear, wedge-shaped sandstone bodies. In comparing the first three "want" areas described earlier (fig. 14) with the thick sandstone areas of figure 15, there is a correlation of "wants" with thick sandstone. A north-south trend is shown in both figures. Furthermore, figure 15 provides important information on sandstone trends in unmined coal, indicating that these three "want" areas are part of the same distributary system and can possibly be connected.



LEGEND

1 Barnes and Tucker No. 14
2 Barnes and Tucker No. 15
3 Barnes and Tucker No. 20
4 Barnes and Tucker No. 24-B
5 Beachy No. 6
6 Bear Rock
7 Berwind-White No. 2
8 Bethlehem No. 31
9 Bethlehem No. 32
10 Bethlehem No. 33
11 Bethlehem No. 77
12 Beunier Puritan
13 Big Bend Nonpareil
14 Blubaker No. 2
15 Blubaker No. 10
16 Carrolltown-Victor No. 9
17 Carrolltown-Victor No. 10
18 CBC-Seldom Seen
19 Commercial No. 2
20 Commercial No. 5
21 Commonwealth of Pennsylvania
22 Cymbria
23 Dorsh No. 1
24 Eastern Associated-Colver
25 Eastern Associated-Sonman No. 2
26 Hastings No. 2
27 Heisley No. 2
28 Hertzog
29 Hughes No. 2
30 HWZ-Bens Creek No. 2
31 Imperial Cardiff No. 1
32 Lanark No. 1
33 Laurel Run No. 2
34 Lilly No. 3
35 Lilly New Slope
36 Lincoln
37 Link
38 Spangler No. 4
39 Miller Run No. 1
40 Navy Smokeless
41 Pennsylvania-Cresson No. 9
42 Pennsylvania-Ehrenfeld No. 3
43 Pennsylvania-Pardee No. 36
44 Pine Valley No. 1
45 Reilly No. 1
46 Sonman Shaft
47 Springfield No. 1 and 3
48 Springfield No. 4
49 Sterling No. 1
50 Sterling No. 3, 4 and 5
51 Sterling No. 9
52 Warren No. 10
53 Webster-Nanty Glo No. 14
54 WH Piper-Sonman No. 2
55 WJ Holtz

"Wants" in coalbed

0 20,000
Scale, ft

FIGURE 14. - Mined-out-area map of mines in the Lower Kittanning coalbed, showing "want" areas.

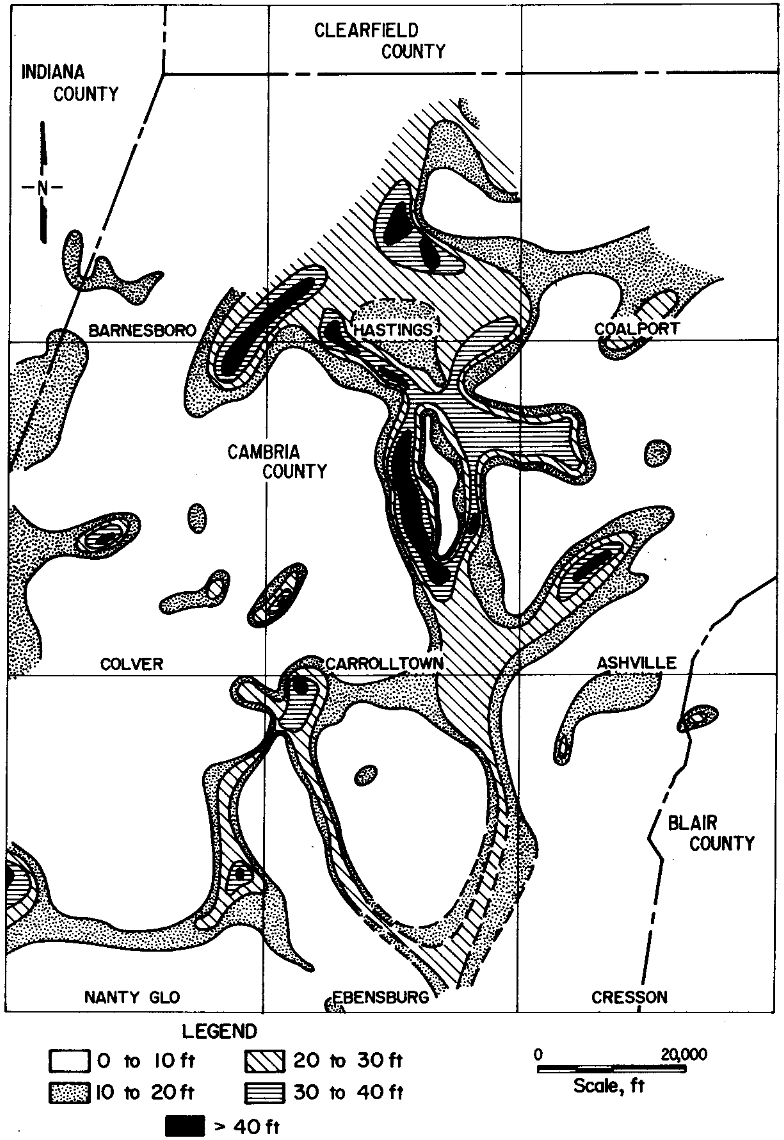


FIGURE 15. - Isopach map of the Lower Worthington Sandstone.

