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Clay Veins: Their Occurrence, Characteristics, and Support

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UNITED STATES DEPARTMENT OF THE INTERIOR

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

ft	feet	m	meter
in	inch	pct	percent
in/d	inch per day		

CLAY VEINS: THEIR OCCURRENCE, CHARACTERISTICS, AND SUPPORT

By Frank E. Chase[1] and James P. Ulery[1]

ABSTRACT

Clay veins found in coal mines have caused numerous injuries and fatalities. These structures plague all phases of mining, including entry development, pillar recovery, and panel extraction. Clay veins also increase production costs and may disrupt or halt mining. These detrimental aspects have prompted the Bureau of Mines to investigate the physical characteristics of and roof instability problems associated with clay veins. This was accomplished by observing and mapping clay veins in surface and underground mines.

The occurrence and origins of clay veins were also investigated to determine predictive capabilities. The investigators found that clay veins normally occur in more stable, less rapidly subsiding coal basins. Clay veins result when tensile stresses develop fissures which are later infilled. These fissures can be propagated by compactional processes and/or tectonic stresses active during and subsequent to coalification.

The Bureau also found that associated faults, fractures, and slickenside planes commonly parallel clay veins and disrupt the lateral continuity of the immediate and, sometimes, main roof. When clay veins parallel or subparallel the direction of face advance, the roof is segmented into cantilever beams, causing unstable conditions. Consequently, the strata on either side of the clay veins should be bolted and strapped together to form a beam.

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[1] Geologist, Pittsburgh Research Center, Bureau of Mines, Pittsburgh, PA.

INTRODUCTION

Accidental roof falls continue to be a major cause of injuries and fatalities in underground coal mines (26).[2] The Bureau of Mines, in keeping with its goal of promoting a safer work environment, has conducted several in-mine investigations to determine the geologic structures and conditions responsible for accidental roof falls. These studies have confirmed that many roof falls can be correlated with specific geologic features. Moreover, the Bureau's investigations have enabled limited prediction of occurrences of these hazardous geologic features in unmined portions of the coalbed.

Previous studies have indicated that clay veins (also referred to as clay dikes, horsebacks, or mudslips)[3] were formed by either compactional processes or tectonic stresses. Occurrence information collected during this investigation seems to confirm both theories. Furthermore, since clay veins are actually infilled fissures, the authors contend that any compactional process or ground stress capable of developing a fissure, or fracture that can later widen, can result in the formation of a clay vein.

CLAY VEIN ORIGINS

Clay veins are infilled fissures. These fissures developed when tensile stresses ruptured the coal and adjacent sediments during or after the coalification process. Previous studies have indicated that the fissures responsible for clay vein formation can be propagated by compactional processes and/or tectonic (regional or mountain-building) stresses active during and subsequent to coalification. Theories advocating compaction suggest that the fissures resulted from the unequal shrinkage of peat (24) or from differential compaction (4, 30). Proponents for a tectonic origin include McCulloch (14), Price (22), and Smith (25). Other investigators, including Gresley (7), and Oldham (19), have attributed fissures to earthquake disturbances, which are often related to tectonic activity.

Fissures may be infilled as a result of gravity, downward-percolating ground waters, or compactional pressures which cause unconsolidated clays or thixotropic sands to flow into the fissures. This latter (plastic-flow) method of infilling occurred in the Upper Freeport Coalbed in Garrett County, MD, where high compressive stresses have pressure-injected unconsolidated underclays into fissures associated with floor heave. Some of the fissures intersect coal ribs, forming mining-induced clay veins.

CLAY VEIN OCCURRENCES

Clay veins occur in the United States, the United Kingdom, Czechoslovakia, New Zealand, and elsewhere. This investigation was limited to the eastern United States (fig. 1) and includes portions of the Arkoma, Illinois, Northern and Southern Appalachian, and Warrior Coal Basins. The information shown in figure 1 was compiled by Bureau personnel based on mine observations. Other clay vein occurrence information was obtained from the Mine Safety and Health Administration (MSHA), State enforcement agencies, State

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

[3] Although sedimentary dike or clastic dike is the more exact geologic term for an approximately vertical, tabular, sedimentary infilled discontinuity, the term "clay vein" is used here because it is firmly established in the coalfields that have the greatest incidence of related injuries and fatalities.

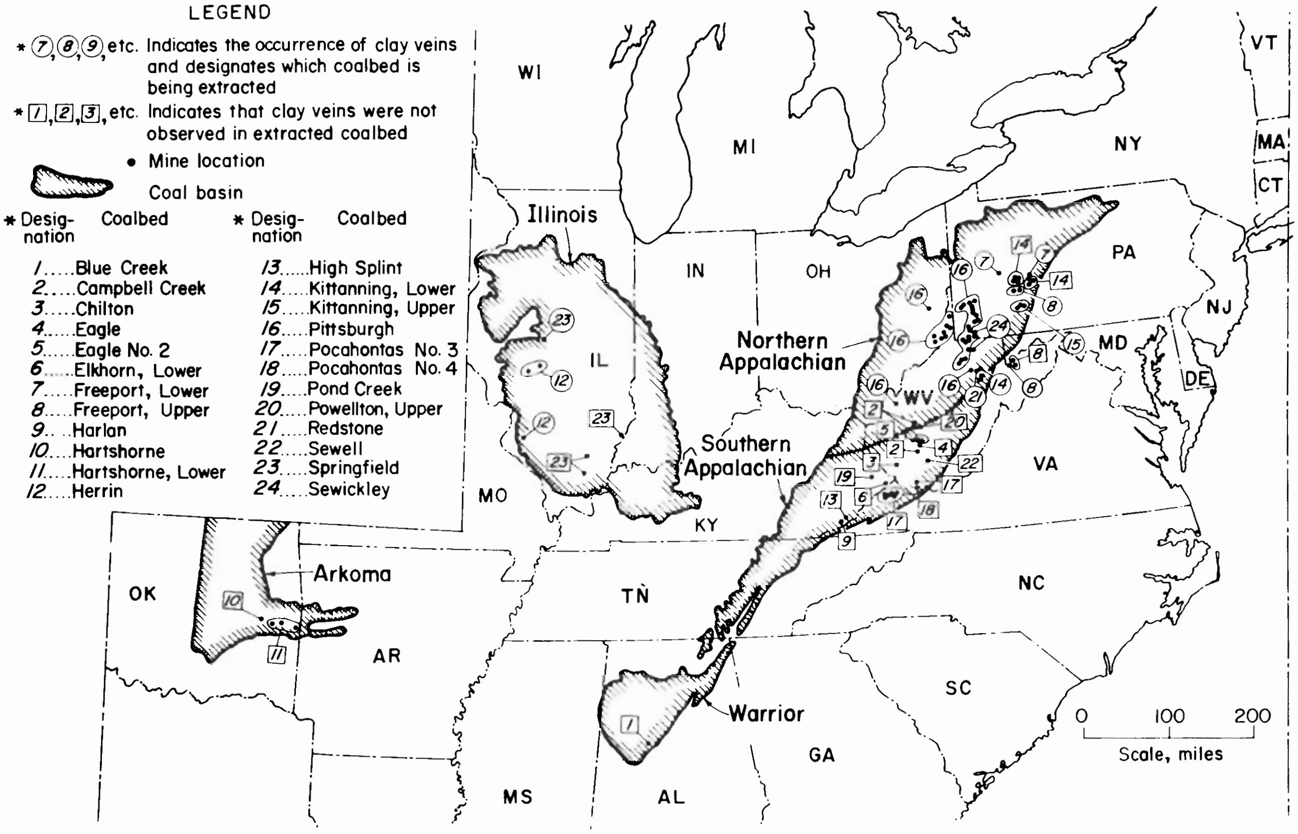


FIGURE 1.—Clay vein occurrence map for the Eastern United States, after McNeal (15).

geological surveys, and mine personnel throughout the eastern and central United States.

Distribution data indicate that clay veins commonly occur with varying frequency in the Illinois and Northern Appalachian Coal Basins (fig. 1). The immediate and main roofs above coalbeds containing clay veins were deposited in various marine and nonmarine environments. Individual roof rock types containing clay veins include thin, massive, or interbedded limestones, mudstones, sandstones, shales, and siltstones; however, clay veins occur less frequently under massive sandstone units.

DEPOSITIONAL SETTING AND INTERPRETATIONS

Depositional conditions in the investigated portions of the Illinois and Northern Appalachian Basins were similar in that both basins were deposited on more stable (less rapidly subsiding) platforms with correspondingly slower rates of sediment influx (9, 27). Clay veins are rarely encountered in the Arkoma, Southern Appalachian, and Warrior Basins. Investigated areas in these basins were deposited on less stable (more rapidly subsiding) platforms with correspondingly faster rates of sediment influx (9, 13, 28). From a depositional point of view, these conditions are optimal for the widespread preservation of fossilized trees kettlebottoms). This is consistnt with information the Bureau has collected in the Southern Appalachian and Warrior Basins.

Depositional conditions in less stable basins were also responsible for similar roof rock types being stacked one above the other, as is the case in southern West Virginia where facies prograde slowly (8). Overall, less differential compaction or deformation occurs when the same type of roof rock is stacked vertically (3). Conversely, rock types prograde rapidly in northern West Virginia where the basin is more stable (8). These conditions are conducive to offset rather than vertical stacking, and consequently, more differential compaction occurs (3).

