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Roof Control of Stress-Relief Jointing Near Outcrops in Central Appalachian Drift Coal Mines

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

ft foot

ROOF CONTROL OF STRESS-RELIEF JOINTING NEAR OUTCROPS IN CENTRAL APPALACHIAN DRIFT COAL MINES

By Gary P. Sames[1] and Noel N. Moebs[1]

ABSTRACT

This report discusses some practical applications of a geotechnical investigation conducted by the U.S. Bureau of Mines that can help mine operators meet revised Federal regulations in their roof control plans. The investigation, designed to characterize roof conditions near the coalbed outcrop in drift coal mines in eastern Kentucky, revealed that weathered stress-relief joints near outcrop are crucial ground control factors in the region. 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 in this report 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.

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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 U.S. Bureau of Mines show that weathering, moisture, and gravity combine to create stress-relief joints (also known to miners as hillseams, mudseams, and mountain breaks or cracks) that are the dominant cause of roof instability and fatal injuries near outcrop (*1*).[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, where 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.

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. It is estimated that drift mining will continue to dominate central Appalachian coal production for the next 40 years before deeper, below-drainage mining becomes prevalent (*3*). Therefore, control of adverse roof conditions caused by stress-relief jointing near outcrop will continue to be 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 (*4*). 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 (*5*). 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 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.

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 which provide the States with authority to approve or disapprove a mining company's plans and thereby control safety barrier design.

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

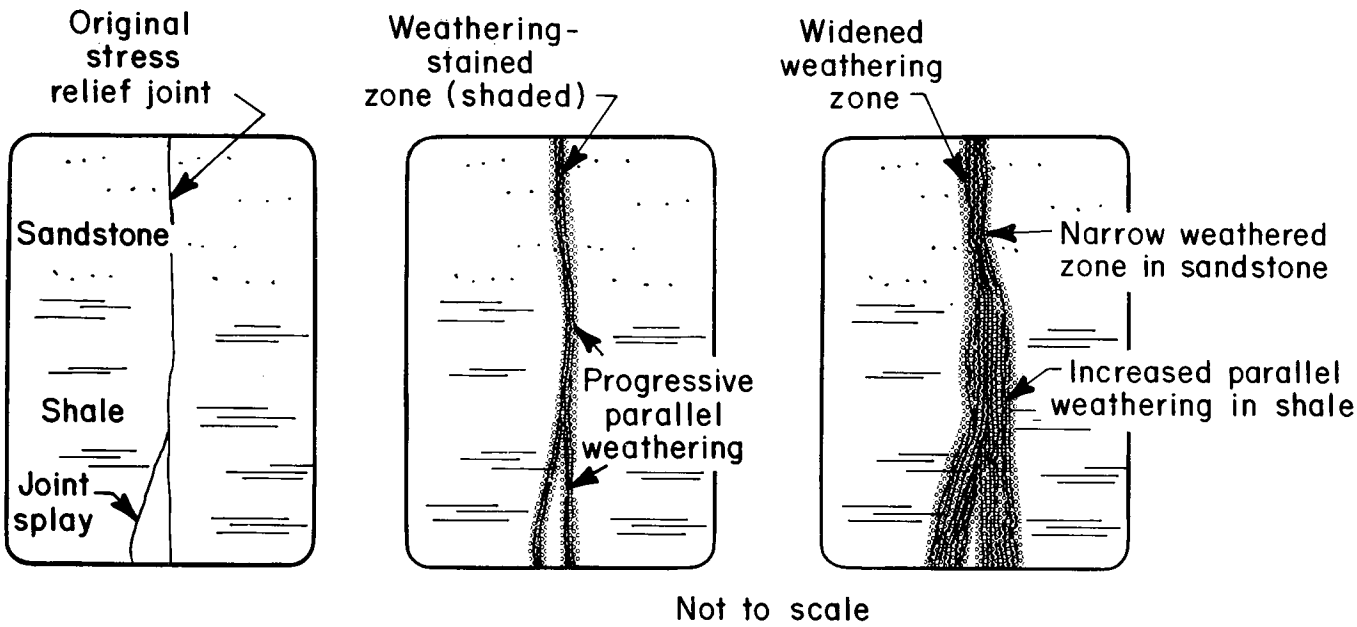

Figure 1.—Schematic drawing of stress-relief joint weathering over time by water percolation.

