IDENTIFYING MOISTURE SENSITIVE ROOF ROCKS IN COAL MINES

Gregory M. Molinda, Research Geologist
David C. Oyler, Mechanical Engineer
NIOSH-Pittsburgh Research Laboratory
Pittsburgh, PA, USA

Hakan Gurgenli, Graduate Research Assistant
University of West Virginia
Morgantown, WV, USA

ABSTRACT

Historically, miners have known that roof rocks originally composed largely of mud were prone to slaking and deterioration when exposed to water and humidity. Mine Safety and Health Administration (MSHA) records show that roof falls are more prevalent in summer and late fall. Field data shows higher bolt loads and increased room convergence in summer months. Laboratory data shows that very high internal pressures can be generated by significant strain in clay-rich rocks. In summer months humidities ranging from 70-100% can cause rock strains up to 7%, and rock pressures of 14,000 psi, more than enough to break apart weak shales and fireclays.

The National Institute for Occupational Safety and Health (NIOSH) conducted wet/dry immersion cycling of clay-rich rocks. Results show that the rocks most prone to moisture deterioration are fireclays, claystones, and sandy shales, all of which have disrupted bedding. Of the 7 mudrocks with a weatherability index above 40%, none showed consistent fissile bedding. Black shales were surprisingly resistant to wet/dry water immersion cycling. Generally, mixed rocks (stackrock), typically susceptible to horizontal stress, are more resistant to moisture-deterioration. Mine roof rocks tested with moisture sensitivity ratings above 50% (moisture sensitivity index ranges from 0-100 with 100 being the most sensitive) all came from mines which had roof skin problems and used supplemental support to prevent rock fall injuries. Some roof rocks showed lateral variability of moisture sensitivity values, suggesting the need for more samples in highly varying roof rocks. Swelling strains of mudrocks showed that almost all of the swelling occurred in the first 24 hours after immersion. The wet/dry immersion cycling test used provides an accurate, quick and inexpensive method for estimating the moisture sensitivity of mudrocks. With this information mine operators can begin to anticipate hazardous ground and prepare appropriate roof support.

BACKGROUND

Mudrocks are generally composed of both clay and silt-sized particles and are the result of deposition in quiet standing water, interrupted periodically by flooding and clastic inflow (Krumbein and Sloss, 1963). Approximately 80% of all sedimentary rocks are shales or mudrocks (Krumbein and Sloss, 1963). Mudrocks are also very common in rock sequences forming the roof of coal mines. Since clay minerals are relatively weak, it generally follows that mudrocks, lacking contact quartz grains and siliceous cement, would also be weak (Molinda and Mark, 1996). Weak mudrocks contribute heavily to roof falls and roof fall injuries. In one study the roof fall rate was higher for weak rock than for stronger rock as defined by the Coal Mine Roof Rating (CMRR) (Molinda et al., 2000). One of the factors which make mudrocks particularly weak is their susceptibility to degrade on contact with moisture. Numerous studies have shown that some roof shales degrade when in contact with humid mine air (Aughenbaugh and Bruzewski, 1973; Conrad, 1936; Cummings et al., 1983; Cummings and Singh, 1981; Fletcher and Cassidy, 1931; Haynes, 1975; Herbert, 1940; Holland, 1956; Huang et al., 1986; Lucas, 1975; Sames, 1985; Unrug and Padgett, 2003). Although some shales may be completely unaffected by moisture exposure, the MSHA typically issues alerts when summer is approaching to warn of roof of instability related to moisture deterioration. The number of rock fall injuries was 15% higher in June, July, August, September and October for the time period 1995-2004 than the annual average for that same time period (MSHA, 2004) (figure 1).

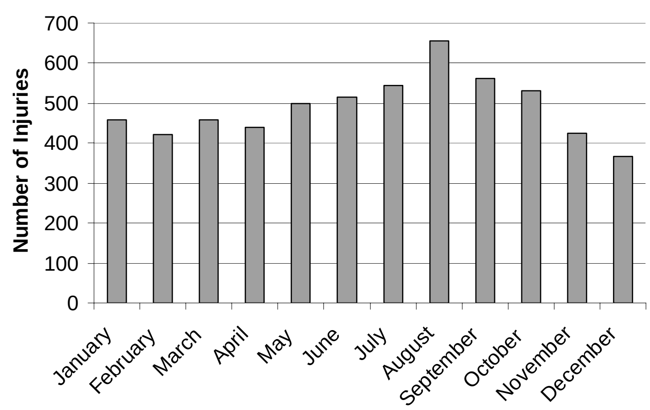

Figure 1. Rock fall injuries increase in humid months (1995-2004).