The type of sediments involved also determines how much differential compaction occurs during lithification (10). In southern West Virginia, where clay veins are rare, sandstone is more abundant than shale (5). The opposite is true in northern West Virginia (21). During lithification, sands are not as readily sheared and/or distorted as are muds (29), which compact into shale. Increased soft sediment deformation, faulting, and fracturing associated with differential compaction during lithification may explain why clay veins occur more frequently in a more stable basin, such as northern West Virginia. In the Illinois Basin, differential compaction may also be responsible for clay veins tending to parallel boundaries between different roof rock types (17).

CLAY VEIN COMPOSITION

Sediments that infill clay veins may be derived from above and/or below the coalbed. Sediments may enter the coalbed fissure via one conduit or feeder (fig. 2) or through smaller, multiple, intersecting (branch-like) feeders (fig. 3). Clay veins are predominantly composed of claystone; however, structures infilled with sandstone, siltstone, and/or limestone do occur. Frequently, large (1 to 8 in), angular to sub-rounded fragments of the wall rock (limestone, coal, sandstone, etc.) are encompassed in the clay vein matrix. Pyrite nodules are common (17), and occasionally, secondary calcite and quartz mineralization occurs within clay veins.

The type of sediments which infills a clay vein may affect mining conditions. Water from continuous miner spraying systems sometimes softens and weathers the claystone matrix of clay veins, causing roof spalling, which continues until adequate support is employed. Mining through structures composed of hard sandstone or siltstone is more troublesome. Typically, roof vibration is severe, and miner bits shear constantly. Frictional heat and/or sparks generated while mining through these harder structures have caused numerous face ignitions. Abnormally high methane emissions often occur when mining through clay veins because these structures act as natural barriers or dams to free gas flow (23).

COALBED AND ROOF ROCK CHARACTERISTICS

Most clay veins have a zigzag appearance, as if the coalbed were pulled apart (fig. 2); others have V- or U-shaped configurations. A clay vein's geometry and cross-sectional width often change along its trend or strike. Marked variations in shape and size are commonly observed on adjacent ribs. Clay veins observed underground ranged from less than 0.1 to 16 ft in width where they entered the coalbed. The lengths of clay veins vary from tens of feet to over 1.5 miles (16). Approximately one-third of the examined clay veins terminated in the coalbed, while the remainder penetrated through the coalbed into the floor. A convex upward bulge in the underclay is sometimes noted where clay veins penetrate the floor.

Upward and/or downward warping of coalbed and roof rock bedding planes commonly occurs on either side of a clay vein. This warping is illustrated in figure 4, which shows normally horizontal bedding planes approaching 30° dips. Bedding plane warping was measured as far away as 8 ft from the clay vein. Normally vertical coal cleat within this warped zone are also inclined. The degree and lateral extent of the zone of inclination appeared to be governed by the severity of deformation associated with the clay vein. Bedding plane and cleat disturbances were readily observable at the face and on adjacent ribs as clay veins were approached. Where present, bedding plane warping and cleat rotation indicate that the clay vein formed after cleat development.

From a support point of view, clay veins can be broken down into two categories: those with associated fracture (fig. 5), fault (fig. 6), and slickenside planes (fig. 7) in the roof, and those without these features (fig. 2). Clay veins without associated planes are normally composed of claystone or shale. These clay veins are sometimes moisture sensitive and weather rapidly. Fault, fracture, and slickenside planes associated with clay veins had dips ranging from 30° to 90° (vertical). Clay vein faults may displace adjacent portions of the coalbed up to 18 ft vertically (11). However, displacements are more commonly less than 3 ft. Fault planes are

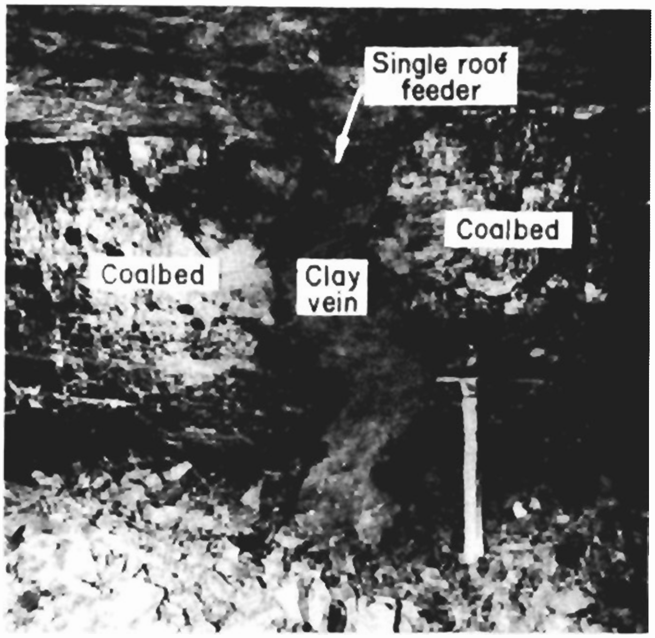


FIGURE 2.—Single-feeder clay vein (with vein outlined in black).

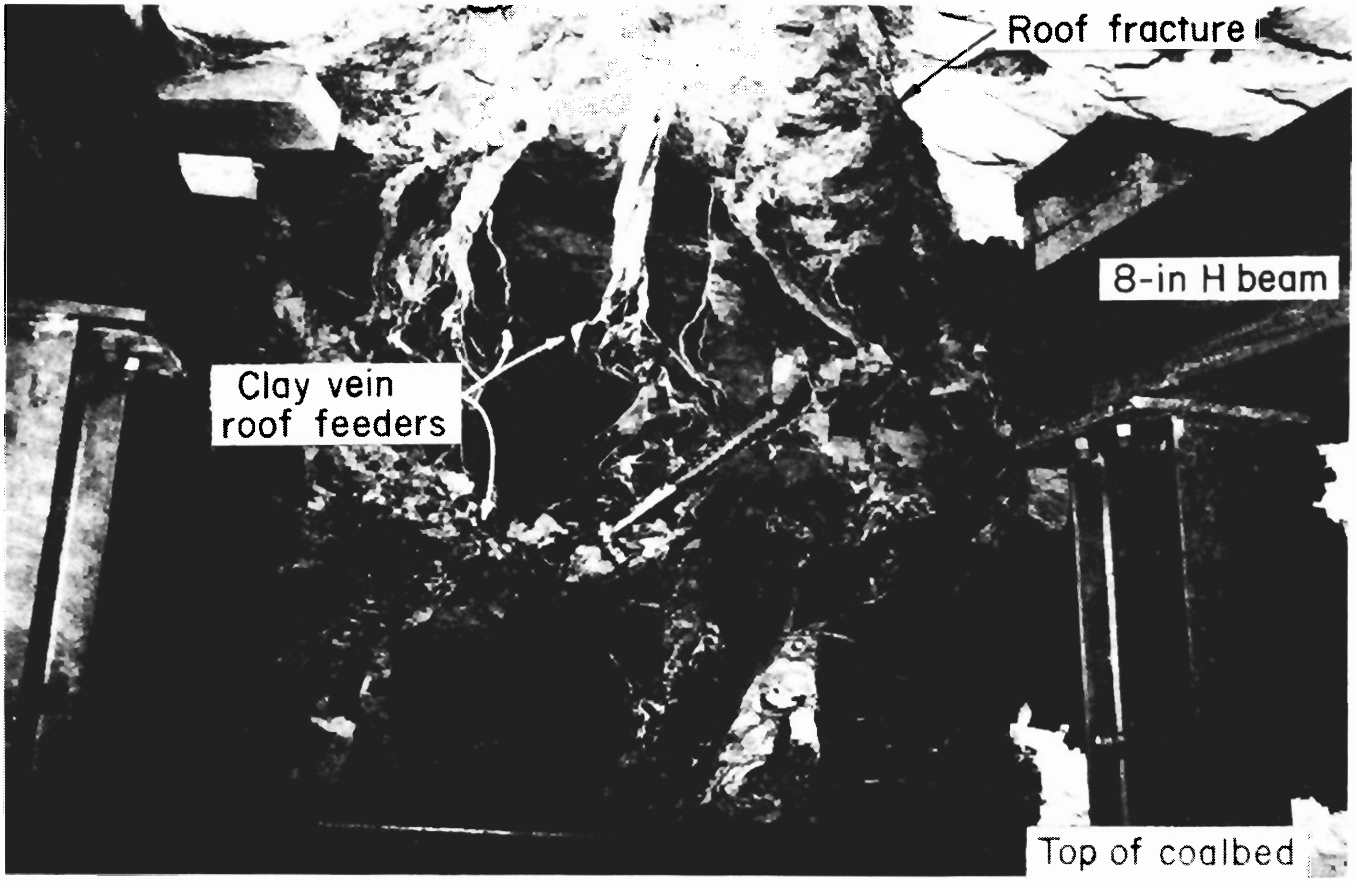


FIGURE 3.—Multiple-feeder clay vein.

