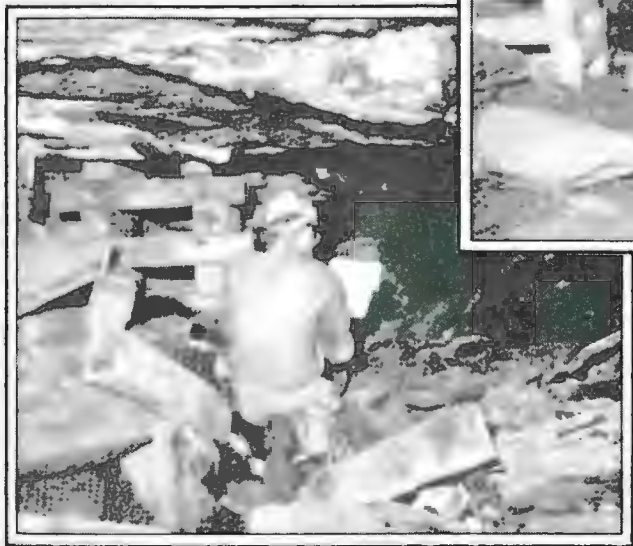
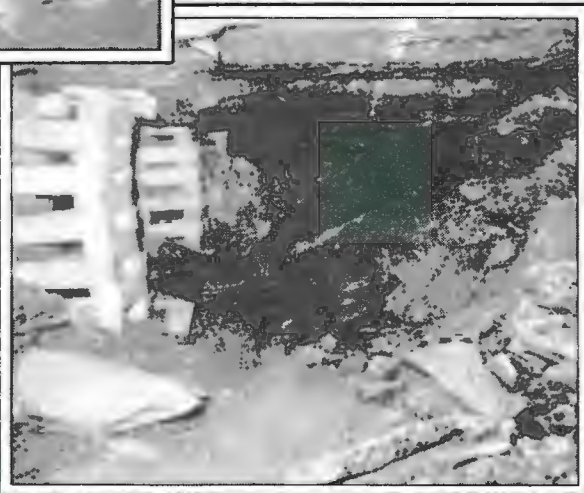


Preventing Coal Mine Groundfall Accidents: How To Identify and Respond to Geologic Hazards and Prevent Unsafe Worker Behavior

**Proceedings: U.S. Bureau of Mines
Technology Transfer Seminar**



Compiled by Staff, Bureau of Mines



United States Department of the Interior



Bureau of Mines

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Cover Photographs: Top, Roof Fall in Highly Stressed Entry; Middle, Severe Rib Sloughage and Poor Roof Conditions in a Highly Stressed Entry; Bottom, Bureau of Mines Personnel Collecting Geotechnical Data on the Factors Responsible for a Roof Fall

Information Circular 9332

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Behavior**

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**UNITED STATES DEPARTMENT OF THE INTERIOR
Manuel Lujan, Jr., Secretary**

**BUREAU OF MINES
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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

ft	foot	min	minute
h	hour	pct	percent
in	inch	psi	pound per square inch
in/d	inch per day	st	short ton
m	meter		

PREVENTING COAL MINE GROUNDFALL ACCIDENTS: HOW TO IDENTIFY AND RESPOND TO GEOLOGIC HAZARDS AND PREVENT UNSAFE WORKER BEHAVIOR

Proceedings: Bureau of Mines Technology Transfer Seminar

Compiled by Staff, Bureau of Mines

ABSTRACT

A major emphasis of the U.S. Bureau of Mines is to perform research on the prevention of fatal accidents at mining operations. The leading cause of fatalities in the underground coal mining industry is groundfalls. This proceedings volume presents several new developments that are helping to prevent fatalities and reduce injuries by groundfalls. The papers focus on the problem from two different perspectives. About half of the papers present information and techniques that can be used to train and motivate miners to protect themselves from groundfalls. The other papers explain how to identify and respond to various geologic conditions that affect the stability of the mine roof. Of the 95 groundfall fatalities that occurred during 1986-90, 75% took place in Kentucky, West Virginia, and Virginia. The rate of groundfall fatalities was much higher at small mines. During 1986-90, the rate of groundfall fatalities at mines employing fewer than 20 people was 4.3 times higher than the rate for larger mines. Because so many groundfall fatalities are occurring at relatively small mines in the southern Appalachian coalfields, many of the papers focus specifically on the needs of this category of mine operations.

INTRODUCTION

Groundfalls have been a major hindrance to coal mine safety and production ever since coal mining began. During the 1930's, groundfalls claimed the lives of over 1,100 U.S. miners each year. Fortunately, the number of deaths because of groundfalls has steadily decreased as a result of improved equipment design, increased automation, and better compliance with mine safety laws. Even with the advances that have been made, groundfalls are still quite costly. These accidents often require that labor, supplies, and equipment be diverted from coal production and used for cleanup, recovery and repair of mine equipment, and resupport of the mine roof. The costs of these activities are quite substantial. Of even greater significance are the financial and intangible losses and the emotional anguish suffered by the families of miners who have been killed or seriously disabled by groundfalls. During 1986-90, groundfall accidents claimed the lives of 95 coal miners, and caused 4,311 nonfatal injuries. An additional 11,340 groundfalls were reported to the Mine Safety and Health Administration (MSHA) in which no one was injured.

Groundfalls are by far the single leading cause of underground coal mining fatalities. They accounted for 46% of all fatal accidents in underground coal mines during 1986-90. Randolph analyzed trends in fatalities caused by roof and rib falls during 1986-90. He found that (1) the States with the highest rate of groundfall fatalities per 200,000 employee hours were Tennessee, Kentucky, Virginia, and West Virginia, and (2) the rate of groundfall fatalities is much higher at small mines (employing fewer than 20 people) than at larger mines. Because many groundfall fatalities are occurring at small mines in the southern Appalachian coalfields, researchers have made an effort to focus specifically on the needs of this category of mining operations.

Two of the Bureau's research programs have been investigating the causes and prevention of groundfall accidents. The ground control research program has been attacking the problem from the perspective of finding better ways to identify and respond to geologic conditions that affect the stability of the mine roof. This proceedings contains four papers discussing the results of their research findings. Chase describes five hazardous geologic structures found in Appalachian coal mines: slips, slickensides, clay veins, kettlebottoms, and sandstone channels. He discusses their physical characteristics, where they are likely to occur, how to anticipate them, and strategies for supporting them. Bauer describes three factors that initiate cutter roof failure: high horizontal stress, surface topographic variations, and geologic anomalies. He makes recommendations concerning how to determine which of these factors is the source of the problem, and given the source, what method controls the problem. Sames and

Moebis discuss the roof support problems caused by weathered stress-relief joints near outcrops in hilltop mining operations. Stress-relief joints are the primary geologic feature that weaken mine roof near outcrops. The authors note that decisions about roof support should consider the degree to which the stress-relief joints are weathered, the orientation and spacing of these joints relative to the direction of mining, and the anticipated failure height. Recommendations are given for the development of mining plans and roof control plans that improve roof stability near outcrops. Molinda describes the major categories of geologic faults. He discusses their physical characteristics and how they affect the mine roof. Recommendations are given concerning (1) methods for anticipating the location of faults, (2) how to adjust the mining plan to minimize the problems associated with faults, and (3) how to control the roof when it becomes necessary to mine across a fault zone.

The other Bureau research program attempting to reduce groundfall accidents is the human factors program. These researchers are developing techniques for training and motivating miners to be able and willing to take actions that would help to prevent groundfall accidents. Two papers in the proceedings are concerned with preventing miners from going under unsupported roof. According to accident investigation reports from MSHA, half of the 95 victims of fatal groundfall accidents were in an area of unsupported roof at the time they were killed. Because so many fatal accidents occur when people go under unsupported roof, research has been conducted to (1) discover more about the reasons miners go under unsupported roof, and (2) to develop recommendations and training materials that mine operators can use to help prevent that behavior. Peters discusses the findings from interviews with 297 miners who work in the face crews of continuous mining sections. Mallett describes materials (videotapes and instructors' guides) that the Bureau has recently developed to help in training miners to appreciate the risks associated with exposure to unsupported roof. She discusses the results of some field tests of these new materials, and makes suggestions concerning how to use them most effectively.

Researchers at West Virginia University's Mining Extension Service have performed an analysis of nonfatal injuries experienced by roof bolter operators in the state of West Virginia during 1983-90. Their methods included: numerical analysis of the injury data, reviewing written summaries of these injuries, and observing a sample of roof bolter operators going through the complete cycle of activities associated with their job. Recommendations are given concerning modifications to equipment and work procedures that would help reduce the risk of roof bolter operators being hit by falling roof material.

GEOLOGIC STRUCTURES THAT AFFECT APPALACHIAN COAL MINES

By Frank E. Chase¹

ABSTRACT

Hazardous geologic structures found in Appalachian coal mines have been responsible for numerous injuries and fatalities. In addition, these structures have been responsible for downtime and in some instances have even resulted in mine closures. For these reasons, the U.S. Bureau of Mines has investigated the physical

characteristics, occurrences, and support strategies to help anticipate and better control these structures. Structures that will be addressed in this paper include slips, slickensides, clay veins, kettlebottoms, and sandstone channels.

INTRODUCTION

Personnel from the U.S. Bureau of Mines, Pittsburgh Research Center have investigated unstable ground conditions associated with hazardous geologic structures in the Northern and Southern Appalachian Coal Basins (fig. 1) (9).² Numerous instances were observed in which geologic hazards were not identified when they were exposed. Also, many hazards that were identified were insufficiently or incorrectly supported. This paper identifies five geologic structures, which were observed to be troublesome. Structures that will be examined include slips, slickensides, clay veins, kettlebottoms, and sandstone channels.

This paper will also examine the physical characteristics of these hazards, their occurrence, and where possible, will suggest support and other mining strategies to minimize their effect. Information contained within this paper is based on in-mine observations by the author, past Bureau research, recommendations of State and Federal roof control specialists, and the experiences of mine operators.

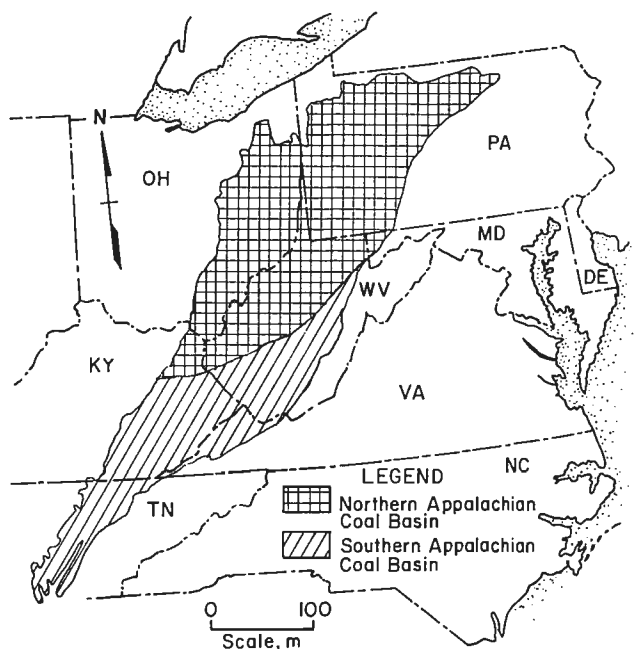


Figure 1.—Northern and Southern Appalachian Coal Basin extent map, after McNeal (9).

¹Geologist, Pittsburgh Research Center, U.S. Bureau of Mines, Pittsburgh, PA.

²Italic numbers in parentheses refer to items in the list of references at the end of this paper.

SLIPS

A slip is a break or crack in the roof rock (fig. 2). From a ground control point of view, slips are the least complicated structure that can cause problems in coal mines. Roof slips are found throughout the Appalachian Coalfields and have been observed in every coal mine roof rock type (shale, sandstone, and limestone).

Where a steeply dipping slip's strike (fig. 3) parallels the direction of mining close to the rib, the roof can react as a cantilever beam (13). Roof sag and fall observations indicate that the roof behaves as two independent

cantilever beams where a steeply dipping slip's strike parallels the direction of mining within a room (figs. 4A and B). Longer and/or angled bolts (especially those anchored into the compression zone above the pillar) used with wooden planks or steel mats help consolidate the roof (figs. 4C and D). Bolts should extend past the slip plane a minimum of 12 in (12) and be anchored into competent strata, which sometimes require bolts to be even longer. Where particularly troublesome slips are encountered, cribbing, crosscuts (fig. 2), or a row of posts on each side of the slip can be used to stabilize the roof.

If a slip will be undermined, and it parallels the direction of mining if a planned crosscut were turned, then mining can proceed beyond the slip, leaving the slip encompassed within the pillar. This procedure of turning a crosscut slightly before or after it was planned to avoid discontinuities, eliminates falls in crosscuts that can continue or run into the intersection.

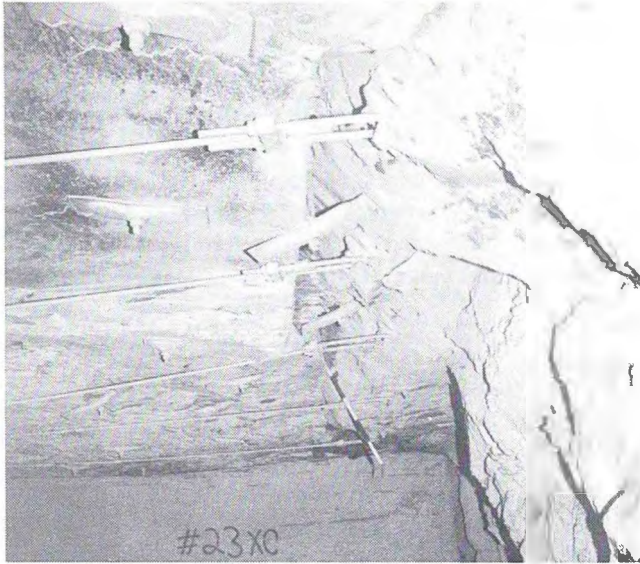


Figure 2.—Truss-bolted roof fracture.

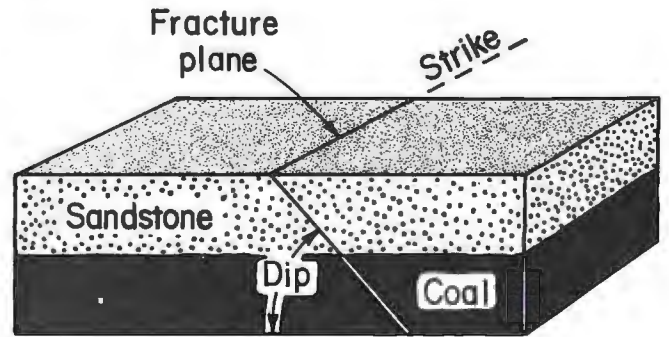


Figure 3.—Block design illustrating strike and dip orientations.

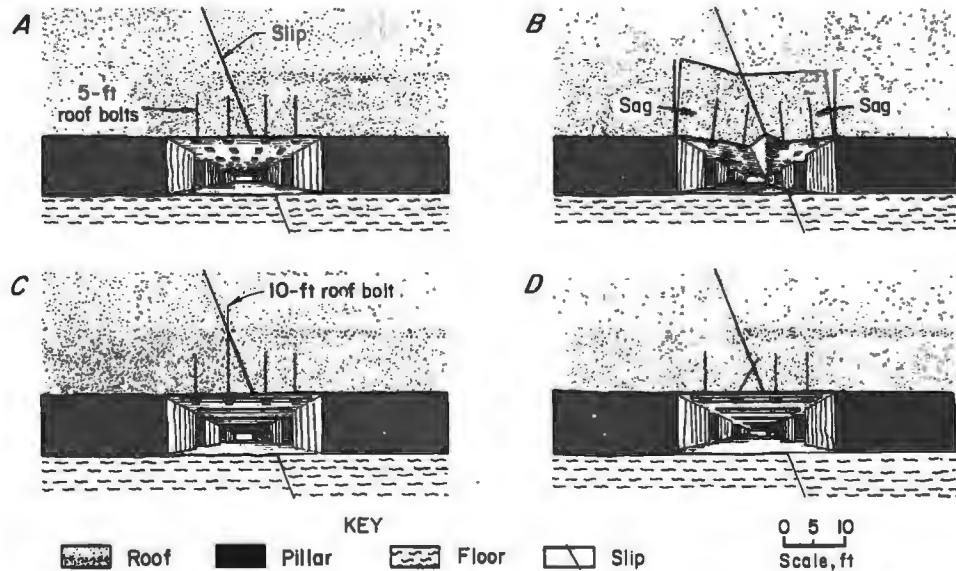


Figure 4.—Slip plane bolting diagram. A, Regular bolting plan; B, roof behaving as independent cantilever beams; C, beam built by using longer roof bolt and mat; D, beam built by using angled roof bolt and mat.

SLICKENSIDES

Slickensides are smooth and highly polished planes of weakness (fig. 5), which are primarily found in mines with shale roof rock. Adverse roof conditions usually result when multiple slickensides occur adjacent to one another. Where slickensides intersect, as shown in figures 6 and 7, an unsupported wedge of roof rock is formed, and in the Southern Appalachian Coal Basin, the resulting structure is commonly called a horseback. Horsebacks are particularly abundant in southern West Virginia and eastern Kentucky where they have been responsible for numerous injuries and fatalities. Operators in mines visited in these areas indicated that horsebacks ranged from 8 to 20 ft in length and extended as high as 7 ft into the immediate roof. When horsebacks are detected during initial undermining, they are sometimes "cut out" of the roof by the

continuous miner operator because these structures are difficult to stabilize. Undetected horsebacks that do not fail during, or subsequent to, entry development have a tendency to "pop out" when they are subjected to abutment pressures generated during pillaring operations. Longer and/or angled bolts, used with planks or mats, can help to stabilize roof rock that contains horsebacks or multiple slickensides (fig. 7).

The structure, illustrated in figure 8, is more correctly described as being a "roof roll." In many instances, roof rolls are the result of channeling or compaction processes. In the Northern Appalachian Coal Basin, structures similar to that shown in figure 8 are also called horsebacks.

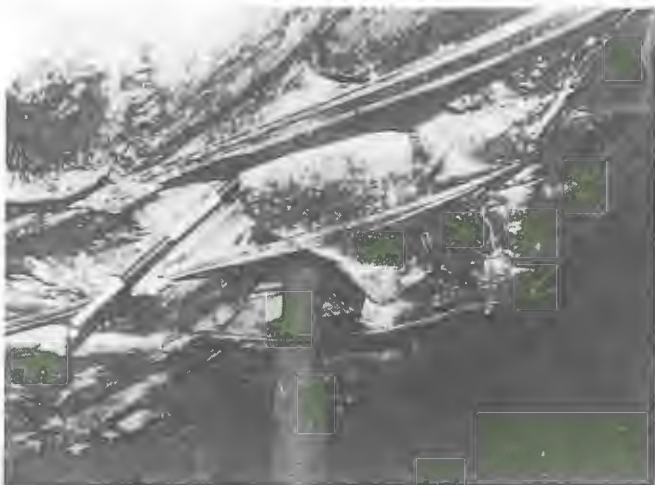


Figure 5.—Slickenside mine roof.

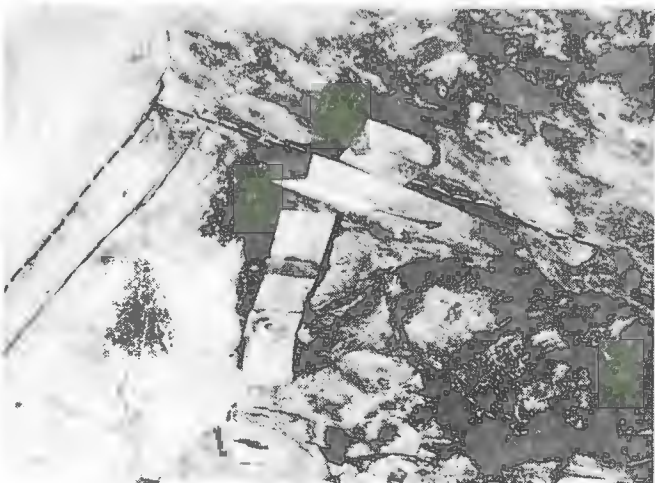
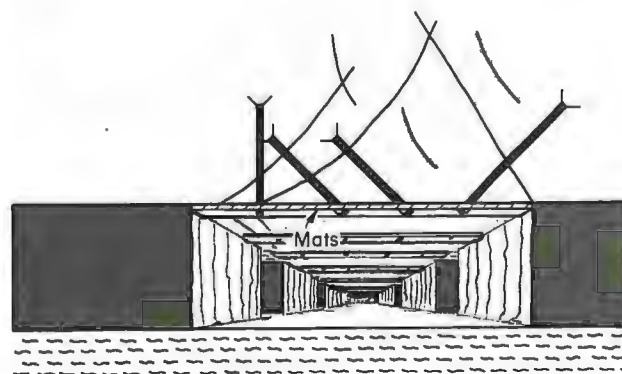
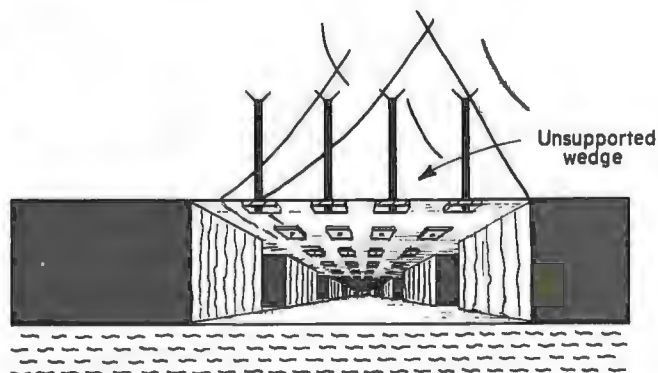





Figure 6.—Southern Appalachian Coal Basin horseback.



KEY

	Coal
	Shale with slickensides
	Underclay

0 5 10
Scale, ft

Figure 7.—Horseback bolting diagram. Top, slickensides ineffectively bolted; bottom, modified bolting plan.

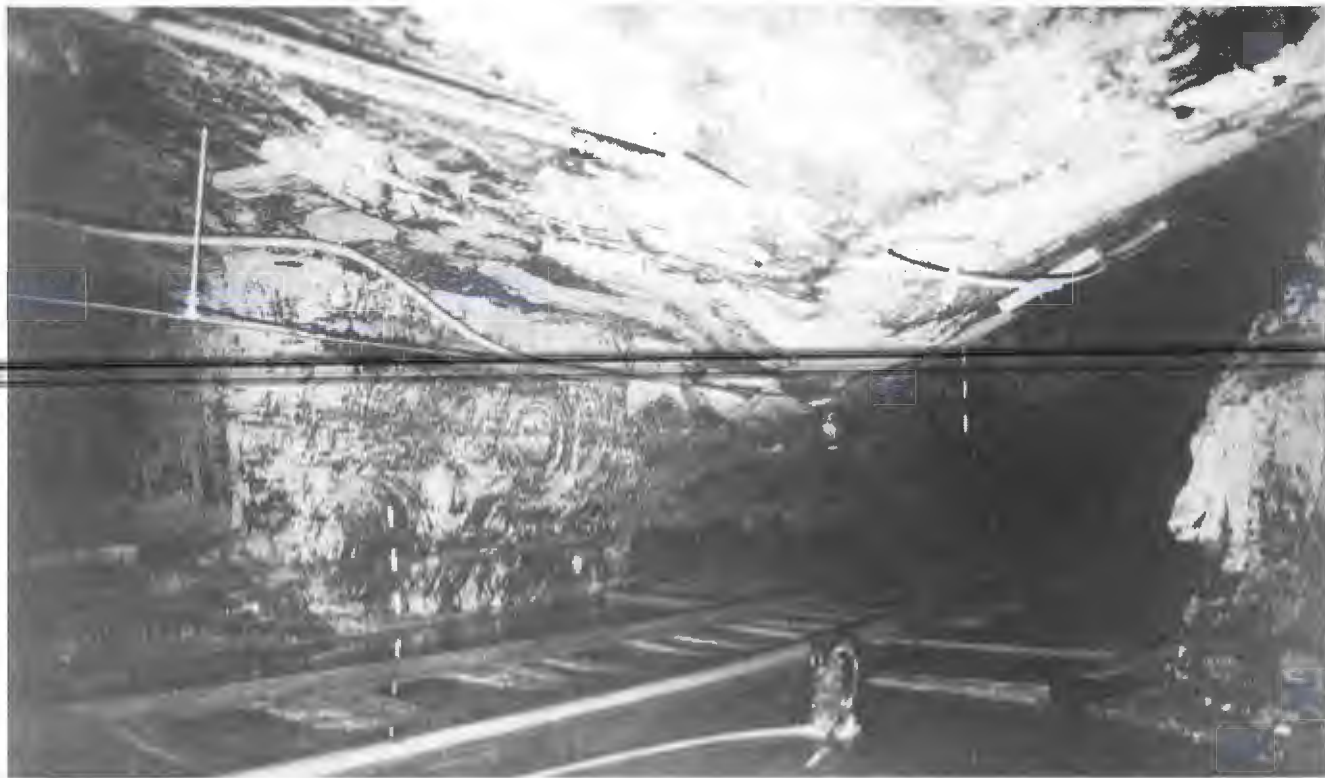


Figure 8.—Northern Appalachian Coal Basin horseback.

CLAY VEINS

Clay veins (also called clay, clastics, and sedimentary dikes) are hazardous geologic structures (fig. 9), which commonly occur in the Northern Appalachian Coal Basin. These structures are rarely found in the Southern Appalachian Coal Basin. 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 or subsequent to coalification (3).

Most clay veins have a zigzag appearance, as if the coalbed were pulled apart (fig. 9); 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 (10).

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. 9) or through multiple intersecting (branch-like) feeders

(fig. 10). Clay veins are predominantly composed of claystone; however, structures infilled with sandstone, siltstone, and/or limestone do occur. 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 (11).

From a support point of view, clay veins can be broken down into two categories: those with associated slips, faults, and slickensided planes in the roof, and those without these features. Clay veins without associated planes are normally composed of claystone or shale. These clay veins are sometimes moisture sensitive and weather rapidly. Fault, slip, and slickenside planes associated with clay veins have dips ranging from 30° to 90° (vertical). Clay vein faults may displace adjacent portions of

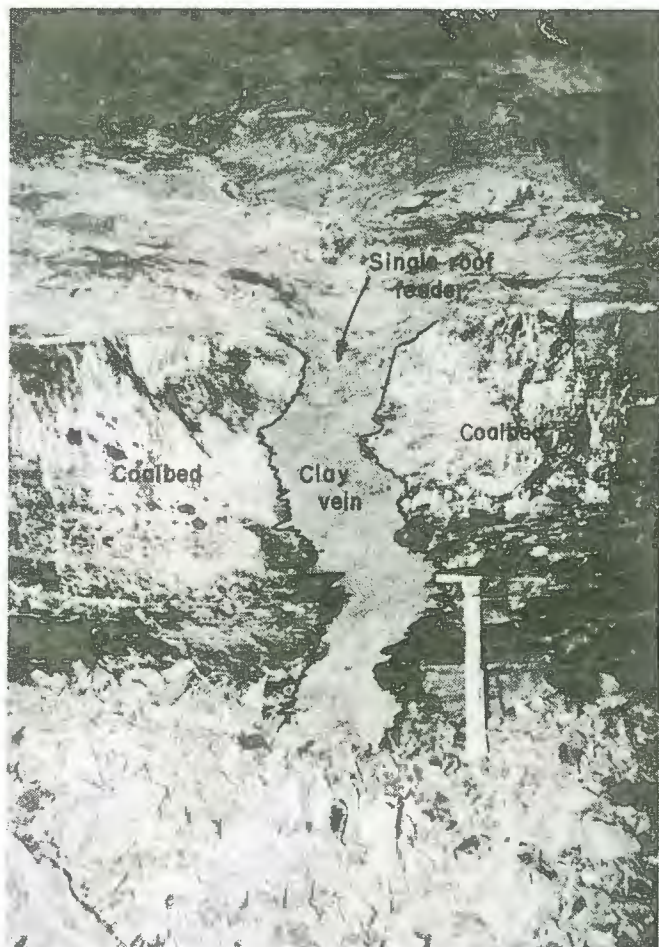


Figure 9.—Single feeder clay vein.

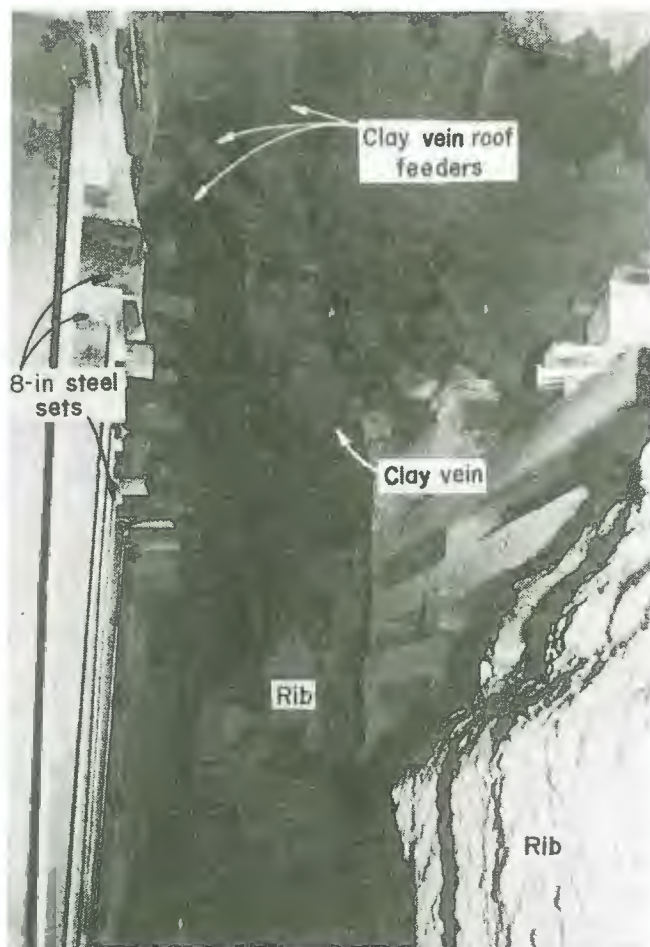


Figure 10.—Multiple feeder clay vein.

the coalbed up to 18 ft vertically (8). However, displacements are more commonly less than 3 ft. Fault planes are distinguished from slip planes, along which no detectable movement has occurred. Fault and slip planes extending as high as 20 ft into the main roof have been observed.

Where a clay vein parallels the direction on mining (fig. 11A), the roof is segmented and tends to sag and cantilever (fig. 11B). Longer (fig. 11C) and/or angled bolts can be used to help stabilize the disturbed rock mass. Bolts should be installed with crossbars or steel mats immediately after undermining to help stabilize slickensides and prevent spalling. Mats should be flexible enough to conform to irregular top.

Tension bolts help compress a loose fragmented roof into a somewhat competent unit (5). 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 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 (4). Based on the above, tensioned resin anchor or mechanical anchor resin assisted 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 bedding planes by infilling fractures and voids, essentially gluing adjacent fragmented blocks. Therefore, in workings where clay veins frequently occur, the routine installation of resin assisted or 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.

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 hazardous clay veins, like the one shown in figure 10, 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. Where a clay vein is coincident with and runs along the ribline (fig. 10), cutter-type roof failure sometimes occurs. Ribline clay veins are particularly haz-

ardous and warrant cribbing. Where equipment maneuverability is a concern, operators have effectively angle bolted ribline 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.

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 ribline clay veins are contained within a pillar. Other mines avoid turning crosscuts that will 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.

Rates of convergence beneath clay veins can sometimes be useful in predicting roof stability. For example, ground control personnel in one mine visited, monitored convergence beneath potentially hazardous clay veins located along the track, belt, and other critical entries and areas. When sag rates exceed 0.2 in/d, experience suggests an impending fall, and additional supplemental support is

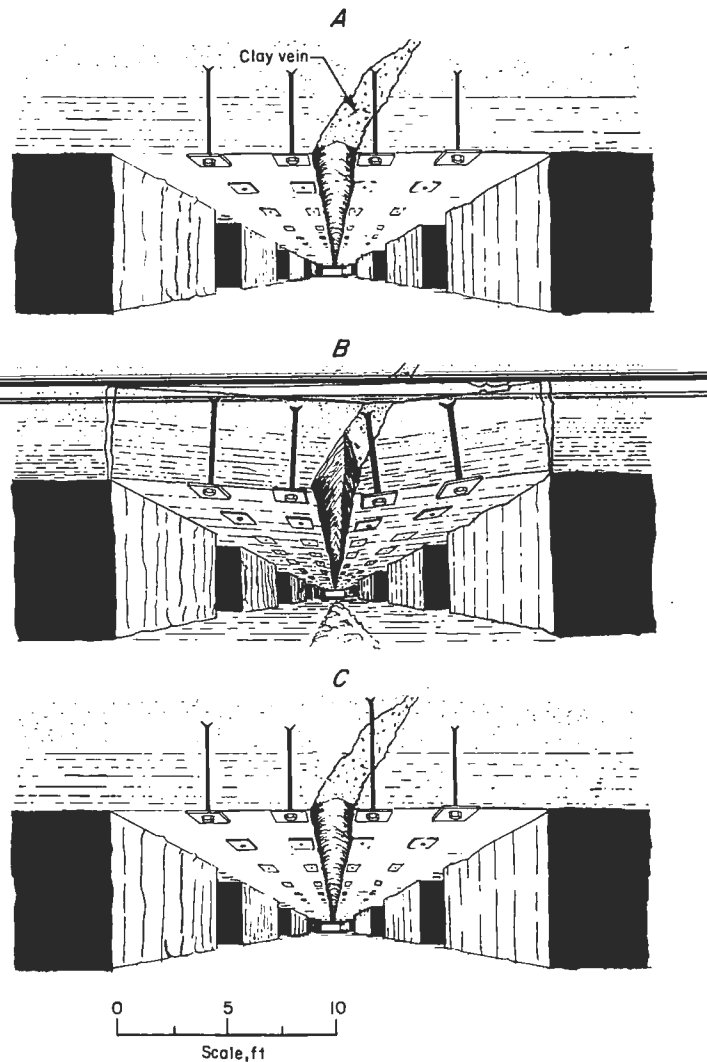


Figure 11.—Clay vein bolting diagram. A, clay vein ineffectively bolted; B, roof behaving as independent cantilever beams; C, beam built by using longer roof bolt.

immediately installed. Rates equaling 1.1 in/d have been recorded beneath clay veins prior to roof failure in this mine.

KETTLEBOTTOMS

Kettlebottoms (also called casts, bells, coal pipes, pot, caldrion bottoms, tortoises, and camelbacks) are the fossilized remains of trees that grew in ancient peat (coal) swamps. Kettlebottoms (fig. 12) occur in every U.S. coal basin, but are particularly abundant in southern West Virginia and eastern Kentucky where they have been responsible for numerous injuries and fatalities. Kettlebottoms can be found in either shale or sandstone roof rock.

Kettlebottoms found in the eastern United States are recognized by their characteristic circular outline in the roof (fig. 13). Normally, kettlebottoms are highly slickensided and surrounded by a 0.25- to 0.75-in "ring" of coal (fig. 13). The adjacent roof strata are also highly slickensided (fig. 14) and only the tensile strength along the different bedding planes within the kettlebottom itself prevents it from failing (fig. 15). When the weight of the kettlebottom is sufficient to overcome the tensile strength

along the weakest bedding plane, which can deteriorate with time and moisture, the kettlebottom will fall without warning (2). This failure may occur during or subsequent to mining; therefore, it is imperative that all observed kettle-bottoms, which do not detach from the roof after undermining, be supported. This is especially true in sections that will be retreat mined because abutment pressures generated during pillaring operations have quite often caused unsupported kettlebottoms to "pop out."

Kettlebottoms are most commonly supported using one of the methods illustrated in figure 16. Method A is the most frequently employed technique, and this is one of the reasons why so many miners have been seriously and fatally injured by kettlebottoms. It should be readily apparent that the kettlebottom can and often does extend higher into the roof than does the bolt. In one eastern Kentucky mine visited, a kettlebottom extended 16 ft into the roof. After experiencing this problem, some mine operators began angle-bolting kettlebottoms, as shown in method B. However, the vibration during drilling is sometimes sufficient to dislodge the kettlebottom, and this has caused several roof bolter operators to be injured, some very severely. This problem also exists with bolting method A. If method B is used, the automated temporary roof support pad must be set beneath the kettlebottom to prevent it from dislodging during drilling. Bolting method C is the safest and most effective way to support kettlebottoms. The bolt is placed close enough to the kettlebottom so that a wooden half header or a steel header can extend beneath the structure for support. Kettlebottoms over 3 ft in diameter should be secured by using two bolts and a wood plank or steel strap (method D). On occasion, the installation of an additional bolt or bolts (kettlebottoms over 3 ft diameter) may not be necessary. If a bolt to be installed in the regular bolting pattern is in close enough proximity to the kettlebottom, then the bolt can be used to support the structure.



Figure 13.—Sandstone kettlebottom in shale roof rock.



Figure 14.—Slickensided kettlebottom roof void.



Figure 12.—Detached kettlebottom illustrating slickensided surface.

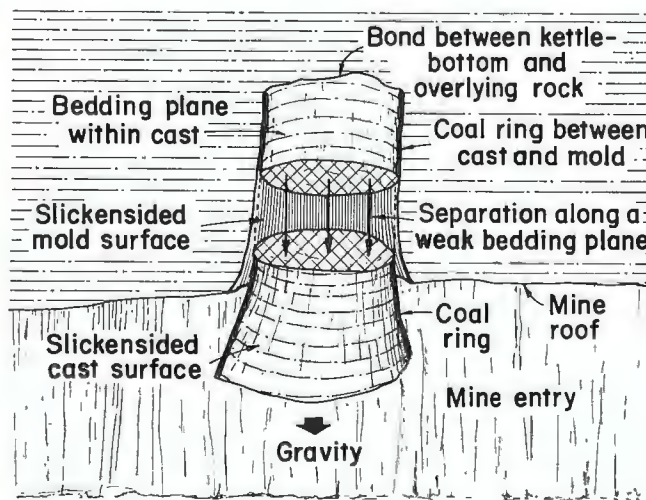


Figure 15.—Kettlebottom detachment along weak bedding plane.

