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Cleat in Bituminous Coalbeds

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Report of Investigations 7910

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By C. M. McCulloch, Maurice Deul, and P. W. Jeran
Pittsburgh Mining and Safety Research Center, Pittsburgh, Pa.

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CLEAT IN BITUMINOUS COALBEDS

by

C. M. McCulloch,[1] Maurice Deul,[2]
and P. W. Jeran[1]

ABSTRACT

The natural vertical fracture system in bituminous coalbeds is called cleat. Cleat orientation commonly controls the direction of mining with major development paralleling the face cleat.

Previous researchers have categorized the origin of cleat as endogenetic, relating the origin of cleat to compaction and coalification, and exogenetic, relating the origin of cleat to tectonic forces. In the coalbeds studied for this report it was found that tectonic forces were the controlling factor of cleat formation. Face cleats were formed as extension fractures during structural deformation, and butt cleats, as release fractures during erosion and uplift.

The face cleat of the Pittsburgh coalbed rotates from N 80° W in northwestern West Virginia to N 57° W in southwestern Pennsylvania; the face cleat maintains a perpendicular orientation to the shifting axial trend of local structures. Cleat orientation in other bituminous coalbeds in Virginia, Utah, Oklahoma, and Central Pennsylvania showed a similar relationship to local structure.

Directional permeability of coal is directly related to cleat. Holes drilled perpendicular to the face cleat yield from 2.5 to 10 times the amount of gas released as compared with holes drilled perpendicular to the butt cleat.

INTRODUCTION

Coal is a sedimentary rock consisting mainly of residue of degraded biologically, physically, and chemically altered plant tissues and plant tissue extract. Bituminous coalbeds are generally well layered and stratified parallel to the bedding planes except when strongly metamorphosed dynamically by tectonic forces. Rarely are coalbeds free of detrital materials; commonly silt and clay accumulations within the coalbed are thick enough to distinctly separate the coalbed into two or more parts (benches).

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[1] Geologist.
[2] Supervisory geologist.

Bituminous coal tends to separate along certain prominent bedding planes when removed from the mine face. The blocky structure often exhibited by extracted coal is due to separation along bedding planes and along the joint planes that are universally present in banded bituminous coals. The cleat frequency depends on the rank and geologic history of the coal, but for a given rank in a coalfield the frequency is determined by the coal type. In 1954, Macrae and Lawson (23),[3] in a study of several seams in the Yorkshire coalfield, found the durain bands that were thicker than 6 inches had less than five fractures per foot, whereas the clean, bright coal had 70 fractures per foot. It was also shown that the cleat frequency may determine the size of run-of-mine coal. Coal in place in underground mines rarely shows separations along bedding planes except where the coal has been undercut or where roof falls have induced slumping pillars and along ribs. Usually the overburden pressures are high enough to close any openings along the bedding plane; typically such static rock pressures can be calculated and are on the order of 100 psi per 100 feet of rock cover.

ACKNOWLEDGMENTS

The authors thank the officials of the mining companies who supplied that data necessary for this study. The management of the following companies were helpful in the collection of data: Consolidation Coal Co.'s Loveridge mine; Eastern Associated Coal Corp.'s Federal No. 2 mine; Bethlehem Steel Corp.'s Marianna No. 58, Somerset No. 60, Cambria Nos. 32 and 33 mines; Jones & Laughlin Steel Corp.'s Shannopin, Gateway, and Vesta No. 5 mines; Howe Coal Co.'s Howe mine; Carbon Fuel Co.'s No. 3 mine; and Island Creek Coal Co.'s Beatrice-Pocahontas mine.

The authors are especially grateful to the following reviewers who made helpful comments and suggestions: Samir Khoury, Department of Earth and Planetary Science, University of Pittsburgh, Pittsburgh, Pa.; Ralph Gray, U.S. Steel Corp. Research Laboratory, Monroeville Pa.; and Jack Vonfeld, Consolidation Coal Co., Library, Pa. (now retired).

CLEATS (OR JOINTS) IN COAL

Jointing (see appendix) is commonly observed in all rock but is perhaps most prominent in sedimentary rocks. Joint planes in flat-lying or nearly flat-lying strata are usually perpendicular to the bedding plane that is, vertical or nearly so. In coalbeds such joints are commonly called cleats or cleat surfaces.

The cleat directions, especially in bituminous coals, are important in establishing preferred directions of mine development. The coal tends to break along its natural fracture systems (the face cleat, also known as main or master cleat, and butt cleat, also known as cross or board cleat). Therefore it is much easier to mine parallel to the cleat directions than at an angle to the cleats.

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[3] Underlined numbers in parentheses represent items in the bibliography preceeding the appendix.

Included in this report along with the results of analysis of field studies conducted recently is a survey of previous work on the origin of cleats.

PREVIOUS WORK ON ORIGIN OF CLEATS

Coal has been mined parallel to the directions of the cleat almost since the start of coal mining, but the explanations of why the cleat exists have always been controversial. Raistrick and Marshall in 1939 (28) quoted the first published report on cleat by Edward Mannett in 1834. Mannett stated, "The extraordinary uniformity in the direction of the slynes (cleats) and of the parting of the rocky strata seems to have been determined by the operation of some law not yet understood."

Later investigators concerned with the origin of cleats believe that the cleats are due to either tectonic forces such as formed the folded Appalachians or nontectonic processes such as compaction and dehydration.

As early as 1908 Kaiser (17) stated that cleat structure was produced by tectonic forces; he pointed out that in England the strike or direction of the cleat has been found to be the same in a succession of parallel coalbeds and that the cleat strike was also parallel to the formation fissures in the region. However, Dran (6) in 1925 reported that in the Scottish coalfields, cleat trends may even vary between upper and lower seams in the same colliery. Fraiser in 1914 (8) said that the production of cleat by lateral pressure is plainly apparent in the Falkenau of northern Bohemia. Stutzer in 1940 (30) stated that he felt that "cleats consist of parallel rupture planes produced by pressure." Ver Steeg in 1942 and 1944 (31-32) in Ohio also found a relationship to the cleats in the coal and the present structure.

The nontectonic origin of cleat formation was originally championed by Hofer in 1915 (15), who believed that the origin is inherent in the coal itself. Hofer maintains that cleats are fissures produced by contraction of carbonaceous material during progressive coalification of the original plant material to bituminous coal. From work accomplished in New York and eastern Pennsylvania in 1932, Moore (24) felt that this idea was basically correct but thought tectonics might also play a role in the formation of cleat.

Recent studies resulted in combining these two original ideas. Ammosov and Eremin (1) follow both ideas to explain the two types of "fractures" found in coal. One type is "endogenetic," dependent on "the nature of the rocks," where contraction takes place during cooling, desiccation, and recrystallization. The other type, "exogenetic," is due to the effect of external forces during the last stage of development of the folding processes (tectonics). These basic ideas parallel some of DeSitter's (5) work. Secor (29) says that the fundamental fracture (joint) pattern of a rock mass is established early in its history and believes pore pressures to be more important than overburden pressure as a causative factor. Nickelsen and Hough (26) show that the dominant joint sets in coal, referred to as face cleats, are usually nearly perpendicular to the fold axis of the local rock structure; they state "that nonsystematic joints indicate that a relict tectonic principal stress, related to topography and unloading are important to their genesis."

More recent investigators continue to have divergent opinions on the origin of coal cleat.

SURVEY OF FIELD AND LABORATORY RELATIONSHIPS OF CLEAT ORIENTATION

Nickelsen and Hough (26) show that the dominant systematic joint sets mapped in the field are usually nearly perpendicular to the fold axis; they believe there is a relationship between the systematic joints and nonsystematic joints that in coal, are called face and butt cleats. According to Griggs and Handin (10), fractures are due either to shear or extension. There are two main types of extension fractures: Those formed parallel to a compressive force, and release fractures that form perpendicular to the greatest principle stress axis.

The results of M. P. Billings' (2-3) laboratory studies suggest that extension fractures such as the face cleat would form in a water-saturated state and under high confining compressive pressure. These would be parallel to the direction of the compressive force and formed early in the folding state as suggested by Hough (16) and Secor (29). Subsequently, after the load is released, the coalbed would exhibit numerous fractures parallel to the axis of compression forming the butt cleat. The fractures result from expansion of the rock units upon removal of the load through the processes of erosion and uplift. Hodgson (13) noted that the nonsystematic joint (butt cleats) are secondary features that he felt developed after the formation of the systematic joint (face cleat); Griggs (9) felt that release fractures result indirectly from compression.

