Diagnosing and Controlling Moisture-Sensitive Roof in Coal Mines

Gregory Molinda
Lead Research Scientist,
NIOSH-Pittsburgh Research Laboratory, Pittsburgh, PA
GMolinda@cdc.gov

Ted Klemetti
Research Engineer, NIOSH-Pittsburgh Research Laboratory. Pittsburgh, PA
TKlemetti@cdc.gov

ABSTRACT

Historically, coal miners have known that roof shales can deteriorate in contact with humid mine air, causing massive roof falls and injuries from falling rock. It is critical to recognize rocks prone to weathering and to adequately support these rocks in order to ensure the long-term stability of the openings. In a recent study, NIOSH has used a wet/dry cycling test to determine the moisture sensitivity of over 800 specimens of roof rock from 25 U.S. coal mines. Fireclays and some gray shales are the most moisture-sensitive. Rocks with disturbed bedding, in contrast to flat-bedded rocks, are also more sensitive to water. Black shales are relatively un-reactive to moisture and serve to protect more reactive gray shales above. Mines that have roof rocks with moisture-sensitivity indexes above 40% can experience slaking roof conditions, and many require high coverage surface controls. Three case studies are presented in which the moisture-sensitivity index is correlated to roof conditions underground, and can be used to indicate long term deterioration. Engineering measures are described to control moisture-sensitive roof. In one case, roof screen not only reduces injuries from rock fall but also is shown to reduce roof falls.

Keywords: coal mining, roof control, slaking, roof support, rock falls

INTRODUCTION

In the last 5 years, over 2,400 injuries have occurred to U.S. coal miners due to rock falls (MSHA, 2006). Even though the rock fall injury rate has been decreasing, over 400 injuries are still occurring to coal miners every year. Although all miners are exposed to rock falls, injuries happen more frequently to miners at the working face, and most frequently to roof bolters and continuous mining machine operators. These miners have the most exposure to rock that is newly undermined. It is a rare miner which has not had at least some injury caused by the fall of roof rocks.

There are a number of causes of rock falls in coal mines, including horizontal stress, excessive roadway width, stream valley effects, and multiple seam mining interactions. Strong roof may be able to withstand many of these assaults, but weak roof rock is susceptible to failure from all of these forces. Weak roof rock sequences can be defined in several ways. A Coal Mine Roof Rating (CMRR) less than or equal to 45, uniaxial compressive strength less than 3,000 psi, and RQD between 25 and 50% have all been used to describe weak or poor quality rock (Mark et al, 2004). Weak roof rock is a function of the depositional environment in which the rocks were formed, the subsequent compaction and lithification process imposed on the sediments, and the tectonic history of the local region.

A number of features can make a rock weak. These include weak bonding on bedding planes, structural discontinuities like slips and coal spars, plant debris like tree trunks, branches, or leaves, or disturbed bedding from roots and animal burrowing. Another factor that weakens a roof rock, and is the subject of this report, is moisture-sensitivity. A majority of roof rocks are composed of clay minerals, feldspar, quartz clastics, and a small fraction of other silicate and carbonate minerals. These shales and fireclays can be composed of 50-80% clay minerals. They are essentially rocks made of lithified mud. Clay minerals have a platy structure and can absorb water. Water absorption causes swelling, which can loosen bedding and break apart the flat-bedded mineral structure, resulting in rock deterioration.

Historically, miners have known that roof rocks, originally composed of mud, were prone to slaking and deterioration when exposed to water and humidity. Some shales are largely stable through time and moisture exposure, and some are highly sensitive to moisture. Clay minerals can absorb water rapidly and generate pressures that can break apart weakly bonded rocks (Huang et al., 1986). This degradation can occur months or years after exposure, or it can occur within days. Numerous studies confirm that it is the cycle of wetting and drying that occurs with seasonal weather changes that cause rocks to deteriorate. Some shales will not weaken significantly even when immersed in water, but will fail if subjected to repeated wetting and drying (Aughenbaugh, 1981). In the dry air of the Utah coalfields such deterioration is not as severe, but in the eastern and Midwestern coalfields summer humidity can cause weak shales to "rain rock" in beltways, travelways, and other outby areas.

Fireclays and claystones represent "over-compacted" rocks that can be activated by moisture that releases trapped strain energy and causes swelling. Negative pore pressures then "suck" in water and advance the reaction (Duncan et al., 1968). Other shales, including black shales, and some gray shales, are stronger and not over-compacted and are more stable.

Time-dependent deterioration of shales can be seen in the core box. Unrug and Padgett (2003) found that RQD averaged a 42% decrease as the core aged from the "barrel to the box to the lab." Some rocks deteriorate to the point where testing is impossible. Conversely, it is clear that some rocks gain strength as they dry out (Bauer, 1980; Van Eckhart and Peng, 1975).

There is abundant evidence that exposed coal measure roof rock responds to changes in humidity in mine air (Unrug and Padgett, 2003). Cripps and Taylor (1981) report that overconsolidated clays will relax in a time-dependant way upon the removal of confinement by mining. This relaxation causes micro tension failures in weak shales and allows for the increased infiltration of moisture. Increased moisture exposure results in swelling and more tension failures, leading to progressive deterioration. This mechanism may explain the time dependant roof failures of some rocks which may occur years after mining. In fact, this relaxation deterioration may occur even without moisture infiltration.

Aughenbaugh and Bruzewski (1976) showed that roof failure in moisture-sensitive rock can occur by anchor slippage as bulk swelling in the roof loads up roof bolts. Roof failure has occurred by rock fracturing between bolts with no prior bolt loading. This is also due to bulk swelling. This indicates that the weak rock fractured before any load could be transferred to the roof bolt. Slip of point-anchored bolts has been more prevalent in highly humid summer months than dryer winter months. Bolt loading, as determined by lengthening and shortening of the bolt due to rock mass swelling, also increases in summer months due to higher humidity (Aughenbaugh and Adam, 1980). Matsui et al. (1996) report vertical closure in wet entries was 40-60 cm, whereas in dry entries it was only 5-15 cm. Some of this closure was due to the heave of floor members. Cummings and Singh found roof convergence to be seasonally related; with increased convergence in summer and decreased convergence in winter (1981).