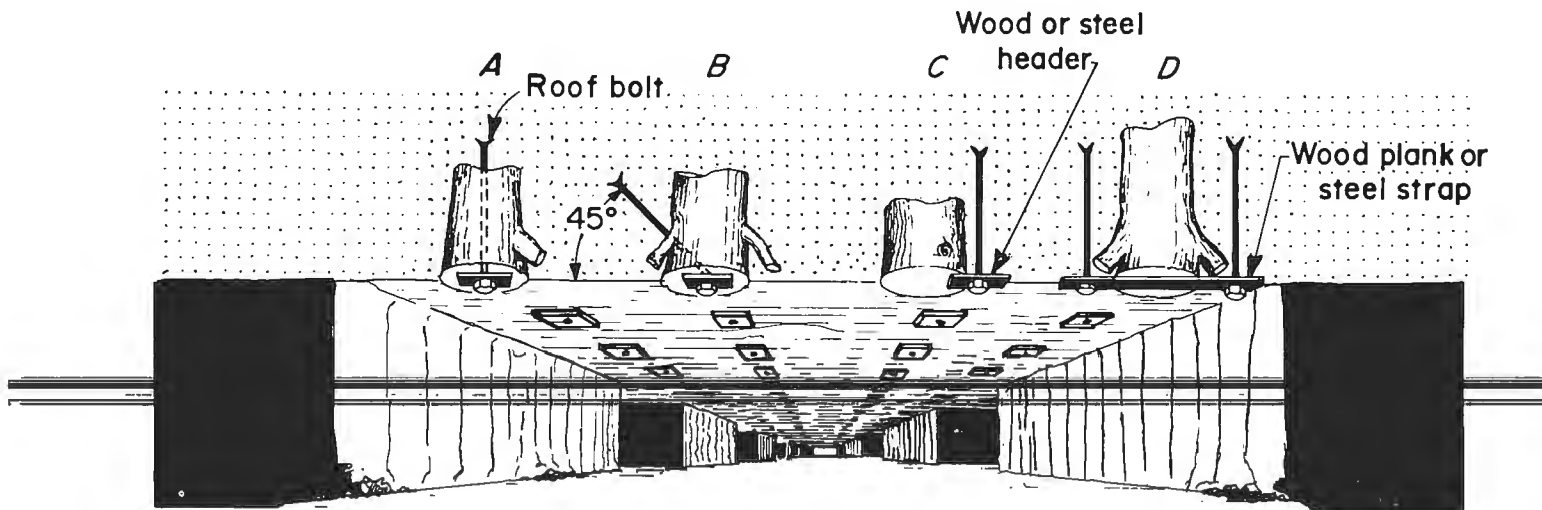


Figure 16.—Kettlebottom bolting diagram. A, improperly supported kettlebottom; B, angle bolted kettlebottom; C, properly supported kettlebottom; D, properly supported large kettlebottom.

ANCIENT STREAM CHANNELS

Ancient stream channels (also called paleochannels, washouts, wants, etc.) are the lithified remnants of rivers and streams, which were active during or subsequent to peat formation. Paleochannels (fig. 17) are found in both Appalachian Coal Basins and are usually composed of sandstone or siltstone. In addition to eroding part or all of the coalbed, paleochannels have also been responsible for face ignitions and bumps. Massive channel deposits have been responsible for bumps occurring under cover as shallow as 200 ft in southern West Virginia. The inability to cave massive sandstone channel deposits during pillaring operations has also caused destructive air blasts in the Southern Appalachian Coal Basin.

Paleochannels are particularly troublesome because several other hazardous structures and conditions can be associated with them. These include: slips, faults, slickensides, clay veins, kettlebottoms, coalbed rolls, transition zones, and stackrock (6). Coalbed rolls (fig. 18) can occur along paleochannels, and are the result of sediments being differentially compacted around a relatively unyielding sandstone body (7). Changes in coalbed elevation as much as 15 ft within a horizontal distance of 50 ft (17° dip) have been measured in southwestern Pennsylvania. This is so steep, that the continuous miner was unable to stay in the face. Lateral transition zones (fig. 19) occur where roof

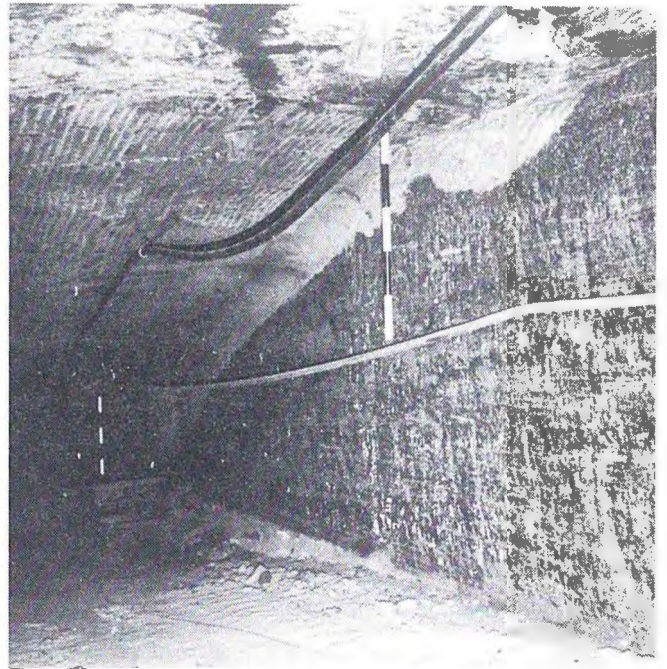


Figure 17.—Paleochannel eroding coalbed. (Photo by P. Jeran, Pittsburgh Research Center.)

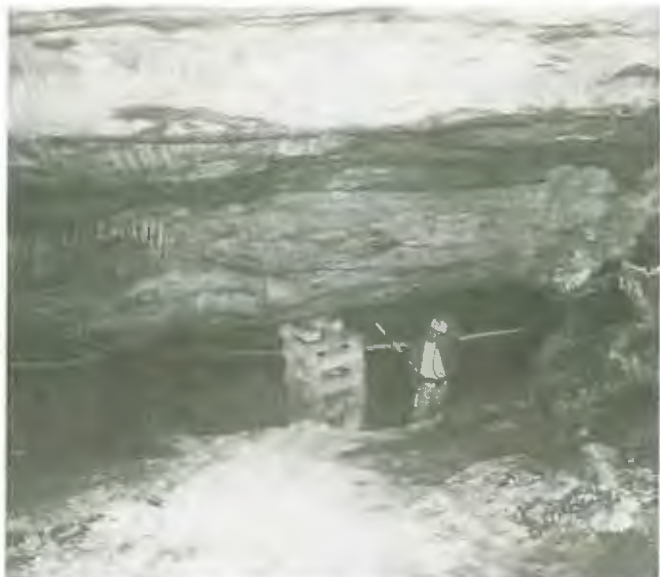


Figure 18.—Coalbed roll associated with paleochannel.

shales, mudstone, etc., abruptly terminate against paleochannels composed of sandstone. Shales adjacent to sandstone channels are typically highly slickensided, broken up, and difficult to control, even with resin or resin-assisted bolts. In one mine visited, large roof falls commonly occurred where there was a lateral transition from sandstone to mudstone. Falls normally only occurred when the sandstone unit was 5 to 8 ft above the coalbed. As a strata control technique, roof bolters drilled 10 ft test holes every 100 ft to determine problem areas. Within transition zones, it is not uncommon to see extensive cribbing and 12 to 14 ft mechanical bolts being used to anchor into the main roof. The bolting strategies depicted in figure 20 has



Figure 19.—Shale transition zone adjacent to sandstone paleochannel.

worked better than most in controlling transition zones. Also, where a shale roof abruptly terminates against sandstone paleochannels, large slip or fault planes can occur. Longer and/or angled bolts, which are anchored into the channel or above the rib, help to stabilize the roof (fig. 21). The hangers shown in figure 22 illustrate some of the problems encountered when trying to anchor into the sandstone channel when using 12 ft fully grouted resin bolts. Stackrock is also sometimes associated with sandstone paleochannels (fig. 23). The bedding planes between the alternating thin layers of coal, shale, and sandstone in a stackrock sequence are usually very weakly cemented and high roof falls can occur. Along the margins of channels, some roof bolters examine the dust box and monitor drilling rates to determine if stackrock conditions exist.

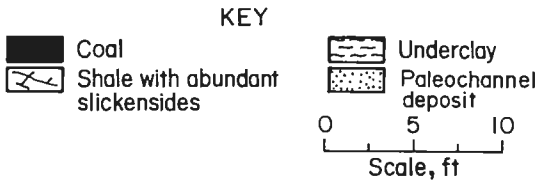
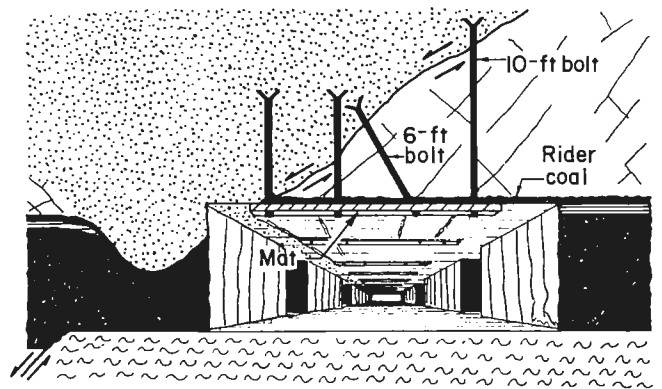
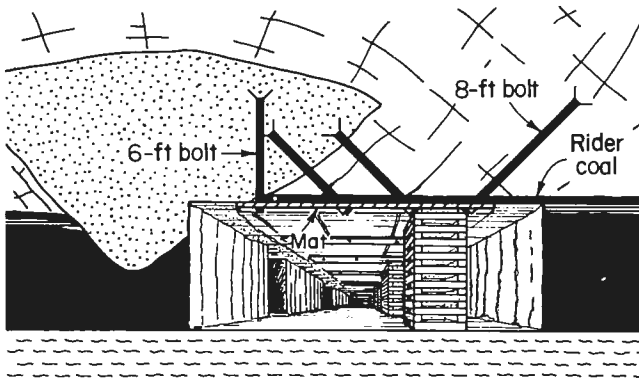
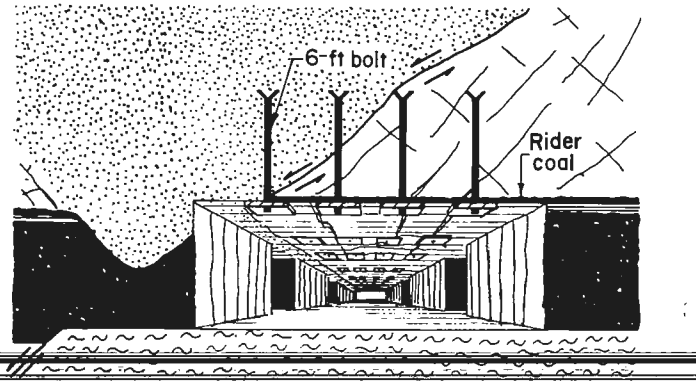
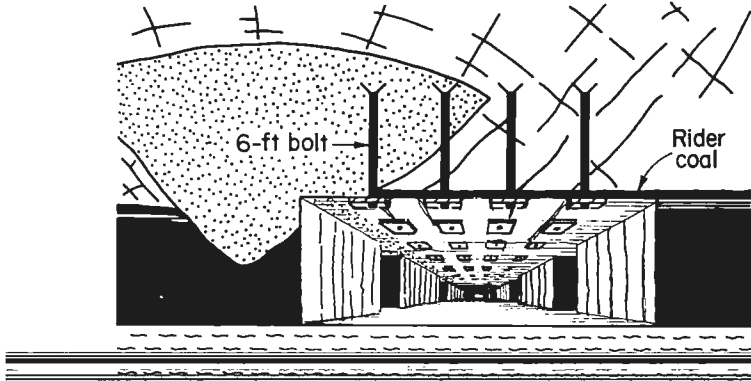


Figure 20.—Paleochannel transition zone bolting diagram. Top, ineffectively bolted transition zone; bottom, modified bolting plan.

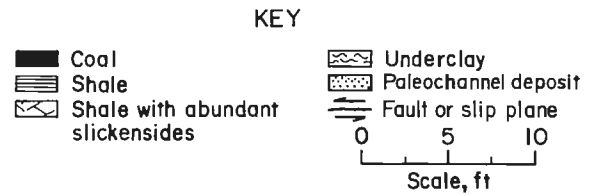


Figure 21.—Paleochannel fault or slip plane bolting diagram. Top, ineffectively bolting plan; bottom, modified bolting plan.

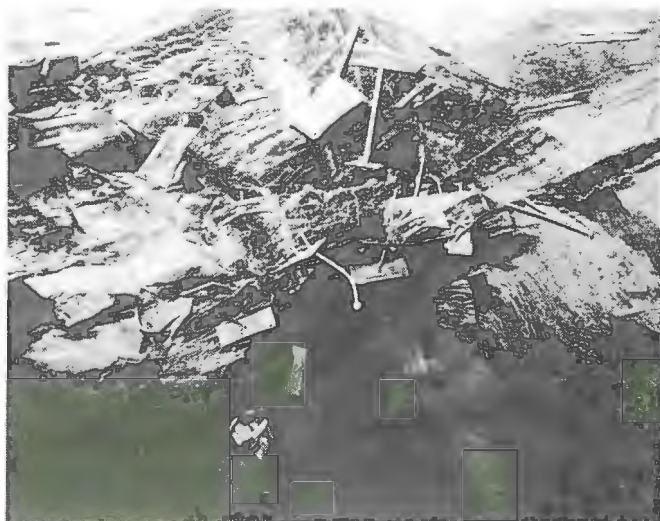


Figure 22.—Resin roof bolt hangers.



Figure 23.—Stackrock roof fall.

CONCLUSIONS

1. Steeply dipping fractures, which parallel the direction of mining, disrupt the lateral continuity of the mine roof and can cause it to cantilever. Steel mats or wooden planks, with longer and/or angled roof bolts, which extend a minimum of 12 in beyond the structure into competent strata, help to stabilize the roof.

2. Horsebacks and kettlebottoms are highly slickensided geologic structures, which may fall out during or subsequent to entry development. Abutment pressures developed during pillaring operations can cause unsupported horsebacks and kettlebottoms to pop out. Therefore, these structures should always be supported. Horsebacks are best supported by using longer and/or angled bolts with steel straps or wooden planks. The safest and most effective method to support kettlebottoms is to place a bolt close enough to the structure so that a wooden half header or a steel header extends beneath the structure for support.

3. Clay veins are near-vertical discontinuities, which complicate every aspect of mining. In addition to fractures, faults, and slickensides, which are commonly associated with clay veins, the structure itself is sometimes composed of incompetent claystones or highly fractured shales and should never be anchored into with mechanical bolts. The roof tends to sag and cantilever where a clay vein strike parallels the direction of mining. Full-column resin tensioned, resin anchor, or mechanical anchor resin-assisted bolts better insure stability in clay vein-disturbed roof rock.

4. In addition to eroding part or all of the coalbed, paleochannels have been responsible for face ignition, bumps, and air blasts. Paleochannels are particularly troublesome because of other commonly associated hazardous structures and conditions. These include: fractures, faults, slickensides, clay veins, kettlebottoms, coalbed rolls, transition zones, and stackrock.

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ROOF CONTROL NEAR COALBED OUTCROP IN SMALL HILLTOP OPERATIONS

By Gary P. Sames¹ and Noel N. Moebis¹

ABSTRACT

This paper discusses some practical applications of a geotechnical investigation conducted by the U.S. Bureau of Mines (USBM) that can help operators of small mines meet certain revised Federal regulations. These regulations require a description in the roof control plan of the method that will be used to protect workers when mining approaches within 150 ft of the coalbed outcrop. The investigation, designed to characterize roof conditions near the coalbed outcrop in drift coal mines in eastern Kentucky, revealed that weathered stress-relief joints are the predominant cause of roof instability near outcrop.

The joints' origin and character were determined through underground mapping of many joints in coal mine roof and detailed observations and measurement of joint trends and physical characteristics in widely separated strip mine highwalls and roadcuts. This resulted in an understanding of stress-relief-joint patterns and the effect of various rock types on the intensity of weathering in the joints. That information is used to show how stress-relief joints contribute to roof failure and how, through improved roof support and mine planning, safer roof support plans can be developed.

INTRODUCTION

Room-and-pillar drift mines are the chief underground coal producers in southern West Virginia, eastern Kentucky, and southwestern Virginia. The steep topography, high relief, and shallow coalbed depths typical of the region often result in small mines with extensive workings near outcrop. Geotechnical investigations by the USBM show that weathering, moisture, and gravity combine to create stress-relief joints (also known to miners as hill-seams, mudseams, and mountain breaks or cracks) that are the dominant cause of roof instability and fatal injuries near outcrop (2).²

Bureau research shows that stress-relief joints in central Appalachia are a form of deep-seated hill-slope failure. Erosion of the valleys removes confining pressure, allowing expansion of the strata through vertical stress-relief jointing parallel to the valley walls. Walls of the joints weather

over time by water percolation, separating parallel slabs of rock in progressive stages (1-2) (fig. 1). Stress-relief joints in fine-grained rocks such as shale generally weather into wide zones of closely spaced vertical slabs of rock, sometimes separated by thin layers of clay. Stress-relief joints in sandstone tend to be narrower, less weathered, and therefore, less hazardous.

Stress-relief joints occur in the shallow overburden where surface slopes are steep, with the greatest frequency and degree of weathering in mine roof within 200 ft laterally of coalbed outcrop. They are usually discontinuous along strike, and decrease in frequency and degree of weathering to about 700 ft from the outcrop and under 300 ft or more of overburden, as the effects of stress relief gradually disappear (fig. 2). Most are vertical, but many nearest the surface may dip slightly parallel to the surface slope. Because they are formed by stress relief, most of the joints tend to parallel the dominant topographic contour lines and ridges. However, in the nose of a ridge, stress relief acts parallel to both the ridge and the nose, resulting in intersecting stress-relief joints.

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²Italic numbers in parentheses refer to items in the list of references at the end of this paper.

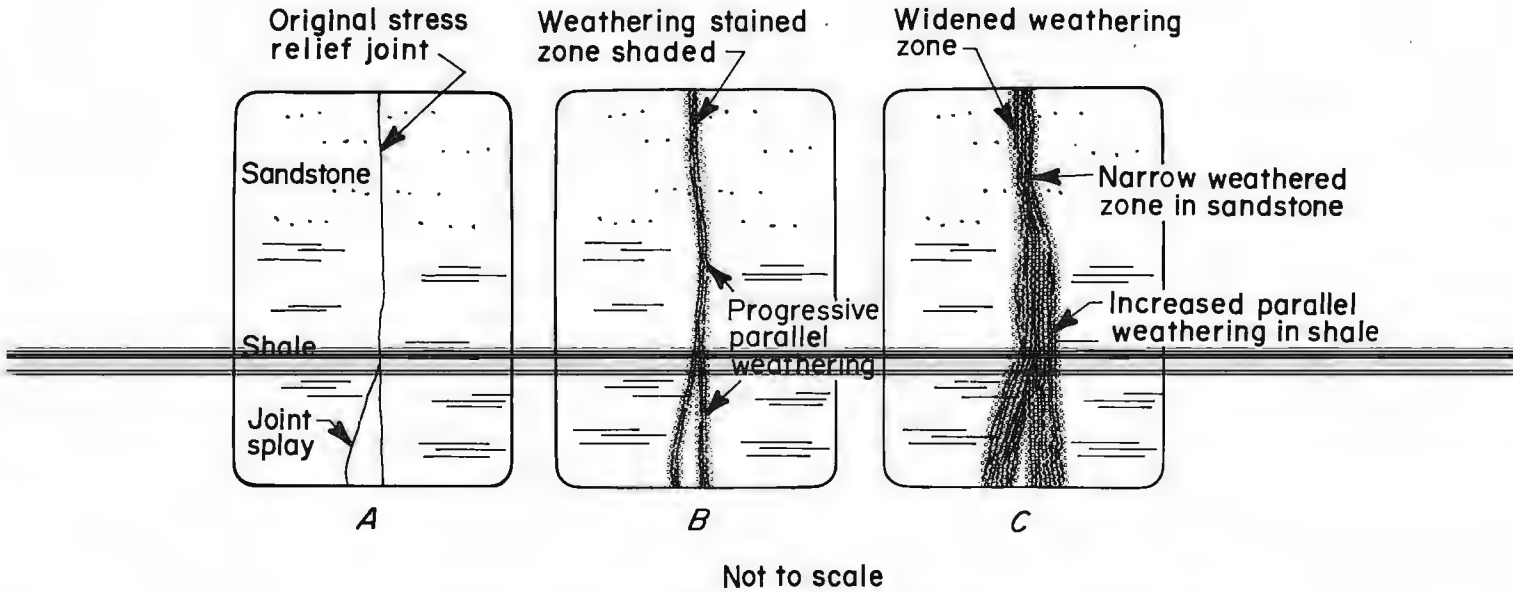


Figure 1.—Schematic drawing of stress-relief joint weathering over time by water percolation.

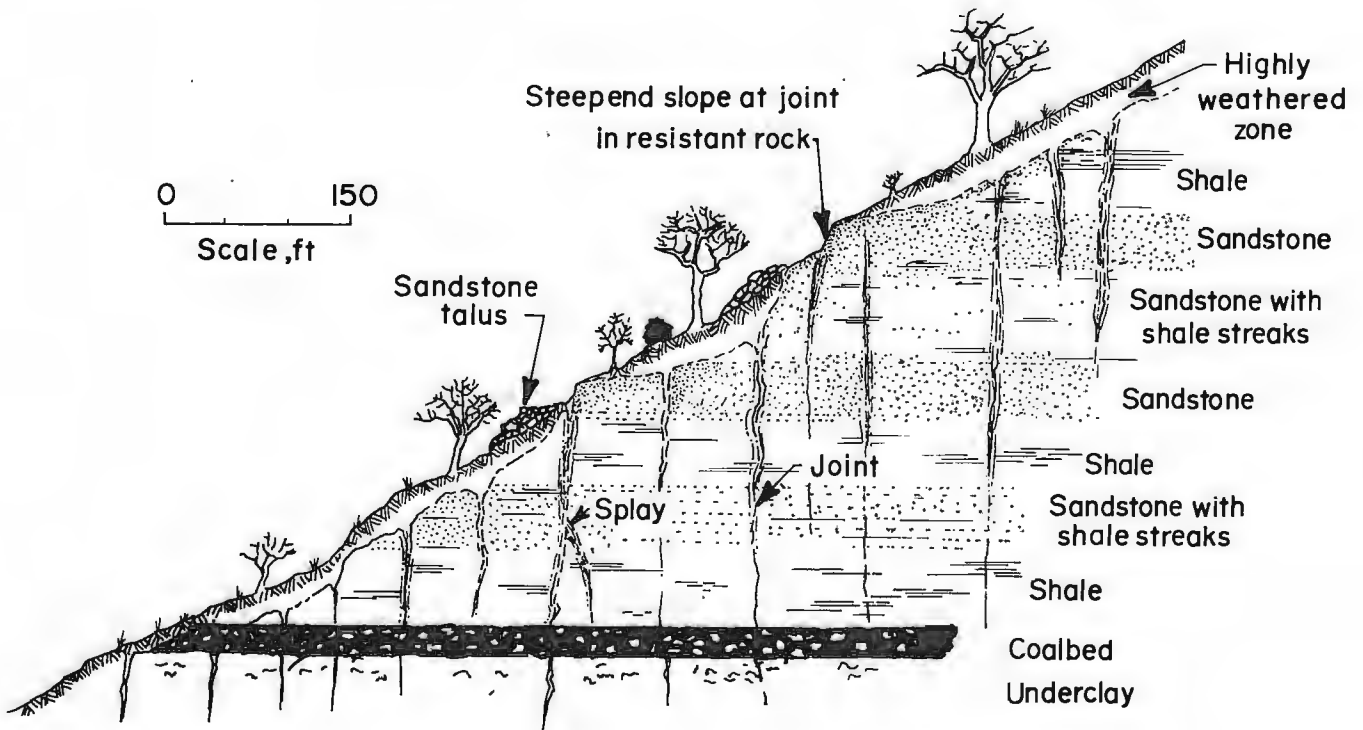


Figure 2.—Cross section of hill slope showing typical stress-relief joint distribution.

State and Federal accident data examined for the Mine Safety and Health Administration (MSHA) District 6 in eastern Kentucky, covering the period 1980 to 1987, revealed the following statistics: five fatal accidents and

two serious injuries from 1980 to 1985, one fatality in 1986, and two fatalities and one serious injury in 1987 were attributed to roof falls where stress-relief jointing was a major contributing factor. These statistics indicate that

control of adverse roof conditions caused by stress-relief jointing near outcrop is an important aspect of effective mine planning.

Individual States control outcrop safety barrier design through the authority to approve or disapprove mine plans, with most barrier widths based on experience with internal and property barriers (3). The Federal Government now controls the type and pattern of support used near outcrop

through approval or disapproval of the required roof support plans submitted in accordance with the Code of Federal Regulations (4). Although any geologic discontinuity that can cause coal mine roof instability can occur near the outcrop, stress-relief joints are unique and prevalent near outcrops, and plans for hilltop mining should emphasize their control.

ACKNOWLEDGMENTS

The authors wish to thank Raymond A. Bradbury, president and general manager, and Ed Chafin, safety director, of Martin County Coal Corp., Inez, KY, for complete access to their underground and surface mines for this investigation. The authors also thank Willard

Stanley, now retired Commissioner of Kentucky's Department of Mines and Minerals, for encouraging the assistance they gratefully received from the department's regional personnel.

OUTCROP SAFETY BARRIER LEGISLATION

Clearly defined limits for outcrop safety barriers are very seldom specified, and when they are, rules of thumb rather than scientific designs govern the barrier limits. Barrier pillar legislation has, in the past, been limited to property boundary barriers for approaching an abandoned mine. Although no State has a clearly defined method for computing outcrop barriers, they have other requirements that provide the States with authority to approve or disapprove a mining company's plans and thereby control safety barrier design.

Kentucky Revised Statutes (3), for example, do not address the subject of outcrops with respect to requirements for a barrier. Property boundaries and adjacent mines, only, are discussed in Chapter 352, Section .090 and .490. A 25-ft barrier is required in both instances. Mine operators, with the approval of the Department of Mines

and Minerals, Mine Inspection Division, generally adopt a 100-ft wide safety barrier in hilltop drift mines to avoid shallow overburden, weathering, and fractures.

Two Federal agencies, MSHA and Office of Surface Mining Regulation and Enforcement, are responsible for enforcing regulations regarding mining. However, neither agency prescribes limits or design criteria for outcrop safety barrier widths. There are no stringent design criteria for outcrop safety barriers, the width being largely determined by local surface slope and shallow subsurface conditions. However, Title 30, Chapter I, Subchapter O, Part 75, Subpart C, section 75.221 of the U.S. Code of Federal Regulations now requiring in the roof control plan "a description of the method of protecting persons...when mining approaches within 150 ft of outcrop" allows for barriers of less than that width (4).

STRESS-RELIEF-INDUCED ROOF INSTABILITY

Underground observations and accident data show that stress-relief joints weaken mine roof (1-2). Even barely detectable stress-relief joints deserve close attention because of their tendency to change in character along strike. However, not all stress-relief joints in mine roof require the same degree of support. Three primary factors should influence support decisions: the degree of weathering, their orientation and spacing relative to the direction of face advance, and estimated failure height.

DEGREE OF WEATHERING

The degree of weathering is determined by the width of weathering between walls of unaltered rock at the point a stress-relief joint intersects a coalbed. Stress-relief joints generally are more weathered the closer they are to the surface. As the distance from outcrop increases, the vertical distance from the surface to the coalbed also increases. The uppermost 10 to 20 vertical feet of a stress-relief joint

300 ft above a coalbed may be heavily weathered, while at the coalbed it may be only an iron-stained joint. The degree of weathering in a single stress-relief joint is most critical in anticipating their influence on roof control.

Very narrow, slightly weathered stress-relief joints exert the same influence on roof stability as common joints. Interlocking irregular surfaces create frictional resistance to initial movement, thus normally allowing effective beam building by roof bolting. This type of occurrence is common in massive sandstone. The nature of progressive weathering adjacent to a stress-relief joint in sandstone is visible in figure 3.

As the degree of weathering in stress-relief joints increases, so does the potential to cause roof instability. Wide stress-relief joints consist of many vertically parallel slabs of rock separated by thin layers of wet clay (fig. 4). Clay reduces frictional resistance within the stress-relief joint and drastically alters the physical properties of the roof rock in that zone. Wide joints can deform internally when detachment occurs at or above the bolting horizon, allowing vertical movement and failure of the roof beam.



Figure 3.—Close-up of incipient weathering and parallel fracture development adjacent to stress-relief joint in massive sandstone.

ORIENTATION AND SPACING

Narrow stress-relief joints that strike transversely to mining (direction of face advance) generally are the least troublesome. Two solid beams remain in the roof and are supported at both ends by the adjacent coal ribs. Very wide, intensely weathered stress-relief joints transverse to mining tend to spall or fail in small slabs between splaying joint surfaces, but without severely affecting overall roof stability. Figure 5 shows a section of a short-joint splay that fell out between supports.

~~Stress-relief joints that are subparallel to parallel to~~ mining can induce roof instability by interrupting the roof span. Figure 6 shows the cantilever effect created by a stress-relief joint paralleling development. This is especially important in heavily weathered joints that can deform internally, allowing one or both sides to drop.

Multiple, and especially intersecting, stress-relief joints within an opening often create isolated blocks or wedges of roof prone to failure. Although degree of weathering also plays a role in these situations, roof failure caused by even narrow stress-relief joints is more likely when the continuity of the roof is disrupted in two or more places. Figure 7 shows two schematic views of a roof fall, caused by intersecting stress-relief joints, which resulted in a fatality. In this case, the roof failed en masse between joints and about 1 ft above the bolting horizon, generating enormous dead weight (fig. 8).

FAILURE HEIGHT

Because roof falls involve complex failure modes, it is difficult to predict, with certainty, at what height the roof

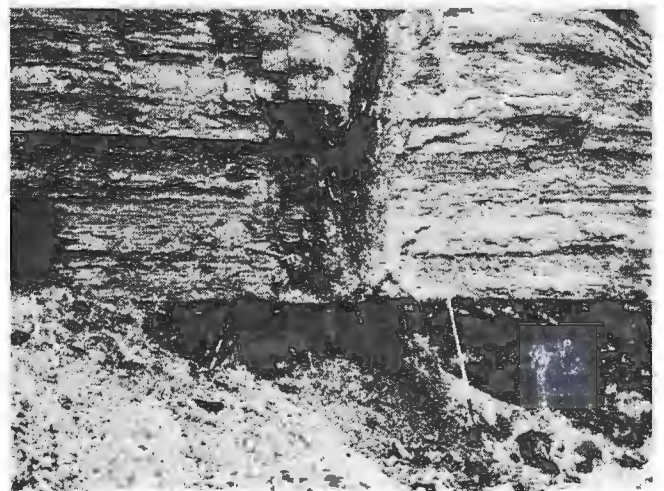


Figure 4.—Heavily weathered stress-relief joint in shale above coalbed.

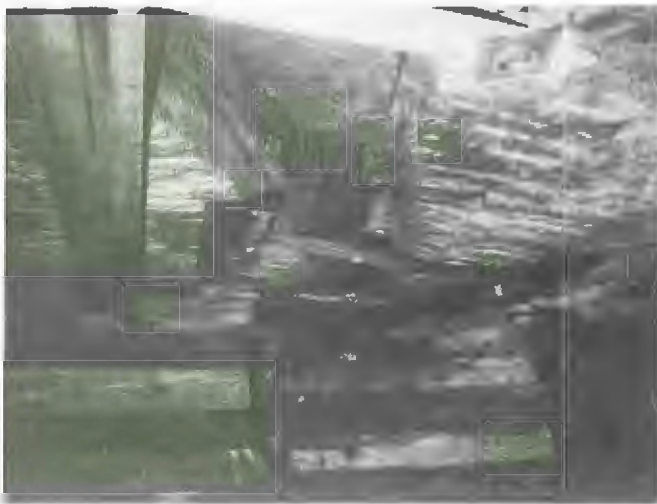


Figure 5.—Small rock fall between joint surfaces in massive sandstone roof.

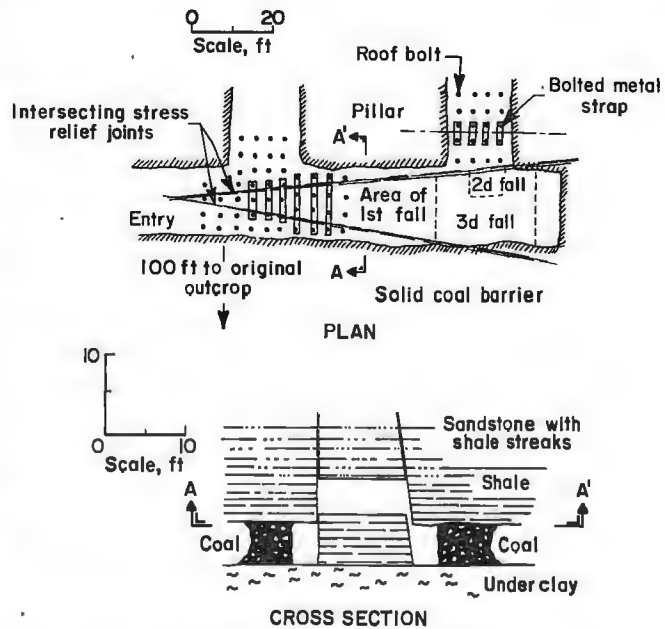


Figure 7.—Plan and cross section views of roof fall caused by intersecting stress-relief joints.

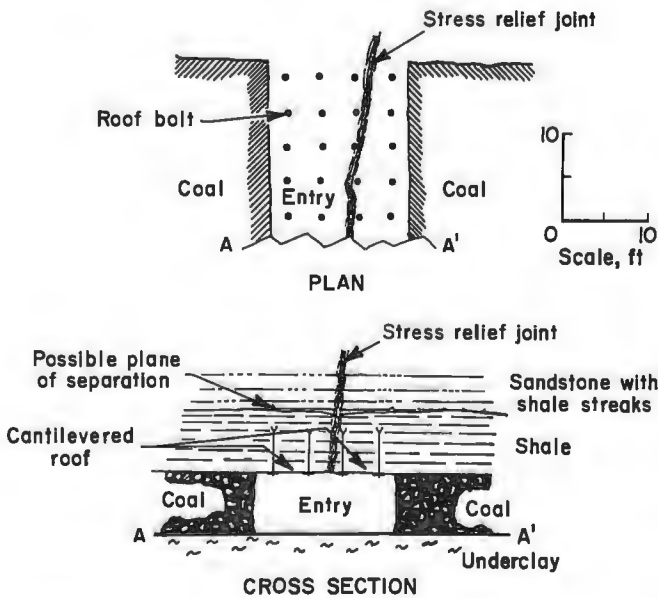


Figure 6.—Plan and cross section views of cantilevered roof failure caused by stress-relief joint paralleling development.

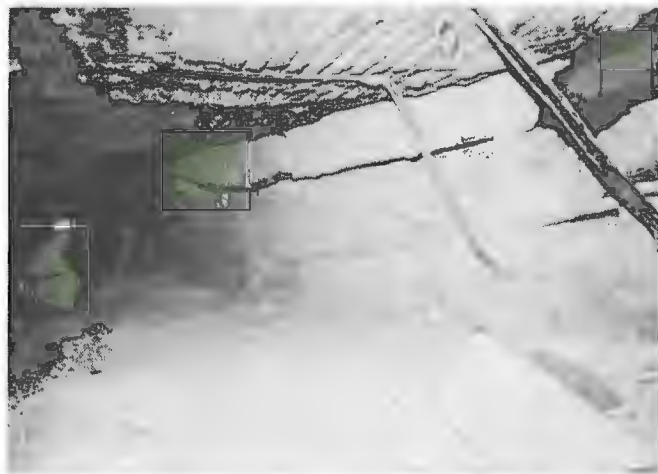


Figure 8.—Massive nature of roof fall caused by intersecting stress-relief joints within entry.

will break once failure starts. However, two important controls of failure height, bolt length and roof lithology, usually are known.

Failure height in roof unaffected by geologic discontinuities often is controlled by bolt length. Therefore, failures of less than the installed bolt length should not be anticipated. The thickness and character of the immediate roof also is important.

A contact between competent shale roof and sandstone at some short distance above the bolt height should be considered a likely failure horizon. If the thickness of the shale is two to three times the bolt length, failure will likely occur near anchor height.

Fissile shale and thinly interbedded sandstone and shale in the immediate roof possibly can fail below the bolting horizon between supports. Separation is more likely at the

next weakly bonded-bedding plane above the bolting horizon.

Massive sandstone roof is the least likely lithology to fail due to stress-relief discontinuities. Unless the

stress-relief joint occurrence is heavily weathered, the walls usually undulate and interlock. Failure height in this case can be assumed to be bolt length, unless a weakly bonded contact with an overlying lithology is known to be present.

SUPPORT SELECTION

The amount and type of roof support installed in most mining operations is limited by cost and clear-opening requirements for ventilation and haulage. Often, a single support pattern (generally included in the roof support plan) controls all stress-relief joint occurrences regardless of their nature or potential for failure. Understanding the nature of stress-relief jointing-induced roof failure, and the effect of that failure on various support installation patterns, is helpful in planning efficient, effective roof control.

Understanding failure mode is most important for long-lived and well-traveled areas of a mine (portal, ventilation, haulage, and escapeway entries) where they encounter the worst stress-relief conditions. This is usually within 200 ft of outcrop. As the distance from outcrop increases, less emphasis can be placed on supplemental support to control en masse roof failure. As the degree of weathering observed in encountered stress-relief joints decreases, immediate, on-cycle installation of supports with an observable reaction to pressure should be emphasized.

INSTALLATION OF SUPPORTS

The potential load that can be generated by stress-relief jointing-related roof failure is dependent on degree of weathering, orientation, and failure height. The known geometry, combined with an assumed failure height, enables a reasonable estimation of required support.

Where stress-relief joints simply cross an entry at or near 90°, support for en masse failure load usually is unnecessary. Installation of wood headers or metal straps across the occurrence usually is sufficient. Wood headers bolted tightly to the roof will give a better indication of incipient movement by strain deformation.

Stress-relief joints that parallel an entry are more difficult to control. A stress-relief joint closely paralleling one rib can be treated similarly to cutter roof (5), in which the roof rock fails in shear over the ribline. It is important to install support quickly to prevent any yielding of the roof. Angled bolts, installed to intersect the joint and anchor above the pillar, are effective supplementary supports in this situation (fig. 9). If a tilt-head bolter is not available, posts or cribs along the affected rib are effective.

Stress-relief joints that parallel the centerlines of entries are difficult to support and still maintain useful openings. Most stress-relief joints gradually diminish in degree of weathering and disappear along strike, regardless of their distance from outcrop. Therefore, if an unavoidable stress-relief joint does parallel mining, its effect will not persist. If the occurrence is in a planned return entry, installation of posts or cribs in the entry offers effective support without critically affecting movement of miners or ventilation air.

