Factors Affecting Coal Roof Rock in Sullivan County, Indiana

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Abstract

Maintaining a safe and stable roof is both an economic and geologic aspect of an underground mine operation. Roof falls occur when the rock is too weak to support the overlying pressure across the open span where coal has been removed. Roof falls are related to characteristics of the rocks. They may be described as dust, lenticular, concretion, slate, clay squeeze and massive falls. Lithology and thickness of beds, jointing, strength of bedding plane bond, and the effect of moisture are important considerations. No single criterion seems to be adequate for practical roof evaluation.

Introduction

Probably no single aspect of underground coal mining is less understood than the evaluation of roof strength before actual mining begins. Certain areas of good roof and certain areas of poor roof may be recognized but the roof in most of the area is likely to be of questionable strength. Before mining begins the geologist can, by using cores of the roof rock, run physical and chemical tests that characterize the roof rock. During the mining operation the engineer can devise a system of mining that leaves approximately 50% of the coal as supporting pillars and a system of roof support using roof bolts, supplemented by posts, rails, or bars. If the roof collapses, the engineer can design a method of cribbing to stabilize the roof in the roof fall area. Coal mines, however, should operate at a profit and if too much material and too many man hours are required for roof control this cost is more than the margin of profit and the mine has a deficit operation regardless of the efficiency of actual coal removal. The mine superintendent must see that the roof is supported well enough that it will not endanger the miners nor collapse in rooms or entries and restrict the flow of fresh air through the passages, or the flow of coal out on conveyor belts. On the other hand, his job is to keep costs down and put the minimum amount of money into roof control.

In an attempt to characterize good versus poor roof condition, information has been accumulated intermittently during the past 15 years. Data for this report was gathered from drill holes and from the underground workings of the Minnehaha, R. S. and K., and Thunderbird Mines, all in Sullivan County.

Kinds of Roof Falls

The roof in an underground mine collapses when the rock is too weak to support the overlying pressure across the area where the coal has been removed. The kinds of rocks are most important in an evaluation of the roof. Thick homogeneous beds are more competent than thin heterogeneous ones. In general, thick massive sandstone or limestone provides the best roof, and shale or mixed sand, silt, and shale beds are the poorest. However, a fairly homogeneous gray shale may be a satis-

factory roof. Vertical joints across a bed and abundant mica and carbon films in a bedding plane allow slippage and decrease the competence of the rocks. Expandable clays in the rock swell in the presence of moisture and cause disruptive pressures. Water in the rock also adds weight to the roof, tends to weaken some rocks, and lubricates the moving surface. A combination of the above parameters may produce a variant of the six different kinds of roof falls described below.

A dust roof fall (Fig. 1) is related to the thin soft dark gray shale that overlies the coal in some places. This shale contains finely dissiminated pyrite, calcareous shells, and carbon films. As soon as the coal is removed and moist air comes in contact with the pyrite in the shale, the iron sulfide (pyrite) changes to an iron sulfate and swells, and the shale literally falls apart. Alternate moist and dry air that circulates through the mine may hasten the dissociation of the shale. This soft shale crumbles into dust and falls out between the roof bolts even if large metal or woods plates are used at the bottom of the bolt. Not much can be done about holding this part of the roof, but such falls are not a serious problem because this shale commonly ranges only a few inches to a foot in thickness and the dust that falls to the floor creates only a minor nusiance.

The lenticular roof fall is related to a sandstone roll (Fig. 2). In this situation, the bottom surface of the sandstone is quite irregular and the upward concave areas are filled with dark gray to black shale that at that place forms the roof of the coal. This shale is fairly soft and is not well cemented to the sandstone. Thus when the coal is removed, this lenticular unit of shale will come down.

Coal beds, such as the Springfield coal (V), that are overlain by black fissile shale (called slate by the miners) that contains ironstone concretions have two special kinds of roof falls—the concretion fall (Fig. 3) and the "slate" fall (Fig. 4). In areas where the ironstone concretions are developed they are from an inch to four feet in diameter and commonly occur at the top of the coal and the base of the overlying black shale. When coal is removed these concretions may hang down from the roof into the passage (Fig. 3). They are called pots or kettles by the miners who generally pry them out of the roof before they fall.

In areas where the black slaty shale does not contain concretions it commonly makes a good roof. If a break occurs, a large slab of rock may pull partly loose from the roof (Fig. 4) and hang there for days before falling unexpectedly.