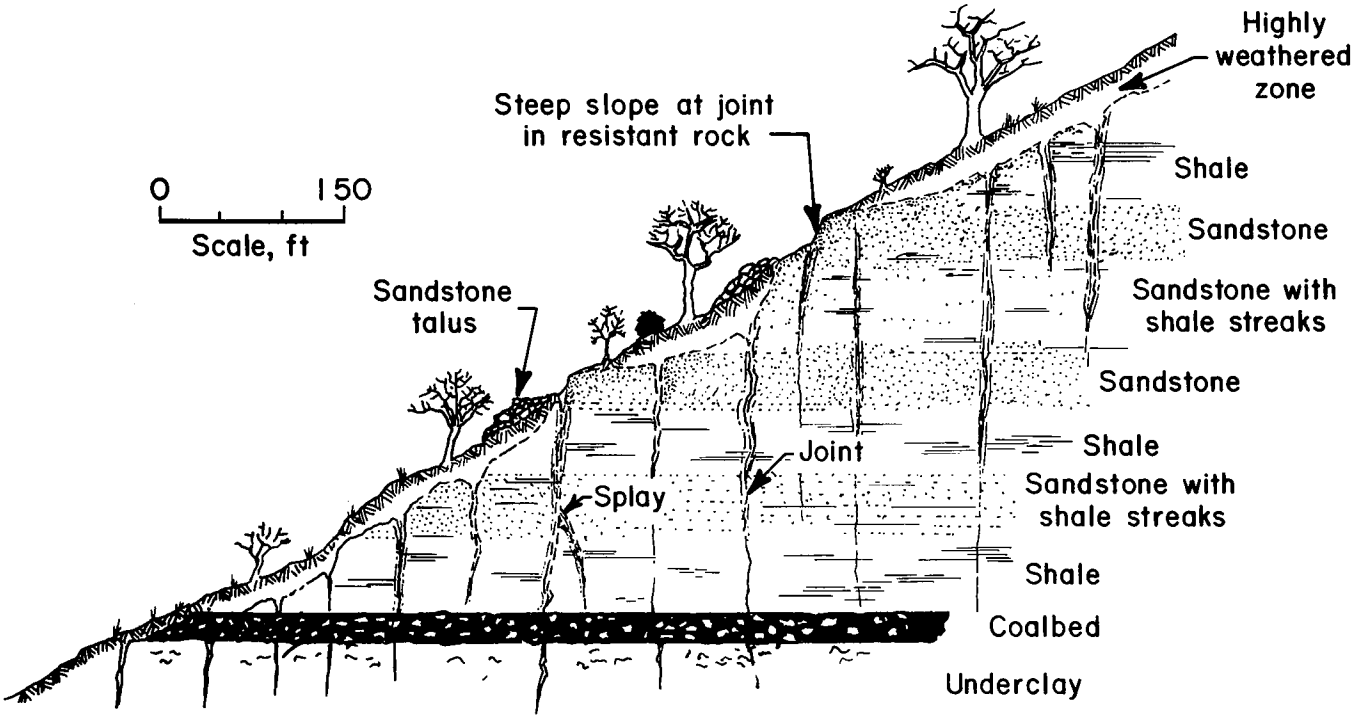

Figure 2.—Cross section of hill slope showing typical stress-relief joint distribution.

Kentucky Revised Statutes (*4*) 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 on advance to avoid shallow overburden, weathering, and fractures.

Two Federal agencies, MSHA and Office of Surface Mining Reclamation and Enforcement (OSM), 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 (*5*).

