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Geologic Factors Causing Roof Instability and Methane Emission Problems

The Lower Kittanning Coalbed, Cambria County, Pa.

UNITED STATES DEPARTMENT OF THE INTERIOR

Report of Investigations 7769

Geologic Factors Causing Roof Instability and Methane Emission Problems

The Lower Kittanning Coalbed, Cambria County, Pa.

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UNITED STATES DEPARTMENT OF THE INTERIOR
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GEOLOGIC FACTORS CAUSING ROOF INSTABILITY AND METHANE EMISSION PROBLEMS

The Lower Kittanning Coalbed, Cambria County, Pa.

by

C. M. McCulloch[1] and Maurice Deul[2]

ABSTRACT

A geologic study of Mines 32 and 33 in Cambria County, Pa., was conducted as part of a methane control research program. Areas of high methane emission and roof instability are encountered which are related to the structural and stratigraphic features that characterize the geologic setting of these mines. Locally the folds trend N 20° E ±2°, the direction of the butt cleat in the Lower Kittanning coal. The face cleat strikes at N 69° W ±2° and the systematic rock joint in the surface bedrock strikes N 67° W ±2°. This suggests that a directional stress oriented N 70° W produced the folds and influenced the directions of coal cleat and systematic joint sets. Analysis of SLAR indicates three directions of prominent regional lineation: N 39° E, N 31° W, and N 70° W.

Little gas was encountered during development mining; large volumes of gas are encountered when roof falls. Most of the gas comes from strata above the mined coal; therefore, to control methane, roof instability must be controlled.

Roof falls and high rates of methane emission are most likely where less than 30 feet of many thin layers of limestone, shale, and sandstone occurs between the Lower Kittanning coal and the next coal and in zones along the margins of a sandstone channel.

INTRODUCTION

The Cambria Nos. 32 and 33 mines are located in western Pennsylvania near Ebensburg, about 60 miles east of Pittsburgh. The No. 33 is a slope mine, whereas the No. 32 is a shaft-type mine; both are presently working beneath 300 to 1,000 feet of cover in the Lower Kittanning coalbed. Data on the compass directions of joint sets and coal cleats, together with regional structure and stratigraphic observations, were analyzed for indicators of geologic control of the emission of methane from the coalbed into the mine workings, and of relationships to roof falls in the mines.

[1]Geologist.
[2]Supervisory geologist.

This project was conducted as part of the methane control research program to determine the cause of the large amount of methane being emitted into the mine workings. Areas of large methane emissions were found to be areas of roof instability. Therefore, for these mines, studies of roof instability were a natural consequence, although not the original objective.

ACKNOWLEDGMENTS

We acknowledge the cooperation and assistance of the management of Bethlehem Mines Corp. with whom we have held cooperative agreements for many years. Special thanks are due to personnel of the Cambria division for their personal interest and support, notably A. T. Sossong, the division engineer. We acknowledge the assistance of Lou Benedict from the Bethlehem Research Center for the time and effort he devoted in the field and for his critical comments. We also thank Bion Kent of the U.S. Geological Survey for his critical review and many thoughtful suggestions.

PREVIOUS AND CONCURRENT WORK

The first geologic work in the Cambria County area was done by H. D. Rogers in 1858 (15),[3] who conducted the first geologic survey of the entire State of Pennsylvania. In 1877, F. Platt and W. G. Platt (14) did a geologic study of the Cambria and Somerset districts. Both these reports were excellent and have been updated recently.

In 1905, Charles Butts (3) completed the next major work on the Cambria County area with his "Ebensburg Portfolio," a geologic study of the Ebensburg 15-minute quadrangle that included a structure map drawn on the Upper Freeport coalbed. The stratigraphy of the area was described in that report but the group, formation, and member names of some of the units have been changed.

Ashley, Sisler, and Reese (1), 1925-1928, of the Pennsylvania State Geological Survey wrote a report on the "Bituminous Coal Fields of Pennsylvania." This was a description of individual coalbeds, coalfields, and a summary of resources of Pennsylvania.

Dutcher (5) produced a field trip guide to this general area for the Pittsburgh meeting of the Geological Society of America.

Concurrent work in the Cambria County area is being done by Lou Benedict of Bethlehem Steel Corp. on some of the same problems dealt with in this paper. His results to date agree generally with the findings of this report even though his techniques are somewhat different.

STRATIGRAPHY

Only the Allegheny group of the Pennsylvanian system will be discussed since all the coalbeds that are important to this study are included within it.

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

The Allegheny group extends from the base of the Brookville coal to the top of the Upper Freeport coal (8). The average thickness in Cambria County is approximately 250 feet. This group is composed of shale, siltstone, sandstone, coal, and some fresh-water limestone lenses found in the upper third of this group. Flint (8) states that the Johnstown limestone is persistent and is used as a stratigraphic guide in Somerset County to the south. In the surface area around Ebensburg, where this study was conducted, and from core hole data, this limestone, although less persistent, is still found in 10 of the core holes.

The Allegheny group is subdivided into three formations following Shaffner (16) and Williams (17). These are Clarion, Kittanning, and Freeport. The boundary between the Clarion and Kittanning formations falls within the Lower Kittanning coal group. The Kittanning formation (18) is made up of

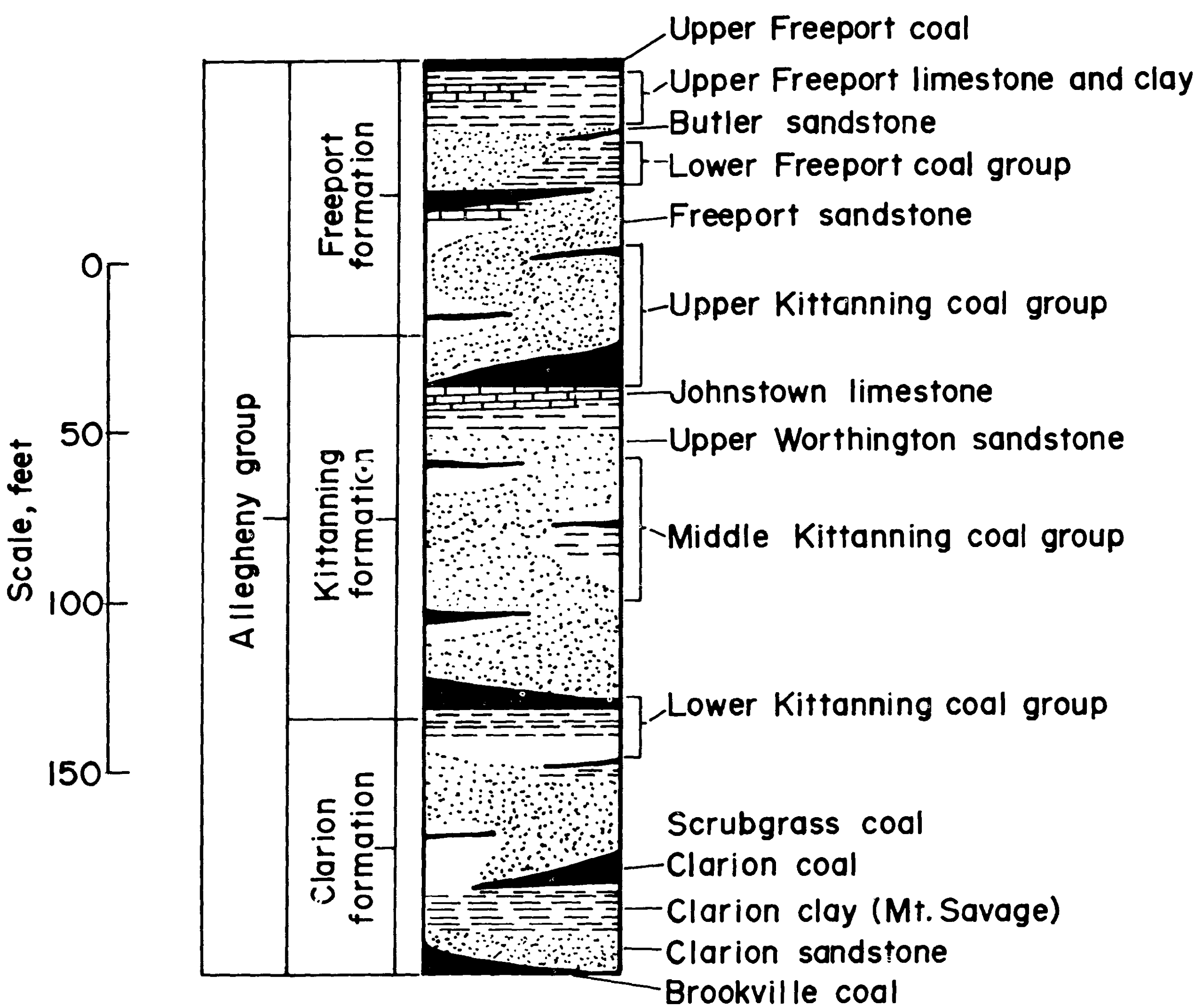

FIGURE 1. - Generalized section of the Allegheny group of the southern part of Somerset County, Pa.

"strata between the base of the underclay beneath the upper coalbed of the Lower Kittanning coal group and the top of the lower bench of the Upper Kittanning coal group." The average thickness of this sequence determined from the core hole data in this report is 106 feet. The persistent sandstone that overlies the Lower Kittanning coalbed is the Worthington Sandstone (14).

The three Kittanning coalbeds have alternate letter designations. They are sometimes referred to as follows:

Lower Kittanning coalbed--"B coal"
Middle Kittanning coalbed--"C coal"
Upper Kittanning coalbed--"C prime coal"

The Johnstown limestone, the most persistent limestone in the area, is found underlying the Upper Kittanning coalbed.