However, stress-relief joints at midentry in haulage or belt entries have to be supported while maintaining useful

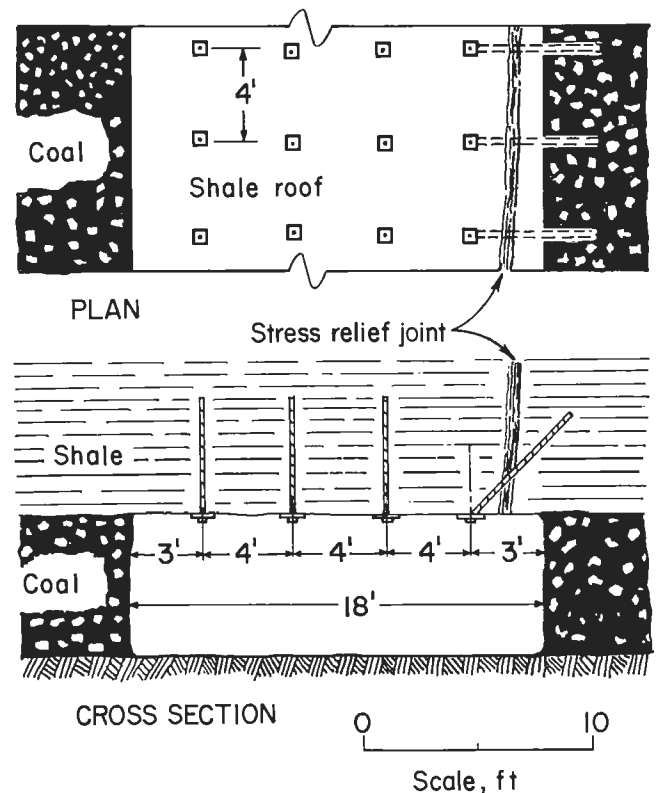


Figure 9.—Roof bolts angled to intersect stress-relief joint and anchor over pillar.

open-entry dimensions. Where a tilt-head bolter is available, supplemental bolts angled across the stress-relief joint and anchored into the roof on either side provide effective resistance to initial movement, and therefore, ultimate failure (fig. 10). Truss bolts also can be effective in this situation. Figure 11 shows a typical truss installation with the resultant forces transferred into the roof indicated by arrows. Compression generated by the truss at midspan inhibits deformation within the stress-relief joint if detachment occurs. Trusses can be installed either on cycle or as supplemental support.

If angle-bolting capabilities are not available, then use of posts with crossbars, or small cribs with crossbars, spanning the roof may be necessary, depending on the severity of the occurrence. If only a slightly weathered stress-relief joint is to be supported, wood headers tightly bolted across the joint can give an indication of movement if it occurs, although they provide little resistance to movement.

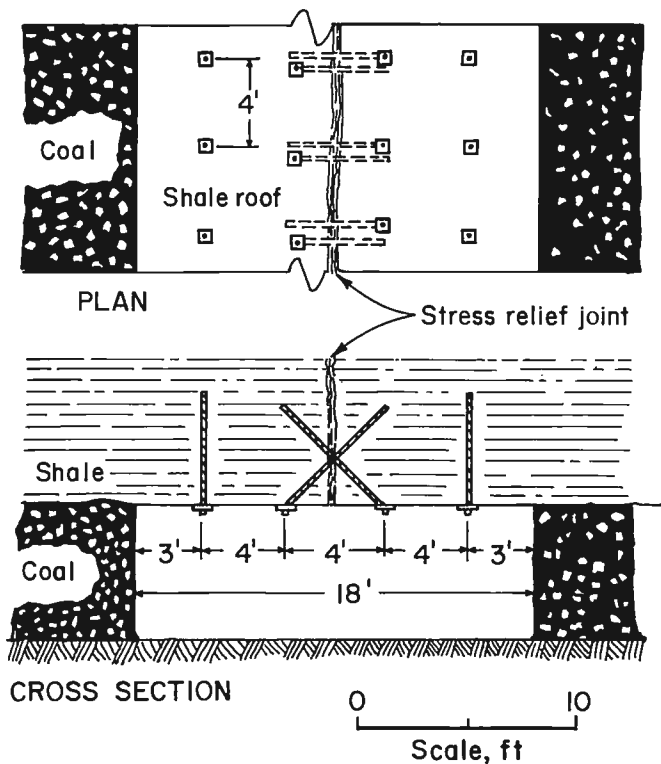


Figure 10.—Roof bolts angled across stress-relief joint at midspan to tie roof together.

The most difficult stress-relief joint occurrences to plan effective support are multiple or intersecting joints within an entry. The behavior of the roof in this situation is difficult to predict. If a block of roof isolated by stress-relief joints is in a critical entry that cannot be isolated from movement of miners and machinery, it may be necessary to calculate the weight of the block and plan supplemental support accordingly. Again, bolts angled through the stress-relief joints and anchored in competent rock, and roof trusses, offer the most support with the least obstruction of the entry. Posts or cribs along both ribs with either heavy wood or steel beams spanning the entry can support large loads in the event of massive roof failure between stress-relief joints. The amount of support in these situations is a matter of judgement by the operator based on the severity of the joint occurrences, experience with roof failure, and importance of the entry.

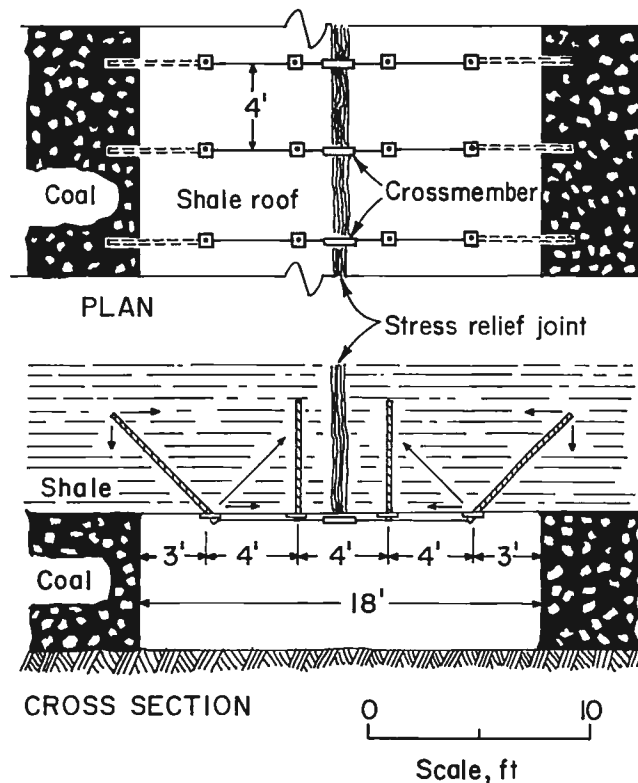


Figure 11.—Typical roof truss installation to support stress-relief joint at midspan, with arrows indicating resultant forces.

DESIGN CONTROLS

Design controls are steps taken to alleviate stress-relief jointing-induced roof instability before it is encountered. In hilltop operations, these steps include good portal preparation, a plan for approaching and mining near the outcrop barrier zone on advance, and a separate plan for retreat mining near the outcrop barrier. Several simple, logical steps in planning can improve safety and roof stability during each of these phases.

PORTAL PREPARATION

In planning a new hilltop operation's portal entries, several design options are available to improve roof conditions in this important, long-lived and well-traveled area of the mine. Because the most severe stress-relief roof conditions occur nearest the outcrop, strip mining the portal highwall to the deepest practical extent will result in improved roof conditions in these well-traveled entries.

Reducing the number and the width of initial entries driven into the hill reduces the number of potential problems that may occur. Tunnel liners could be considered for long-life mines if conditions closest to the outcrop are very severe. Once the roof quality is such that few stress-relief joints are likely to be encountered further from the outcrop, then the main drifts can be expanded to any number of entries desired.

When driving the portal entries, pay close attention to roof conditions where crosscuts are to be turned. Avoid turning crosscuts parallel to stress-relief joints if possible. This keeps the worst roof conditions above the pillars and eliminates long disruptions of the roof span. Make allowance for longer crosscut centers to control adverse roof conditions in the initial roof control plan. This will provide greater flexibility in turning crosscuts without violating the approved roof control plan.

MINING ON ADVANCE

Development of the portal entries, or close inspection of existing portal entries, gives a good indication of conditions that can be expected when approaching outcrop on the rest of a mine property. Entries that are planned to parallel the outcrop should be kept at the distance from outcrop where the stress-relief joints previously exerted little or no effect on roof stability. If that distance is much greater than the approved outcrop barrier zone, then entries can be driven perpendicularly from those paralleling the outcrop towards the barrier. Roof conditions

can be closely monitored and crosscuts staggered to avoid paralleling stress-relief joints, thereby keeping the potentially worst roof conditions above the coal pillars.

Mining often enters the nose area of a hill on development, with outcrop approaching from three sides. In this case, as few entries as possible should be driven down the middle of the nose towards the outcrop barrier. Entries then could be driven perpendicularly towards the outcrop ~~while again closely monitoring roof conditions and staggering~~ crosscuts if necessary to avoid paralleling any stress-relief joints that are encountered.

MINING ON RETREAT

Most of the severe injuries caused by roof falls associated with stress-relief joints were found to occur during retreat mining. Roof deformation (sag, convergence, and failure initiation under load) is greatly accelerated during retreat mining, enhancing the failure potential of large blocks of roof bordered by stress-relief joints. These facts stress the importance of maintaining an accurate map of stress-relief joints during development. By knowing the location and condition of joints before mining pillars, a safer mining plan is possible.

Where the outcrop barrier was approached perpendicularly during development, retreat mining can progress from the worst roof conditions back towards better roof. Although the use of staggered crosscuts on development may complicate retreat planning, it is at this stage that staggered crosscuts are most significant. As abutment pressure from the pillared area is transferred to remaining pillars, less instability will occur around stress-relief joints that only transect entries.

By planning pillar cuts so that any stress-relief joints will fall over an edge of the pillar being cut, exposure to unplanned roof falls can be minimized. Mines using remote-controlled continuous miners have an advantage during retreat mining by allowing the operator to remain farther from the immediately pillared area.

It is impossible to anticipate or try to describe every possible scenario under which retreat mining is likely to occur near the outcrop barrier zone. Nevertheless, the importance of understanding the nature of stress-relief joints, how they affect roof stability, and knowing beforehand where they occur in the mine can help mine operators to plan a safe, effective retreat sequence near outcrop.

SUMMARY AND CONCLUSIONS

Individual States control outcrop safety barrier design through the authority to approve or disapprove mine plans. Currently, most outcrop barriers are designed with widths based on experience with internal and property barriers. The Federal Government (MSHA) now controls the type and pattern of support used near outcrop through approval or disapproval of the required roof support plans submitted in accordance with the Code of Federal Regulations.

This paper attempts to aid both regulators and operators to understand the nature of roof instability caused by weathered stress-relief joints near outcrop. Operators can use this information to develop mine and roof control plans that improve roof stability near outcrop. Regulators, in turn, can use it to evaluate those plans.

Stress-relief joints are the primary geologic feature unique near outcrop that weaken mine roof. Their degree of weathering, orientation and spacing relative to the direction of mining, and anticipated failure height are the primary factors influencing support decisions to control stress-relief-induced roof instability. The support and mining options discussed in this paper when applied and modified to suit particular minesites, should enhance roof stability, and therefore, safety, when mining near outcrop. Unless otherwise stated, the supports mentioned are for stress-relief joints that have caused previous roof instability in a given mine environment.

1. Very narrow, slightly weathered stress-relief joints have the same effect on roof stability as common joints. As the degree of weathering in stress-relief joints increases, so does their potential for causing roof instability. The most severe stress-relief conditions are usually encountered in portal entries, where the outcrop is actually penetrated. Resin bolts provide better support than mechanical bolts in portal areas where anchorage may be in altered rock. If conditions are very severe, tunnel liners provide the most effective protection of both miners and equipment.

2. Slightly weathered stress-relief joints that lie transverse to entries are the least troublesome, creating two solid beams that span the roof. Wood headers tightly bolted across these joints will indicate incipient movement by strain deformation. Heavily weathered joints transverse to entries may require additional support to stop material from falling within the joint zone.

3. Stress-relief joints that parallel entries near one rib mimic the effects of cutter roof. Supplemental bolts angled through the joints and anchored above the pillar, or cribs or posts along the affected rib, are effective supplementary support.

4. Stress-relief joints that parallel the entry centerline require posts or cribs. If open-entry space is required, bolts angled through the joint from both sides tie the roof beam together, roof trusses put the roof in compression, or where tilt-head bolters are unavailable, posts or cribs with crossbars may be necessary to hold the anticipated weight of a fall.

5. Multiple or intersecting stress-relief joints within an entry require careful consideration when planning supplementary support. If the area cannot be isolated from the movement of miners and machinery, bolts angled through the joints and anchored in competent rock, or posts or cribs along both ribs with heavy wood or steel beams spanning the entry, can support large loads in the event of massive roof failure. The amount of support in these situations is a matter of judgement by the operator based on the severity of the joint occurrences, experience with similar roof failure, and importance of the entry.

6. Extensive stripping of overburden and coal at new portal sites can eliminate the most severe stress-relief conditions. Keeping the number and width of entries driven into the hill to a minimum, while avoiding turning crosscuts parallel to any joints encountered, will reduce the amount of roof instability that is likely to be encountered. Allowance for long crosscut centers to control adverse roof in the initial roof control plan will provide this flexibility.

7. Entries driven parallel to outcrop during mine development should be kept outside the area of stress-relief-induced roof instability encountered elsewhere in the mine. Entries can then be driven perpendicularly towards outcrop and crosscuts staggered to avoid paralleling any encountered stress-relief joints.

8. Most severe injuries associated with stress-relief jointing-induced roof instability occur during retreat mining. By approaching outcrop perpendicularly during development, retreat can progress from the worst roof conditions near outcrop back towards better roof conditions under deeper overburden. Stress-relief joint locations recorded on a mine map during development can aid in developing an effective retreat plan.

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MINER'S VIEWS ABOUT HOW TO PREVENT PEOPLE FROM GOING UNDER UNSUPPORTED ROOF

By Robert H. Peters¹

ABSTRACT

Groundfall accidents have been the leading cause of fatalities in the underground coal mining industry for many years. Statistics from the Mine Safety and Health Administration (MSHA) indicate that approximately half of the victims of these fatal accidents were in an area

where no devices had been installed to support the mine's roof. This paper summarizes the opinions of 268 coal miners and 29 first-line supervisors concerning why people go under unsupported roof, and how to prevent this behavior. Interviews were conducted at six minesites.

INTRODUCTION

Going under unsupported roof is a very dangerous activity. It directly contributes to many fatalities and severe injuries in the underground coal mining industry. According to MSHA's accident statistics, in most years, roof fall accidents continue to be the leading cause of fatalities in underground coal mines. During the 5-year period 1987-91, 87 coal miners were killed by falls of roof and rib, and over 4,000 were injured. According to Krese (1),² approximately half of the miners who are killed by roof falls are in an area of unsupported roof at the time of the accident.

Groundfalls have been a major threat to miners' safety ever since mining began. Most miners are told repeatedly that "it is very dangerous to go under unsupported roof" and know that mine safety regulations prohibit this behavior. Nevertheless, accident investigations and data from interviews with coal miners suggest that there are individuals in the coal mining work force who, in certain circumstances, do not hesitate to go under unsupported

roof (4-5). It appears that very little research has been performed on this issue. Therefore, the U.S. Bureau of Mines performed the work described in this paper to learn more about why miners go under unsupported roof and how to prevent this behavior.

Some of the reasons for going under unsupported roof are directly related to the task being performed. However, to fully understand what causes people to go under unsupported roof, one must also consider other factors. These other factors include: the miner's perception of the company's policy concerning going under unsupported roof and how it is enforced, the attitudes and behavior of the employee's supervisor and coworkers, and the employees' own attitudes and expectations regarding the risks and benefits of doing things under unsupported roof. Interview data were also collected on these other factors. The complete findings from interviews with 297 miners can be found in Bureau of Mines Information Circular 9300 (4). The focus of this paper is limited primarily to miners' views about what types of activities are likely to be performed under unsupported roof, and what types of actions might help to prevent miners from performing these tasks under unsupported roof.

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²Italic numbers in parentheses refer to items in the list of references at the end of this paper.

METHODS

A sample of miners and section supervisors was asked to respond to a variety of questions concerning going under unsupported roof in one-on-one interviews. All interviews were conducted in private, usually at a dinner area near the miner's worksite. Employees were interviewed only if their job required them to work near face areas of the mine on a daily basis. All participants were assured that their responses would be held in confidence and were told that their participation was completely voluntary. Interviews required approximately 25 min to complete.

Data were collected from February 1989 to March 1990. A total of 297 employees from six underground coal mines participated in the study. Table 1 shows the mine, the number of miners interviewed, the number of underground employees, the location, the rate of lost-time injuries per 200,000 h of exposure, the seam height, and whether or not miners were represented by a union. All mines were using the room-and-pillar method of extraction, remotely operated continuous miners, and roof bolters equipped with automated temporary roof supports.

Table 1.—Characteristics of mines included in sample

Mine	Number of miners interviewed	Number of underground employees	Location	Injury rate ¹	Seam height, in	Union
A ..	66	437	West PA	19.14	48-54	Yes
B ..	45	260	East OH	9.32	66-72	Yes
C ..	56	285	West MD	28.07	84-86	No
D ..	53	430	South IL	6.35	84	No
E ..	50	480	North AL	4.50	40-42	Yes
F ..	26	50	West CO	2.05	84-90	No

¹Per 200,000 employee-hours of exposure.

One should not conclude that the results of this study are representative of the entire industry. The sample of mines that participated in the study was small, and it was not randomly selected. Several mining companies who were invited to participate in the study were unwilling to do so.

REASONS FOR GOING UNDER UNSUPPORTED ROOF

This section presents miners' responses to three sets of interview questions concerning why miners sometimes go under unsupported roof. In the first set of questions, miners were asked to describe an incident in which they have recently observed a coworker doing something under unsupported roof. In the second set of questions, miners were asked to describe the most recent instance in which they unintentionally went under unsupported roof. In the third set of questions, miners were asked to identify tasks that are apt to be performed under unsupported roof by people who perform their type of job (e.g., roof bolters).

OBSERVATIONS CONCERNING COWORKERS

One way to determine what might cause miners to go under unsupported roof is to ask them to describe a recent incident in which they observed a coworker doing something under unsupported roof. Miners were asked several questions concerning such incidents. They were first asked, "Have you ever seen someone go under unsupported roof?" Eighty-six percent of the sample said that they could recall an instance in which they had seen someone go under unsupported roof. Miners were next told, "Consider the most recent time you saw someone go

under unsupported roof. Has it been within the past 6 months?" Of the 225 miners who said that they had seen someone under unsupported roof, 130 (58%) said that the most recent time had been within the past 6 months. These 130 miners were asked several questions about the most recent incident. The questions and their responses are listed below:

"Do you think this person was aware that he/she was under unsupported roof?"

	Percent
Yes	71.5
No	27.7
Uncertain	0.8

"Did this person take a look at the roof before he/she went under it?"

	Percent
Yes	59.2
No	28.5
Uncertain	12.3

"How far in by the last row of supports did he/she go?"

	<i>Percent</i>
0 to 5 ft	52.3
6 to 10 ft	30.0
over 10 ft	17.7

"How long was he/she there?"

	<i>Percent</i>
a few seconds	54.6
1 or 2 min	22.3
under 10 min	12.3
10 to 20 min	7.7
over 20 min	3.1

These responses suggest the following: 72% of those who reported recently seeing someone under unsupported roof thought that the incident *had* been an intentional act. In about half of the incidents that were described, it appears that the people under unsupported roof had tried to be cautious about their behavior. They looked at the roof before going under it, they went less than 10 ft beyond the last row of supports, and they were under unsupported roof for only a few seconds. Of course, miners may behave differently when they realize that someone could be observing them than when no one is present. It could be that miners who go under unsupported roof are less cautious about it when they know no one is around to observe them. Miners were also asked to describe what the person who they observed under unsupported roof was doing. The most frequently mentioned replies were as follows:

- Walking through unbolted crosscuts (17).³
- Walking (11).
- Operating a continuous miner (11).
- Hanging or extending ventilation tube (10).
- Retrieving things left laying on the ground (7).
- Marking the roof (5).
- Rock dusting (5).
- Repairing a continuous miner (4).
- Operating a scoop (4).
- Operating a mobile bridge (3).
- Examining a roof fall (3).
- Restoring power to a remote continuous miner (3).
- Carrying supplies (3).
- Operating a roof bolter (3).

³Numbers in parentheses indicate the number of persons who replied.

Miners were next asked:

"Does this person often go under unsupported roof?"

	<i>Percent</i>
Yes	15.4
No	76.9
Uncertain	7.7

Relatively few persons indicated that the person they had most recently observed under unsupported roof was doing it on a frequent basis. (However, at each mine, at least a few miners would mention that, although going under unsupported roof was not common at the mine where they were currently working, it was done rather often at mines where they used to work). If the miner's response to the question above was no, the miner was asked, "Had anything unusual happened on that day that might have caused this person to go under unsupported roof?" Most were unable to identify any type of unusual event or circumstance. Those who were able to cite something unusual thought that the following events or circumstances may have been at least partially responsible for why the person had gone under unsupported roof:

- There had been a roof fall (5).
- The roof had fallen on the continuous miner (2).
- A rib fall had tripped the circuit breaker on the continuous miner so it could not be operated by remote (1).
- Poor roof conditions had caused us to get behind on production (1).
- The person had only recently been assigned to the job that was being performed (1).
- The continuous miner was broken down and could not be moved (1).
- An unbolted area had been partially rock dusted (1).
- There had been a power outage (1).
- They were working on a Saturday to get caught up on production (1).

Unintentionally Going Beneath Unsupported Roof

Some of those who go beneath unsupported roof may not realize that they have gone beyond the last row of bolts, i.e., their action was unintentional. Miners were asked questions to determine whether this happens very often and to find out what activities are usually being performed when people unintentionally go under unsupported roof. Miners were first asked if they had ever unintentionally gone into an area of unsupported roof. Eighty-two percent of the sample indicated that they could

recall such an incident. Those who could recall a time that they had unintentionally gone under unsupported roof were asked to estimate how long ago the most recent incident had occurred. Approximately 60% of those who could recall an instance in which they had unintentionally gone under unsupported roof estimated that the most recent incident had occurred within the past year. About 24% thought that the most recent incident had occurred within the past month.

~~Miners were next asked:~~

"What were you doing when you realized you were under unsupported roof?"

The most frequently mentioned replies were as follows:

- Walking (59).
- Hanging or extending ventilation tube (11).
- Operating a scoop (9).
- Repairing a continuous miner or bolter (8).
- Hanging ventilation curtain (8).
- Rock dusting (7).
- Operating a bolter (7).
- Operating a continuous miner (6).
- Carrying supplies (6).
- Setting timbers (5).
- Operating a ram car or shuttle car (4).

Several of those who said that they were walking somewhere when they discovered that they had gone under unsupported roof noted that no warning devices had been

posted at the last row of bolts. In a few cases, miners noted that the area they were walking in had been rock dusted, leading them to believe that it was bolted. At one mine, several miners noted that the sliding (telescoping) ventilation tubes would often become jammed, causing miners to have to go to the end of the slider closest to unsupported roof and pull on it to get it to fully extend.

In summary, it appears that a significant proportion of people who work at the face unintentionally go under unsupported roof. This suggests that it is very important that warning signs always be posted at the edge of unsupported roof, and that these signs are highly visible.

Job-Specific Reasons

To determine what might cause miners who perform a particular face crew job to go under unsupported roof, each participant was asked to respond to the following open-ended question:

Considering the different tasks involved in doing the [INSERT MINER'S JOB TITLE (e.g., roof bolter's)] job, which ones are most likely to cause them to go under unsupported roof?

Table 2 lists some of the most frequently cited tasks and indicates the number of people from each job category who mentioned it. For example, the first column of numbers shows the number of continuous miner operators or helpers who mentioned each task listed along the left side of the table as being likely to cause miner operators or helpers to go under unsupported roof.

Table 2.—Activities cited as likely to cause miners to go under unsupported roof

Activity	Job Title						Other
	Miner operator	Roof bolter	Mechanic	Haulage operator	Scoop operator	Section supervisor	
Walking through unbolted crosscuts	2	2	2	6		5	9
Unintentionally walking (no signs)		2	1			3	4
Hanging ventilation curtains	8	1		6			1
Hanging or extending ventilation tubing	11	1		9		2	4
Cleaning up and resupporting after roof falls . .		8		1		2	2
Restoring power to continuous miner	14		3	2		4	
Repairing continuous miner	8		9			2	
Retrieving wrenches and steels		18				1	
Operating the scoop beyond supports					13		3
Advancing the shuttle-ram car beyond bolts . .				18			

PREVENTIVE MEASURES

As previously explained, miners were asked to identify tasks that are likely to be performed under unsupported roof by miners who do their type of job. Whenever miners identified such a task they were also asked the following question:

What could be done to make it less likely that [INSERT MINER'S JOB TITLE] would go under unsupported roof while [INSERT TASK CITED]?

This section presents miners' ideas about actions that might be taken to make it less likely that miners would go under unsupported roof to perform various tasks. Some of their ideas may not yet be feasible given the status of current technology and the resources typically available to mine operators.

Activity associated with going under unsupported roof: hanging ventilation curtain.

Suggested countermeasures:

- Use spring loaded ventilation curtain.
- Use miners equipped with scrubbers so the ventilation curtain does not have to be kept so close to the face.

Activity associated with going under unsupported roof: hanging or extending ventilation tube.

Suggested countermeasures:

- Use telescoping ventilation tubes (sliders).
- Put a handle on the end of the slider so it can be extended by pushing on the handle with a long pole.
- Devise a way to attach the slider to the continuous miner so it will automatically feed out as the miner advances.

Activity associated with going under unsupported roof: repairing continuous miners or bolters that break down under unsupported roof and cannot be moved.

Suggested countermeasures:

- Perform better preventive maintenance.
- Perform preoperation maintenance checks.
- Communicate potential equipment problems to those who will be using the equipment on the following shift.
- Ensure that an adequate supply of timbers or safety jacks is kept reasonably close to the face.

- Set temporary supports to protect the mechanic, and a warning sign should be posted so the mechanic will realize that the machine is under unsupported roof.

- Make clear who is responsible for setting temporary supports in these situations.

Activity associated with going under unsupported roof: restoring power to a remote continuous miner.

Suggested countermeasures:

- Develop a method of resetting the breaker from the remote, the power center, or some place that is outby the last row of bolts.
- Develop a guard that will protect the power off button or emergency stop button from being accidentally activated if pieces of coal fall into the operator's compartment.

Activity associated with going under unsupported roof: advancing the continuous miner beyond supports when the machine is being operated from the cab.

Suggested countermeasures:

- Hang long warning flags from the last row of bolts on the side that the operator can see most easily.

Activity associated with going under unsupported roof: pulling the continuous miner cable.

Suggested countermeasures:

- Develop a reel for taking up slack in the cable.

Activity associated with going under unsupported roof: cleaning up and resupporting the roof after large and/or high roof falls.

Suggested countermeasures:

- Use a remotely operated continuous miner to remove the fallen material.
- Use a remotely operated scoop to remove the fallen material.
- Use bolters equipped with temporary roof supports that can be extended to reach high areas of the roof.
- Keep safety jacks someplace on the bolter that will prevent them from getting covered with dirt, grease, etc.

Activity associated with going under unsupported roof: marking the roof to indicate where bolts need to be installed.

Suggested countermeasures:

- Mount a measuring device (e.g., antenna) near the front of the bolter to help the operator line up the machine properly for the first row of bolts.

Activity associated with going under unsupported roof: unintentionally walking under unsupported roof.

Suggested countermeasures:

- Do not leave an area of unsupported roof without posting warning devices.
- Do not rock dust an area until it has been bolted.
- Use a standardized warning device with some type of unique feature (e.g., a unique color) to warn people who are approaching unsupported roof, and do not use this device for any other purpose (to rule out the possibility that miners might misinterpret what it means).
- Do not leave crosscuts and breakthroughs unbolted at the end of a shift; if the situation does occur, multiple warning signs should be posted.

Activity associated with going under unsupported roof: retrieving wrenches and steels that fall under unsupported roof.

Suggested countermeasures:

- Install a wrench holder near the bolter head.
- Use a bolt or a pole with a hook on the end to retrieve tools that fall beyond supported roof.
- Use "lock-in" wrenches that are less likely to come off unexpectedly.
- If a wrench or steel falls beyond supported roof leave it there and use another one.

Activity associated with going under unsupported roof: repositioning straps or pans that fall off as the bolter moves forward.

Suggested countermeasures:

- Use bolters equipped with devices that hold the straps securely in place while the bolter is moving forward.
- If a pan or strap falls beyond supported roof, leave it there and use another one.
- Use a bolt or a pole with a hook on the end to retrieve the pan or strap.

Activity associated with going under unsupported roof: scaling the roof.

Suggested countermeasures:

- Ask the continuous miner operator to use the cutter head of the miner to knock down loose pieces before pulling out of the cut.

Activity associated with going under unsupported roof: advancing the shuttle car or ram car operator's compartment beyond the last row of bolts.

Suggested countermeasures:

- Hang long warning flags from the last row of bolts to help the operators of remotely operated continuous miners judge when the car operator is beneath the last row of bolts.
- Install longer conveyors on the back of the continuous miner.
- Develop a sensor that could be placed on remotely operated continuous miners to show the operator its location with respect to the last row of bolts.

RECOMMENDATIONS

It appears that mine operators currently rely primarily on threats of disciplinary action and classroom safety lectures to discourage miners from going under unsupported roof. However, several other options may also be worth pursuing. The following is a list of suggestions for keeping miners away from unsupported roof. (For additional details concerning how to carry out these six actions see Peters (2) (pages 20-27), and Peters (3)).

Action 1. Eliminate sources of motivation for going under unsupported roof as feasible by changes in equipment, work procedures, policies, etc. To accomplish this, it may be helpful to ask miners to identify situations

that are likely to tempt people to work under unsupported roof, and to suggest what might be done to prevent these situations from occurring. This input could be obtained through interviews, surveys, or small group discussions. The Bureau's research suggests that many of the factors influencing miners to go under unsupported roof vary from mine to mine. Therefore, it is important that the operators of each mine perform their own assessment.

When to perform action 1: Evaluate the situation at least every year or two, and whenever new equipment or work procedures are introduced to a face crew.

Action 2. Offer incentives for eliminating the precursors of going under unsupported roof. For example, miners may go under unsupported roof unintentionally because warning signs are not posted immediately after a cut of coal has been removed by the continuous miner. In such a situation, a system could be developed for randomly measuring performance on this task and tying rewards to how often the signs are missing at locations where they should have been posted.

When to perform action 2: Do not necessarily offer incentives on a continuous basis. They should be used whenever the target behaviors (or target conditions) appear to become less prevalent.

Action 3. Increase fear of the harm that roof falls can cause. For an illustration of this approach, see the paper by Mallett in this proceedings.

When to perform action 3: Use with all new employees, and as a reminder to first-time transgressors.

Action 4. Conduct behavioral modeling to show supervisors how to interact with miners who they find under unsupported roof.

When to perform action 4: Use with all new section supervisors, and conduct refresher training every few years.

Action 5. Have high level managers communicate their commitment to the goal of keeping people away from unsupported roof.

When to perform action 5: Do this at least annually and whenever someone has been found violating this rule.

Action 6. Use disciplinary actions.

When to perform action 6: Threaten formal action with first-time transgressors. Use formal action if a second transgression occurs. If the behavior reappears after one attempt has been made at formal punishment, the person should be quickly eliminated from working near areas of unsupported roof. If the person has other types of useful skills, offer them an inherently safe job, one that is removed from areas of unsupported roof and that is unlikely to tempt the person to perform other types of unsafe acts, e.g., a job in an office or some other safe work area aboveground.

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TRAINING THAT ENCOURAGES MINERS TO AVOID UNSUPPORTED ROOF

By Launa G. Mallett,¹ Charles Vaught,¹ and Robert H. Peters²

ABSTRACT

Groundfall accidents have been the leading cause of fatalities in the underground coal mining industry for many years. Investigations of fatalities due to groundfalls reveal that approximately half of the victims were in an area where no devices had been installed to support the mine's roof. Three new sets of training materials have recently been developed. They are intended to discourage miners

from going under unsupported roof. Each set consists of a videotape and an instructor's guide. This paper was prepared by the U.S. Bureau of Mines to (1) present evidence from a recent field test of these training materials, and (2) provide some suggestions to mine operators about how to make effective use of these materials.

INTRODUCTION

Groundfalls have been a major threat to miners' safety ever since mining began. Most miners are told repeatedly that "it is very dangerous to go under unsupported roof" and know that mine safety regulations prohibit this behavior. Nevertheless, accident investigations and data from interviews with coal miners suggest that there are individuals in the coal mining work force, who in certain circumstances, do not hesitate to go under unsupported roof (Peters, 5-6).³ During the period 1986-90, 95 coal miners were killed by falls of roof and rib, and over 4,000 miners were injured. Appendix A shows that fatal groundfall accidents account for a major portion (46%) of the total fatalities in underground coal mines. Approximately half of the victims of these fatal groundfall accidents were in an area where the roof was unsupported (Krese, 3). These statistics clearly indicate that there is a great need to identify and apply techniques that will be effective in encouraging miners to avoid areas of unsupported roof.

To address this problem, the U.S. Bureau of Mines is conducting research to (1) learn more about why miners go beneath unsupported roof, (2) develop training materials to discourage miners from going beneath unsupported roof, and (3) provide recommendations to mine operators concerning changes in equipment, work procedures, or policies that would reduce the incidence of miners going under unsupported roof. The first task listed above has been accomplished by interviewing 297 face crew workers from six different mines. The data gathered during those interviews is the base of information being used for all remaining project activities. The second task, development of training materials, provides the focus of this paper.

In March 1991, several mine safety and health specialists were brought together to discuss findings from the Bureau's interview data and a review of related literature. These individuals also discussed how that information could be provided to the mining industry in ways that might help lower the incidence of workers going under unsupported roof. The recommendation of this group was that several short training packages be prepared for use separately or in combinations. These packages should consist of materials that are presented in different forms and target different populations within the industry.

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³Italic numbers in parentheses refer to items in the list of references preceding the appendixes at the end of this paper.

FINDINGS FROM THE LITERATURE

The usual techniques for discouraging miners from going inby supports appear to be limited to those verbal warnings about the danger of going under unsupported roof made during safety talks, and in some cases, threats concerning disciplinary actions that might be taken if an employee engages in such behavior. However, these techniques have some significant drawbacks. The effects of verbal warnings to avoid dangerous acts or conditions are often of short duration. After employees have heard these warnings a couple of times, further repetitions probably have little or no impact. Supervisors are often reluctant to use formal disciplinary actions because they wish to avoid interpersonal conflicts and various other undesirable responses (Arvey, 1). Also, owing to the layout of a typical underground working section, it is impossible for section supervisors to monitor closely what each member of the face crew is doing and where they are with respect to the last row of permanent roof supports. Other options need to be examined.

Fear messages are a widely used strategy for encouraging employees to perform self-protective acts or avoid unsafe ones. Fear messages may emphasize threats to physical safety, emotional health, social functioning, financial well-being, or other risks. Leventhal (4) argued that the most effective use of fear includes a threatening message followed by appropriate recommendations. Those who make use of fear messages hope that employees will perceive the recommended behavior as leading to a reduction of the threat and that they will begin following the recommended actions. The research evidence is quite clear in showing that fear communications can be effective in persuading people to modify their attitudes and intentions toward adopting some form of preventive act or treatment to avoid an unwanted outcome. Leventhal (4) cites over 20 empirical studies in which fear messages produced significant changes in attitudes toward taking various types of precautionary measures.

This technique may be especially beneficial in stopping miners from going under unsupported roof. Research (Leventhal, 4) indicates that fear messages are more likely to have an impact when the consequences of the unsafe act can be portrayed as severe. In the case of roof fall accidents, this would not be hard to do. The consequences of being hit by a roof fall are often harsh. They are the most frequent cause of accidental death in coal mines. If the person survives, it often takes them an extended period to recover, and they may be permanently disabled.

It is especially important to instill fear of unsupported roof in all new miners before they even have an opportunity to go under it. It is very likely that if they walked under unsupported roof a few times, nothing would fall on

them. This would, unfortunately, tend to make them even less afraid of going inby supports. The more time miners spend under unsupported roof, the more likely they will be to doubt that such activity is dangerous, and the greater is their chance of being harmed. If new miners can be taught to form safe work habits, it will be relatively easy for them to avoid going under unsupported roof. Once an unsafe habit has formed, it is difficult to break. Rather extreme forms of influence must be used to stop the habitual behavior, and if the influence is not applied long enough for the new safe work habit to become well-established, the old habit will soon return.

Several strategies could be used to influence miners to avoid unsupported roof, including incentives, disciplinary action, supervisory training, and employee surveys (5). When communicated successfully, however, fear messages have an important advantage over techniques such as the use of rewards and punishments (which must be imposed by the supervisor or some other external agent). Consider two miners, Al and Bill. Al's attitude toward avoiding unsupported roof is that "I will stay away because my boss does not want me to do it; however, I really don't think anything bad would happen if I did it." Through training, seeing someone else get hurt by falling rock and experiencing some close calls of his own, Bill's attitude has become, "I will stay away from unsupported roof because I am afraid that I will get seriously hurt by it."

Bill's motivation to avoid unsupported roof comes from within, not from some external agent who punishes or rewards. This means that Bill is going to avoid unsupported roof regardless of whether he is being offered a reward or threatened with punishment, regardless of whether anyone is watching, regardless of whether it would take only a few seconds to accomplish something that could be done easier or faster by going under unsupported roof, etc.

On the other hand, Al's actions are influenced by many situational factors. Situations will arise in which he decides that there really is no good reason why he shouldn't go inby supports. If he is caught under unsupported roof and is in some way punished, he is apt to become frustrated and hostile toward his supervisor and management because he feels that he really didn't do anything wrong.

In comparing internal to external control systems, the one that is clearly superior is the one that functions internally. Therefore, it would appear that attempts should be made to convince miners that it is extremely dangerous to go under unsupported roof. Efforts should be made to make miners so scared of what unsupported roof can do to them that they make a concerted effort to stay away from it regardless of the circumstances. The

costs involved in using this strategy are minimal. They would include only whatever time and resources might be needed to plan and execute the communication on a

periodic basis. In summary, it appears valuable to use fear messages to discourage miners from going under unsupported roof.

DESCRIPTION OF THE TRAINING PACKAGES

Unfortunately, there appears to be very little available in the way of films or other forms of communication that are apt to produce a high level of fear or aversion to going under unsupported roof. The first set of short training packages to be developed based on the Bureau's research is an attempt to meet that deficiency. These packages, compiled collaboratively by the Mine Safety and Health Administration and the Bureau, were designed to (1) instill fear of going under unsupported roof, and (2) generate group discussions about what miners need to do to ensure that they do not expose themselves to such hazards.

Each of the three packages that have been constructed contains one short (10 to 15 min) videotape and a four-page instructor's guide. The lengths of these tapes were limited so that they could be used for short safety talks or, with other materials, for longer sessions. The instructor's guides were designed to help trainers utilize the tapes as part of an effective training activity.

All three tapes follow a uniform format. First, a miner tells about either witnessing or being involved in a roof fall accident and then an interviewer asks some specific questions regarding the event. Professional actors are not used. Instead, a Bureau researcher interviews the

individual who experienced the fall and lets him tell the story of the event in his own words. When the miner has finished, questions are asked by the interviewer to highlight specific training points.

~~A separate instructor's guide is available for each tape.~~ These guides consist of two pages of information for the instructor and two pages that can either be duplicated and handed out to trainees or made into overhead transparencies. The first page introduces a tape, gives hints for using it, and lists other sources of information that may be useful for trainers in preparing to teach their class. Sample discussion questions with suggested training points are given on the second page. These questions, without answers, are provided so that they can be distributed to the class or used as an overhead transparency. A figure of the accident scene is also provided. Each instructor's guide stresses that discussion following any showing of the video is the most important segment of the training exercise. Trainers are encouraged to conduct classes in such a way that trainees will ask questions, express their ideas, and relate the material to their worksites. (See Appendix B, "Instructor's Guide.")