The fifth type of fall is related to weakness through jointing or fracturing, in the roof rock and in the coal. This weakness is most obvious when it is also a clay squeeze (Fig. 5). An underclay squeeze occurs where the clay beneath the coal flows, probably by a combination of shear and plastic flowing, from beneath the coal into a vertical crack or joint in the coal. In some cases the clay moves through the coal and several feet above the coal into a joint in the roof rock. During mining the clay may flow in mined-out entries or rooms. Although clays

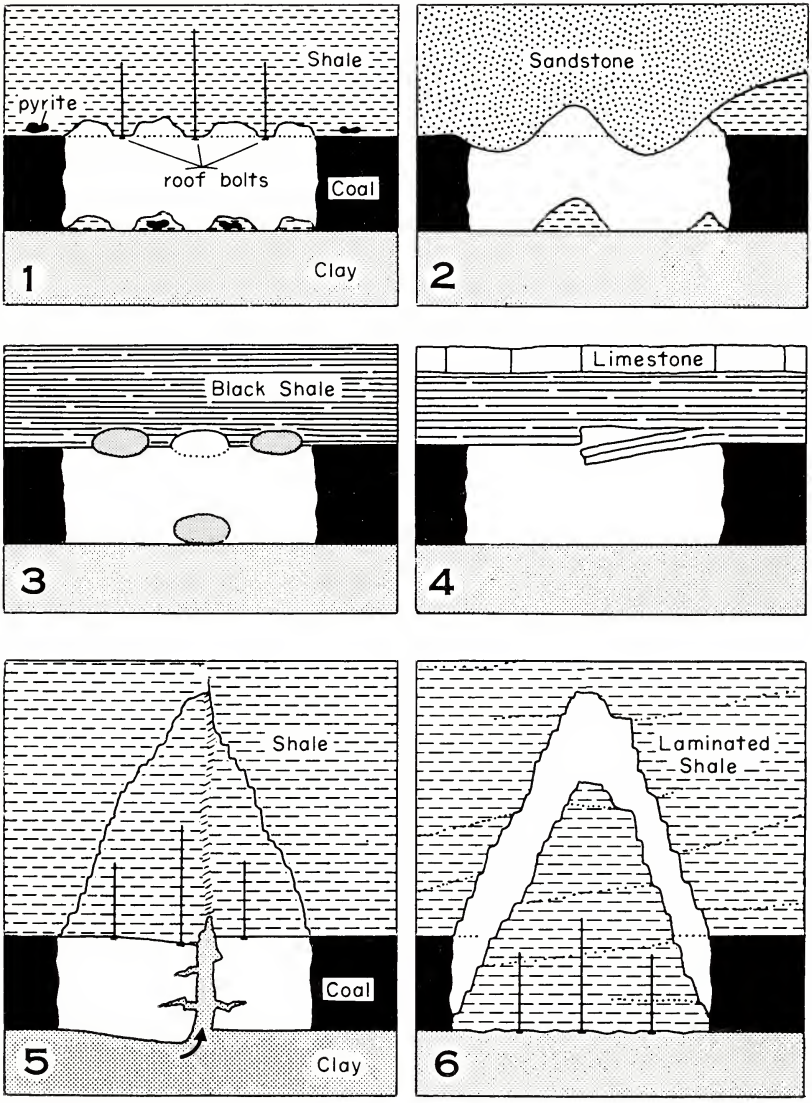

FIGURE 1. *Dust roof fall.*

FIGURE 2. *Lenticular roof fall.*

FIGURE 3. *Concretion roof fall.*

FIGURE 4. *Slate roof fall.*

FIGURE 5. *Clay squeeze and fall.*

FIGURE 6. *Massive roof fall.*

that readily squeeze have somewhat different physical properties than those that do not, the trigger that starts the process is differential weight on different parts of the coal bed and thus on the underlying clay. Thus if a clay squeeze occurs across a mined-out area, commonly the clay moves out from under the coal on one side of the joint lowering the coal and the overlying roof rock relative to the mostly undisturbed coal and roof rock on the other side of the joint. The roof then is considerably weakened and the probability of a roof fall is increased tremendously.

