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**Determining Cleat Orientation
of Deeper Coalbeds
From Overlying Coals**



UNITED STATES DEPARTMENT OF THE INTERIOR

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**Determining Cleat Orientation
of Deeper Coalbeds
From Overlying Coals**

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DETERMINING CLEAT ORIENTATION OF DEEPER COALBEDS FROM OVERLYING COALS

by

C. M. McCulloch,¹ S. W. Lambert,¹ and J. R. White¹

ABSTRACT

Examination of several coalbeds in Walker County, Ala., Cambria, Greene, and Fayette Counties, Pa., and Raleigh and Wyoming Counties, W. Va., indicates that cleat orientations are similar throughout a vertical sequence of strata.

Studies of cleat orientation were carried out in underground mines that are operating in separate coalbeds vertically above one another. The data show that over a vertical separation of 100 to 400 feet, the average difference in coal cleat orientation between mines is 04° for the face and 08° for the butt cleat. Variations of coal cleat direction between coalbeds examined in strip-mined areas show similar values. Cleat orientations measured at outcrops agree well with the directions measured underground, suggesting that the amount of vertical separation between coalbeds has little effect on the resulting differences in cleat directions. The largest variation of cleat directions between adjacent coalbeds occurs where a large horizontal distance separates two sample locations. Cleat orientations for deeper coalbeds are most reliable where the data are taken from directly above.

INTRODUCTION

The Bureau of Mines has demonstrated that the amount of gas flowing through a coalbed is controlled by the orientation of natural fractures present within the coal (6-7, 9).² Such fractures appear to occur universally in all ranks of coal (5, 9-13) and impart important directional permeability properties to coalbed gas reservoirs. Production of fracture orientations in advance of mining is becoming increasingly important as new mines open and operate under greater overburden pressures where gas content is expected to be high. The ability to predict cleat orientation in advance of mining by studying overlying coals is essential to developing a rational degasification program for reducing explosion hazards, for increasing mine productivity, and for conserving natural gas contained in the coalbeds.

¹Geologist.

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

Coal may contain several sets of fractures. Those normal to bedding in coal are called "cleat" and are analogous to joints in other rock types. Cleat in coal occurs as two fracture sets oriented at approximately 90° to each other. One cleat is usually much better developed than the other, exhibiting larger and more continuous fracture surfaces. This fracture is commonly known as the face cleat. The other set, called the butt cleat, is less continuous, is often curved, and frequently terminates against the face cleat.

Cleat orientations were measured in Pennsylvania and Alabama where coal is mined from coalbeds one above the other and in Pennsylvania and West Virginia where a number of coalbeds are being stripped in a vertical sequence. The purpose of this study was to determine the relationship between cleat directions for coalbeds located at different stratigraphic levels at a given location.

ACKNOWLEDGMENTS

The authors thank the staffs of all the mines and companies from which data were collected. Cleat surveys were made underground and in the strip pits with the cooperation of the individual company officials. Without the assistance of the individual companies a report of this type would not be possible.

HISTORICAL BACKGROUND

As early as 1915, Hofer (4) recognized that the orientation of coal cleats and rock joints was essentially the same throughout a vertical sequence. Ver Steeg (15) in eastern Ohio, Hodgson (3) in Arizona and Utah, Parker (11) in New York, and Stutzer and Noe (14) and Kendall and Briggs (5) in Great Britain have all noted similar findings, but have different explanations as to how rock joints and coal cleats were formed.

There have been reports that coal cleats do not always show the same directions through a vertical sequence. In 1925, Dron (2) studied coalbeds in Scotland and found that the cleat directions varied between upper and lower seams in the same coalfield.

In 1967, Nickelsen and Hough (10), working in the Appalachian Plateau, demonstrated that for similar rock types throughout the stratigraphic section, joints (including cleats) showed similar strike and spacing.

CURRENT STUDIES

In 1974, McCulloch, Deul, and Jeran (9) reported that cleat orientations varied only slightly within individual mines; where the variation was large or differed greatly, the area was closely examined and often structural faults were located.

Diamond, McCulloch, and Bench (1) found that underground cleat orientations over a large area could be successfully predicted from surface joint

measurements and photolines obtained from infrared photographs. Cleat orientations of individual mines were predicted approximately 80 pct of the time using surface data gathered directly above and adjacent to the mine.

The ability to predict fracture orientations in advance of mining is becoming increasingly important as new mines open in deep coalbeds where the gas content is expected to be high. Such fractures in coal are natural avenues through which fluids flow most easily and provide directional permeability characteristics to the coalbed (6-7). In one study, coal gas flow parallel to the more continuous face cleat was found to be 2.5 to 10 times greater than flow parallel to the butt cleat (9). Advance knowledge of the cleat orientation will assist in the planning of degasification programs as to the most efficient placement of vertical, horizontal, or directional slant boreholes.

STUDIES OF ADJACENT COALBEDS MINED UNDERGROUND

Little multiple-coalbed mining has taken place in this country since in the past the low price of coal and the readily available supply of petroleum has discouraged such mining practices. However, increasing demand for fuel, the increasing depths necessary to acquire high-quality coal, and the unresolved disputes about surface mining will probably make multiple-coalbed mining more necessary.

Three areas were found where two coalbeds are being actively mined, one over the other: In Greene County, Pa., the Sewickley and Pittsburgh coalbeds; in Cambria County, Pa., the Upper and Lower Kittanning coalbeds; and in Walker County, Ala., the American and Mary Lee coalbeds. It should be pointed out that mines in these areas do not necessarily have active workings directly over each other. Normally the lower coalbed advances first and the upper coalbed is mined in the same area later; eventually both coalbeds are accessible in the same area.

Sewickley and Pittsburgh Coalbeds

In southeastern Greene County, Pa., where the Sewickley and Pittsburgh coals are mined, the vertical separation is approximately 100 feet. The Sewickley, the upper coalbed, is mined from the Warwick No. 3 mine operated by Duquesne Light Co., whereas the deeper Pittsburgh coalbed is mined from the Shannopin mine, operated by Jones and Laughlin Steel Corp.

Figure 1 shows the location and the relation of the mines to each other. Figure 2 is a stratigraphic column of the area showing both coalbeds and adjacent strata.

Face cleat orientations measured in the Warwick No. 3 mine indicate an average face cleat direction of N 77° W for the Sewickley coalbed. The butt cleat has an average orientation of N 18° E.

Measurements taken of the Pittsburgh coal cleat in the Shannopin mine indicate the face and butt cleats to be oriented at approximately N 73° W and

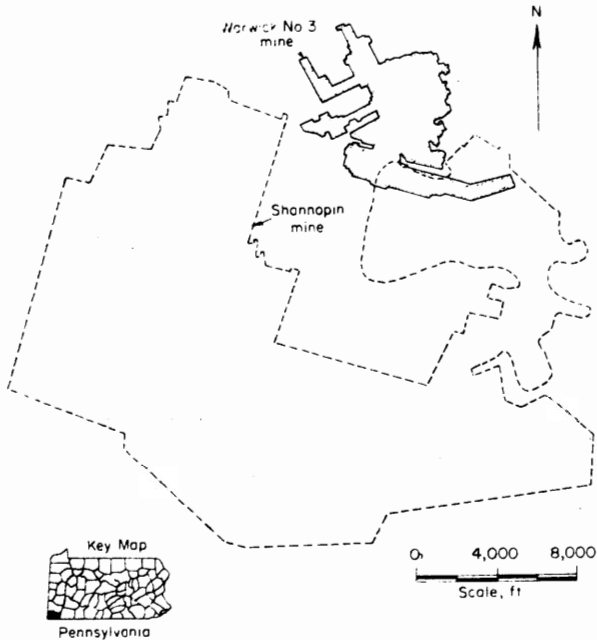


FIGURE 1. - Location of Warwick No. 3 mine (Sewickley coalbed) in relation to the Shannopin mine (Pittsburgh coalbed), Greene County, Pa.