DEVELOPMENT OF TRAINING PACKAGES

The materials were designed in two parts: (1) videotaped interviews, and (2) instructor's guides. All three interviews were videotaped at the National Mine Health and Safety Academy in Beckley, WV. After initial editing was done, these tapes were shown to groups of attendees at the National Mine Instructor's Conference held at the academy in October of 1991. Reactions from these mine safety and health specialists, discussed below, provided information used during further editing of the videotapes and in writing the instructor's guides.

Individuals, who participated in the sessions conducted at the Instructor's Conference, provided verbal feedback about their reactions to each videotape. This feedback included comments on interview content, which resulted in the subsequent editing of one tape. Feedback was also given on information thought to be needed in any accompanying instructor's guide, including key training points that could be made by showing each of the videos. Design of the guides was based largely on these discussions.

In general, those individuals, who attended sessions at the Instructor's Conference, reacted favorably to all three videotapes. Evaluation questionnaires were distributed after each tape was shown and discussed. One question asked respondents to rate the video in terms of usefulness as a mine training aid on a five item scale: (1) extremely useful, (2) very useful, (3) useful, (4) somewhat useful, and (5) not at all useful. Ninety percent of the 60 people who responded rated each tape at least "useful." No one rated any of the tapes as "not at all useful." On a similar scale, over half of the respondents (54.8%) rated all tapes as interesting or very interesting. Such responses do not prove the validity of these materials. Regardless, if those instructors present had not found the videotapes to be interesting, or had not thought them to be useful training tools, they would not be likely to incorporate them into future mine training programs. Workers' assessments of the effectiveness of these materials will be discussed next.

MINERS' EVALUATIONS OF TRAINING PACKAGES

Field testing of the roof fall videotapes and instructor's guides began in January 1992. This section outlines the protocol that was used and discusses worker attitudes toward the value of this package as an intervention strategy. A critical aspect of any attempt to estimate the apparent validity of a training approach is to ask for respondents' judgments of its authenticity and functional worth. To reflect these two qualities, affected individuals ought to rate any treatment high with respect to its intended goal of influencing their knowledge or behavior. If they do not, the device in question would be invalid no matter what its other properties, because it would not be accepted or judged worthwhile by the audience for which it was intended. Even so, indications of ostensible utility, while necessary, are not sufficient to allow for estimations of real-world impact. These assessments must be based on some observed or self-reported change in thought or action.

Mine A is the first site for which there are complete data. At this operation a total of 113 workers (five annual retraining classes) watched the same two videos. The instructor followed an unvarying procedure in each of the five classes. First, he would introduce a tape by showing an overhead projection of the line drawing from his instructor's guide and explaining what was being done at the worksite. After trainees had viewed this videotape, the class was broken into five groups with approximately three miners in each. Every group was given a different question from the instructor's guide to deliberate among themselves. One person was chosen to report the results of this dialogue for his or her group. A general discussion then followed the group reports. The second videotape was then shown. After both videos had been shown and discussed, the trainer administered a short questionnaire, which is included as appendix C.

Approximately 11% of the trainees can be classified as maintenance technical personnel, a category that includes mechanics, electricians, surveyors, engineers, and others who work underground although not directly in coal production. Another 13% were in management positions. All the remaining respondents were miner laborers; those workers who regularly labor at coal production jobs in the mine. Their mean age was almost 38 and the average length of time they had worked underground was 15 years (table 1).

Data from these questionnaires show that a preponderance of workers rated both videotapes highly in terms of ability to hold trainee interest and the ease with which tapes and materials were understood. Approximately ninety-eight percent of all respondents agreed that problems described in the taped interviews could happen in real life and that watching the videos was useful. Perhaps

something of a surprise, given the veteran nature of mine A's workforce, is the fact that almost three-fourths of these individuals agreed they had learned something new from each tape and the discussion following. Most importantly, 92% of those questioned agreed that the exercise would cause them to be more careful to avoid unsupported roof. The complete array of responses is given in table 2.

Table 1.—Demographic characteristics of trainees at Mine A

Characteristic	Number	Mean	Standard Deviation	Frequency, pct
Age	109	37.79	6.22	N/A
Experience	104	14.91	3.98	N/A
Miner-Laborer	86	N/A	N/A	76.1
Management	15	N/A	N/A	13.3
Maint.-Tech	12	N/A	N/A	10.6

NA Not available.

Table 2.—Miners' ratings of materials' validity and utility

	Number	Yes, %	No, %
Introduction was useful	113	93.8	6.2
Videotape was interesting	112	92.9	7.1
Tape dialog was easy to follow	113	95.6	4.4
Diagram was easy to understand	112	92.0	8.0
Could happen in real life	113	97.3	2.7
Watching the tape was useful	112	98.2	1.8
Something new was learned	108	73.1	26.9
Follow-up discussion was useful	113	96.5	3.5
Something new was learned from discussion	108	72.2	27.8
Exercise took too long to complete	110	15.5	84.5
Exercise will help them remember	113	96.5	3.5
Will be more careful	113	92.0	8.0
Worth effort to avoid unsupported roof	113	95.6	4.4
Remember worker going inby supports	112	78.6	21.4
Have been tempted to go inby supports	111	62.2	37.8

Approximately 6 weeks after the training classes were held at mine A, Bureau researchers conducted a follow-up evaluation. This post-training questionnaire was administered as the first part of a safety talk on the dangers of going under unsupported roof. This talk was given at the beginning of each shift by one of the Bureau researchers. Eighty-two of those 113 trainees, who originally responded, completed a follow-up questionnaire. Another seven individuals, who had not seen the videos, were asked to do a portion of the evaluation. The post-training questionnaire is included as appendix D, and the complete presentation of their answers is contained in table 3.

One interesting observation taken from table 3 is that only slightly more than one-fourth of the respondents reported talking with others about either of the tapes after their training was over. Yet, almost three-fourths of the

trainees indicated they had thought more than usual about the possibility of getting hurt by a roof fall and 89% said that they had become more careful to avoid going under unsupported roof. Finally, roughly half of all respondents (43% and 57% respectively) suggested that they and/or their buddies had changed some of their work habits as a result of having been sensitized to the dangers of going inby permanent support.

In sum, the trainees at mine A exhibited positive attitudes toward these training materials, concluding they were authentic, appropriate, fairly easy to comprehend and would help them to remember important points. Moreover, 92% of all respondents said originally they felt the training exercise would cause them to be more careful to avoid going under unsupported roof. This stance was reiterated in the follow-up evaluation, where 89% of those questioned indicated that they had indeed been more

careful to avoid getting beyond the bolts. Such a high agreement between self-reported intention and subsequent action strongly suggests the videotapes did have at least a short-run effect on miners' attitudes and behavior.

Table 3.—Miners' posttraining evaluations of videotapes

	Number	Yes, %	No, %
Remember seeing the tapes	89	92.1	7.9
Talked about the videos with anyone . . .	84	26.2	73.8
Talked about causes for going inby supports	91	48.4	51.6
Thought more about being injured	93	73.1	26.9
More careful to avoid unsupported roof . .	93	89.1	10.9
Changed habits to avoid unsupported roof	91	42.9	57.1
Co-workers changed habits'	86	57.0	43.0

INSTRUCTOR'S EVALUATION OF TRAINING PACKAGES

Approximately 1 month after training had been completed at mine A, the instructor who had conducted all field test sessions was interviewed by telephone. He had used the material as part of a standard 8-h annual refresher training program, which was developed and then presented to those classes discussed above. As mentioned earlier, two of the three videotapes were shown to each class. During the telephone interview, this instructor explained how he and his colleague chose which training packages to use. The instructors decided that not enough time could be devoted to ground control to show all three tapes. They therefore chose not to use Larry Strayer's account because one of the miners, who would be in their first class, had sustained a similar injury. The trainers thought that issues could, in that case, be too sensitive for a productive training discussion to take place.

In describing some effects of this training program on his classes, the instructor noted these points: All the miners watched the tapes intently. They seemed to be "a

little stunned" as they recognized how real the risks are that were being discussed. The best classes occurred when one or more trainees had been in a situation similar to that described on a particular tape and were willing to tell about their experiences. In general, class discussion was an important part of the activity. Trainees seemed talkative and willing to contribute comments and insights after watching the Dave Garry account. They were particularly interested in discussing methods for supporting the top and the amount of supporting that should be done during an emergency response. They were also especially interested in the advisability of staying under a canopy rather than trying to out-run a fall. Less discussion took place after watching the Dave Murone account. This video, which describes a fatal accident, appeared to have more of an emotional impact and the miners responded to it by becoming very quiet. While these instructors chose not to use the Larry Strayer account this year, they are considering using it in the future.

KEY TRAINING POINTS COVERED

As development of the three training packages began, certain issues were chosen as focal points of the material. These included (1) the danger that unsupported roof poses, (2) possible consequences of being caught by a fall, and (3) the impact of an accident on people other than the person caught by a roof fall. Mine safety and health specialists at the National Mine Instructor's Conference agreed that these were important topics and that they could be addressed effectively by showing the three

videotapes. The instructor's guides discuss these points in terms of certain details about each account.

On the evaluation questionnaire, trainees were asked to list one or two important training points that were covered during the session. Many miners highlighted the importance of staying under supported top regardless of the circumstance with comments such as: "Don't go under unsupported roof for any reason"; "Never, under any conditions, do you go under unsupported roof"; and "... don't ever,

ever, go under unsupported roof - ever!" Also noted was the possible consequences of being caught by a roof fall: "Everyone should remember we get desensitized to dangers and should remember you can be killed too." Both of these issues, as anticipated, were seen as important by those miners who answered this question on the evaluation and post-evaluation forms.

A third topic that was to be covered according to the package design plans was impact of accidents on individuals other than those people actually injured or killed by the fall. During one interview, some effects of the victim's injuries on life with his family is discussed. The respondents did see the effects on family as significant: "I think the most important effect is the after affect on individual involved and families."

The importance that trainees would accord to the impact of an event on co-workers, however, was not fully anticipated. The specific issue of protecting would-be rescuers in case of a roof fall was mentioned: "When trying to rescue someone, remember to support roof or make it safe for yourself." Thoughts about emergency response, in general, were also offered as key training points: "You

can't help a victim if you get hurt in the process." The fact that in both accounts responders endangered themselves when attempting rescue was discussed during all classes and written on the evaluation forms as an important point. Six miners made direct reference to this issue on the postevaluations, which were completed 1 month after training: "[A key training point was] the guy that remembered the details of how it happened and how they did not set timber to get [the continuing fall] stopped." Several miners also noted the effect witnessing such an event had on the miner telling his story. On other post-evaluation questionnaires miners stated such key training points as: "The reality of fear and death the man conveyed to us about his friend who was killed"; and "How imprinted the accident was in their mind long after accident." This training activity was designed to convey the effect that an accident has on witnesses and responders. Data obtained both from the trainees and instructor during this field test show that this issue was even more important to them than was anticipated. They not only discussed protection needed for responding to a roof fall but also the precautions needed for any emergency response.

CONCLUSIONS

The overall response of miners and mine safety trainers to these training packages has been very positive. All three videos hold the attention of a class and provide a basis for discussion of important safety topics. Additionally, the videotape interviews and accompanying instructor's guides follow guidelines that research (Sutton 7, Cohen 2) suggests will maximize the effectiveness of fear communications:

(1) The message should attempt to evoke a high (versus low) level of fear—high fear of personal injury or death due to a roof fall accident and high fear of the consequences of one's death or disability on one's family.

(2) It should be made clear that staying away from unsupported roof is an effective deterrent to being harmed by a roof fall.

(3) The actions that are suggested for avoiding unsupported roof should be relatively detailed and specific. The message needs to show how various tasks can be performed without exposing oneself to unsupported roof. It needs to show exactly what types of situations are likely to

prompt miners to go under unsupported roof and how these situations can be avoided.

(4) The source of the communication should have high credibility.

(5) Face-to-face, two-way forms of communication should be employed (as well as other forms).

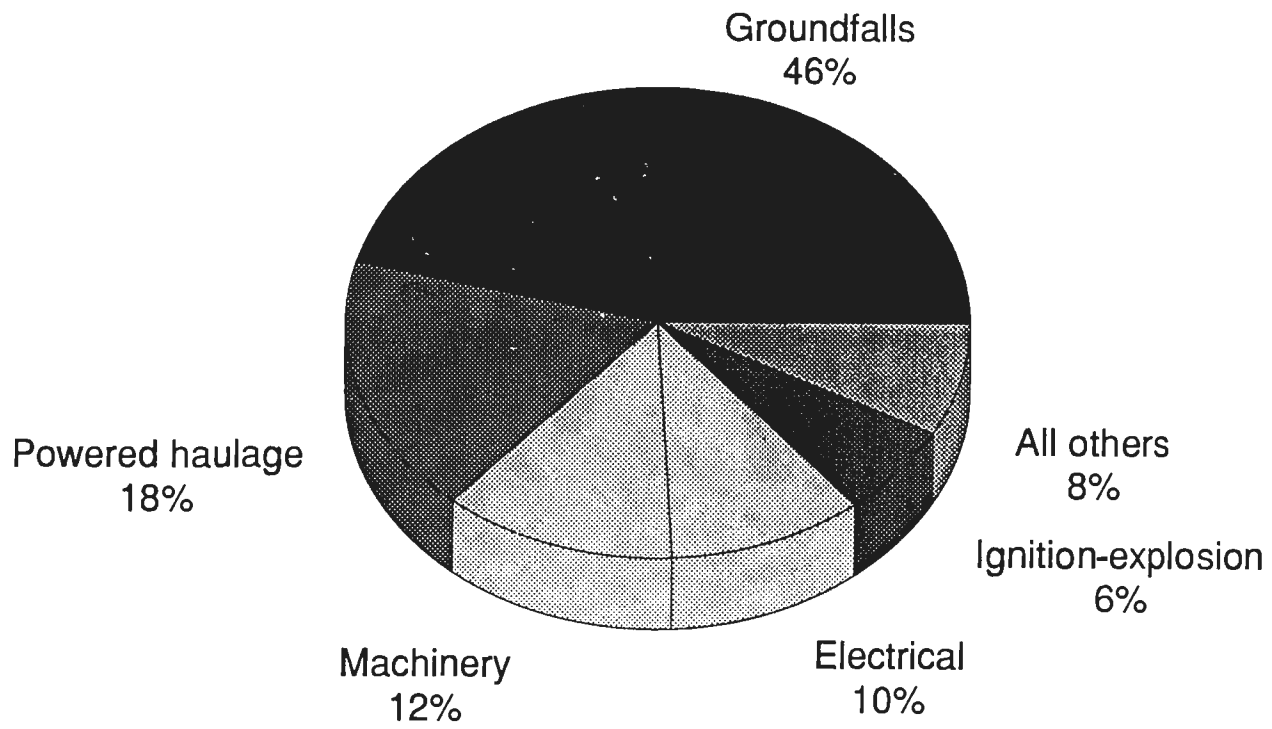
(6) Efforts should be made to promote acceptance of the message by not only those who work in underground production crews, but also anyone who works with or supervises these employees.

While conclusive evidence about behavior change is not available, this field study does show that at least some of those miners involved in the training sessions thought about dangers of going under unsupported roof during this year's annual refresher class and remembered details of that training 1 month later. Perhaps more importantly, the videotapes in these packages seemed to catch workers' attention and hold their interest. That is the first step to an effective mine safety training session.

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**APPENDIX A.—UNDERGROUND COAL MINE FATALITIES BY CAUSE
OF ACCIDENT (1986-90)**



APPENDIX B.—INSTRUCTOR'S GUIDE ROOF FALL ENTRAPMENT VIDEOTAPE

Instructor's Guide ROOF FALL ENTRAPMENT VIDEOTAPE *Dave Garry's Account*

This instructor's guide is designed to accompany a videotape of an interview with a miner helper who witnessed a roof fall that covered the continuous mining machine. He discusses efforts that were made ~~inby supports to rescue the trapped, but unharmed~~ operator. He recognizes that danger could have been minimized by installing temporary supports before continuing rescue. The video would be beneficial for use with (1) those who are responsible for ensuring that miners are trained to properly respond to emergencies and (2) anyone who works in a face crew. This guide contains suggestions to help you use the tape as part of an effective training session.

Other Tapes in This Series

There are three videotapes in this series. Each is approximately 12 minutes long and deals with the experience of one miner just before, during, and after a serious roof fall. The individuals on the tapes are not professional actors, but are miners or former miners. The videotapes all follow the same format. First the miner tells about the event and then an interviewer asks some specific questions so that important points will be covered. While all three of the tapes illustrate the dangers of unsupported top, each presents the information with a different focus. Descriptions of the other two tapes follow:

Larry Strayer's Account

Larry tells about a fall that occurred while he and another miner were attempting to bar down top just inby the last row of supports. He explains that the other miner was injured but eventually recovered. Larry, however, lost a leg as a result of this accident. It is stressed that going even a short distance inby supports is not worth the possible outcome of an accident.

Dave Murone's Account

Dave tells about the experience of having to recover the body of a friend who was killed by a roof fall. The individual who was killed was inby supports at the time of the accident. Dave speculates on why his friend was under unsupported top and discusses the effect that witnessing this accident had on him.

Preparing for Class

Read through the rest of this guide and view the videotape to become familiar with the presentation. ~~Review the Discussion Ideas section of this guide for help with preparing to lead the class discussion. For more information you may want to look at the items listed below as Other Resources.~~

The only materials necessary for this training session are a VHS player and a monitor that can be clearly seen and heard by all members in the class. If desired, the pages showing a diagram of the accident scene and the list of discussion questions could be copied to hand out to each trainee or put onto transparencies and shown on an overhead projector.

The videotape can be shown with little or no introduction. However, if the class is not familiar with retreat mining, it may be helpful to explain that on a retreat section coal pillars are completely extracted. In the video when Dave refers to a push out stump, he is talking about the last part of a coal pillar which is removed. Showing the diagram on an overhead may also help class members to understand what was happening at the time of the fall.

The discussion following the videotape is the most important part of the training exercise. One method for leading this activity is to divide your class into small groups and ask them to decide on joint answers to the discussion questions provided in this guide. Give them a limited amount of time to arrive at answers and then ask each group to report their answers to the class. Be sure to leave enough time for the entire class to discuss the responses.

Other Resources

1. Short articles on this subject by Robert Peters and Arnold Love appear in the first four issues of the *1992 Holmes Safety Bulletin*.
2. Bureau of Mines IC Reports 9283 and 9300. For copies contact Robert Peters at (412) 892-6895.

If you have questions or comments concerning this Instructor's Guide contact Launa Mallett, Bureau of Mines (412) 892-6658.

Discussion Ideas for the Instructor

After viewing the videotape, trainees should be given an opportunity to ask questions and express their ideas and opinions about the material that was presented. They should be encouraged to relate the discussion to their work setting. Questions that may be used to guide the class discussion and information related to each are provided below. Choose questions which are appropriate for the class members and can be talked about within the time that you have available for the session.

1. **Should the rescuers have taken the time to support the roof before attempting to help the trapped miner? Why or why not?**

Miners should always be trained to set supports before attempting to rescue anyone. This protects the rescuers and the trapped miner. Miners in your class may bring up the point that given the position of the trapped individual with respect to pieces of fallen rock and mining equipment, it may not be physically possible to find a place to set adequate roof supports before rescuing the person. While this may be true and miners sometimes take such risks during rescue efforts, they should never be encouraged to do so. When asked about the availability of posts, Dave explains that they were not far away, and that it would only have taken a few minutes to support the lip of the fall. Dave says, "We weren't thinking, just reacting. We decided to throw caution to the wind and get the miner operator out right away." Train your miners to think about creating a safe area for rescue before taking action.

2. **Should the miner operator have been left alone after being rescued from the roof fall?**

As Dave points out, "We forgot about Charlie". When we returned we saw that he was shaking and visibly sick. Point out that even if individuals appear to be unharmed, it is important that someone stays with them because shock is a serious threat.

3. **Should equipment operators who are protected by canopies attempt to get out and run away from a roof fall?**

Canopies have saved many lives. No one we have talked with is aware of any incidents in which a miner under a canopy was killed by a roof fall. If someone in your class knows of such an incident,

have that person explain the situation and ask the class if such an incident is likely to occur again. Encourage the trainees to think about and talk about whether they would be safer under a canopy or without one.

4. **When you are underground, will you be able to tell if a roof fall is about to happen?**

It is not always possible to judge how stable the roof is just by looking at it. Dave points out that he and the others who rescued the miner operator were lucky that they did not get killed. Although the roof appeared stable after the initial fall, it ended up falling three more times after they had gotten the miner operator out.

As this accident shows, miners sometimes hear or see things that warn them that the roof is about to collapse. However, often this is NOT the case. In the tape, Dave explains that the miner operator told him after the accident that he was focused so intently on his job that he had no idea that a roof fall was imminent. Be sure the miners in your class know that they cannot assume that they will have enough warning to escape from a roof fall.

5. **Does your mine have a plan concerning what miners are to do in the event that a roof fall causes people or equipment to be trapped? If yes, what are you supposed to do according to that plan?**

This question can be used to determine if each miner understands company procedures for actions to be taken when a roof fall occurs. Discuss who should be contacted and what actions, if any, should be taken by the miners at the scene of the fall.

6. **Can you think of one or two situations which might cause you or your co-workers to go under unsupported top? Can equipment or work procedures be changed to prevent that situation from coming up in the future?**

Recent Bureau of Mines research has shown that miners often know of tasks that make going under unsupported top more likely. Furthermore, they sometimes think of ways to eliminate that hazard. See the Holmes articles listed in **Other Resources** for more information.

DISCUSSION QUESTIONS for DAVE GARRY'S ACCOUNT

1. Should the rescuers have taken the time to support the roof before attempting to help the trapped miner? Why or why not?

Are temporary supports always available in the sections where you work?

2. Should the miner operator have been left alone after being rescued from the roof fall? Why or why not?
3. Should equipment operators who are protected by canopies attempt to get out and run away from a roof fall? Why or why not?
4. When you are underground, will you be able to tell if a roof fall is about to happen?
5. Does your mine have a plan concerning what miners are to do in the event that a roof fall causes people or equipment to be trapped?

If yes, what are you supposed to do according to that plan?

6. Can you think of one or two situations which might cause you or your co-workers to go under unsupported top?

Can equipment or work procedures be changed to prevent that situation from coming up in the future?

GROUND FALL ACCIDENT STATISTICS 1986-1990

Fatalities	95*
Injuries	4,299
Non-injury accidents	11,288
Total	15,682

**Half of these fatalities occurred under unsupported roof. Groundfalls are the leading cause of fatalities in U.S. underground coal mines.*

Diagram for Dave Garry Account

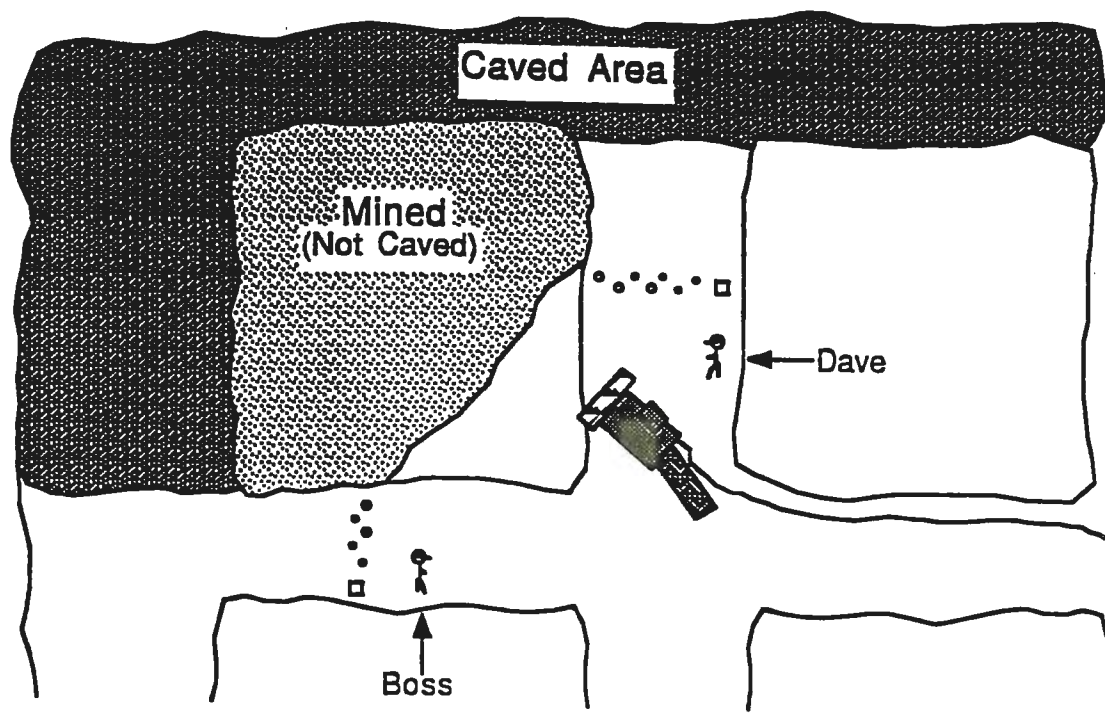


Figure B-1.—Position of miners and equipment before fall.

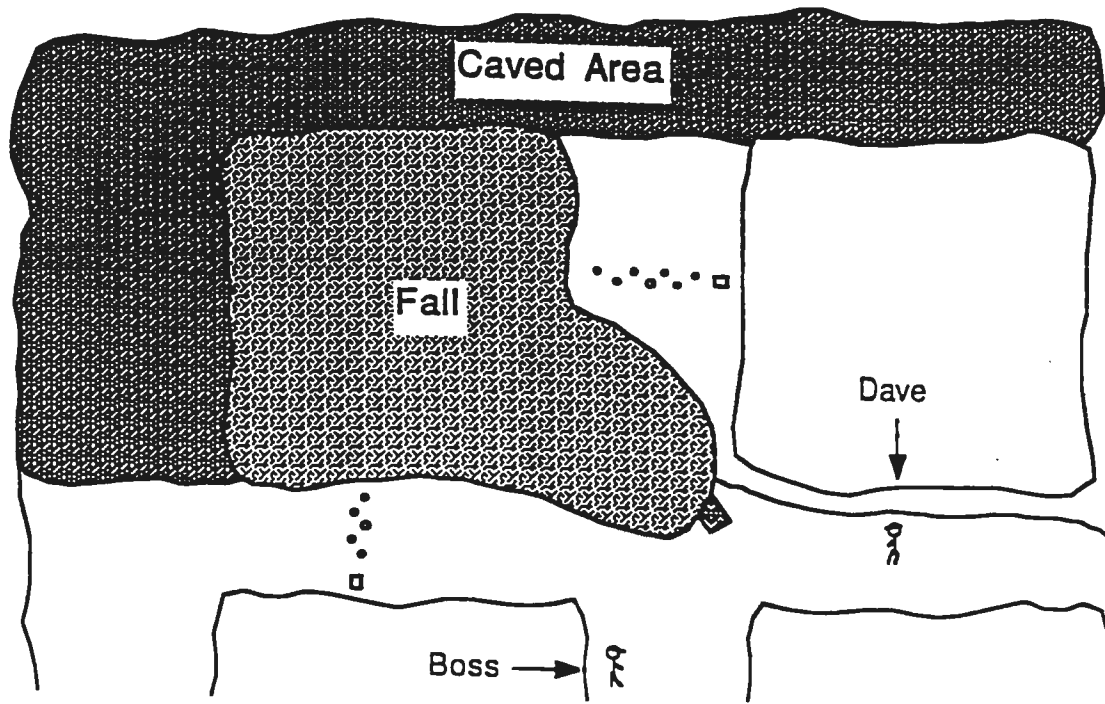


Figure B-2.—Position of miners and equipment after fall.

APPENDIX C.—MINER'S EVALUATION OF ROOF FALL VIDEOTAPES

Mine: _____

Date: _____

MINER'S EVALUATION OF ROOF FALL VIDEOTAPES

Job title: _____

Age: _____ Years experience as underground coal miner: _____

~~Name of Miner in Video(s) (Please Circle): Dave Malone Dave Garry Steve Strayer~~

Think about the training exercise you just completed. Please circle the number which tells how much you agree or disagree with the following statements about the training session. If a statement does not apply to your situation, circle N\A.

	STRONGLY AGREE		STRONGLY DISAGREE	DOESN'T APPLY	
1. The introduction given before the videotape was useful.	1	2	3	4	N\A
2. The videotape was interesting to watch.	1	2	3	4	N\A
3. It was easy to follow what the people on the videotape were trying to say.	1	2	3	4	N\A
4. The diagram of the accident was easy to understand.	1	2	3	4	N\A
5. The problems described in the videotape could happen in real life.	1	2	3	4	N\A
6. Watching the videotape was useful.	1	2	3	4	N\A
7. I learned something new from the videotape.	1	2	3	4	N\A
8. The discussion that took place after watching the videotape was useful.	1	2	3	4	N\A
9. I learned something new from the discussion that took place after the tape was over.	1	2	3	4	N\A
10. The training exercise took too long to complete.	1	2	3	4	N\A
11. This training exercise will help me remember something important if I am ever in a similar situation.	1	2	3	4	N\A
12. This training exercise will cause me to be more careful to avoid unsupported roof.	1	2	3	4	N\A
13. It is worth spending extra time and effort to avoid going under unsupported roof in the mine where I work.	1	2	3	4	N\A
14. Did this training exercise cause you to remember any instances at your mine:					
a. when someone went under unsupported roof?	YES		NO		
b. when you were tempted to go under unsupported roof?	YES		NO		
15. Please write the one or two most important points covered during this training session on the back of this page.					

IMPACT OF CUTTER ROOF FAILURE ON SMALL MINE OPERATORS

By Eric R. Bauer¹

ABSTRACT

The U.S. Bureau of Mines has conducted research to gain a basis for recommending methods to predict and prevent the occurrence of cutter roof failure, a common ground control problem in the Appalachian Coalfields. Cutter roof failure can be difficult to predict and control, and be especially devastating to small mine operators with limited resources and small profit margins. Bureau research has found four distinct factors to be initiators of cutter roof failure: (1) high horizontal roof stress, (2) surface topographic variations, (3) roof rock characteristics, and (4) geologic anomalies. Effective control of

cutter roof is possible through improved bolting techniques, entry and mine reorientation, and entry and pillar size modifications, all of which may not be economically feasible for small mine operators. The result is that small mine operators are forced to continue mining where less than ideal roof conditions are present. Ultimately, cutter roof failure could result in the closure of some small mine operations. Extensive Bureau cutter roof research can increase small mine operator's awareness of this ground failure, provide insight for predicting its cause, and suggest appropriate methods of controlling its occurrence.

INTRODUCTION

Cutter roof failure exposes miners to the danger of falling roof rock and frequently results in massive roof failures. This causes delays in production, increased mining costs, and loss of recoverable reserves. In response to this, the U.S. Bureau of Mines investigated the causes of this type of roof failure to provide the mining industry with improved methods of predicting and preventing its occurrence.

According to its definition, cutter roof "...is a failure process that begins as a fracture in the roof rock parallel to, and located at the intersection of the roof and rib. The fracture propagates upward into the roof over the mine opening at an angle usually steeper than 60° from the horizontal (fig. 1) taken from reference (1)."² Cutter roof is also known in the coalfields as snap top, kink roof, pressure cutting, rippers, and shear roof.

Bureau research has shown that cutter roof occurs in each of the major coal basins where underground mining is practiced (fig. 2). Cutter roof is unpredictable, creating widely variable problems. The uniqueness of this problem has limited the techniques available for its treatment. Trial and error has proven unsatisfactory in many cases, as the causes often differ from mine-to-mine, making selection of the optimum control technique difficult (2).

Previous research has suggested several explanations of the causes of cutter roof failure, however, in-mine verification has been far from comprehensive. A correlation between cutter roof failure and high horizontal stress fields has been proposed by several researchers (3-4). Others suggested that roof rock type was an important factor in cutter development (5). Still others have reported on the geologic influences of cutter roof failure (6-7).

The extent of the cutter roof problems in U.S. coal mines has been difficult to ascertain, especially the number of small mines experiencing this problem. Locating all mines that experience cutter roof has not been

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²Italic numbers in parentheses refer to items in the list of references at the end of this paper.

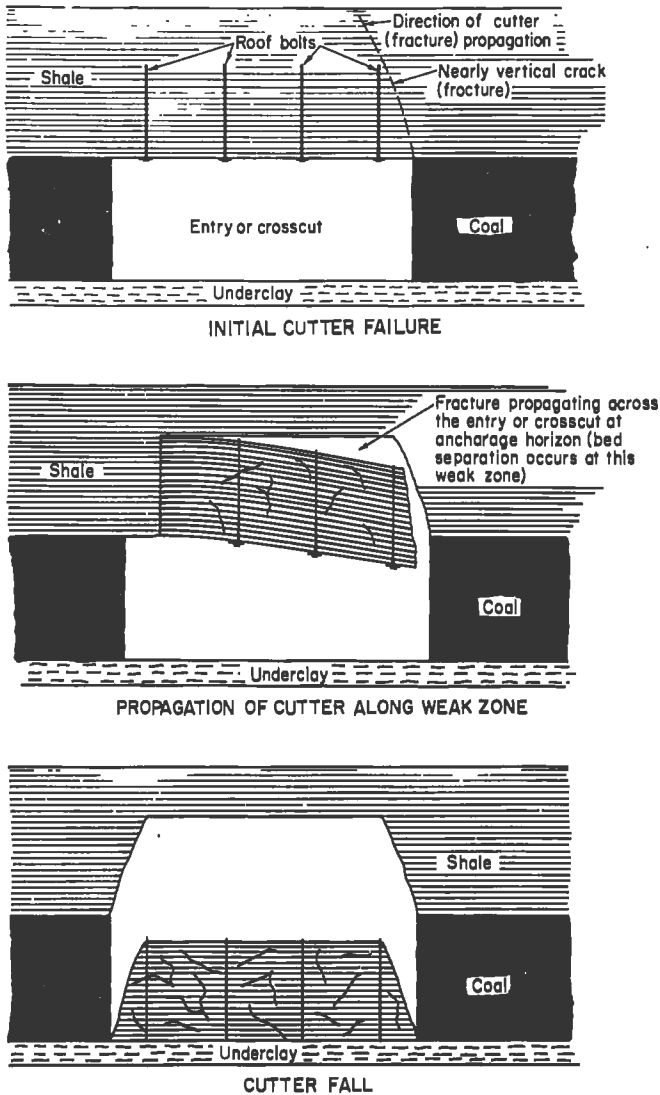


Figure 1.—Schematic of cutter roof failure sequence (2).

BASIC CAUSES OF CUTTER ROOF FAILURE

In most cases, cutter roof failure can be attributed to either one or a combination of the following factors: (1) high horizontal roof stress of regional or localized origin, (2) variation of surface topography, (3) roof rock characteristics, and (4) geologic anomalies (clay veins, bedding planes, paleochannels, joints, etc.). It is logical to assume that the potential exists for these factors to occur in any mine, irrespective of size.

HIGH HORIZONTAL STRESS

Classic cutter roof failure is usually attributed to abnormally high horizontal stress. This high horizontal stress can be a localized condition (geologically induced by

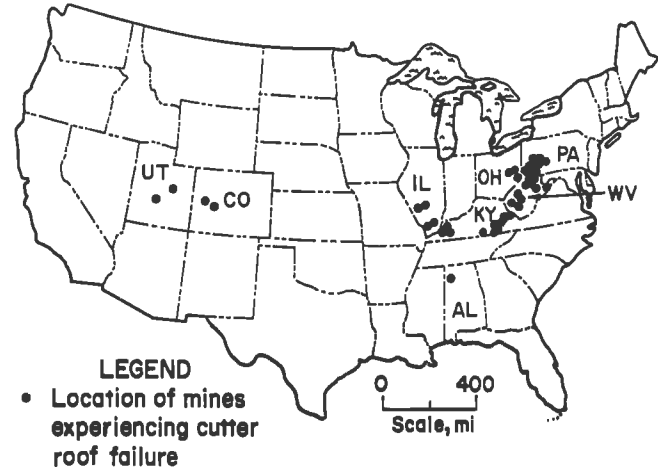


Figure 2.—Map of the location of mines experiencing cutter roof.

totally successful. Of interest to small mine operators are the coalbeds where cutter roof failure has occurred. In West Virginia, Virginia, and Eastern Kentucky where many of the small mines are located, cutter roof has been found in the Beckley, Lower Kittanning, No. 2 Eagle, Upper Freeport, Pittsburgh, Redstone, Sewell, Winifrede, No. 2 Gas, Lower Elkhorn, Harlan, Imboden, and Ceesh coalbeds. Although it is impossible to predict if small mines operating in these coalbeds will experience cutter roof problems, operators at small mines should be aware that the potential for cutter roof does exist.

This paper summarizes the results of in-mine analyses of cutter roof failure, presents information on methods of predicting where cutter roof failure will occur, suggested control techniques, and the impact of this ground control problem on small mine operators.

anticlines, synclines, and faults) or be part of a regional stress field (tectonically induced). It is the maximum component of the stress that leads to cutter roof failure in entries and crosscuts that are perpendicular to the maximum stress. Since small mines are typically located above drainage and out of the influence of major geologic structures, classic cutter roof failure would not be expected to occur.

SURFACE TOPOGRAPHY

Stream valleys and rapid elevational changes are surface topographic features that can result in cutter roof failure. Again, because of the above drainage location of most

small mines, stream valleys are not a cause of concern. When rapid surface topographic changes occur over short horizontal distances, as is typical over small drift mines, zones of high stress can develop. This stress is rarely sufficient to cause cutter roof failure, but when other factors are present, cutter roof can result. Figure 3 illustrates this principle and the likely zone of high stress.

ROOF ROCK CHARACTERISTICS

Variations in the strength of individual rock layers comprising the immediate roof is another cause of cutter type

roof failure. A relatively strong, yet thin, immediate roof, coupled with a series of weaker strata that tend to sag and slowly load the immediate roof below (fig. 4) are the roof strata characteristics that induce this type of failure. This roof fracturing is similar to cutter failure and tends to occur in the center of the entry, rather than at the roof-rib interface as occurs during classic cutter roof failure. This is a problem small mine operators should be on guard for when mining "under the mountain" where overburden is greatest.