ENGINEERING FACTORS

Outcrop safety barriers are planned to provide entry stability, protection from water inflow, and air seals for ventilation purposes. Factors to consider when choosing barrier width include: previous roof control experience in the same locality, the surface slope, depth of overburden, intensity of weathering, abundance of stress-relief joints, and strata composition.

The greater the surface slope, the more rapidly drift mine entries will penetrate the weathered zone, with only a narrow width required to achieve barrier integrity. Geologic conditions, however, can be variable and overshadow the importance of simple engineering relations. For example, in eastern Kentucky, where a 100-ft-wide barrier usually assures a stable entry and competent roof, the presence of stress-relief joints occasionally cause severe problems with roof failure and water and mud inflows much farther inby the barrier. Understanding the character and occurrence of stress-relief joints before mining, therefore, provides some basis for designing an appropriate barrier. Although it is not the purpose of this report to provide new design criteria for outcrop barrier pillars, a brief discussion of the design methods that are currently available and in use is appropriate.

DESIGN METHODS

The current method of estimating barrier widths is the result of experience with internal and property barriers. From a safety standpoint, it was considered important to leave a barrier to prevent impounded water from endangering the lives of miners working underground. As a result, research historically was directed toward design of internal and property barriers rather than outcrop barriers. For example, the State of Pennsylvania organized a commission in 1927 to study the problem of barrier pillars between adjacent mines and to formulate recommendations for interior barrier widths. The formula they derived was named after George H. Ashley, the state geologist at the time and one of the persons on the commission (*6*). After much discussion and deliberation the following formula was derived:

$$W = 20 + 4t + 0.1D$$

where W = barrier width, ft,

t = coalbed thickness, ft,

and D = overburden thickness, ft,

or, if water is involved, the height of the hydrostatic head possible if it is greater than the vertical thickness of the overburden. The width, W, was to be divided equally on both sides of a property line. For example, a 4-ft coalbed with 60 ft of overburden:

$$W = 20 + 4 \times 4 + 0.1 \times 60 = 42 \text{ ft.}$$

A width of 42 ft for an outcrop barrier pillar would be somewhat less than half of the 100-ft width commonly used in drift mines based on experience and a rule of thumb, which doubles the calculated width as a safety factor.

Although Ashley's method was not intended as a guide to determine the width of outcrop barrier pillars, it has been used for this purpose. However, it does not consider many of the geologic factors, such as stress-relief-joint density and weathering, which will affect the integrity of the barrier.

A recent study analyzed the stability of a surface slope for various topographic and geologic configurations, described modes of failure, and formulated guidelines for the estimation of a safe outcrop barrier pillar width.[3] Owing to the absence of actual case studies, the design guidelines are based chiefly on analytical studies, including the finite difference method. Therefore, while a variety of geologic and hydrologic situations are assumed, actual subsurface conditions, such as might be encountered in the drift mines of central Appalachia, are yet to be determined.

Another recent study (*7*) was conducted principally to develop design criteria for outcrop barrier pillars which will minimize the seepage of impounded water. The study included computer modeled seepage analysis, an overburden blowout analysis, and a wedge stability analysis. While the problem of roof stability was not directly addressed, design criteria are provided that should assure stability of a surface slope at the barrier zone.

[3]Contract J0215032, Geo-Hydro Consulting, Inc.

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 ft 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.

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, that 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).