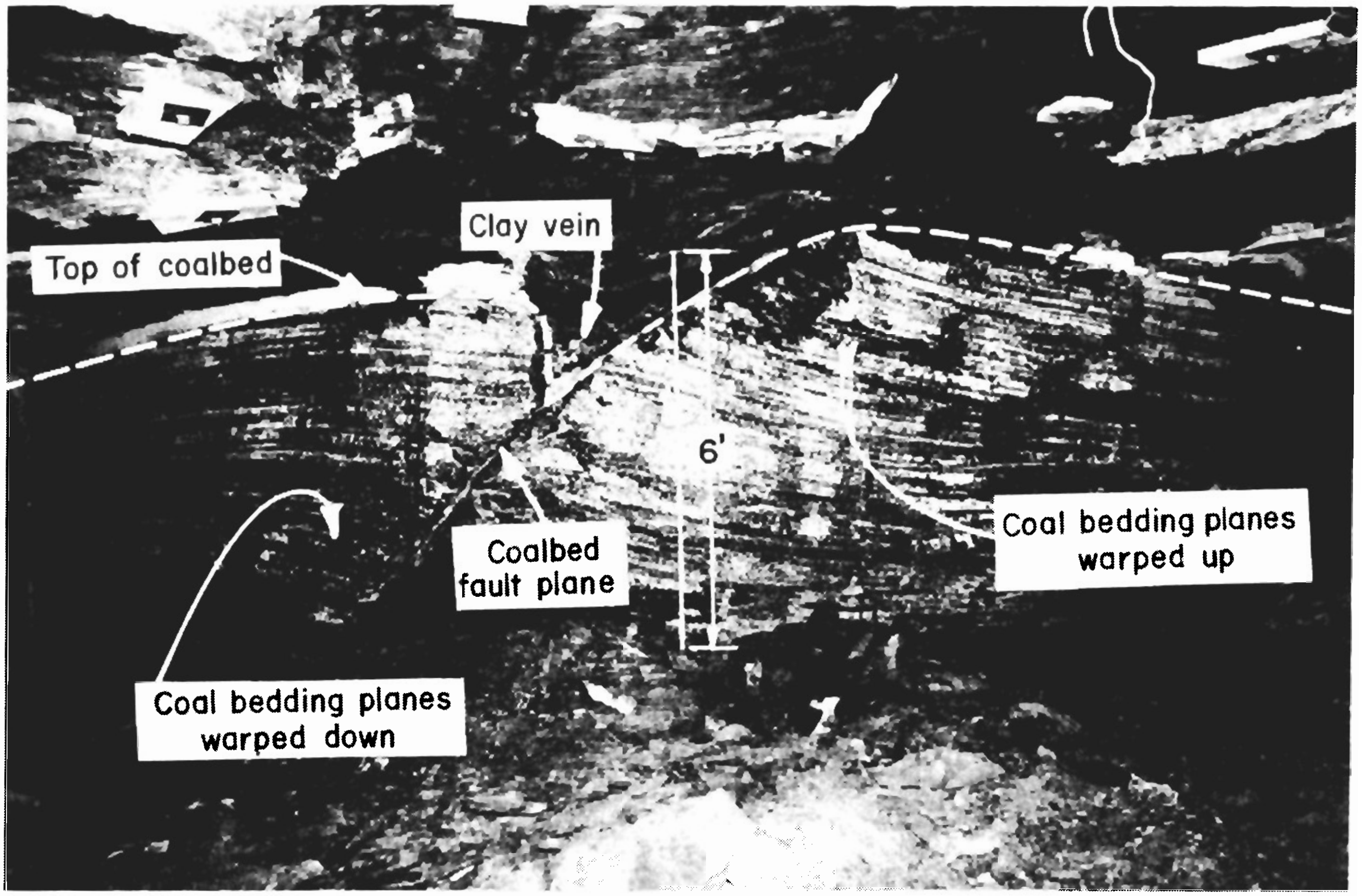


FIGURE 4.—Coalbed bedding plane warping in proximity to a clay vein.

distinguished from fracture planes, along which no detectable movement has occurred. Fault and fracture planes extending as high as 20 ft into the main roof were noted in the Springfield (also referred to as No. 5 or Harrisburg) Coalbed near Springfield, IL.

Slickensides are highly polished and striated planes of weakness. Slickensides associated with clay veins may be oriented in parallel sets or randomly. Parallel sets of intersecting slickenside planes are oriented in one of two ways, "V up" (fig. 8) or "V down." The clay vein generally occurs in the middle of the intersecting sets, as shown in figure 8. Some major slickenside planes are actually warped and striated bedding planes. When clay veins become larger, the associated slickenside planes increase in frequency and magnitude (figures 7 and 9), expanding the disturbed zone laterally. Figures 7 and 9 were taken 10 ft away from clay veins and only show the set of parallel slickenside planes on the left sides of two different "V-down" clay veins. In addition to the major planes mentioned above, minor or secondary sets of intersecting fracture and slickenside planes are associated with some clay veins (fig. 7). The cumulative effect of all fracture sets is a loose and fragmented roof.

ROOF SUPPORT

Clay veins with associated fault, fracture, and slickenside planes disrupt the lateral continuity of the immediate and, sometimes, main roof. Where the clay vein's strike is parallel or subparallel to the face, the clay vein divides the roof slab into parallel beams. However, where the strike parallels or

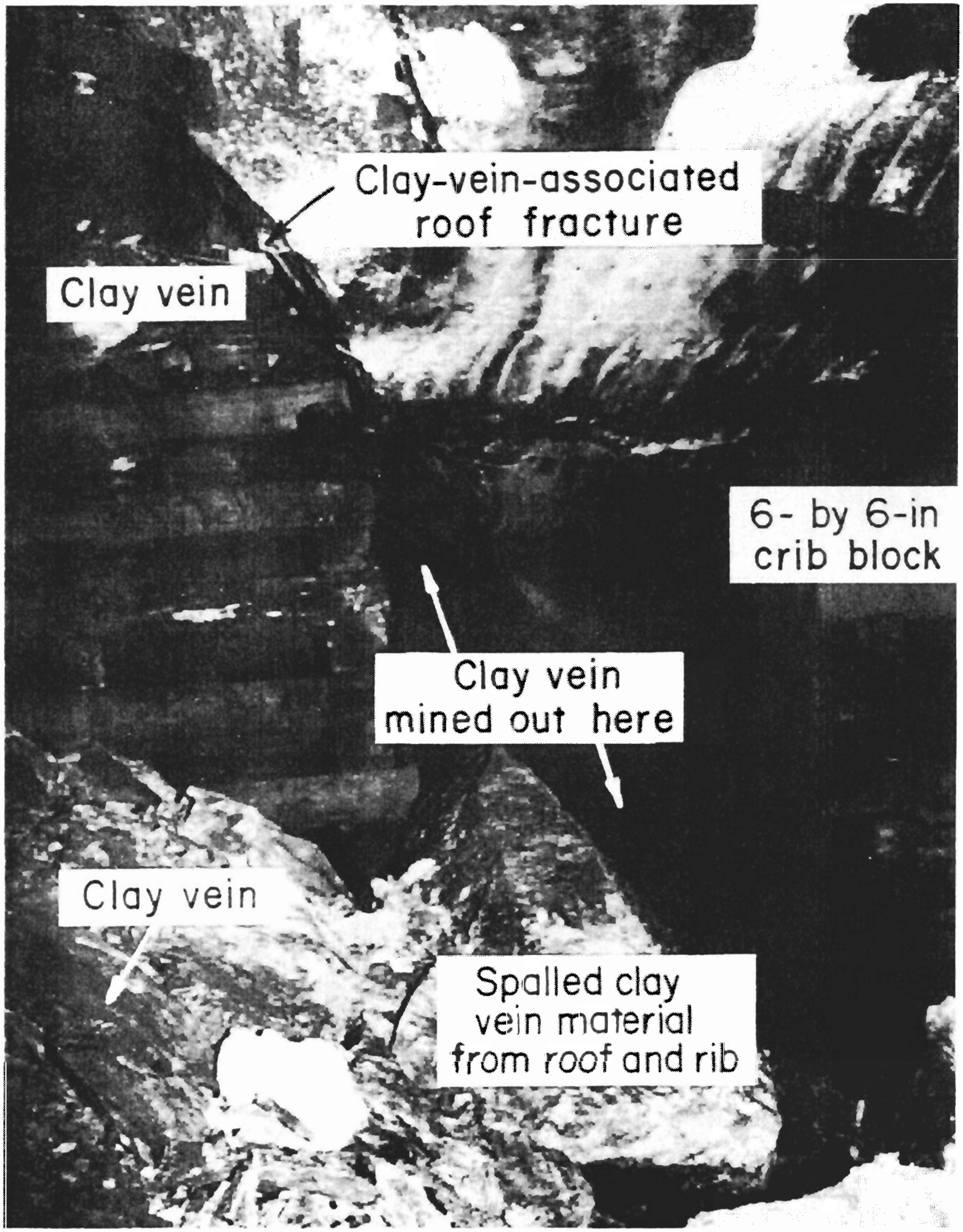


FIGURE 5.—Clay-vein-associated fracture plane.