There is convincing evidence, both in the laboratory and in the field, to show that some shales can be highly reactive to moisture exposure. This exposure can lead not only to hazardous roof surface failures but to large roof falls years later. A NIOSH study has documented the distribution of roof falls in a West Virginia mine. In this mine, numerous falls continued to occur up to 6 years after roof exposure (Mark et al., 2004). In the beltway of the same mine, highly fractured roof was documented by videoscope. These fractures and voids provided almost unlimited access of humid mine air to highly moisture-sensitive roof rocks.

Moisture-Sensitivity Testing

Advance knowledge of the amount of deterioration to expect from a shale is a valuable property for mine planning and support design. Mine openings in highly moisture-sensitive rock will not survive years of service without special support measures. NIOSH is engaged in a research project to characterize moisture-sensitive roof rocks. The goal of the project is to find an effective method for evaluating the potential of shales to deteriorate with exposure to mine humidity.

In order to develop a database that covers the range of moisture-sensitivities of typical roof shales, NIOSH has collected roof rock samples from 25 mines around the U.S. Over 800 individual rock tests were completed. In all but 2 mines the samples were roof slabs collected underground. The remaining 2 were exploration cores. All samples were roughly fist-sized and prepared from the roof slabs as broken pieces, cut, or drilled samples. These roof samples represent rock from mines with roof conditions

Figure 1: Moisture-sensitivity samples were collected from U.S. coal mines.

ranging from excellent to extremely poor. Figure 1 shows the distribution of U.S. coal mines that were sampled for roof rock moisture sensitivities.

There are a number of tests that can be conducted on shales to determine their sensitivity to moisture. The lab tests typically involve some type of water or moisture exposure/immersion and a measurement of the rock response. Other tests involve measurement of clay mineralogy to determine the reactive components of the rock. In an underground coal mine the wetting and drying cycles that accompany the change of seasons is recognized to cause roof deterioration. Because it mimics this cycle, the wet/dry immersion test developed by Kot Unrug (1997) was chosen for use in this study.

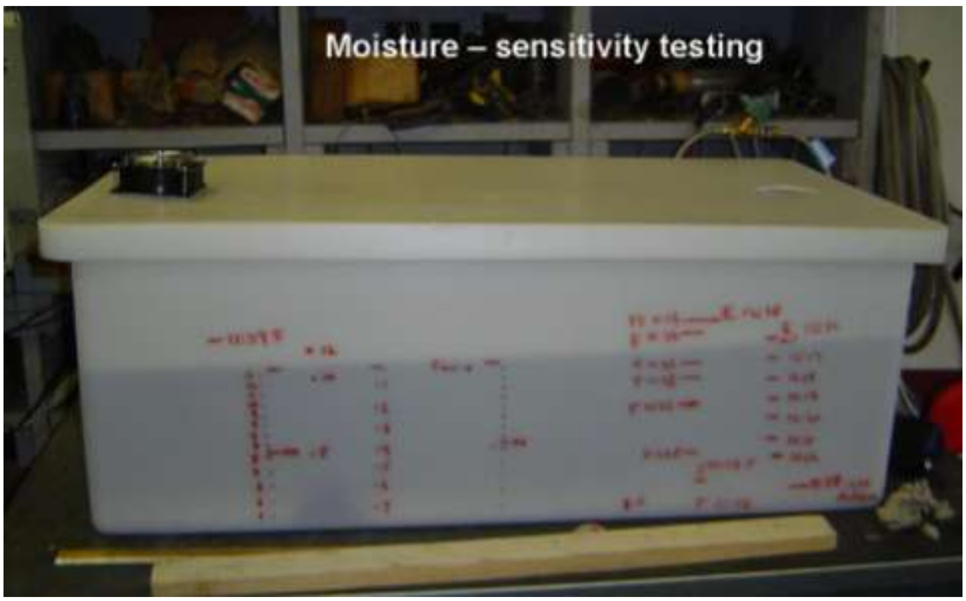

Figure 2: Wet/dry cycling immersion test determines moisture-sensitivity of roof rocks.

In this test, fist-sized samples of rock or 2 in cores drilled from roof slabs are placed on a screen in a tank (Figure 2). The tank is flooded until the samples are completely immersed for 1 hour. The tank is emptied and the samples are air-dried for 6 hours. The cycle is repeated 3 times. The Weatherability Index is calculated as follows:

$$WAI = \frac{W_{ini} - W_{rem}}{W_{ini}} * 100$$

Where WAI = Weatherability Index, %,
W_{ini} = Initial weight of sample, grams.
W_{rem} = Weight of the largest remaining fragment of a sample, grams.

An advantage of this test is that samples can be batch-tested (up to 30 at a time). Considering that the composition of some rocks can be highly variable, more tests are preferred.

Figure 3: Roof rock samples before water immersion cycling test.

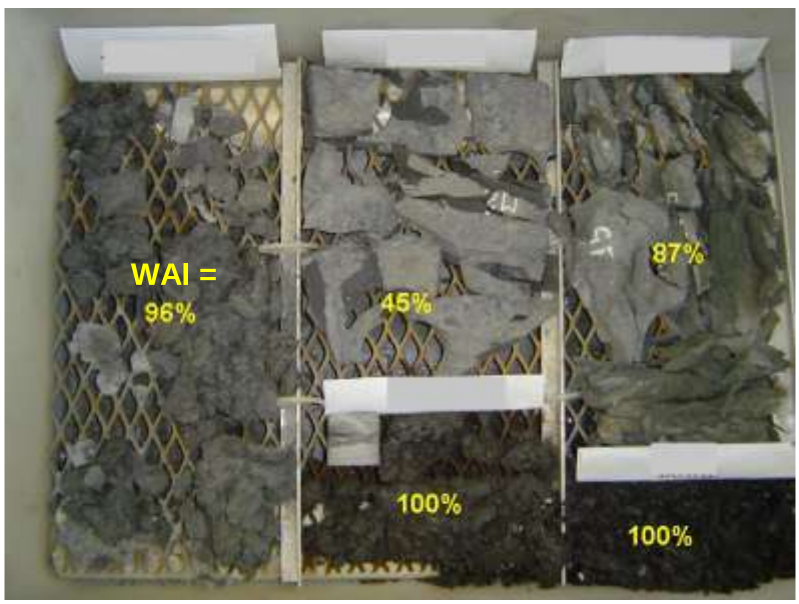

Figure 4: Roof rock samples after three cycles of water immersion.