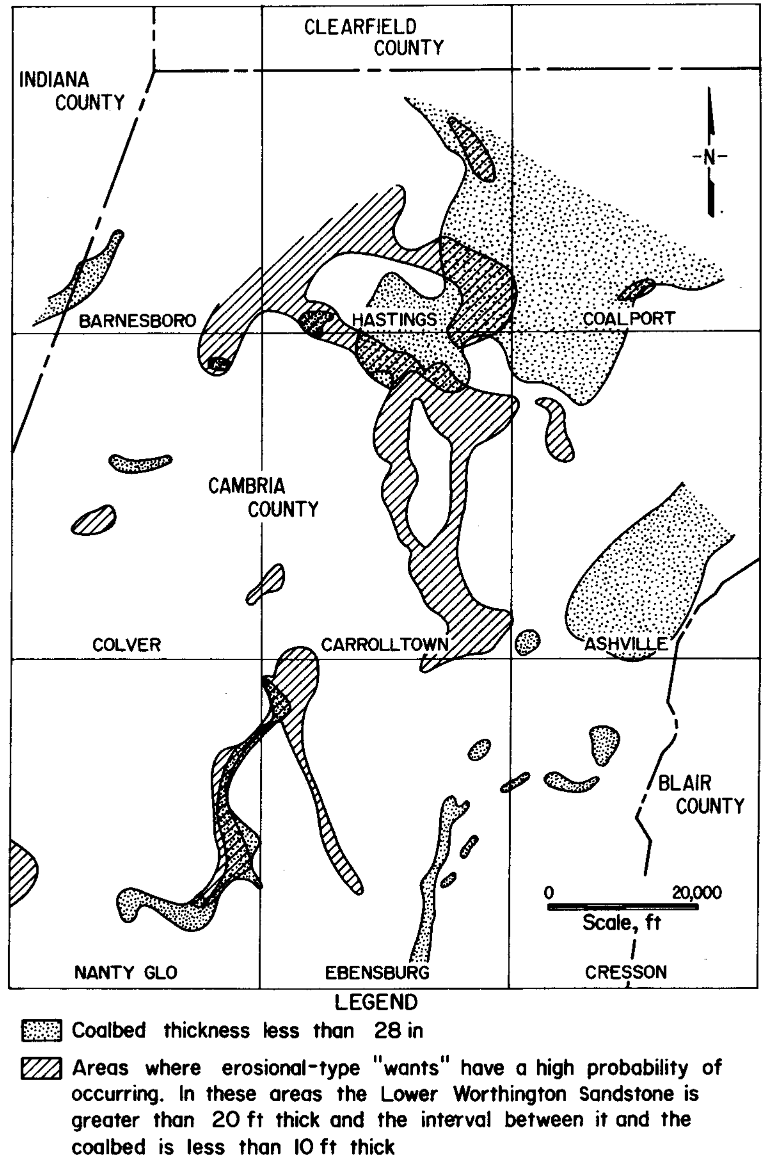


FIGURE 16. - Map showing the correlation of the thick Lower Worthington Sandstone with "wants" in the Lower Kittanning coalbed.

Correlation of sandstone-filled channels with "wants" is further improved by constructing a map (fig. 16) showing areas of thin coal in relation to the Lower Worthington Sandstone where it is at least 20 feet thick and within 10 feet of the underlying Lower Kittanning coalbed. The 28-inch line (fig. 16) was arbitrarily selected to indicate possible "want" areas because the continuous-mining machines used in this area have a lower limit of 28 inches. It is believed that "wants," indicated by the 28-inch line and associated with areas where the Lower Worthington Sandstone is at least 20 feet thick and within 10 feet of the underlying coalbed, are of the erosional type.

There may be a "want" in the north-south-trending area of Lower Worthington Sandstone in the Carrolltown quadrangle (fig. 16). Although all the cores from that area show a minable thickness of coal (fig. 17), two show a thick sandstone directly on top of the coalbed. In areas adjacent to those from where these cores came, it is possible that this sandstone extends down into the coalbed to reduce its thickness or perhaps even cut it out completely.

Another type of "want" is one in which a minable coalbed splits into several thinner coalbeds which are not mined individually or together because of the excessive intervening rock. Often the total thickness of the split coal is less than that of the total undivided coalbed. This is referred to as a depositional "want" or "split." Moore (13) explained the origin of splits as follows:

> Splits are due to the fact that while the vegetal matter is being laid down in the swamp there are periods when clay or sand is brought in by water from the surrounding lands and carried out over the vegetal matter.

The Lower Kittanning coalbed, generally 4 feet thick (fig. 17), splits into as many as three coal units within 25 feet of section in the northeastern portion of the study area (figs. 18-19). This "want" area (less than 28 inches of coal, fig. 17) is considered to be depositional in origin based on the stratigraphic cross sections (figs. 18-19).

Types of Unstable Roof

Roof-rock strata affect the physical condition of the roof and type of support needed to maintain a good roof in a coal mine. Observation of many roof falls and areas of unstable roof in the five underground mines led the authors to identify five types of unstable roof related to the geologic conditions. They are characterized as follows:

1. Slickensided disconformities on the underside of the channel sandstones.

2. Randomly oriented slickensided slip planes resulting from slumping as the sediments were undergoing consolidation. Commonly found in black shales above the coalbed.