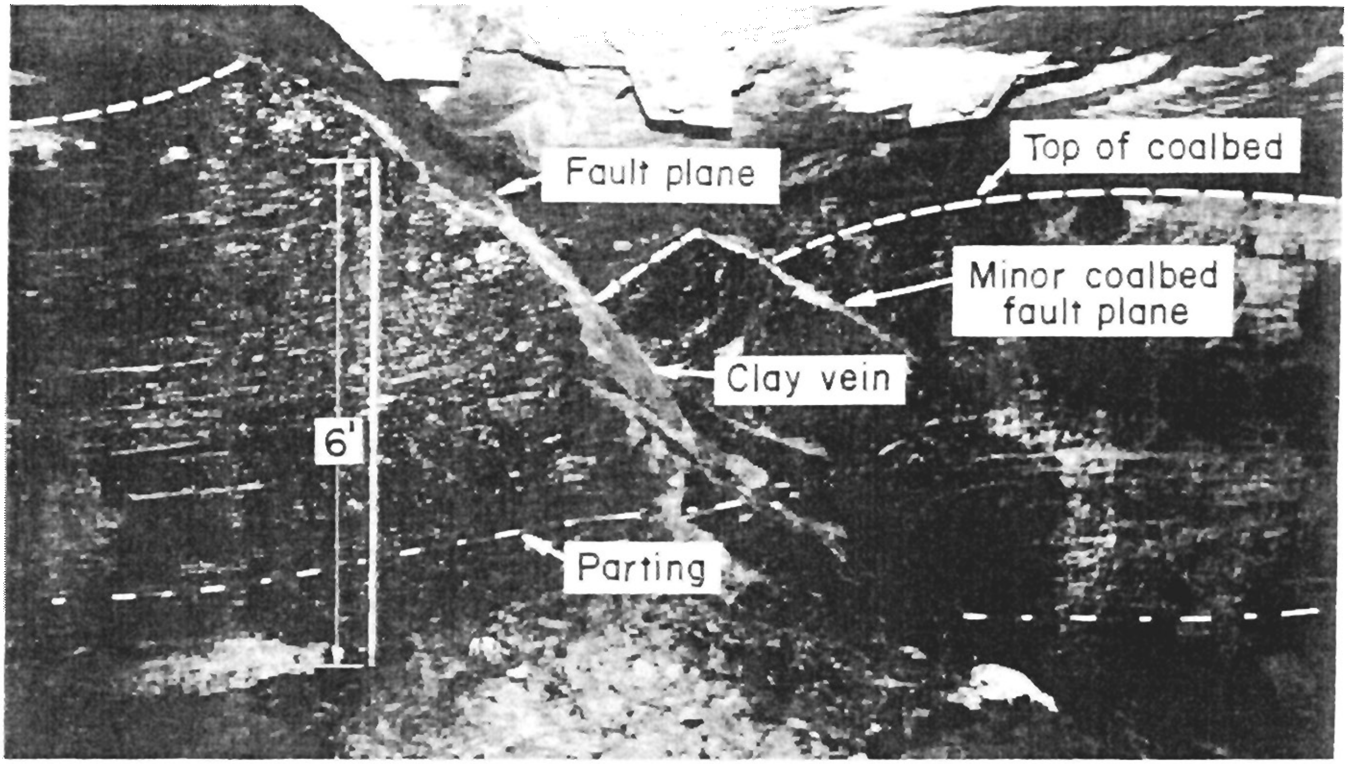


FIGURE 6.—Clay-vein-related fault plane.

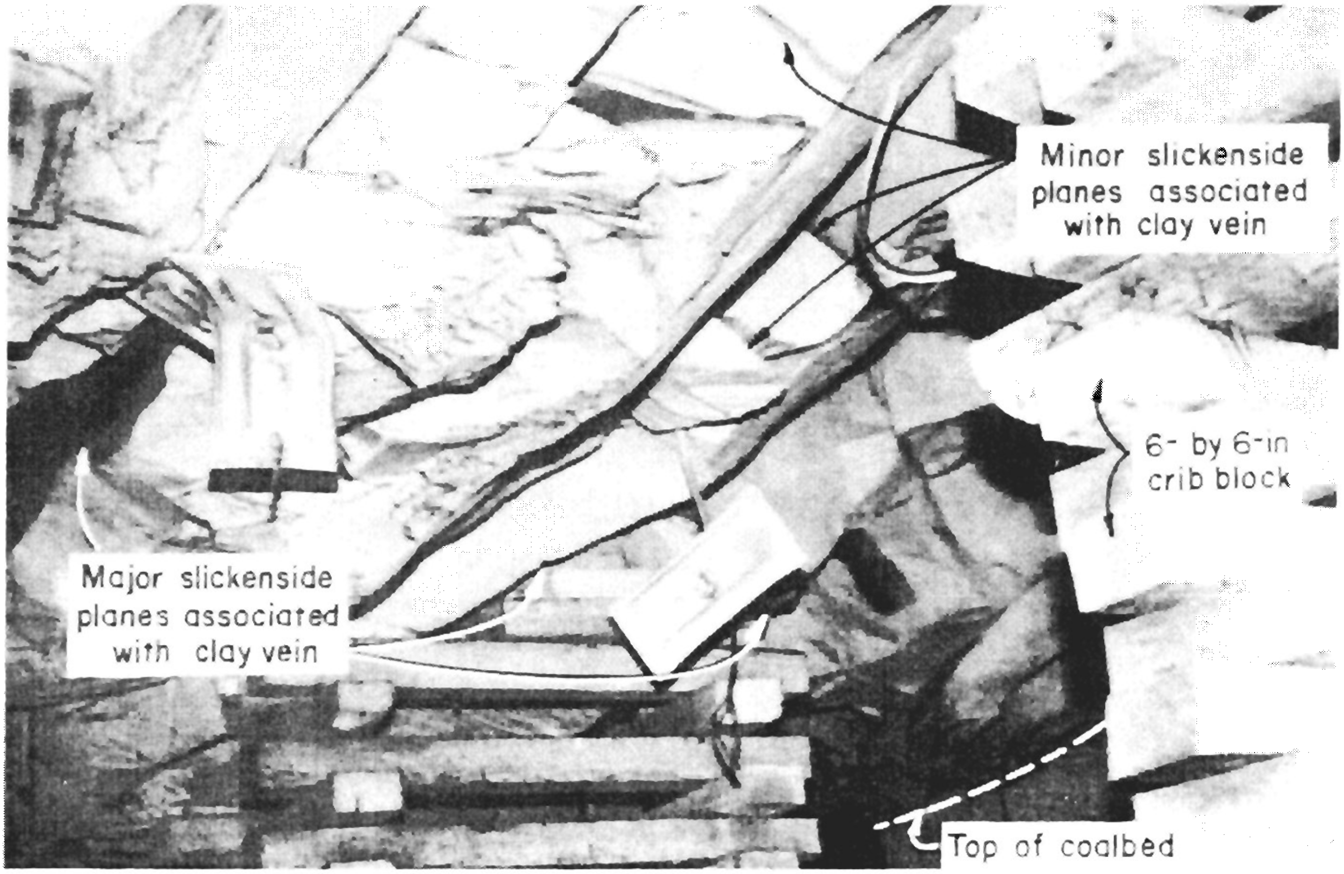


FIGURE 7.—Major and minor slickenside plane sets associated with a large clay vein.

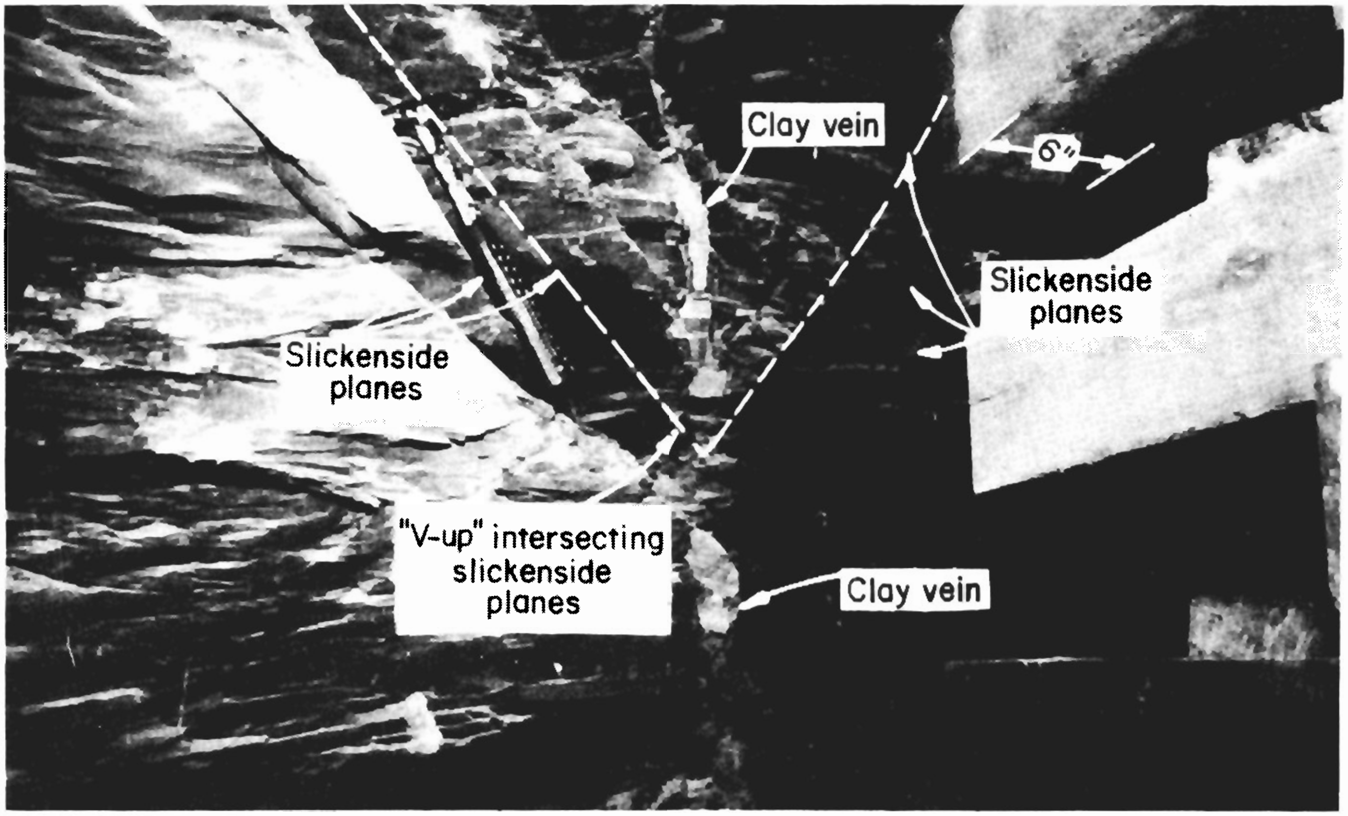


FIGURE 8.—Clay-vein-associated slickenside plane sets displaying a "V-up" pattern.