Ver Steeg (31-32) observed in Ohio that the change in orientation of the joints in the Appalachian coalbeds appear to be arranged in an arc, convex to the west, and that this corresponds to the arc of folded Appalachians in the same latitude of Pennsylvania. Ver Steeg believed the joints were created by deformation at the time of Appalachian folding. The work of Nickelsen and Hough (26) in southwestern and central Pennsylvania supported this.

CURRENT STUDIES

Cleat orientations were measured to detect changes due to local and regional structure. A Brunton compass--a combined handheld alidade and clinometer--was used for the measurements following procedures outlined by Lahee (22).

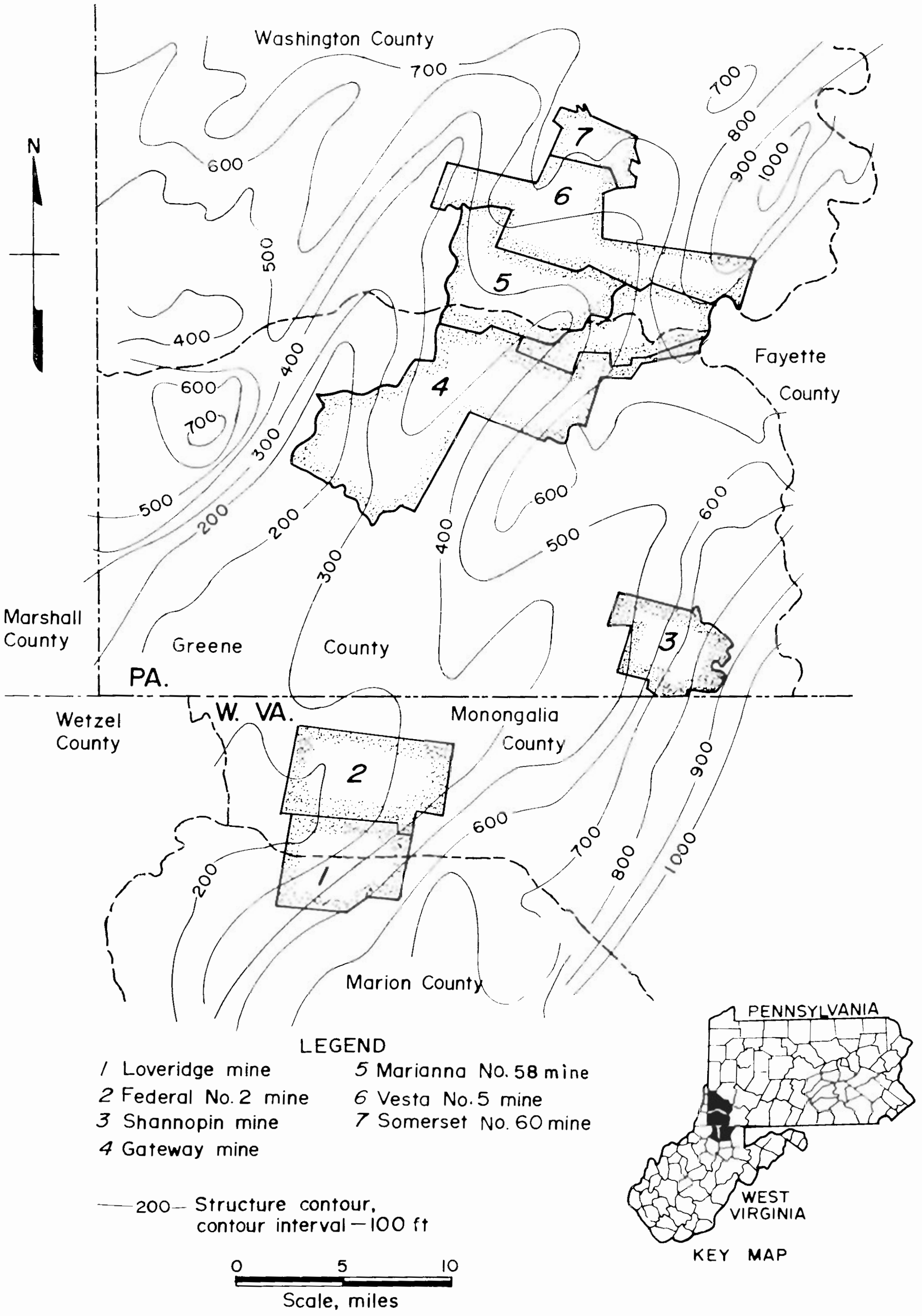


FIGURE 1. - Location of mines superimposed on structure of base of Pittsburgh coalbed.

Pittsburgh Coalbed

The Bureau of Mines conducted surveys in seven underground mines in Monongalia and Marion Counties, W. Va., and in Greene and Washington Counties, Pa. These mines are in the Pittsburgh coalbed and west of the Appalachian front. Table 1 shows the orientations of the face and butt cleats in the seven mines surveyed. The locations of these mines and the structure of the area based on the Pittsburgh coalbed are shown in figure 1.

TABLE 1. - Surveyed mines in Pittsburgh coalbed and their major cleat directions

Mine[1]	Face cleat	Butt cleat
Loveridge	N 80° W	N 15° E
Federal No. 2	N 77° W	N 17° E
Shannopin	N 73° W	N 18° E
Gateway	N 68° W	N 28° E
Marianna No. 58	N 68° W	N 28° E
Vesta No. 5	N 66° W	N 30° E
Somerset No. 60	N 57° W	N 30° E

[1] The mines listed in this table are arranged according to their relative geographical position, with Loveridge being the southernmost mine and Somerset No. 60 being the northernmost mine.

These data show that there is a rotation in the cleat direction that corresponds roughly to the change in strike of the anticlines and synclines in this area (fig. 2). The measurements recorded are similar to those made by Parker (27) in western New York and eastern Pennsylvania and by Ver Steeg (32) directly to the west in Ohio, which relate to the axial trend of the Allegheny front.

A good example of structural control on the orientation of cleat can be found in the Shannopin mine. Figure 3 shows the structure of the coalbed in the vicinity of the mine. The cleats are controlled by the Fayette anticline, the dominant structure in the area, because the structural contour lines parallel its axial trend, and the face cleats, which strike N 73° W, are perpendicular to it.