Shale deterioration is not only a skin control problem, but may lead to weakening in the rock mass and large scale roof falls. In one study mine, roof falls were much more frequent in August than any other month (Mark et al., 2004). Stateham and Radcliffe (1976) report that the frequency of roof falls is related to absolute humidity and lags it by 14 days. This is an indication of the average amount of time needed for humidity to act to deteriorate rocks and cause a roof fall. Some mudrocks are largely stable through time and moisture exposure, and some are highly sensitive to moisture. Swelling clay minerals can absorb water rapidly and generate pressures which 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. A NIOSH study has documented the distribution of roof falls in a West Virginia mine. In this mine, numerous falls continue to occur up to 6 years after roof exposure (Mark et al., 2004). The CMRR recognizes the danger of slaking roof rocks by degrading the CMRR as much as 15 points.

Numerous studies show that it is the cycling of wetting and drying that occurs with seasonal weather changes that causes rocks to deteriorate. Some shales will not weaken significantly 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 causes weak shales to "rain rock" in beltways, travelways and other outby areas.

Other studies have focused on the changes of mechanical rock properties as rocks are exposed to moisture. Aughenbaugh and Bruzewski (1976) report confined swelling pressures of 4,000 psi regularly and up to 14,000 psi developed in humidity tests on shales. Kelly (1969) reports swelling pressures of approximately 5,000 psi, well beyond the tensile and compressive strength of many shales. Shale samples were found to lose weight when subjected to low humidities and gain weight at high humidities (>80% relative humidity), indicating moisture absorption and increased pore pressures. Expansion of claystone samples reached 7% at 100% humidity and samples actually shrunk (contraction) at 0% humidity. At lower humidities (<70%) swelling strains were greatly diminished (Cummings and Singh, 1981). Fireclays and claystones represent "overcompacted" rocks which 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 mudrocks, black shales and gray shales, are stronger and not overcompacted and are more stable. Chugh and Missavage (1980) compiled data from several investigators and report that even in sandstones, unconfined compressive strength (UCS) and modulus were reduced by as much as 75% from the original values when rocks were subjected to immersion or humidity changes (Fabjanczyk and Gale, 1999). Matsui et al., (1996), and Zhang et al., (2004) also reported a significant reduction in UCS with increasing moisture content. Bauer (1980) reports UCS values of oven-dried samples were 2-3 times greater than rocks saturated 100% with water. Aughenbaugh and Bruzewski (1973) found that average sclerscope hardness and fracture toughness decreased with increasing relative humidity.

Time dependent deterioration of mudrocks can be seen in the corebox. Unrug and Padgett (2003) showed that RQD averages a 42% decrease as time increases 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 Eeckhout and Peng, 1975).

There are a number of mechanisms which have been offered to explain the failure of mudrock with moisture exposure. These include secondary mineralization, chemical deterioration, pore pressure increase, frictional reduction, fracture energy reduction, and capillary tension increase (Van Eeckhout and Peng, 1976). As rock is unloaded, i.e., stream valley downcutting, tunneling, or mining; relaxation causes internal tension and opening of new fractures or movement adjacent to existing ones. At a large scale, the tension cracks are seen as hillseams, and at a smaller scale, relaxation of slickensides occurs, causing expansion of rock masses and opening conduits for moisture. Seismic wave velocity increases away from the walls of tunnels, indicating that weaker, fractured rock has moved in response to lower confinement (Duncan et al., 1968), with the effect diminishing away from the opening. With this opening of the rock mass, water conduits are created allowing exposure to mine air and rock deterioration. Water is drawn into the rock by the action of strong capillary forces which compress air in its path, resulting in disruption of the rock (Anwar et al., 1999).