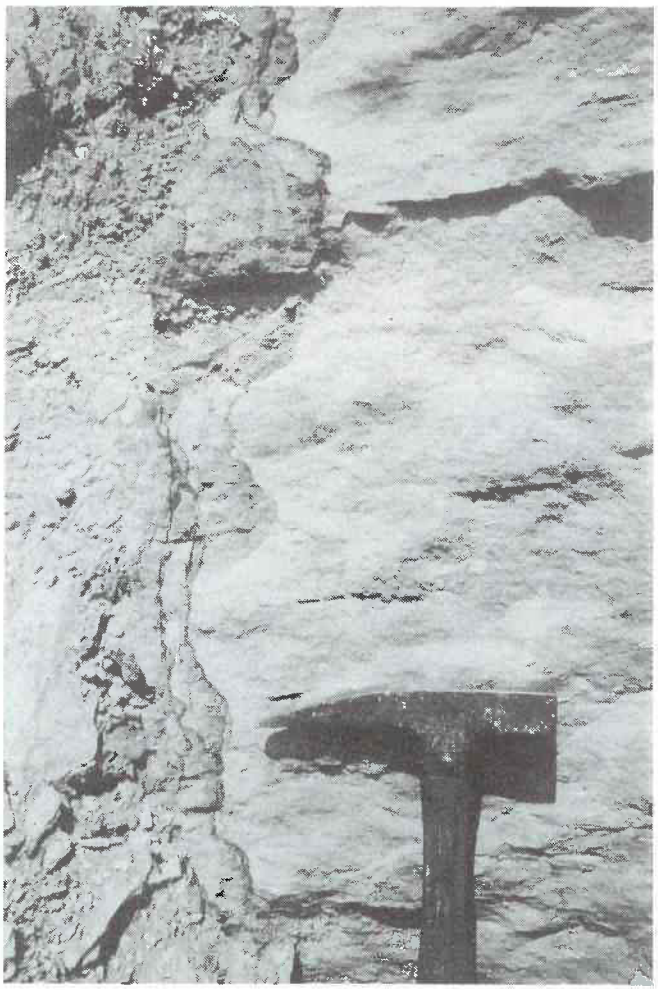

Figure 3.—Close-up of incipient weathering and parallel fracture development adjacent to stress-relief joint in massive sandstone.