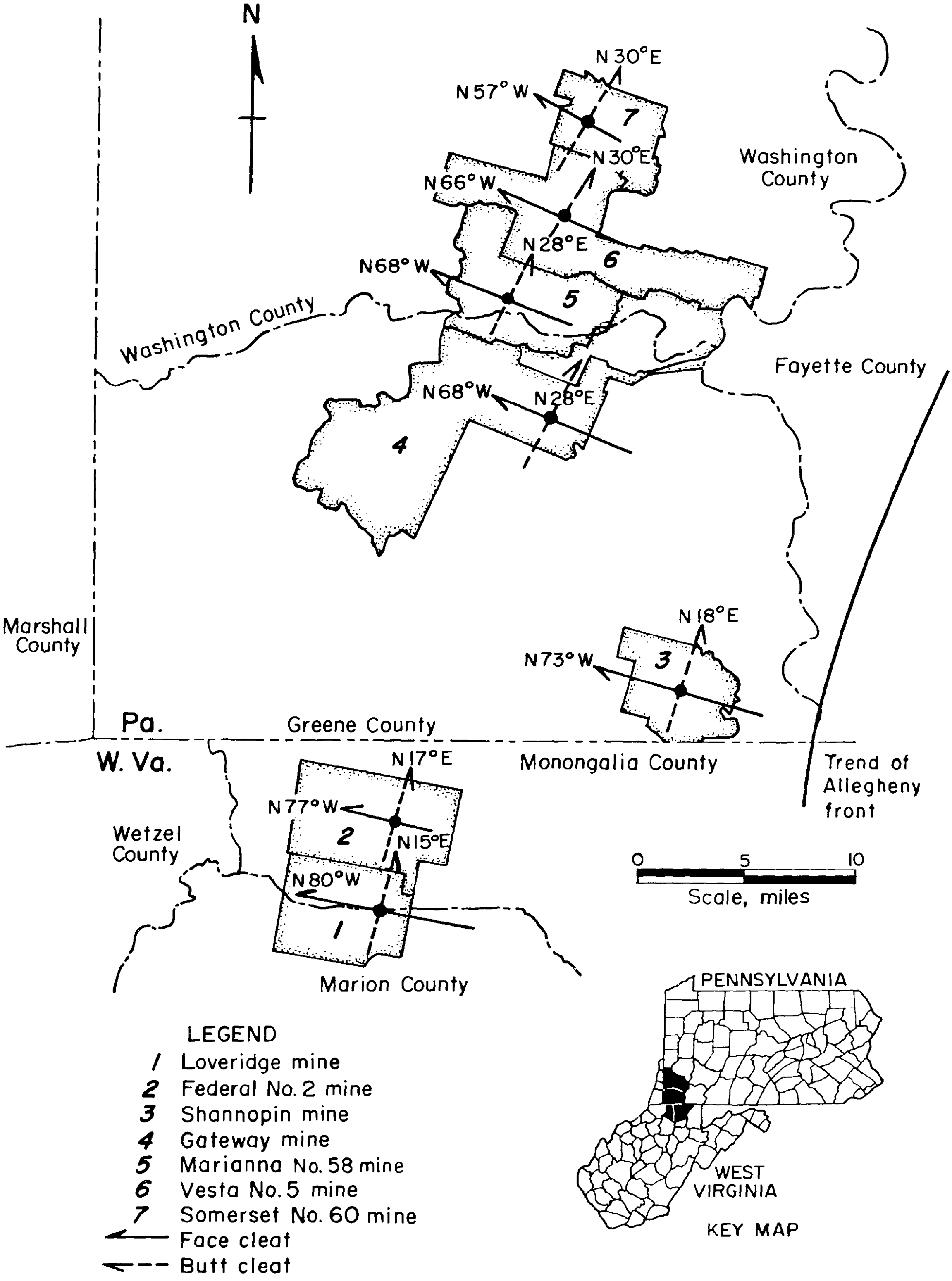


FIGURE 2. - Coal cleat orientations in seven mines operating in the Pittsburgh coalbed showing cleat rotation.

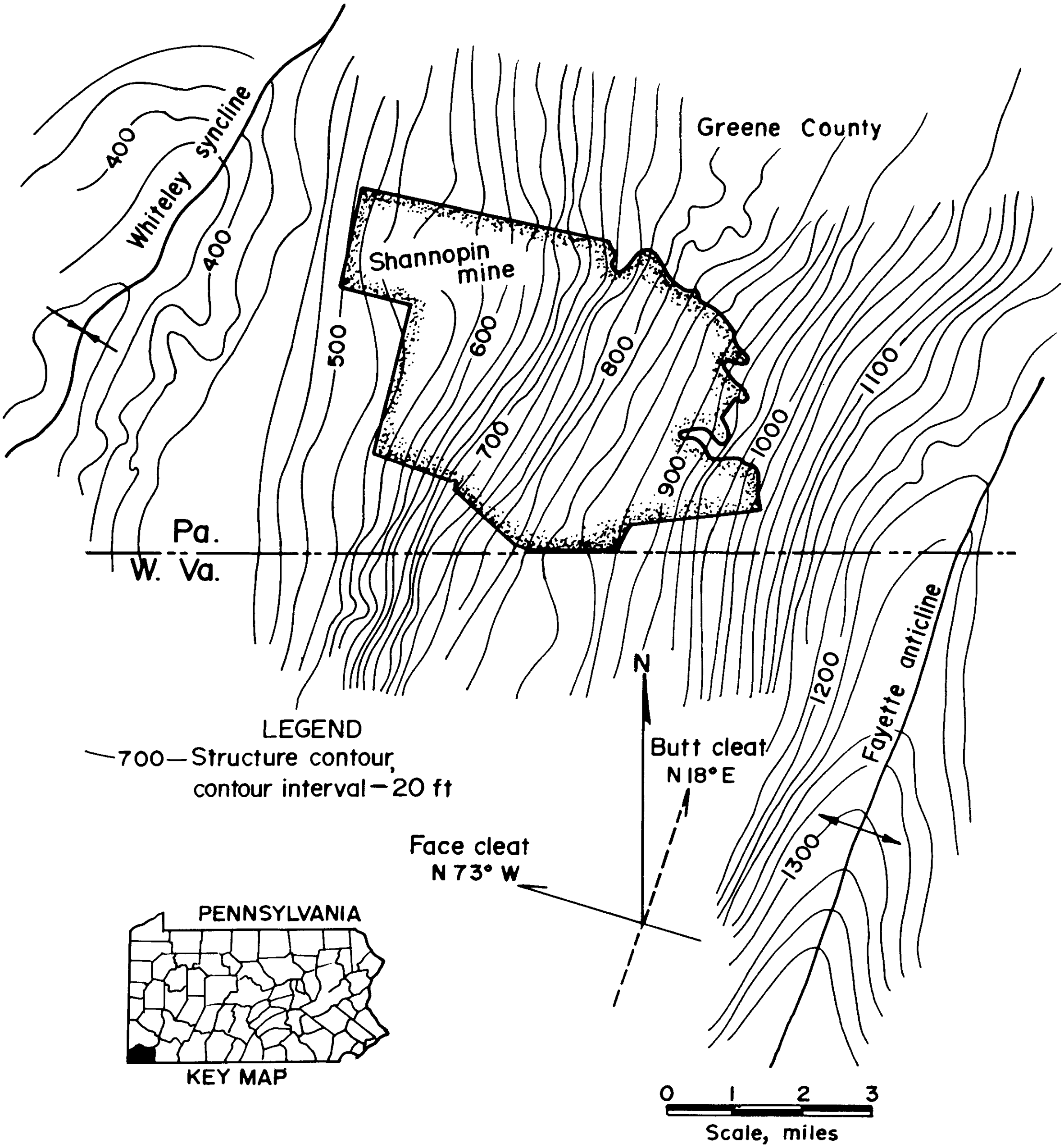


FIGURE 3. - Structure of Pittsburgh coal in area of Shannopin mine and coal cleat readings.

Lower Kittanning Coalbed

A detailed geological study was also conducted in and around the Cambria Nos. 32 and 33 mines near Ebensburg, Pa., about 80 miles north and east of the seven Pittsburgh coalbed mines surveyed. Both mines are located in the Lower Kittanning coalbed. The coal face cleat strikes N 69° W and the butt cleat strikes N 19° E. The axial direction of the local folding ranges from

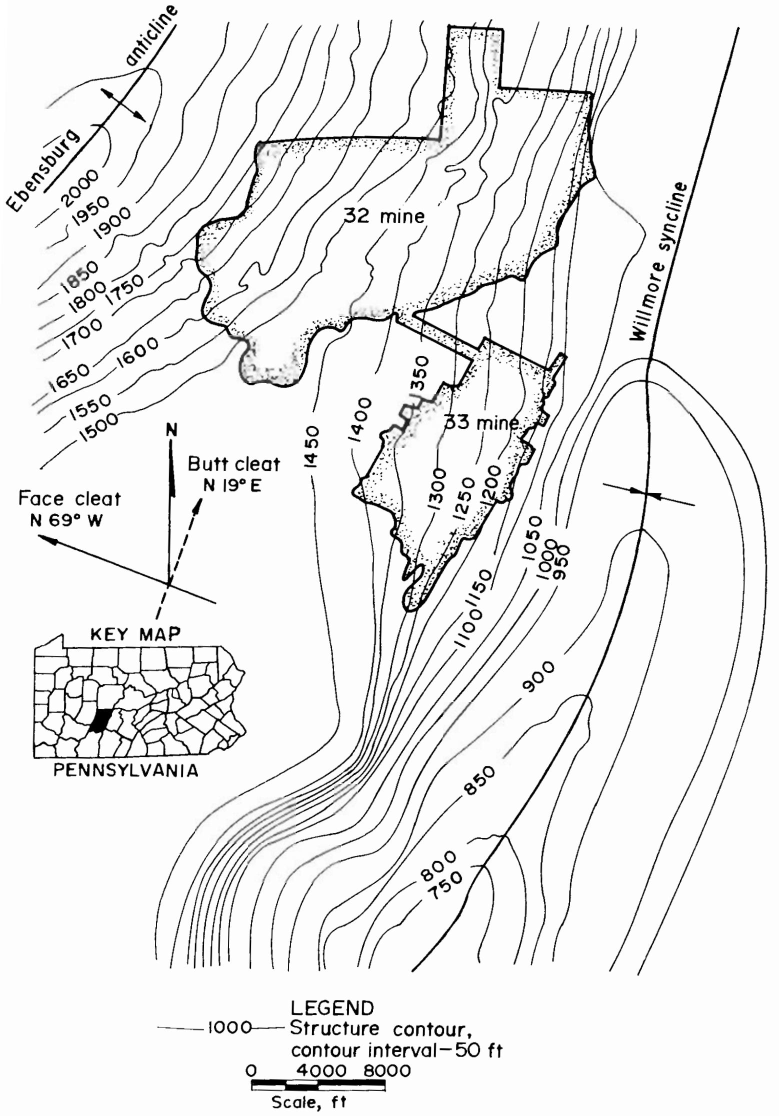


FIGURE 4. - Generalized structural contour map of area around Cambria Nos. 32 and 33 mines.