Seedsman (1986) identified two mechanisms for the swelling of shales when immersed in water; 1) compression of entrapped air and 2) osmotic swelling. If muds are exposed to air and dry, shrinkage causes tension cracks to form. As the water evaporates it is replaced by air. When water is reabsorbed by shale during burial, air is trapped and compressed in capillary openings causing more tensile stresses and rock deterioration (Holland, 1956). In the lab, samples with high quantities of montmorillinite generally show the greatest volume change. In the field, roof rocks with high quantities of montmorillinite have been associated with bad roof (Holland, 1956). The presence of expansive clay minerals is only part of the answer since rapidly deteriorating mudrocks are also known which contain no expansive clay minerals. Holland found that only one of 38 roof shales from southwest Virginia, Illinois, and Indiana had detectable amounts of montmorillinite. 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 and Missavage, 1981). This may well be the more important mineralogic source of swelling. Although some of these mechanisms remain the subject of debate, the outcome is still the same; mudrocks deteriorate with exposure to moisture.

There is abundant evidence that undermined coal measure roof rock masses respond to changes in humidity in mine air (Unrug and Padgett, 2003). Cripps and Taylor (1981) reports 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. Carboniferous rocks which begin to "weather," show marked reductions in modulus and failure transitions from brittle to plastic. Depending on the composition, this "weathering" can take place in the real time between excavation and roof fall (0-6 yrs), and beyond.

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 also occurred by rock fracturing between bolts with no prior bolt loading, also due to bulk swelling. This indicates that 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) reports 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 heave of floor members. Cummings found roof convergence to be seasonally related; increased convergence in summer and decreased convergence in winter (Cummings and Singh, 1981)

Aughenbaugh and Adam (1980) found that holes drilled into samples to simulate open roof bolt holes greatly facilitated access to moisture. This indicates that open holes, even when protected by roof plates, may provide excellent conduits for moisture. Moisture also moves much more readily along bedding planes than perpendicular to it. Young's modulus and Poisson's ratio of shales increased rapidly perpendicular to bedding as compared to parallel to bedding. Van Eeckhout and Peng (1975) likened this to adding water between the cards in a deck and compressing it. The deck has swelled more perpendicular to bedding and thus deforms more in that direction, indicating that moisture has infiltrated parallel to bedding. In mine openings this can translate into roof bulking and sag.

Recent data shows an unexpectedly high percent of fully encapsulated resin roof bolts have lost resin to the rock mass (Compton and Oyler, 2005). When roof bolts were inserted under high pressures (5,000-6,000 psi), overcoring showed resin injected into both vertical joints and horizontal bedding planes. Uphole loss of resin can result in several inches to several feet of open hole at the bottom of the roof bolt. In moisture-sensitive rock, this exposure may result in unraveling from the roof line upwards.

A rock classification which characterizes the swelling potential of shales was proposed by Huang et al. (1986). The model uses the Moisture Activity Index because of its close association with other physical properties and because it can be defined by simple laboratory testing. Mudrocks were subjected to varying amounts of humidity and the subsequent weight gain was measured and used as an index to describe the swelling capability of various mudrocks (Huang et al., 1995). Using the Moisture Activity Index, the plasticity of shale, the configuration of particle arrangement, and the percent weight of clay size particles, shales are partitioned by their response to low, medium, and high humidities. The swelling pressure and strain are predicted for stable, mildly susceptible, and moisture sensitive shales. Olivier (1979) related Duncan free swelling values and uniaxial compressive strength to generate a "geodurability" classification which groups rocks into categories from very low strength to very high strength. With this relationship, the swelling potential of mudrocks may be related back to the unconfined compressive strength. Other work documents efforts to evaluate index tests which would aid in the prediction of moisture-sensitive roof rocks. Shakoor and Sarman (1992) measured 13 mudrock properties to determine if swelling properties could be predicted. He developed a "swelling property index" broken into 5 categories and based on combinations of the 13 properties, including grain size distribution, clay content, clay mineralogy, texture, absorption, adsorption, Atterberg limits, specific gravity, density, slake durability, compressive strength, volumetric increase, and swelling pressure.

There is convincing evidence, both in the laboratory and in the field, to show that some mudrocks can be highly reactive to moisture exposure. This exposure can lead not only to hazardous roof skin failures but to large roof falls years later. NIOSH is undertaking a two part investigation into the problem of moisture sensitive shales. The first part is a program of rock testing to identify moisture sensitive mudrocks. The second part will correlate these rocks to roof falls and roof damage in order define the expected standup time for purposes of mine planning and roof support design.

The ability to accurately predict the long term stability of common mudrocks would be a valuable tool for mine design and planning. If moisture sensitive rock types can be identified, a number of roof controls may be considered. These include leaving head coal to seal off moisture, taking down sensitive drawrock, installing additional support necessary to prevent time dependent falls, and applying skin control to prevent injuries.