In this study, roof rock moisture-sensitivities ranged from completely un-reactive to complete disintegration of the sample. In some cases this occurred in only 60 seconds. Figures 3 and 4 show samples before and after immersion. Significant deterioration has occurred after three cycles of wetting and drying.

Of the rocks tested, the most water-sensitive rock types are the gray shales and fireclays (Figure 5). These include: dark gray sandy fireclay (327), sandy claystone (347), sandy fireclay with limestone nodules (437), dark gray sandy fireclay with limestone modules (427), gray shale (124), and gray fireclay (127). The corresponding numbers are classification numbers developed by John Ferm for rock identification (Ferm and Smith, 1981). For clarity, the various rock types have been consolidated into groups based on rock fabric and mineralogy (Figure 5). Of the 5 rock types, fireclays were the most water-sensitive. Fireclays are well known for creating muddy floor conditions that can bog down equipment. They also can make for difficult roof conditions due to discontinuous bedding and a propensity to fail as lumps between roof bolts.

The average gray shale moisture-sensitivity shows this rock type as the next likely to deteriorate with exposure (Figure 5). Flat-bedded shales tend to separate and sag on bedding. When separation occurs, vertical tension fractures allow further access to water which then moves along bedding. The internal structure of clay minerals contributes to the absorption of moisture. Some clay minerals have a phyllosilicate, or platy structure. This platiness gives the shale its flat or fissile bedding. Moisture is absorbed easily along well-developed bedding but moves with more difficulty across bedding (Figure 6). The generic rock term “shale” is defined as “an unmetamorphosed, very fine-grained argillaceous (predominantly clay and silt) rock with a distinct fissility parallel to the bedding” (Moorehouse, 1959). The definition allows for a wide variability in mineralogic composition. This, in turn, is reflected in a wide variability in moisture sensitivity. Figure 7 is a distribution of the moisture sensitivity of 161 samples of shale (Ferm No. 124). While a majority (58%) of the values fall into the moisture-sensitive range (>40%), there are a number of samples that are not reactive to moisture. This can be attributed to the inclusion of un-reactive silt-sized quartz. While bedding character may correlate to moisture-sensitivity, visual inspection alone may not be sufficient to indicate the moisture-sensitivity of the rock. Rocks that appear identical in color, texture, and bedding may have very different reactivities to moisture. For this reason it is necessary to test rock samples for moisture-sensitivity.

In contrast to flat-bedded shales, fireclays all have some degree of disturbed bedding. Ferm (1981) distinguishes fireclays and claystones as having an “irregular fracture or irregular streaks.” The irregular bedding often is a loading feature that is the result of compaction of saturated soft clay deposits. Disrupted bedding may also be due to chemical alteration of clays and fracture infilling. It appears that it may be this irregular bedding which is common to the most water-sensitive rocks. When bedding is disrupted due to rooting, burrowing, or overcompaction, water can more easily move by capillary action

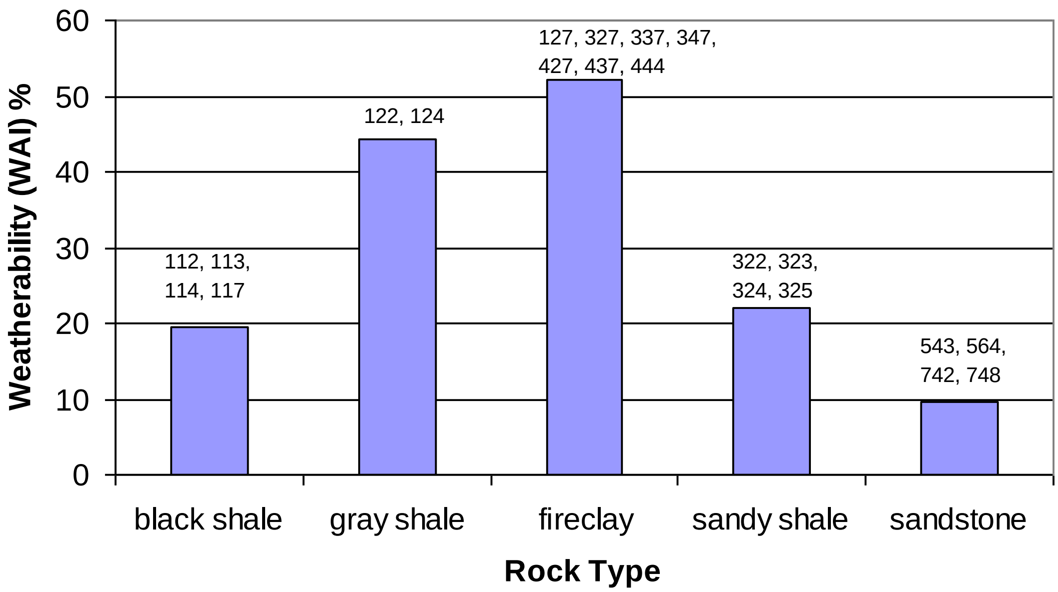

Figure 5: Moisture-sensitivity of roof rocks grouped into common roof rock types (Ferm numbers of groups are indicated on bars. Ferm and Smith, 1981).

across bedding (Figure 8). The bedding of roof rock samples was classified as "irregular" or "flat" and plotted against the average moisture-sensitivity of each bedding type. Figure 9 shows that samples with irregular bedding were, as a group, more moisture-sensitive than flat-bedded samples. This progressive infiltration of moisture through irregular bedding may allow for the exposure of swelling clays and begin the deterioration of the rock mass. Rock then falls between bolts and prevents load transfer to the bolts.

Figure 6: Water moves more readily along bedding than across bedding.