N 17° E to N 22° E. This is subparallel to the butt cleat direction. This would be expected if the structure tended to control the cleat direction and if the butt cleat was due to the release of compression and was at right angles to the direction of compression after relaxation of the applied force. Figure 4 illustrates this relationship.

The strike of the systematic surface rock joints in the area is N 68° W. The three main directions of regional lineations are (1) N 70° W, (2) N 31° W, and (3) N 39° E; these data are from a report by McCulloch and Deul (<u>25</u>). Therefore it is evident that there is a parallelism between the N 70° W major regional lineations, the face cleat, and the systematic rock joint direction, which are all nearly perpendicular to the local axial trends of the Ebensburg anticline and the Wilmore syncline situated on either side of the mine.

In figure 5 this relationship in orientation can be seen from the rosette diagrams showing the cleat orientations, the rock joint measurements, and the regional lineations.

Approximately 30 separate joints were measured in the mine roof underground. One extended upward more than 20 feet where exposed by roof falls. Seventy-five percent of the rock joints measured trended N 64° W to N 75° W, which is approximately parallel to the face cleat of the coal.

This is not to say that all cleats and joints formed at the same time. The coal face cleats may have formed earlier, as suggested by Nickelsen and Hough (<u>26</u>), "because the coals were the first to develop cohesive strength or because the coals are weaker than the other types of rocks." From this

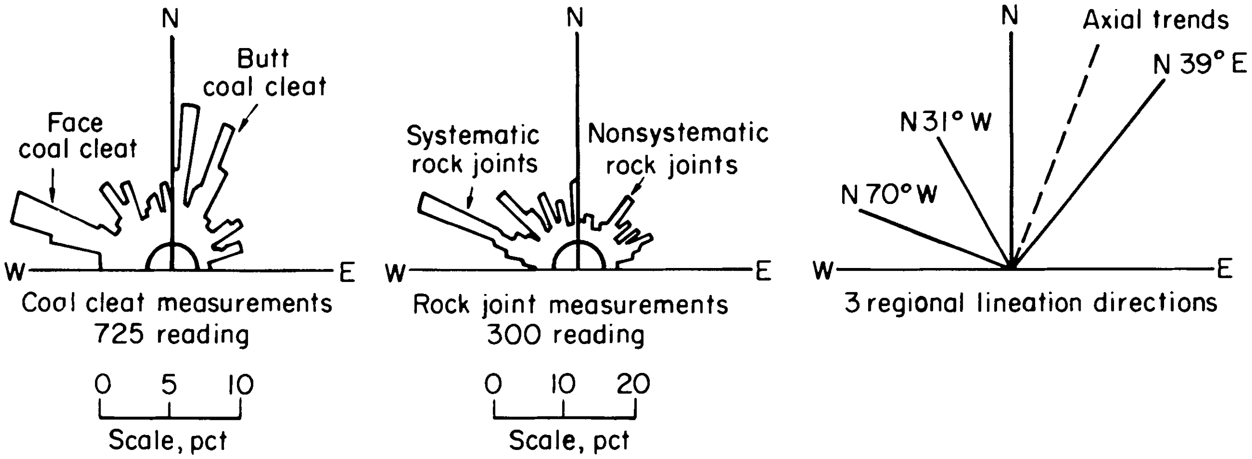


FIGURE 5. - Strike of coal cleats, rock joints, and regional lineations.

evidence, the authors conclude that the compression was in a northwest-southeast direction, and that the face cleat was formed during early folding of the strata, the butt cleats being release fractures formed later when the compressive forces were released.

Surveys of the following two mines in the Western States show similar relationship of cleat orientations to geological structure.

Lower Hartshorne Coalbed

At the Howe Coal Co. mine in the Lower Hartshorne coalbed, located 6 miles south of Poteau, Le Flore County, Okla., on the southern border of the Arkoma coal basin, the strike of the butt cleat is N 74° E, subparallel to the local axial trend. The strike of the nonsystematic rock joints in this area is N 72° E, also subparallel to the regional trend. The face cleat in the coal and the systematic rock joint both strike N 15° W, which is subperpendicular to the trend and, therefore, parallel to the axis of compression. These details are illustrated in figure 6.

Subseam 3 of the Castlegate Group

At the Carbon Fuel Co. No. 3 mine (near Helper, Utah) operating in the subseam 3 of the Castlegate Group, the face cleat strikes N 80° W and the butt cleat strikes N 16° E. The axial trends of the local structures are subparallel to the butt cleat. The structure dips generally to the north and

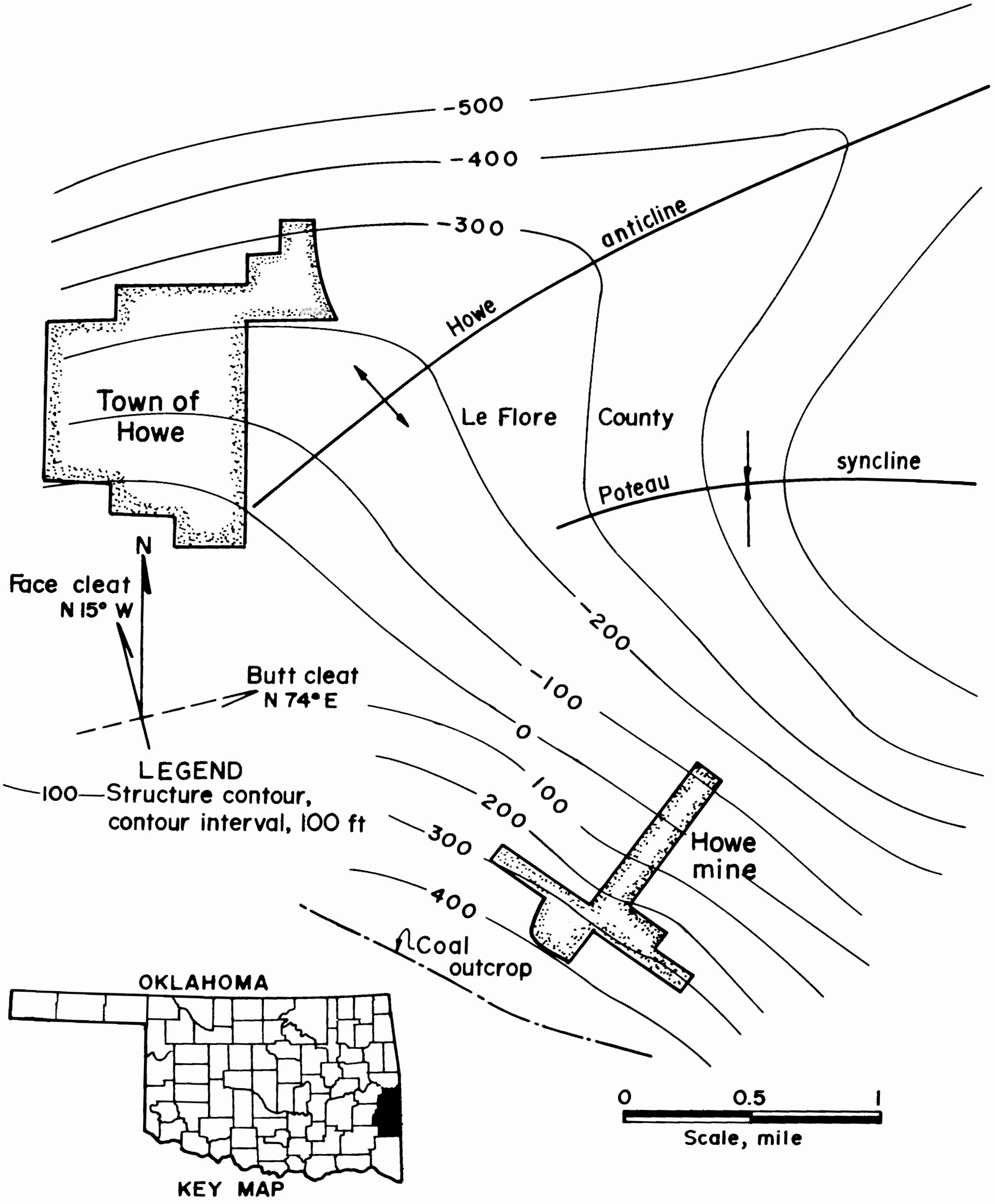


FIGURE 6. - Structure of the Lower Hartshorne coalbed.

and northeast as shown in figure 7; local deformation is mainly to the east of the mine. No studies have been conducted in other mines remote from this zone of deformation, but in this mine there is a demonstrable relation of cleat orientation and local structure.