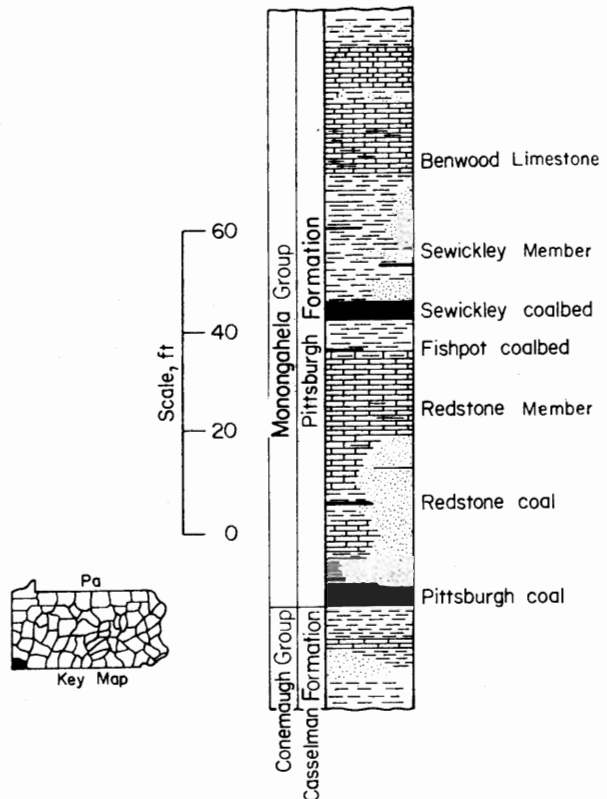


FIGURE 2. - Stratigraphic column showing Sewickley and Pittsburgh coalbeds and adjacent strata.

N 18° E, respectively. The distributions of face and butt cleat directions for both the upper and lower coals are shown on figure 3.

Comparison of cleat orientations in both mines indicates that cleat directions are similar even though the two coalbeds are vertically separated by 100 feet. The N 77° W face cleat direction for the Sewickley coalbed compares favorably with the N 73° W face cleat measured in the Pittsburgh coalbed. The average butt cleat directions are identical. Table 1 summarizes the information obtained from cleat readings taken in both mines.

TABLE 1. - Face and butt cleat orientations in the Warwick No. 3 and Shannopin mines

Mine	Coalbed	Approximate vertical separation, ft	Average orientation		Degrees of separation ¹
			Face cleat	Butt cleat	
Warwick No. 3.	Sewickley.	100	N 77° W	N 18° E	95
Shannopin.....	Pittsburgh		N 73° W	N 18° E	91
			±04°	±00°	-

¹Separation is defined as the angular difference between the average face and butt cleat directions. Ideal separation is 90°.

²Difference in cleat direction.

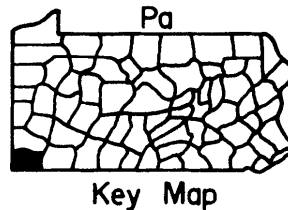
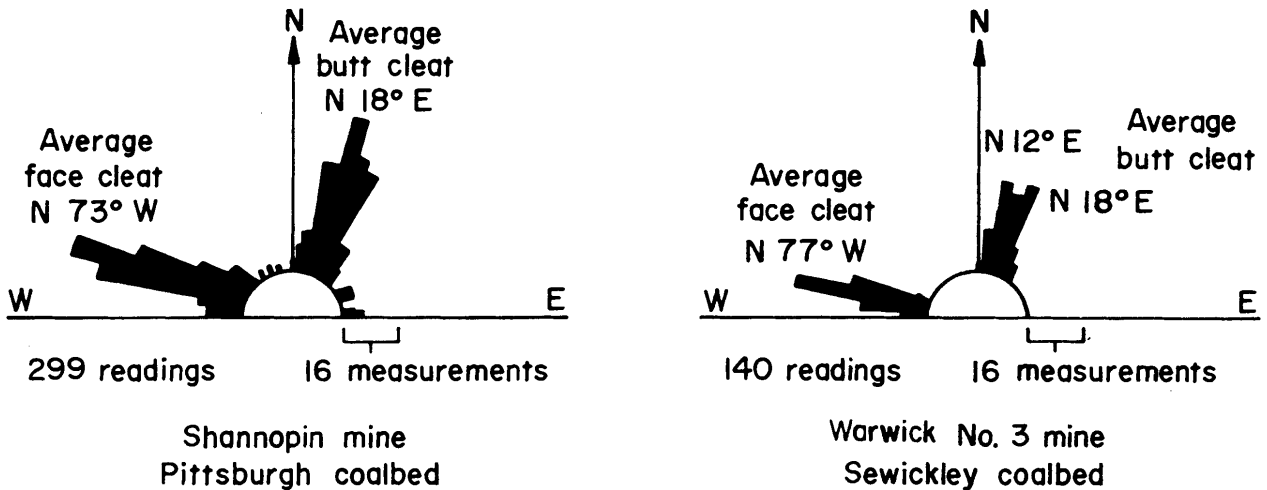


FIGURE 3. - Rose diagrams of coal cleat orientations of the Beckley and Pittsburgh coalbeds.
Upper and Lower Kittanning Coalbeds

In Cambria County, Pa., the Upper and Lower Kittanning coalbeds are mined at the Cambria No. 33 B and C' mines. The vertical separation is 100 feet. Both mines are operated by Bethlehem Mines Corp. The Lower Kittanning (B coalbed) has been mined for 11 years, whereas the Upper Kittanning (C' coalbed) has only been worked for 5 years. Figure 4 shows the spatial relation of the coalbed workings to each other. Figure 5 is a stratigraphic column taken from company core logs showing the position of both coalbeds and adjacent strata.

Cleat orientations for the Lower Kittanning coalbed are shown in figure 6. The face cleat trends approximately N 69° W. The butt cleat direction averages N 19° E.

The Upper Kittanning coal cleat directions also are shown in figure 6. The average face cleat direction is N 67° W. The butt cleat shows variation in trend with at least three peaks shown on the rose diagram, but the average butt cleat direction is N 22° E.

