Part 1 of a 2-part series

The diagnosis and reduction of mine roof failure

The classification of failures into stress-related and geology-related categories is the first step for remedial action and prevention

by Noel N. Moebs and Raymond M. Stateham

Coal mine roof falls can be categorized according to character, trend, or pattern of occurrence. We propose two principal categories—geology-related and stress-related failure—as well as a number of subcategories. Then, by reflecting the probable cause of failure, each subcategory can suggest an appropriate technique for reducing the incidence of failure. These control techniques, depending on local conditions, may include supplementary support, destressing, or reduction of mine air humidity.

Diagnosis

Roof bolting practices are largely empirical because based on much experimentation and trial and error. And bolting theory itself is still more descriptive than mathematical. Given the complexity of a coal mine's subsurface environment, the failure of bolted mine roof is difficult to fully describe. Yet, even a qualitative identification of the conditions leading to roof failure can provide some basis for modifying mine design and thus improve safety.

Changes in roof conditions that occur in the course of mining can vary from very subtle to quite proounced, and most operators have a difficult time in either predicting these changes or responding to them with an appropriate supplementary support or revised mine layout. However, if a general characteristic of individual falls (or a pattern of multiple falls) can be accurately recognized, an operator will then at least have some valid clue as to as to the causative factor and will be able to undertake remedial action.

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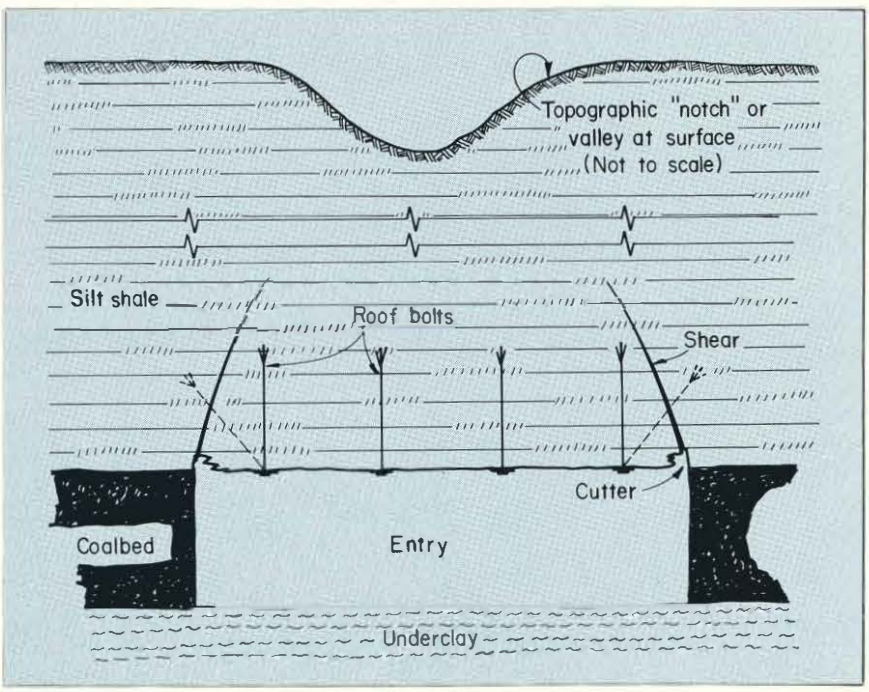
Fig. 1—Subtype S, roof failure attributed to topographic "notch."



In this article, we will try to give you a guide for determining the probable cause of persistent roof failure based on the occurrence, character, and distribution of the mine falls, and then offer some suggestions to avoid further roof failure.

The diagnosis of roof falls is based chiefly on the careful examination of a mine roof fall map, and on recognizing certain characteristic patterns of distribution or modes of failure. This requires diligent documentation of a *significant* number of falls. Please note that occasional widely distributed falls are seldom sufficient for such an analysis. (Occasional failure can result from improper bolt installation, but this factor is outside the scope of our present discussion.) Roof fall information must be accompanied with maps of roof structures such as clay dikes, surface topography, and super- or subjacent mining in order to complete the correlations necessary for a thorough diagnosis of roof failure.