3. Slickensided slip planes caused by differential compaction of sandstone and adjacent shale.

4. Abrupt lateral pinchouts or wedges of strata (generally thin sandstone pinchouts).

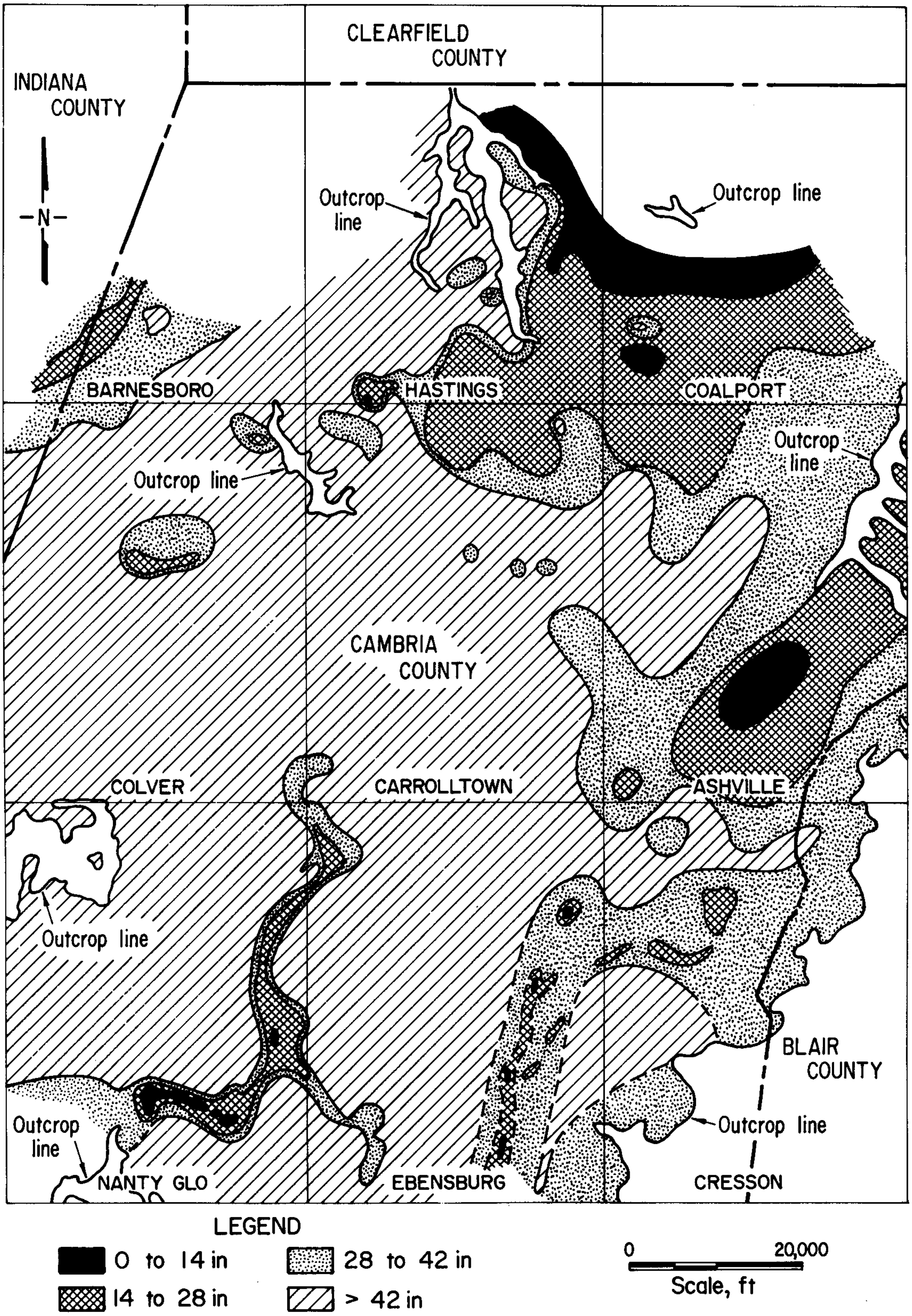


FIGURE 17. - Isopach map of the Lower Kittanning coalbed (including shale partings less than 1 foot in thickness).