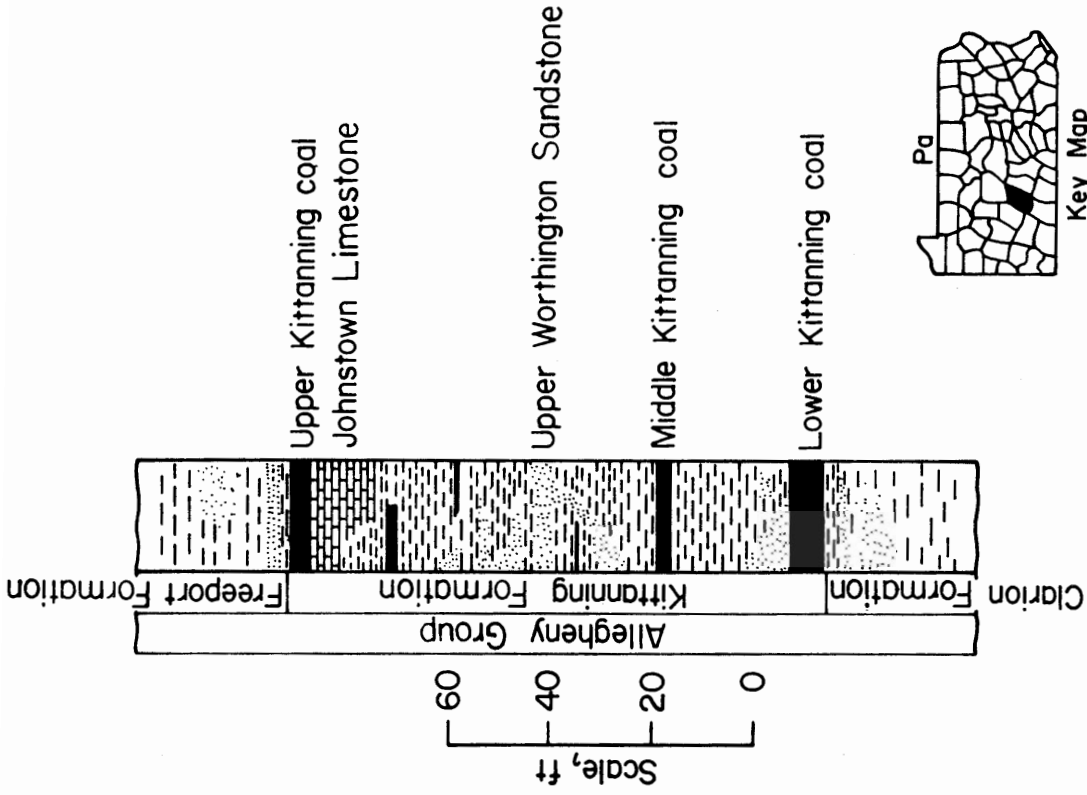


FIGURE 5. - Stratigraphic column showing the Upper and Lower Kittanning coalbeds and adjacent strata.

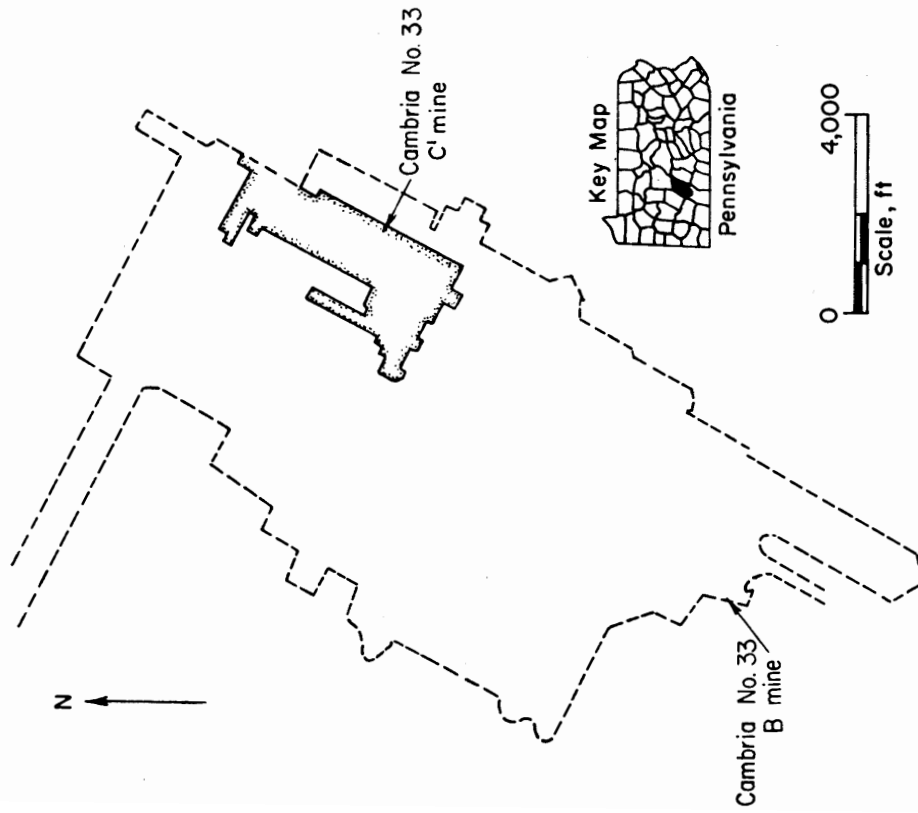


FIGURE 4. - Location of Cambria No. 33 C' mine (Upper Kittanning coalbed) in relation to the Cambria No. 33 B mine (Lower Kittanning coalbed), Cambria County, Pa.

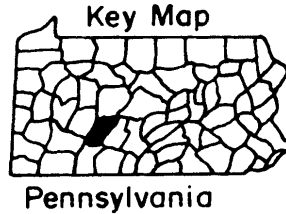
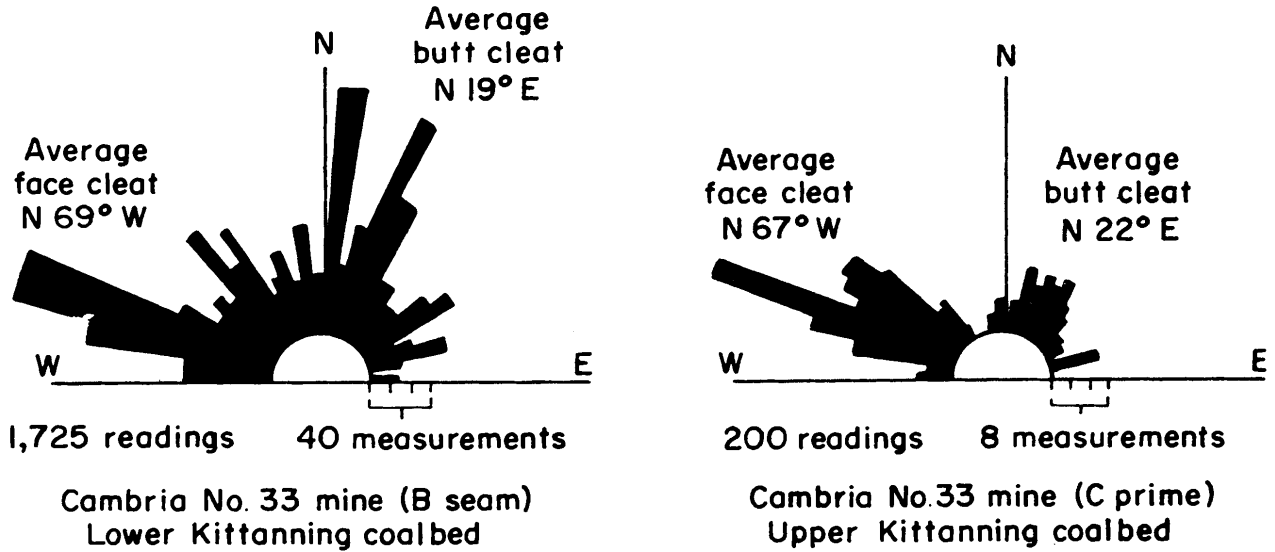


FIGURE 6. - Rose diagrams of coal cleat orientations of the Upper and Lower Kittanning coalbeds.

There is a very close correlation between the average coal cleat directions in the upper and lower coalbeds. The difference in face cleat directions is only 02°, and the difference in butt cleat directions is only 03°. The information is summarized in table 2.

TABLE 2. - Face and butt cleat orientation in the Cambria No. 33 C' and B mines

Mine	Coalbed	Approximate vertical separation, ft	Average orientation		Degrees of separation ¹
			Face cleat	Butt cleat	
Cambria No. 33 C.	Upper Kittanning.	100	N 67° W	N 22° W	89°
Cambria No. 33 B.	Lower Kittanning.		N 69° W	N 19° E	88°
			±02°	±03°	-

¹Separation is defined as the angular difference between the average face and butt cleat directions. Ideal separation is 90°.