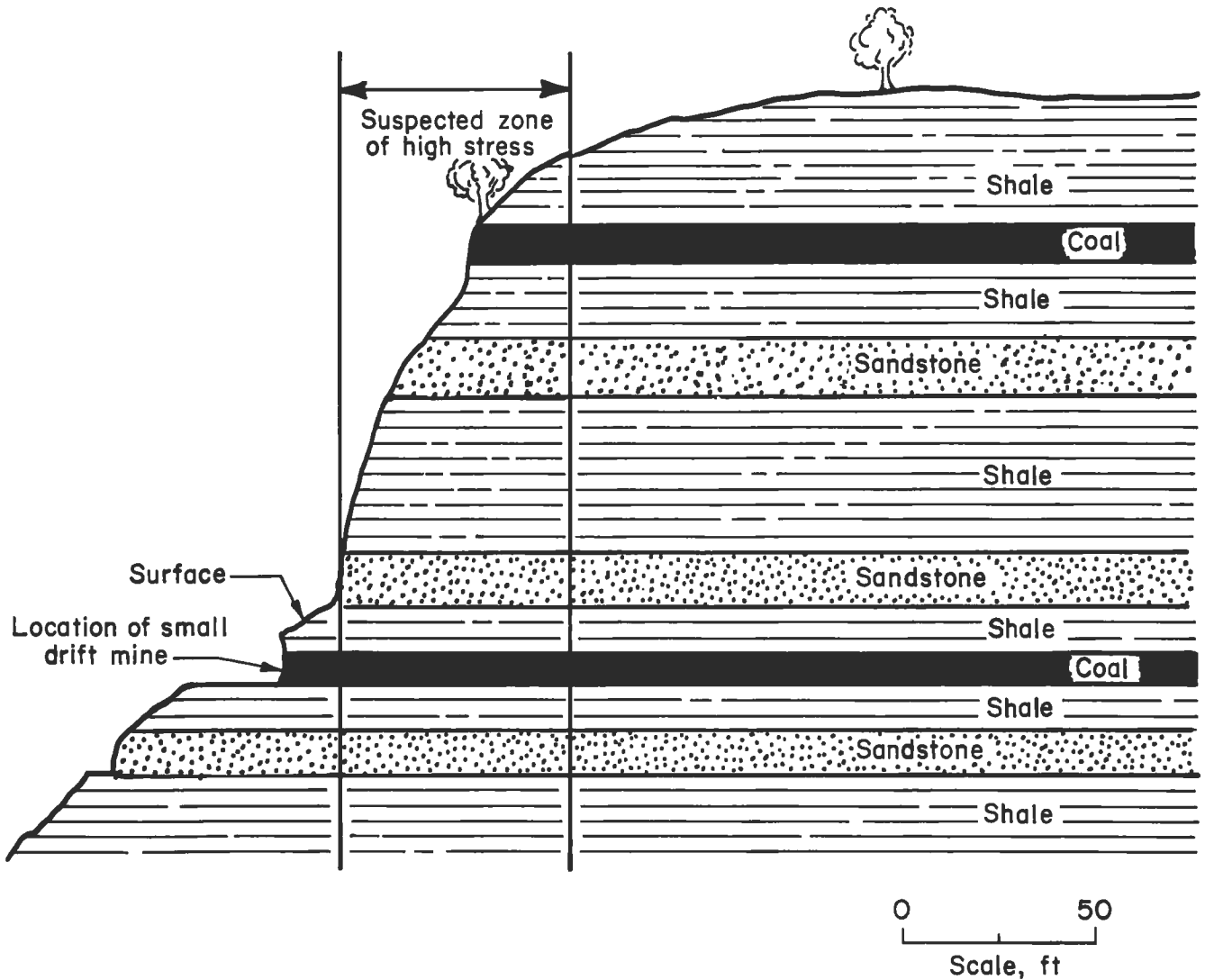


Figure 3.—Zone of high stress due to rapid surface topographic changes.

GEOLOGIC ANOMALIES

A final cause of cutter type failure is the influence of geologic anomalies (minor geologic structures) (8).

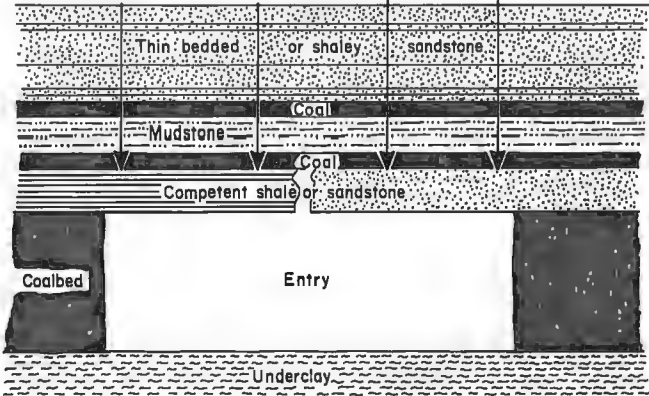


Figure 4.—Illustration of roof rock variation as cutter roof failure cause.

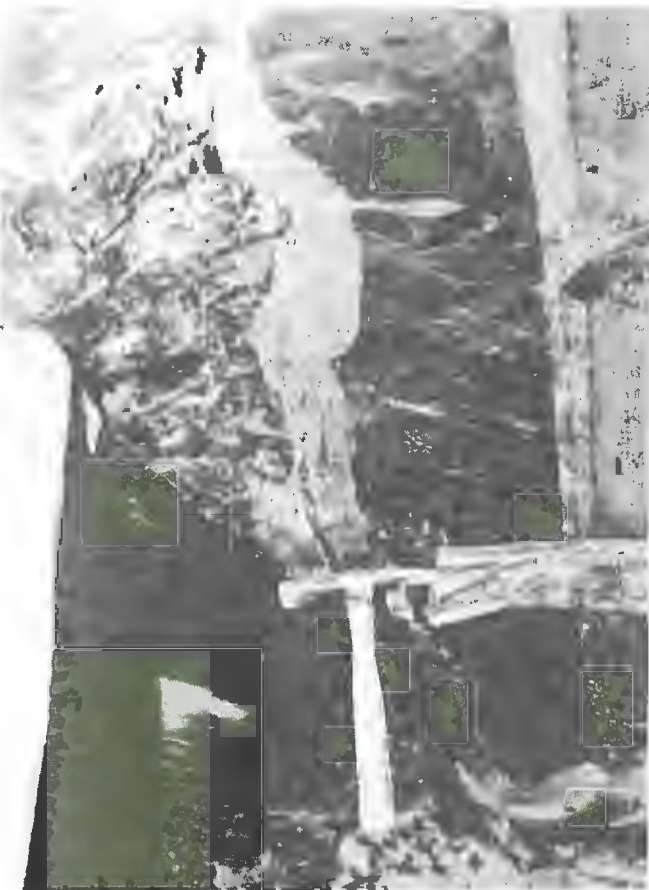


Figure 5.—Clay vein and associated disturbed mine roof.

Geologic structures such as clay veins (fig. 5), bedding planes, jointing, paleochannels, and rolls can lead to roof fracturing (cutters). Primarily, they weaken or sever the roof strata, reduce the strength of the roof beam, creating zones where the roof can move or sag. The resulting fractures appear very similar to cutter roof failure and usually are found at the intersection of the geologic anomaly and the roof-rib interface (fig. 6). Failure is primarily a cantilevering of the mine roof strata (fig. 7).

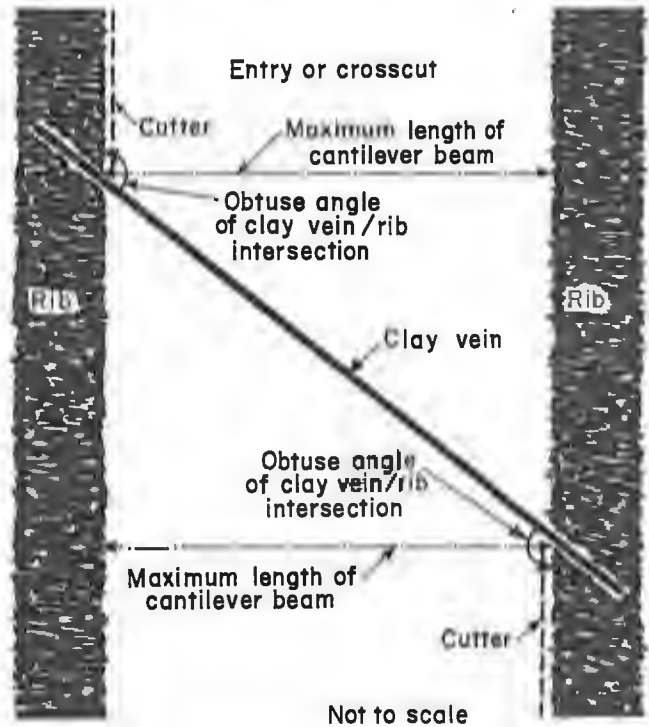


Figure 6.—Probable location of cutter failure and geologic anomaly.

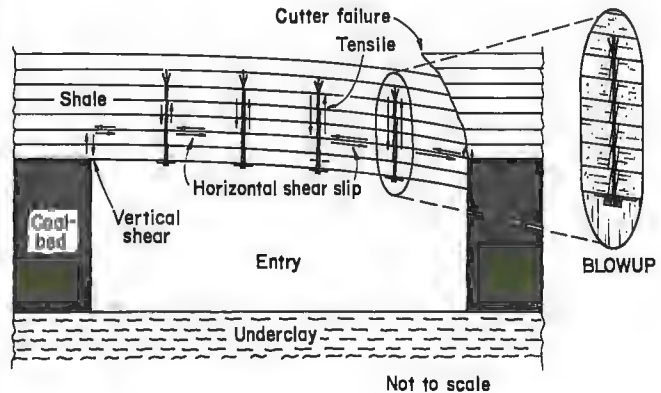


Figure 7.—Schematic of cantilevering mine roof failure (8).

ASSOCIATED GROUND CONTROL PROBLEMS

Cutter roof problems can vary widely from mine-to-mine and section-to-section and may or may not adversely affect mining. In some instances, the only evidence that a problem exists is the telltale fracturing (cutting) at the roof-rib interface. Most often the result of cutter roof failure is a massive roof fall. Also, the problems are compounded by the seemingly unpredictable nature of its occurrence.

Following the progression of failure shown in figure 1 a small fracture begins at the roof-rib interface (fig. 8), then as the cutter propagates upward into the roof strata it disturbs more roof rock. Just prior to complete roof collapse as more roof rock is disturbed, the roof would look similar to that shown in figure 9. If effective control is not implemented and a cutter is allowed to continue disturbing the roof, the most likely result is a total collapse of the mine roof (fig. 10).

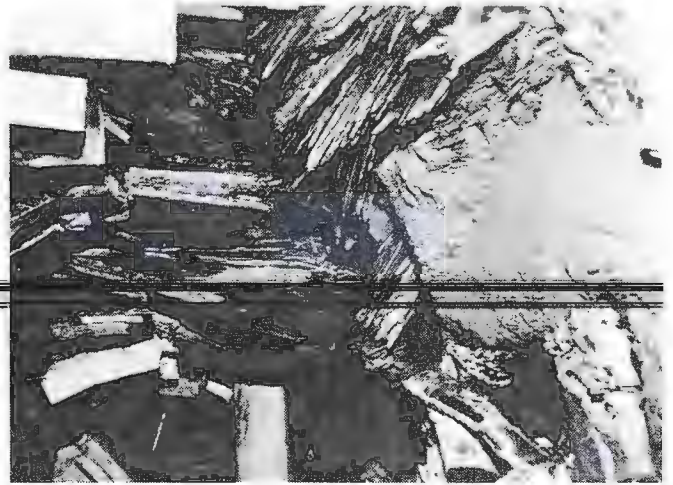


Figure 9.—Severe cutter roof failure.



Figure 8.—Initial cutter roof failure (2).

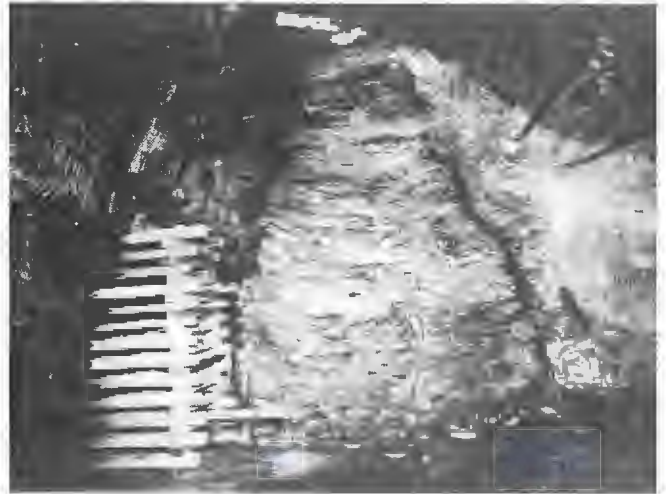


Figure 10.—Roof fall resulting from cutter roof failure (8).

ELIMINATION-CONTROL TECHNIQUES

Cutter roof failure can be controlled or eliminated by addressing one of two areas, either mine design or support modification. Mine design changes are employed to eliminate the initiation of cutters, or to force the failure to occur in a specified manner or desired location. On the other hand, roof support modifications are applied to roof that is already damaged by cutter failure to prevent further roof deterioration.

MINE DESIGN CHANGES

Mine design changes such as pillar or entry width alteration and mining directional adjustments are used to eliminate cutter roof failure by altering the in situ stress field, or by avoiding geologic features responsible for cutter failure. In either case, the exact cause of cutter failure must be known for this method to be successful.

Entry Reorientation

One of the simplest techniques in principle, yet one that may not be practical to implement, is entry reorientation. This method is applicable where cutter roof and roof falls have a preferred orientation, either because a biaxial stress field exists or geologic anomalies occur in a specific direction. In the case of high stress, reorienting mine headings so that both entries are perpendicular to the same least stress value will offset the influence of the stress field (1) (fig. 11). When geologic anomalies are the cause, it is best to reorient mine headings to intersect the anomalies at right angles. This exposes less of the geologic anomaly and the least amount of disturbed roof.

A second concept of entry reorientation is the avoidance of probable cutter roof causes or areas of suspected cutter roof failure. For instance, when it is known that certain geologic features (clay veins, highly laminated shale roof, etc.) cause cutter roof failure, it is advisable to avoid mining where these are present. One particular example of this is shown in figure 12 where a crosscut was turned where a clay vein was located, resulting in nearly complete roof failure because of cutter roof failure. By simply moving the crosscut ahead by 10 to 15 ft, this might have been avoided.

Sacrifice Entries, Pillar Softening, Notching, and Roof Slotting

When the effects of the in situ stress cannot be minimized by entry reorientation, other more drastic measures may be warranted. Sacrifice entries or caving entries (fig. 13), pillar softening, notching (fig. 14), and roof slotting have been used successfully. These methods are designed to reduce the stress in mine roof, minimizing the occurrence of cutter roof. Although these techniques have shown some promise in reducing cutter roof failure, they are impractical to use efficiently during production.

One final method that has received attention is the use of yield pillars. In theory, their yielding and transfer of roof loads to the abutments makes them a possible

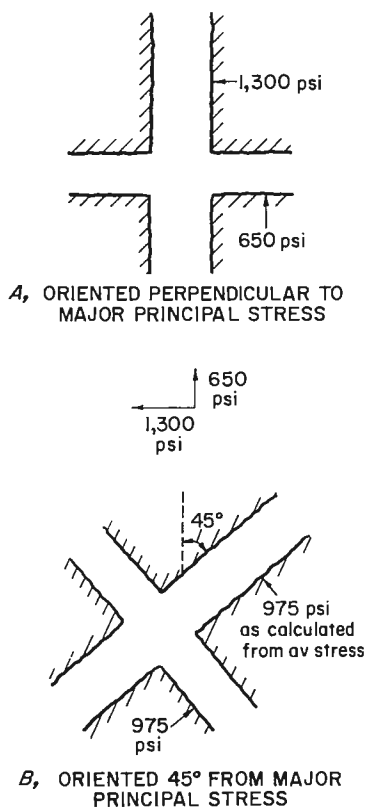


Figure 11.—Entry reorientation for stress reduction (2).

solution for controlling cutter roof failure. To date, no conclusive proof of yield pillar effectiveness for reducing cutter roof failure is available.

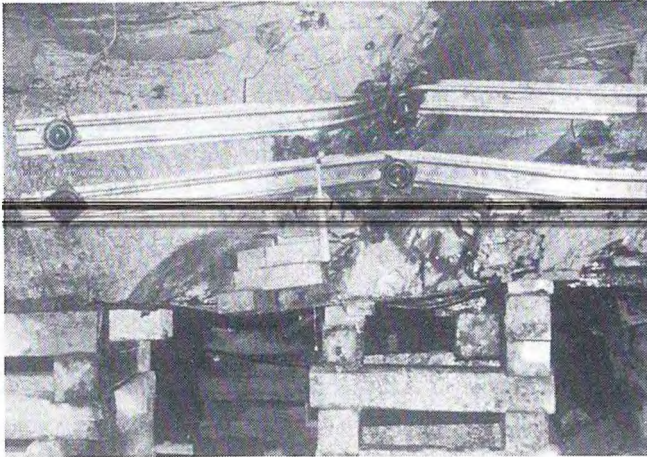


Figure 12.—Roof stability in a crosscut that is severely affected by a clay vein (7).

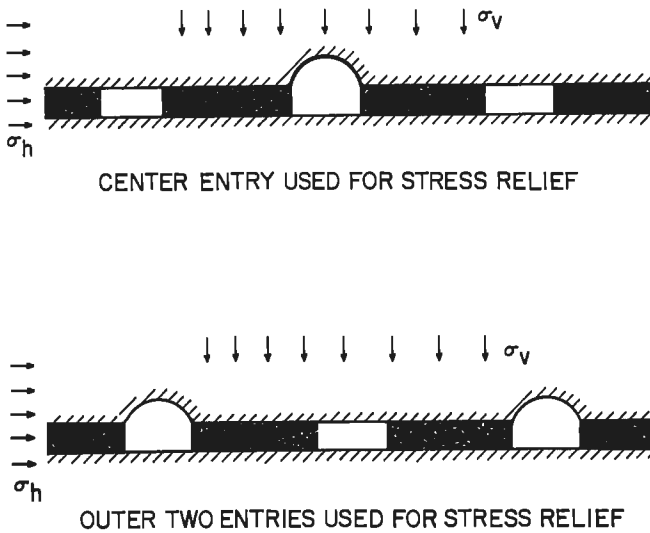


Figure 13.—Sacrifice or caving entries for stress reduction.

ROOF SUPPORT MODIFICATION

The past practices of installing additional artificial support after cutter failure has damaged the roof has generally been unsuccessful. The exception has been to install improved support systems on cycle and prevent cutter failure from seriously damaging the roof. Support systems such as angle bolting, roof trusses, and super bolts (fig. 15) have been used to support cutter affected roof when installed on cycle or soon after mining. The key is to get these high strength, active supports in place before the cutter failure can seriously damage the roof. In many cases, cutters will still be present, but a sufficiently strong roof beam will be created that resists total roof failure.

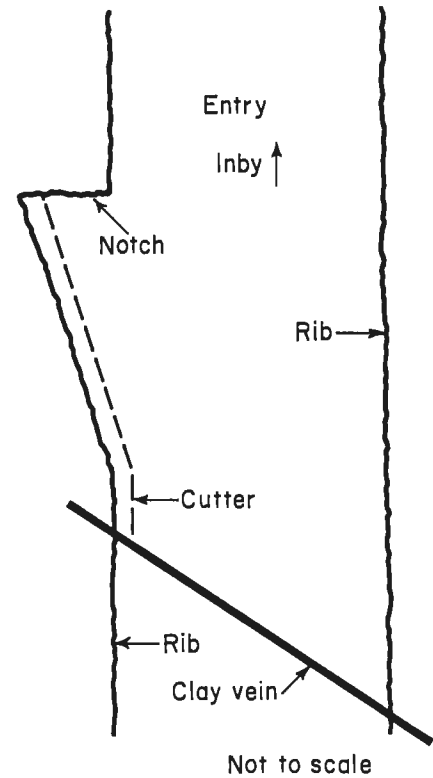


Figure 14.—Example of notching to control cutter roof failure.

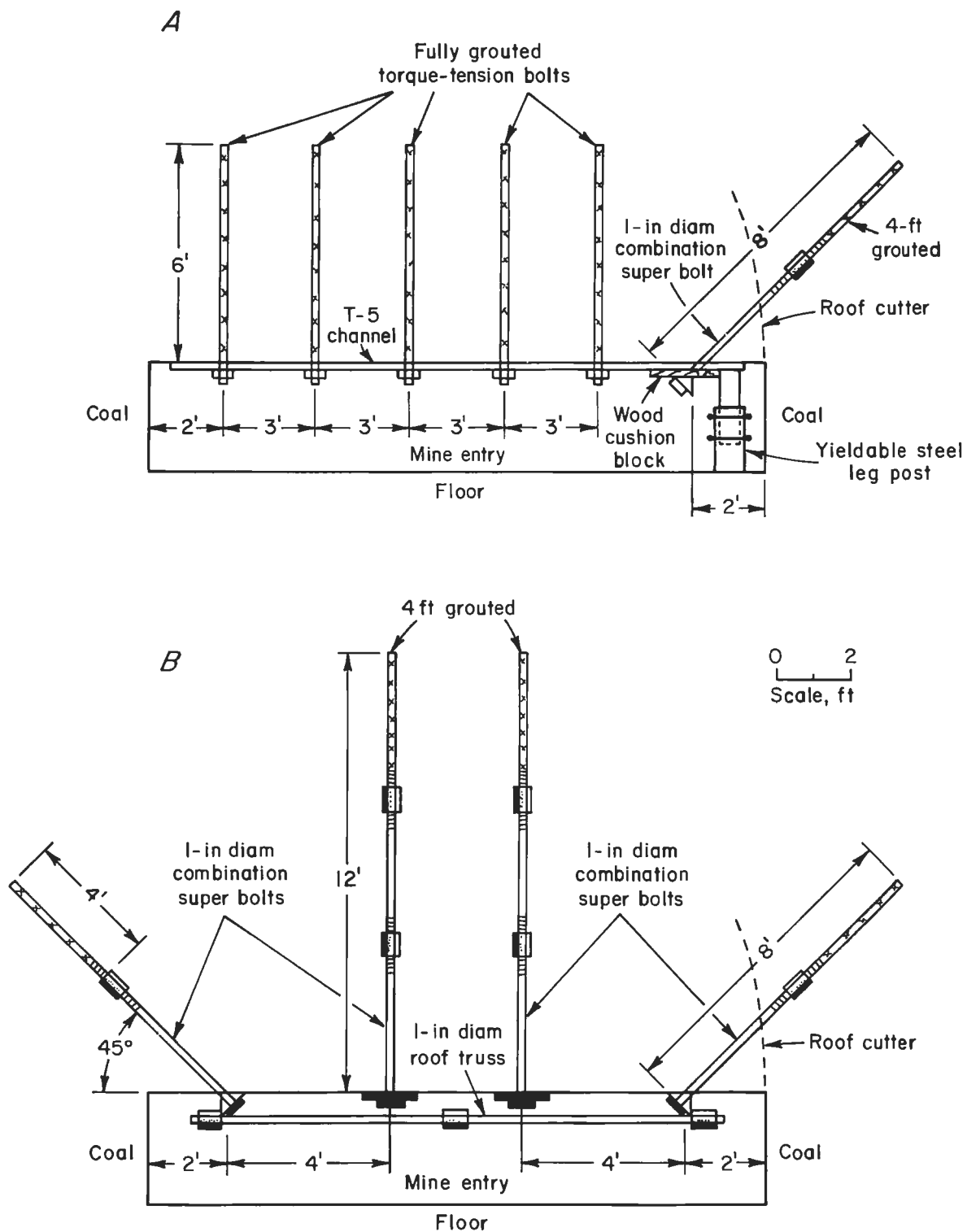


Figure 15.—Support systems for control of cutter roof failure.

IMPLICATIONS FOR SMALL MINE OPERATORS

Small mine operators must be able to identify the cause of failure, then implement a control method to overcome cutter roof failure. Since most small mine operations are contract mines that operate on a small profit margin, have limited capital available, and minimal engineering and geologic expertise, the identification of cause and implementation of controls are major obstacles. Compounding the problem is the fact that few simple and inexpensive identification and control techniques exist.

To identify the cause of cutter failure, small mine operators must utilize the expertise of all available

resources including the experience of miners, the surrounding mine operators, the larger coal company for which the operator is contract mining, and State and Federal mining agencies. Then to identify the probable cause a specific process of elimination, starting with geologic influences (surface topography, roof rock variations, and geologic anomalies) should be followed (fig. 16). If all geologic influences are eliminated, then determination of the stress condition is necessary. Based on the pattern of cutter failure, it is possible to determine

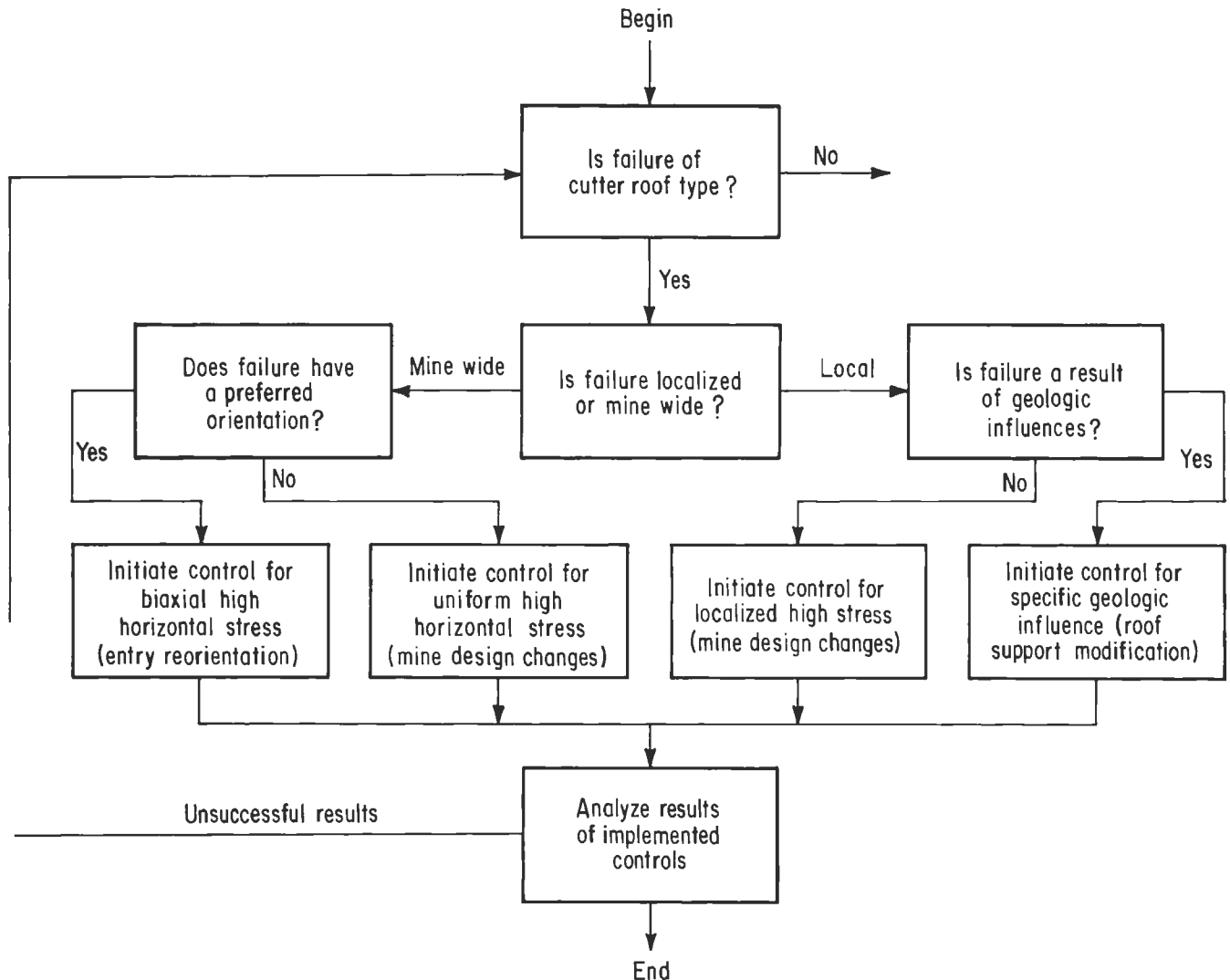


Figure 16.—Simplified decision diagram for determining the cause of cutter roof and selecting control methods.

if a localized high stress (cutters in one part of the mine only) or a regional high stress (cutters throughout the mine, in one specific direction, or similar problems in surrounding mines) is the cause. In either case, it is not practical for the small mine operator to determine the actual orientation and magnitude of the stress field through instrumentation.

Once a reasonable assumption of the cause of cutter failure has been reached, the operator must select and implement appropriate control techniques. These range from simply building a few cribs where geologic anomalies are the cause to mine closure when high horizontal stresses are the failure initiator. Hopefully, small mine operators can find a control technique, suitable to their particular situation, rather than exercise the mine closure option.

The obvious control technique is to avoid mining in areas where cutter roof is likely to occur if reserves are sufficient to permit this practice. Most small mines do not have this option, thus they must deal with the problem. Again, a systematic selection and elimination approach based primarily on the cause of cutter failure is essential to selecting an effective control technique. When geology is the cause, mine operators should start by altering the roof support plan. Cribs or posts can be installed adjacent to geologic anomalies (fig. 17), or straps placed across the anomaly to prevent cantilevering roof movement. Longer, high-strength, or combination anchorage bolts can be used to reinforce the roof beam and anchor it to more competent strata when roof rock variations are the cause of cutter failure. Finally, roof trusses installed as supplemental support (fig. 18) or on cycle are an excellent control technique for most causes of cutter roof failure.

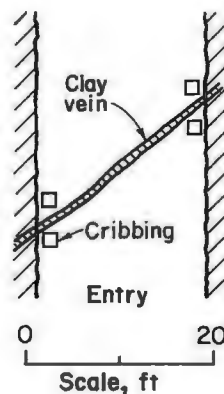


Figure 17.—Crib placement for support of a clay vein (7).

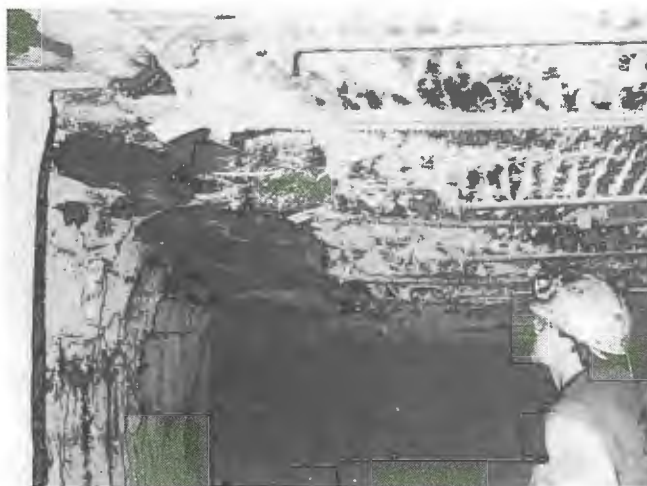


Figure 18.—Roof trusses as supplemental support for stabilizing cutter roof (8).

CONCLUSIONS AND RECOMMENDATIONS

Cutter roof failure continues to plague the U.S. coal mining industry, with resultant delays in production, increased mining costs, and loss of recoverable reserves. Bureau research indicates that cutter roof failure can be caused by several different factors, either singly or in combination. The most frequently found reasons for cutter roof include high stress, surface topography, and geologic anomalies. Each occurrence of cutter roof must be analyzed on a case-by-case basis if the true cause is to

be determined. Then, once the cause is known, control techniques can be implemented, although no unique solution exists for controlling or avoiding cutter roof failure (1).

It is imperative that small mine operators utilize all available sources of help when analyzing the causes of cutter roof failure and evaluating control techniques, if they are to successfully eliminate cutter roof failure in future mining operations.

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RECOGNITION AND CONTROL OF ROOF FALLS CAUSED BY FAULTS

By Gregory M. Molinda¹

ABSTRACT

The intersection of geologic faults by mine workings can be both hazardous and nonproductive. The severity of the impact on roof quality is related to the extent and type of movement of the fault. Faults are caused by three different processes. These are (1) large crustal movements (Pine Mountain Overthrust), (2) compressional slips caused by valley stress relief, and (3) compactional faults caused by lithologic transitions (ancient stream channel fills).

Fault offsets range from inches to hundreds of feet vertically and from inches to miles horizontally. Roof effects include falls, pinched coalbeds, splits, slickensides, offsets, rolls, and crush zones. Recognition criteria for different faults are developed to help the operator realize that many sudden coalbed discontinuities are related to larger geologic events. Ground control strategies include mine designs that minimize fault exposure. Mining plans can be adjusted based on type and extent of fault movement.

INTRODUCTION

A fault, as used in the following paper, can be defined as a natural break in the horizontal or vertical continuity of a rock or rock sequence along which there has been movement. This definition distinguishes a fault from those features, which in mining jargon, have commonly been described by the word fault (i.e., sandstone channel, split coal seam, want, roll, swag, etc.). The word "natural" in the definition further identifies rock faults as structures that are present in the roof and coal *before* mining occurs and not the result of mining.

It is a rare coal mine that does not have faults on some scale in the roof, coalbed, or floor. Ground control problems resulting from faulting range from imperceptible to warped, rotated, crushed, offset, and otherwise severely disturbed strata (fig. 1). Economically, faulting can have a dramatic effect on the production of a coal mine. Large offsets (20 ft or greater) can necessitate costly fault crossing projects requiring significant extra support

(1),² or require the sinking of an additional shaft on the other side of the fault to provide access.

Large faults can be a significant problem in other parts of the world. Some European mines have complex geology, including faults, which require considerable engineering effort to overcome. The National Coal Board in Great Britain regards seismic surveying as a way to reduce costs rather than adding to its production costs, especially in complexly faulted areas (2). Fortunately, most American coal mines are situated in relatively simple geologic settings. The very large structural faults are confined to specific geologically disturbed regions around the country and are not common.

Although 100 ft offsets are rare, there are numerous examples of 2 to 6 ft coalbed offsets that seriously disrupt mining (3-4). Conversely, many faults can disrupt roof integrity without affecting the coalbed at all. In fact, this is most often the case.

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²Italic numbers in parentheses refer to items in the list of references at the end of this paper.

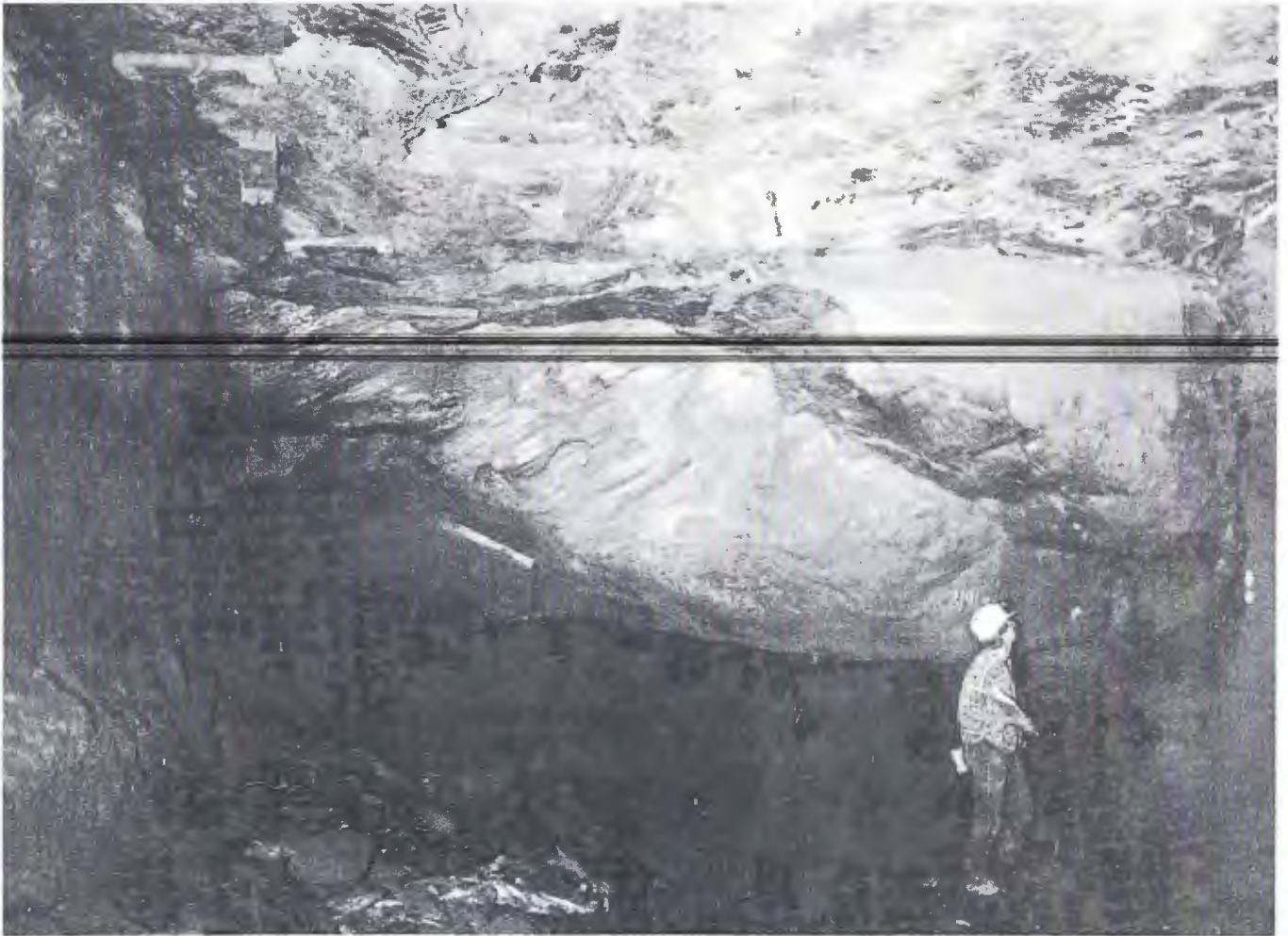


Figure 1.—Roof falls caused by exposed fault plane.

ORIGIN AND MECHANISM OF FAULTS

As mentioned, faults occur on all scales. They range from a 2-in offset in a rider coalbed to overthrusting of crustal blocks for tens of miles (5). Generally, coal measure faults can be grouped as follows: (1) small faults (generally <2 ft), which reflect local warping associated with overburden loading before rocks were lithified; (2) larger faults, due to slippage of bedding surfaces underneath stream valleys; and (3) large faults, which are a result of the stresses associated with major crustal movement, affecting more than one stratum, and perhaps a large section of strata.

In reality, a fault usually occurs as a series of fault surfaces rather than the single planar surface commonly portrayed. As a result, the hazard zone related to a fault can be very wide. Faults are also classified by the nature of movement along the fault plane. From this movement, several types of faults can be identified: normal faults due to tension, thrust and bedding plane faults due to compression, strike slip faults from shear forces, or normal,

reverse, and strike slip (a combination of the above) (fig. 2). Fault planes can be straight, curved, hinged, stepped, or discontinuous. Many times the planes dip in opposite directions and have a range of orientations about the main trend. Opposite dipping fault planes can cause the roof to drop out in blocks. Also, the roof is generally broken up and may contain fault gouge (crushed rock with a claylike texture) throughout the width of the affected zone (up to several 100 ft and more). This fault gouge can be extremely dangerous because it is not self-supporting, weathers easily and rapidly, and is difficult to rock bolt. Conventional rock bolting in a fault zone is difficult because of uncertainty about the shape of the roof blocks that need to be pinned together.