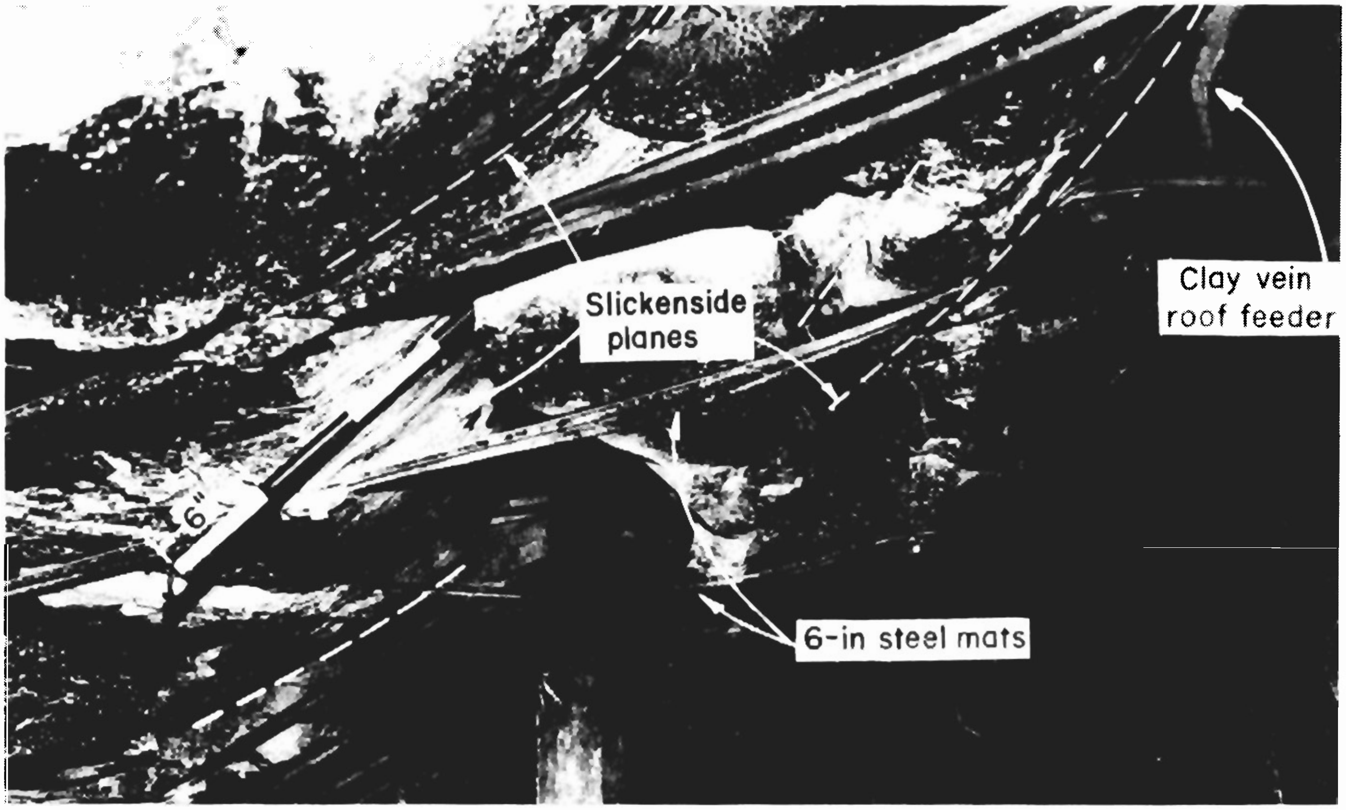


FIGURE 9.—Steel mats effectively controlling fragmented clay vein roof with slickensides.

subparallels the direction of face advance, the roof slab is divided into one or two cantilever beams. One cantilever beam occurs if the clay vein coincides with or runs along the rib line, as shown in figure 10. Two cantilever beams are formed when the clay vein occurs within the entry or crosscut as in figures 5 and 11A. To determine if there is a correlation between roof stability and a clay vein's strike with respect to the direction of face advance, 471 clay vein segments were analyzed in a mine operating in the Upper Kittanning Coalbed in southwestern Pennsylvania. Observations were categorized as follows: (1) clay veins striking parallel to subparallel to the direction of face advance (0° to 30°), (2) clay veins striking subperpendicular to perpendicular to face advance (61° to 90°), and (3) clay veins striking intermediately (31° to 60°). An analysis of the data in table 1 indicates a direct correlation between roof stability and a clay vein's strike, corroborating the above mentioned beam theories.

The cantilever effect often associated with clay veins can sometimes be corrected by bolting and strapping the roof on each side of the major fault or fracture plane together to construct a beam. Mine personnel should be aware of the plane's orientation (strike and dip) so they can determine the proper bolt length and angle of installation (fig. 11). The orientation of major fracture or fault planes may be hidden in the roof prior to spalling. However, in certain cases, examination of the clay vein material in the coalbed reveals one or more smaller parallel fault or shear planes (fig. 6). Observations indicate that these smaller coalbed fault or shear planes can be used to approximate the orientation of the major fault or fracture planes in the roof.

Whether or not a beam can be built in highly fractured rock with multiple intersecting major and minor slickenside planes is debatable. Some operators and roof control specialists believe that the fragmented rock mass must be suspended or keyed to insure stability. Under controlled laboratory conditions, highly fractured rock can be stabilized, provided the fragments are compacted by vibration and confined laterally in boxes until bolted (12). Unfortunately, underground conditions do not afford these amenities, and quite commonly, the fragmented roof sometimes associated with clay veins sags and unravels (spalls) prior to and subsequent to bolting.

Rates of convergence beneath clay veins can sometimes be useful in predicting roof stability. For example, ground control personnel in a central Illinois mine monitor convergence beneath potentially hazardous clay veins located along the track, belt, and other critical areas. When sag rates exceed 0.2 in/d, past experience suggests an impending fall, and additional supplemental support is immediately installed. Rates equaling 1.1 in/d have been recorded beneath clay veins prior to roof failure in this mine.

Tensioned bolts help compress a loose fragmented roof with slickensides into a somewhat competent unit (6). Mechanical bolts can be used, provided they are anchored out of the disturbed clay vein zone in competent strata. However, delimiting the disturbed zone both vertically and horizontally immediately after mining is often difficult. Where mechanical bolts are anchored into clay veins composed of incompetent claystones or highly fractured shales with internal

TABLE 1. - Roof instability associated with different clay vein strikes

Strike of clay vein with respect to direction of face advance	Total observations	Roof falls requiring cleanup	
		Number	Pct of total observations
Parallel to subparallel (0°-30°).........	141	63	47
Intermediate (31°-60°)..................	173	15	9
Subperpendicular to perpendicular (61°-90°)..............................	157	12	8