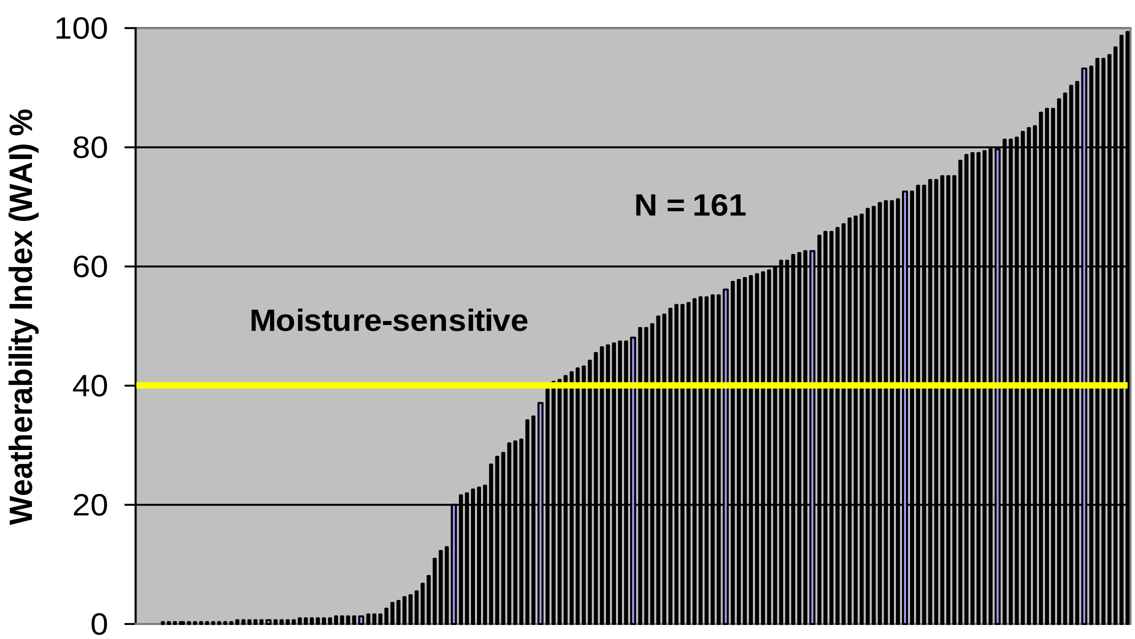

Figure 7: Variability in the moisture-sensitivity of common shales (Ferm No. 124).

Clay minerals, such as montmorillonite and bentonite, are more likely to swell than other clay minerals. It has been thought that this is a prime reason for roof deterioration. In order to test this theory, X-ray diffraction tests were conducted on 10 roof samples to look for the presence of swelling clays. Table 1 indicates the rock types and range of moisture-sensitivities for the samples. No swelling clay minerals were detected in any of the samples. Holland also found that deteriorating roof shales are known which contain no expansive clay minerals. Only one of 38 roof shales from southwest Virginia., Illinois, and Indiana had detectable amounts of montmorillonite (Holland, 1956). Pyrites, found in roof shales and coals, can oxidize in the presence of moisture and form ferrous sulphates which absorb water and swell considerably (Chugh, 1981).

Figure 8: Fireclay showing disturbed bedding and water moving easily on bedding.

Table 1: Mineralogic composition of selected roof rock samples

Roof sample number	Rock type	Moisture sensitivity (WAI %)	Mineralogy % wt						
			Muscovite/ illite	Kaolinite	Feldspar	Quartz	Chlorite	Siderite	Pyrite
BW-1	Black fireclay	100	50-55	25-30	3-5	11.1			
VGW-3	Layered shale	87	55–60	5-10	3-5	21.3	3-5	3-5	
W-336	Black shale	4	65-70	5-10	3-5	10.2	1-3	1-3	5-10
W-326	Gray fireclay	100	50-55	5-10	5-10	24.3	1-3	5-10	
W-322	Gray fireclay	100	40-45	5-10	5-10	29.2	1-3	1-3	
W-290	Gray shale	68	60-65	5-10	5-10	16.5	1-3	1-3	
W-374	Sandy shale	43	40-45	5-10	5-10	30.0	3-5	3-5	
W-375	Sandy shale	69	40-45	5-10	5-10	32.2	3-5	3-5	
W-172	Layered shale	3	45-50	5-10	5-10	16.0	3-5	3-5	
W-171	Layered shale	1	50-55	5-10	5-10	15.7	1-3	3-5	

Sandstones were the least moisture-sensitive rocks due to their inert mineralogy. Black shales and black fireclays are also relatively non-reactive (Figure 5). Holland (1956) cites data showing that rocks containing organic compounds such as fatty amine acetate are less plastic, shrink and swell less, and are more resistant to swelling. This may explain why organic-rich rocks such as black shales are resistant to moisture deterioration. Coal and bone coal are commonly used to protect moisture-sensitive shales in the roof above, and black shales are an extension of these organic-rich rocks.

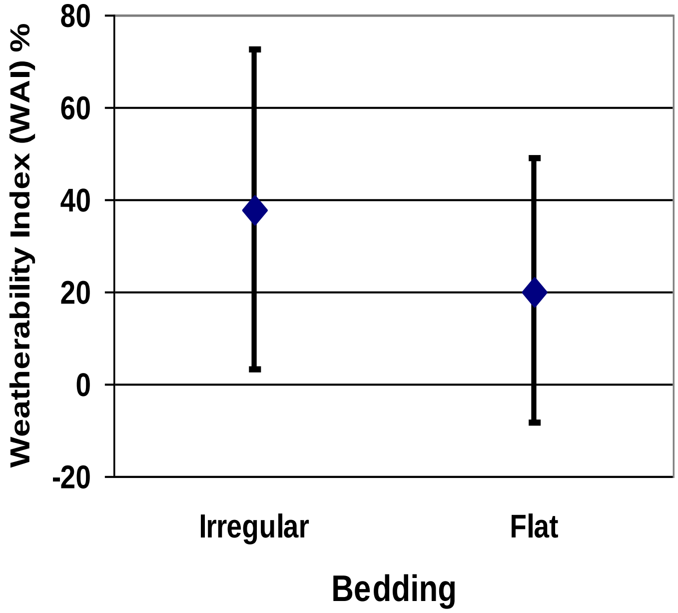

Figure 9: The average moisture-sensitivity of irregularly bedded rocks was higher than flat bedded rocks. The bars represent one standard deviation about the mean.