IDENTIFICATION OF MOISTURE SENSITIVE ROOF ROCKS

As discussed above, there are a number of ways to attack the problem of identifying moisture sensitive rocks. These approaches have included, measuring the capacity of the rock matrix to absorb moisture, tracking the change in mechanical properties of rocks with humidity changes, and measuring the fractions of swelling clays which may contribute to rock deterioration (Shakoor and Sarmon, 1992; Zhang et al., 2004; Bauer, 1980). For this study NIOSH is focusing on utilizing a practical index test which will provide an estimate of the deterioration of common roof rocks with exposure to moisture. An index test can often provide the desired measure of a rock property in a relative sense. If rock deterioration is the property of interest, then a test which measures it directly may be a valuable tool for support design.

NIOSH has begun testing roof rock using the wet/dry cycling test developed by Unrug (1997). This test simulates the exposure of roof rocks to the seasonal humidity changes in mine ventilation air. Exposed core was subjected to a cycle of immersion in water for one hour and then air dried for six hours. This cycle was repeated 3 times. The weatherability (WAI) Index is then calculated as follows:

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

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

Samples of roof rock were collected from 14 mines from various coal basins around the U.S. (figure 2). Lump samples from roof slabs were also tested. Figure 3 shows the distribution of water sensitivities for 26 common roof rocks. The rock types are distinguished using the Ferm rock classification system (Ferm and Smith, 1981). Rock numbers and descriptions are included in the Appendix. The Ferm rock classification system is based on a number of rock properties including bedding fracture, mineralogy, grain size, color, and inclusions. It is intended to provide a numeric value to aid in the field distinction between rock types. The continuous variation of the above properties means that the Ferm classification can provide only an approximation of the actual rock type. The values are plotted as an average for each rock type. Roof rock moisture sensitivities ranged from completely unreactive to complete disintegration of the sample. In some cases this occurred in only 60 seconds. Figures 4 and 5 show samples before immersion and after immersion. Significant deterioration has occurred after three cycles of wet and dry.

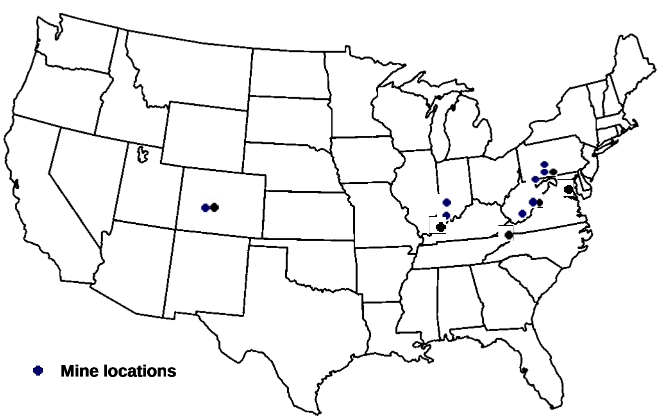

Figure 2. Weatherability samples were collected from roof rock at the above mine locations.

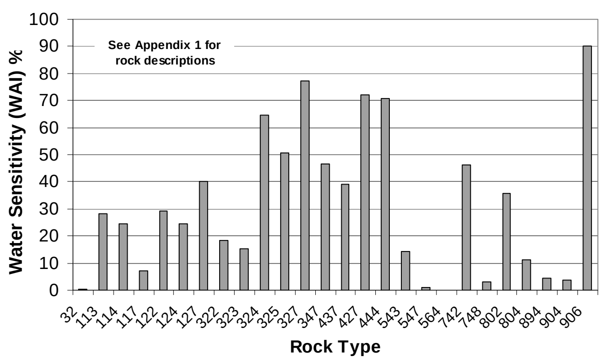

Figure 3. Average water sensitivity (WAI) of rock samples identified by Ferm numbers.