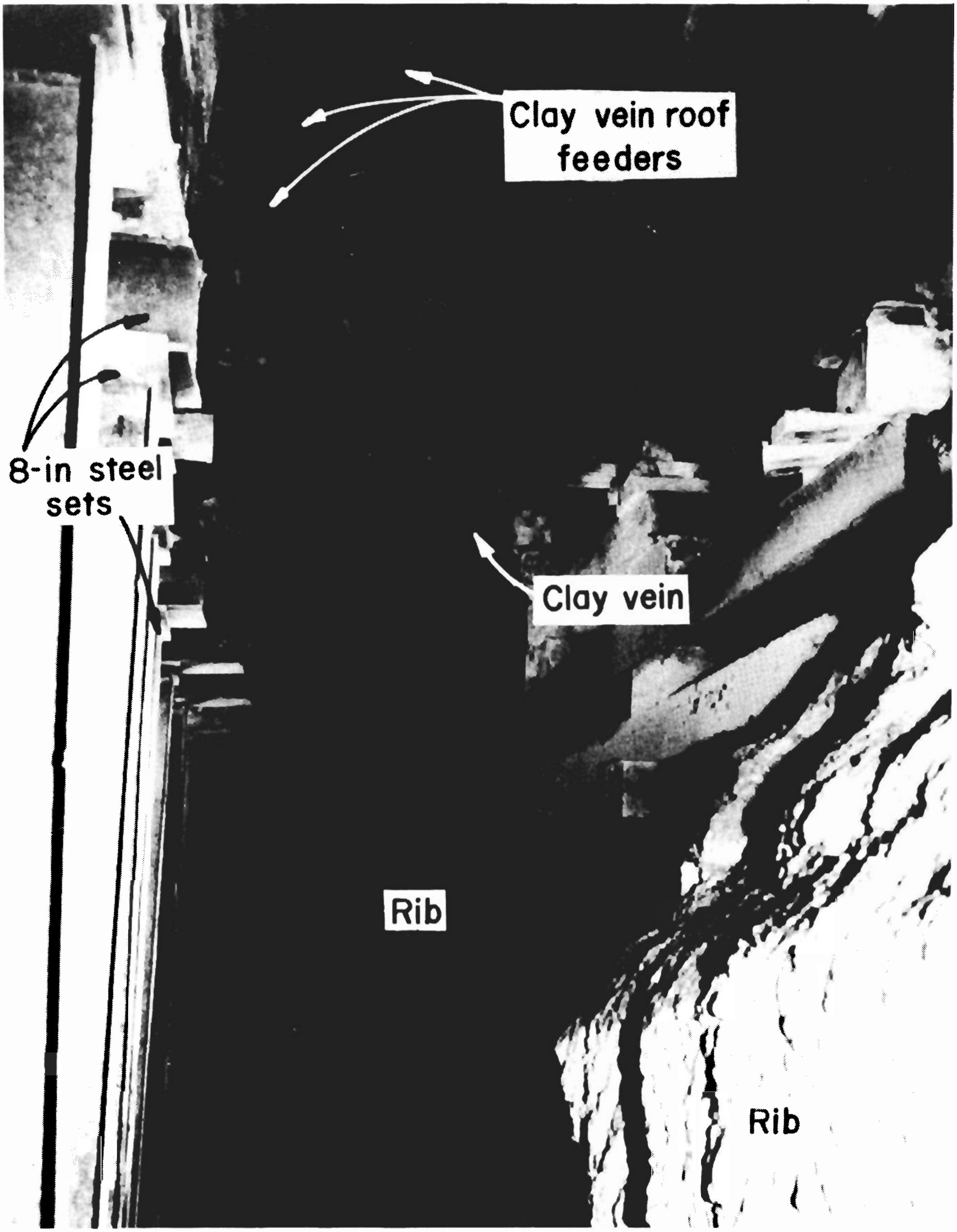
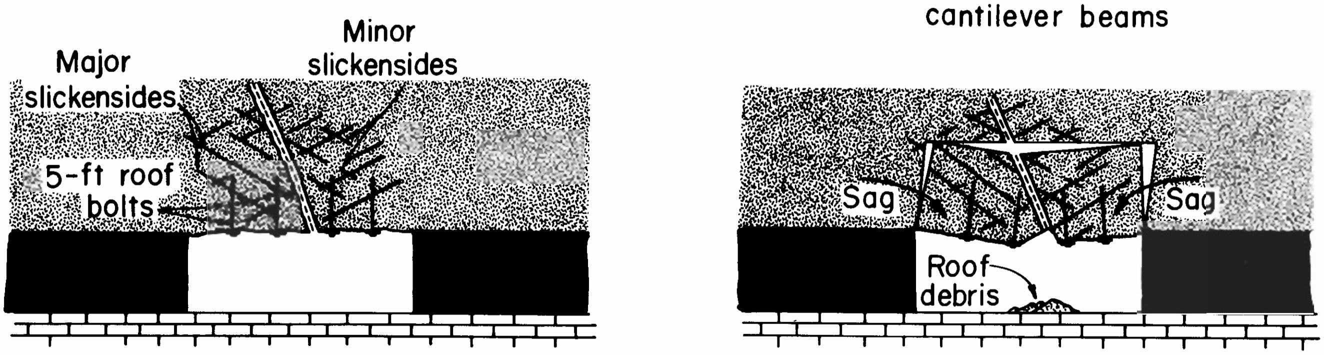


FIGURE 10.—Rib-line clay vein.



A Ineffective bolting

B Roof behaves as independent cantilever beams

C Beam built by using longer roof bolt and mat

D Beam built by using angled roof bolt and mat

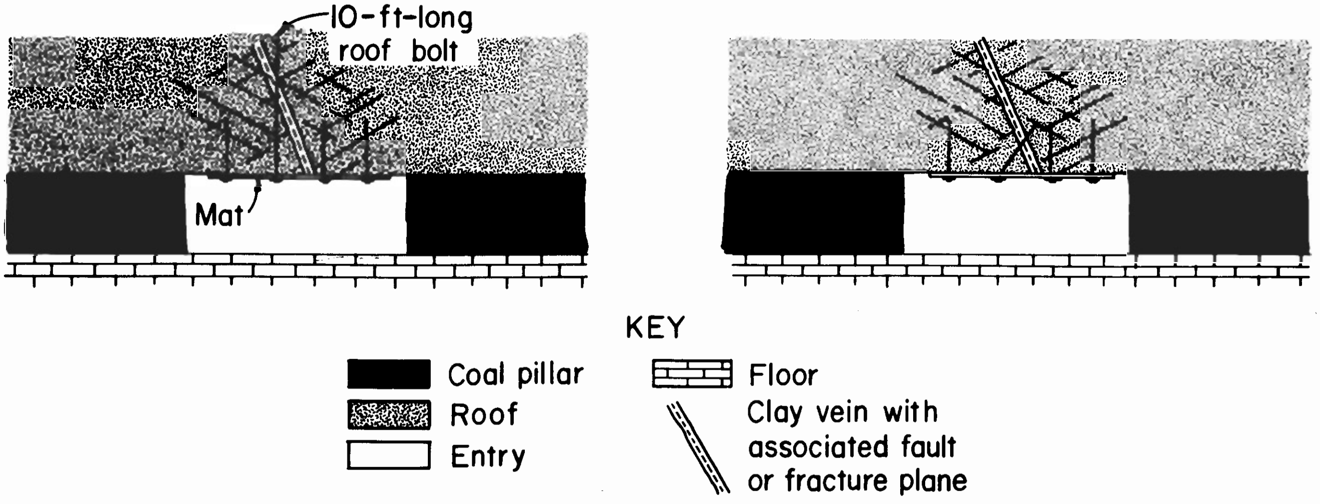


FIGURE 11.—Clay-vein-associated fracture and fault plane bolting diagrams.

planes of weakness, stress concentrations at the anchor may crush or break already weak or fractured rock (1). Under these conditions, excessive bleedoff or an inability to attain or maintain required torque values may be a signal that longer bolts or resin anchorage is needed. Conversely, resin-grouted bolts insure better stability in weak rock with a low anchorage capacity (2). Based on the above, tensioned point-anchor resin bolts should insure better stability in clay-vein-disturbed rock. Underground observations confirm this.

Full-column resin bolts are also effective in controlling some clay veins. Although nontensioned, fully grouted bolts eliminate problems associated with moisture along the length of the bolthole (1) and help to prevent slippage along planes by infilling fractures and voids, essentially gluing adjacent fragmented blocks. Therefore, in workings where clay veins frequently occur, the routine installation of resin grouted bolts should be considered. Since many northern West Virginia mines have converted to resin grouted bolts, the West Virginia State Department of Mines has reported fewer clay-vein-related ground control problems.

Bolts should be installed in conjunction with crossbars or steel mats immediately after undermining to help stabilize slickensides and prevent spalling. Crossbars and mats should be installed perpendicular to the clay vein's strike for maximum effectiveness. Mats should be flexible enough to conform to irregular top. Fiber-reinforced concrete also controls clay vein spalling, and roof sealants prevent moisture-sensitive clay veins from deteriorating. Pressure grouting with polyurethane binders also helps to consolidate broken strata with randomly oriented slickensides. For supporting large or hazardous clay veins like those shown in figures 10 and 12, even the best bolts prove ineffective. Physical support in the form of steel sets and/or cribbing is required. In critical entries where equipment maneuverability is a concern, roof trusses have proven very successful in controlling large or hazardous clay veins (fig. 12). When a clay vein is coincident with and runs along the rib line, cutter-type roof failure sometimes occurs. Rib-line clay veins are particularly hazardous and warrant cribbing. Where equipment maneuverability is a concern, operators have effectively angle bolted rib-line clay veins into the compression zone over pillars. If a clay vein occurs where a crosscut is being turned, turn posts should be employed until the cut is permanently supported.

PREDICTION AND MINE PLAN MODIFICATIONS

Short- and long-range predictions of clay vein occurrences can be made, depending on their origin. Clay veins resulting from tectonic stresses should display the same or a similar preferred orientation from one mine property to the next. This is because fissures or fractures resulting from tectonic stresses can form parallel (22, 31), perpendicular (22, 25), and/or at oblique angles (22, 25) to the maximum compressive principal stress, which is referred to as sigma