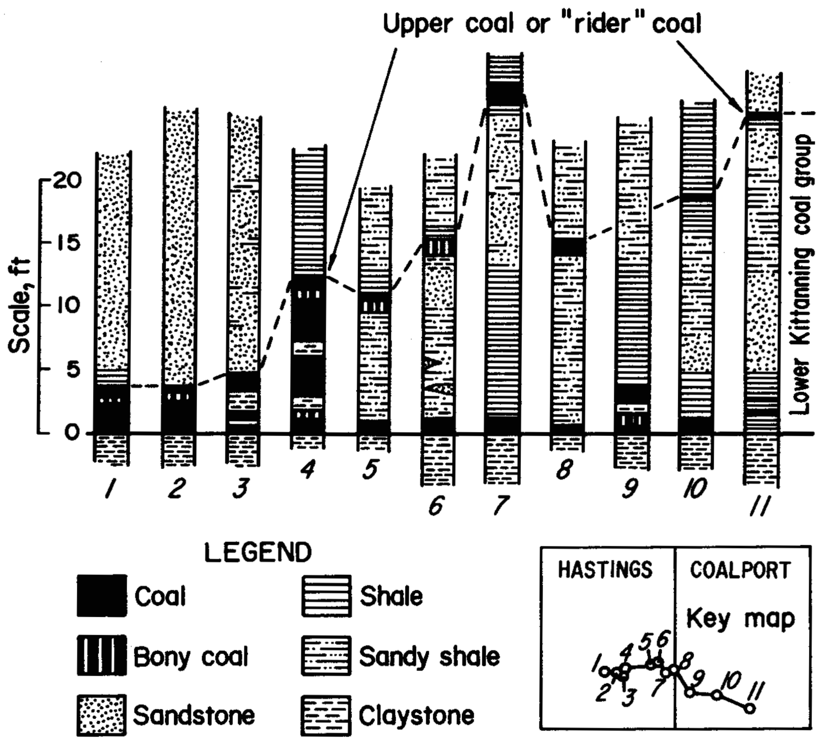


FIGURE 18. - Stratigraphic sections of the Lower Kittanning coal group and location of cross sections.

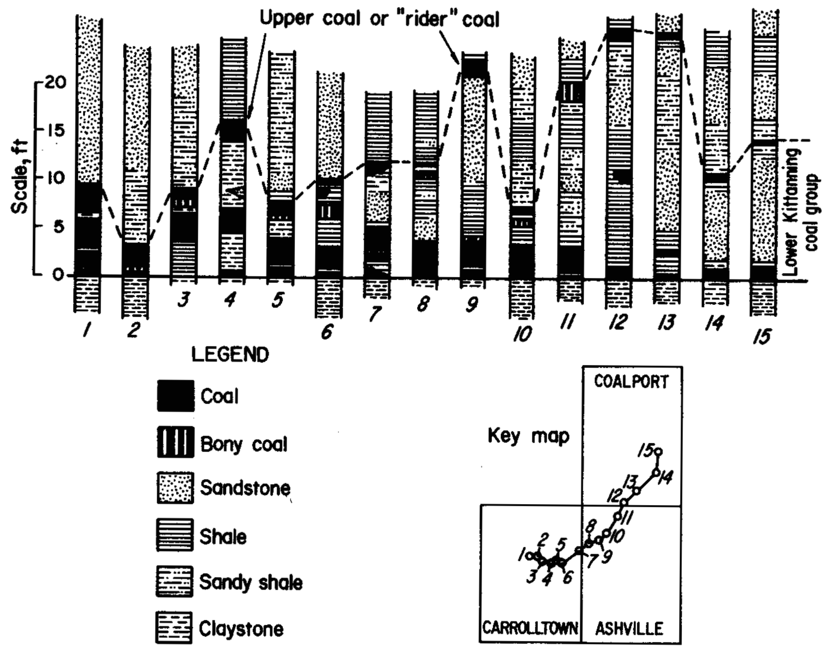


FIGURE 19. - Stratigraphic sections of the Lower Kittanning coal group.

5. Abrupt lithologic boundaries between clays, shales, siltstones, sandstones, and coal, causing planes of weakness.

Of the five types of unstable roof, areas with slickensided surfaces on the underside and adjacent to the Lower Worthington Sandstone and abrupt lithologic boundaries of the Middle Kittanning coalbed can be identified, with the aid of core log data, in advance of mining.

Slickensided fractures are commonly present adjacent to and on the underside of the thick channel sandstone above the Lower Kittanning coalbed (fig. 20). These fractures are caused by differential compaction and by soft-sediment sliding along and adjacent to the contact between the sand-filled channels and the shale that underlies the sandstone.

The slickensided surfaces are planes of weakness. When unsupported, shales, clays, and thin "rider" coals beneath and adjacent to channel sandstones easily separate and fall into mine rooms (12). The underside of such a channel represents a disconformable surface. The closer the underside of the channel sandstone is to the top of the coalbed, the greater the chance of roof failure. Figure 21 shows areas where the interval from the top of the Lower Kittanning