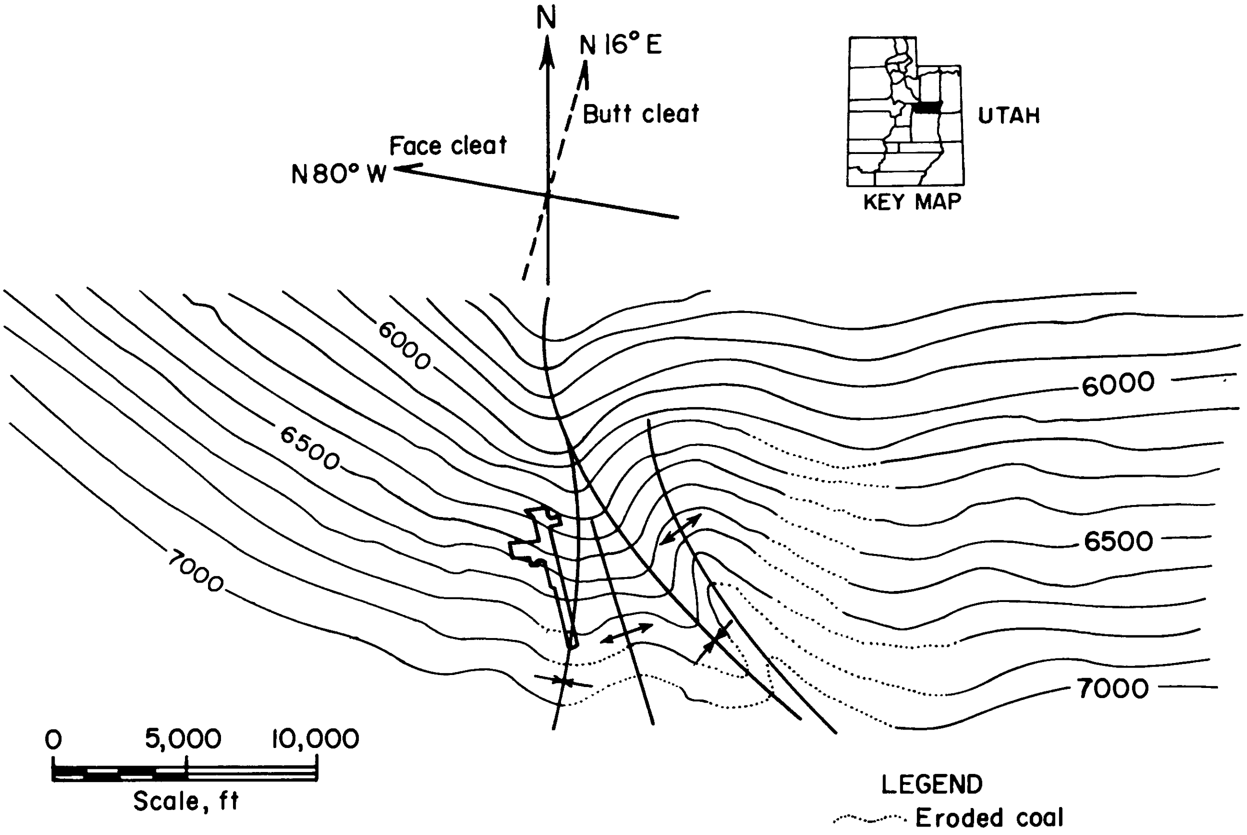
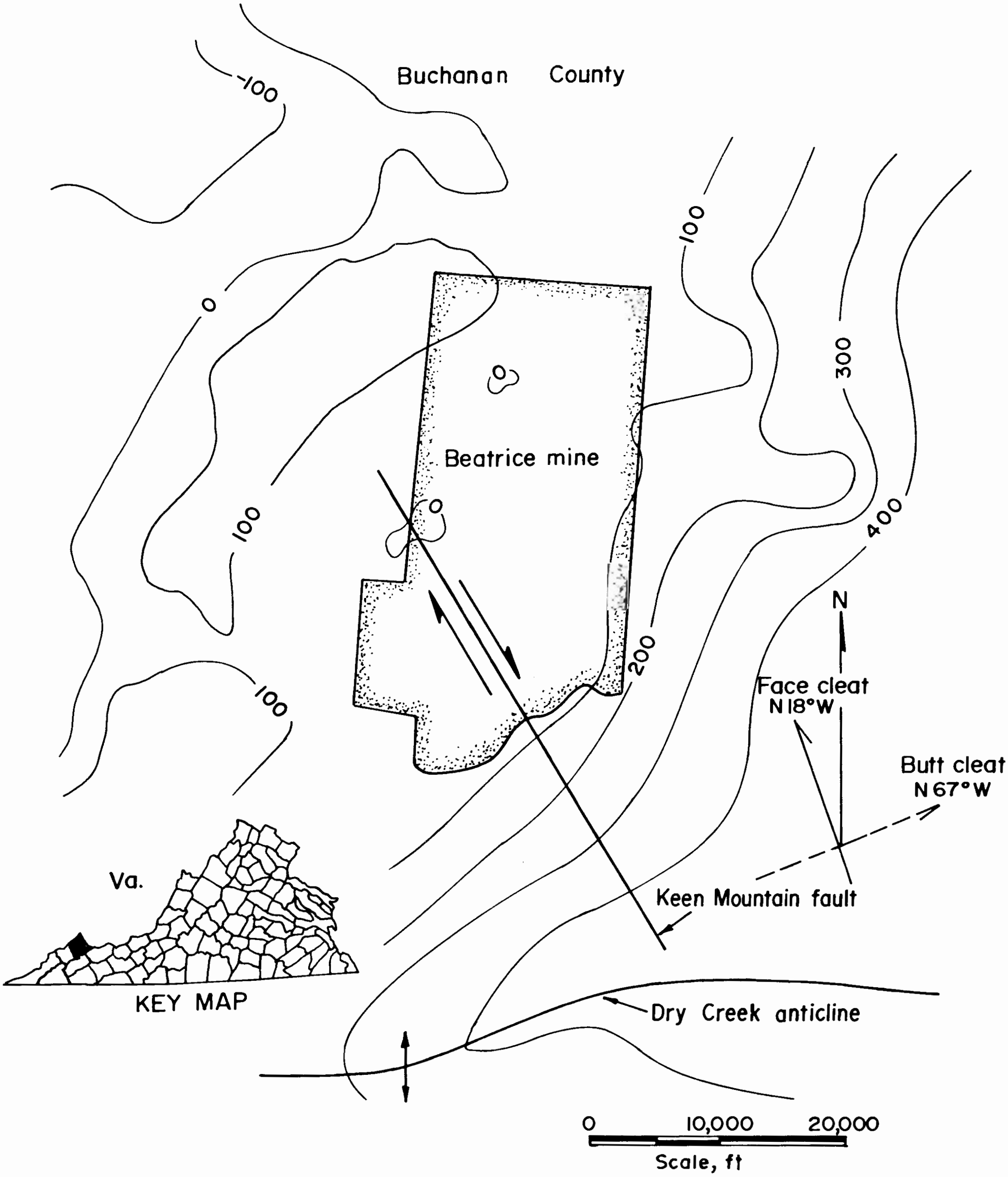


FIGURE 7. - Generalized structure map in vicinity of Carbon Fuel No. 3 mine, Carbon County, Utah.

Because the Howe Coal Co. mine and the Carbon Fuel No. 3 mine fit the present theory of the relationship of cleats in coal to geological structure, it does not necessarily follow that all other mines in Oklahoma and Utah will do so, but without data to the contrary, this premise is applicable to the areas studied.

Pocahontas No. 3 Coalbed

In all the areas thus far considered, folding has been the dominant structural feature. In Buchanan County, Va., both folding and faulting are evident in the Beatrice mine. The butt cleat of the Pocahontas No. 3 coal strikes N 67° E--again nearly parallel to the axis trend of the folds (fig. 8). The face cleat strikes N 18° W at right angles to the axial trend of the folds. A strike-slip fault has been found to run across this mine. The coal on both sides of the fault, for about 30 feet, is badly disturbed. Figure 9 shows the results of steronet analysis of the cleat measurements arbitrarily separated into zones 0 to 2,000 feet and 2,000 to 4,000 feet on either side of the fault. Cleat orientation in the northeast 2,000-foot zone adjacent to the fault was affected by faulting, but cleat directions in the other zones apparently were not affected. One explanation for this is that the southwest block moved against the northeast block (acting as a buttress), against which the energy in the southwest block was dissipated.