Moisture-Sensitivity and Roof Conditions

An index test can only be valuable as an indicator of potential roof problems if it is confirmed by field experience. Underground mapping of roof conditions provides this confirmation. The moisture-sensitivity values of all samples from each mine were averaged to produce a value that was used to represent the roof of each mine. Figure 10 shows the average moisture-sensitivity for each of the 25 study mines. Thirteen of the mines had moisture-sensitivities averaging 40% and above. Eleven of the 13 mines at or above 40% moisture-sensitivity had significant roof slaking problems. These problems included rapid deterioration of roof (several months) in intake air, chandelier bolts, roof rashing between bolts, heavily loaded screen, and significant cleanup in travelways. Nine of 12 mines with average moisture-sensitivities below 40% had no roof slaking or scaling problems. Three mines with moisture-sensitive values below 40% still had scaling problems. These problems were due to slickensided roof and horizontal stress damage. Eight of the mines above the 40% threshold used screen to help control the roof surface. The threshold line at 40% moisture-sensitivity may be extended into a range (30-40%) depending on the variability of the roof rock, and the roof slaking experience at individual mines. Highly variable roof rock underscores the need for numerous samples in order to adequately represent the likelihood of roof deterioration. In roof that is layered, and when several variable units are located within the bolted horizon, it is important to test each layer for moisture-sensitivity. Mining height may change and high places can be cut to remove moisture-sensitive units.

This correlation of rock testing and roof deterioration indicates that the cycling moisture-sensitivity test is valuable as an indicator of potential roof deterioration. It may be used to design increased surface

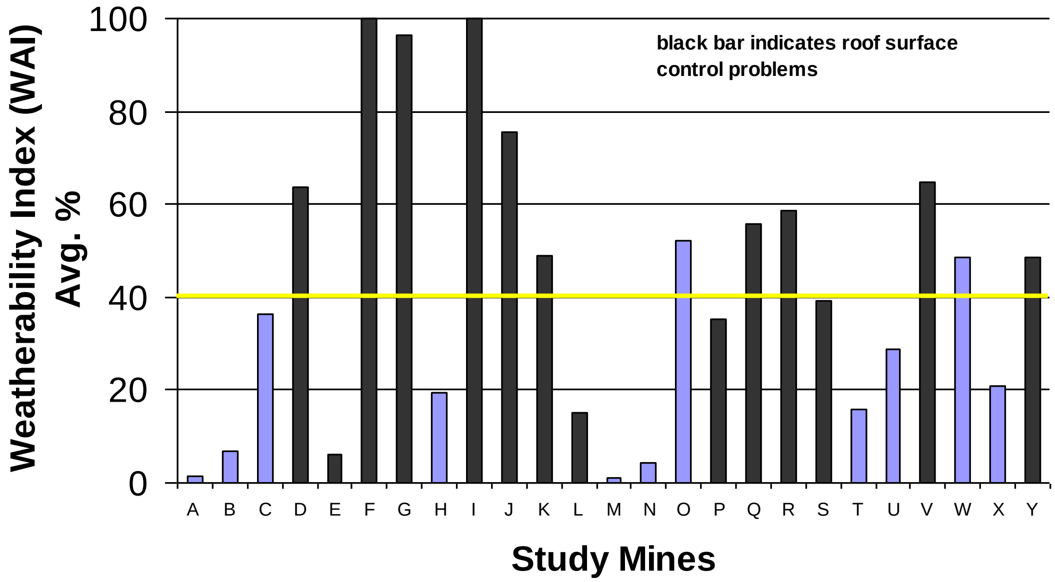

Figure 10: The average moisture sensitivity for each of the study mines.

coverage and supplemental support, especially for long-term openings.

Case Studies

Two case studies presented below, one in western Kentucky and one in West Virginia, show that roof rocks that tested as highly moisture-sensitive correlated well to mapped zones of roof deterioration.

Study Mine A – This mine works the #9 seam in western Kentucky. The roof is a two-component roof consisting of 0.5-2 ft of black shale overlain by 30-50 ft of gray shale. The Weatherability Index (WAI %) for the roof rocks is as follows:

Black shale = 8.3% Gray shale = 70.5%
(* Note: Higher values indicate more moisture-sensitivity; up to a maximum of 100%.)

Typically the black shale forms the immediate roof. This rock is brittle, thinly bedded, and susceptible to horizontal stress, but does not slake with humidity. In western Kentucky it is well known that the black shale over the #9 seam must be maintained or serious deterioration will occur in the overlying gray shale. In this case, the mine cut out the black shale in one location along the travelway in order to increase roof height. The gray shale was exposed and weathered badly within 6 months (Figure 11). Two to four ft of roof sloughed off around the bolts creating loose roof slabs. By contrast, in the adjacent crosscut, the black shale was maintained and showed no signs of deterioration. In the crosscut

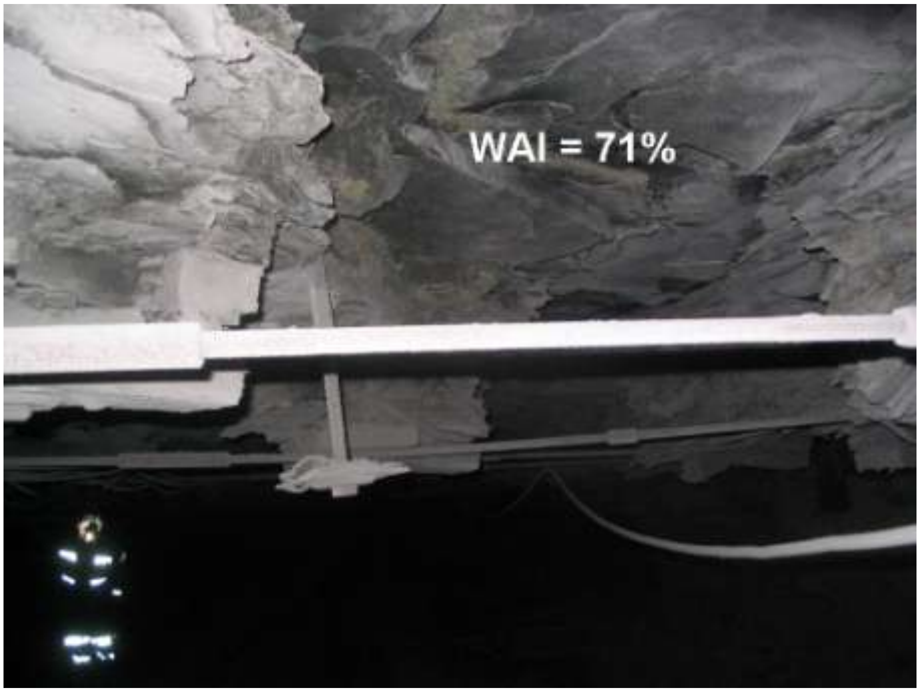

Figure 11: Gray shale roof in a mine in western Kentucky weathers badly when protective black shale is removed by mining.

the highly moisture-sensitive gray shale was shielded from humidity exposure and effectively sealed by the non-reactive black shale.