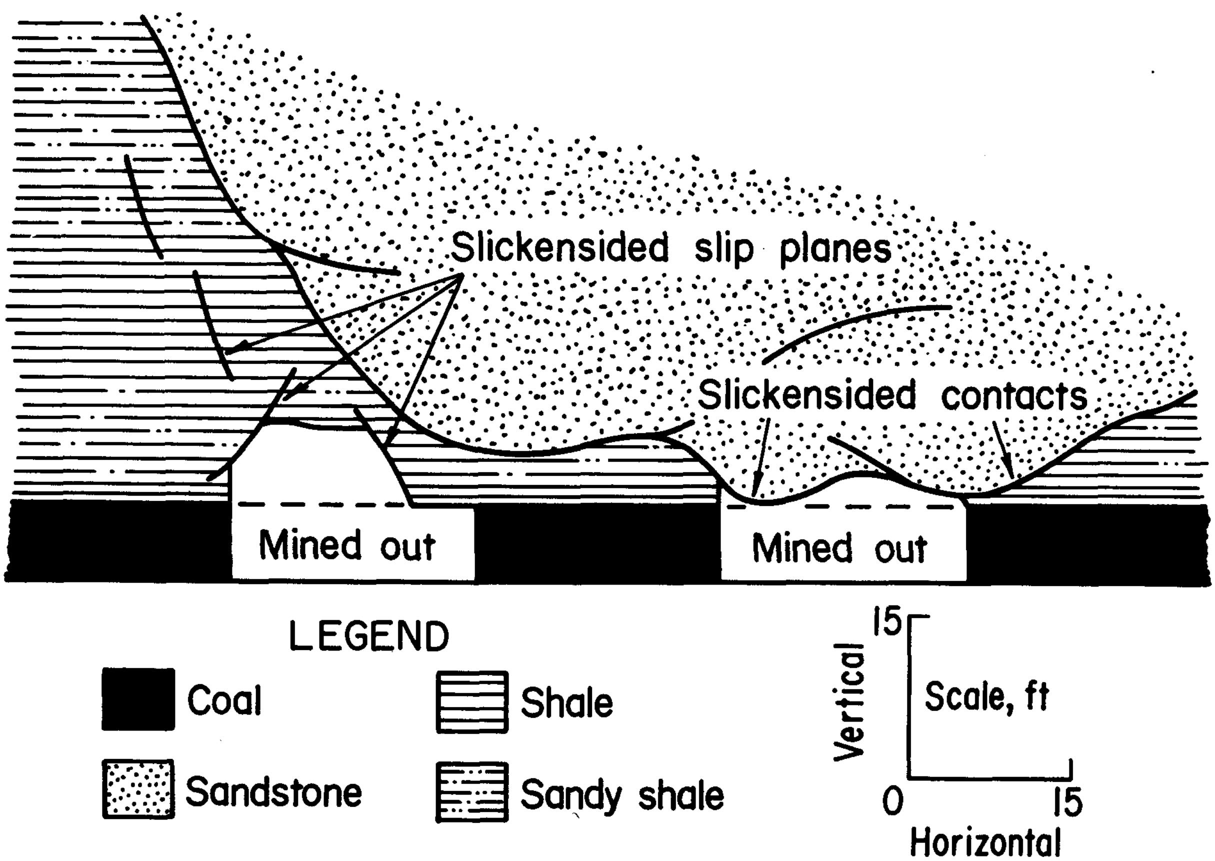
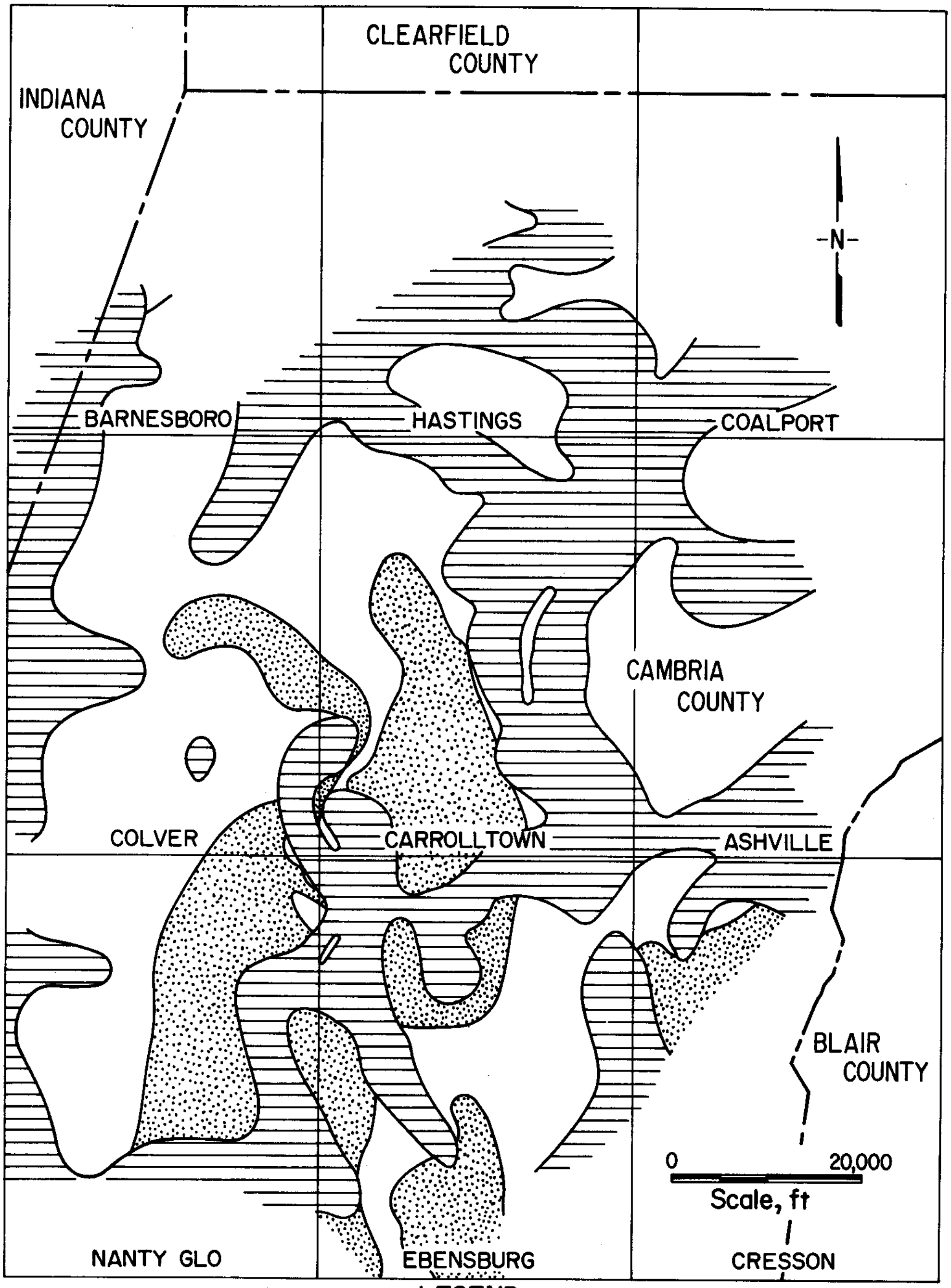


FIGURE 20. - Generalized cross section of characteristic unstable roof associated with sandstone channels.