In most instances, the fault is not a clean break. Depending on the direction and magnitude of the stresses responsible for the faulting, the coalbed may be thrust up into the roof (compression) (fig. 3), dragged parallel to the strike of the fault plane (strike slip), or pulled apart with

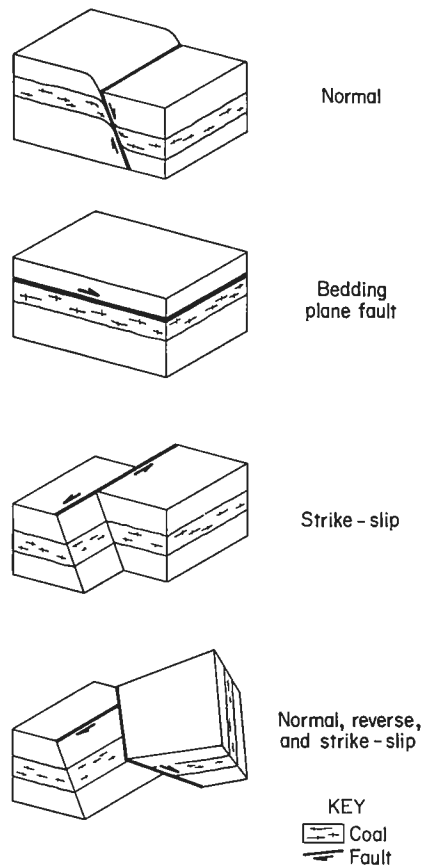


Figure 2.—Types of faults and associated movements.

one limb down dropped (tension). Because of frictional resistance, the coalbed, at the point of failure, may be severely mangled and will not function as a stable roof member. The type of roof failure and resultant roof control strategy are dependent on the type and magnitude of the movement along the fault surface.

Large-scale faulting is caused by a variety of major crustal movements. Mountain building events can cause compression or tearing of crustal plates, which can result in folding and faulting of strata. Normal faults can occur on the crests of folds, bedding plane faults result from slippage on weak layers due to compression (6), and

rotation of blocks result in strike slip and bedding plane slip (3). Large faults can affect the whole sequence of strata from below the coalbed up to the surface. When multiple seams are affected by the same fault, it is clear that the fault is not a local effect and is due to some large tectonic response. Sometimes these faults can be detected on the surface as lineaments. In these cases, it is still necessary to know the nature of movement and dip of the fault zone to anticipate their effect on coalbeds.

The stresses, which cause faults, can also change with time. The horizontal compressional stress field that created the Appalachian Mountains was directed NW to SE. Today's Appalachian stress field is oriented NE to SW (7). The Wabash Fault System in Illinois is another example of changing stress fields. These normal faults were created by a west-northwest to east-southeast tensional stress field, while numerous recent measurements show the current compressional stress field oriented nearly east-west (8). So while faults in and of themselves can create roof hazards, their deformation can be complicated by the addition of reoriented horizontal stress.

Faulting has been shown to occur beneath stream valleys as a result of valley stress relief (9). As stream valleys cut into rocks, they remove the confining weight of overburden and allow underlying beds to become stress relieved by bending, and ultimately faulting upward (fig. 4). As valleys become deeper, load is transferred from the valley flanks towards the valley bottom, compressing and buckling floor members. This failure has been observed at the surface in road cuts, dams, quarry, and foundation excavations (10-11). It has also been documented at depth in bedding plane faults with fault gouge zones. Evidence of this effect has been documented at 450 ft below the surface (9). There is also evidence that stream valleys act to redirect horizontal stress by interrupting the lateral transfer of that stress. Measurements of stress beneath a valley in southern West Virginia indicate a northwest oriented horizontal stress field. Mapped roof failures beneath the valley, oriented northeast, confirm a northwest stress field that is about 90° off the commonly measured northeast regional stress (9).

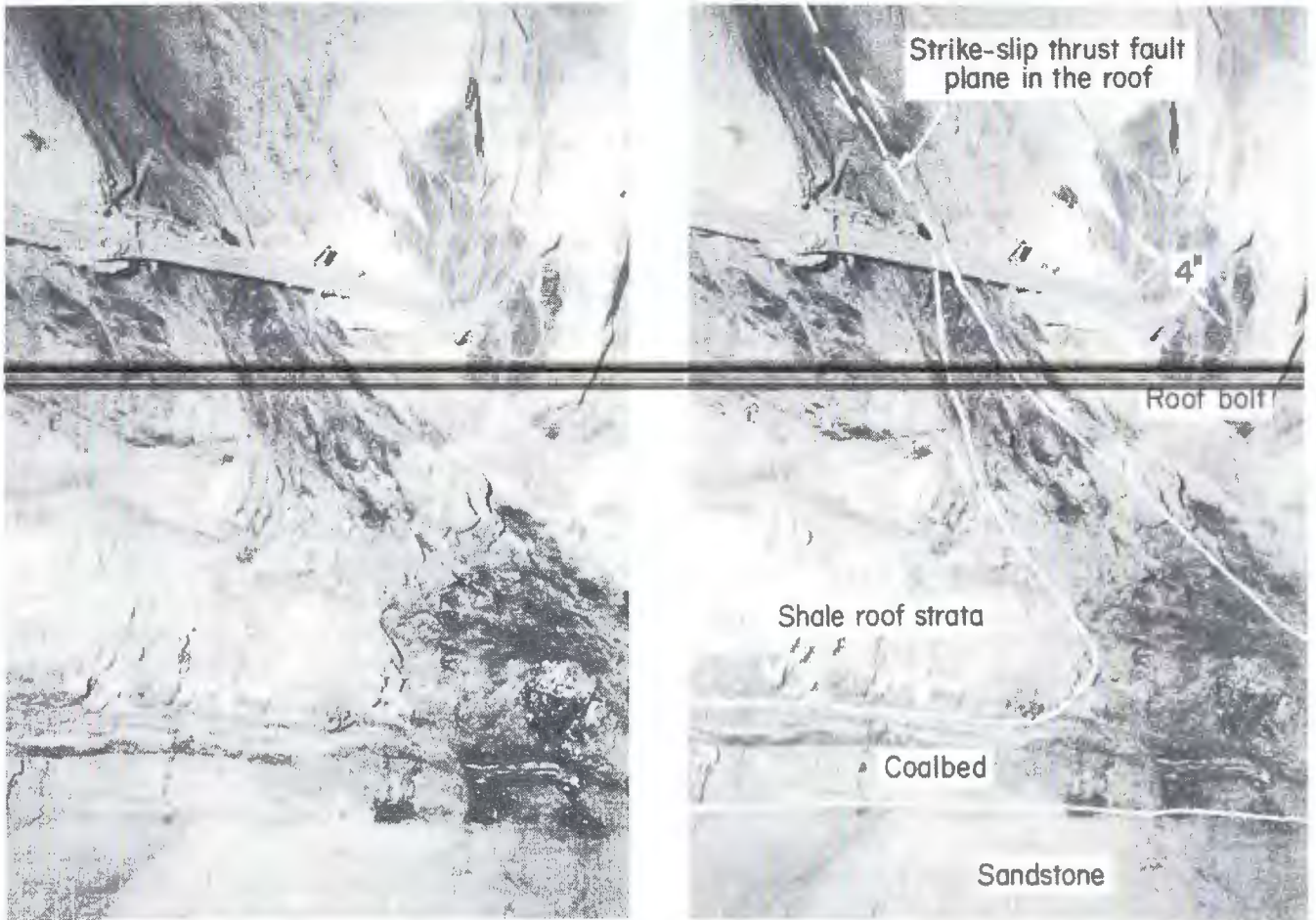


Figure 3.—Severe strata deformation and unstable roof caused by thrust faulting. Coalbed overturned and dragged upward.

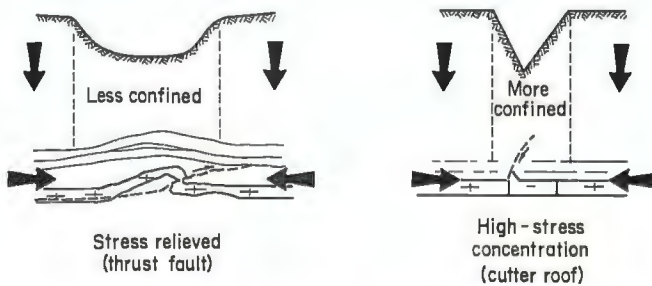


Figure 4.—Theoretical effect of valley shape on horizontal stress and roof control at depth.

As mentioned, the most common form of faulting affecting coal measure rocks is small-scale slippage caused by local strata readjustment and differential compaction. As peat forms in a coal swamp, portions of the swamp are buried by overbank flood deposits from nearby stream or river channels, or inundation by marine waters. With complete burial of the peat, these heavier deposits compact to different volumes than the lake muds, which also bury the peat. With this compaction, slippage occurs

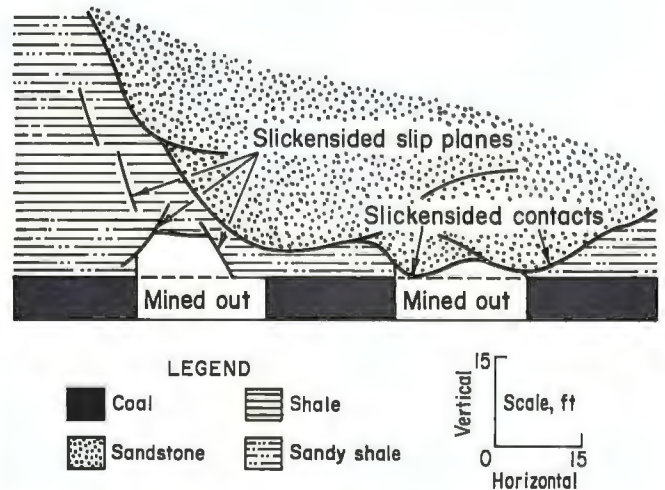


Figure 5.—Generalized cross section showing slip planes along transition zone between shale and sandstone (15).

along the transition of these different rock types, creating high angle normal faults (fig. 5). These faults are highly

slickensided providing no cohesion between roof blocks. The margins of ancient stream valley fills (paleochannels) are particularly hazardous areas for other reasons. There may be several different rock types filling the abandoned valley within a very short distance. These lithologic changes in rapid succession present many transition zones, which are highly angled and prone to failure. Along the margins of the ancient valley fills are other hazardous structures. These are slump blocks that form as soft fill deposits slide and are subjected to horizontal loads. Soft sediment flows create extremely deformed rock with numerous slip planes and shears, and are also roof hazards (fig. 6) (18).

Occasionally, clay veins are associated with faulting. This occurs as a two stage process. First, tensional faults are opened up in a coal seam. Then, if the immediate roof or floor material is soft and pliable enough, loading may cause this material to flow into the fault. These structures are known as clay dike faults or clay veins. They occur individually or in swarms, causing serious roof problems. Additionally, clay veins have been known to act as barriers to gas migration, and when penetrated by mining or drilling, can release hazardous methane into the mine (12).

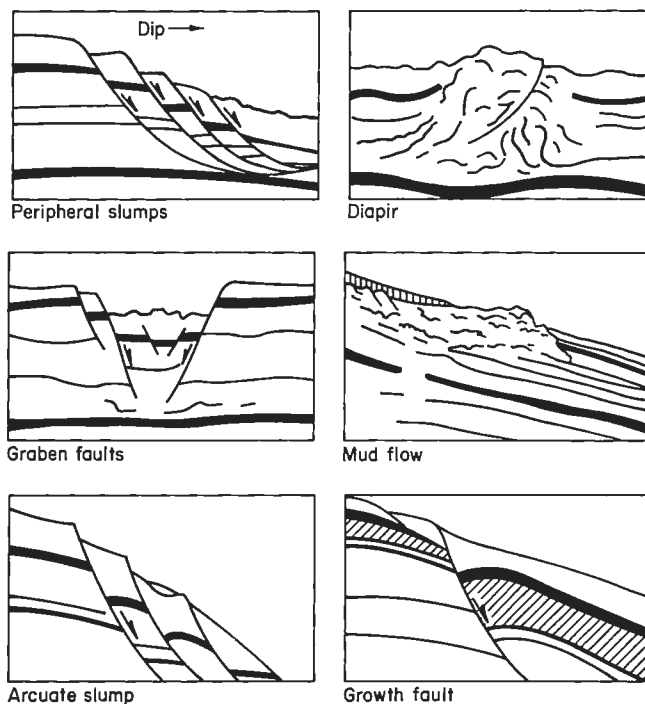


Figure 6.—Soft sediment deformation of channel fill due to gravity (18).

EXAMPLES OF GROUND HAZARDS CREATED BY FAULTING

Several examples of the effect of faulting on roof quality and production will be presented. Additionally, recognition criteria and engineering solutions will also be presented.

LARGE-SCALE STRUCTURAL FAULTING

Wabash Mine

The Wabash Mine is located in Wabash County, IL and is worked in the Springfield No. 5 coalbed. It is located in the Wabash Valley Fault System, which is a series of high angle normal faults that breakup the strata into large blocks. This fault zone crosses Illinois at about N. 25 E. and reaches 20 miles wide. Figure 7 shows the section of the Wabash Mine that is affected by the New Harmony Fault Zone (1). The fault zone was encountered by mining from east to west in 1984. It is approximately 2,500 ft wide with the main area of disturbance being approximately 600 ft wide. The total vertical offset is 120 ft with the downthrown side to the west and a fault angle of 12° to 14° (fig. 7).

It was decided that it would be cheaper to cross the fault than to sink a shaft on the west side to reach the coal

reserves. Still, it was a costly project to drive six entries down through highly deformed rock. All six entries were supported by steel arches with wood timbers and steel lagging the entire distance because of the highly fractured rock in the fault zone. Numerous smaller faults were mapped on both sides of the fault zone. These were created at the same time as the major fault by the same tensional forces. All minor faults penetrate the coalbed and extend into the roof, causing minor problems. Generally, the closer to the large offset, the more disturbed the roof.

This fault zone, because of its extent, would normally be easily detected from the surface and aerial photography. In this area, Illinois is covered by a thick blanket of glacial outwash, which obscures the fault. Regardless, the mine operators were aware of the fault in advance of mining because of drill hole data. Many other smaller faults remain undetected until exposed by mining. This is often the first indication of any coalbed or roof offset. Often the first encounter occurs after an operator has committed himself to a mine plan. Other times a fault is exposed by an adjacent mine, but this information is lost because of poor communication.

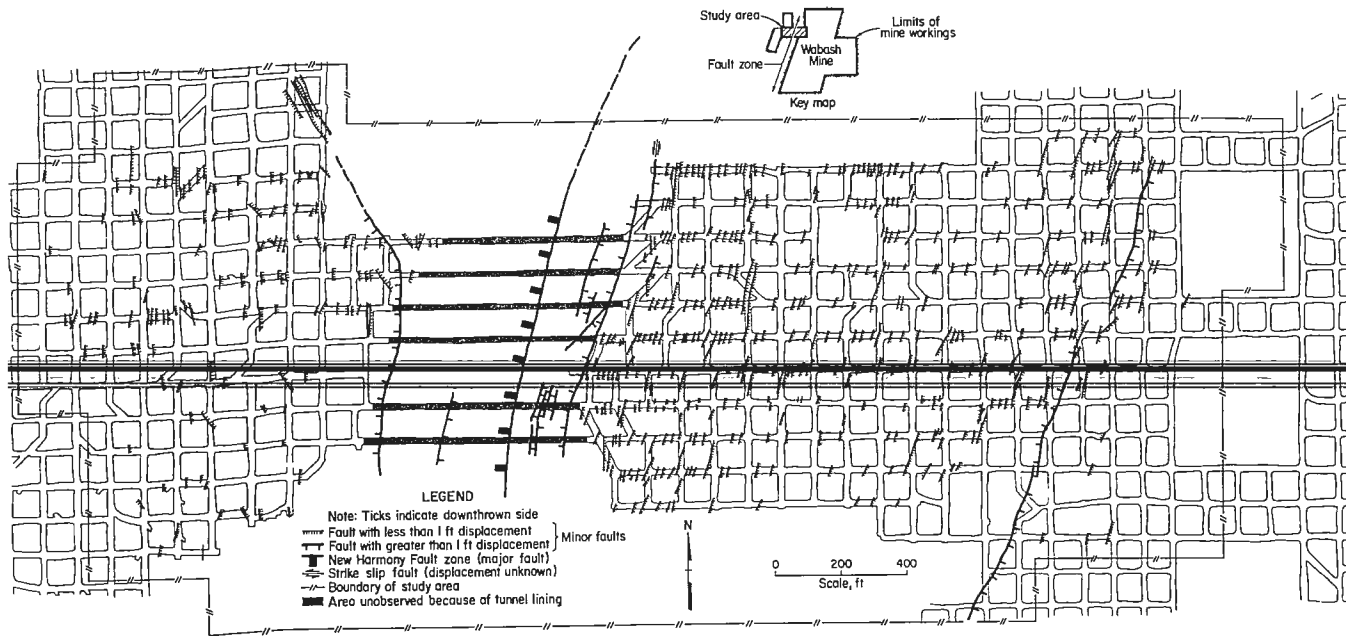


Figure 7.—New Harmony Fault Zone and related structures at Wabash Mine.

Virginia Overthrust Area

The coalfields of southwestern Virginia are some of the most structurally disturbed coalfields in the Eastern Coal Province. The Pine Mountain overthrust sheet is a detached section of crust about 125 miles long and about 25 miles wide, which has been moved in a northwesterly direction as a slab, up and over existing rock for many miles (3). This rectangular sheet is located at the junction of Virginia, Kentucky, and Tennessee in the southern Appalachian coalfield (fig. 8).

The overthrust sheet was thought to have rotated about a pivot point located near the intersection of the Russell Fork Fault and the Little Paw Paw Fault. As a result of this rotation, the bounding tear faults (Russell Fork, Little Paw Paw, Jess Fork, Keen Mountain, and Pistol Gap) show some secondary compressional overthrusting, as well as the primary strike slip movement (fig. 8). Lateral movement of the sheet along the tear faults is thought to be greatest (10 miles) near the Jacksboro Fault and the least (4 miles) near the Russell fork fault (5).

Two faults in particular are known to seriously affect roof quality in the area (fig. 9). The first is the Keen Mountain fault, which is a strike slip, compressional fault, with up to 18 ft vertical displacement observed in an underground mine. The other fault is the Pistol Gap fault with the same type of movement. The effect of these faults on roof quality will be described from observation in several mines and two coal mine highwalls.

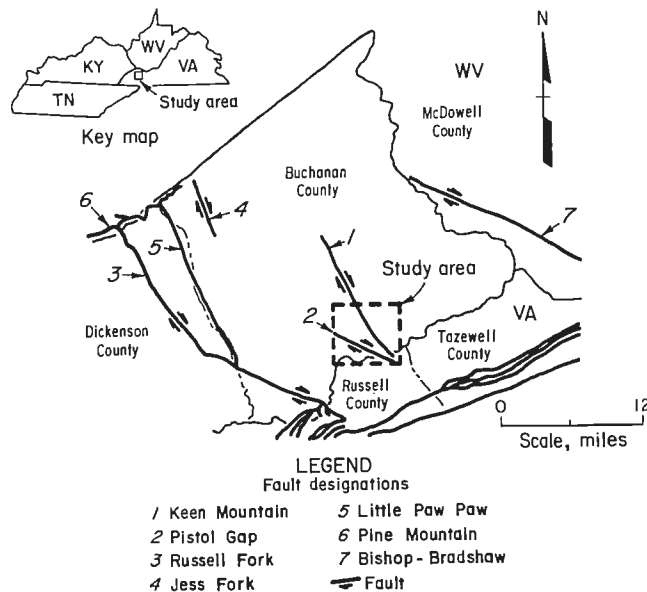


Figure 8.—Structural map of Buchanan County, VA.

Several mines in up to seven coal seams in Buchanan Co. have been affected by the Keen Mountain and Pistol Gap faults. Effects range from poor roof conditions and difficult mining to mine closure due to truncated coal seams. Figure 10 shows the areas of disturbance created by faulting in the Falcon Fuel Mine. It was only when each of the faults had been exposed several times by mining that the lateral continuity of the structures was

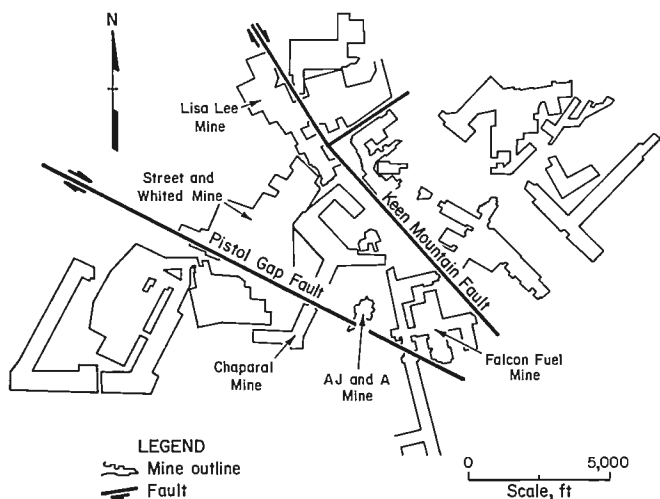


Figure 9.—Faults causing mining problems in Buchanan County, VA.

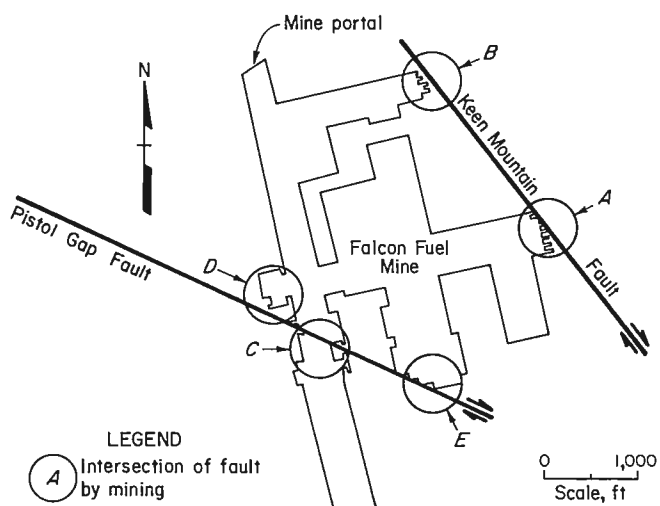


Figure 10.—Falcon Fuel Mine with developments affected by faults (circled).

realized. Mapping shows that the movement on the fault, which created the most difficult mining conditions, was compressional (fig. 11). Bedding plane slippage was severe and in some places truncated the coalbed by smearing it down to nothing. Highly polished slickensides between roof beds as well as within beds made for poor roof conditions. Fault gouge, coal fragmentation, and rotated blocks also combined to make roof conditions hazardous. The fault zone was up to 200 ft wide, with falls averaging 8 ft high, and extending up to 20 ft. Figure 11 indicates that the type of movement on the fault can change rapidly in only 100 ft. Owing to compression, several fault exposures had a swag in the coalbed to one side of the fault. This feature represents the down-buckling of the seam prior to failure. As a consistent

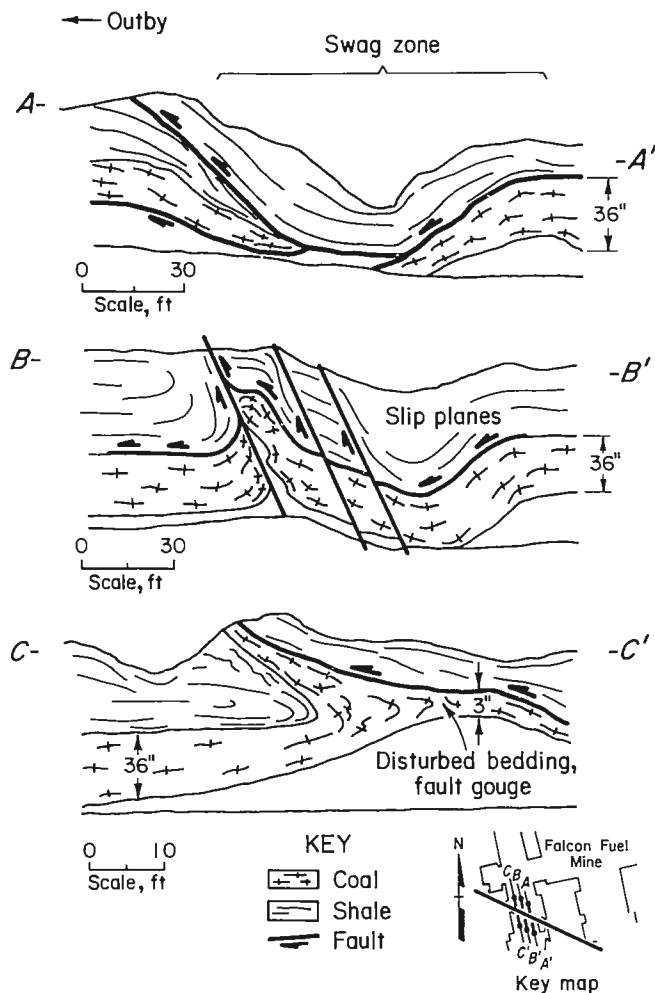


Figure 11.—Series of cross sections of Pistol Gap Fault exposed in the Falcon Fuel Mine.

feature, the swag may be used by the operator as an indicator of upcoming fault offset. Figure 12 shows the nature of the Pistol Gap fault at the AJ&A Mine. Offset as well as roof slips are caused mainly by compression.

Similar conditions prevailed at the Lisa Lee Mine, which has exposed the Keen Mountain Fault (fig. 13). This mine has intersected the Keen Mountain Fault in three places and a spur fault in a fourth. Several developments have been truncated due to coalbed offset and poor quality roof. The Jawbone coalbed thickened up to 86 and 96 in, respectively in two different entries at location A before the coalbed ran out. An additional problem is the severe restriction to ventilation that occurs when trying to neck down the development to cross the fault at location D. In several smaller seams farther up in the section towards the surface, offsets from the Keen Mountain Fault are less, but still affect the roof. Highwall exposures and surface lineaments confirm the extension of the two faults to the surface.

FAULTING DUE TO STRESS RELIEF UNDER STREAM VALLEYS

It has long been observed that coal mine roof, appeared to become unstable when mining beneath stream valleys (13-14). Although still not adequately defined, this "valley effect" appears to be the result of transfer of stress from the valley walls to the floor members, causing buckling and failure of this strata. This effect is commonly seen at the surface in excavations, but has also been documented to 450 ft in coal mines (9). Bedding plane faults, slips, and shears, along with folding and crushing are the structures which most damage the roof. Several case studies will be presented to demonstrate the effect of stress relief faulting on roof quality.

Lucerne No. 8 Mine

The Lucerne No. 8 Mine is located in Indiana County, PA in the Upper Freeport coalbed. Several ground

control problems are localized beneath surface stream valleys (fig. 14). Thrust faults and bedding plane faults are responsible for roof instability in several areas. The area known as the Flats has particularly unstable roof. The valley above is between 300 to 400 ft wide with approximately 200 ft of relief. The depth of the mine ranges from 50 to 100 ft. Poor ground conditions necessitate the use of odd-shaped pillars, and the loss of coal due to the inability to mine pillars in the retreat mining phase.

The structural failures in the Flats area are thrust faults. These thrust faults and associated roof falls are closely aligned with the valley trend. The compressional failures affect both the roof and the coalbed (fig. 15). Severely disturbed roof strata, with numerous bedding plane slips, falls out easily up to 15 ft. Fault gouge from slippage is a serious problem because of its inability to be supported. Crushing within the coalbed also makes for poor rib conditions. Figure 15 again demonstrates the variability of fault movement over short distances. The extent of fault movement appears to diminish over three successive entries. Severe movement in the upper diagram diminishes to only slight crinkling of the top of the coalbed in the bottom diagram.

Bedding plane and thrust faults are again exposed beneath other valleys on the property at South Mains and North Mains.

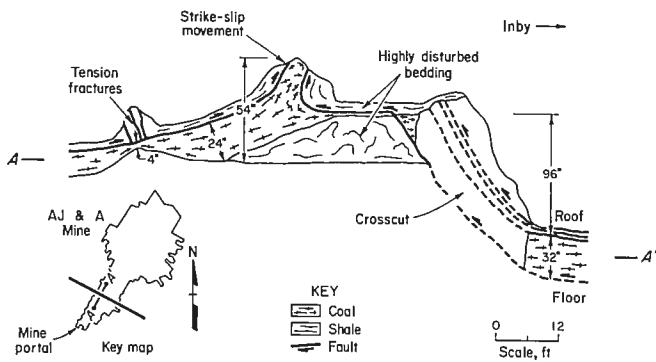


Figure 12.—Cross section of Pistol Gap Fault Zone at AJ&A Mine, showing coal and roof deformation.

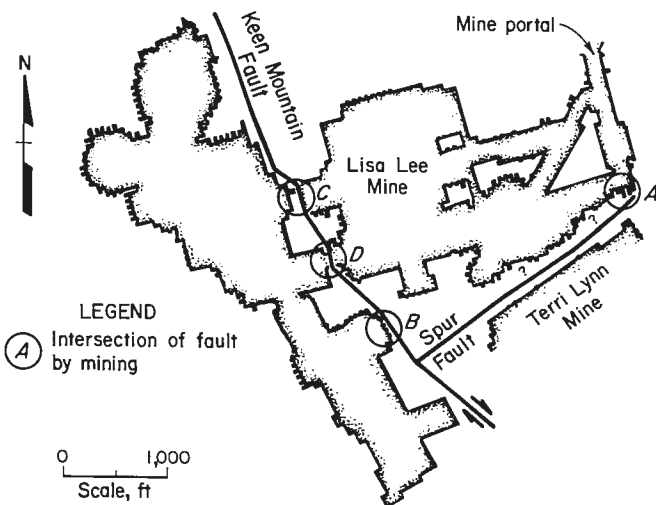


Figure 13.—Lisa Lee Mine outline and areas (circled) affected by Keen Mountain Fault.

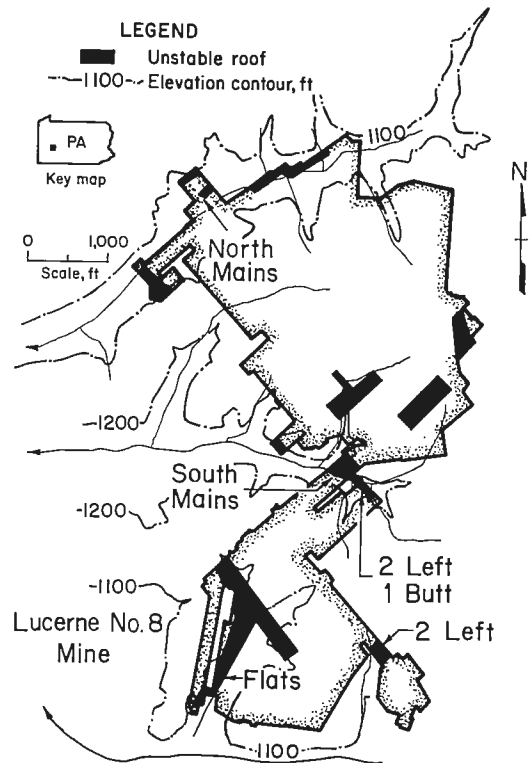


Figure 14.—Lucerne No. 8 Mine outline and relationship of unstable roof to surface drainage.

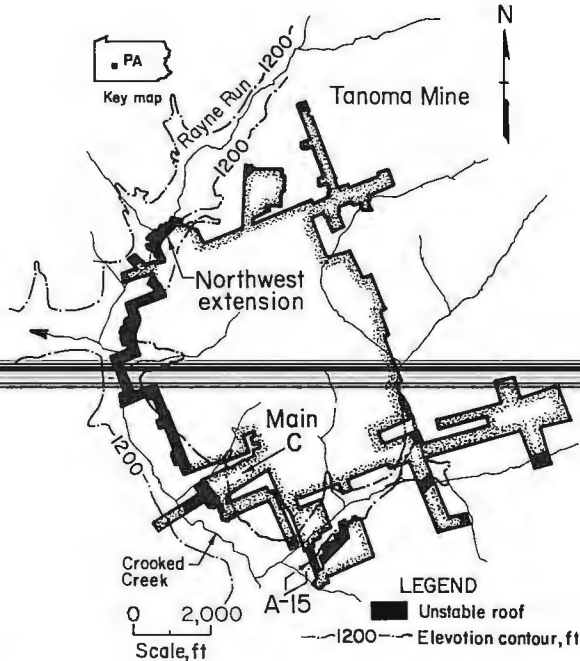


Figure 17.—Tanoma Mine outline and relationship of unstable roof to surface drainage.

Mining section A-15 crosses beneath a tributary of Crooked Creek (fig. 17). The development was necked down to three entries because of unstable roof rock and excessive water leakage. In addition, larger pillars were used to stabilize the hazardous zone. The valley bottom at this point is 400 to 500 ft across, with approximately 284 ft of overburden. Again, the roof instability in this section appears to be a result of horizontal compression perpendicular to the trend of the valley. Bedding plane faults parallel to the valley cause the major roof falls. Throughout the zone of unstable roof, the faults curve upward and intersect to isolate blocks of roof which then fall into the mine openings (fig. 18).

In the case of Tanoma Mine, it is clear that there is a relationship between poor quality roof and mining beneath a stream valley. In this case, the characteristic bedding plane slips accelerate the delamination process that occurs with roof sag. Once beds are delaminated and begin to separate, the process of roof failure is well underway.

FAULTING DUE TO DIFFERENTIAL COMPACTION AND OTHER DEPOSITIONAL PROCESSES

As peat swamps are buried and the coalification process begins, faults are created by strata movement due to uneven gravity loading. These small slips (usually <6 ft) are preserved in the coal and roof and may create hazards when undercut by mining.

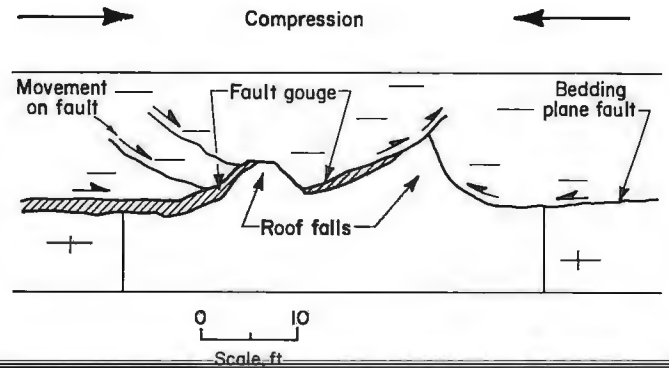


Figure 18.—Horizontal slippage and roof failure in Tanoma Mine caused by compression beneath valley.

Gateway Mine

The Gateway Mine is located in Greene County, PA in the Pittsburgh coalbed. This mine was plagued by several scour channels extending down from the Pittsburgh Sandstone into the roof and coalbed. As in modern delta distributory systems, channels and subsequent channel fills occur in swarms and can cover a large area.

This same Pittsburgh Sandstone affects a large area of the Pittsburgh coalbed throughout western Pennsylvania. Associated with the sandstone are several compactional and slump features, which combine to make mining hazardous and uneconomical.

As the surface drainage across a peat swamp changes direction or is abandoned, the channels are filled with a sediment load that may slide or slump if it becomes unstable. Slip planes become established in this way and as subsequent burial takes place, loading on the slips causes further movement (figs. 5-6). Slickensides are created over time and roof blocks fall out when undermined. With slumping or sliding, bed distortion occurs, creating more hazards. When sandstone wedges exist side by side with shale, the shale will compact more than the sandstone causing slip planes to occur at the transition. These slips or faults are preserved in the roof and are hazardous when undermined. As horizontal and vertical loading occur, roof deformation continues.

At Gateway Mine, a channel system trending north has caused the redirection of the West Mains and numerous hazardous roof conditions. Supplemental support as well as mine design changes have been necessary. Figure 19 shows the type of deformation that occurs with channel systems. Slickensides, crushed zones, faults, and distorted bedding planes caused difficult mining conditions.

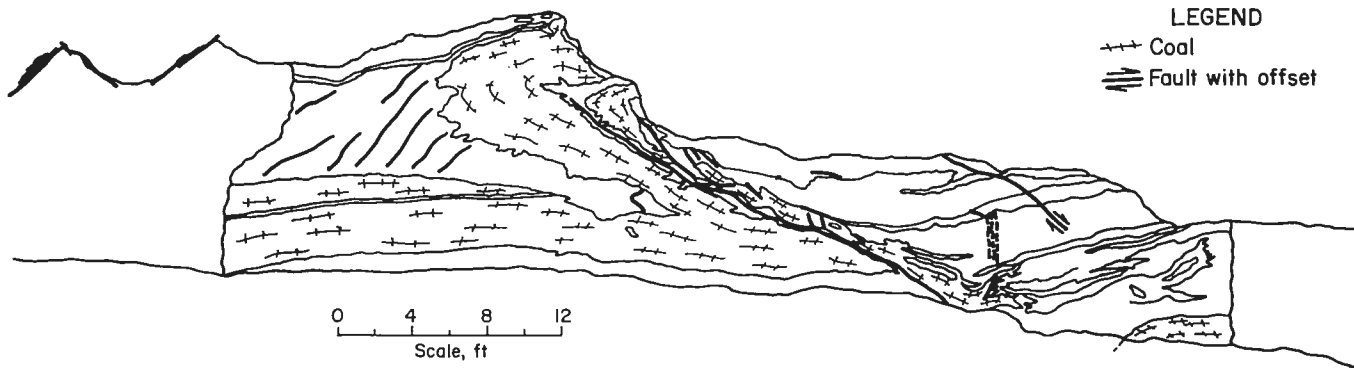


Figure 19.—Coalbed washout with channel fill. Severe deformation due to slumping and compaction.

Other examples of depositional faulting that has affected roof quality exist. Iannacchione and Puglio describe similar faulting in the Barnes and Tucker No. 20 Mine in Indiana Co., PA, which they attributed to "soft

sediment slumping" (15). The Pittsburgh Sandstone is again the cause of roof problems in the Shannopin Mine in Greene Co., PA. A large channel cut out is responsible for poor roof all around its margins (16).

RECOGNITION OF FAULTS AND ASSOCIATED GROUND CONTROL HAZARDS

In the case of large structural faults, it is essential to recognize individual discontinuities as possibly being related to one structure. In the examples from the Pine Mountain Overthrust in Virginia, some operators were unaware that the numerous exposures of both the Keen Mountain and the Pistol Gap faults were related. A basic understanding of how faults occur is necessary. Exposures in highwalls and overlying coal mines indicates the vertical continuity of the faults.

The use of surface linears is not always effective, but in this case their use would have pinpointed the location of the Keen Mountain fault (17). Discriminating use of linears, combined with a knowledge of regional structure would have aided in this identification.

Communication with other operators is very important in projecting the trend of large-scale faults. Similar experiences of operators in overlying coal seams and also in adjacent mines would help to locate the fault trace.

It is extremely difficult to detect faulting with drill hole data unless there is a large offset. Vertical faults are difficult to detect, and bedding plane faults often go unnoticed because they resemble bedding. If slump features are encountered by core drilling, it is possible to anticipate failure. Channels are localized features and difficult to detect with drilling.

High resolution seismic profiling is being used more frequently, but is most effective for large faults. The

resolution needed to profile small offsets (less than the seam height) is not easy to obtain.

To anticipate the roof hazards associated with a specific type of fault, it is helpful to identify recognition criteria specific to the fault. For example, the thrust faults, which were exposed in the mines in Buchanan Co., VA, were characterized by a swag to one side of the fault. The coalbed rolled down over a distance up to 200 ft, and dipped 8 ft or more. This swag was caused when the seam buckled by compression before faulting. Upwards in the section toward the surface, the offset in the Keen Mountain fault became less and less until only the swag remained. Recognition of this feature should help operators to anticipate the fault. In the same area, bedding plane slip occurs on many planes in the roof. Additionally, fault gouge is common along where softer rocks are encountered. This gouge and slip planes may be used as an indication of actual failure at some point close to the fault gouge. This crushed rock has very low strength and should be avoided as a sole anchor for roof bolts.