²Difference in cleat direction.

American and Mary Lee Coalbeds

The American and Mary Lee coalbeds are mined in Walker County, Ala., in what is physiographically known as the Warrior basin. The vertical separation here is approximately 400 feet, with the American being the upper coalbed. The coalbeds are mined by the Alabama By-Products Corp. from the Gorgas No. 7 and Mary Lee No. 1 mines. Figure 7 shows the location and relation of the mines to each other. Figure 8 is a stratigraphic column of the area showing the position of the two coalbeds and adjacent strata. Cleat orientations for both mines and coal outcrop are represented by rose diagrams shown on figure 9.

The American coalbed is mined from the Gorgas No. 7 mine. Cleat orientations for the American coalbed are face cleat N 58° E and butt cleat N 37° W, a separation of 95°. The Mary Lee coalbed is mined below from the Mary Lee No. 1 mine (fig. 7). Here the face cleat orientation is N 63° E, while the butt cleat averages N 33° W.

Again the face cleat directions of both coalbeds are similar. In this example, the face cleat varies only 05°, and the butt cleat by 04°.

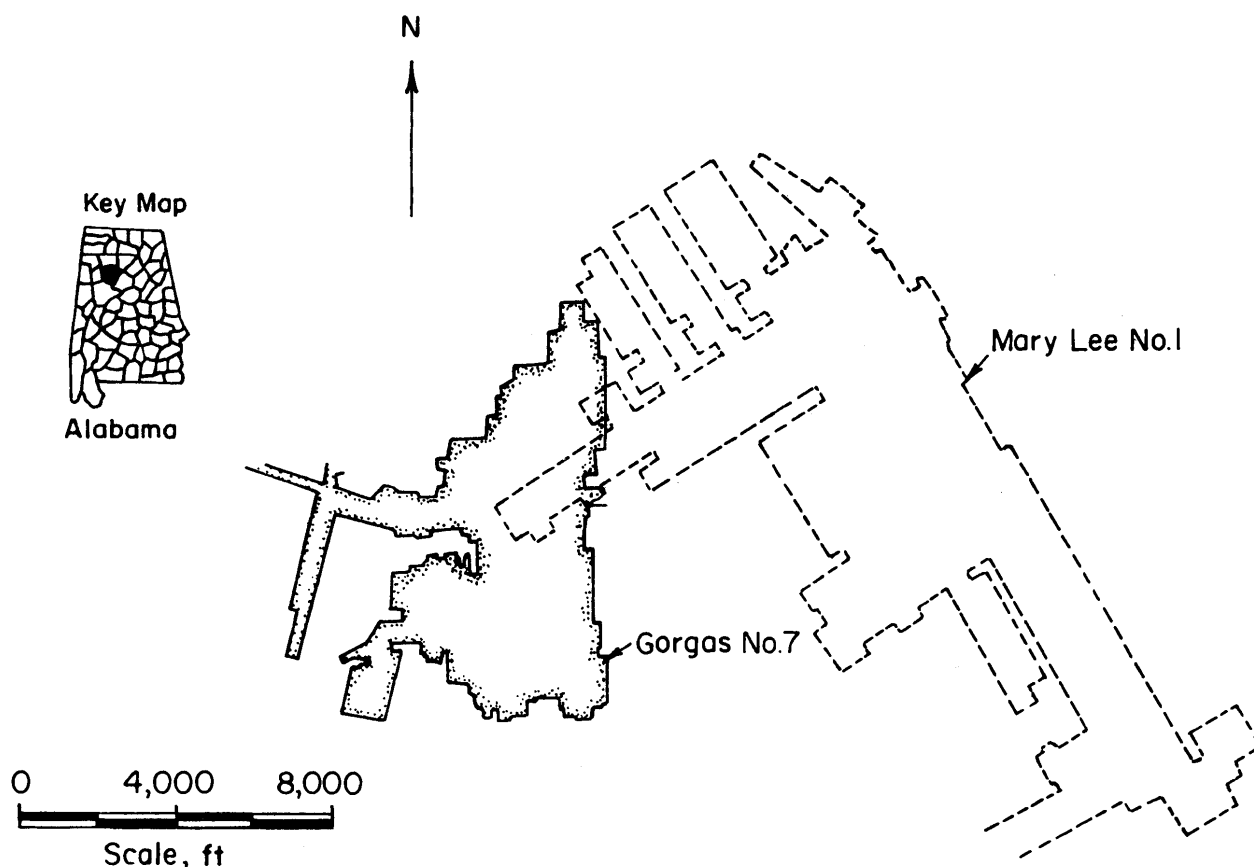


FIGURE 7. - Location of Gorgas No. 7 mine (American coalbed) in relation to the Mary Lee No. 1 mine (Mary Lee coalbed), Walker County, Ala.

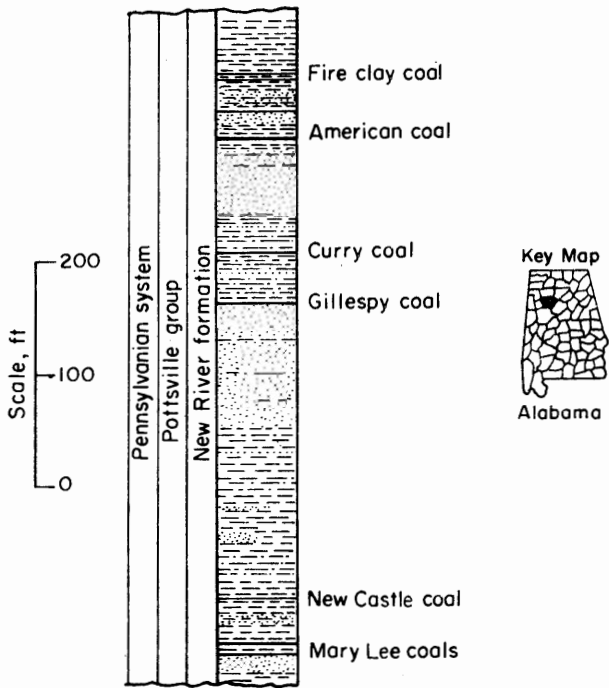


FIGURE 8. - Stratigraphic column showing the American and Mary Lee coalbeds and adjacent strata.

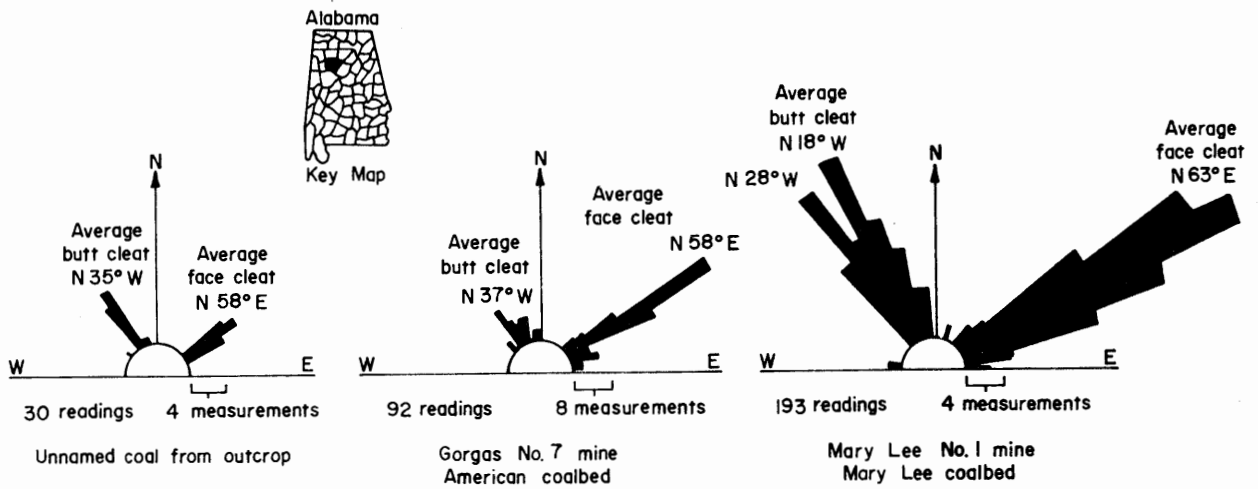


FIGURE 9. - Rose diagrams of coal cleat orientations of the American and Mary Lee coalbeds and coal cleat measured from the outcrop.