LEGEND

Areas where roof falls, related to sandstone channels less than 20 ft above the coalbed, have a high probability of occurring

Areas where roof falls, related to an interval of less than 30 ft between the Lower and Middle Kittanning coalbeds, have a high probability of occurring

FIGURE 21. - Map showing the high-roof-instability areas related to the stratigraphic position of the Lower Worthington Sandstone and the Middle Kittanning coalbed.

coalbed to the bottom of the Lower Worthington Sandstone is less than 30 feet. Roof instability increases greatly in such areas.

Another type of roof instability is associated with the abrupt lithologic boundaries of the Middle Kittanning coalbed (fig. 22). Benedict (1) noted this characteristic in the Bethlehem No. 32 mine:

> According to the experience of mine operators, when the thickness of this unit is less than 20 feet, the bond between the overlying coal and its associated underclay often fails, thus causing the entire stratigraphic unit to fall into the mining area below.

Benedict mapped the interval from the Lower Kittanning coalbed to the next highest coalbed, because a thick "rider" coalbed occurs locally between the Middle and Lower Kittanning coalbeds on Bethlehem's property. However, regionally this coalbed is discontinuous and very thin, unlike the regionally persistent Middle Kittanning coalbed (fig. 7).

Wherever the Middle Kittanning coalbed is less than 30 feet above the Lower Kittanning coalbed, the frequency of roof falls is increased. In one area of the Colver mine, where the interval is less than 30 feet, more than half of the existing roof falls extended upward to the top of the Middle Kittanning coalbed.

The increase in this type of roof instability is related to the sharp lithologic contacts between the Middle Kittanning coalbed and the shale above and the underclay below this coalbed. These contacts represent planes of structural weakness. In this thin interval, void of channel sandstones, alternating lithologies are generally gradational, unlike the coal-shale and coal-underclay contacts. Figure 21 shows areas where the interval is less than 30 feet, indicating areas where this type of unstable roof will increase in frequency. This type of unstable roof is common in mines in eastern Nanty Glo, western Ebensburg, eastern Colver, and western Carrolltown quadrangles (fig. 21).

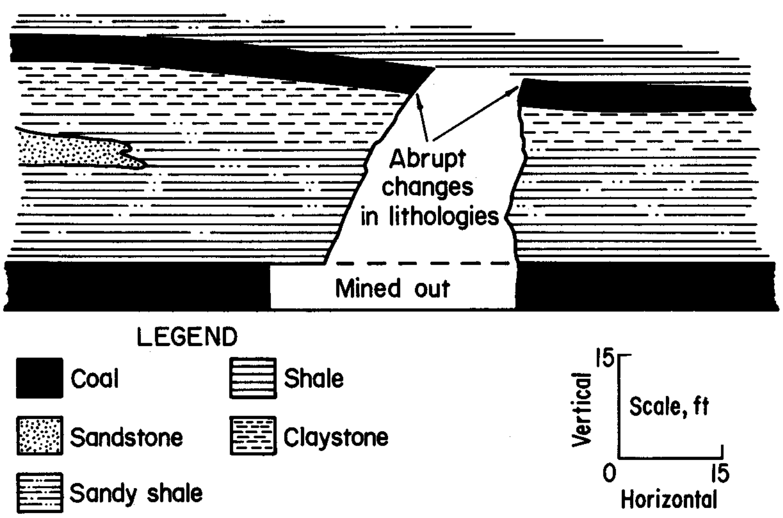


FIGURE 22. - Generalized cross section of characteristic unstable roof associated with thinning of the interval between the top of the Lower Kittanning coalbed and the bottom of the Middle Kittanning coalbed.

Unstable roof strata described above may occur when supporting coal is first removed. Also over long periods of time, moist mine air, moving through fractures and slickensided planes in the roof, weakens contact bonds between lithologies. Shales and especially claystones soften and become difficult to support, so that some roof falls may occur in the later stages of mining. Unstable roof associated with slickensides resulting from slumping and abrupt lateral pinchouts of strata were found to be local in extent and extremely difficult to predict in unmined areas.

So far we have discussed unstable roof problems associated with geologic conditions. However, not all unstable roof can be related to geologic influences. An example of this is an elongated roof fall occurring parallel to the rib, commonly referred to as a "cutter." The origin of "cutters" is unclear. They generally occur parallel to the ribs (fig. 23) but are also found to cut across entries. There are no bedding disturbances or slickensided surfaces associated with a "cutter." One of the more probable explanations for their occurrence could be abnormally high horizontal stress forces in the rock strata. "Cutters" are among the many roof failure conditions observed that need to be investigated in much greater detail.

METHANE EMISSION

Methane is always present in coal and can constitute a serious safety hazard in coal mining. Several other gases are associated in far less amounts with methane in coal. These include hydrogen, water vapor, nitrogen, carbon dioxide, and helium (7). Gas content of a coalbed is primarily influenced by depth and rank. During mining, methane emission from a coalbed is controlled by porosity, permeability, and gas pressure.