An understanding of the type of fault and its movement may help in the recognition of the fault from cores. For example, a repeat of a sequence of strata indicates a reverse fault. A loss of strata in the core record may indicate a normal fault.

ENGINEERING RESPONSE TO RECOGNIZED GROUND CONTROL HAZARDS

For mine planning purposes, the advantage of advance knowledge of existing faults is important. If the fault cannot be avoided, then its effects can be minimized by limiting the number of main entries that cross the fault zone. Provided they are located far enough from the zone to avoid poor roof conditions, submain entries can be driven parallel to the fault zone, and short panels can be mined toward the fault zone until conditions become non-productive or hazardous. Where necessary to cross the ~~fault zone, the headings should be turned at right angles~~ to the trace of the fault to minimize the exposure to the

fault. Also, long pillars should be cut through the zone before driving a crosscut, and the actual number of entries crossing the fault should be minimized. At least, driving entries parallel to faults should be avoided. To support roof strata broken up by faults oriented at varying angles, angle bolting and strapping should be used to oppose the fault angle. Angle and orientation (strike and dip) of the slip or fault plane should be considered when determining the length and angle of installation of the roof bolt. In ~~severely crushed roof strata, anchorage may become im-~~possible. It will then be necessary to use standing support.

SUMMARY

Faulting can occur on all scales in coal measure rocks and severely affect the quality of the roof. Large structural offsets are not common, but are the most easily detected. Although rare, these large faults can be extremely costly and hazardous to encounter. Smaller faults related to valley stress relief, and differential compaction are more common. Recognition criteria include

slickensides, fault gouge, offsets, disturbed bedding, loose roof blocks, bedding plane slips, swags, and rolls. This information, with Landsat imagery and regional mine map information, is essential to prediction of a fault occurrence. Once anticipated, faults can either be avoided or appropriate mine design changes or support changes can be made.

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INCREASING ROOF BOLTER OPERATOR AWARENESS TO RISKS OF FALLING ROOF MATERIAL DURING THE BOLTING CYCLE

By Michael J. Klishis,¹ Ronald C. Althouse,² Larry A. Layne,³ and George M. Lies⁴

ABSTRACT

The reduction of injuries due to falls of roof material is a longtime concern of the mining industry. Bolter operators are continually exposed to rib and roof falls as they perform their normal work tasks. Massive roof falls rather than the typical small falls have been the traditional focus of mine safety practitioners. However, falls of smaller amounts of roof material are a common source of injuries to roof bolter operators and other miners who perform roof-bolting work.

This paper presents the findings of a study on roof bolter operators' exposure to falls of roof material. The results are important to the development of safer work practices for all underground miners who are assigned to roof-bolting tasks and related roof support activities.

A detailed microanalysis of accident data was combined with worksite observations of bolting activities. Specific

tasks associated with injuries as well as the causes of roof fall injuries were identified and organized according to four work routines: (1) preparing the work place, (2) tramming and positioning equipment, (3) drilling, and (4) bolting. The lack of detail on injury reports hindered the analysis of hazards that may lead to injuries among all bolters. A roof bolter observation checklist was developed to be used by safety personnel, trainers, and supervisors.

In addition, the results of lost-time injuries found in the accident reports were combined with time studies of roof bolter operators to develop a set of risk and severity-weighted indices. An analysis of the four roof-bolting work routines revealed several safety problems and led to a series of recommendations for improving operator safety.

INTRODUCTION

Prevention of fatalities and severe injuries due to falls of roof material is a perennial concern in the mining industry. For roof bolter operators and others who perform roof-bolting tasks, the problem is more critical because these miners have to work under temporarily supported top and near unsupported top when they bolt a cut.

Roof bolter operators are continually exposed to rib and roof falls because they have the job of supporting

newly cut places. During bolting work they can be struck by falls of coal, rock, or slate while they complete specific bolting tasks such as operating machinery, preparing to bolt a place, drilling holes, and installing bolts.

Massive roof falls rather than the typical small falls that injure roof bolters have been the traditional focus of mine safety practitioners. The former problem involves falls of large sections of roof that result in the death or maiming of miners, damage to and/or covering up of equipment, or the blocking of mine entries.

Falls of smaller amounts of roof material, however, often lead to many injuries among roof bolter operators and other miners. These nonfatal incidents involve the fall of pieces of rock or coal from roof, rib, and face. Injuries related to this type of roof fall often lead to severe cuts,

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bruises, and fractures among roof bolter operators and involve a good deal of lost work time and/or production delays.

This paper presents the findings of a study on roof bolters' exposure to falls of roof material. The research methods consisted of (a) observations of job tasks, (b)

identification of roof fall occurrences, and (c) determination of risk and severity indices. The recommendations are important to the development of safer work practices for all underground miners who are assigned to roof-bolting tasks and related roof support activities.

BACKGROUND

~~Traditional research on the prevention of accidents~~ typically uses an approach that focuses on the accident itself. This approach assumes that accidents can be prevented if one understands the causes of human errors. Krause, Hidley, and Lareau (3)⁵ noted that this approach has not been successful because it does not identify the underlying cause of human error accidents—unsafe behavior.

Workers' unsafe behaviors often go undetected in the performance of a job unless an accident occurs, yet a good deal of unsafe behavior occurs prior to the accident. Krause, Hidley, and Lareau (3) claim the analysis and control of unsafe behavior is the key to accident prevention strategies, and that research has to include at least the following components: statistical analysis, review of safety programs, interviews with management and workers, and observations of workers. They further state that practitioners should develop a "critical behavior inventory" (CBI) and provide the workers with performance related feedback.

Based on earlier work to achieve mine safety improvements [Klishis (2)], researchers at West Virginia University have been using an approach that coincides with the methods described by Krause, Hidley, and Lareau (3). The goal of the researchers' approach, however, is to identify situations that create hazards or critical exposure points in specific job tasks. The methods include: data analysis, worker observations, and time or ergonomic studies. To be effective, this approach depends on management's decisions to act to alleviate poor conditions, to make changes in unsafe work practices, or to modify machine design and/or operating procedures.

For this study, the researchers concentrated on roof fall injuries to roof bolter operators. The aim was to identify situations where operators become exposed to roof hazards for an array of reasons. Among the central concerns were

- What causes roof bolter operators to be injured by falls of roof material?

~~Which tasks are more likely to result in injuries from falling roof materials?~~

- What conditions expose workers to falls during bolting work?
- How does human behavior increase the likelihood that a bolter will be struck by falling roof material?
- Does the design and operations of roof-bolting equipment relate to risk among miners?

To address these points, researchers developed a detailed description of the bolting process and identified critical exposure points in the roof bolter operator's job. The study combined results of two methods: (1) a detailed microanalysis of accident data and (2) worksite observations of bolting activities. This approach enabled researchers to identify the specific job tasks and/or conditions that are likely to expose miners to falls of roof material.

First, researchers examined the empirical data and written summaries of about 3,600 bolting-related injuries among more than 25,000 accidents reported in the West Virginia Safety Information System (WVSIS) for the period 1983 through 1990. The number of bolting-related incidents that occurred at the face was 2,685. Falls of roof material (911) accounted for nearly 4 of every 10 of the 2,685 reported personal injuries (RPI's).

This analysis helped to identify specific tasks associated with injuries as well as the causes of roof fall accidents. The identified tasks were organized according to four distinct work routines: general face preparation, tramming and positioning the machine and setting the automated temporary roof support (ATRS), drilling holes, and bolt installation (Layne (4), Grayson (1)). These tasks in each work routine are listed as follows

General face preparation:

- Set temporary roof support.
- Scaling, barring.
- Handle ventilation material.
- Handle supplies.
- Empty dust box.
- Examine workplace.
- Rock dust.

⁵Italic numbers in parentheses refer to items in the list of references at the end of this paper.

Tramming, positioning, repositioning, setting ATRS:

- Tram-align bolting machine.
- Set roof-floor jacks.
- Handle cables.
- Set ATRS; position canopy.
- Position boom, drill head.

Drilling bolt holes:

- Insert steel.
- Drill hole.
- Remove steel.
- Add extension.
- Change drill bit.

Bolt installation:

- Making up bolts.
- Bending bolts.
- Insert bolt-resin.
- Align bolt.
- Raise-spin bolt.
- Torque bolt.

Further analysis of the WVSIS injury data, however, found that only 2,111 of the 2,685 bolting accident reports contained enough specific data to classify the injury by a specific job task for comparison. The balance of the reports (574) did not contain sufficient detail to link the injury to a specific task.

Next, a roof bolter observation checklist (fig. 1) was developed to be used for worksite inspections and/or job safety sampling by safety personnel, trainers, and supervisors. The chart was the product of research that had identified critical exposure points during numerous mine-site observations of bolting work.

Finally, the results of lost-time injuries found in the accident reports were combined with earlier time studies of roof bolter operators (Stobbe, Plummer, and Mariner (5)) to develop a set of indices. This enabled researchers to develop a severity-weighted index (SWI) that could be useful for determining risk by the amount of time bolter operators spent in performing specific work routines as well as the seriousness of their injuries.

ANALYSIS OF JOB AND TASK RELATED INJURIES

Roof bolter operators are exposed to falls of rock, slate, and coal from roof and rib at certain points in the bolting cycle. To better understand the bolters' exposure to falls, researchers identified the specific job tasks associated with incidents commonly caused by falls. The reported personal injuries (RPI's) were then organized according to the four roof-bolting work routines and later analyzed for severity, which is a function of the number of nonfatal days lost (NFDL's).

Table 1 shows the distribution of the 2,111 RPI's that were identified with a job task in a work routine. It presents a comparison of bolting-related incidents involving the fall of roof material (566) and incidents due to other hazards (1,545).

The higher proportion of roof fall incidents for drilling, compared with that of bolting, may be partly due to one reason: the vibrational effects of the drill against the top disturbs the surface area around the hole. This situation may lead to falls of small- and medium-sized pieces of coal, rock, or slate. Otherwise, the incidence of injuries

related to falls of material are evenly distributed across the other work routines.

**Table 1.—Fall of roof versus other injuries
for bolting routines**

Work routine	Fall of roof injuries		All other injuries		Total injuries	
	Freq.	%	Freq.	%	Freq.	%
General face preparation.	112	19.8	314	20.3	426	20.2
Tram, position, set ATRS.	81	14.3	411	26.6	492	23.3
Drilling holes . .	232	41.0	440	28.5	672	31.8
Bolt installation.	141	24.9	380	24.6	521	24.7
Total	566	100.0	1,545	100.0	2,111	NAp
Percent of total injuries.	NAp	(26.8)	NAp	(73.2)	NAp	(100.0)

NAp Not applicable.

SOURCE: West Virginia Safety Information System Data, 1983-90.

ROOF BOLTING OBSERVATION SHEET

Row 1* Row 2 Row 3 Row 4 Row 5
 * May include open test hole (mark test hole with a "T")

Drilling (w. starter)
Hand on Rotating Steel

Safe

Exposed

Hand on Mast/Drill Head

Safe

Exposed

Observer: _____

Date: _____ Crew #: _____ Cut #: _____

Comments on unsafe acts and/or exceptional performance _____

Removing Steel from Hole

Safe

Exposed

Drilling (w. finisher)
Avoid Pinch Points

Safe

Exposed

Hand on Rotating Steel

Safe

Exposed

Hand on Mast/ Drill Head

Safe

Exposed

Removing Steel(s) from Hole

Safe

Exposed

Bolting
Aligning Bolt & Wrench

Safe

Exposed

Hand on Bolt while Inserting (raising/spinning)

Safe

Exposed

Hand on Mast while Inserting Bolt

Safe

Exposed

Bolt Spin Times (fully grouted bolts only)

Time in seconds Manufacturer's recommended time: _____

Bolt torqued

Yes Torque range: _____

Other Observations: circle observations (use the back of this sheet for additional comments)

<p>Bolts Bent not seen</p> <p>a) Jams bolt into ground (like bow)</p> <p>b) Bends over tire</p> <p>c) Bends elsewhere on bolt</p>	<p>Dust Box Emptied not done</p> <p>a) After bolting place</p> <p>b) When filled</p> <p>c) Due to no suction</p>	<p>Canopy no canopy</p> <p>a) Inadequate size</p> <p>b) Bolter doesn't stay under</p>	<p>Bolt pattern followed y / n</p> <p>Personal protection worn y / n</p> <p>Scaling done properly y / n</p>
<p>Laying Bolts Out not done</p> <p>a) On ground</p> <p>b) On bolt</p> <p>c) Against rib</p>	<p>Methane Checks not done</p> <p>a) Done incorrectly (no extension rod, etc)</p> <p>b) Done correctly</p>	<p>ATRS</p> <p>a) Not properly positioned</p> <p>b) Not pressurized to roof</p> <p>c) Stab jacks not set</p>	<p>Supplying done properly y / n</p> <p>Test Hole (if needed) y / n</p> <p>Tramming properly y / n</p>

Figure 1.—Roof bolter operator observation chart.

SEVERITY, EXPOSURE, AND RISK

The average severity for injuries due to falls was measured by NFDL's for those injuries that had reportable lost time. Table 2 shows the percentage of injuries classified as NFDL and the average severity of each injury. Approximately 53% of the 566 RPI's due to falls involved days lost. The average severity was 29.3 NFDL's, or more than one working month away from the job.

Table 2.—Nonfatal days lost injuries by work routine

Work routine	Total roof fall injuries	NFDL injuries, %	Average NFDL
General face preparation	112	52	28.6
Tram, position, set ATRS	81	53	45.0
Drilling holes	232	55	23.7
Bolt installation	141	48	30.6
Total	566	53	29.3

SOURCE: West Virginia Safety Information System Data, 1983-90

Of the four routines, the tasks involved in tramping, positioning, and setting the ATRS had the higher average severity (45.0 NFDL's per lost-time injury). By comparison, the tasks involved in drilling had a lower average severity (23.7 NFDL's). Face preparation (28.6 NFDL's) and bolt installation (30.6 NFDL's) were higher than drilling, but lower than tramping.

Injuries due to falls may be more severe if moving machines are involved in the accident. Machine related incidents typically find workers becoming pinned against a rib or caught between moving parts. The tasks of drilling and bolting, in contrast, occur after workers have already stabilized the bolting equipment and are preparing to bolt the place.

The body part injured in any of the four routines is linked to the requirements of the task. For example, operators need to use their hands to complete drilling and bolting tasks; therefore, hand and finger injuries are common in the drilling and bolting routines. Traumas to the lower limbs and trunk are more common in tramping

and positioning activities where workers are not under the canopy, near the ribs, and/or close to moving equipment.

The incident rate for roof-bolting activity may be inflated by injuries to other classified miners who fill-in for an absent bolting crew member. However, the distribution of accidents to nonbolters looks similar to that of bolters. Table 3 shows a comparison of incidents for roof bolter operators and other miners who were injured during bolting work.

Table 3.—Fall of roof injuries by roof bolting work task

Work task	Roof bolter		Nonroof bolter	
	Freq.	%	Freq.	%
General face preparation:				
Set temporary roof supports.	19	4.1	6	5.6
Scaling, barring	36	7.8	12	11.2
Handling ventilation material.	5	1.1	1	1.0
Handling supplies	4	.9	6	5.6
Examine, mark, dust . . .	20	4.4	3	2.8
Tram, position, set ATRS:				
Tramming machine	26	5.7	3	2.8
Setting roof-floor jacks . .	15	3.3	3	2.8
Handling cable	7	1.5	2	1.9
Set ATRS, position canopy.	22	4.8	3	2.8
Drilling the hole:				
Insert steel & drill hole . .	183	39.9	38	35.5
Remove steel	8	1.7	1	1.0
Change drill bit	2	.4	0	.0
Bolt installation:				
Making up bolts	24	5.2	3	2.8
Bolt in hole, align	74	16.1	20	18.7
Raise-spin bolt	14	3.1	6	5.6
Total	459	100.0	107	100.0
Percent of bolting fall of roof injuries.	NAP	(81.1)	NAP	(18.9)

NAP Not applicable.

SOURCE: West Virginia Safety Information System Data, 1983-90.

SEVERITY AND RISK INCIDENT INDICES

The development of a risk incidence incorporates (1) the total number of accidents for a particular work routine, and (2) the amount of time miners usually spend to complete those tasks. This approach leads to the construction of an incidence index that is specific to a particular job and permits a comparison among the bolting-work routines.

To determine exposure, researchers used data from roof-bolting observations made in eight mines owned by five different companies and located in five States (Stobbe, Plummer, and Mariner (5)). Observations covered the bolting of a regular cut over entire or 10-h shifts. Conditions varied among type of bolting machine, ATRS, and type of bolt used, including resin, conventional, and

combination type bolts. Seam heights varied from 1.65 to 2.7 m (5.4 to 9 ft).

The average time for bolting a place was 26.9 min (Grayson (1)). The calculations of the average time included the period from when the bolting crew trammed to a cut until the crew backed-out of the fully bolted place. Times varied among cut, bolting crew, and mine. The drilling routine accounted for more of the bolter operator's time (33.6%) than the other routines. This was followed by general face preparation (26.6%); tramping, positioning, and setting the ATRS (22.8%); and installing bolts (17.1%).

The amount of time a miner spends performing job tasks is as important in determining exposure as the total number of accidents identified for a work routine. If the differences in time among work routines is great enough, then time could prove to be a more precise indicator of exposure than accidents. Table 4 gives the incidence index for the four bolting routines.

Table 4 shows that the routine of installing roof bolts accounts for the second largest proportion of the roof fall incidents (24.9%), but involves the least amount of time (17.1%). The combination of these two factors, however, produces a higher incidence index of 1.45 among the four routines. Drilling, on the other hand, had a higher percentage of injuries (41.0), but it took longer (33.6%) for crews to perform this work. Therefore, the drilling

incident index of 1.22 is somewhat lower than bolting because crews are exposed for a longer period.

Table 4.—Incident index by bolting routine for fall of roof material

Work routine	Injuries, %	Time, %	Incident index
General face preparation ..	19.8	26.58	0.75
Tram, position, set ATRS ..	14.3	22.78	.63
Drilling holes	41.0	33.56	1.22
Bolt installation	24.9	17.08	1.45

Incident index = percent of accidents/percent of time (1).

SOURCE: West Virginia Safety Information System Data, 1983-90.

Table 5.—Severity weighted index by bolting routine for fall of roof material

Work routine	Average severity	Roof fall incident index	Severity weighted index
General face preparation ..	28.62	0.75	21.5
Tram, position, set ATRS ..	45.01	0.63	28.4
Drilling holes	23.70	1.22	28.9
Bolt installation	30.65	1.45	44.4

Severity weighted index = Average severity X Incident Index (1).

SOURCE: West Virginia Safety Information System Data, 1983-90.

RECOMMENDED SAFETY IMPROVEMENTS

The combined use of injury data analysis and worksite observations along with ergonomic studies led to the identification of improvements in roof-bolting operations. This implies that one must find practical and feasible solutions that will lead to safer operating procedures at the worksite.

The hazards of falling roof material and the effect on specific tasks can be shown by addressing each of the four primary work routines. To fully determine critical exposure points, researchers analyzed the 2111 RPI's by specific tasks within each of the four primary work routines. Table 6 summarizes this analysis and indicates the specific task-related incident. This also provides a way to compare fall of roof material versus all other bolting-related accidents across the specific tasks.

Worksite observations of workers were then used to identify potential behaviors and potential causes of task-related injuries. The following analysis addresses the four

work routines and reveals several problems and some possible solutions.

WORK ROUTINE: General Face Preparation.

- Set temporary roof supports, scaling and barring, handle ventilation material, handle supplies, empty dust box, examine workplace, rock dust.

Roof bolter operators are involved in a variety of preparation tasks. After making a methane check, and depending on roof conditions, they may have to scale or bar the roof or ribs. Other measures may include handling ventilation material, clearing the canopy and/or bolting machine of loose rock, and emptying the dust box. During the bolting cycle, operators may have to handle supplies and scale the roof some more. After completely bolting the top, some operators are required to rock dust the area.

Table 6.—Roof bolting injuries by work task

Work task	Fall of roof injuries		All other injuries	
	Freq.	%	Freq.	%
General face preparation:				
Set temporary roof supports . .	25	4.4	87	5.6
Scaling, barring	48	8.5	31	2.0
Handling ventilation material . .	6	1.1	42	2.7
Handling supplies	10	1.8	122	7.9
Examine, mark, dust	23	4.6	32	2.1
Tram, position, set ATRS:				
Tramming machine	29	5.1	148	9.6
Setting roof-floor jacks	18	3.2	89	5.8
Handling cable	9	1.6	118	7.6
Set ATRS, position canopy	25	4.4	56	3.6
Drilling the hole:				
Insert steel & drill hole	221	39.1	274	17.7
Remove steel	9	1.6	158	10.2
Change drill bit	2	.4	8	.5
Bolt installation:				
Making up bolts	27	4.8	115	7.4
Bolt in hole, align	94	16.6	109	7.1
Raise-spin bolt	20	3.5	156	10.1
Total	566	100.0	1,545	100.0
Percent of bolting fall at the face accidents.	NAP	(26.8)	NAP	(73.2)

NAP Not applicable.

SOURCE: West Virginia Safety Information System Data, 1983-90.

The tasks of scaling and barring are obviously the most hazardous in this work routine. Bolters are exposed to falls of roof material while they are trying to clean up roof hazards. Lack of awareness to roof conditions is not a typical concern here because workers are obviously attending to roof at the time of injury. Many roof bolters in fact are struck by falling material that bounce off the bolting machine.

Problem: Difficulties in avoiding falling rocks while scaling high top.

Observation: Roof bolters often have to scale loose roof rock. However, the length of most scaling bars (4 and 6 ft) is too short for scaling in high-top conditions where heights often are 8 to 10 ft or more. Bolter operators, therefore, have to get extremely close to loose roof rock to bar down the roof; in fact, some workers at times have to climb on top of the drill station canopy to scale the top. Or else they tram the bolter to a position directly under the bad roof to do the job.

Recommendation: The use of a longer scaling bar is advised for high-top areas. Observed workers at one mine modified a scaling device by welding a 2-ft end piece of a scaling bar to the end of an 8-ft metal pipe with a 1-in hollow diameter. This 10-ft device was relatively

lightweight and strong. It allowed miners to bar down loose rock in high-top conditions while they remained under the canopy.

WORK ROUTINE: Tramming, positioning, repositioning, setting ATRS.

- Tram-align bolting machine, set roof-floor jacks, handle cables, set ATRS, position canopy, position boom, drill head.

When bolters arrive at a new cut, they tram the machine toward the face, and set the ATRS and jacks. As they near this unsupported place, they are generally attentive to potential roof hazards, and they examine for conditions as they position and stabilize the bolter. To bolt a place, they have to continually reposition the machine and the ATRS, position the canopy, and position and reposition the boom and drill head.

While this routine accounts for the lowest percentage of roof fall related accidents, these accidents are among the most severe, averaging 45 NFDL's per accident. Compared with other bolting-related accidents, the injuries associated with setting the ATRS and canopy have a higher severity. One factor that may increase the bolter operator's exposure to falling roof material is the pressurizing of the ATRS against the top: this task disturbs the roof and can cause material to fall. Also as they adjust the canopy, bolter operators often are not under canopy protection, thus increasing their exposure. Two specific problems and suggestions for improvement are as follows.

Problem: Bolters moving into position before the setting of the ATRS.

Observation: On occasion, the miner who is not setting the ATRS may start to position the boom-drill head in anticipation of drilling before the other bolter operator has pressurized the ATRS against the roof. As a result, the first worker is being exposed to unsupported top that may loosen and fall because of the pressure of the ATRS against the roof.

Recommendation: Write up a procedure or construct a job aid that emphasizes the importance of waiting for the ATRS to be set before beginning to bolt. A mandatory provision (CFR 30; Part 75.202) covers this situation.

Problem: Overextending the ATRS.

Observation: Some bolting crews may extend the ATRS beyond the 5-ft legal limit to install an extra row of bolts, rather than reposition the bolting machine. While the mine's roof control plan may permit this, the miners are

in an at-risk situation because they are technically under unsupported top.

Recommendation: Review the roof control plan and 30 CFR part 75.221(a)(6). Determine the possible dangers because of pressure on the roof when operators over-extend the ATRS.

WORK ROUTINE: Drilling bolt holes.

- Insert steel, drill hole, remove steel, add

~~extension, change drill bit.~~

As the drill steel begins to penetrate the roof, operators may encounter some splintering of the top that causes roof material to fall. Generally the worker can use the canopy to avoid getting hit by falling material. However, they may have their arm extended out from under the canopy to grab the drill steel or add an extension steel. In these cases, their arms are directly below where the drill steel is vibrating against the roof surface area.

This routine accounts for the largest proportion of injuries caused by falling roof materials. Most of these injuries are linked to the specific tasks of drilling the top.

Problem: Hands on rotating steels.

Observation: A bolter at times will position a drill steel and (while steadying it) keep a hand on the steel. This may occur when the worker either starts to drill a hole or removes the rotating steel from the hole. Injury data analysis has pinpointed this particular practice to be a very important source of injury to bolter operators in the industry. Drilling tasks are more likely to cause pieces of rock to fall from the roof because of roof disturbance. When a miner places a hand around the drill steel, the hand and arm are not under the canopy; these limbs are directly below where material is likely to fall from the top.

Recommendation: To minimize hand, arm and shoulder injuries due to falling rocks, the operator's hand should not be beyond the canopy while the drill is penetrating the top. To remove drill steels, workers should be reminded to stay under the canopy, near the controls, until the steel is almost completely out of the hole. This procedure will reduce the time that the worker's arm and hand are not under the canopy. A mine should have a hands-off safety procedure for drilling holes. Bolter operators also should be made aware of the danger of falling pieces of roof rock.

Problem: Laying free hand or arm across the drill head while drilling.

Observation: Roof bolters may tend to lay their free hand or arm across the drill head, boom, or on the suction hose while they are drilling holes. Observed workers have noted that they tend to do this because they are trying to unload body weight because of fatigue or uncomfortable body positions in low heights. However, their extended hands and arms are beyond canopy protection. They tend to do this as the drill head is raised to a height between waist and chest levels. If a miner's free hand or arm is on or near the mast, it may be hit by pieces of roof rock that splinters and falls during the drilling activity.

Recommendation: Develop a safety procedure and/or job aid that emphasizes the dangers of rock pieces falling from the roof. It also should note the safety feature of keeping the free hand or arm under the canopy and away from moving equipment such as the drill masthead.

WORK ROUTINE: Bolt installation.

- Making up bolts, bending bolts, insert bolt-resin, align bolt, raise-spin bolt, torque bolt.

Roof bolter operators may move in front of the machine to place the bolt in the drill pod. In some cases, they are out from under the canopy where their entire body may be exposed to unsupported top.

Installation of bolts accounts for many injuries due to falls of roof material. Several of these accidents occur when workers install the last row of bolts. Exposure may be greater at the last row because workers are exposed to potential falls from unsupported roof as well as the face and ribs. Several situations may contribute to this task's high injury incident rate. One is the tendency for workers to rest a free hand on the mast while they are installing a bolt; the other is the common practice of keeping a hand on or near the bolt as it penetrates the hole. In both cases, the miner's hand and arm are unnecessarily exposed to falls of coal, rock, or slate. The tendency to overextend the ATRS may be a third factor that contributes to the high injury rate when bolting the last hole.

Problem: Reaching the top to insert glue and bolts.

Observation: High coal conditions may cause miners at times to climb on the raised drill head to reach the roof so they can insert the glue and bolt. In extremely high top, an operator who is on the drill head may also try to reach the drill head control levers by extending a leg out in an unbalanced stance. In either case, the miner is out from under canopy protection in an environment that may include flaking top.

Recommendation: Miners need to be cautious about the roof conditions when they go out from under canopy protection. Mine operators may need to install some type of overhead protection across the top of the ATRS to provide protection from falling pieces of roof rock. Any modification of the machine of course may entail a legal responsibility that would make it necessary to contact both the manufacturer and MSHA.

OTHER CONCERNS: Equipment (re)design and ergonomics.

The canopy offers roof bolters protection from falling roof material during drilling, bolting, and repositioning tasks. Unfortunately, the protection may often be limited because of a canopy's size or local mining conditions.

Problem: Workers not fully covered by the drill station canopy.

Observation: Workers in low coal must often contend with cramped conditions and uncomfortable positions. A restricted canopy can further reduce the working space and seam height. The tendency is for miners to lean out from under the canopy and even back away from under it. They do this intentionally to avoid cramped positions and to gain a good line of sight of the roof.

In coal seams of 6 or 7 ft high, the canopy's size may be so limited that the bolter operator cannot stay under it and work easily. A larger canopy may provide greater

protection, but its dimensional size creates difficulties when miners bolt in a corner against the rib.

High coal presents another problem because some types of drill station canopies are steeply sloped and extended high in the air. The canopy's height and angle are a function of the roof height—the higher the roof, the more severe the canopy's height and angle, and the more likely falling roof material will slide off the canopy and strike the operator.

Recommendation: Mine operators should emphasize the importance of workers staying under canopy protection while they are drilling and bolting. If the canopy is not level or if it is too small, the mine should evaluate the benefit of modifying the design to either level it or enlarge it to fit the mine's height and conditions. The mine also should approach MSHA for assistance and field testing to further protect operators.

Problem: Lack of canopy protection.

Observation: Several miners have pointed out that some roof-bolting machines lack canopy protection, which leaves the roof bolter exposed to falling top. Also miners have noted that they may not use the roof jack because the roof breaks up when the jack is pressurized against the roof.

Recommendation: Mine operator's should examine the possibility of placing canopies on the machine's roof jacks even when canopies are not required by law. A company policy on this situation may be one option.

SPECIFIC EQUIPMENT (RE)DESIGN

Bolter operators have revealed that they have a problem with high places. If a place is slightly higher than the ATRS, the operators must either (1) build cribbing on the ATRS or (2) set rib boards under the ATRS to provide additional height so the ATRS is properly pressurized against the roof. In extreme roof heights, bolting crews must use temporary jacks to provide support for the roof.

Problem: Extending the ATRS in high places.

Observation: Bolting in high, potted-out places is a common occurrence in coal mines and many bolter operators admit that they do not follow the correct procedures. They will either (1) leave the ATRS suspended in the air and bolt the place anyway, or (2) go inby and place cribs on the ATRS. Operators are exposing themselves to

unsupported top in both cases. (Note: Crews do have the option of tramping the machine back a few feet and securing the cribs to the ATRS; tramping back into position, and then bolting under supported top.) This problem is more likely if crews lack sufficient bailing wire for securing the cribs to the ATRS or if they do not have jacks for providing temporary support. The latter situation seems to be quite common since the introduction of the ATRS.

Extensions for the ATRS are available from manufacturers. Unfortunately the extensions are not easily installed in confined working conditions. Miners do not like to use extensions for the ATRS if they have to repeatedly install and remove them. High-top conditions, however, give bolters more options because of the additional working space.

Recommendation: Mines should ensure that extensions are available for the ATRS. Also, the storing of lightweight, portable hydraulic jacks on the machines may provide an alternative safety measure if the extendable

height of the ATRS poses problems for particular machines. Another suggestion is for mine operators to ensure that the bolting crews have easy access to bailing wire or similar material for securing cribbing to the ATRS.

CONCLUSIONS

This paper focused on the problems related to the fall of rock, coal, and slate during roof-bolting operations. ~~The combined use of injury data analysis and worksite observations by researchers underlies an improved approach for identifying workers' exposure to falls of material, and gives some indication of the risk involved in the roof bolter operator's job.~~

This observation based approach, often called safety sampling, has been employed successfully by at least one coal company (Waitkus (6)). In this study, for example, in the area of scaling, some safety recommendations are tied to equipment such as: longer scaling bars and better canopies. Also mine safety and training personnel may use this safety sampling approach to improve drilling and bolting work practices where crews are more exposed to material falling from roof and ribs.

The importance of addressing factors other than frequency of injuries is also important. Three factors—**injuries, time, and severity**—play significant roles in the calculation of a severity weighted index (SWI) that helps determine specific areas for safety improvements. In the case of roof fall injuries to bolter operators, the data indicated that mining operations can achieve the greatest safety benefits by focusing on critical exposure points in the work routines of drilling (41% of injuries) and bolt installation (44.4 SWI).

Better accident reporting is one key to the implementation of better safety programs. Lack of detail in accident reports, however, hinders this approach. ~~More than 20% of the 2,685 reportable incidents in this study~~ could not be analyzed because report narratives did not contain sufficient detail to identify a specific job task. Adequate information in a report about an accident is crucial for identifying hazards and analyzing the situation to improve mine safety.

It may be that the person who writes-up an accident report assumes that miners are fated to incur roof fall injuries, and therefore details on falls of roof material are inconsequential to the report. Such an attitude will not lead to prevention of roof fall injuries to bolter operators, regardless of the efforts made by mine operators, government agencies, and equipment manufacturers.

The identification of improvements in roof-bolting operations implies that one must find practical and feasible solutions. This requires the combined use of accident data analysis and worksite observations to determine problems in work practices. The data analysis, observations, and recommendations provide some ways for mining companies, government agencies, and manufacturers to reduce the incidence of roof-bolting injuries related to falls.

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A STATISTICAL PROFILE OF GROUND FALL INJURIES

By Robert F. Randolph¹

ABSTRACT

This paper contains statistical analyses of groundfall injuries in the U.S. underground coal mining industry. The analyses are based on data from Mine Safety and Health Administration (MSHA) records of mining accidents. Most of the analyses focus on the most recent 5-year period (1986-90). During this period, groundfalls accounted for 48% of the fatalities and 8% of the lost-time injuries. The total cost of these injuries, based on the U.S. Bureau of Mine's accident cost indicator model (ACIM), was \$125 million. Higher rates of groundfall injuries were found for smaller mines and lower seam heights, although these factors are somewhat confounded. As other authors have already recognized,

Tennessee, Kentucky, and Virginia had the highest groundfall fatality injury rates. The picture for lost-time injuries is somewhat different, however. Colorado and Illinois were found to have the highest lost-time groundfall injury rates. Differences between States correlated somewhat with differences in mine sizes and seam heights within each State. A comparison of injury experience with a 1986 study of demographics showed that job categories at the highest risk of fatal and lost-time groundfall injury were roof bolter-rock drillers, continuous mining machine operators and helpers, and working managers. These occupations typically perform work near the face and are most likely to be exposed to groundfall hazards.

INTRODUCTION

According to accident data compiled by the Mine Safety and Health Administration (MSHA), groundfalls are the most common type of fatality in underground coal mines, far outdistancing powered haulage, machinery, electrical, and other types of fatal accidents. Groundfalls are also a significant source of lost-time injuries. While these facts are well known, the solution to the groundfall problem remains elusive. This paper will provide statistical information about groundfalls that may be useful in arriving at causal explanations and successful interventions aimed at reducing groundfall injuries. The orientation of these analyses will be descriptive—theoretical interpretations of the underlying behavioral, technological, and geological causes will be left to others to explore based on these statistics.

Befitting the gravity of the problem, there have been several previous statistical characterizations of groundfall

injuries. For instance, a U.S. Bureau of Mines publication by Pappas (3)² characterized groundfall injuries up through 1984. Pappas documented the frequency, severity, and estimated cost of groundfall accidents, in addition to providing descriptive information on the accident characteristics. Since the accident data have recently been placed in a relational analysis data base, the Pappas findings can be updated and several more detailed analyses can be performed. Also, a data base containing detailed information on the mining work force has become available (1), and it can be used to help measure the risk of groundfall accidents to different subpopulations of miners. Some analyses using these new data sources were reported by Peters and Randolph (4) for mining accidents through 1989, and their statistics have now been updated to account for 1990 data.

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²Italic numbers in parentheses refer to items in the list of references at the end of this paper.

METHODS

This study employed a retrospective correlational design to analyze statistical relationships within the entire population of U.S. underground coal mines and mining accidents described in MSHA and Bureau accident records.

DATA SOURCES AND LIMITATIONS

The data presented here are drawn from MSHA's data base of mining accidents. MSHA gathers these data in accordance with Part 30 of the Code of Federal Regulations. To collect this information, MSHA requires mines to submit a form (numbered 7000-1) that describes each reportable accident. Also, each working mine must submit quarterly information about their operations, including production, employee-hours, and mine characteristics on another standard form (numbered 7000-2). The Bureau has access to computerized copies of this information for all mine operators from 1975 to 1990. The Bureau does not have access to computerized data about mining contractors, who have become a more significant part of the work force in the past decade. Consequently, the numbers presented here will be slightly smaller than analyses that include mining contractors. Also, reporting requirements for contractors are somewhat different from those for operators and the work performed by contract employees tends to be substantially different from work performed by mine operator employees, so the data are not readily comparable.

The analyses presented here cover the years 1986 through 1990. A 5-year span was selected to have enough data to minimize the impact of annual fluctuations. Now, the 1990 data are the most recent available in the Bureau's copy of the MSHA data base. The analyses are also restricted to underground operations at coal mines. Because this study focused on groundfalls that occur underground (rather than surface highwall falls and other surface hazards), surface and office workers, who are not normally exposed to underground hazards, were excluded from the analysis.

Another limitation of the MSHA data is that not all of the information on the reporting forms is complete for all the mines in the data base. For instance, information on seam heights, employment, production, and the injured employee's age are often missing or incorrect. The following steps were taken to groom the data set for analysis:

- Mines reporting 16,000 employee-hours or less or zero reported production were excluded from the sample. The rationale behind this was to exclude mines with less than one minimal full-time production crew (8 miners at 2,000 h/yr). Mines with less than a full-time crew may have been operating intermittently during the year, and the

associated startup and shutdown activities are likely to pose different kinds of hazards from normal production mining.

- Seam heights less than 20 in were treated as erroneous and omitted from analysis. The MSHA files contain reported seam heights as low as 2 in. These numbers clearly do not reflect actual working heights and should not be allowed to influence other statistics.

- Reported ages of injured miners were considered missing if they were more than 80 or less than 16. Reported ages in the MSHA files included values as extreme as 3 years and 89 years.

The injury data analyses will focus on two types of injuries: fatalities (MSHA "Degree of Injury" code 1) and lost-time injuries, referred to as nonfatal days lost injuries in MSHA documents ("Degree of Injury" codes 2 through 5).

Attempts to account for differences in fatality rates through statistical analysis are difficult. Often, fatalities are too rare to accumulate clear distributions. Since most mines had not had any fatalities during the sample period, their rate was zero. Groundfall fatality rates do show a small, but statistically significant, correlation with lost-time rates ($R = 0.080$, $p < 0.001$), so many of the correlational analyses presented here will emphasize lost-time rates as a more statistically useful measurement of accident rates.

GROUPING AND UNIT OF ANALYSIS ISSUES

It is important to be clear about the unit of analysis employed in the statistical calculations. These units can be at different levels of aggregation. For instance, the MSHA injury data can be aggregated or grouped by industry sector, by year, by mine, or by individual miner.³ One consideration is to have enough data points at the chosen level of aggregation to capture many observations of a range of values. For some of the analyses presented below, the data were aggregated by mine across the 5-year span, 1986-1990. For each mine, its total numbers of fatal and lost-time injuries were computed together with the total and average employee-hours and production. Finally, the last reported seam height was used. A total of 2,023 mines met the selection criteria of reporting nonzero underground production and at least 16,000 employee-hours during at least one of the years studied.