In this area there are a number of outcrops of coal. Cleat measurements were taken; the face cleat was found to be N 58° E (fig. 9), and the butt cleat was N 35° W. Again, from table 3, it is evident that the cleat directions from all three coalbeds are similar, despite a total vertical separation of 600 feet.

TABLE 3. - Face and butt cleat orientations in the outcrop and in the Gorgas No. 7 and Mary Lee No. 1 mines

Mine	Coalbed	Approximate vertical separation, ft	Average orientation		Degrees of separation ¹
			Face cleat	Butt cleat	
Outcrop.....	Unnamed.	200	N 58° E	N 35° W	93
Gorgas No. 7..	American	400	N 58° E	N 37° W	95
Mary Lee No. 1	Mary Lee		N 63° E	N 33° W	96
			² 05°	² 04°	-

¹Separation is defined as the angular difference between the average face and butt cleat directions. Ideal separation is 90°.

²Maximum difference in cleat direction.

STUDIES OF ADJACENT STRIP-MINED COALBEDS

Several strip-mined locations where two or more coalbeds have been exposed were examined. Measurements were taken from at least two coalbeds within a single stripped area and compared to determine cleat orientation relationships. Two areas were examined. The first was in southwest Pennsylvania, where two adjacent coals are strip-mined, and the second was in southern West Virginia, where several coalbeds are being stripped in the same vicinity. This area also has several underground coal mining operations where cleat orientations were measured and compared with surface cleat directions.

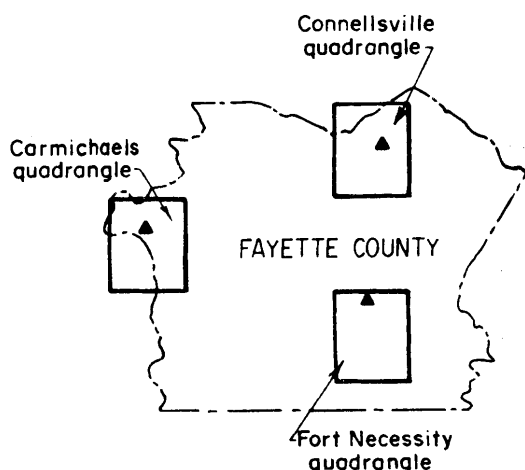
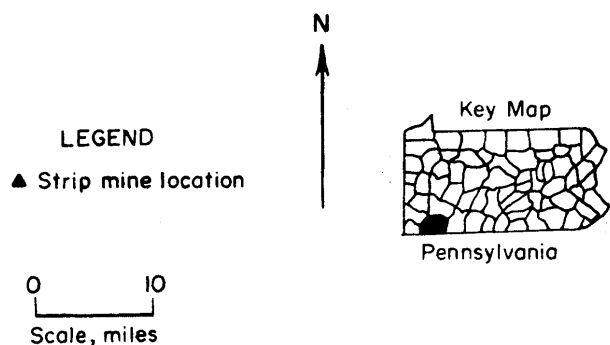


FIGURE 10. - Location map showing three strip mine locations, Fayette County, Pa.

Southwestern Pennsylvania

Examinations of cleat orientations were conducted in three areas of Fayette County in southwestern Pennsylvania. The three sites are located in figure 10. A generalized stratigraphic column of the strata surrounding these coalbeds is presented in figure 11.

The first area examined is in the Fort Necessity 7-1/2-minute quadrangle where the Brookville coal is mined while the overlying Clarion coal is discarded. Cleat orientations for both coals are shown in figure 12. Vertical separation of the two coals in this area is approximately 80 feet. The average cleat orientations in the Clarion coalbed are N 64° W for the face cleat and N 19° E for the butt cleat. The Lower Brookville coalbed's face cleat is N 68° W, while the butt cleat trends N 27° E.

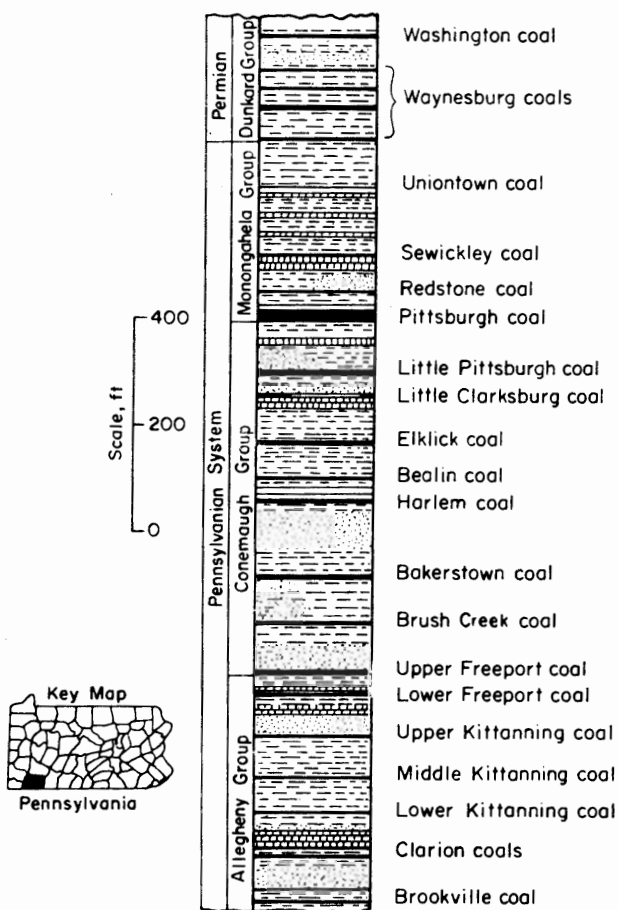


FIGURE 11. - Generalized stratigraphic column of coalbeds, Fayette County, Pa.

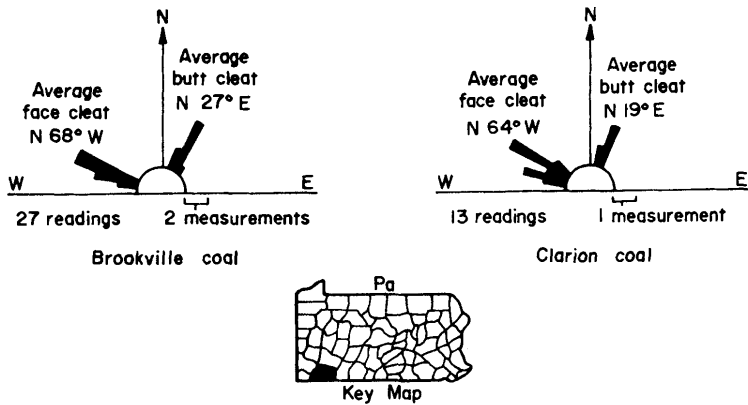


FIGURE 12. - Rose diagrams of coal cleat orientations of Clarion and Brookville coalbeds, Fort Necessity quadrangle, Fayette County, Pa.