Of the two stratigraphic columns shown, the first (fig. 1) is the "generalized section of the Allegheny group of southern Somerset County, Pa." (8). A stratigraphic column of the Kittanning formation of the area considered in this report (fig. 2) has been drawn from core hole data and underground fall areas observed in the mines; this uses Flint's terminology.

REGIONAL AND LOCAL STRUCTURE

The Cambria Nos. 32 and 33 mines are located in the area where the main structures are the Ebensburg anticline and the Wilmore syncline (fig. 3). These features are part of the Allegheny Mountain section of the Appalachian Plateaus province and trend northeastward.

The structural contours in figure 3 were drawn on the bottom of the Lower Kittanning coalbed from mine and core hole data.

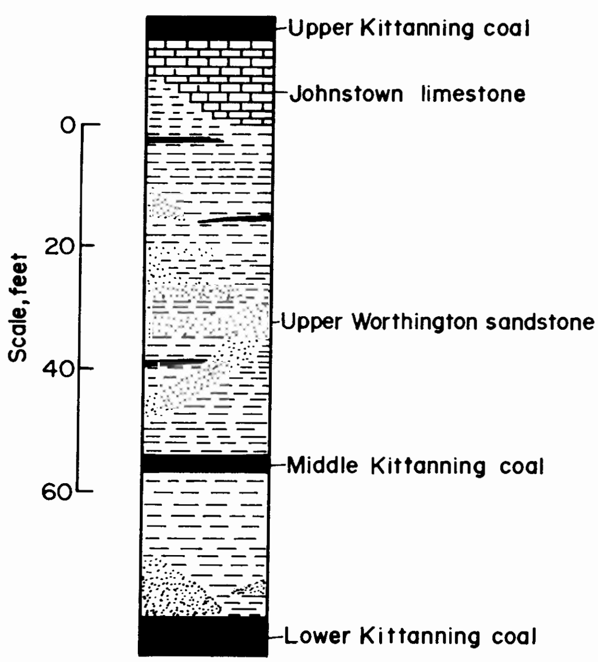

FIGURE 2. - Generalized section of the Kittanning formation of central Cambria County, Pa.

SLAR Imagery

The SLAR (side look airborne radar) imagery was used to supplement the fieldwork and computer treatment of field data. The main utility of SLAR imagery is that it permits systematic examination of large areas making it possible to note subtle topographic differences (lineations, faults, etc.) over long distances that would have been missed by normal geologic methods (4, 10).

The interpretation of the SLAR imagery is similar to that used in

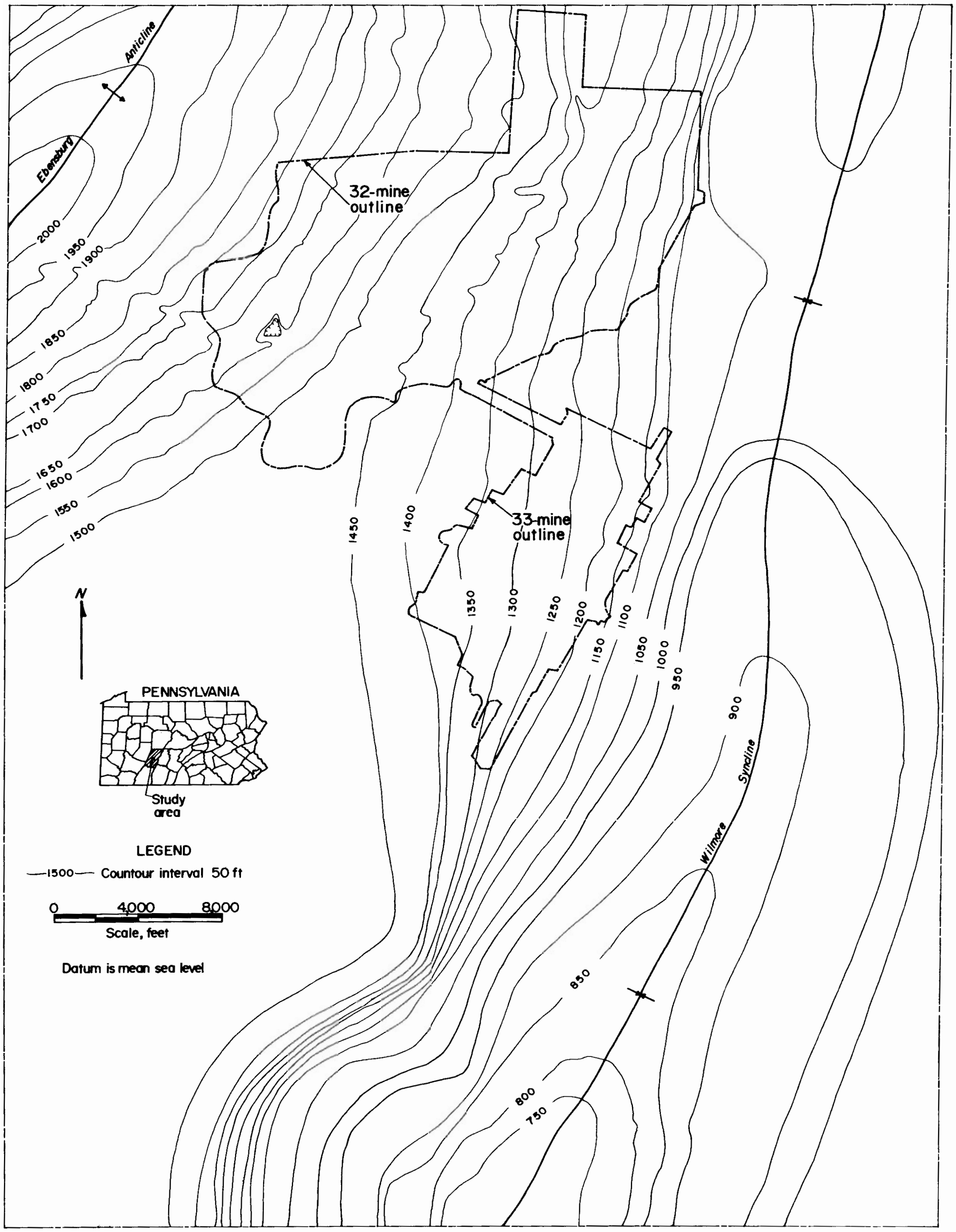

FIGURE 3. - Generalized structural contour map of area around Cambria Nos. 32 and 33 mines.

standard photogeologic interpretations. A Ronchi grating (a type of diffraction grating) can be used between the eye and the imagery; when rotated, strong lineations will become easily visible. The grating is to SLAR what stereographic glasses are to paired aerial photographs.

SLAR imagery was adjusted for true distances and directions from geological reconnaissance studies. According to MacDonald (12), "This computation can be accomplished most easily where a known distance between two points on the ground can be compared with the same two points on the radar imagery."

SLAR imagery of Cambria County, Pa., was studied for this report. Three prominent directions of lineations were observed on the SLAR imagery; these are (1) N 39° E, (2) N 31° W, and (3) N 70° W. These directions are indicated on figure 4.

Rock Joints and Coal Cleats

The strike and dip of the coal cleats and the surface rock joints were measured. The orientations of the various cleat and fundamental joint system directions are shown in figure 5. Nickelson (13) divided the fundamental joint system into two parts: (1) systematic joints and (2) nonsystematic joints.

According to Nickelson (13), "The complex pattern of jointing results from overprinting of two or more fundamental systems" with the systematic joint having well-defined axes whereas the nonsystematic joints are poorly defined.

From table 1 the average strike for the face cleats of the coal is N 69° W, whereas the average strike for the systematic surface rock joint is N 67° W, including the measurements of rock joints at location 4 in figure 4. The strikes of the two features are about the same, suggesting that there is a relationship between the strike of the systematic rock joints and the coal face cleats.

TABLE 1. - Average strike of coal face cleat and systematic rock joints

	Measurements	Strike[1]
Coal face cleat.................	1,725	N 69° W
Systematic rock joints..........	159	N 69° W (1)
Do.........................	332	N 69° W (2)
Do.........................	195	N 68° W (3)
Do.........................	189	N 58° W (4)
Do.........................	170	N 66° W (5)
Total.................	1,045	

[1]Number in parentheses corresponds to position on index map. All are ±2° compass directions.

The general locations of surface joint measurements are shown in figure 4.

