Part 2 of a 2-part series

The diagnosis and reduction of mine roof failure

Geology-related failures: what they are, and what can be done about them

by Noel N. Moebs and Raymond M. Stateham

We have divided into four subtypes the "Type G" roof failure attributable to geologic defects or character of rock. The four subtypes are: Low rock strength (G_1); Water sensitivity (G_2); Bedding plane spacing (G_3); and, Minor structures (G_4). Let's look at each in some detail.

Low rock strength

This Subtype G_1 category includes all roof rock that is relatively soft, usually poorly laminated, and low in RQD (rock quality designation), point load, and compressive strength. The physical properties for this subtype commonly would fall below the following values:

Point load index	0.3 MN/m^2
Shore hardness	20
Compressive strength	2,500 psi

Low-strength rocks include most claystone, especially the "drawslate" that overlies the coalbed, and underclay or seatearth. These rocks generally are not self-supporting for normal entry widths (see Fig. 1), tend to fall from the roof soon after coal extraction, and therefore must be supported as quickly as possible after exposure.

Bolted headers or straps are usually needed, and trusses are useful in severe cases, where the deadweight of collapsing roof is not excessive; otherwise posts and crossbars become necessary. Although full-column resin bolts have adequately sup-

Fig. 1—Subtype G_1 roof failure attributed to low rock strength.

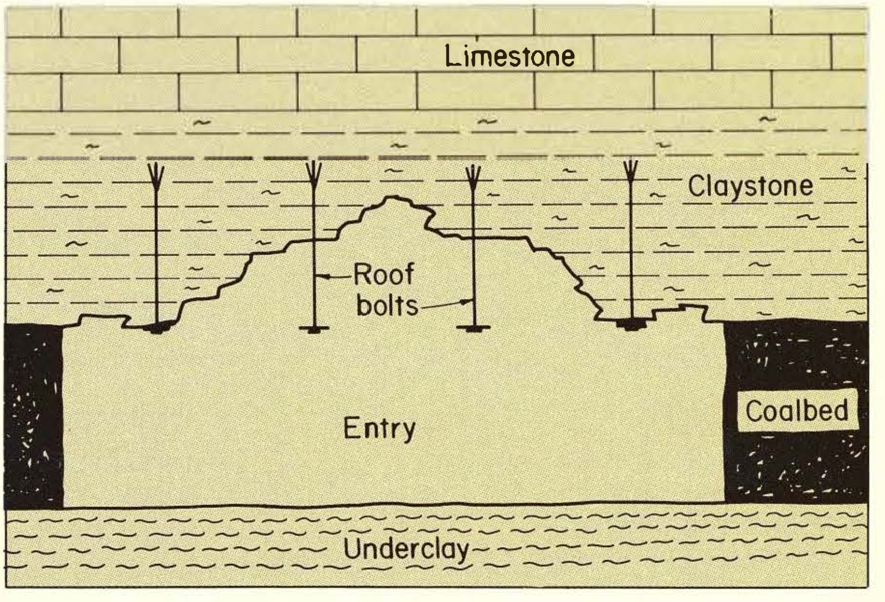
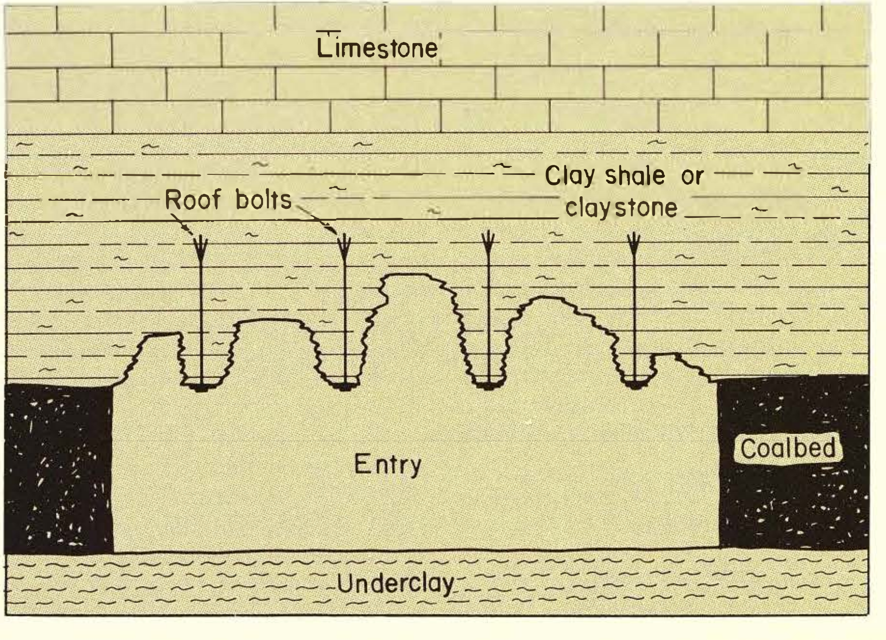
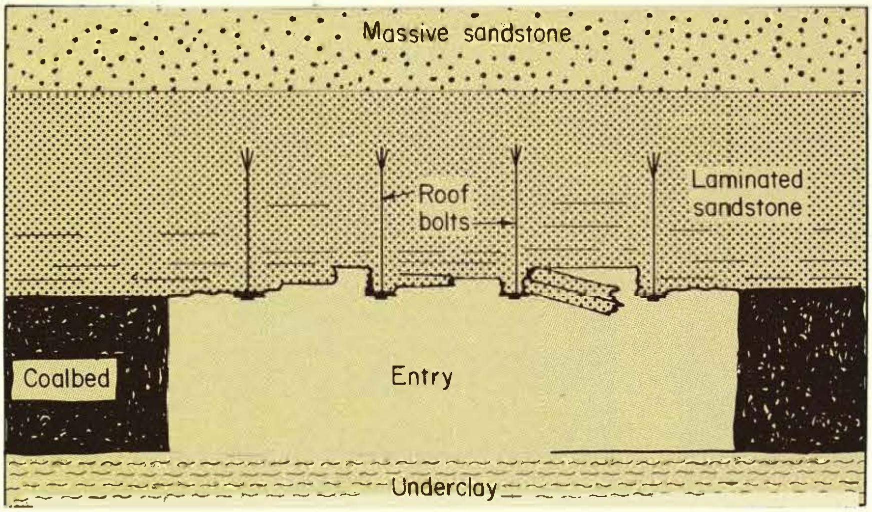