LEGEND

——100——Structure contour,
contour interval—100 ft

FIGURE 8. - Generalized structure of Beatrice mine showing structural contours and Keen Mountain fault.

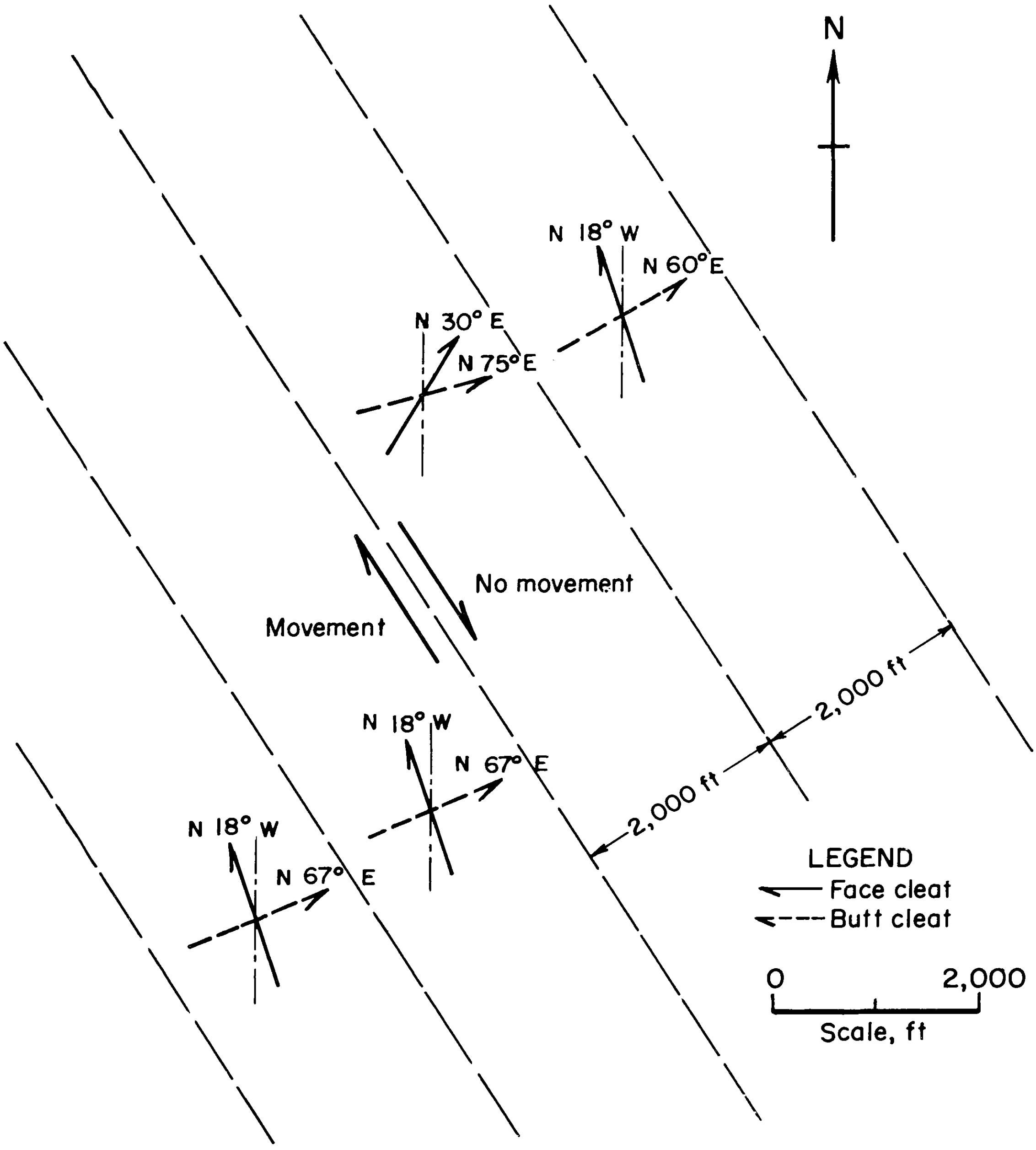


FIGURE 9. - Stereonet analysis of cleat orientation 4,000 feet on either side of the Keen Mountain fault in the Beatrice mine.

DIRECTIONAL PERMEABILITY RELATED TO COAL CLEAT

Directional permeability in coalbeds has been observed often during the conduct of Bureau research. This permeability is directly related to the two main cleat directions. An attempt was made to quantify this relationship. According to Kissell (20), a hole drilled into the coalbed perpendicular to the face cleat would be expected to yield a much higher gas flow (up to a factor or 10) than one perpendicular to the butt cleat. The reason for this is that the face cleat is a longer, more continuous joint surface. It crosses bedding planes in the coal and can extend for a distance of many feet. The butt cleat is short, often curved, and is a discontinuous feature that frequently terminates against the face cleat.

From this it can be seen that holes drilled horizontally and parallel to the butt cleat (perpendicular to the face cleats) would intersect the more permeable face cleats and, therefore, drain a greater area. In contrast, a hole drilled horizontally and parallel to the face cleat (perpendicular to the butt cleat) would intersect the butt cleats that are shorter in length and less frequent.

The tests that support this observation have been conducted in several different mines. The results of some of this work are discussed below.

The Cambria No. 33 mine, located near Ebensburg, Pa., is operating in the lower Kittanning coalbed. Two holes were drilled horizontally into the coalbed parallel to the N 65° W and N 25° E direction. The gas pressure, after the hole was sealed along the N 65° W direction, was 12 psi, whereas the gas

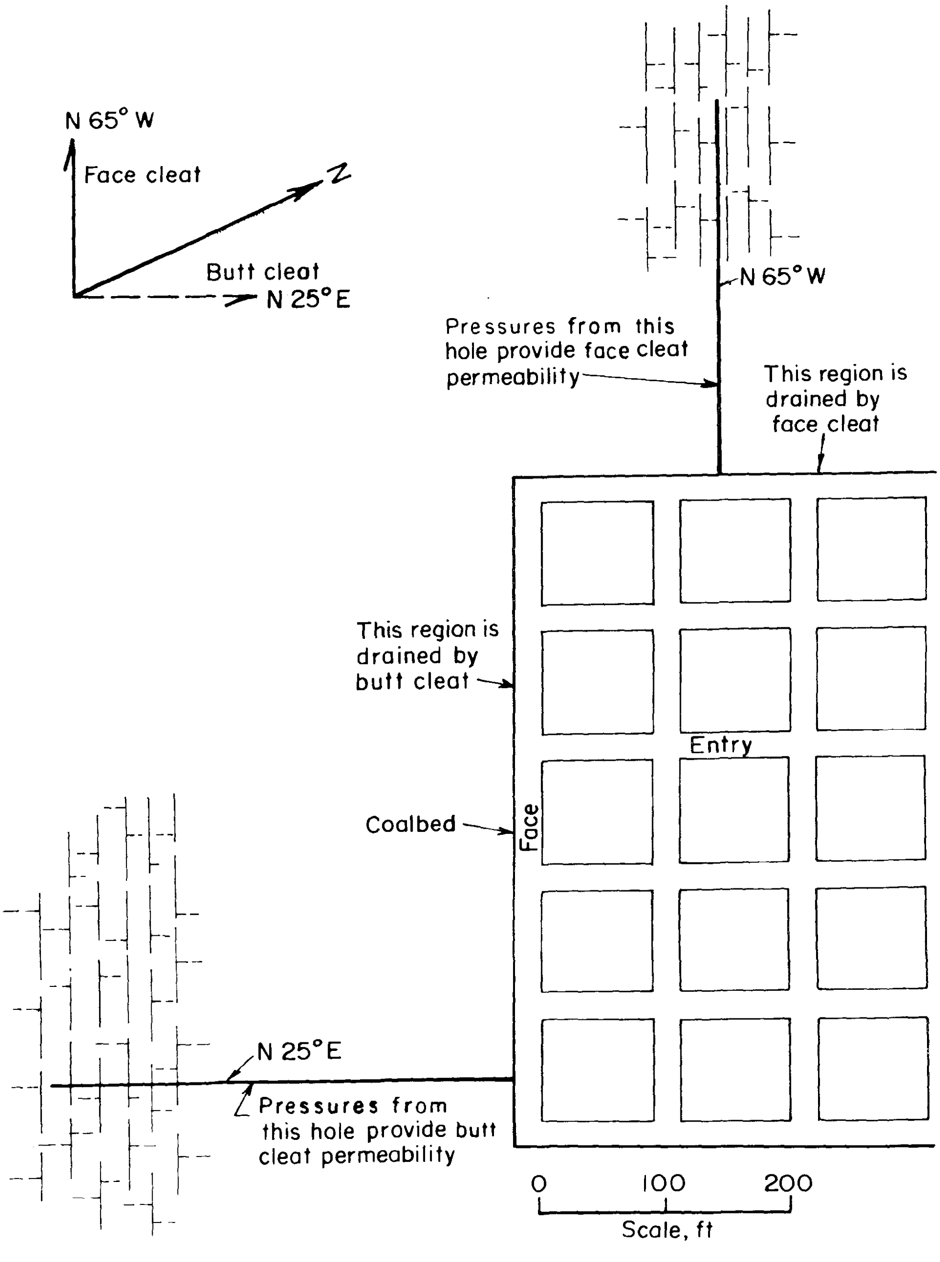


FIGURE 10. - Horizontal holes drilled into Lower Kittanning coalbed (Cambria No. 33 mine) subparallel to cleat direction.

measured along the N 25° E direction was 30 psi. The direction along which these measurements were made approximate the face and butt cleat directions, which average N 68° W and N 19° E, respectively. 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 (fig. 10).