Roof fall patterns became discernible when we examined numerous roof falls in scores of coal mines in the northern Appalachian region, and conducted a review of supplementary geologic information on each property and an interview with underground personnel. Some patterns of roof falls were erratic or dif-

Table I—Tabulation of roof fall occurrences.

Mine	Total falls	Falls at intersections No.	%	Falls between intersections No.	%	Falls at minor structures No.	%	Falls > 1 pillar length No.	%	Principal cause of failure
1	200	163	82	23	11	4	2	10	5	Low-strength roof rock, requiring bolted headers, straps, and trusses.
2	129	4	3	10	8	0	0	115	89	High lateral stresses (cutter roof) requiring posts and crossbars.
3	383	21	5	12	3	0	0	350	92	High lateral stresses (cutter roof) requiring posts, cross-bars and steel sets.
4	44	10	23	—	—	34	77	—	—	Minor structures, chiefly clay veins, requiring straps, or header block.

ficult to explain, and some were found to correlate with a transition in bolt type, mining cycle, or entry design.

Before describing roof fall patterns and their significance, we want to emphasize that any supplementary information—such as maps showing the character and thickness of roof strata, or discrete roof structure such as rolls, clay veins, and paleochannels—may help explain the occurrence of falls and indicate the appropriate remedy.

Improperly installed bolts can generally be detected prior to failure by torque measurements. But poorly installed full-column resin bolts are not so readily detected; sometimes, partially mixed cartridges or incompletely filled bolt holes can be discovered only when examining a roof fall. Aside from inappropriate support plans, installation, or excessive entry width for prevailing conditions, roof failure in most cases can be attributed to either high stresses or defects in the roof structure, including inherently weak rock units. Since these two categories tend to cause roof falls of contrasting character, let's describe them in some detail.

Previous work

Several schemes for classifying mine roof have been attempted, chiefly for the purpose of predicting the occurrence of roof falls from a knowledge of local geologic features. For example, Weir has described six different kinds of roof falls: shale dusting or slaking, sandstone rolls, concretions, slabbing, clay seams, and massive.[1] Although these categories probably predominate in the specific area of Indiana that was studied, they are of limited usefulness for the entire region.

Hylbert has proposed a classification of roof falls based on the structural and compositional character of roof at a mine in eastern Kentucky.[2] His scheme proved useful in projecting trends of roof condition as an aid in anticipating problem areas in advance of mining. Some inferences can be drawn from this scheme as to the appropriate support method for each of the four types of roof conditions described.

Patrick and Aughenbaugh have devised a four-category classification (dome, arch, minor, and sloughing) which is based only on the geometry of a roof fall.[3] This simplified scheme is intended to expedite the reporting of roof falls independent of local conditions, and to serve as a first step toward predicting the occurrence and extent of future falls. While some inferences as to the cause of failure can be drawn from a geometric classification only, further usefulness in analyzing roof control problems is very limited.

Our proposed classification requires somewhat more information than that needed in the works of the investigators we have mentioned, but it should provide for broader usage, supply a sound basis for diagnosing the underlying causes, and indicate some appropriate means of reducing the rate of roof failure.

Often, a simple inventory of roof fall occurrences will indicate the probable cause of failure, as shown in Table I, which is based on examples from four selected mines in western Pennsylvania and northern West Virginia. This method requires extensive mapping of roof falls, however, and is too broad for classification purposes—although it may be useful in conjunction with our proposed classification scheme.