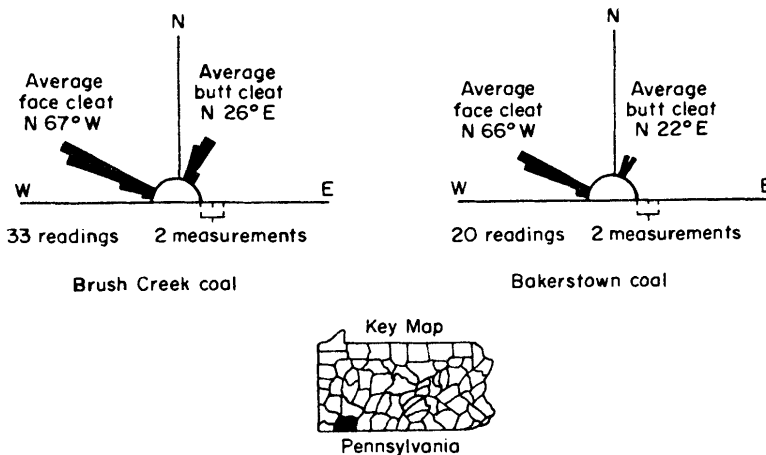


FIGURE 13. - Rose diagrams of coal cleat orientations of Bakerstown and Brush Creek coalbeds, Connellsville quadrangle, Fayette County, Pa.

The second area examined is in the Connellsville 7-1/2-minute quadrangle. Here the upper coalbed, the Bakerstown coal, has an average face cleat direction of N 66° W and an average butt cleat of N 22° E (fig. 13). The lower coalbed, the Brush Creek, has a face cleat striking N 67° W and a butt cleat striking N 26° E. The two coalbeds are separated by about 60 feet of sandstone and shale.

The third strip-mined area studied is in the Carmichaels quadrangle. The Washington coalbed, the upper coalbed, has a face cleat striking N 71° W; the butt cleat strikes N 19° E. Fifty feet below, the Waynesburg coalbed has a face cleat striking N 65° W with the butt cleat striking N 29° E. Figure 14 shows rose diagrams of the cleat orientations for both these coals.

Face and butt cleat orientations for all three strip mines are shown on table 4.

In the three strip-mined areas of southwestern Pennsylvania studied, there appears to be an excellent correlation of cleat orientation through vertical sequences of coalbeds. The largest angular difference between cleat orientation of upper and lower coalbeds observed was 06° for the face cleat in the Carmichaels quadrangle and 10° for the butt cleat in the Connellsville quadrangle. The average deviation of face and butt cleats between vertically separated coalbeds is 04° and 07°, respectively. Similar deviations in cleat directions have been noted in individual coalbeds at a single location.

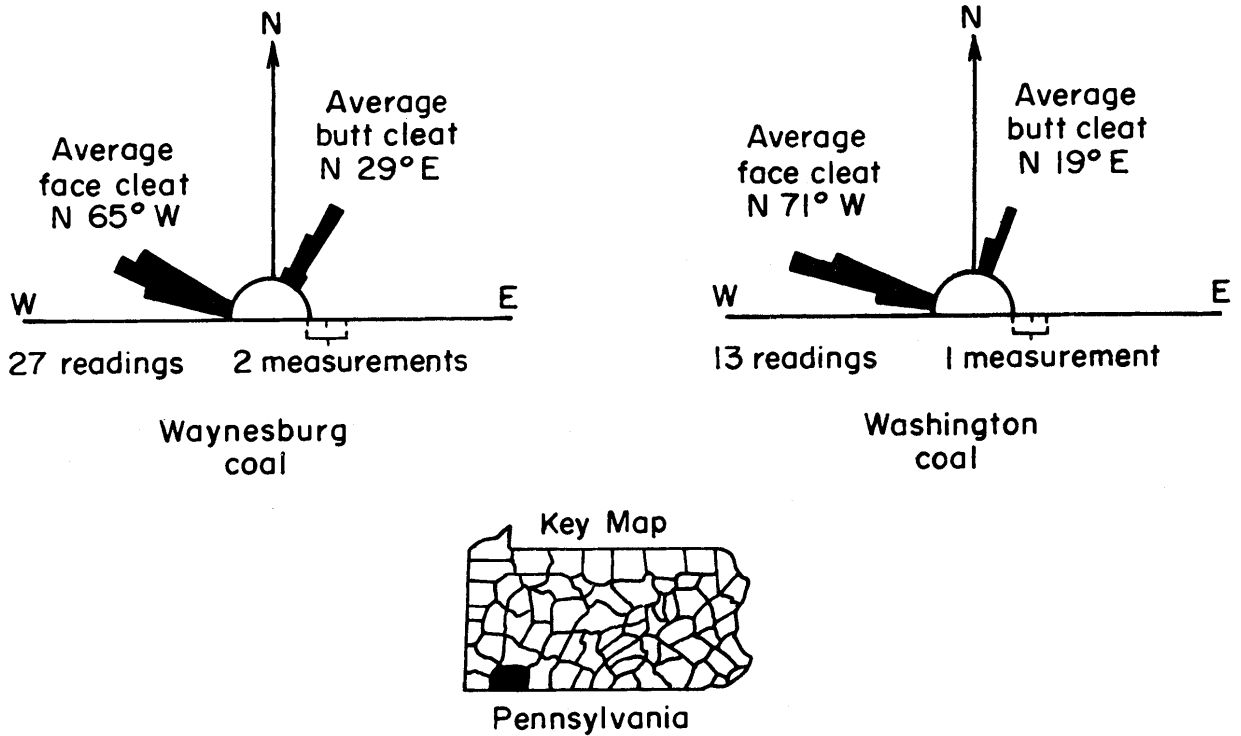


FIGURE 14. - Rose diagrams of coal cleat orientations of Washington and Waynesburg coalbeds, Carmichaels quadrangle, Fayette County, Pa.

TABLE 4. - Face and butt cleat orientations in strip mines studied in Fayette County, Pa.

Coalbed	Approximate vertical separation, ft	Average orientation		Degrees of separation ¹
		Face cleat	Butt cleat	
Fort Necessity quadrangle:				
Clarion.....	80	N 64° W	N 19° E	83
Brookville.....		N 68° W	N 27° E	95
Connellsville quadrangle:				
Bakerstown.....	60	N 66° W	N 22° E	88
Brush Creek.....		N 67° W	N 26° E	93
Carmichaels quadrangle:				
Washington.....	50	N 71° W	N 19° E	90
Waynesburg.....		N 65° W	N 29° E	94
		± 07°	± 10°	-

¹Separation is defined as the angular difference between the average face and butt cleat directions. Ideal separation is 90°.

²Maximum difference in cleat direction.

Southern West Virginia

Surface and subsurface information gathered in Raleigh and Wyoming Counties, W. Va., indicates cleat orientations to be similar throughout the sequences of strata examined.