Tests conducted at the Federal No. 2 mine located in Monongalia County, W. Va., operating in the Pittsburgh coalbed yielded much the same results. Here four holes were drilled, three perpendicular to the face cleats and a

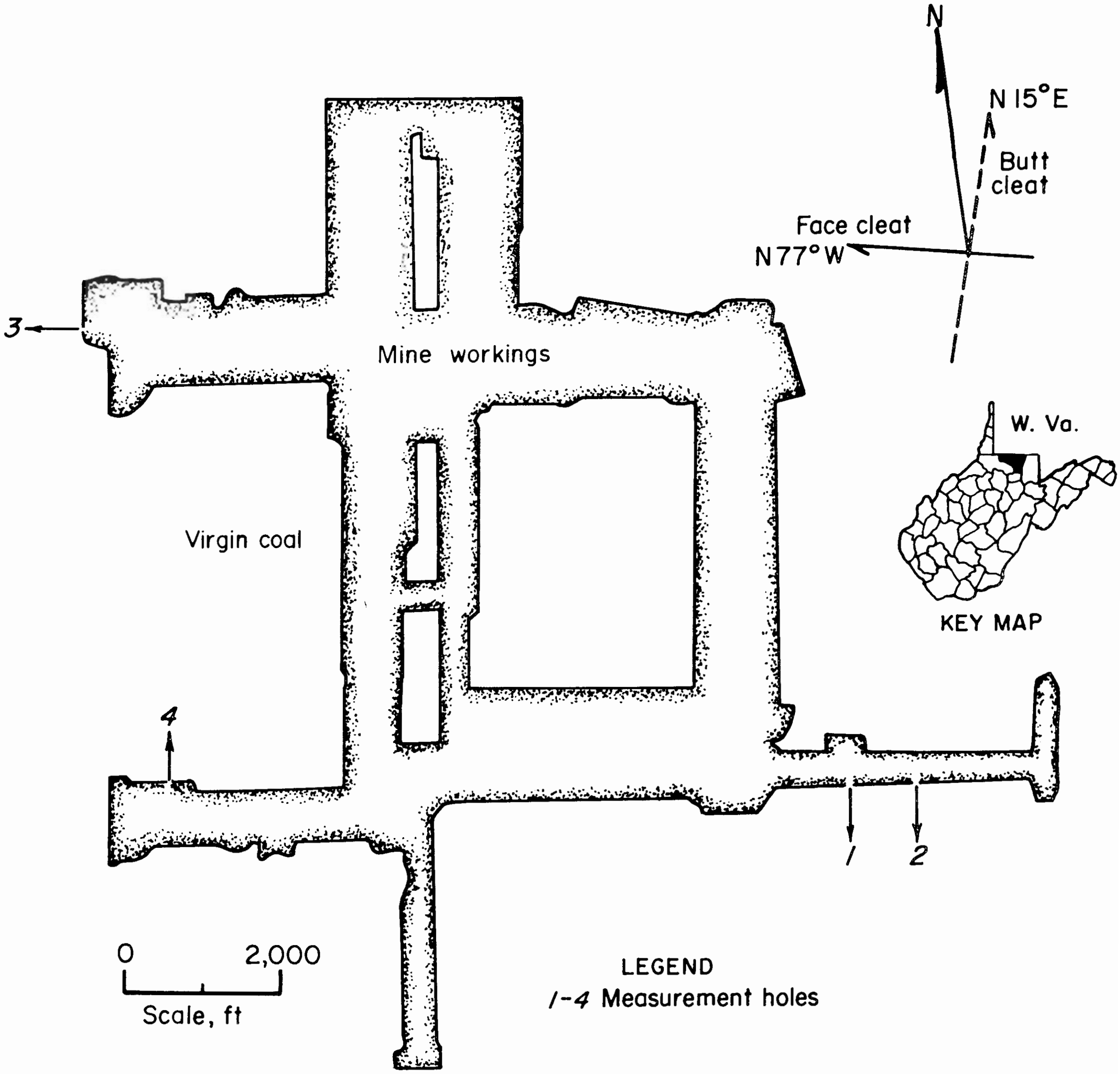


FIGURE 11. - Map of Federal No. 2 mine showing horizontal pressure measurement holes.

fourth parallel to it. These holes were all drilled to different depths into the coal and at different time intervals following mining. Figure 11 shows the relative position of these holes to the cleat directions.

Hole 1 was drilled perpendicular to the face cleat 75 days after the entry was mined; pressures of 16 psi at the 40-foot horizontal depth and 19.4 psi at the 78-foot depth were measured.

Hole 2, also drilled perpendicular to the face cleat 18 days after the entry was mined, had a pressure of 62 psi at the 49-foot depth and 74 psi at the 69-foot depth.

Hole 3, drilled parallel to the face cleat 15 days after the entry was mined, showed a pressure of 9.5 psi at 43 feet and a pressure of 27 psi at 113 feet.

Hole 4 was drilled perpendicular to the face cleat 60 days after the entry was mined. Pressures of 11.6 psi at the 40-foot depth and 21.1 psi at the 100-foot depth were measured.

Considering the age of the entries it is evident that hole 3, drilled parallel to the face cleat, developed the lowest pressure gradient as a consequence of a higher gas flow rate. The pressures measured in hole 3 were comparable with those measured in hole 4, which was 45 days older and had a longer time to flow and to desorb the coal (21). This again is a good example of the effects of directional permeability.

Near the Federal No. 2 mine, a multipurpose borehole has been driven vertically to the Pittsburgh coalbed. Holes were drilled radially into the coalbed at the bottom of the hole. Again the same correlation was found, in that the holes drilled parallel to the face cleat showed the lowest permeability, while those drilled parallel to the butt cleat had the highest permeability and gas flow. Figure 12 shows a drawing of the multipurpose borehole and the radiating holes; also shown are the face and butt cleats directions. Table 2 shows the individual data on the horizontal holes as taken from a report by Fields (7).

TABLE 2. - Initial data on the seven degasification holes (7)

Hole[1]	1	2	4	5	6	7	8	Total
Length..........ft..	646	850	549	500	616	608	556	4,325
Gas emission..........1,000 cfd..	201	257	159	171	104	79	150	1,121
Gas flow per square foot of coal surface in holes.......cfd..	396	385	369	435	215	166	344	2,310
Angle of hole with respect to face cleat..........deg..	83.5	28	35	61	12	28.5	59	-
Distance from gas well........ft..	-	180	160-400	130-370	300	-	-	-
Average water discharge......gpm..	6.5	6.8	5.6	8.0	5.0	5.0	6.2	43.1
In situ gas pressure at 199-ft depth..........psi..	-	-	-	-	-	-	-	203

[1] Figure 12.