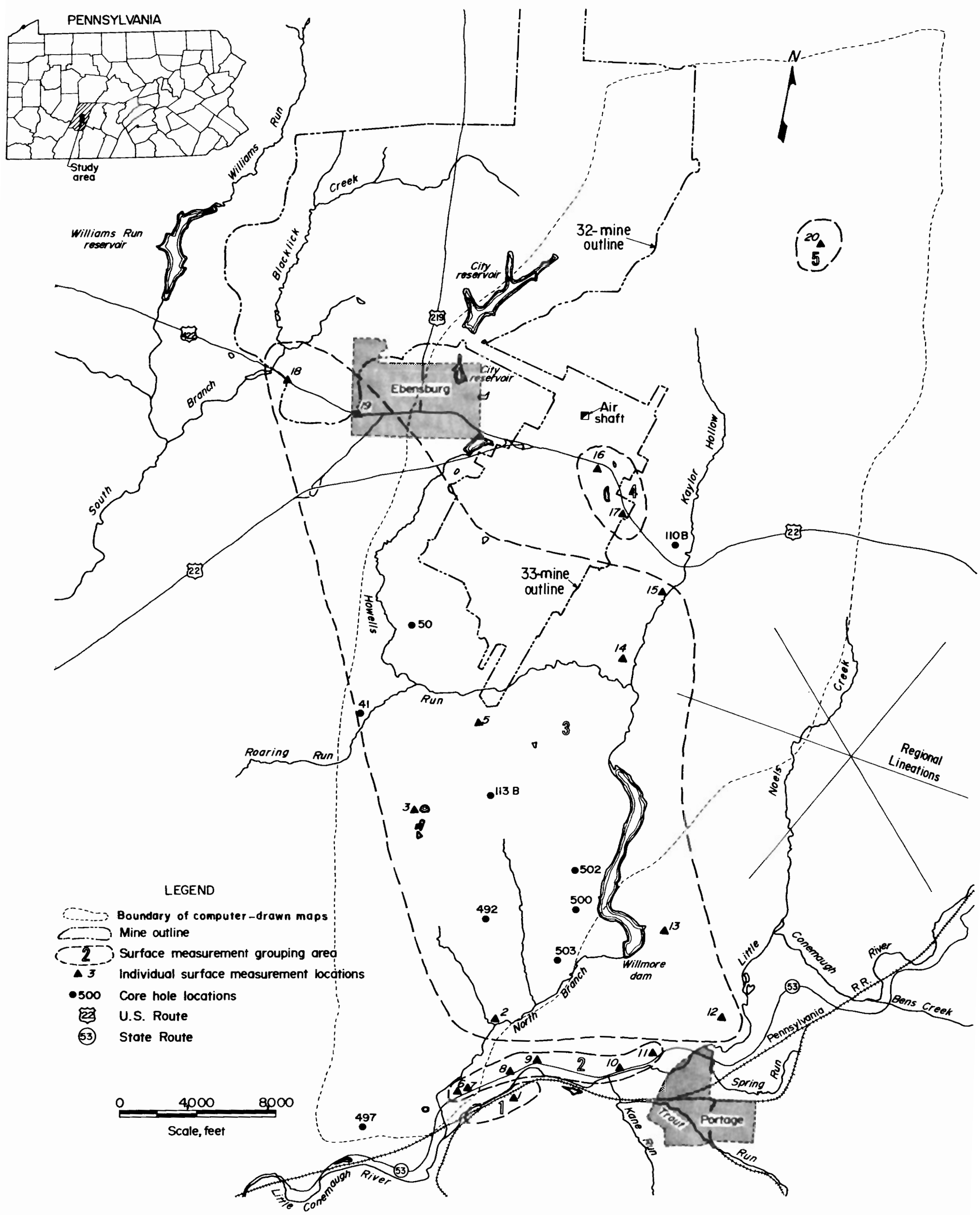

FIGURE 4. - Index map of surface joint sampling locations.

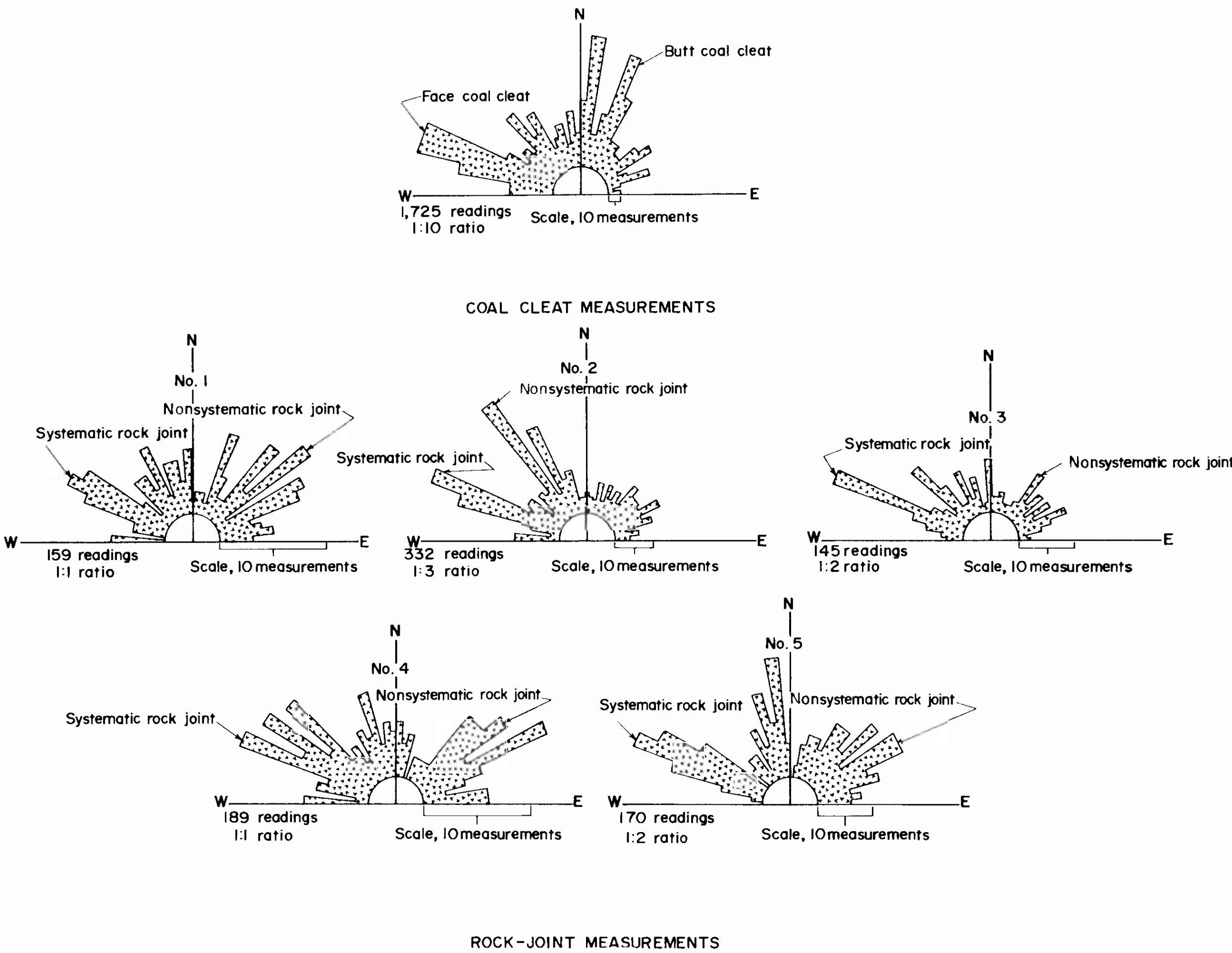

FIGURE 5. - Strike of coal cleats and rock joints.

Measurements at location 4 were made at sites where we found later there had been major surficial dislocation either by slumping due to erosion of adjacent stream valleys or to caving of underground workings. Comparing figure 4 with figure 6, it can be observed that "individual surface measurement locations" 16 and 17 are directly over areas where roof falls have occurred, supporting the idea that caving may be a factor in the deviation of these measurements from the norm. The computer program used to treat these data selected the center of a trimodal distribution as the strong direction rather than one of the extremes. Figure 5 illustrates the trimodal distribution at location 4. It appears that the lower of the three northwest lobes is the stronger but the difference is small. Field checks show that the most prominent direction is the one designated at location 4 as being the "systematic rock joint," N 68° W, very close in direction to the other four areas of surface measurement, but the other two lobes indicate some change or rotation and contribute to making the average direction N 58° W.

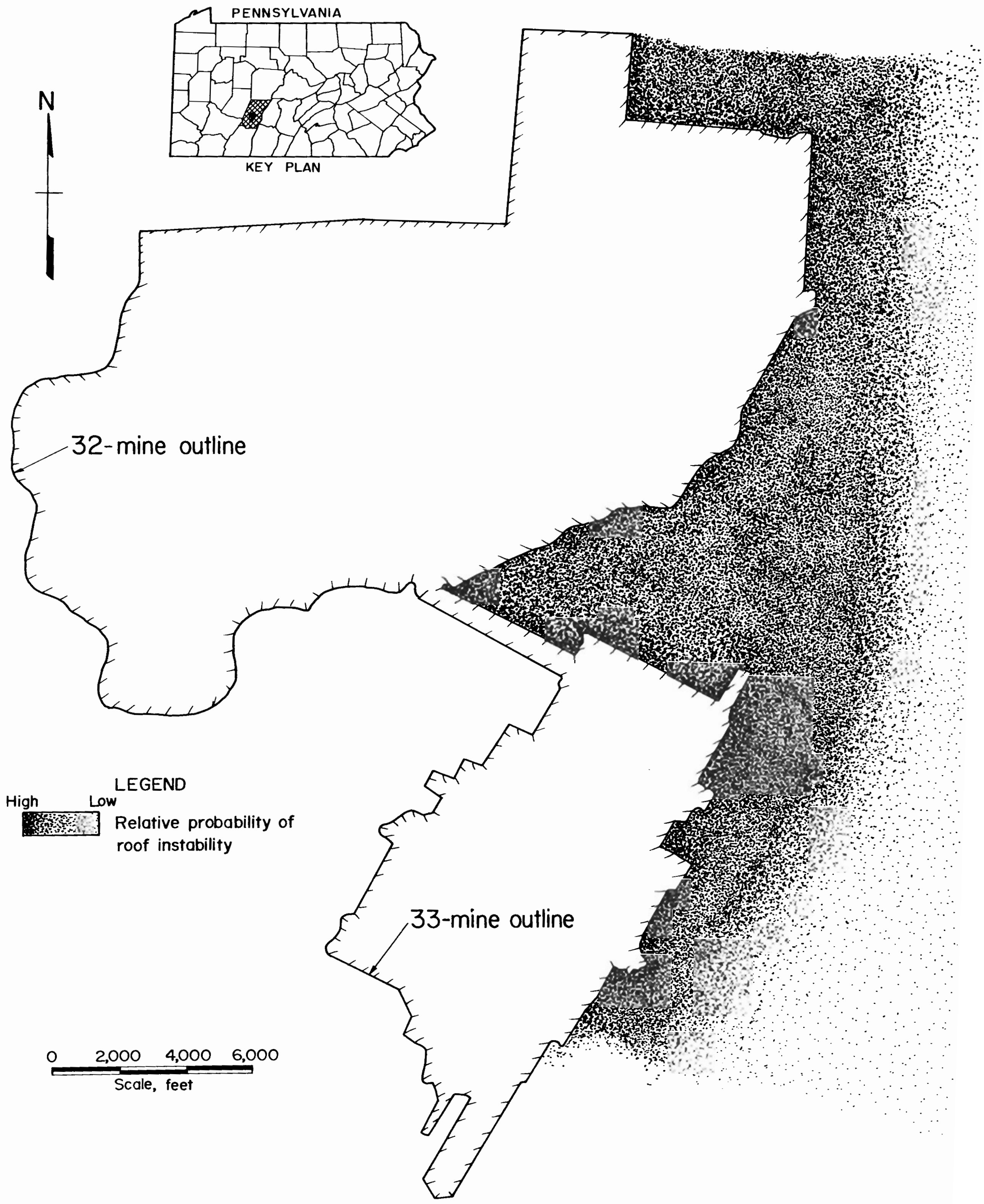

FIGURE 6. - Sketch map showing where unstable roof is likely to occur.