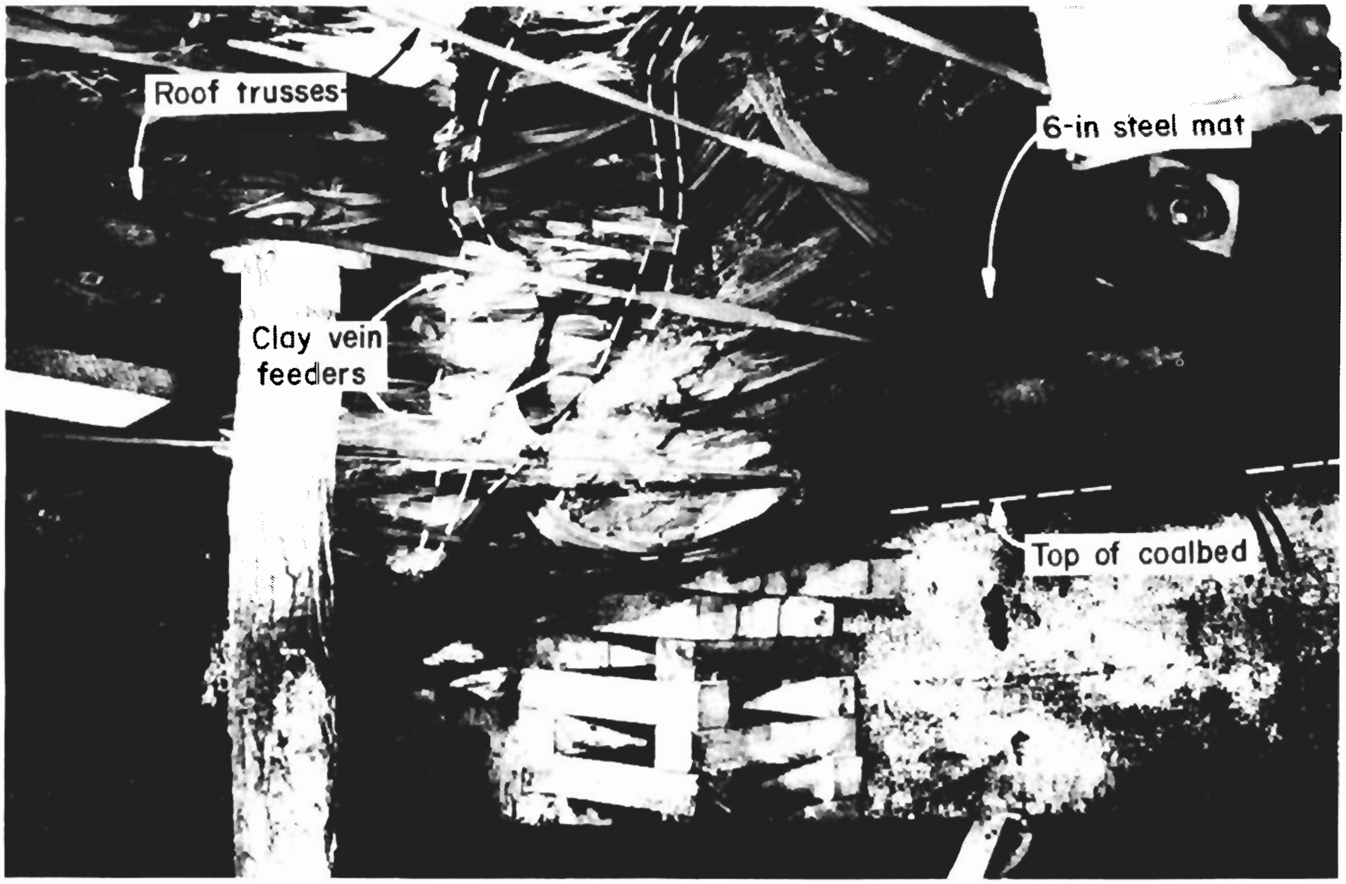


FIGURE 12.—Roof trusses effectively controlling clay-vein-disturbed roof.

one (σ_1). Therefore, clay vein distributions observed underground may be unidirectional, bidirectional, or multidirectional. To determine if the clay veins in a particular mine resulted from tectonic stresses, it is necessary to plot on a mine map the trend of every clay vein encountered. Clay veins are easily distinguished prior to rock dusting, and minimal time is required for the face boss to plot the structure's trend (orientation or strike) on a mine map. Analysis of clay vein distribution can be achieved by dividing the clay vein trends into straight-line segments and plotting the length of these segments versus their spatial orientation.

Figure 13 represents the bidirectional clay vein distribution of a particular mine site. More complicated multidirectional distributions are more easily visualized and interpreted using a 360° rose diagram (fig. 14) rather than a histogram, although some distortion does result. The 6 miles of clay vein data shown on figure 15 were mapped along the northwestern flank of the Johnstown Syncline in Somerset County, PA. The average dip encountered was 11°. Analysis of figure 14 indicates a clustering of clay veins approximately at right angles to the northeast-southwest-directed maximum compressive stress (18). This suggests that these clay veins originated as release fractures that were both formed and later widened during stress release or unloading. The clustering of clay veins at 45° to σ_1 may have originated as shear fractures which later widened during unloading. Although a certain amount of scatter about the idealized peaks is apparent in figure 14, this may be attributed to the fact that the rock mass was subjected to and fractured by at least two distinct stress fields (18). Roof control problems associated with clay veins are compounded in tectonically disturbed areas. As figure 16 illustrates, up-dip lateral shifting due to flexural slip folding often masks zones of clay-vein-disturbed roof.

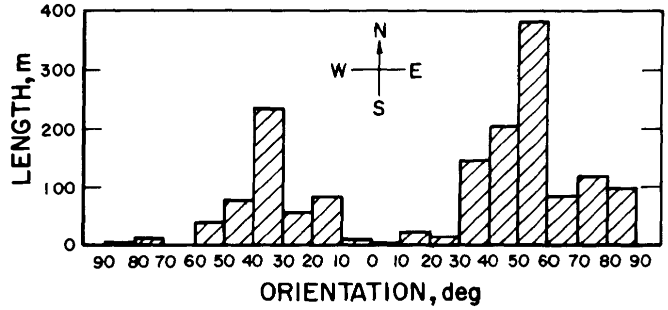


FIGURE 13.—Histogram of bimodal clay vein distribution.

Knowledge of preferred clay vein orientations enables mine operators to plan main entries perpendicular to or at oblique angles to the maximum number of clay veins in order to achieve optimum roof conditions. Barring other mining factors, longwall panels should be oriented so that the face obliquely intersects preferred clay vein orientations. The longwall face should never parallel a preferred clay vein orientation.

Clay veins associated with compactional processes may or may not be predictable. If clay veins are coincident with paleotopographic (ancient topographic) highs or lows as defined by coalbed structure contour maps, then clay veins can be anticipated under similar conditions in advance of mining. Patterns associated with topographic irregularities may be linear or radial. Some clay veins also appear to be byproducts of slumped and/or faulted sediments that have been differentially compacted adjacent to coarser paleochannel (ancient stream channel) deposits. The paleochannels and clay veins shown in figure 17 were mapped in southwestern Pennsylvania in the Pittsburgh Coalbed. Figure 17 indicates that all 16 of the clay veins over 50 ft in length occur within 50 ft of the paleochannel system. Thirteen of the 16 clay veins occur along the margins of the two largest channels. Pesek (20) has also noted the occurrence of clay veins in proximity to paleochannel deposits.

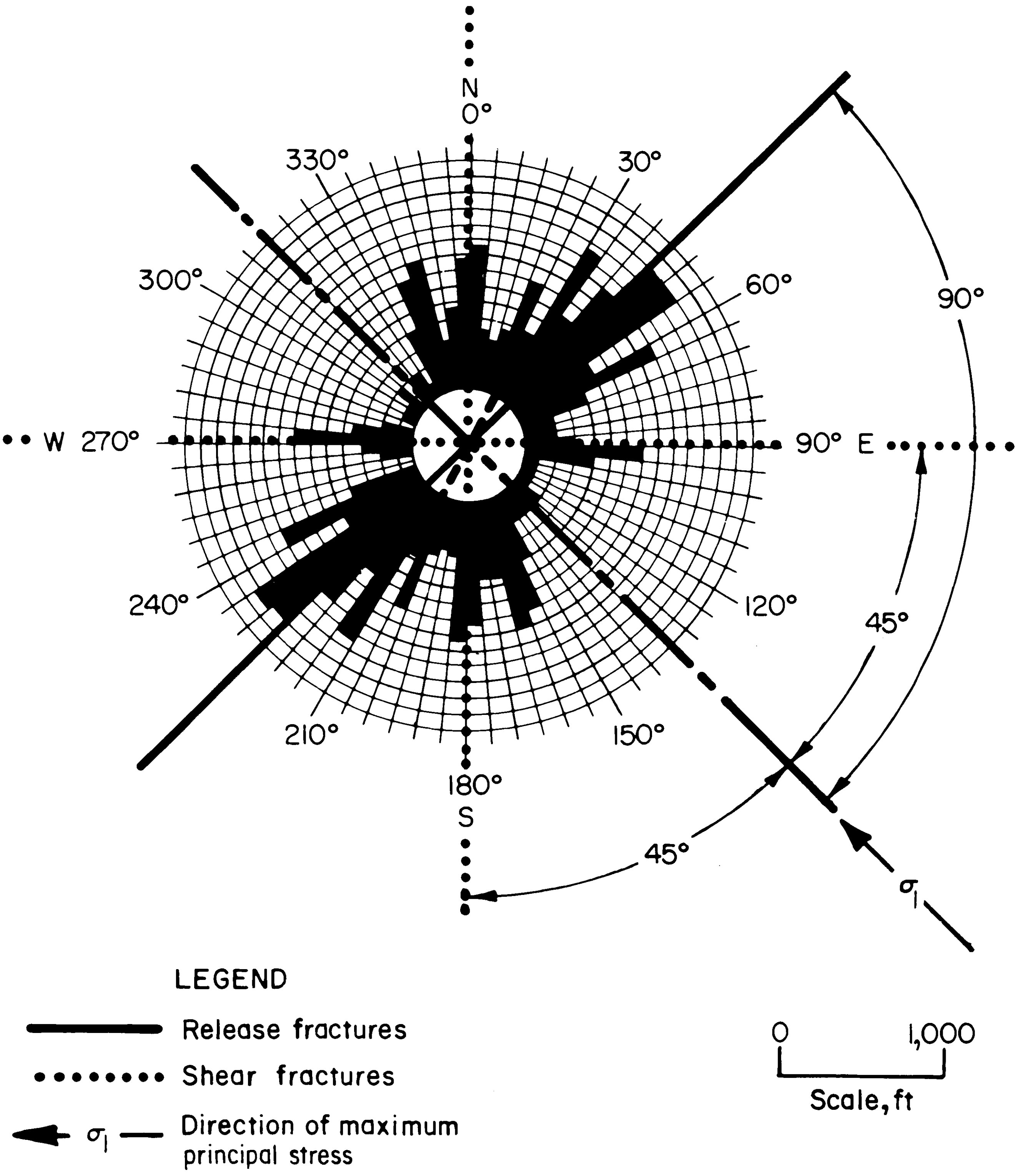


FIGURE 14.—Rose diagram of multidirectional clay vein distribution.