Categories of roof falls

For the sake of simplicity and clarity, we have decided to illustrate the various types of roof fall patterns in schematic diagrams (and without identifying the mines involved). It should be understood, however, that the cause of roof failure is often obscure: it cannot be determined with any degree of certainty, or only through prolonged and sophisticated research. The categories we will be presenting are intended merely to guide mine operators and safety personnel to a preliminary and rapid assessment of roof problems using observable patterns of roof failure and geologic information.

We have grouped all roof fall patterns into either of two categories—Type S or stress related, and Type G or geology related.

Let's look first as the Type S patterns.

Subtype S_1, Valley Effect (see Fig. 1). In the northern Appalachian coal region, one of the most common and easily recognized types of roof failure occurs beneath narrow stream valleys in areas of high relief. It is referred to by various miner's terms such as "pressure falls," "snap top,"

Fig. 2—Subtype S_2 roof failure attributed to high lateral regional stress.

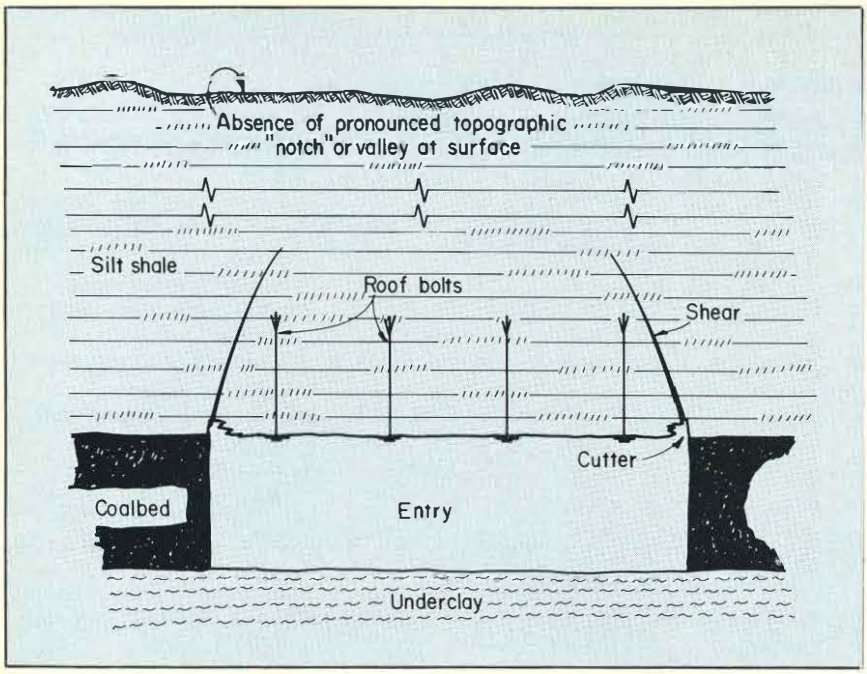
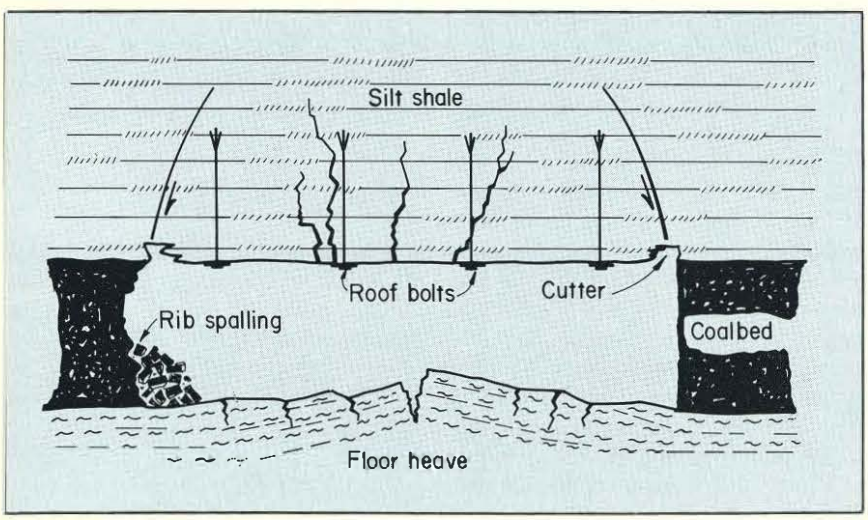