From table 2 the average strike for the butt cleat is N 19° E, and the average strike for the nonsystematic rock joint is N 04° W. As can be seen from the data, the variations in the nonsystematic joint measurements are too great to have any significance; this was also supported by the computer program printout.

TABLE 2. - Average strike of coal butt cleat and nonsystematic rock joints

	Measurements	Strike[1]
Coal butt cleat....................	1,725	N 19° E
Nonsystematic rock joints..........	159	N 52° E (1)
Do............................	332	N 38° W (2)
Do............................	195	N 50° W (3)
Do............................	189	N 68° W (4)
Do............................	170	N 62° E (5)
Total....................	1,045	

[1]Number in parentheses corresponds to location on index map. All are ±2° compass directions.

There is a relationship between the axial direction of the local folds and the strike of the butt cleats. The local fold axes range from N 35° E to N 12° E but mostly between N 17° E and N 22° E, nearly the same as the average butt cleat direction of N 19° E. Figure 5 shows a relationship between the coal face cleat and systematic rock joint direction but shows no relationship between the coal butt cleat and nonsystematic rock joint direction.

This is a summary of the strikes of the coal cleats and rock joints:

1. Strike of face coal cleat--N 69° W.

2. Strike of systematic surface rock joint--N 67° W.

3. Stnike of butt coal cleat--N 19° E.

4. Strike of nonsystematic surface rock joint--N 04° W.

From this it is evident that there is a parallelism between the N 70° W major regional lineation, the face coal cleat, and the systematic rock joint. No relationship is evident between any of the three major regional lineations determined from SLAR imagery and the butt cleat or nonsystematic rock joint strikes.

Methane Emission in the Cambria Mines

Underground, in the Cambria Nos. 32 and 33 mines, water seepage and methane emission from the roof is observed along prominent fractures that trend N 70° W, a direction that parallels the systematic joint sets, the coal face cleats, and the major regional lineations.

The amount of gas emitted directly from the Lower Kittanning coal into the mine working is known to be small. Upon development of mine workings and in preparation for installation of longwall mining equipment, methane emission rates are very low. In one methane emission study in a development section, only 23 cfm of methane was measured. In contrast, when longwall mining is being conducted, methane emission rates rise to more than 800 cfm from a single section (11). Normally, in these mines, most of the methane emission occurs when retreat longwall mining induces roof falls with subsequent methane accumulation in the gob. Methods of removing this methane have been described by Elder (6) and by Ferguson (7).

Methane emission rates from all the principal coal mines of the United States are listed in a report by Irani (9). These reported data do not include the amounts of methane removed from gobs by vertical boreholes.

Because methane occurs in the strata immediately above the Lower Kittanning coalbed in these mines, unexpected roof falls are the main cause of high rates of methane emission in development sections. Consequently, methane control during development is best accomplished by controlling roof.

Bureau of Mines studies demonstrated that within any mine directional permeability does exist. The face cleat is the dominant cleat direction; because it has greater horizontal length and is usually better developed, one would expect to encounter more gas in mining perpendicular to the face cleat. This is a demonstration of directional permeability.

Two holes were drilled horizontally into the coalbed at N 65° W and N 25° E. The gas pressure along the N 65° W direction was 12.0 psi, whereas the gas pressure measured along the N 25° E direction was 30 psi. The direction of these measurements approximate the face and butt cleat directions, which average N 68° W and N 19° E. Because the face cleat is more continuous, it would be expected to yield more gas where transected; this is supported by the fact that the horizontal borehole drilled at N 25° E (almost parallel to the butt cleat) yields 2.5 times as much gas as the hole drilled parallel to the face cleat.

Roof Joints and Roof Falls

We have observed roof instability (1) where differential compaction and folding have occurred along the side of channel sandstone deposits, as along the east side of the Cambria 32 mine, and (2) where the sandstone has formed a sheetlike structure and numerous (greater than nine), thin lithologic units occur directly above the Lower Kittanning coal within an interval of 30 feet. Where the next coal above the Lower Kittanning occurs less than 30 feet above, and/or where the space between joints is less than 4 feet, roof instability is even more likely. Most of the roof falls observed showed coal in the upper part of the fall and the vertical interval was less than 30 feet.

Roof joints were measured underground where possible. Most (26 out of 35) ranged from between N 65° W to 73° W, roughly parallel to regional lineation of N 70° W (SLAR). The other nine readings were scattered, but at least two each mirrored the other regional lineations (N 31° W, N 39° E) as determined from the SLAR.

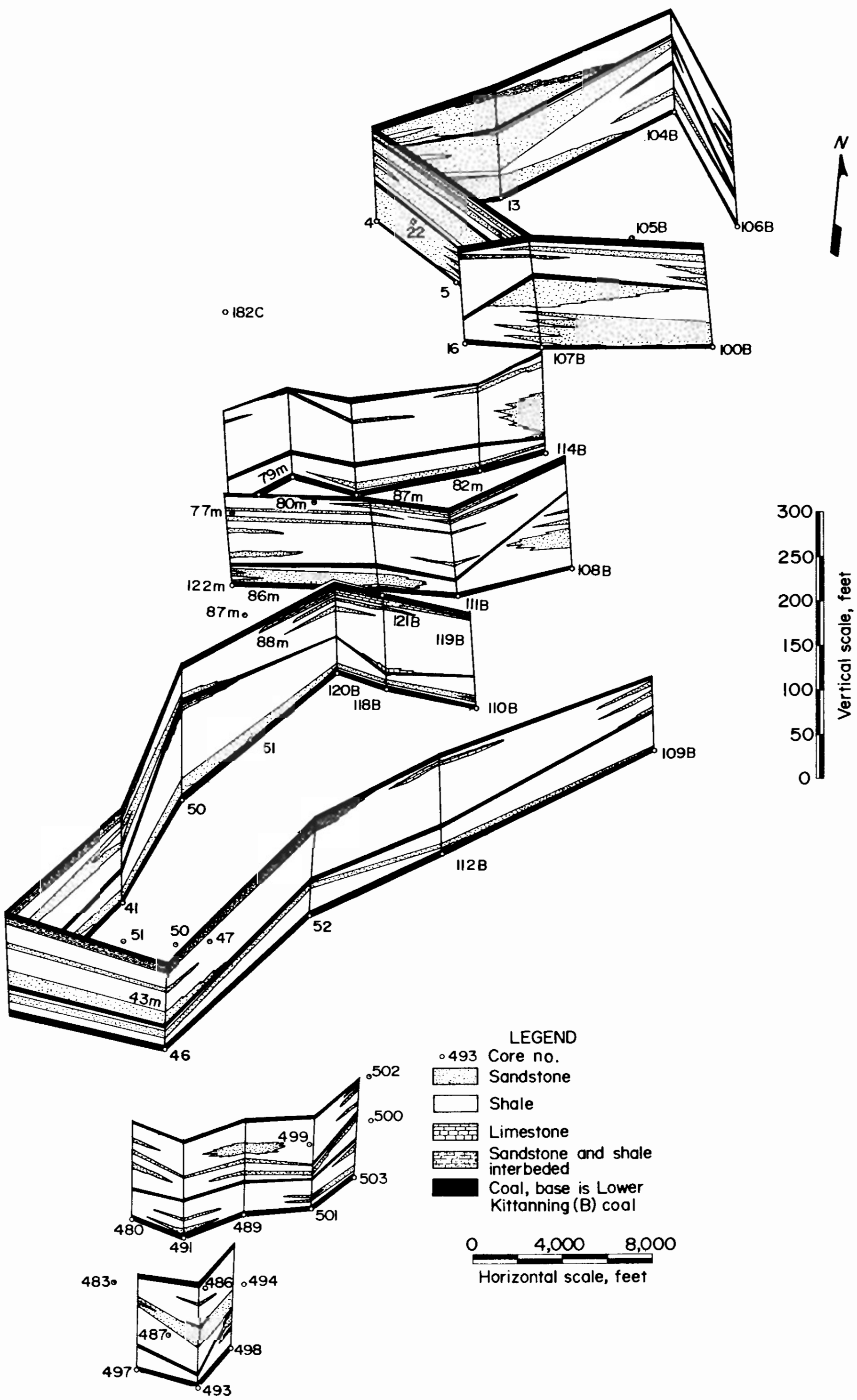

FIGURE 7. - Panel diagram of interval between Lower and Upper Kittanning coalbeds.

Jointing is not the sole cause of roof falls in these mines. It is a contributory factor. Where roof might have been stable under all other conditions a very close joint spacing contributes to unstable roof.