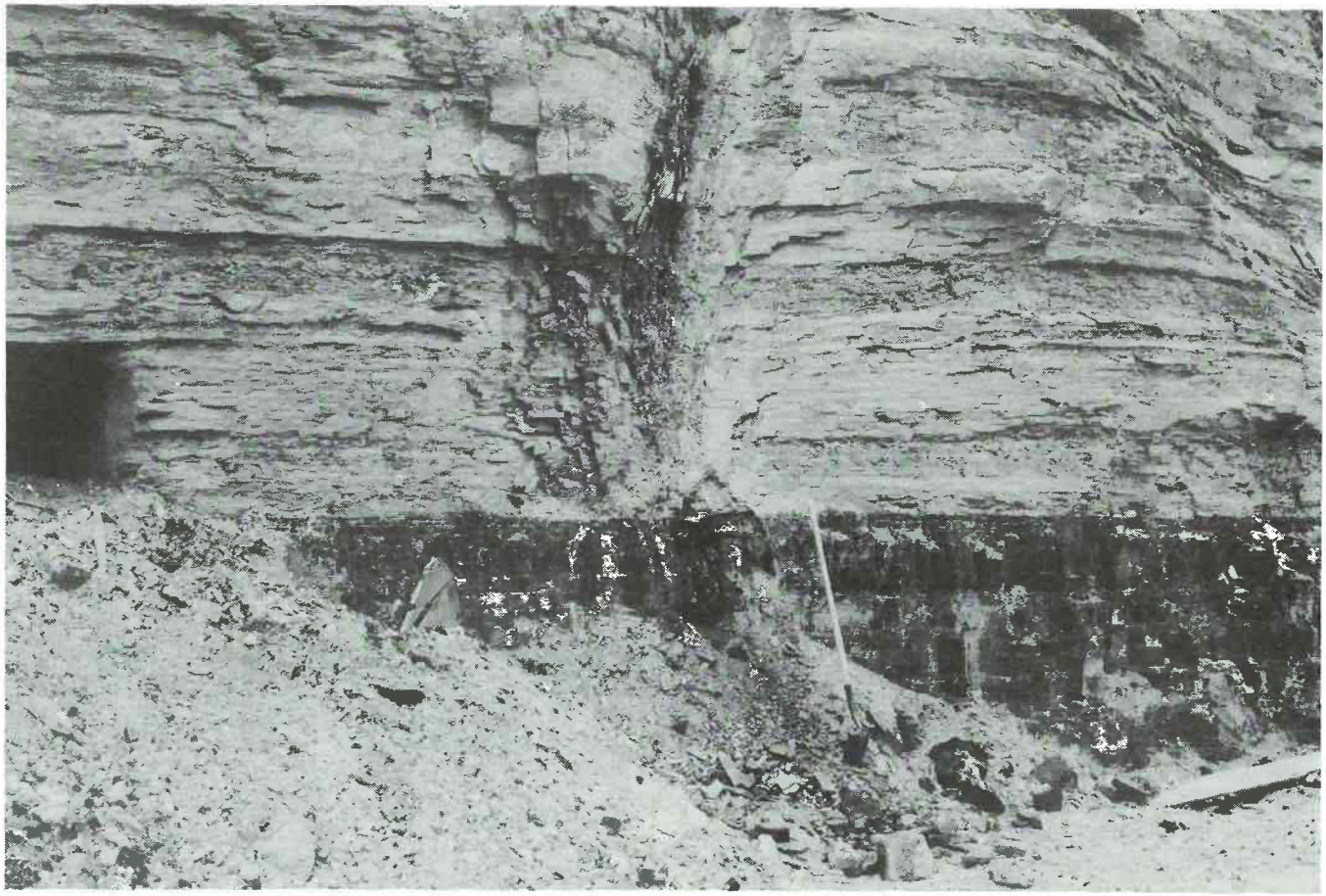

Figure 4.—Heavily weathered stress-relief joint in shale above coalbed.

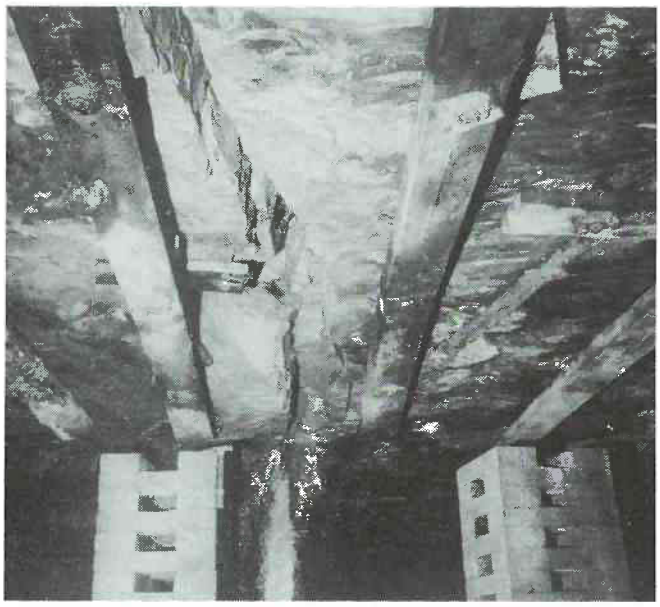

Figure 5.—Small rock fall between joint surfaces in massive sandstone roof.

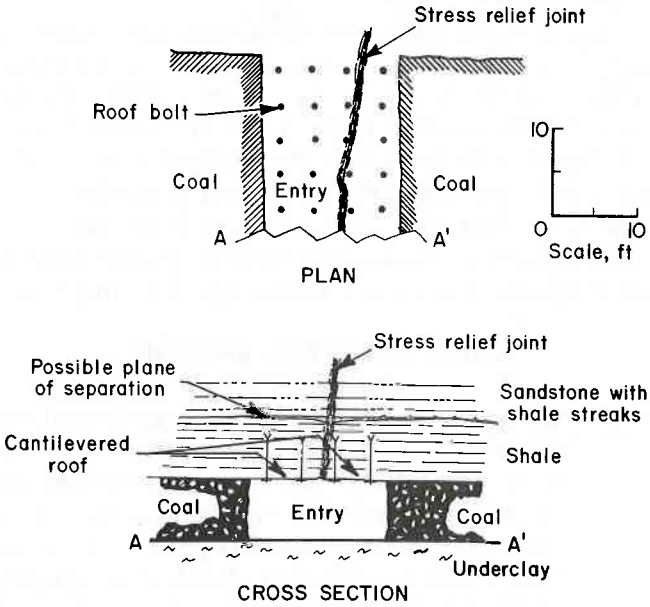

Figure 6.—Plan and cross section views of cantilevered roof failure caused by stress-relief joint paralleling development.