The most easily documented geologic factor influencing methane content of coal is depth. Generally at greater depths and therefore higher pressures, a greater volume of gas is held within the coal. Also, since the gas at greater depths is contained under higher pressure, it is released in larger volumes during mining (2). Figure 24 is an isopach map of the overburden above the Lower Kittanning coalbed. It is expected that in the deeper parts of the study area, the gas content of the coalbed will increase. This is partly substantiated by work done by Puglio (15) in nearby Indiana County. A sample of the Lower Kittanning coalbed taken from a depth of 623 feet contained only about 1 cm^3/g (32 ft^3/ton) of methane, while a sample taken from a depth of 1,060 feet contained about 11 cm^3/g (352 ft^3/ton).

A second geologic factor influencing the methane content of coal is rank. Kim (8), in comparing actual gas contents of coals with different ranks and depths, considered rank as an aid in estimating methane content of bituminous coals. Stach (17) stated that in the different coalification stages large amounts of methane are generated in the medium-volatile to anthracite range. Additionally, Joubert (6) showed that increased moisture content in coal reduces its capacity to absorb methane. Because the Lower Kittanning coalbed in the study area is a low- to medium-volatile bituminous coal (high rank, low moisture content), it contains more methane gas than lower rank coals.

FIGURE 23. - "Cutter" occurring parallel to the rib.

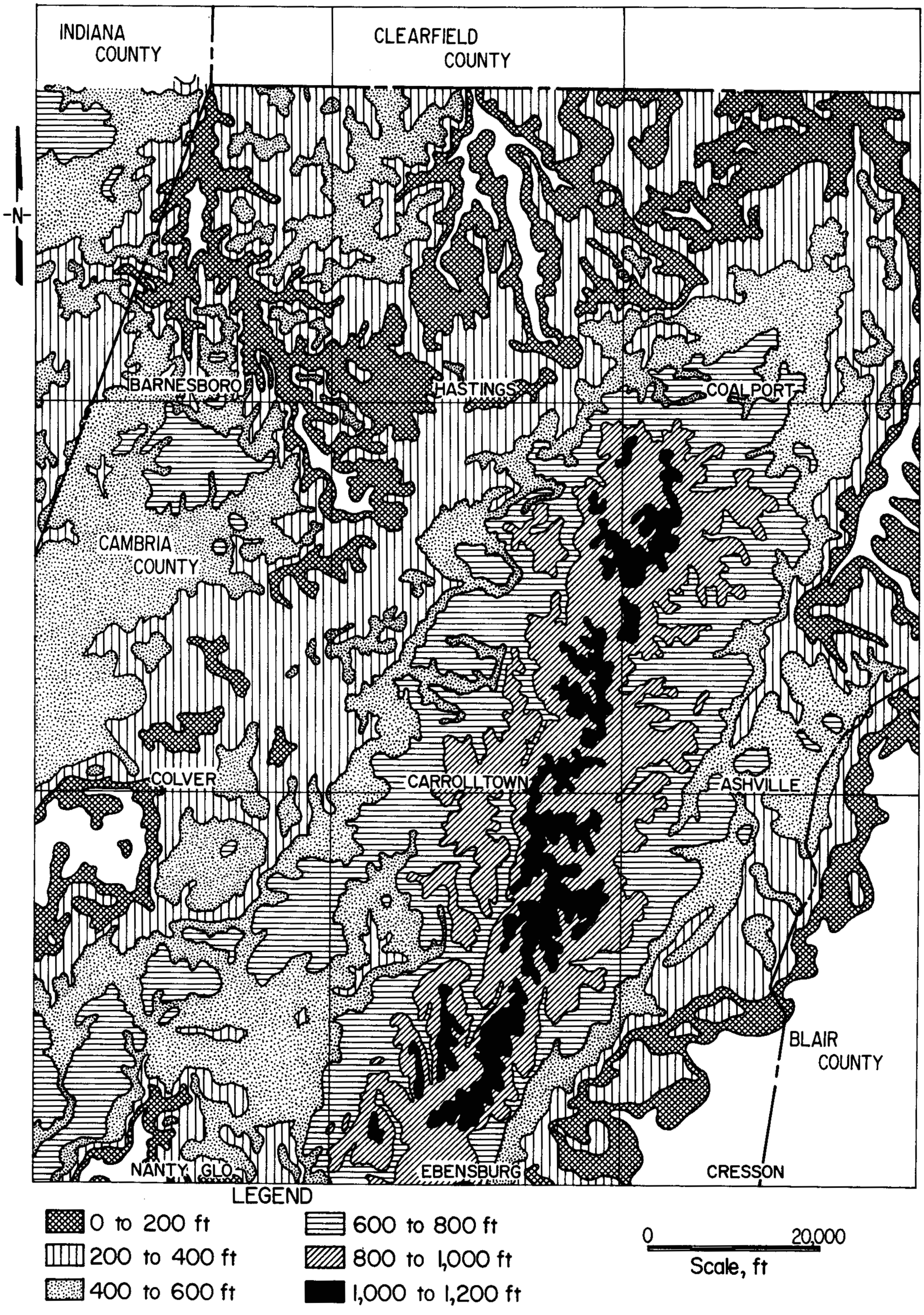


FIGURE 24. - Isopach map of the overburden above the Lower Kittanning coalbed.