Fractures or joints in the roof rock either in bedding planes or across bedding planes may be present and not easily recognized. It is difficult to predict the probability of a roof fall in this case. The roof may look the same as in Figure 1, but a massive roof fall occurs unexpectedly filling the entry and extending 20 or 30 feet upward, mostly through thin-bedded and interlaminated shale, sandstone, and siltstone. This material is full of weak bedding planes that consist mostly of carbonaceous films and mica. When the coal is removed, the weight of the overlying material begins to pull these bedding planes apart; the individual beds start breaking and form nearly vertical cracks. If water seeps in through the cracks, it weakens the shale further, acts as a lubricant to bedding plane movement, and adds weight making the chances of roof fall much greater. This interbedded material ordinarily does not contain water in the natural state. The shale beds effectively seal off the sand beds and lenses from each other and make the whole material more or less impermeable, that is, before cracking takes place.

Two conditions are favorable for the accumulation of water: 1) a thick-bedded porous sandstone on top of the coal or close enough to be reached by the 4- to 8-foot long roof bolt holes, and 2) swags or struc-

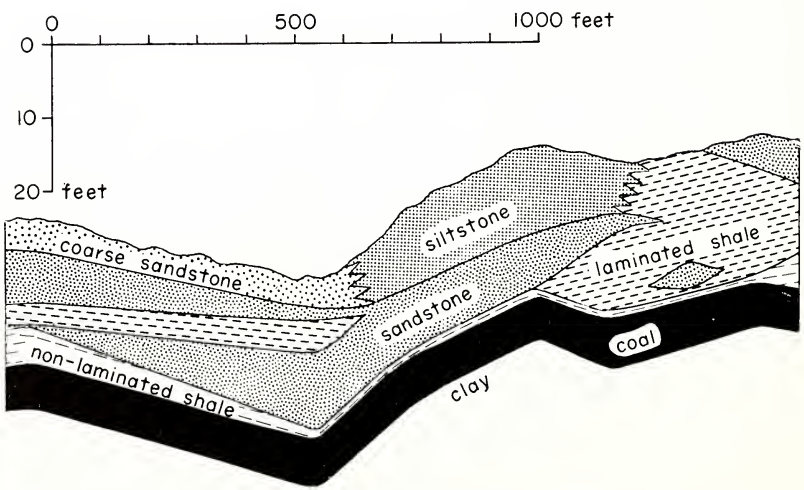

FIGURE 7. *Cross section near the east side of Thunderbird Mine showing variations in dip of the coal and in the distribution of kinds of roof rock.*

tural lows in the coal. These two conditions are well illustrated at the east end on Main East in the now abandoned Coal VI workings of the Thunderbird Mine (Fig. 7). Where a porous sandstone rests on top of the coal (and may cut into the coal) it likely will cause a water problem even without being in a structural low. On the other hand a structural low that has a less porous laminated sandstone may allow the roof to be saturated with water so that it becomes quite heavy. Water may weaken the bonding ability of the clay and increase the probability of collapse. Another minor factor in some roof falls may be gas pressure. At places where mining progresses up hill, gas in the top of the coal and in the roof may exert some lateral pressure on the roof where it is slightly downhill and where the coal has just been mined.

Evaluation of the Rocks

In an attempt to try to predict areas of massive roof falls in the Hymera coal (VI) in the Thunderbird Mine, 43 cores were studied in detail. The common sequence for the 20 feet of rocks above Coal VI is, from the top down: 1) thick-bedded sandstone, 2) laminated sandstone, 3) laminated shale, 4) dark gray non-laminated shale, and 5) dark gray shale containing plant fossils and pyrite.

1) Sandstone: light-gray, medium-grained, thick-bedded; locally may be replaced by siltstone, laminated sandstone, or laminated shale; locally cuts down into coal.

This medium-grain, thick-bedded sandstone, should theoretically be an excellent roof where it is close to the coal, because it is structurally strong. But in some areas it carries much water and completely saturates the underlying laminated sandstone and shale such that they fall from as high as the base of the sandstone.

2) Sandstone: light- to medium-gray, laminated with 10 to 50% shale; contains chlorite, mica, and carbonaceous material in bedding planes.

3) Shale: dark- to medium-gray, laminated with 10 to 50% fine-grained sandstone; contains mica and carbonaceous material in bedding planes.