LITHOLOGIC VARIABILITY

Underground exposures and core log data show that the sandstone immediately above the Lower Kittanning coalbed occurs either as a channel fill deposit changing abruptly to shale or as sheetlike deposits which interfinger with shales.

To display the lithologic variability of this area, a panel diagram (fig. 7) was prepared from core logs using the interval between the Lower and Upper Kittanning coalbeds. In the north, sandstone is the predominant rock; southward, the shale becomes dominant. The panel diagram shows a channel area along the east margin of the mine that eventually broadens to form a sheetlike structure to the south and west.

As an aid to analysis of the sedimentation and to insure complete objectivity, the following maps were drawn by computer to indicate the following: lithologic frequency of the interval between the Lower Kittanning and Upper Kittanning coalbeds, lithologic frequency of the interval between the Lower Kittanning and the next higher coal, percentage of sandstone in coalbed area, percentage of shale in coalbed area, shale plus limestone to sandstone ratio, and the interval between the Lower Kittanning and the next higher coalbed. This was done by laying a grid over a base map of the core holes; these could be located by the computer program along X (distance in feet east of the starting point or zero point) and Y (distance in feet north of the zero point) coordinates. The X and Y values are used in the computer program only to locate the core holes on the map. The data to be plotted (the Z value) are selected from the core logs as required; for example, the percent sandstone for a given interval as in the maps indicating the percentage of sandstone, or the number of lithologic units as in the maps on lithologic frequency. The Z value is established for each core hole, and this value plus the X and Y coordinates are used in the computer program to plot a map using an appropriate contour interval. The X and Y coordinates are constant for all computer output maps, and only the Z value and the contour interval vary.

Lithologic Frequency

A lithologic frequency map (fig. 8) shows the number of separate lithologic units for a given interval. The interval is arbitrarily selected depending on the information to be illustrated. This lithologic frequency map was drawn using as contours the number of lithologic units occurring in the approximately 100-foot interval between the Upper and Lower Kittanning coalbeds. The number ranges from four to 24 lithologic units. A lithologic unit is defined here as any thickness greater than 0.5 foot in thickness.

One area showing an extremely large number of lithologic units, more than 20, and two other areas showing more than 15, were found. These areas coincide with known areas of roof instability in the mine. When conducting underground surveys in these areas of roof instability, it was noted that the joints in the roof were closely spaced and that the distance to the next coal above the Lower Kittanning was less than 32 feet wherever the roof had fallen. In contrast, a smaller number of thicker lithologic units would indicate relatively stable roof conditions.

The close proximity of zone of a very high and low number of lithologic units is an indication of rapid sedimentational changes and a site of potentially unstable roof.

Lithologic Frequency Between Lower Kittanning Coal and the Next Higher Coal

A low lithologic frequency indicates areas where relatively stable roof rock can be expected. Areas of intermediate lithologic frequency may or may

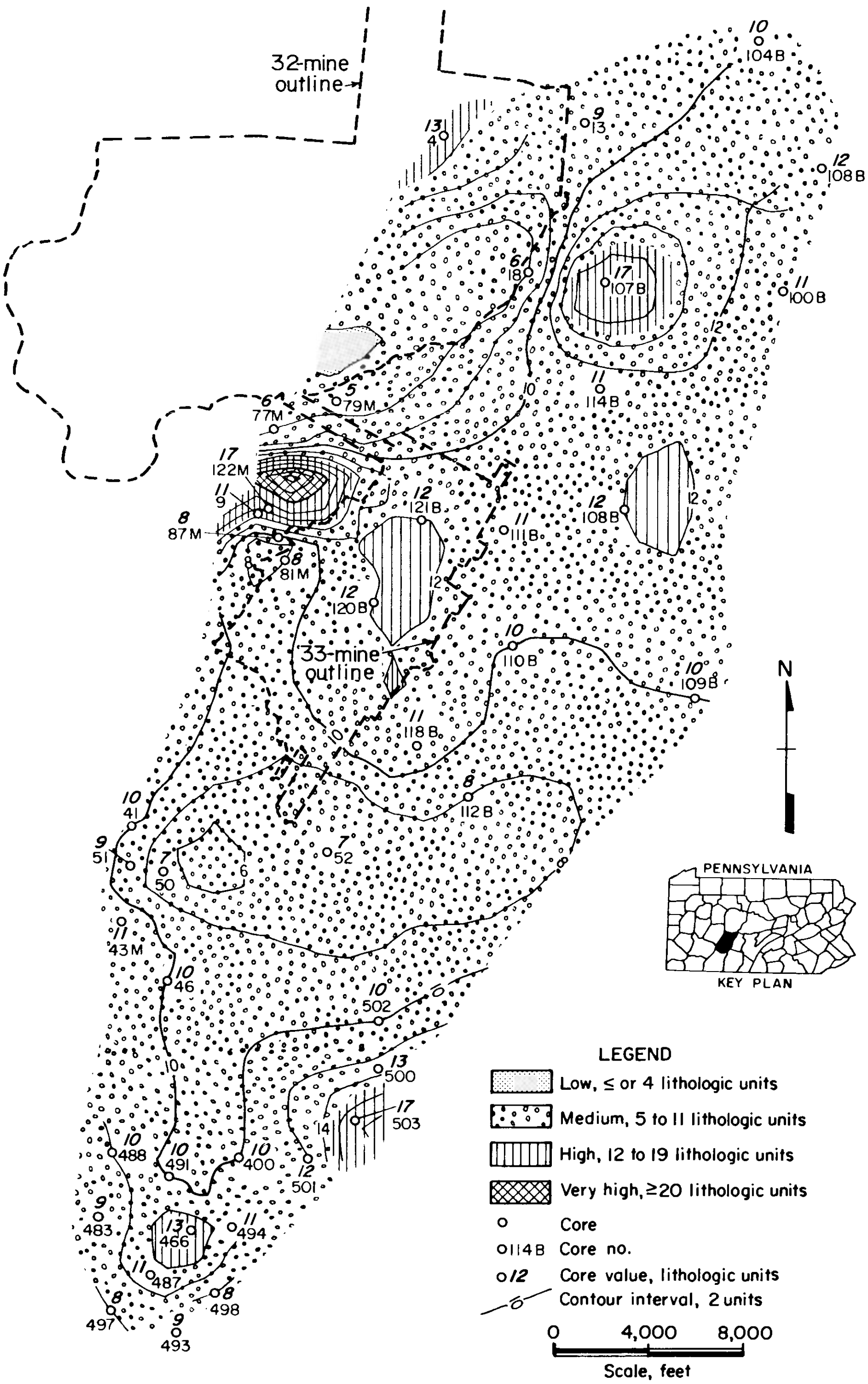

FIGURE 8. - Lithologic frequency map of interval between Lower and Upper Kittanning coalbeds.

not present a problem: Other factors that contribute to roof instability are a small vertical distance to the next higher coal and close joint spacing. A large distance to the next coal and wide joint spacing would greatly increase the probability of stable roof. Figure 9 is similar to the other lithologic frequency map (fig. 8) except that a variable coal-to-coal interval is involved. The interval now is from 20 to 55 feet, depending on where the next coal above the Lower Kittanning coal appears. There is a marked similarity between these two maps, especially in the northwestern part where there is rapid transition from less than five lithologic units to more than nine lithologic units in a horizontal distance of 2,000 feet. The interval between the Lower Kittanning and the next higher coal (whether the Middle Kittanning or a wild coal) was selected because, as was stated earlier, it was observed underground that the upper extent of most roof falls was the bottom of the coal directly above the Lower Kittanning coalbed.