In a mine-level analysis, smaller mines have a greater influence than they do in a State or national-level analysis

³Aggregating by individual miners is actually not feasible since identifying data for individuals are confidential and omitted from the data files.

because their overall average is treated as a single data point and given the same weight as the averages drawn from larger mines. This level of aggregation is more appropriate for some questions than others. For instance, State- or national-level statistics are useful to gauge the overall risk to miners, while mine-level data are useful to

gauge the risk performance of different types of mines and to correlate these differences with mine characteristics. Because the summary statistics differ markedly depending on the level of analysis, this paper will identify which analyses were based on mine-level aggregations.

FINDINGS

The characteristics, frequencies, and costs of groundfall injuries were compared to other types of underground coal mining injuries. Then, groundfall accidents were isolated from all other types. The statistical relationships between groundfall accident rates and mine characteristics (size, location, seam height) were evaluated through correlational analyses and comparisons between subpopulations of the mining industry.

GROUND FALL FREQUENCY RELATIVE TO OTHER ACCIDENT TYPES

MSHA categorizes accidents according to 21 major classifications. Groundfalls are characterized by two different codes: "fall of face, rib, side, or highwall" (code 6) and "fall of roof—fall of back" (code 7). According to the

MSHA coding manual, these categories also include pressure bumps and bursts. Figure 1 shows the number of fatalities according to the MSHA accident categories from 1986 to 1990, and figure 2 shows the same breakdown for lost-time injuries. During the years 1986 through 1990, groundfalls accounted for 48.5% of the fatalities (95 out of 196) and 8.4% of the lost-time injuries in underground coal mines.

Figure 3 compares normalized data for groundfall fatalities and lost-time injuries with injury rates for all other categories of accidents. The year with the fewest groundfall fatalities (1988) also had the lowest fatality rate. There were no clear trends for lost-time injury rates, except an overall increase in reported lost-time injuries from 1986 to 1987.

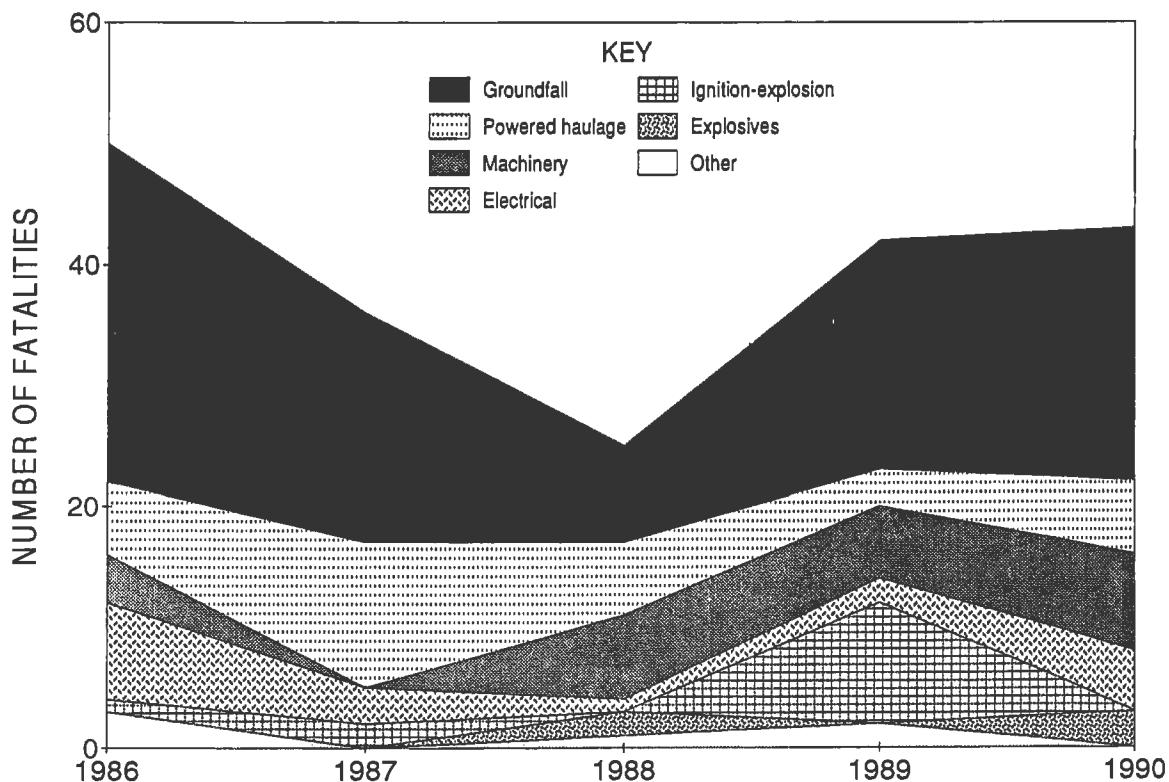


Figure 1.—Numbers of underground coal mining fatalities attributed to the major MSHA accident categories, 1986-90.

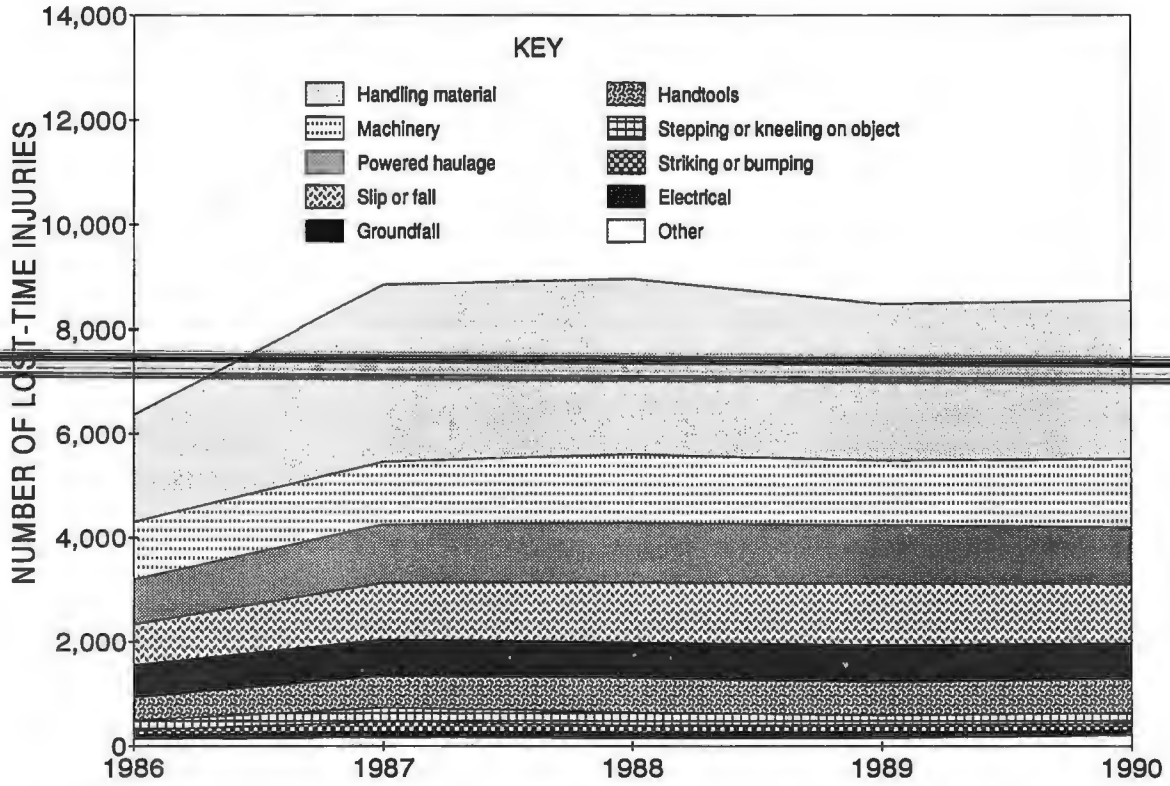


Figure 2.—Numbers of underground coal mining lost-time injuries attributed to the major MSHA accident categories, 1986-90.

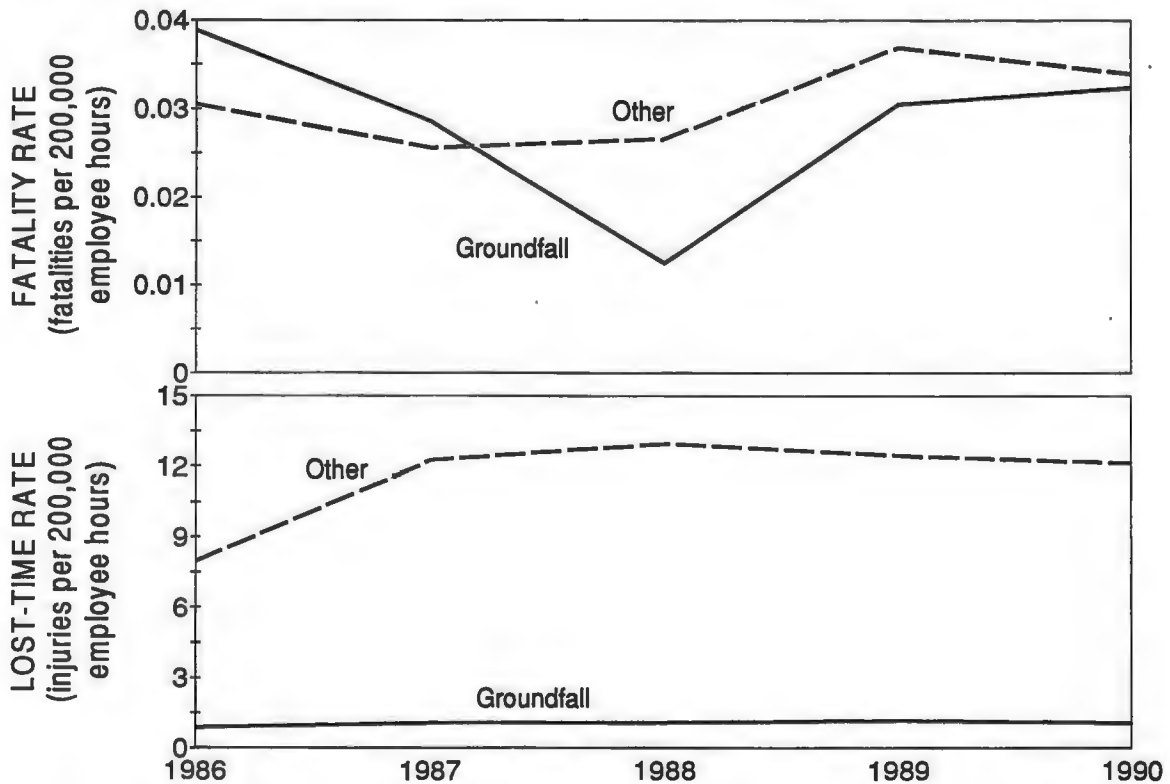


Figure 3.—Normalized rates of fatal and lost-time groundfall and other accident types in underground coal mines, 1986-90.

ESTIMATED ACCIDENT COST

The Bureau maintains a computer program that can estimate direct and indirect costs of mining accidents. This program, the ACIM, is based on a stochastic model of accident costs (2). Descriptive information about each accident is drawn from the MSHA accident characteristics data. Factors such as regional medical costs, wage scales, injury severity, and price of coal are combined to obtain a picture of the costs of each mining accident to the industry, the public sector, and the miner's family. Specific cost estimates are provided for lost production, the miner's lost wages, state worker's compensation, social security, union benefits, medical treatment, as well as the cost of conducting a fatality investigation.

According to analyses conducted with the ACIM, total costs for the all fatal and lost-time underground coal mining accidents during 1986-90 were more than \$575 million. Figure 4 shows how these costs can be divided between fatalities, and lost-time injuries and then further divided into groundfall and other types of accidents. More than \$99 million (17%) of this total was due to the 95 groundfall fatalities during this period and over \$25 million (4.4%) was attributable to lost-time groundfall injuries. The average groundfall fatality cost \$1.05 million, while the average cost of a lost-time groundfall injury was \$7,356.

WORKER ACTIVITY

The descriptive codes for the activity the injured miner was performing at the time of the groundfall accident provide some information about which activities are most dangerous. Since there are no exposure data available to estimate how much time is spent normally performing these activities, true risk statistics cannot be calculated. The most frequent activities are listed in descending frequency for fatal (table 1) and lost-time (table 2) injuries. Ten categories are listed for lost-time injuries, while 11 are listed for fatalities because of a three-way tie for the last item on the list. Seven activities are duplicated on the two lists, although in somewhat different order. Also, there are several items shared with similar tables compiled by

Pappas (3) for 1980-84 data. Specifically, the only fatality-related activities not shared with the Pappas table were, "load-haul-dump," "move power cable," and "handling explosives." For lost-time injuries, the listed activities duplicated Pappas' list, except "observe operations" and "shuttle car."

Table 1.—Most common activities of underground coal miners at the time a fatal groundfall injury was incurred 1986-90

Worker Activity ¹	Number of Fatalities
Continuous miner ²	12
Observe operations	9
Roof bolter, inserting bolt	8
Roof bolter, other	8
Walking, running	7
Timbering	7
Bar down	6
Load-haul-dump	4
Handling supplies	3
Move power cable	3
Handling explosives	3

¹Listed in descending frequency.

²Machinery names or types are listed if the injured miner was operating the machine when injured.

Table 2.—Most common activities of underground coal miners at the time a lost-time groundfall injury was incurred 1986-90

Worker Activity	Number of Injuries
Handling supplies	474
Continuous miner	274
Walking or running	242
Roof bolter, other	202
Idle (eating lunch, etc.)	199
Machine maintenance	189
Bar down	179
Move power cable	135
Observe operations	126
Shuttle car	88

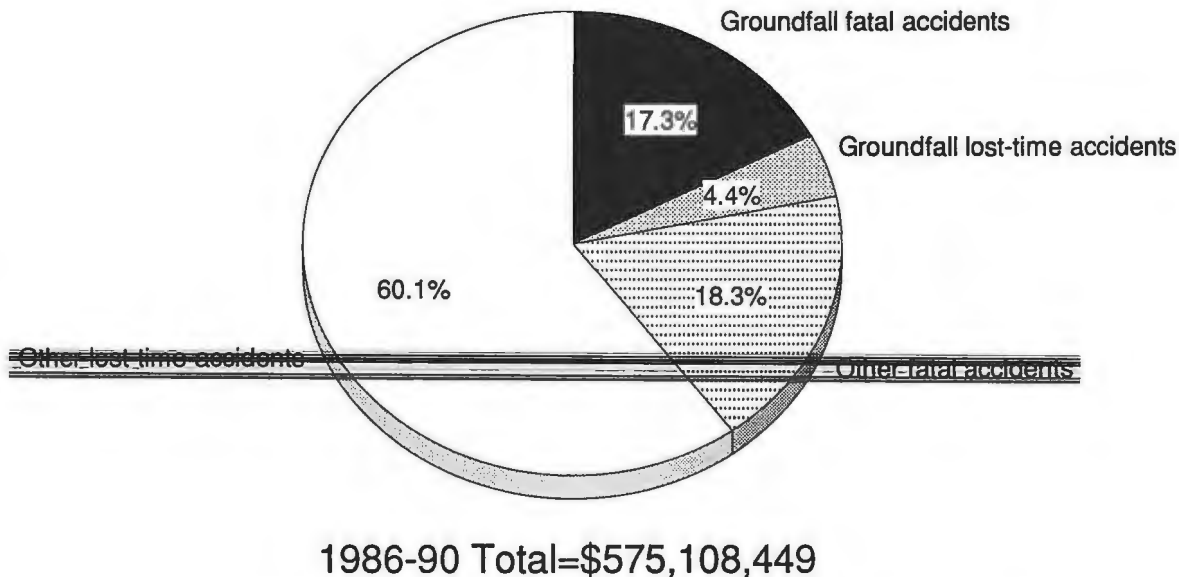


Figure 4.—Costs of fatal and lost-time underground coal mine accidents during 1986-90.

DEMOGRAPHIC ANALYSIS

A survey of the demographic characteristics of the mining work force conducted during 1986 (1) allows more detailed assessments of risk than is possible from accident reports alone. The survey was used to determine the proportion of the underground coal mining work force that fell into each of 15 occupational categories. MSHA accident data were then used to determine what proportion of fatal and lost-time injuries occurred to miners in the 15 occupations.

Figure 5 shows a comparison between the work force and injury experience. Occupations are listed from left to right in the figure, in order of descending estimated frequency in the 1986 mining population. For instance, the largest group, laborer-miner-utility worker, comprised 23.2% of the 1986 work force and is placed first, at the left end of the graph. Occupations comprising less than 5% of the work force are excluded, leaving 10 categories. For each occupation, the proportion of total fatalities and lost-time injuries that occurred to miners in that group are indicated by bars. Data are included for 1986, the year of the survey, as well as a 1986-90 average. The 5-year period is included to determine whether the 1986 rates appeared to be stable over a longer period. Overlaying the bars is a line indicating the work force baseline—the proportion of the work force in each job category. Injury data bars that extend above this line indicate the job categories that have more than their proportionate share

of groundfall accidents. From the chart, it is apparent that "Roof bolter-rock drillers" and "Continuous miner and related machine operators" have consistently elevated rates of fatalities and lost-time injuries from groundfalls. These categories were expected to have higher rates because their work requires them to be near areas of unsupported roof. The category of "Working manager-supervisor," which consists primarily of crew supervisors, has consistently elevated fatality experience. Although this category accounted for only 5% of the mining work force in 1986, they experienced 25% (7 out of 28) of the groundfall fatalities in 1986 and 15% (14 out of 95) of the 1986-90 groundfall fatalities. Fatalities among the "General manager-supervisor" category were also elevated in 1986, but less than proportionate during the 1986-90 period.

MINE CHARACTERISTICS

Size

The size of a mining operation usually refers to the work force employed there, rather than physical dimensions. For these analyses, the number of hours worked by underground employees were used as a measure of size. Figure 6 shows the fatality and lost-time rates broken down by four size groups: less than 40,000 employee hours, 40,000-69,999 employee hours, 70,000-299,999 employee hours, and 300,000 employee hours and over. In the graph, there is an apparent trend toward higher injury

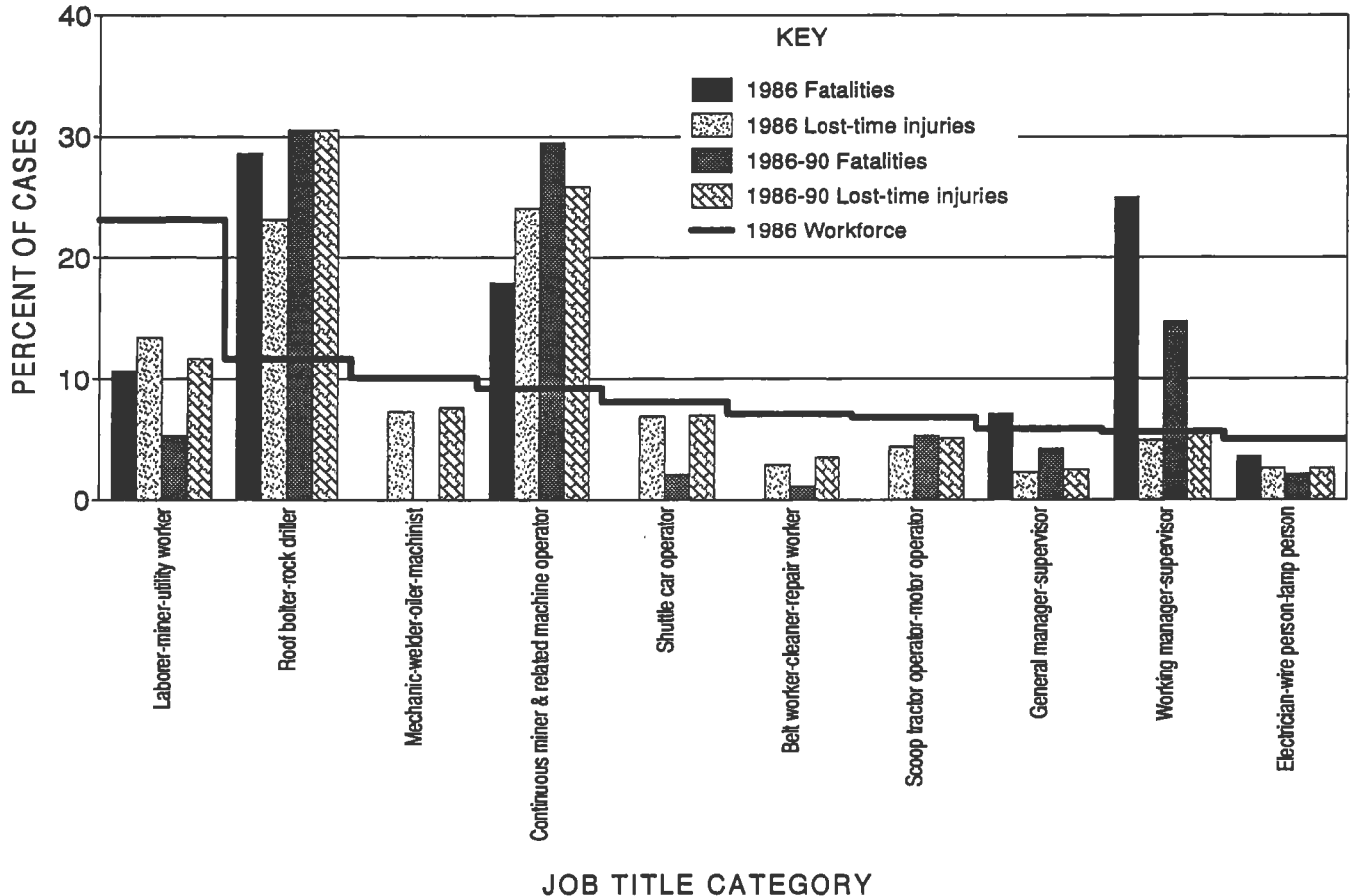


Figure 5.—Variations in risk of being injured or killed by groundfall across jobs.

rates among smaller mines, particularly for fatalities. In a mine-level analysis, employee-hours correlated -0.029 with mines' groundfall fatality rate and -0.027 with groundfall lost-time rate. Neither of these correlations were statistically significant at the $p < 0.05$ level, however.

Location (State)

Figure 7 shows a State-level analysis of groundfall fatality and lost-time rates. The States with the highest groundfall fatality rates were Tennessee (0.068), Kentucky (0.045), and Virginia (0.045). States with the highest groundfall lost-time rates were Colorado (1.77), Illinois (1.46), and Virginia (1.40).

Turning to a mine-level analysis allows for statistical tests of differences between States. Table 3 shows averaged data for fatal and lost-time injury rates, seam height, mine size (in employee-hours), and production. This

table is different from the previous figures because it uses individual mines as the unit of analysis rather than aggregated State data. The results from using mines as the unit of analysis rather than the entire State are somewhat different. For instance, Alabama's overall groundfall lost-time injury rate was 0.61 (as shown in figure 7) while the average of its mines' injury rates was 2.543. This was probably because of a large range in lost-time rates among the State's mines (0 to 34.7), and the mine with the highest rate also happened to be the smallest (17,292 employee hours). An analysis of variance using State as the independent variable and mines' groundfall lost-time injury rates as a dependent variable showed a statistically significant difference ($F_{15,2007} = 1.933, p = 0.017$). A similar analysis for groundfall fatality rates was not statistically significant, however, probably because of the low statistical power of an analysis involving very few fatalities for some of the States.

Table 3.—Mine-level averages of groundfall fatality rate, groundfall lost-time rate, seam height, employee-hours, and production stratified by State

State	Average fatality rate ¹	Average lost-time rate ¹	Average seam height, in	Average employee hours	Average short tons produced	Number of mines
Iowa	0.000	3.243	54.00	61,679	99,087	1
Oklahoma . . . . .	.000	2.851	46.50	40,161	36,220	2
Alabama . . . . .	.007	2.543	53.38	441,617	894,254	17
Virginia . . . . .	.082	1.538	49.00	53,152	137,713	356
Colorado . . . . .	.012	1.505	89.60	155,553	548,727	15
Illinois . . . . .	.013	1.346	74.71	484,154	1,283,682	34
Utah . . . . .	.045	1.310	96.33	160,331	755,592	27
Maryland . . . . .	.060	1.310	78.67	197,808	858,269	3
West Virginia . . . . .	.065	1.122	55.06	84,444	246,518	592
Tennessee . . . . .	.033	1.096	37.13	55,442	106,508	63
Kentucky . . . . .	.047	1.000	45.43	56,041	166,532	781
Pennsylvania . . . . .	.015	.660	56.01	188,254	421,958	103
Indiana . . . . .	.171	.522	59.67	59,937	270,451	6
Ohio . . . . .	.006	.431	56.00	334,920	803,560	18
New Mexico . . . . .	.000	.355	101.00	93,279	251,872	2
Wyoming . . . . .	.000	.196	100.00	97,075	334,307	3

¹Per 200,000 employee-hours of exposure.

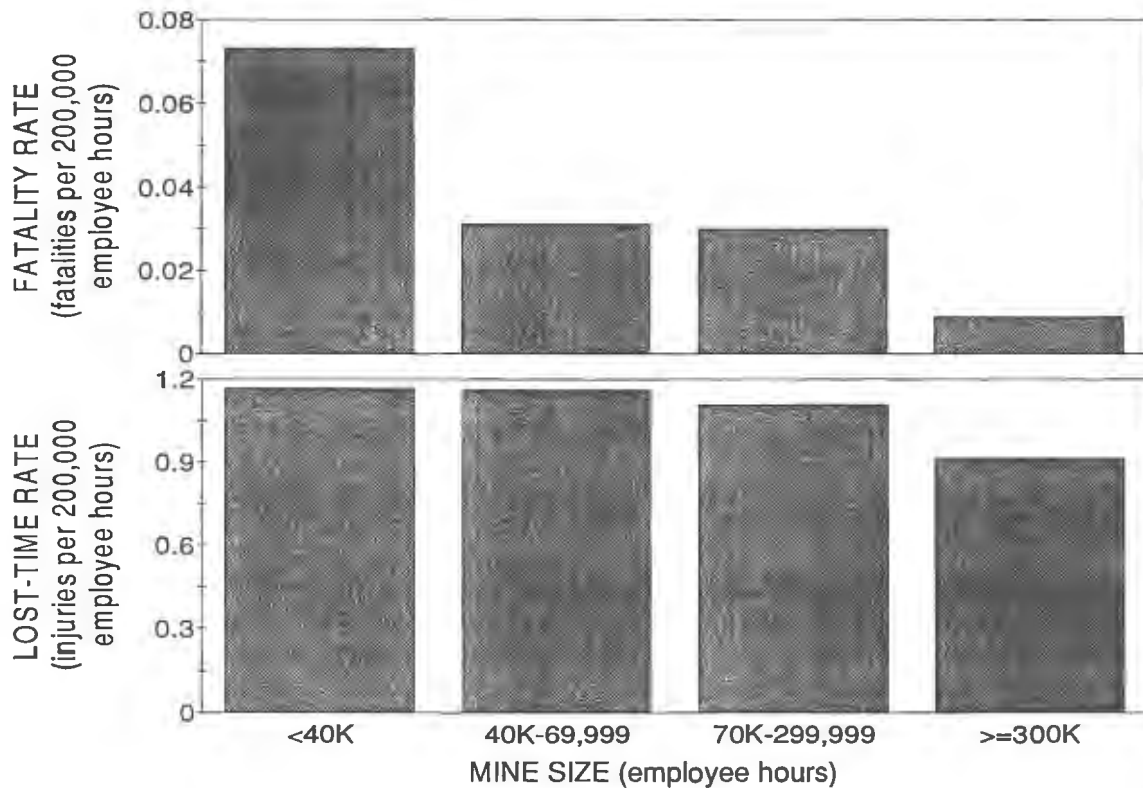


Figure 6.—Fatal and lost-time accident rates stratified by four mine employment size groups.

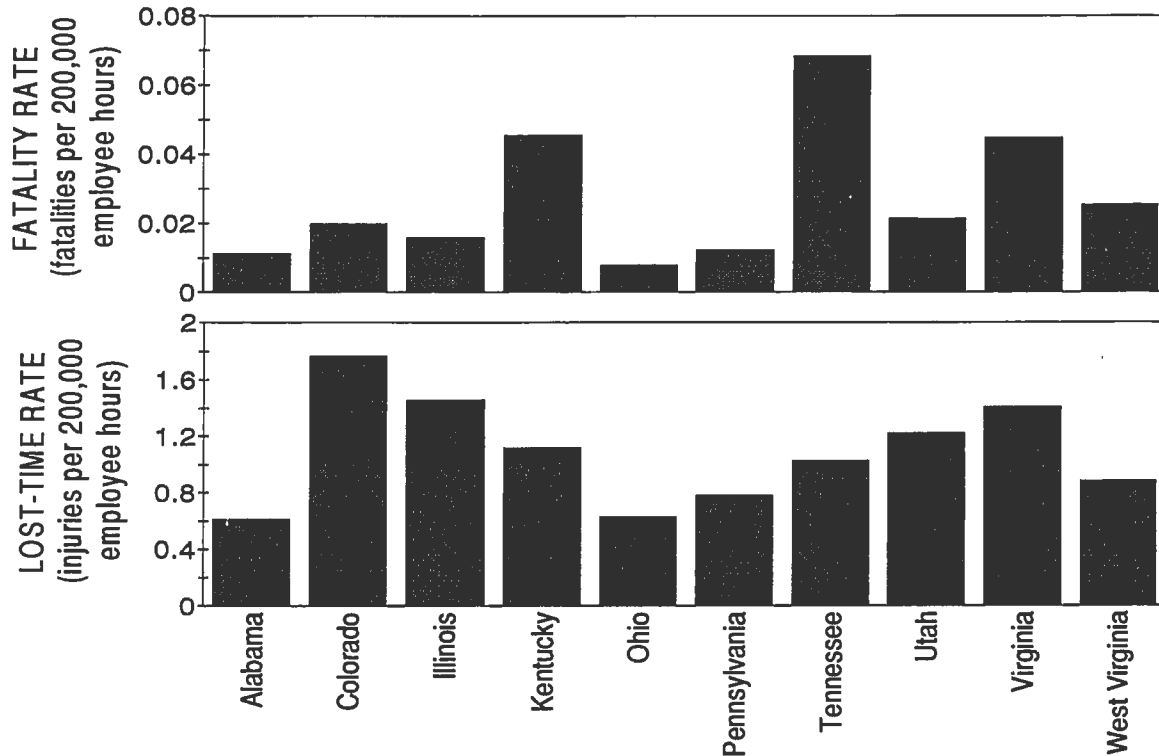


Figure 7.—Fatal and lost-time accident rates stratified by State. States with fewer than seven mines meeting the sample criteria were excluded from the graph.

To distinguish the individual relationship of each State to the accident rate data, a series of dummy variable analyses were performed. A dummy variable takes on a value of one if a case or observation belongs to a given group and zero otherwise. These binary values can then be used in correlational and linear modeling analyses alongside more conventional continuous variables. Dummy variables corresponding to each State in the analysis were computed for each mine's data. For instance, each mine in West Virginia was assigned a value of one for its "West Virginia" dummy variable and zero for all the other State dummy variables.

The correlation between a single State dummy variable and accident rate indicates the extent to which the distribution of accident rates for that State differs from all other States. The only State dummy variables that were correlated with lost-time injury rates to a statistically significant degree ($p < 0.05$) were Alabama and Virginia. These findings were due to the higher than average groundfall injury rates in these States. Alabama's average rate of 2.54 was 223% of the national average rate of 1.14, and Virginia's rate of 1.54 was 135% of the national average. The dummy variable analysis showed that several

other States with high accident rates (Colorado with 1.50 and Iowa with 3.24) had either too few mines or too much variability among their mines to find a statistically significant difference between their averages and the rest of the industry. Several western States (New Mexico, Wyoming, Utah) had the highest seam heights while Tennessee, Oklahoma, and Kentucky had the lowest seams. The States with the largest average employee-hours were Illinois, Alabama, and Ohio while Tennessee, Virginia, and Oklahoma had the lowest average employment numbers.

Seam Height

In a mine-level analysis, seam height (in inches) correlated -0.034 with mines' fatality rates and 0.040 with lost-time rates. Neither of these correlations were statistically distinguishable from a correlation coefficient of zero at the $p < 0.05$ level. The data were also stratified by 11 seam height groups. That is, for each seam height group, all the injuries were totaled together and normalized by the total number of employee-hours reported by mines in the group. Figure 8 shows an apparent overall trend towards higher groundfall fatality rates in lower seam mines,

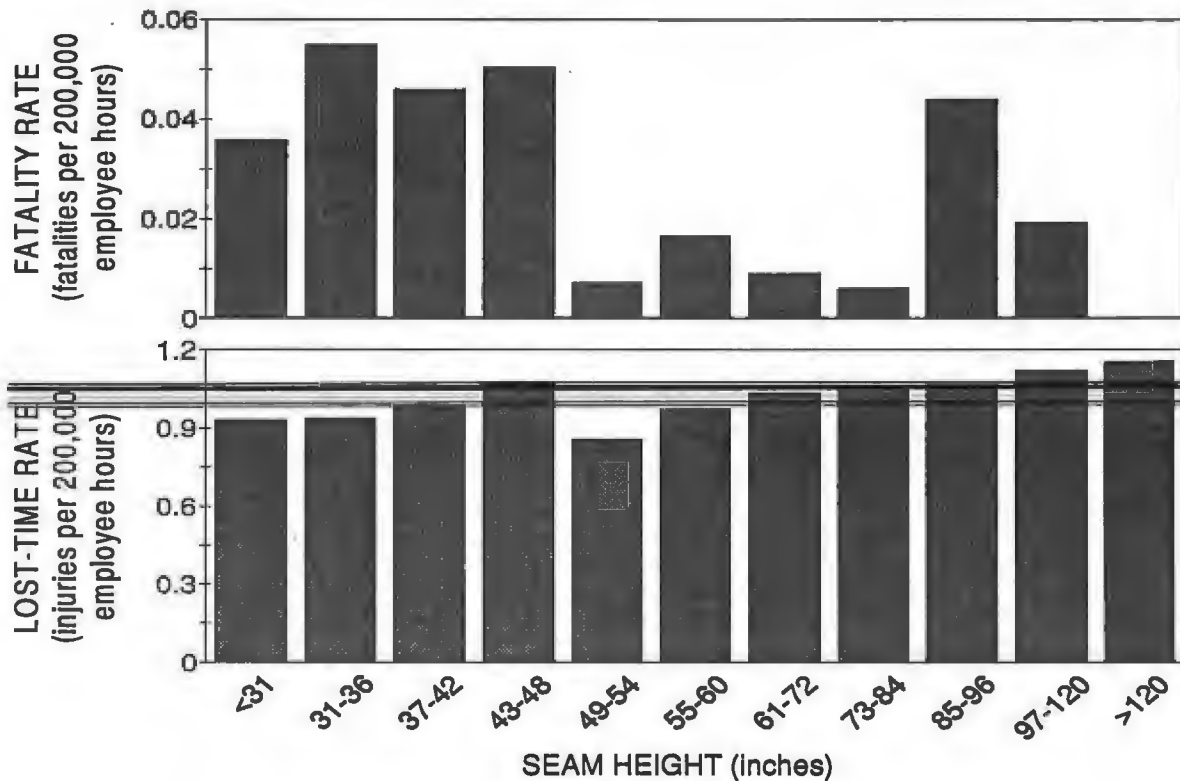


Figure 8.—Fatal and lost-time accident rates stratified by eleven seam height groups.

although there are elevated rates for the 85-96 in group and the 97-120 in group. The graph for lost-time rates shows what appears to be a different relationship, however. All the seam height groups have similar groundfall lost-time rates (0.858 to 1.158 injuries per 200,000 employee hours) and there appears to be a slight positive relationship between seam height and injury rate.

Productivity

Productivity was measured as the number of short tons of coal produced per employee-hour worked, as reported to MSHA. Several other studies (summarized in reference 5) have shown a negative correlation between accident rates and productivity. That is, mines with higher productivity rates tended to have lower accident rates. This relationship was not evident in the current sample. Correlation coefficients between productivity and both fatality rate and lost-time rate were small (-0.016 and 0.039, respectively) and did not reach the $p < 0.05$ significance level. Further analysis showed that productivity was positively related to seam height, as expected ($R = 0.33$, $p < 0.001$), and negatively related to overall

employment ($R = -0.059$, $p < 0.05$). The negative relationship with employment was not expected, since larger mines tend to have the resources and economies of scale to achieve higher productivity. However, since the productivity calculation uses employee-hours in the denominator, the negative correlation may simply be a mathematical artifact.

Combinations of Size, State, Seam Height, and Productivity

The technique of multiple regression analysis was used to investigate the relationship between combinations of mine characteristics and accident rates. Regression equations were computed using various combinations of State dummy variables along with seam height, size (employee-hours), and productivity to account for variations in lost-time injury rates.

Using the Alabama and Virginia dummy variables along with productivity, seam height, and employee-hours yielded a regression equation that accounted for a small, but statistically significant, 1.5% of the variance in groundfall lost-time rates ($R^2 = 0.015$, $F_{5,2004} = 6.24$, $p = 0.000$).

Adding all the other State dummy variables increased the explained variance slightly (to 1.9%). Without any State dummy variables, productivity, seam height, and size

accounted for just 0.3% of the lost-time rate variance. By themselves, the Alabama and Virginia dummy variables accounted for 1.0% of the variance.

DISCUSSION

The analyses presented here show that groundfall injuries continue to be a major source of human and financial costs to the mining industry. They also identify job titles, States, mine sizes, and seam heights that tend to be associated with higher rates of groundfall injuries. The State in which a mine was located turned out to account for a greater degree of the differences between mines' groundfall safety performance than did seam height, mine size, and productivity. In many of the mine-level analyses, correlations between injury rates and measures of the mines' characteristics (employment, production, seam height) and injury rates were relatively low. This means that, while often large and meaningful differences were observed between different groups of mines, it would be difficult to make an accurate, reliable prediction of the safety performance of an individual mine based solely on its State, size, and seam height. This does not mean, however, that there are no differences between the mines. Since the data represent the entire population of mines that report to MSHA, the differences and relationships are exactly as reported—no inferences are necessary beyond making judgements about the quality and meaning of the data the mines report.

The finding of significantly higher lost-time rates for mines in Alabama and Virginia was consistent across both simple correlational and multiple regression analyses. While several other States (Iowa, Oklahoma, Colorado,

Illinois, etc.) also had high injury rates, these differences were not statistically significant either because of few mines in the State or large variations across the mines. Although the average injury rates in Alabama and Virginia were not the highest in the United States, their mines appeared to be more homogeneous in their injury experience. It may also be true that Alabama and Virginia mines tend to be more similar than most in the types of mine characteristics that influence groundfall injuries. Across the industry, there tended to be much more variability in injury rates among the mines in each State than between States.

More descriptive information than that available in the MSHA data bases would improve our ability to directly identify the key causes of groundfall accidents. For instance, the State information is useful when more direct causes (geological conditions, mining practices, regulatory systems) can be inferred from the mine's location. If data on these characteristics were known directly and did not have to be inferred, the specific relationship of each characteristic to safety performance could be measured independently. The industry data reviewed here can be used to suggest the areas where problems lie, but more accurate data-based explanations can be made with more specific information on the geological, technological, managerial, and human factors that all play a part in causing—or avoiding—groundfall injuries.

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