FAILURE HEIGHT

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

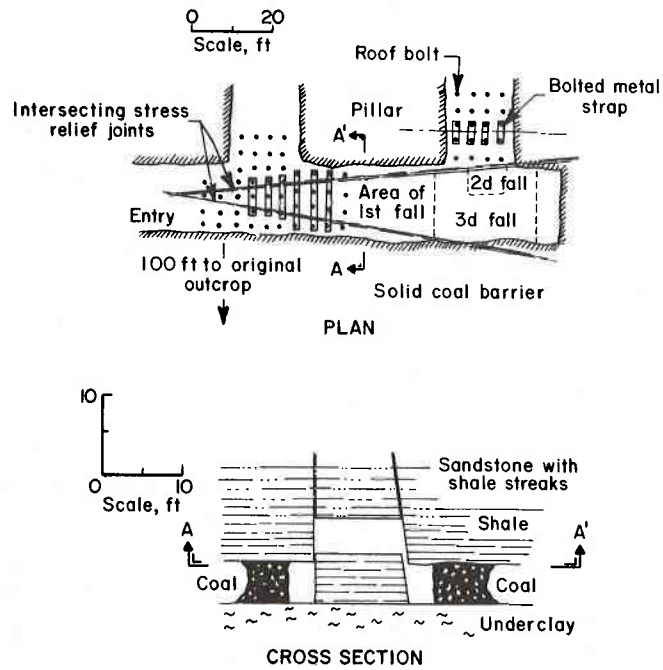

Figure 7.—Plan and cross section views of roof fall caused by intersecting stress-relief joints.

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

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. In many cases, a single-support pattern (generally included in the roof support plan) is used to control 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 (*8*), 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 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

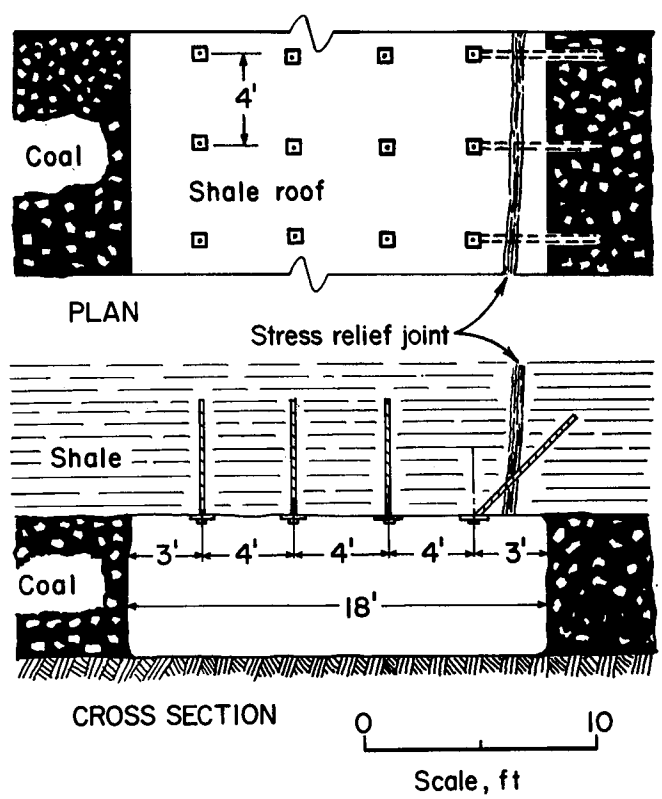

Figure 9.—Roof bolts angled to intersect stress-relief joint and anchor over pillar.