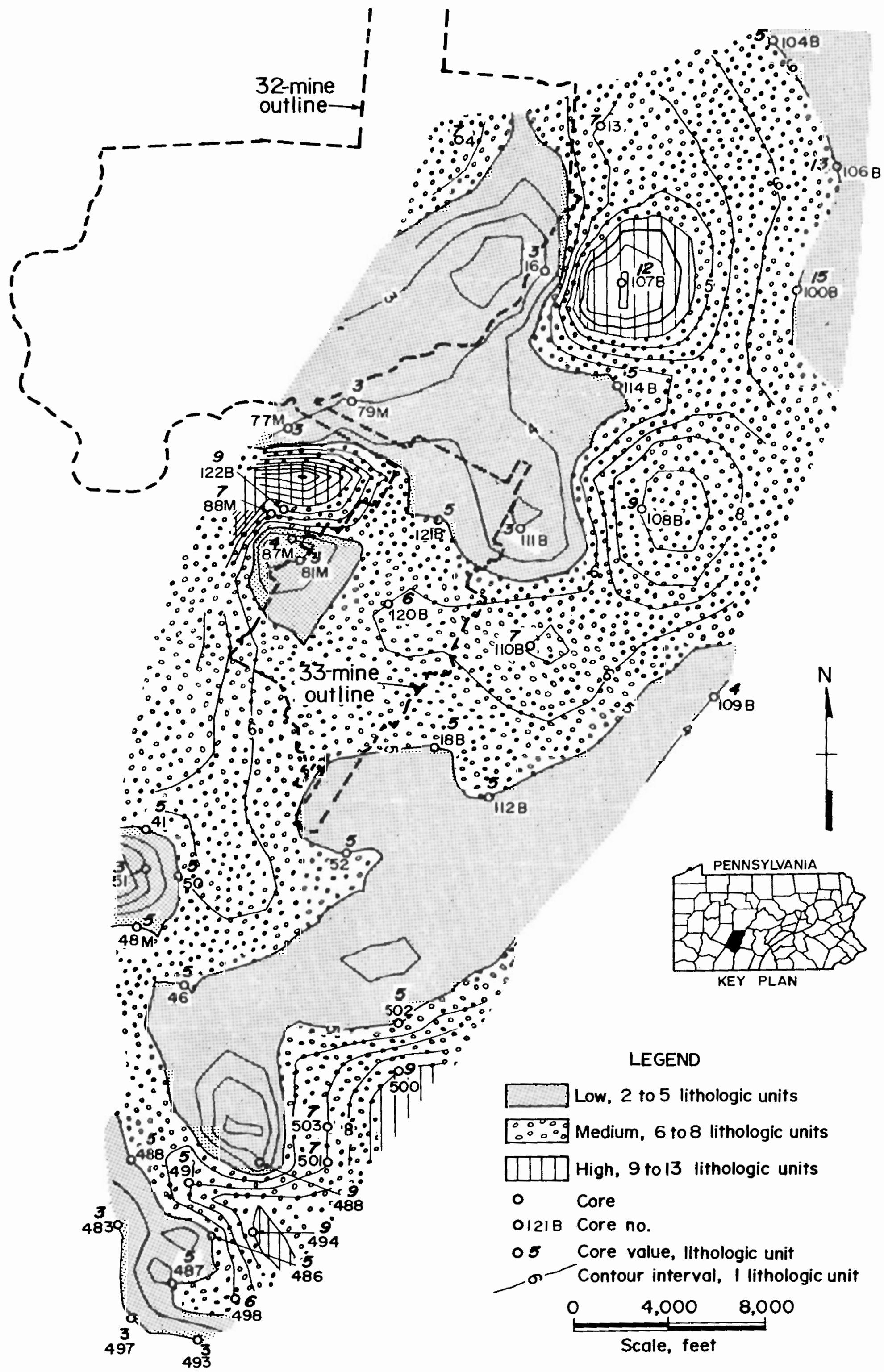

FIGURE 9. - Lithologic frequency map of interval between Lower Kittanning coalbed and next higher coalbed.

Relative Distribution of Sandstone and Shale

The maps showing the percentage of sandstone and the percentage of shale (figs. 10-11) outline a channel. In preparing these maps, the interval used was the 50 feet immediately above the Lower Kittanning coalbed. These maps show a high percentage of sandstone and a low percentage of shale, which define the channel area. Outside the channel there are, conversely, high shale and low sandstone percentages.

Shale Plus Limestone to Sandstone Ratio

Study of figure 12 substantiates the existence of a channel. A relatively large ratio number indicates a small percentage of sandstone in relation to shale and limestone. The small ratio numbers, representing sandstone-rich zones, can be followed through the middle of the map, indicating channel and sheetlike sandstone deposits. At the southern end, no definite sandstone pattern can be detected. The trend of the channel as inferred from this study is shown in figure 13. This shows that the inferred boundary between the channel sandstone deposit and shale follows the trend of known roof instability in the mines.

Vertical Thickness of Interval Between Lower Kittanning Coal and the Next Higher Coal

The interval between the Lower Kittanning coal and the next higher coal is critical because the uppermost plane along which the roof tends to separate is the bottom of the coalbed immediately above (whether a wild coal or the Middle Kittanning coalbed). From falls observed underground and related to this map (fig. 14) we find a correlation between roof instability and a thin zone, less than 30 feet (vertically) between the upper coal and the Lower Kittanning coalbed, especially where the roof strata are well jointed. Where this interval is more than 50 feet, the probability of roof instability is greatly decreased. The areas of highest occurrence of roof falls correlate with the thin areas of this interval on the isopach map and the areas of high frequency of lithologic units.

DISCUSSION AND ENGINEERING APPLICATIONS

On June 23, 1972, after the main theme of this report had been developed, a plan view of the two mines was received from the Bethlehem Mines Corp. showing areas of unstable roof. This map (fig. 15) was then reduced in size to overlay it on the panel diagram (or fence diagram) and the other maps used in this study. By comparing the map of unstable roof areas with the maps drawn by us, it became apparent that falls most commonly occur along the roof-margins of the channel fill sandstones which parallel the eastern boundary of both the Cambria 32 and 33 present mine workings. From these data we compiled a map (fig. 6) that shows where unstable roof is likely to occur in the future.

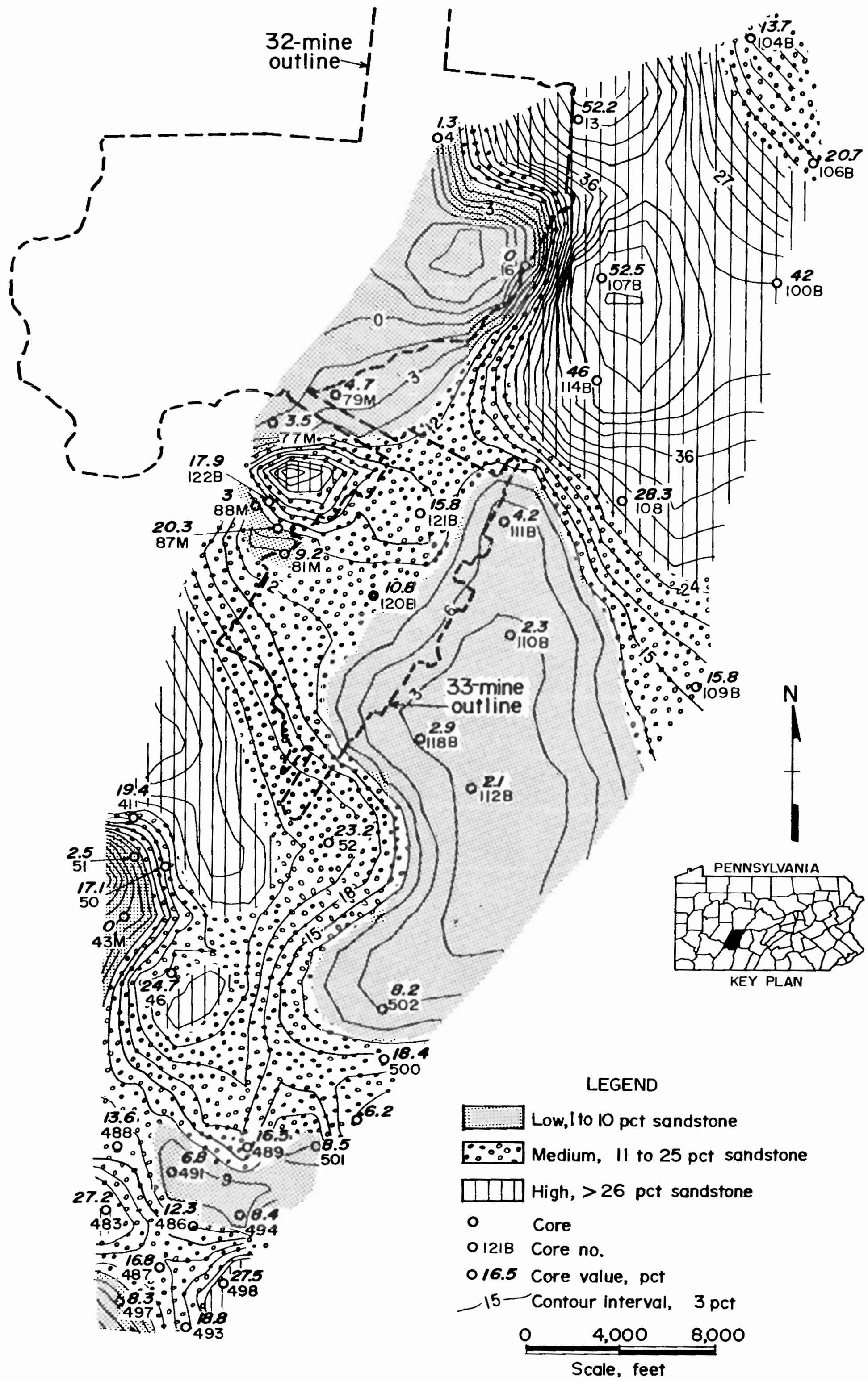

FIGURE 10. - Percentage of sandstone 50 feet immediately above the Lower Kittanning coalbed.