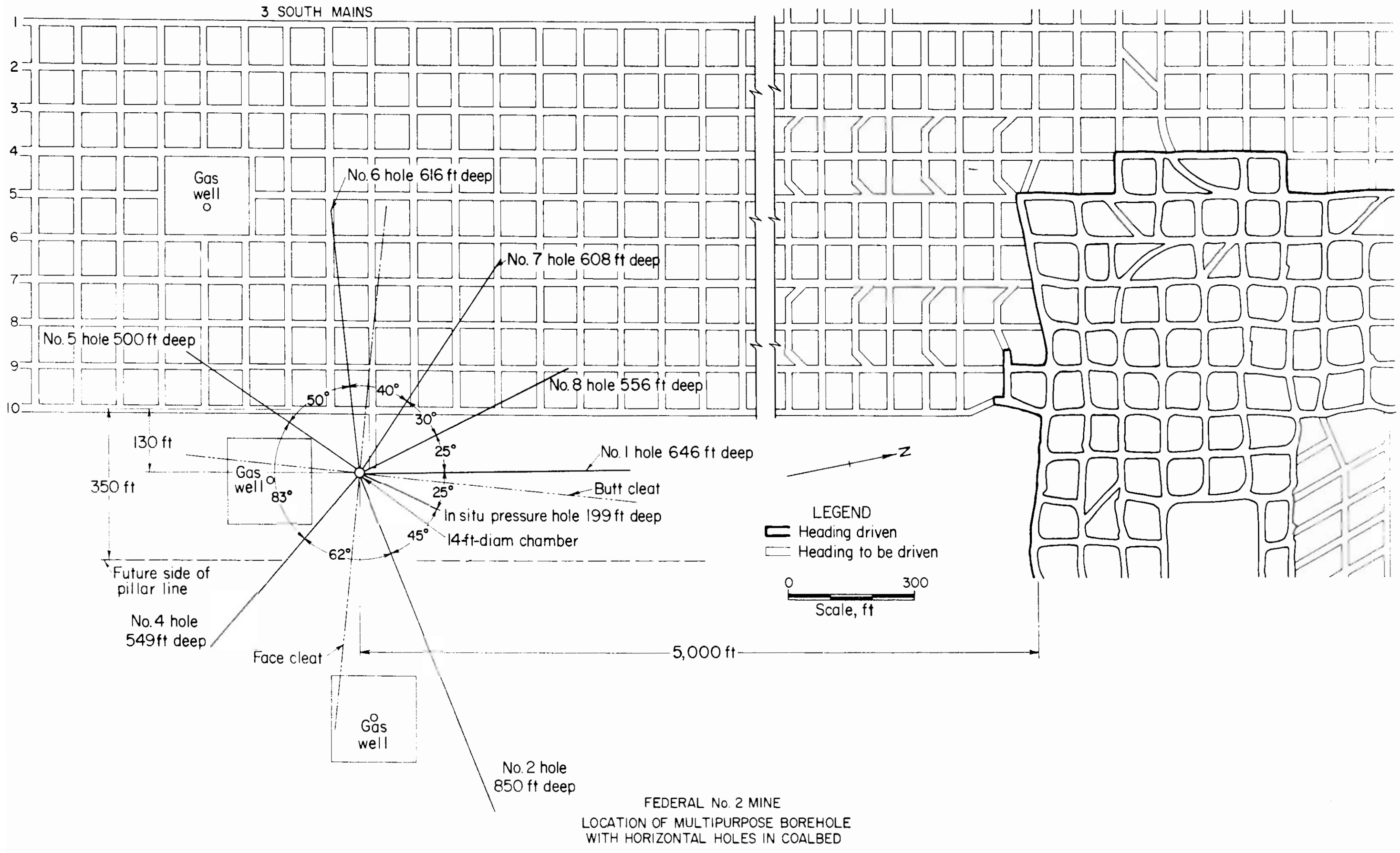


FIGURE 12. - Location of bleeder holes and gas wells in multipurpose shaft.

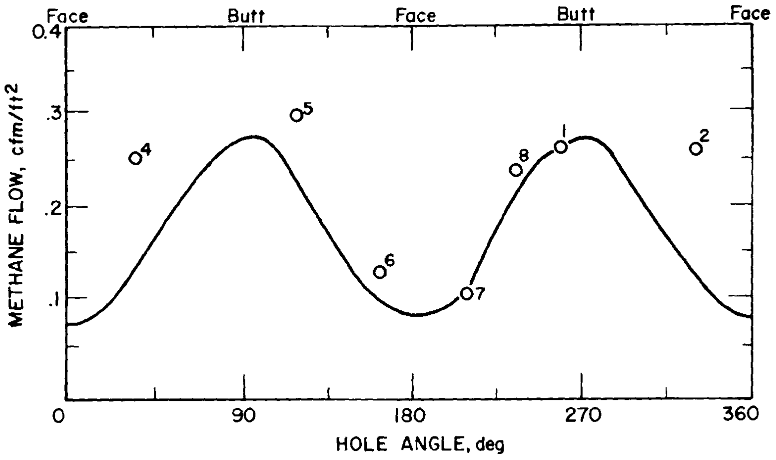


FIGURE 13. - Initial gas flow rates from horizontal holes drilled in virgin coal.

Figure 13 shows the "calculated trend curve of initial gas emission rates from the degasification holes." Holes 6 and 7 which are more nearly parallel to the face cleat (therefore intercepting butt cleats), have the lowest methane flow, whereas the holes drilled subparallel to the butt cleat--1 and 5, for example--have much higher gas flow.

Figure 13 shows the effects of directional permeability on the flow (35) where the maximum flow is from holes drilled along the butt cleats (butt) and perpendicular to the face cleats (face). Also it is pointed out that gas wells in the area have an effect on the gas flow; quoting from reference 35, "however, since boreholes that pass near wells may have flow rates above the predicted values, it is not surprising to find that the initial flow rates from holes 2 and 4 were approximately twice as high as those to be expected. Furthermore, comparing the flows from holes 4 and 7 (two diametrically opposed holes), it can be seen that the flow from hole 4, which passes near a gas well, was about 2.5 times higher than that from hole 7, which does not pass near a well."

CONCLUSIONS

Cleat in the bituminous coalbeds studied is formed by local structural forces rather than by internal forces within the coal such as result during diagenesis and compaction. The face cleats tend to be perpendicular to the axial trend of the folds and probably formed as extension fractures. The butt cleats tend to be parallel to the axial trend and formed after compressive forces were released.

The authors' research supports the view that in the Pittsburgh coalbed the orientation of the cleat structure shows an axial rotation perpendicular to the Allegheny front. There are some anomalies but these can readily be explained by showing relationships to local structural variations.

Studies of cleat orientations in mines other than in the Pittsburgh coalbed as far away as central Pennsylvania, Oklahoma, Virginia, and Utah show the importance of local structural control on the orientation of cleats with the same general dependence of face cleat and butt cleats to the axial trend of folds.

The directional permeability of coal is due to the orientation and magnitude of the cleat planes, which control the flow of water and gas through the coalbed. A hole drilled perpendicular to the face cleat produces 2.5 to 10 times as much gas as one drilled perpendicular to the butt cleat.

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APPENDIX.--GLOSSARY OF TERMS

1. Bedding plane--A planar or nearly planar bedding surface that visibly separates each successive layer of stratified rock (of the same or different lithology) from its preceding or following layer.

2. Butt cleat--A short, poorly defined cleavage plane in a coal seam usually at right angles with the face cleat and sometime terminating against it.

3. Cleat--In coal seams, a joint or system of joints along which the coal fractures. There are usually two cleat systems developed perpendicular to each other.

4. Desiccation--A complete or nearly complete drying out or drying up, or a deprivation of moisture or of water not chemically combined.

5. Dip--The angle at which a structure or any planar feature is inclined from the horizontal. The dip is at a right angle to the strike.

6. Extension fracture--Fracture that forms parallel to a compressive force. In a sense this is a tension fracture.

7. Face cleat--A well-defined joint or cleavage plane in a coal seam. The major joint in a coal seam.

8. Fissure--An extensive crack, break, or fracture in rocks.

9. Joints--Fractures in rock, generally more or less vertical or transverse to bedding, along which no appreciable movement has occurred.

10. Pore pressure--The hydrostatic pressure of the water in the pore space of a soil or rock.

11. Rank of coal--A generalized classification of coals according to their degree of metamorphism, or progressive alteration, in the natural series from lignite to anthracite.

12. Release fractures--Fractures that form perpendicular to the greatest principle stress axis. The assumption is that these fractures form when the load is removed, hence their name.

13. Rosette diagram--Circular or semicircular diagram for plotting strikes (or dips) of planar features, such as joints and cleats.

14. Shear fracture--A fracture that results from opposed stresses that tend to displace one part of a rock mass past the adjacent part.

15. Stereographic analysis--(Schmidt Net) A coordinate system used in structural geology for statistical analysis of planar orientation data.

16. Strike--The direction of the trace of an inclined bed of planar structure projected to a horizontal plane. It is perpendicular to the direction of the dip.

17. Tectonic forces--The forces involved in deformation of the earth's crust resulting in folding and faulting.

18. Tension fracture--A fracture that is the result of stresses that tend to pull material apart.