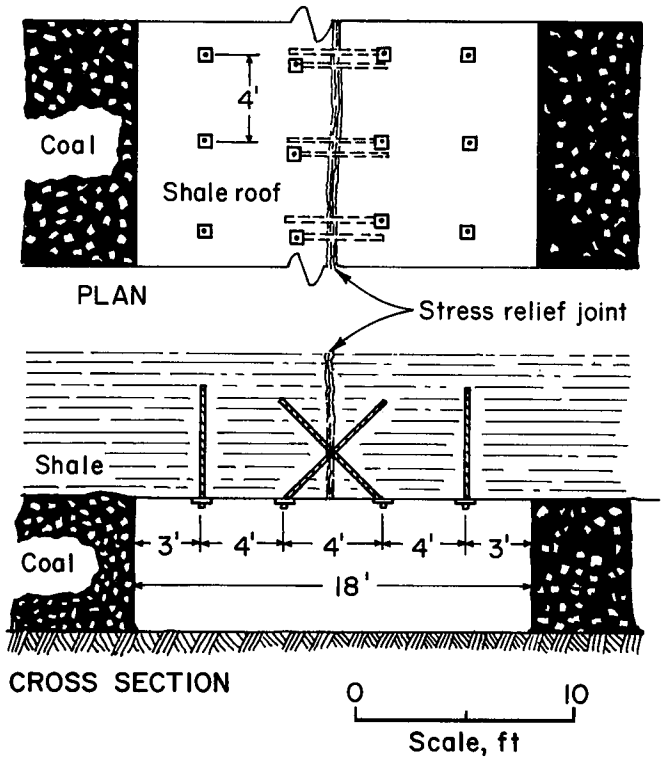

Figure 10.—Roof bolts angled across stress-relief joint at midspan to tie roof together.

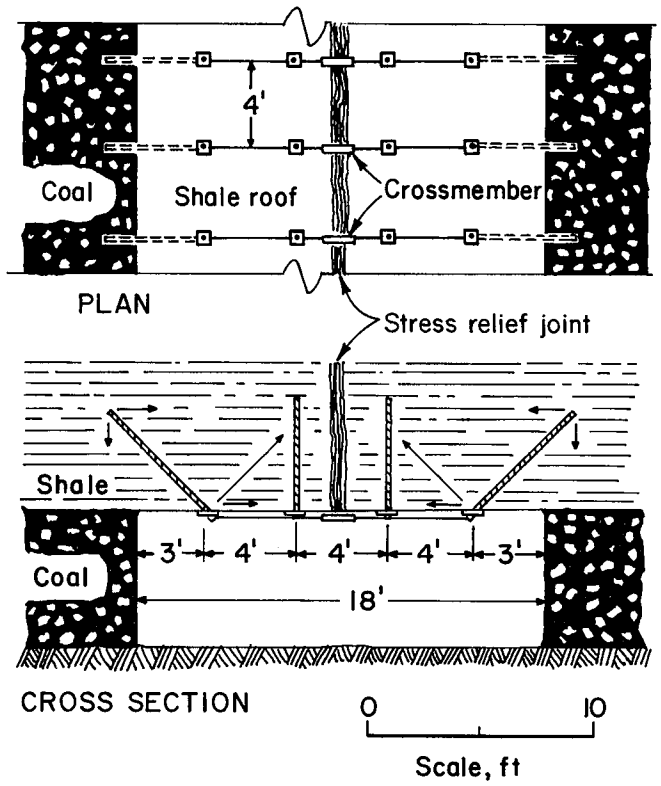

Figure 11.—Typical roof truss installation to support stress-relief joint at midspan, with arrows indicating resultant forces transferred into roof.

the joint can give an indication of movement if it occurs, although they provide little resistance to movement.

The most difficult stress-relief joint occurrences to plan effective support for 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 maybe 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.

DESIGN CONTROLS

Design controls are steps taken to ameliorate 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 it is known that the most severe 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 which 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 report 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 report 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.

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 supplemental 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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