Fig. 3—Subtype S_3 roof failure attributed to mining induced stress.



and "cutter roof." These falls can be recognized by comparing their occurrence with a map showing surface stream valleys where topographic relief is at least 100 ft. Several operators have estimated that when mining beneath or near such stream valleys, severe roof fall problems will develop 90% of the time. Examination of these falls shows little if any evidence of jointing as a contributor to this failure, which in known to occur even in the most competent and firm rock. The falls frequently result from a concentration of high lateral compressive stresses, a phenomenon described by several authors including Belvins[4]; Roley[5]; Agapito, Aggson, Mitchell, Hardy, and Hoskins[6]; Aggson[7]; and Lang.[8] Underground, they are sometimes recognizable by an audible snapping sound immediately after mining, or by the development of a steeply dipping shear or "cutter" at the intersection of rib and roof within a few days to a week or two after mining. This type of failure usually develops between intersections but may progress along shears or "cutters" across one or more intersections for perhaps several hundred feet.

In some instances of S_1 roof failure, further falls have been prevented by the installation of supplementary angle bolts to intersect the shear plane and anchor above the pillar (Fig. 1). Currently, angle bolting is being tested in at least three mines for this purpose. The immediate installation of support to prevent any yielding of roof is commonly recommended. More severe S_1 failure will require posts and crossbars or possibly roof trusses. It may be virtually uncontrollable with crushing of posts or cribs leading to massive high roof falls.

Subtype S_2, Regional Stress (see Fig. 2). Roof failure that clearly is caused by high lateral compressive stress, similar to S_1, but that is not limited to occurrences beneath valleys and occurs somewhat randomly, is here classed as regional stress failure. It is characterized by the development of a shear or cutter along the rib line within a few weeks of mining, roof cracks, and usually a sudden fall if not heavily supported. Kripakov describes cutter roof failure in detail, discusses current control methods, and suggests some new alternatives.[9] As with S_1, competent hard shale roof fails under these pressures as readily as softer laminated roof rock. The pattern of these falls commonly shows a preferred north-south trend in the northern Appalachian region. Blevins reported a similar north-south failure condition in the Illinois coal basin.[4] The falls generally begin between intersections and may zigzag around pillars to follow a north-south trend, or may show no clear directional preference. Subtype S_2 falls can be distinguished from those attributed to pillar punching usually by the absence of accompanying floor heave and pillar spalling, and by the evidence of a directional trend.

Under this category of roof failure are placed the roof falls which tend to occur chiefly at the boundaries of multiple-entry mains. These falls typically begin as a shear along the rib line and commonly have been attributed to "abutment pressures." The exact cause, however, remains disputable. When adequate pillar support is provided and there is no evidence of roof deflection in the central zone, the pressure arch theory does not seem to offer an adequate explanation of failure, and in situ stresses are suspected. A change in entry orientation, where possible, has proven to be more beneficial than a modification of pillar design, but experience in controlling this problem is very limited. Destressing of the rock surrounding an entry by means of roof or rib slotting or induced caving of an adjacent entry has been

attempted with varying degrees of success. Destressing, however, while sound in theory, is risky and requires equipment not always available in a mine. Otherwise, supplementary support as described in S_1 falls is suggested.