Fig. 2—Subtype G_2 roof failure attributed to moisture sensitive roof rock.



Mr. Moebs is a geologist at the Pittsburgh Research Center, Bureau of Mines, DoI, Pittsburgh, PA; and Mr. Stateham is a geophysicst at the Denver Research Center, Bureau of Mines, DoI, Denver, CO.

Fig. 3—Subtype G_3 roof failure attributed to thinly laminated strata.



ported this type of roof in some mines, further assessment is needed. With most mechanical bolts, there is a problem of tension bleedoff in soft rock due to anchor slippage, in addition, segments of soft rock tend to fall from between bolts, and the reinforced beam effect of the roof is disrupted.

Systematic drilling, core logging, and point load testing of drill core are useful in delineating areas where low-strength roof rock can be anticipated. This type of rock commonly occurs between coal splits where the roof of the lower bed consists of the underclay of the upper bed and is widespread over the Pittsburgh coalbed in the Upper Ohio River Valley.

Moisture sensitivity

This G_2 category (see Fig. 2) includes those failures due to a significant reduction in the strength of roof rock from exposure to high humidity or water commonly found in the mine environment. The effects of moisture sensitivity consist of a progressive softening or slaking whereby rock gradually disintegrates and eventually reverts back to a mudlike unconsolidated condition.

Slaking is a process of moisture absorption, expansion, and softening. In a humid mine atmosphere, slaking occurs gradually for months and years and ultimately results in a slow failure of roof by attrition as the dislodging of small fragments leads to larger falls. In time, this process can destroy the integrity of an entire mass of roof. Roof bolt tension bleedoff occurs as the rock immediately against the bolt plate becomes softened, or slippage of the anchor occurs. The occurrence of moisture-induced roof failure generally is most pronounced and severe near shaft bottoms and along intake air courses. The rate of roof slaking is greatest during the humid summer months when roof rock commonly is wet with condensation.