In places in the older areas of the mine, the black shale has sagged and has begun to deteriorate due to bed separation. If this deterioration progresses the gray shale may become exposed and result in a time-dependent roof fall.

Study Mine B - This mine works the Sewickley seam in northern West Virginia. There are two types of roof:

1. 6-12 ft of black shale overlain by 15+ ft of massive sandstone. This roof is a uniform clay-rich, highly organic, black shale which is well-jointed. It usually makes a good roof rock in the Sewickley seam.

2. 2 ft of gray shale coarsening upward to a stackrock and then to a massive sandstone. The sandstone moves up and down relative to the roof and occasionally sits right on the roof. There is a distinct relationship between the immediate roof rock and the flatness or irregularity of the roof line. Where the black shale is intact the roof is flat and even. Where the gray shale is exposed the roof is potted and uneven. Figure 12 shows the mine outline along with the roof rock type. Roof condition mapping has been conducted in intersections in various locations along the travel road. The following mapping system estimates the amount of sloughage relative to the roof line.

The mine had to rehabilitate old works to establish the mains. The mine drove through 50 yr-old works (location A) where the roof was the moisture-sensitive gray shale. Eighteen to 20 in of shale had sloughed away and the roof had to be rebolted. Roof conditions continued to deteriorate as the roof transitioned into the black shale around crosscut #29. Conditions improved dramatically after the transition to black shale (location B). The roof rating was consistently a 1 (which correlates to 0-2 in sloughage and good conditions), with original miner bits visible on the flat roof (Figure 13).

Between crosscuts #61-65 the roof begins to transition back to the gray shale. Roof falls occur in this transition, and the roof gets dramatically worse as the black shale feathers out to gray shale (location C). Twelve inch roof pots become common with some extending to 24 in high. Weathering is extreme and the roof drips in the summertime due to high humidity (Figure 14). The mine air remains humid until about crosscut #120 when the air loses its moisture and is finally tempered. The gray shale, if wet, deteriorates in a matter of weeks. If kept dry it will last a few months, but then eventually will also deteriorate.

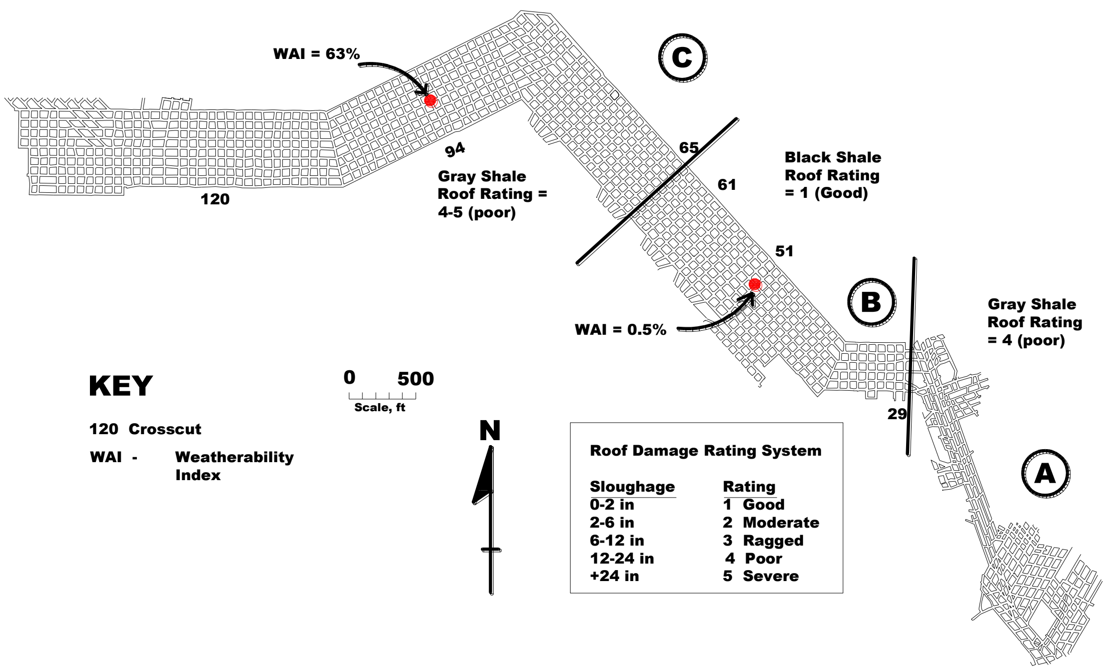

Figure 12: Study mine in northern West Virginia showing good roof conditions in the black shale and poor roof conditions when the gray shale is exposed.

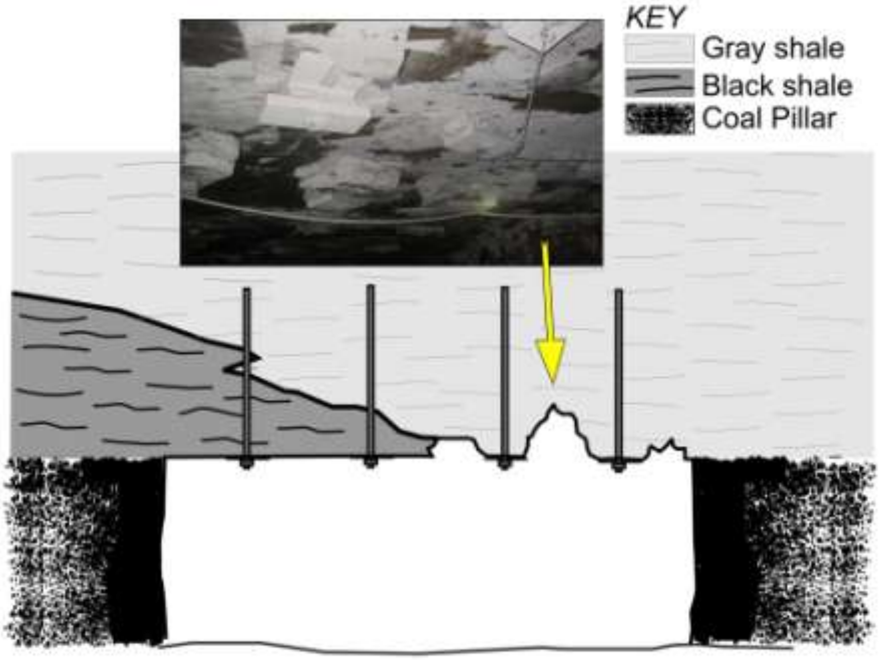

Figure 13: Roof condition is excellent in black shale and deteriorates when gray shale is exposed.