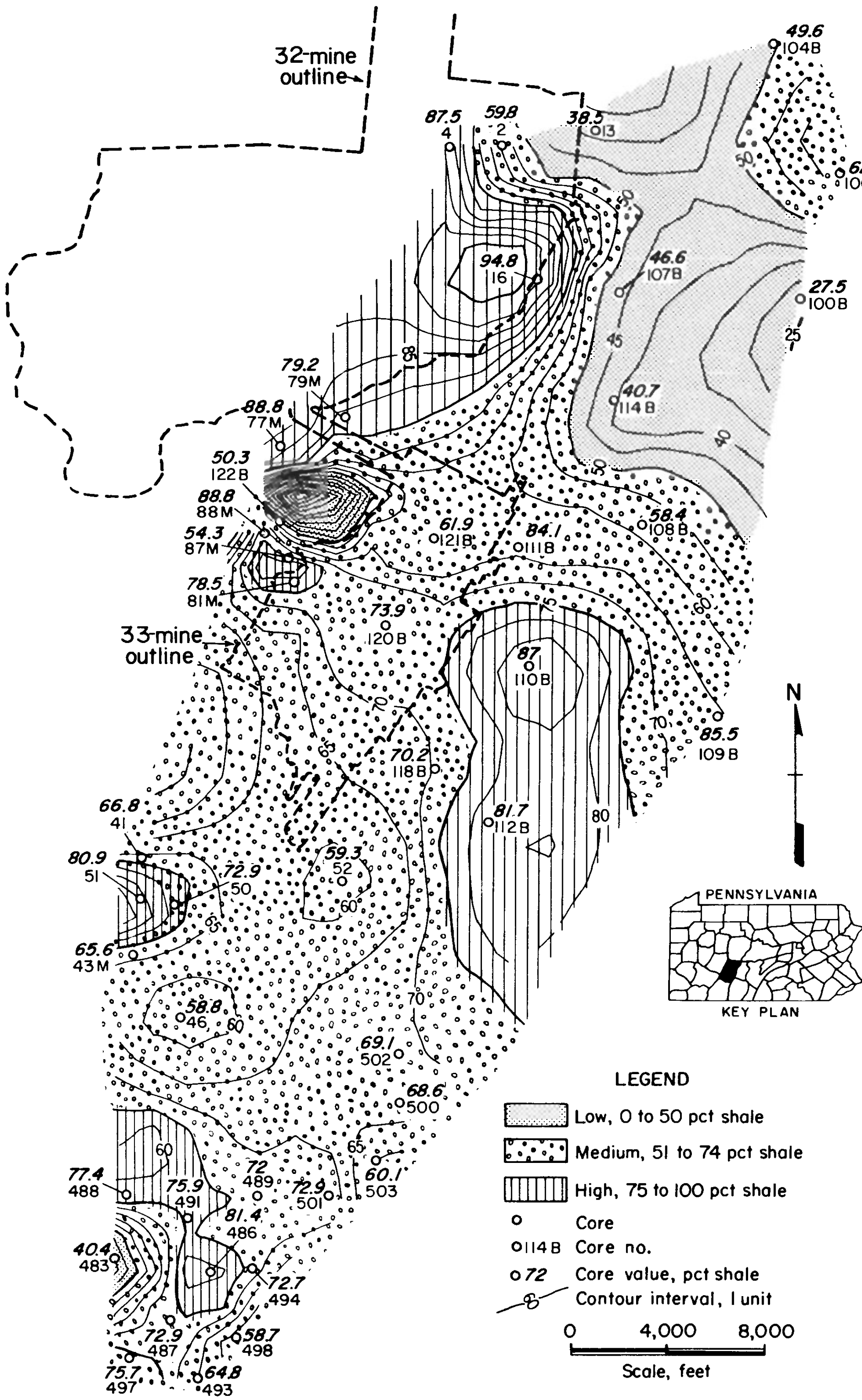

FIGURE 11. - Percentage of shale 50 feet immediately above the Lower Kittanning coalbed.

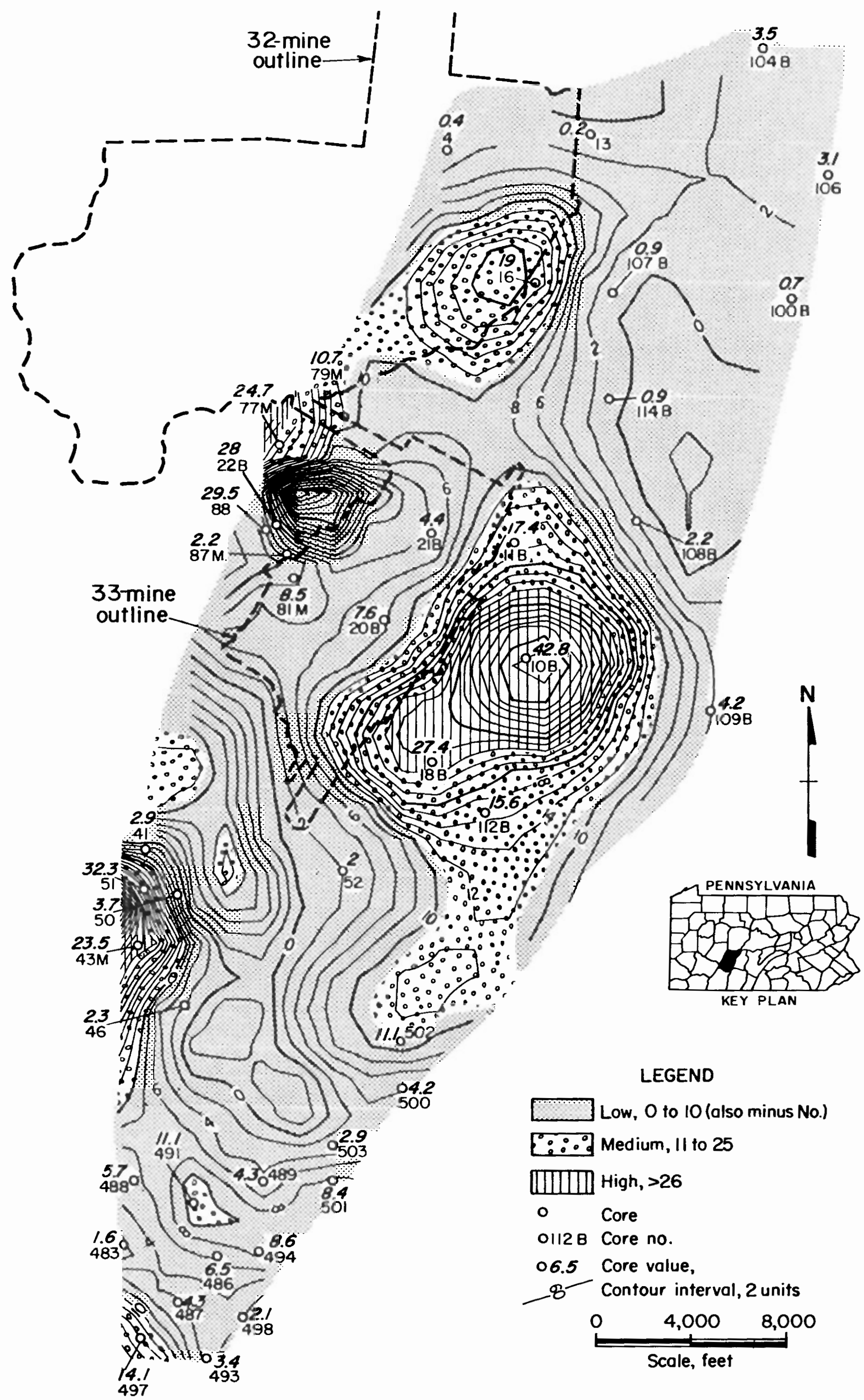

FIGURE 12. - Map of shale plus limestone to sandstone ratio.

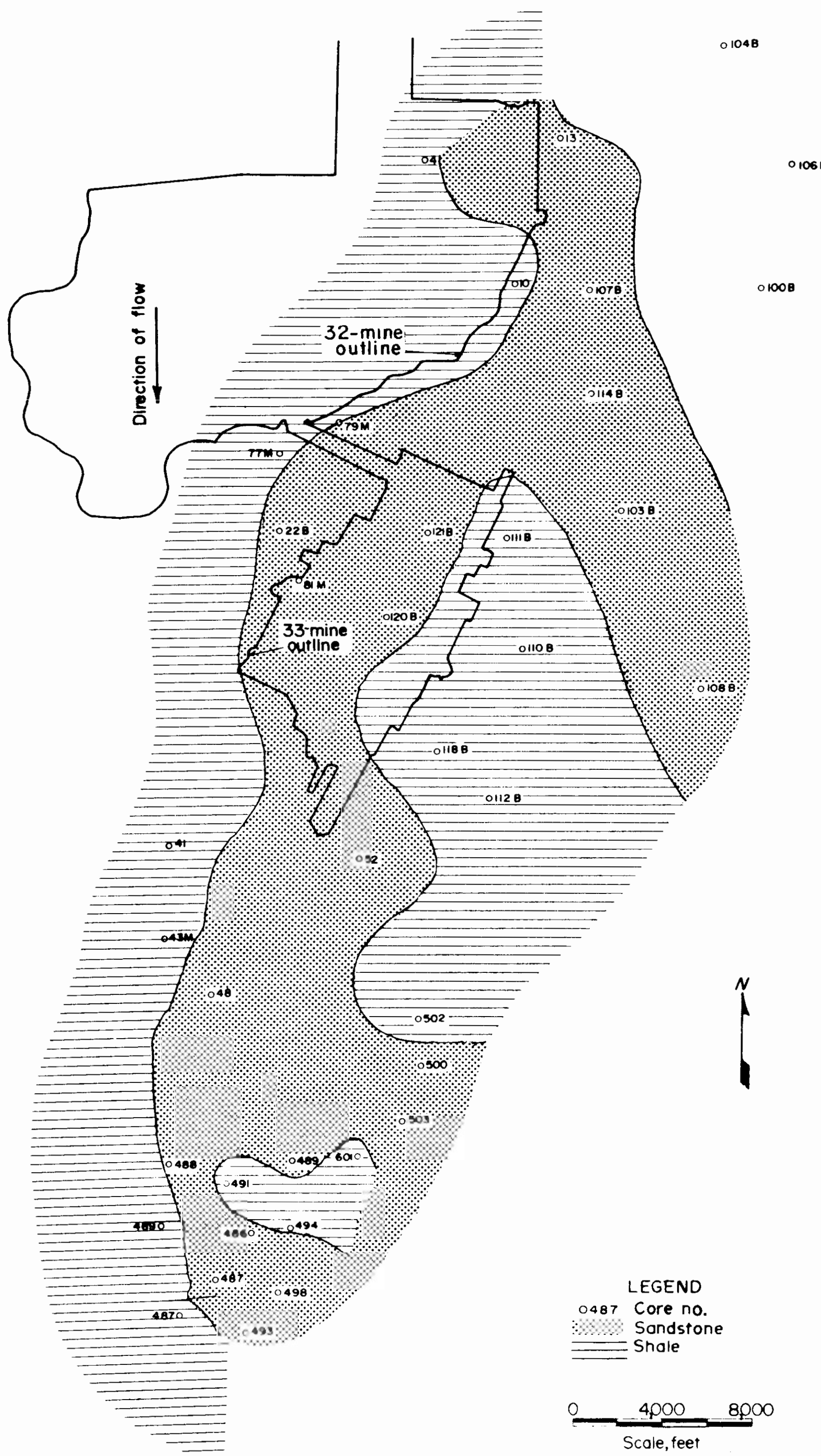

FIGURE 13. - Inferred sandstone-filled channel.