In situations where moisture-sensitive roof rock is thinly interbedded with moisture-stable rock, the bond between the two types of strata is weakened, leading to strata separation and sag unless bolt tension remains high. Moisture rarely affects sandy roof rock rarely except where the sand grains are weakly cemented by a clay matrix which gradually disintegrates, releasing the grains, and the rock reverts to loose sand.

The principal type of moisture-sensitive roof rock in the Appalachian coal region consists of a poorly laminated lumpy claystone containing numerous slickensides, sometimes known as "clod" in miners' terminology. Generally, a simple water immersion test or exposure outdoors will determine the relative moisture sensitivity of roof rock samples and the extent to which this may become a problem underground.

The four principal methods that prevent or control moisture-induced roof failure are:

1. *Head coal*—The uppermost 4 to 6 in. of coalbed, if left unmined, serves as a moisture barrier and may prevent slaking of shale roof.

2. *Sealing*—Sealing entails the coating of exposed roof with an impervious layer of material to exclude moisture. The sealant can consist of an asphalt- or latex-base material with little physical strength, or it may consist of a cement-base gunite with fiber additive sprayed over a bolted wire mesh for added strength and reinforcement. The effectiveness of these measures depends to a large degree on the quality of the sealant and the care with which it was applied.

3. *Mechanical support*—Some form of supplementary support is needed in most cases. The options are numerous and need not be discussed here. Limited experience with full-column resin bolts indicates their superior ability to hold soft, slickensided, claystone-type roof, as opposed to mechanical bolts, which lose tension as moisture attacks the rock at the bolt head and anchor. As moisture disintegration progresses, a larger area of roof than that above the bolt plates requires support, and this usually is provided by bolted headers, straps, or mesh. Long-term disintegration usually necessitates trusses or posts and crossbars to support an increasingly large amount of deadweight from sloughing roof.

4. *Air tempering*—The term "tempering" refers to the modification, adjustment, or stabilization of mine air moisture and temperature so as to decrease humidity levels and fluctuations. Air tempering has been accomplished with water sprays, heaters, and cooling units, depending on the season, but at high cost and with limited success. A passive and more cost-effective method of tempering mine air is through the use of air-tempering rooms or entries, whereby fresh air passes through a set of rooms or multiple entries where it is cooled and loses moisture in the humid season and, to a lesser degree, is warmed and absorbs moisture in the winter months—thus attenuating large fluctuations in humidity and temperature before the air is allowed into haulageways and other active sections. Provision must be made for some roof deterioration in the tempering rooms or entries, which should be included in the original mine design.

Fig. 4—Subtype G_4 roof failure attributed to slickensides.

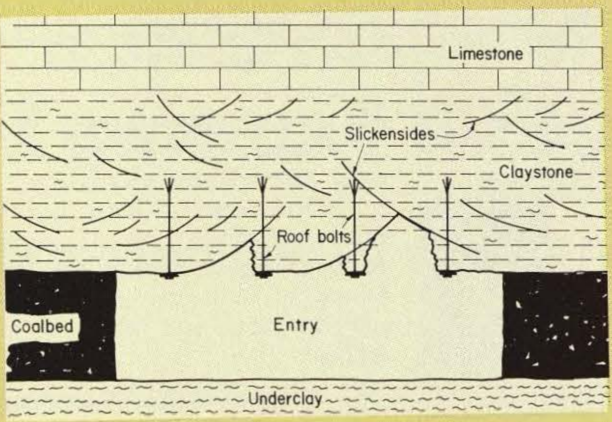


Fig. 5—Subtype G_4 roof failure attributed to kettlebottoms.

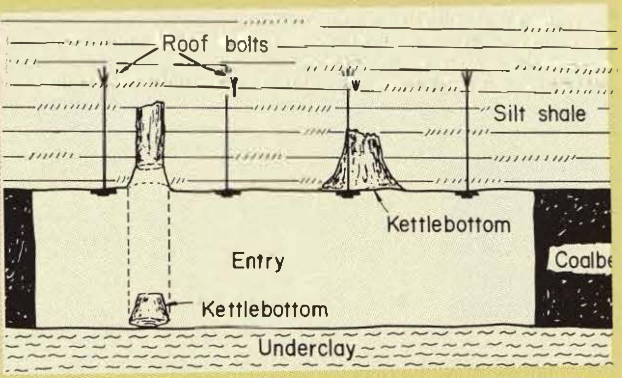


Fig. 8—Subtype G_4 roof failure attributed to joints.