Figure 14: Pinchout of black shale leaves moisture-sensitive gray shale exposed.

Samples of roof rock were moisture-tested in both the black shale (crosscut # 51) and gray shale areas (crosscut # 94) (Table 2). The average moisture-sensitivity of the black shale is .5% (n = 23), and it is essentially un-reactive. Even though this rock is well-jointed, providing good water access, the rock remained intact. The gray shale averaged 63% (n = 8) Weatherability index. Another sample of gray shale collected on an inby active face averaged 52% moisture (n = 16). Both of the samples are above the 40% Weatherability index, a reading which indicates that slaking and scaling is a possibility. In this mine, roof weathering closely correlates with moisture-sensitivity values of roof rocks measured in the lab, indicating that the test can be a reliable indicator of potential roof deterioration.

Table 2: Moisture-sensitivity of roof samples.

Rock type	Mine location	Weatherabililty Index (WAI)
black shale	Crosscut # 51	.5%
gray shale	Inby face	52%
gray shale	Crosscut # 94	63%

The protective value of the black shale in this mine is similar to the value of head coal in protecting overlying moisture-sensitive shales. It is well known in the Pittsburgh seam in the northern Appalachian basin that head coal (6-12 inches) must be left to protect the highly reactive gray shale above. Where this is not done extreme potting due to weathering has occurred. The organic content of the head coal and black shale make them relatively un-reactive to moisture.

Controlling Moisture-Sensitive Roof Rocks

Identifying the moisture-sensitive rock is the first step to controlling the problem. Exploration core drilling and testing of roof rocks can define their swelling properties. Unfortunately data from widely spaced drill holes can be insufficient to characterize an entire property. Changes in roof rock and moisture-sensitivities can occur over short distances. Routine sampling and testing of mine roof as entries are developed will provide the density of data needed to map the roof and project trends of moisture-sensitive roof.

Upon defining the zone of potential deterioration, a number of solutions exist to control it. First to consider is the removal of the offending roof strata. If dilution can be tolerated, and the stratum is not too thick, additional mining height can be achieved by removing the rock. Conversely, if head coal can be left, or a protective organic shale can be left as a protective cap, the sensitive shale can be sealed from the humidity.

The use of air-tempering chambers has been successful in the past in removing humidity from mine air as it was redirected through old workings (Sames, 1985). More recently, air-conditioning was used successfully to remove humidity from intake air by dropping the temperature of outside air to within 4 degrees of ambient mine temperature (Laswell, 1999).

If moisture-sensitive roof rocks cannot be removed or protected, they must be supported. Support of moisture-sensitive roof often boils down to surface control. Weak, swelling shales often fall between roof bolts without transferring any load to the roof bolt. Roof potted after bolting may indicate that surface control is inadequate. The design of surface control should consider the bedded nature of the rock. If the rock is a well-bedded shale with persistent bedding, it is more likely to form a beam and transfer load to the bolts or stay intact between bolts. If the rock has disturbed bedding and falls in lumps, full surface control should be considered. Surface support comes in many products including large bearing plates, pans, header boards, straps, and channels. Screen provides, by far, the most surface coverage and protection of all. Simply put, more coverage is better.

Study Mine C

Several Midwestern coal mines have had great success in reducing rock fall injuries through the installation of roof screen. Study mine C is located in central Illinois. It mines the Herrin #6 seam, under 300-350 ft of cover. The roof rock consists of 0-6 ft of weak, laminated shale, overlain by thick, weak gray shale. Both of these rock types are extremely moisture-sensitive.

The laminated shale averages 89.1%, and the gray shale 91.4% on the Weatherability index. The laminated shale begins to deteriorate within weeks after mining and can be easily broken by hand. Extreme roof potting and deterioration has occurred in an area near the intake shaft after 4 years exposure (Figure 15). This area is currently impassible due to roof and rib deterioration. This roof was not screened for operational reasons. Immediately adjacent to this area is roof that is 14 years old but was screened on cycle. The screen is heavily loaded, but the roof has stayed intact and the entry is passable (Figure 16). The effects of aging and extreme weathering of the roof have been mitigated by roof screen.

Figure 15: Extreme roof deterioration in moisture-sensitive shale at an Illinois coal mine.

Figure 16: Heavily loaded roof screen preserves roof integrity.

Because of the extreme moisture-sensitivity of the immediate roof rock, the roof is screened rib to rib.