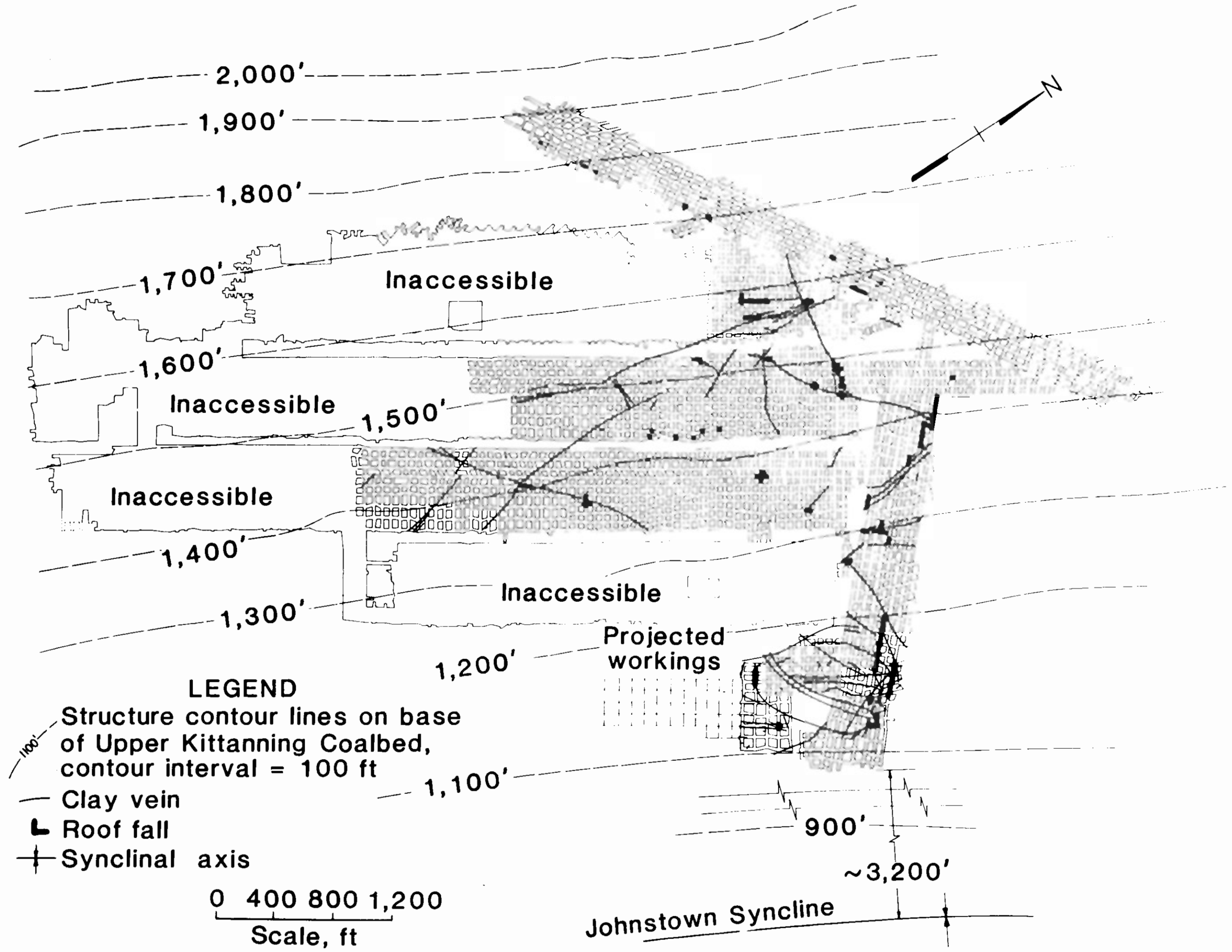


FIGURE 15.—Distribution of clay veins on a synclinal flank.

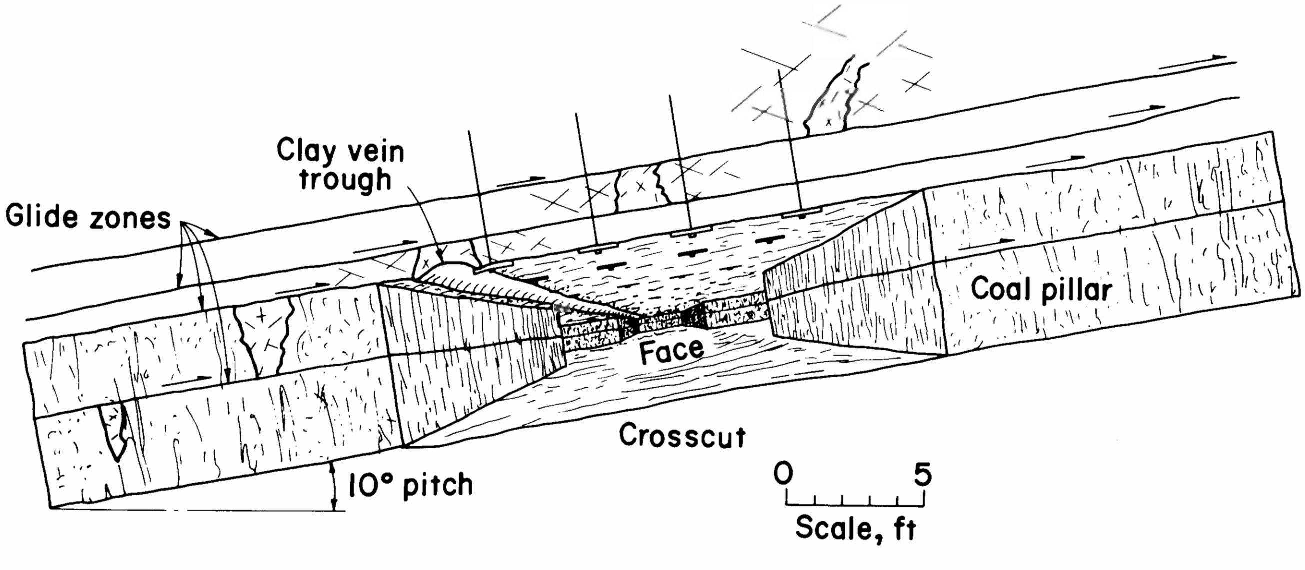


FIGURE 16.—Schematic drawing illustrating up-dip shifting of clay-vein-disturbed rock.

Clay veins generally have a linear to curvilinear strike. Therefore, once mapped, clay veins can be projected for varying distances into unmined portions of the coalbed. Anticipating clay veins in advance of mining sometimes allows minor mine plan modifications that can minimize or eliminate associated roof hazards. For example, some mines shift entry locations so that rib-line clay veins are contained within a pillar. Other mines avoid turning crosscuts that coincide with clay veins. Crosscuts are turned slightly before or after the disturbed zone is encountered. Similar short-term mine plan modifications can be made to avoid hazardous intersections of two or more clay veins. Seven underground observations of three clay veins intersecting were made. In every case, falls up to or above the anchorage horizon were noted by Bureau personnel.

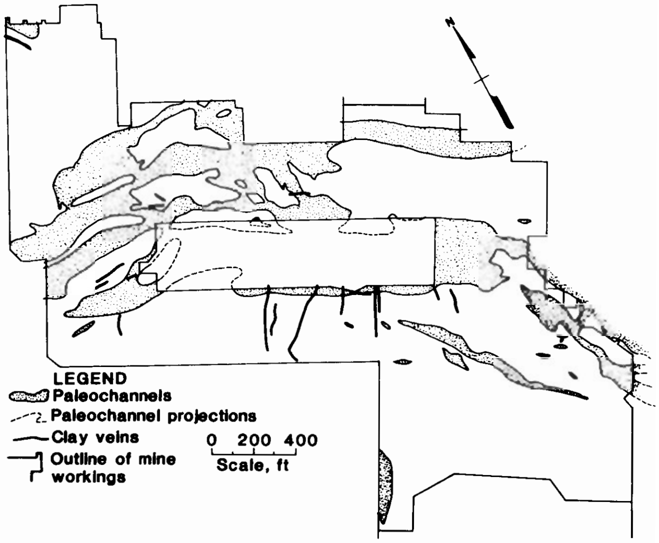


FIGURE 17.—Distribution of clay veins and paleochannels in mine workings.

CONCLUSIONS AND RECOMMENDATIONS

1. Clay veins are infilled fissures. Fissures develop when tensile stresses rupture the coal and adjacent sediments. These fissures can be propagated by compactional processes and/or tectonic stresses active during or subsequent to the coalification process.

2. Distribution data indicate that clay veins frequently occur in more stable coal basins where more differential compaction took place.

3. When clay-vein-related fault or fracture planes parallel or subparallel the direction of face advance, the roof is segmented into cantilever beams. The strata on either side of the clay vein should be bolted and strapped together to form a beam. Mine personnel should be aware of the fault or fracture plane's orientation so they can determine the proper bolt length and angle of installation.

4. A fragmented, sagging, and spalling roof is sometimes characteristic of clay veins with intersecting slickenside planes. Bolts should be installed in conjunction with wire mesh and/or steel mats immediately after undermining to help stabilize slickensides and prevent spalling. Crossbars and mats should be installed perpendicular to the clay vein's strike.

5. Preferred clay vein orientations can only be determined if clay veins are mapped and analyzed. Preferred clay vein orientations should be considered in the planning of main entries and longwalls.

6. Clay veins generally have linear to curvilinear strikes. Therefore, once mapped, clay veins can be projected for varying distances in advance of mining. Anticipating clay veins in advance of mining sometimes enables slight mine plan modifications that can minimize or eliminate associated roof hazards.

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