The laminated shale and laminated sandstone differ mostly in amount of sandstone versus the amount of shale. Both units contain weak bedding planes composed of lineated mica flakes and carbonaceous films (from fossil plants). The sandstone has a greater capacity to contain water (more porous) and a greater capacity to absorb water (more permeable) through the rock if drill holes connect it to water-bearing rock. This water not only makes the roof heavier but tends to react electrochemically with some of the clays and chlorite (in shale laminae) in some bedding planes. The sandstone laminae act as a conduit for the water but remain solid, but shale laminae desintegrate. Montmorillinite clays that expand when wet were not found in the samples tested. Sawed

samples of the more clayey bands of these two units readily break into small pieces when immersed in water for several hours.

4) Shale: dark-gray, not laminated with standstone; locally contains in lower part calcite or pyrite brachiopod shells and crinoid columnals.

This shale, although not particularly strong, is homogeneous and seems to hold fairly well where it is 2 feet or more thick. The strength of this shale is adversely affected by water, but it has a low enough permeability that ordinarily, water is not a problem.

5) Shale: dark-gray; contains abundant plant remains, some of which contain pyrite and some carbon (both vitrain and fusain).

The shale is commonly less than a foot in thickness and is absent in many areas. Where present it commonly falls down on to the floor of the entries as small fragments or as dust.

Physical Tests

In the sequence of rocks discussed the key to predicting good versus poor roof conditions seems to be hidden in the physical and chemical variations of units 2 and 3, the laminated sandstone and laminated shale. Several tests were tried. A few look promising.

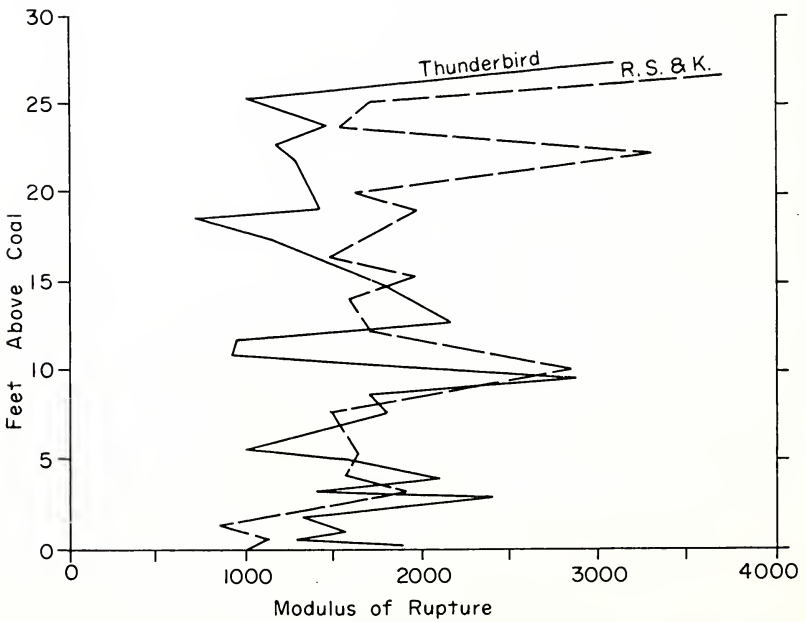

FIGURE 8. *Graph showing vertical variation in modulus of rupture for samples taken from two cores. Solid line represents core from Thunderbird Mine area; dashed line from R. S. & K. Mine area.*

Modulus of rupture was determined for blocks cut both from hand samples and from cores. In general roof rock known to be strong had high shearing strength and poor roof rock had low shearing strength. Where the first 20 feet of rock immediately above the coal was laminated sandstone and shale the readings were irregular. Cores were obtained from an area of poor roof rock in the Thunderbird Mine and from an area of satisfactory roof rock in the R. S. & K. Mine (Fig. 8). Modulus of rupture tests do not show significant difference.

Clays were separated from the shale laminae. Illite is the most abundant clay mineral. X-ray patterns indicate that the 001 peak for illite is usually symmetrical in the area of good roof and asymmetrical in the area of poor roof. The asymmetry indicates a degraded illite that will take water readily and will swell.

Viscosity tests were run on clays by mixing 50 g of clay with 100 ml of water and measuring the resistance to a rotating paddle. The viscosity of the clay slurry is related to internal friction and cohesion of particles. In general the good roof rocks had the highest viscosity, but viscosity varies vertically over short distances.

Conclusions

In evaluating roof rock conditions the geologist must look at the rocks from many viewpoints. No single physical or chemical parameter tells the whole story. Not only are lateral variations in the rocks important but vertical variations are also. Not only may the rock be significantly different from one foot to the next but, in some cases, from one centimeter to the next.