Possibly the best indicator of the high methane content of this coalbed is the high methane emissions encountered in deeper mines. As shown in table 1, the average methane emissions from mines within the study area increase substantially with depth.

TABLE 1. - Average methane emission during coal production and depth of six active deep mines in Lower Kittanning coalbed

Coal mine	Average methane emission (1976), MMcfd	Average depth, feet
Eastern Associated, Colver......	400,000	300
Bethlehem No. 31................	212,000	350
Barnes and Tucker No. 24B.......	274,000	400
Barnes and Tucker No. 20........	2,643,000	500
Bethlehem No. 33................	2,695,000	650
Bethlehem No. 32................	3,101,000	700

Geologic factors influencing methane emissions from a coalbed during mining are porosity, permeability, and gas pressure. Porosity measurements are difficult to make, but porosity is believed to depend on characteristic moisture content (6) and rank (18). Although by definition primary permeability is through the solid coal microstructure, secondary permeability (permeability along cleat fracture planes or fracture permeability) is higher. Fracture permeability is one of the controlling factors in migration and retention of methane in a coalbed.

Directional permeability of coal is dependent on orientation and density of the cleat fracture. Kissell (9) showed gas emissions from the Pittsburgh coalbed in Greene County, Pa., to be 2.5 to 10 times higher where horizontal degasification holes were drilled perpendicular to face cleat than emissions with the holes perpendicular to the butt cleat. Because of the friable nature of the Lower Kittanning coalbed in the study area and several different clusterings of face and butt cleat orientations (fig. 13), it is expected that the fracture permeability will vary in different directions but not as much as that of the more blocky coalbeds.

Only a small percentage of the coal lying deeper than 700 feet has been mined. More than 80 percent of the remaining minable reserves lie deeper than 600 feet in Ebensburg, eastern Carrolltown, western Ashville, and northwestern Cresson quadrangles (fig. 24). Mining in these areas can be expected to encounter very high methane emissions, whereas comparatively low methane emissions can be expected in mining the remaining reserves close to the outcrop in eastern Ashville quadrangle and northern Cresson quadrangle. Direct determination (11) of methane content of coal cores from exploration drill holes will greatly aid in calculating the methane content in the unmined areas of the coalbed.

More localized geologic factors influencing methane emissions are coalbed thickness (fig. 17), presence of other coalbeds above the coalbed presently being mined (fig. 7), porous sandstone lying between source rocks (fig. 7), structure, and proximity to outcrop (fig. 24).

SUMMARY AND CONCLUSIONS

Using data gathered from core logs, mine maps, and geologic mine surveys, the geology of the Lower Kittanning coalbed was investigated and its influence on mining was determined. The important characteristics of the stratigraphy of the coalbed follow:

1. The Lower Kittanning coal group is made up of all the coalbeds between the Kittanning Sandstone and Lower Worthington Sandstone.

2. The Lower Kittanning coal group is generally composed of a thin upper coal (Lower Kittanning "rider" coal) and a thick lower coal (Lower Kittanning coalbed).

3. The lower coal of the Middle Kittanning coal group is distinguished from the Lower Kittanning "rider" coal by the presence of a thick underclay below the former and a carbonaceous shale, siltstone, or sandstone below the latter.

4. The Middle Kittanning coal group lies 20 to 60 feet above the Lower Kittanning coalbed, is erratic in thickness, and splits into many thin benches of coal through the area.

Important depositional variations that were examined and that influence coal extraction follow:

1. The Lower Worthington Sandstone is a sand-filled channel deposit, ranging in thickness from 0 to 60 feet. Locally it erodes through key marker units.

2. The Lower Worthington Sandstone is generally present in the interval between the Lower and Middle Kittanning coal groups. A thickening of this interval is associated with the presence of the Lower Worthington Sandstone.

3. Wherever the Lower to Middle Kittanning interval is less than 30 feet thick, there is generally no channel-type sandstone present. Instead, this interval is composed of thin tabular sandstones and shales that grade vertically and horizontally into sandy and silty gray shales.

4. The most distinctive horizontal breaks or zones of weakness between lithologies occur between the rocks above and below a coalbed and also at the bottom of sandstone channels.

5. "Wants" are either erosional or depositional in nature. Erosion is accomplished by distributary channels cutting into the coalbed and washing it away. Variations in deposition influence the development of "wants" in the form of splits or thinning of the coalbed.

Conclusions drawn from this investigation are--

1. "Wants," located by coal isopach and mine maps, show a high correlation with areas where the bottom of the Lower Worthington Sandstone comes within 10 feet of the top of the Lower Kittanning coalbed. Therefore, the occurrence of "wants" can be predicted in advance of mining if sufficient exploration data are available.

2. Roof rock instability can be linked with the close position of either a channel sandstone or the Middle Kittanning coalbed above the Lower Kittanning coalbed. This condition can be used in predicting areas of unstable roof in unmined coal and can aid in designing an effective roof-bolting plan.

3. High methane emissions in the Lower Kittanning coalbed are influenced by relatively great depths, high rank, and good fracture permeability.

4. The already serious problem of high methane emissions will become even greater in future extraction of the deeper areas of coal.

A long mining history and an active exploration program to delineate deep reserves characterizes the area under investigation. As these deeper reserves are exploited, an understanding of geologic factors affecting mining in the virgin coal will aid in planning more productive mines with better hazard evasion.

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