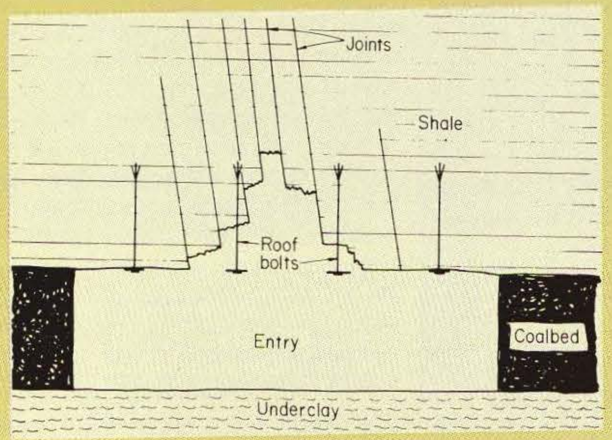
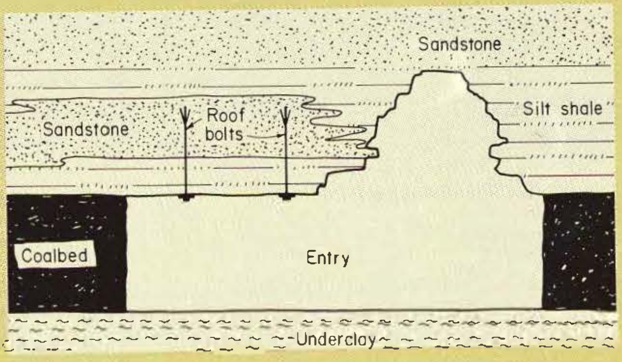


Fig. 9—Subtype G_4 roof failure attributed to pinchouts.



Bedding plane spacing

Subtype G_3 failures are those attributed to thinly laminated strata. A bedding plane in laminated roof strata constitutes a potential plane of separation. The weaker the bonding along the bedding plane, the more likely a roof separation will occur as the coal underneath is removed (see Fig. 3).

Weak bonding usually results from an abundance of mica flakes, clay, or coaly material along the bedding plane, and the more closely spaced the bedding planes or thin laminations, the weaker the roof strata will function as a beam unless strongly reinforced or supported with roof bolts. Thinly laminated roof strata of both low strength and closely spaced bedding planes, such as a "rash" of coal, claystone, and shale, are certain to be troublesome roof to support.

Stackrock, a miners' term for very thinly laminated sandstone, is notorious as a roof that does not respond well to conventional bolting and is prone to fall on exposure. Roof falls attributed to closely spaced and poorly bonded laminations tend to occur most commonly at intersections where the greatest span of roof is exposed, but sometimes occur randomly wherever the roof support plan or installation is inadequate or defective. Falls of roof due to a high density of poorly bonded bedding planes tend to develop first as roof sag, sometimes of substantial amount, because the roof bolts are not anchored into overlying competent thick-bedded strata. As these strata separate along bedding planes and sag, a slippage along the planes also occurs unless this lateral shear movement is prevented by the resistance of full-column resin bolts. This alone, however, is unlikely to prevent eventual roof failure unless some support is provided by longer bolts anchored in overlying competent strata.

Severe sag of thinly laminated strata that does not respond to resin or longer bolts calls for the use of roof trusses, posts and crossbars, or entry narrowing where feasible.

The sagging of laminated strata often results in a tension fracture along the center of the entry roof caused by the bending moment. As sagging progresses further, fractur-

Fig. 6—Subtype G_4 roof failure attributed to a clay vein (clay dike).