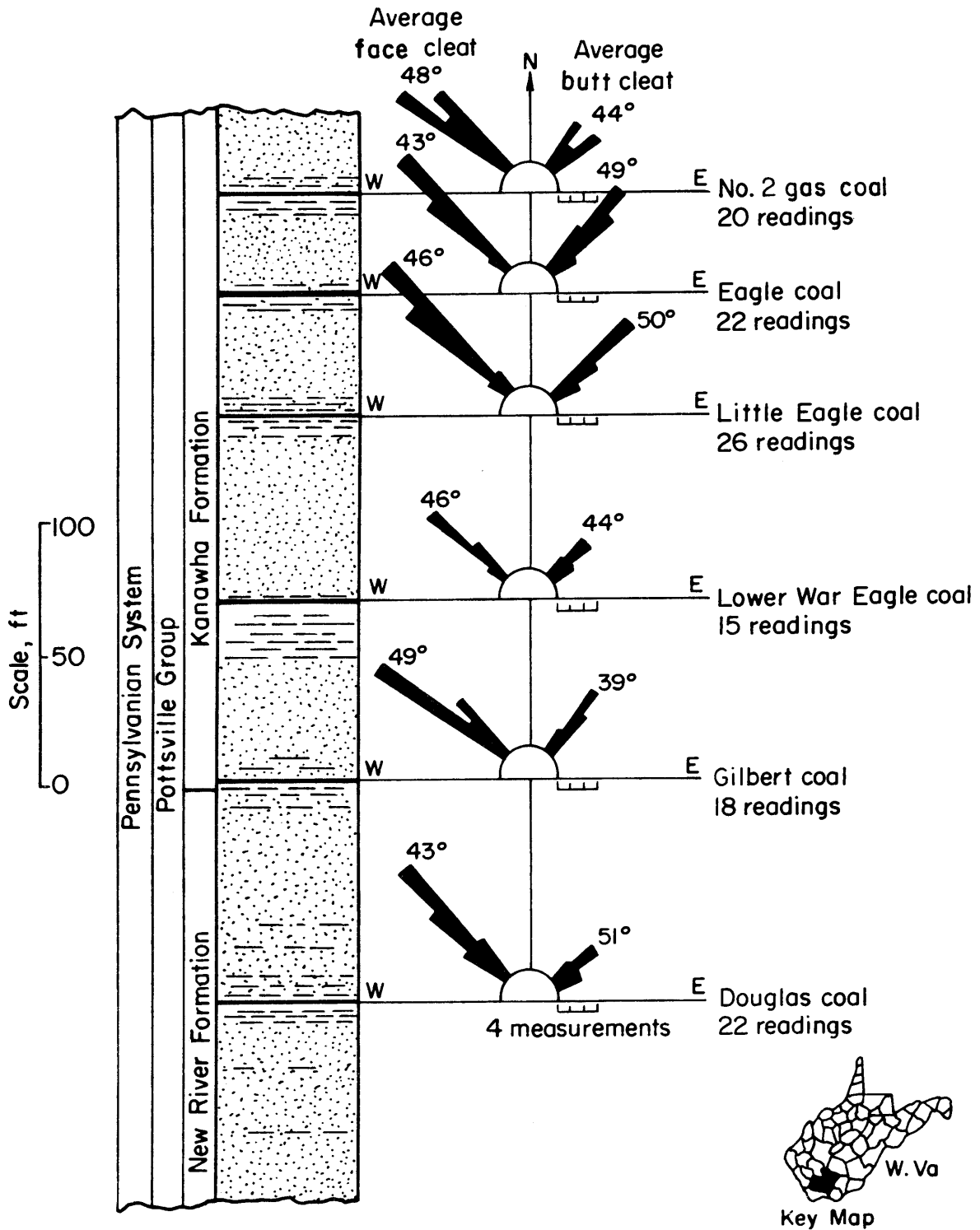


FIGURE 15. - Stratigraphic position and cleat orientations of six coalbeds in Raleigh and Wyoming Counties, W. Va.

A particularly good example of the persistence of cleat direction through a vertical sequence is shown on figure 15. This shows the stratigraphic position and cleat orientation of six different coalbeds which were examined in an area of active strip-mining operations in Raleigh County. The Douglas coal, which is stratigraphically the lowest coal examined, is separated from the uppermost No. 2 Gas coalbed by some 300 feet of sandstone and shale. The six coalbeds were studied within an area of approximately 2 square miles.

The face cleat directions of all six coals are within 06° of each other, the average direction being $N 46^\circ W$. The average butt cleat direction is $N 46^\circ E$, with a separation of 92° . Variation in butt cleat direction is 12° .

Surveys of cleat directions were conducted at three nearby underground coal mines south and east of the strip-mined area by Popp (12) in 1974. Figure 16 shows the locations of these mines. The deep mines are presently working in the Beckley coalbed which is stratigraphically approximately 750 feet below the No. 2 Gas coalbed (fig. 17).

Distributions of cleat directions for all three deep mines have been graphically displayed in figure 18. The average face cleat direction is $N 36^\circ W$. This is 10° from the $N 46^\circ W$ face cleat direction of the six coals examined on the surface. Distributions of butt cleat directions for the three deep mines in the Beckley show greater variation than for the six different surface coalbeds. The average butt cleat direction of $N 60^\circ E$ is 14° to the east of the average butt cleat direction measured on the surface.

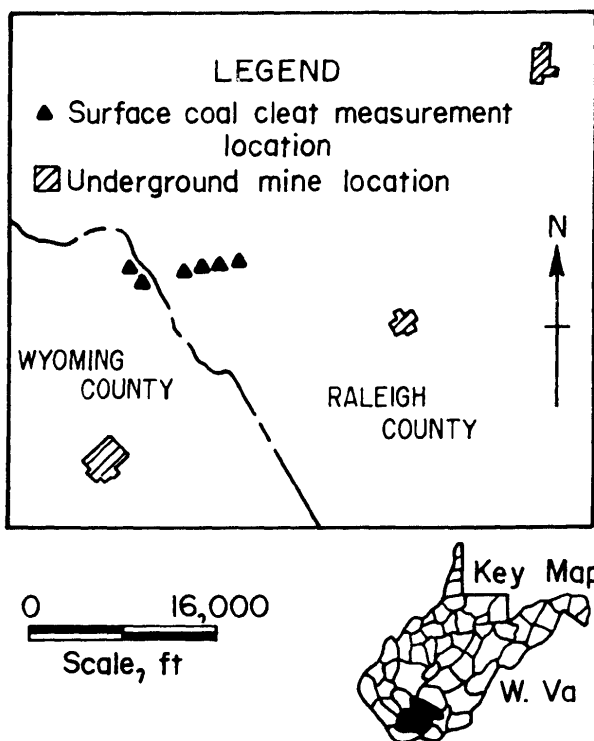


FIGURE 16. - Location of strip mines and deep mines in the Raleigh and Wyoming Counties, W. Va., study areas.