Subtype S_3, Induced Stress (see Fig. 3). The induced-stress type of roof failure nearly always can be related to superjacent or subjacent second mining or to a squeeze or pressure override from a panel that has not fully caved. The map overlay technique, such as that described by Ellenberger,[10] will detect the effects of multiseam mining on entry stability, while pressure overrides nearly always occur within a few hundred feet of adjacent pillar extraction or pillar stumping. Geologic and mining correlations always are useful in resolving the problem of induced stresses, especially with respect to the massive character of strata that transfer overburden weight onto pillars or abutments. Induced stresses from multiseam mining or pressure overrides lead to various combinations of floor heave, pillar spalling or deformation, pillar punching into floor and roof, and cutter roof, with the actual failure of roof sometimes occurring late in the sequence of events.

The remedy for Subtype S_3 roof failure due to pressure overrides probably lies with improved pillar extraction and caving or with oversized pillars. Ground control problems resulting from multiseam mining may be alleviated by following extraction sequencing guidelines as described by Britton.[11] An increase in conventional bolting, strapping, or posting is seldom of much value in preventing further failure, and steel sets generally are needed. □

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In part 2 of this series, we will describe Type G geologic defects.

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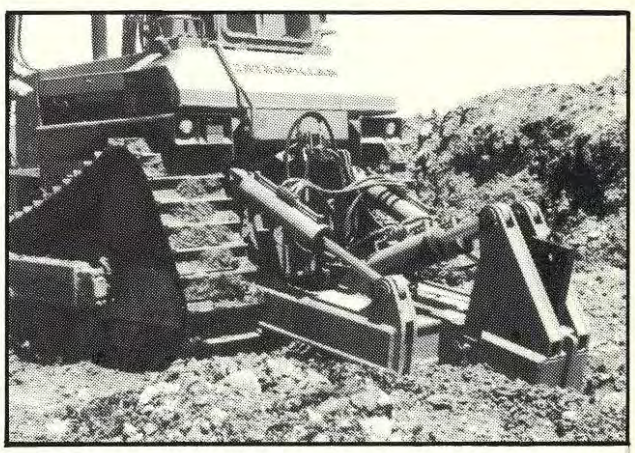

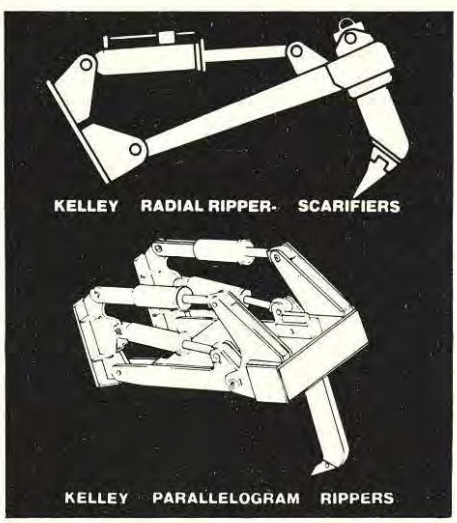

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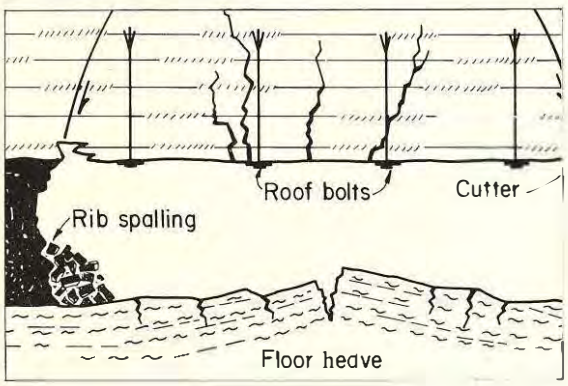

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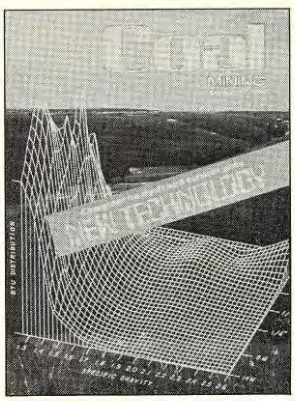

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