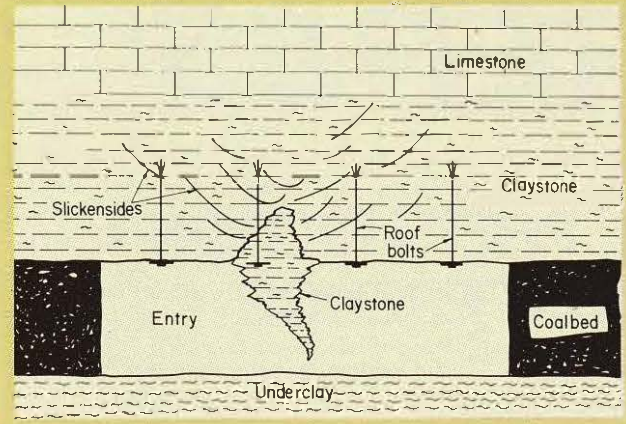


Fig. 7—Subtype G_4 roof failure attributed to a paleochannel (roof roll).

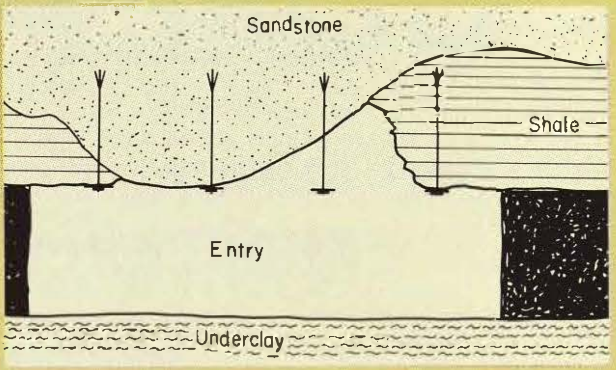


Fig. 10—Subtype G_4 roof failure attributed to concretions.

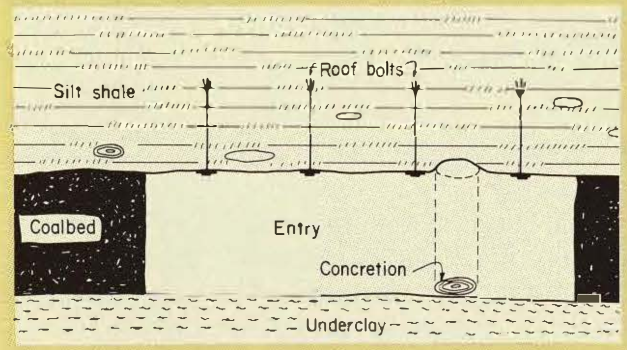
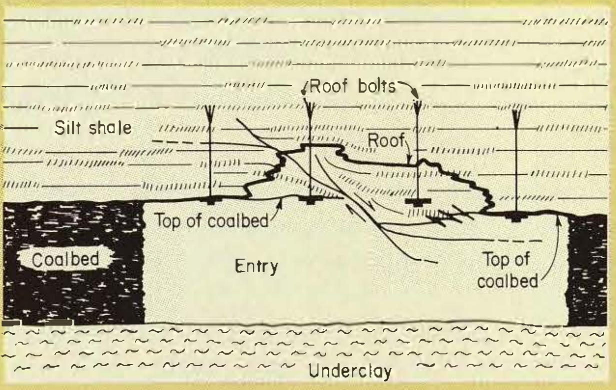


Fig. 11—Subtype G_4 roof failure attributed to faults.



ing of the roof occurs, which eventually destroys roof integrity and leads to a general disintegration and collapse.

Minor structures

Falls of roof attributed to minor geologic structures (Subtype G_4) are generally recognized by a minor structure which is exposed in the roof or fall or lies adjacent to the fall. Minor structures include virtually any geologic feature other than a normal parallel layering of roof strata. In the Appalachian region, these include slickensides (Fig. 4), kettlebottoms (Fig. 5), clay dikes (Fig. 6), paleochannels (Fig. 7), joints (Fig. 8), pinchouts (Fig. 9), concretions (Fig. 10), and faults (Fig. 11). Most minor structures constitute a discontinuity in the normal beam-like structure of mine roof and thereby have a weakening effect. The roof rock around minor structures tends to fall soon after the supporting coal is removed and before a permanent support can be installed.