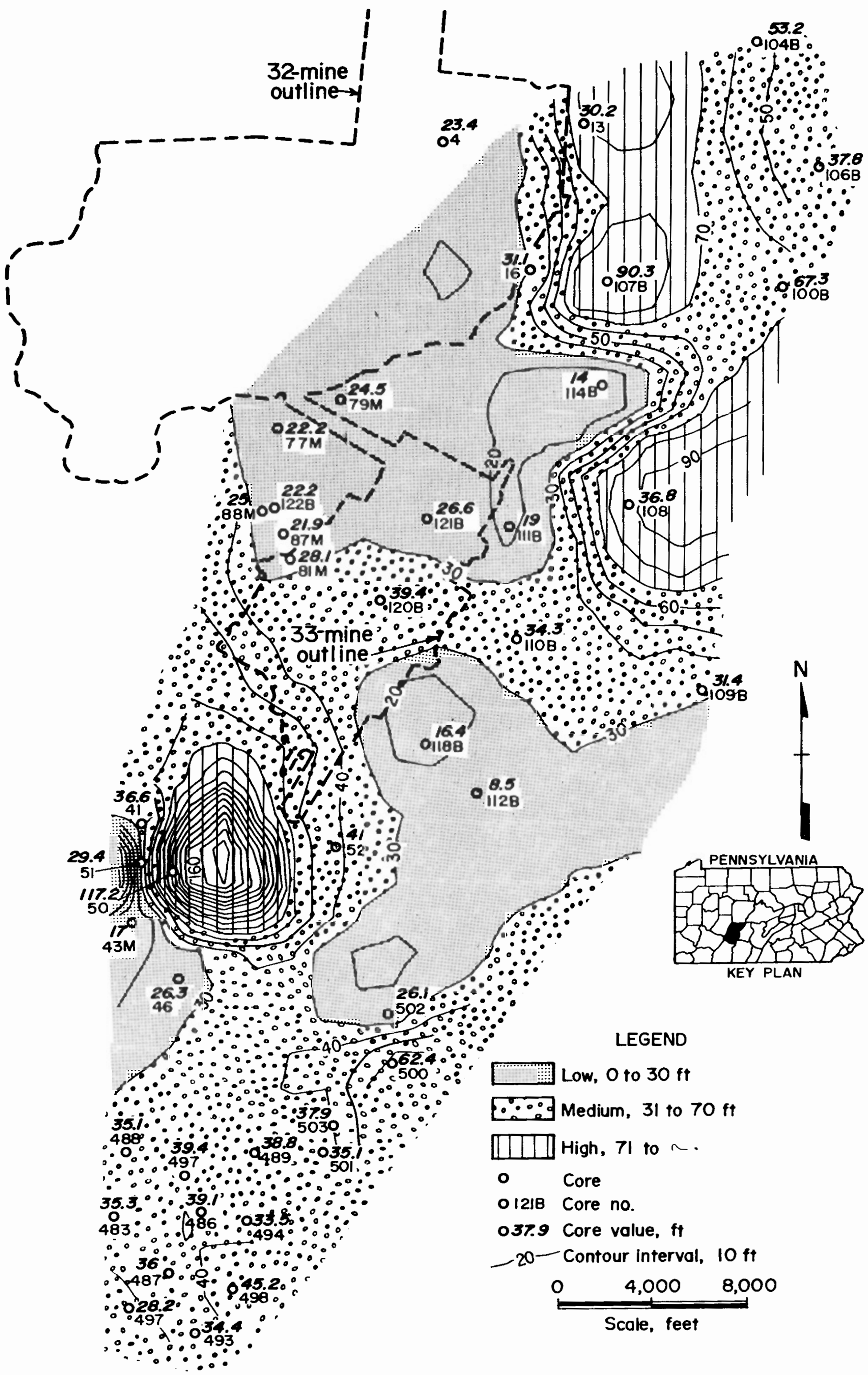

FIGURE 14. - Isopach map of interval between Lower Kittanning coalbed and next higher coalbed.

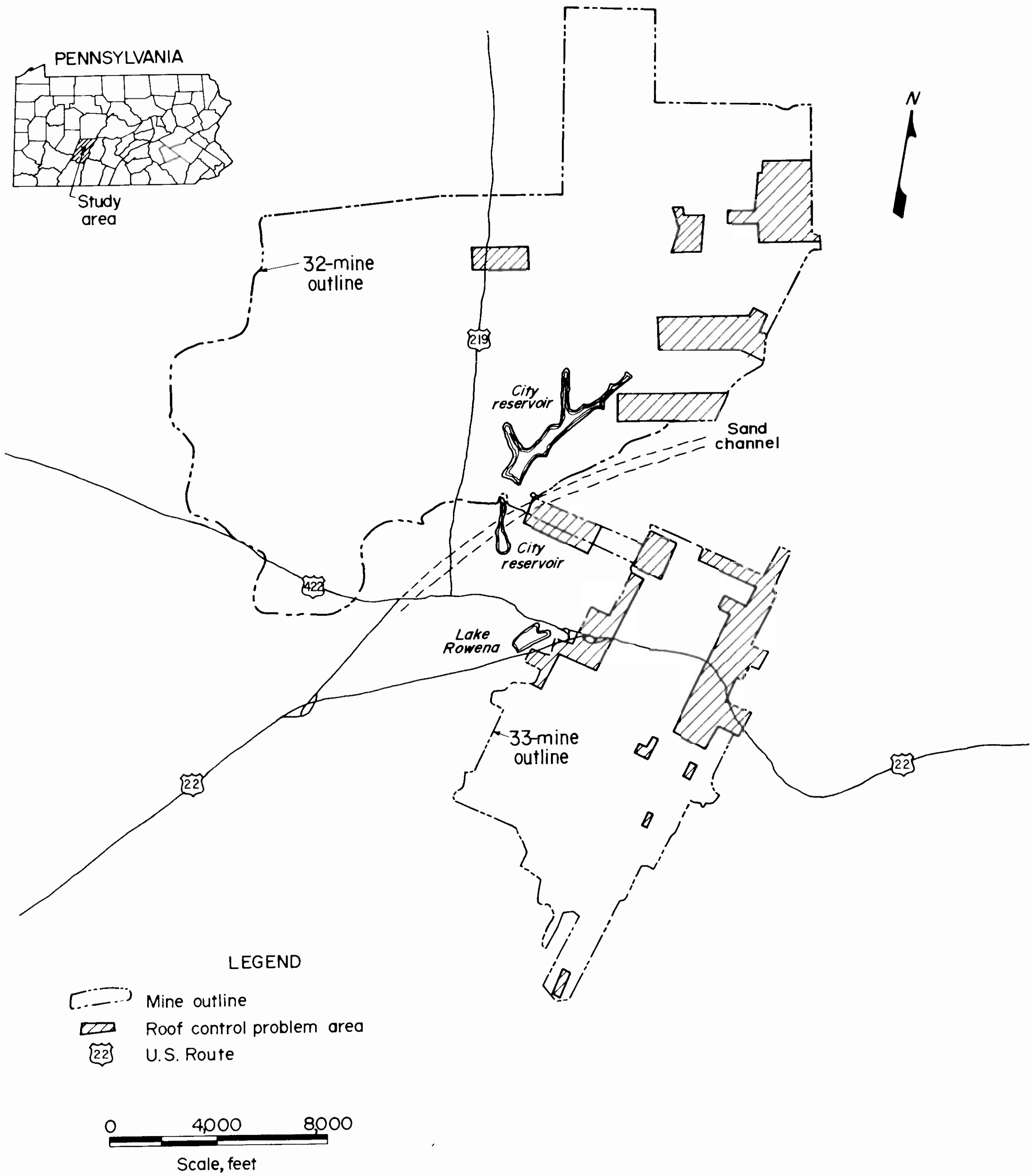

FIGURE 15. - Present mine working outline showing known areas of unstable roof.

CONCLUSIONS AND RECOMMENDATIONS

This study shows that methane emission in these mines is more closely related to roof falls and emission from strata above the Lower Kittanning coalbed than to any other single factor.

A channel sandstone deposit occurs immediately above the Lower Kittanning coalbed along the eastern part of the present No. 32 workings and extends over much of the No. 33 mine (fig. 12); this sedimentational feature is the cause of some of the mining problems encountered.

There are four geologic reasons for inherent roof instability in these mines: (1) Differential compaction of the sediments along the boundaries of the channel sandstone deposit, (2) a large number (generally more than nine) of lithologic units in the 30-foot interval above the Lower Kittanning coalbed, (3) the occurrence of another coalbed about 30 feet above the Lower Kittanning coalbed, and (4) a spacing of less than 4 feet between the systematic joints in the rock immediately above the Lower Kittanning coalbed. Examinations of roof falls in the mine indicate that falls usually are due to at least two of these reasons and that the first two are the major causes.

There is an alinement between the N 70° W regional lineation, the strike of the face cleat of the coal and systematic joints of surface rocks, and at most of the roof joints observed underground.

Consideration of the criteria for roof instability as developed in this report should aid in the planning for further mine development so that unexpected roof falls can be minimized. Furthermore, when development must proceed in areas where there is a high probability of roof instability, the mine operator will be able to anticipate and prepare for the consequences so as to arrive at an alternate plan for mining this area and providing supplementary ventilation to cope with the expected influx of methane.

Valuable data for such interpretation can be acquired from core-drilled vertical holes where detailed geological information is systematically collected. We recommend that more core holes be drilled at a distance no greater than 3,000 feet from the nearest existing hole. This would be especially helpful in determining if the criteria for roof instability are evident to the east and southeast of the present workings of the Cambria No. 33 mine.

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