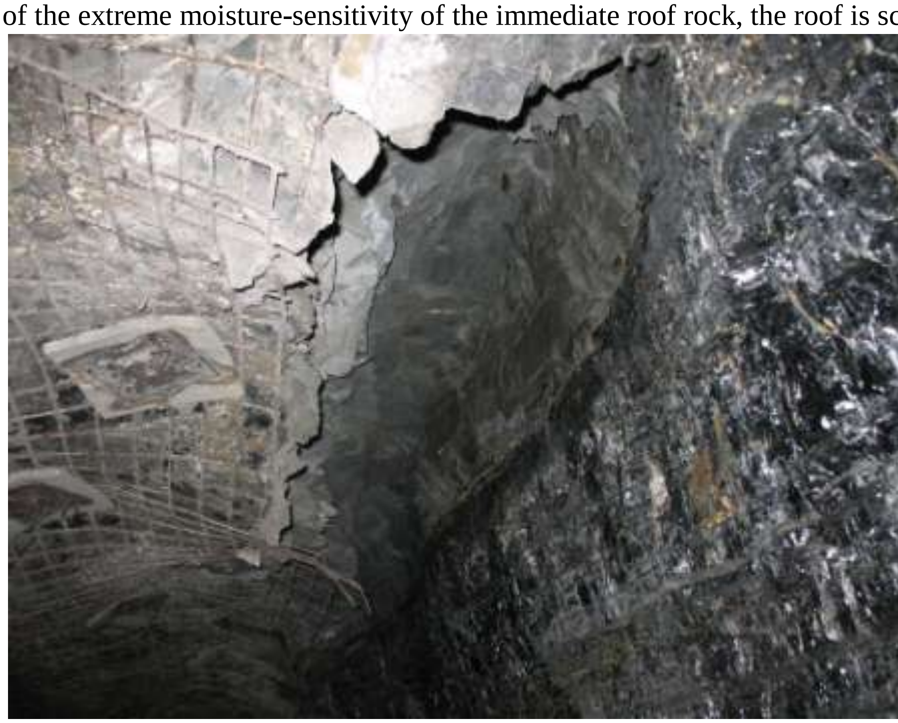

Figure 17: Exposed corners in wide entries can lead to guttering and eventually roof fall.

This preserves the roof-rib corner from cutting and progressive guttering. Where the entry is inadvertently cut wide or the rib sloughs, the corner is exposed beyond the reach of the screen. Once exposed, the corner begins to gutter and unravel (Figure 17). This corner failure has lead to roof falls. The mine has solved this problem by extending roof screen around the corner and down the rib (Figure 18). Since the inception of roof screening in 1994, the mine has dramatically cut injuries due to rock fall (Figure 19).

Figure 18: Full screening down the rib protects exposed corners and prevents rock falls.

This case study provides an example of where screen may provide a support benefit other than surface control. Much like the skin of a pillar provides confinement and strength to the pillar core, steel screen may act to confine roof layers and prevent the progressive delamination which can lead to a massive roof fall. Once rock has loosened and begins to load the screen, the weight of the rock is then transferred to the roof bolts providing active support, instead of falling out between bolts.

The application of cementatious or rubber-based sealants can protect rocks in intakes, shaft bottoms, or long term travelways. Cementatious sealants can also provide some strength and support for long-term sag as well as sealing the rock to the humidity. The application of a cementatious roof sealant preserved the integrity of several hundred feet of track entry in a northern West Virginia mine while the adjacent belt entry experienced 15 roof falls (Mark et al, 2004). The exposed, highly reactive, clay shale deteriorated so badly that the belt entry could not be maintained and the mine was closed.

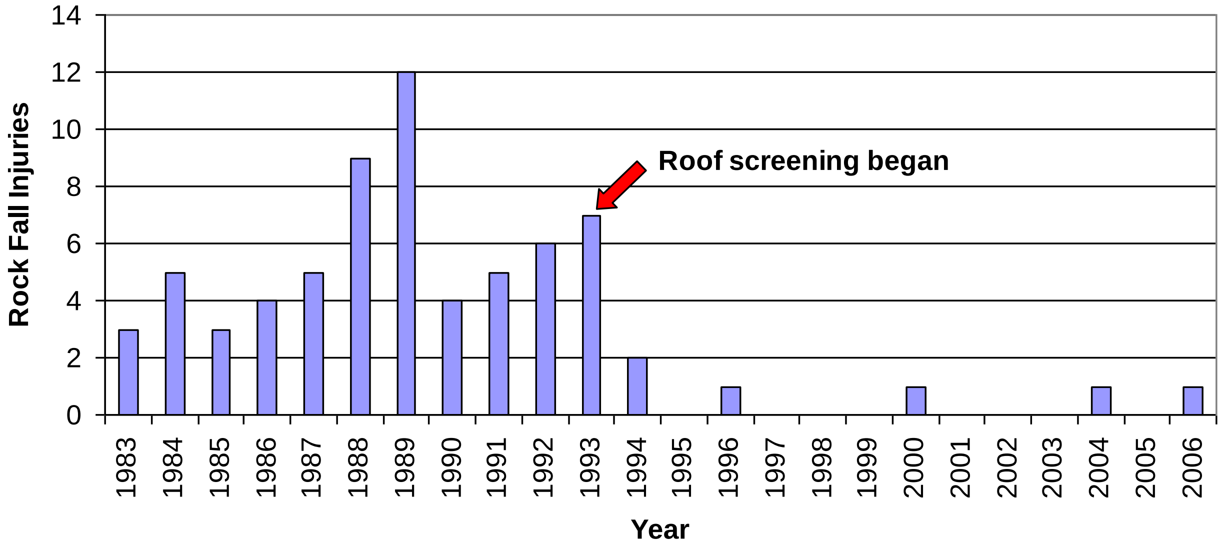

Figure 19: Rock fall injuries dropped dramatically when an Illinois mine began to install full roof screen.

CONCLUSIONS

Moisture-sensitive shales are the cause of numerous injuries due to deterioration from wetting and drying caused by seasonal humidity changes. To address this problem, a test has been selected which uses a wetting and drying cycle to best approximate the seasonal humidity changes in coal mine roof. A database of moisture-sensitive shales has been compiled from roof rocks in major U.S. coalfields. Roof rocks with a weatherability index of 40% and above are susceptible to deterioration. Fireclays have been shown to be the most moisture-sensitive rocks. These rocks can begin to deteriorate within weeks of exposure if subjected to high humidities in the summertime. While the precise standup time of roof rocks remains difficult to determine, it may be important to consider high surface coverage and denser support for rocks that exceed 40% in Weatherability index. Data shows that irregularly-bedded shales are generally more moisture-sensitive. Due to the wide variability possible in shales, it is important to test samples to better define sensitivity.

Two case studies are presented that show gray shale roof with high Weatherability indexes deteriorated when exposed to mine humidity. Both mines had black shale roof which, when present, protected the sensitive gray shale and preserved the roof integrity. Black shales have generally lower moisture-sensitivity indexes and often serve to seal humidity away from overlying reactive rocks.

It is important to identify these reactive rocks with regular testing in order to determine the best control method. Control methods include removal of reactive rocks, and installation of high coverage supports including plates, straps, and screen. Screen has been highly successful in reducing injuries and roof falls.

Disclaimer

The findings and conclusions in this report have not been formally disseminated by the National Institute for Occupational Safety and Health and should not be construed to represent any agency determination or policy.

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