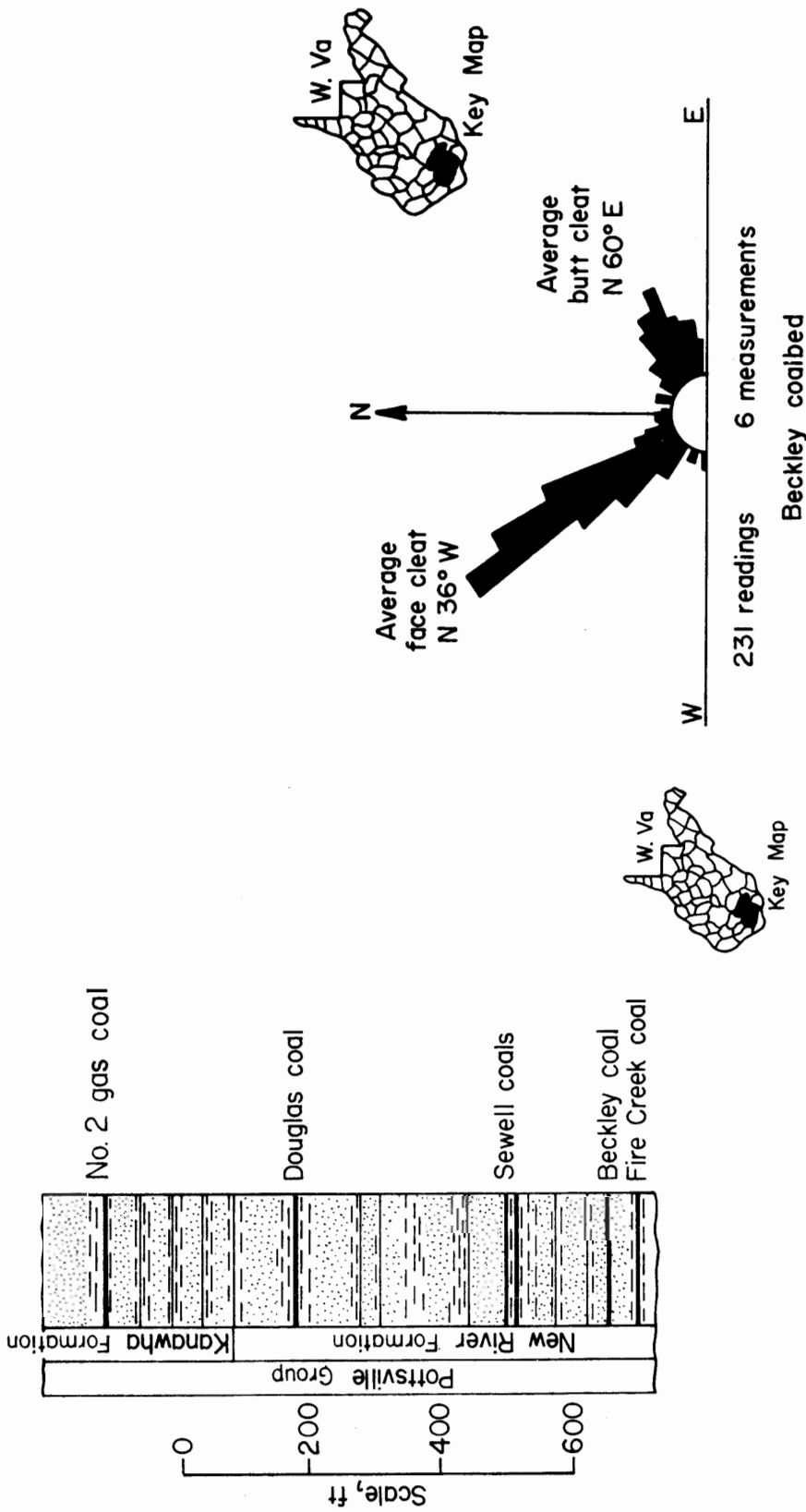


FIGURE 17. - Stratigraphic sections of interval from the No. 2 Gas coalbed to the Beckley coalbed.

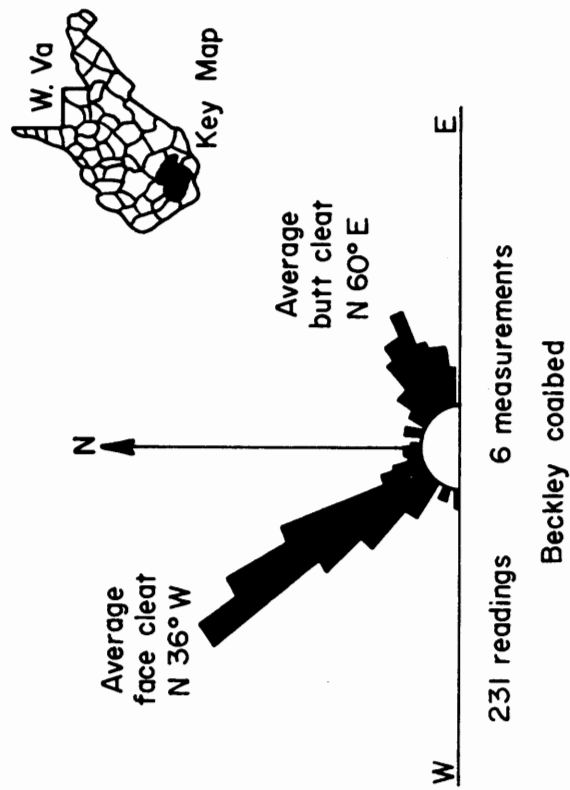


FIGURE 18. - Composite rose diagram of cleat orientation for three underground mines in Raleigh and Wyoming Counties, W. Va.

Face and butt cleat information measured in the six successive coalbeds and in the three deep mines is summarized on table 5.

TABLE 5. - Face and butt cleat orientations in six overlying coalbeds and in three deep mines, Raleigh and Wyoming Counties, W. Va.

County	Coalbed	Approximate stratigraphic separation between coalbeds, ft	Direction		Degrees of separation ¹
			Face cleat	Butt cleat	
Wyoming..	No. 2 Gas.....	35	N 48° W	N 44° E	92
Do.....	Eagle.....	45	N 43° W	N 49° E	92
Raleigh..	Little Eagle...	70	N 46° W	N 50° E	96
Do.....	War Eagle.....	65	N 46° W	N 44° E	90
Do.....	Gilbert.....	85	N 49° W	N 39° E	88
Do.....	Douglas.....	250	N 43° W	N 51° E	94
Do.....	Beckley.....	(²)	N 35° W	N 60° E	95
Do.....do.....	(³)	N 36° W	N 49° E	85
Wyoming..do.....	(⁴)	N 37° W	N 72° E	109

¹Separation is defined as the angular difference between the average face and butt cleat directions. Ideal separation is 90°.

²Maple Meadow.

³Beckley.

⁴Beckley No. 1.

CONCLUSIONS

Bureau research in the Appalachian coalfields shows that the directions of cleat orientations are similar throughout vertical sequences of coal-bearing strata. In areas examined, coals that are separated vertically by as much as 400 to 700 feet show similar directions of cleat orientations.

The vertical distance which separates two coalbeds apparently has very little effect on differences in cleat orientations in the areas examined. Coalbeds studied in some strip-mined areas separated by 50 feet or less show face cleat variations between coalbeds from 05° to 06° similar to coalbeds separated by up to 400 feet of such strata. A corresponding relationship of butt cleat variation with vertical separation also is observed, although butt cleat orientations tend to be irregular and the variations in measurements between coalbeds are somewhat higher.

The largest variations of cleat directions between overlying coalbeds are shown to occur where a large horizontal distance separates two locations where coalbeds were examined. In south-central West Virginia, the strip-mined area examined is over 3 miles from the nearest deep coal mine in which cleat readings were taken. The difference in face cleat directions between the two locations is 10°, while the butt cleat orientations differed by 14°.

The results of this study show that suitable cleat measurements can be taken from coalbeds in a deep mine, strip mine, or outcrop, so long as a representative sample of the cleat orientation is taken. No significant deviations were found in any of the studies to suggest a preferential method to be used, although outcrop readings of sufficient number over a small area are difficult to obtain.

Best results are noted where two coalbeds were measured directly or nearly directly over each other without regard to amount of vertical separation. Differences in cleat orientations between upper and lower coalbeds became significant when the horizontal distance between measuring points increased.

Knowing that coalbeds have the same major cleat orientations throughout a vertical sequence will become more important as mining progresses under deep overburden. Because gas content of coalbeds generally increases with depth, some form of degasification will be necessary if very deep coalbeds are to be mined productively. The ability to predict cleat orientations before degasification will assist in the planning of degasification programs and greatly add to our knowledge of the behavior of coalbed gas reservoirs.

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³Title enclosed in brackets is a translation from the language in which the item was published.