A multitude of minor structures have been encountered in Appalachian coal mines. Few have been fully described as to identity or effect on mine roof. Virtually all are either syngenetic or diagenetic in origin, that is, they are non-tectonic, having been formed contemporaneously with deposition or shortly thereafter during compaction and consolidation. An occasional tectonic structure has been encountered along the eastern limits of the coal region near the folded Appalachian Ridge and Valley province. (Intense deformation and large highly developed folds and faults occur in the anthracite region of eastern Pennsylvania and the bituminous Coosa Basin in Alabama; a discussion of such faults is outside the scope of this article).

The actual character or identity of many minor structures can only be established through careful examination by an experienced geologist. The correlation between structure and roof falls, however, can be fairly readily established by a systematic mapping of roof falls and minor structures, even though the identity or trend of the structure is not always apparent.

Many minor structures such as paleochannels, clay dikes, slickensides, slumps, rolls, and horsebacks, tend towards linearity, so that directional trends of falls soon can be established and projected. Kettlebottoms and concretions tend to be sporadic in occurrence and are common in southern West Virginia.

Intraformational joints are found in virtually every mine where thick, massive strata occur. They commonly will form a boundary of a roof fall but are not a major causative factor as are some of the other structures. Joints are reported to play a much greater role in roof failure in the Western United States than in the eastern regions.

It would be impractical to attempt to describe all the various minor structures and their variants. However, a knowledge of the nature of each structure above the exposed roof can be vital in preventing failure by tailoring the supplementary support to the local conditions. For example, neither kettlebottoms, concretions, nor jointing in mine roof are necessarily better supported by increasing the bolt length, while pinchouts may benefit from this procedure. The support of several minor structures, such as slickensides (slips), paleochannels, and clay dikes, seem to be improved when using angle bolting. Resin injection and dowelling have proven effective in many instances of consolidating clay dike in the roof. Bolted straps and headers, of course, are widely used with virtually any type of a minor structure that constitutes a discontinuity in roof strata.

The severity of failure due to minor structures can be reduced when the general directional trend of these structures can be established and entries turned to intersect them at a large angle as opposed to driving parallel to the structures. At the least, every effort should be made to identify correctly the character and trend of troublesome structures on exposure, as they are not detectable by exploratory drilling, are erratic in occurrence, and tend to fail without warning when unexpectedly encountered during mine development.

Accident prevention

Our scheme for categorizing roof falls is based on causative factors, and requires some data collection as to the pattern and character of roof falls. Each setting has its own ground control problems which can be sorted out into stress effects and geologic defects. These two salient conditions can occur together but require a somewhat different approach in terms of improved roof support. While improper extraction or support methods can contribute to roof failure, these factors usually can be identified by the absence of geologic defects or stress effects and close examination of operating procedures.

Our proposed scheme constitutes only a framework in which the roof specialist of a mining company can begin to sort out the problems. It is not always possible for a mine operator to allocate technical staff members full-time for this kind of study. But if pursued conscientiously, along with some sort of experimentation within the constraints of the approved roof support plan, we have reasons to believe that our scheme could contribute to accident prevention and reductions in cleanup and repair costs. □

Coal
MINING

A Maclean Hunter Publication

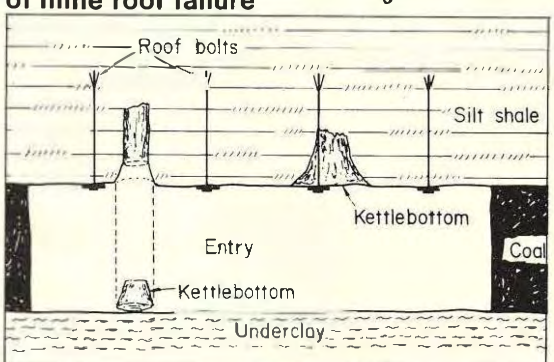
MARCH 1985
VOLUME 22, No. 3

FEATURES

Marketing

Safety

Underground mining



Labor

COVER

Cover: Westshore Terminals' 24-million-tpy capacity makes it the largest bulk commodities terminal on the west coast of North America. As such, the facility, located south of Vancouver, British Columbia, is a key to exporting Canadian coal to Pacific Rim countries. The Roberts Bank pad is a manmade island that can accommodate 250,000-dwt ships.

OPINION

DEPARTMENTS