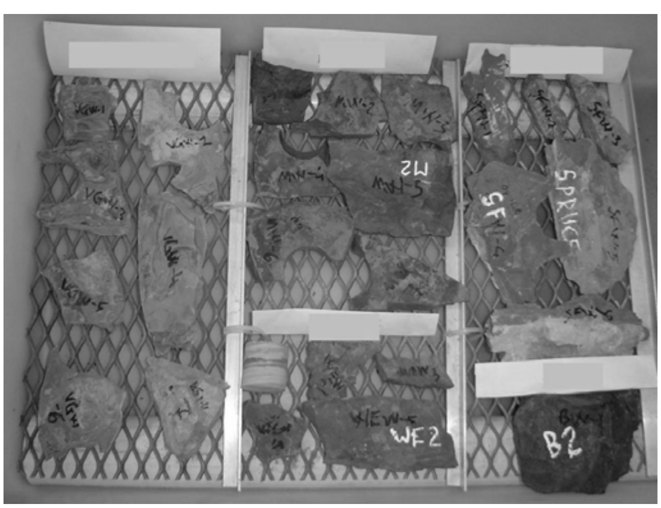

Figure 4. Roof samples before water immersion test.

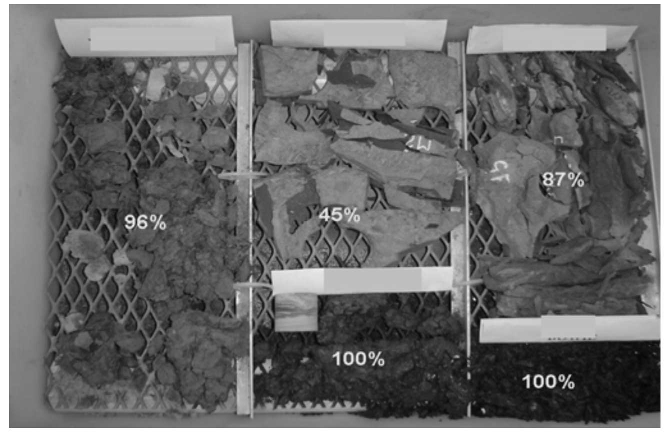

Figure 5. Roof samples after water immersion test. Water sensitivity values (WAI) are attached showing extreme deterioration (WAI = 100%).

Of the rocks tested, the most water sensitive rock types are the mudrocks. The term "mudrock" is here used to group rocks which consist predominantly of clay minerals (Krumbein and Sloss, 1963). These include: sandy shale (324, 325), dark gray sandy fireclay (327), sandy claystone (347), sandy fireclay with limestone nodules (437), dark gray sandy fireclay with limestone modules (427), and gray fireclay (127). All of these rock types had a water sensitivity of 40% or above (figure 3). For clarity, the various rock types have been consolidated into groups based on rock fabric and mineralogy (figure 6). Of the 6 rock types, fireclays and sandy shales were the most water sensitive.

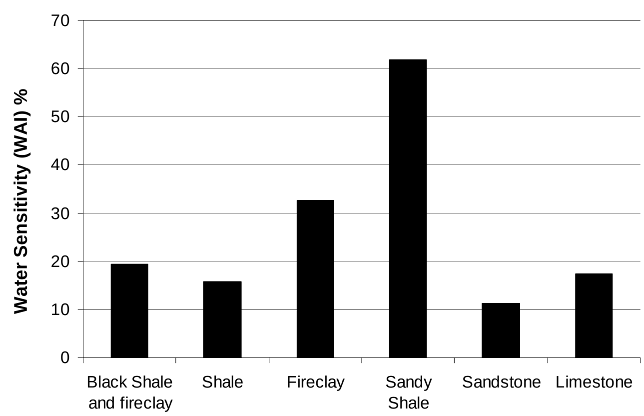

Figure 6. Moisture sensitivity of coal measure roof rocks.

The feature which is common to all of these rocks is that they all have some degree of disturbed bedding. Ferm distinguishes fireclays and claystones as having an "irregular fracture or irregular streaks" and sandy shale as having a "massive or uniform" structure, essentially lacking fissile bedding. It appears that it may be this irregular bedding which is most common to the water sensitive rocks. Clay minerals have a phyllosilicate, or platy structure. This platiness gives the shale its flat or fissile bedding. Flat bedding may act as a barrier to vertical water infiltration, allowing transmission of water along bedding, with transmission across bedding more difficult (figure 7). When bedding is disrupted due to rooting, burrowing, or overcompaction, water can more easily moved by capillary action across bedding (figure 8). This progressive infiltration may allow the exposure of swelling clays and begin the deterioration of the rock mass (figure 9). Rock falling between bolts provides no load transfer to the bolts.

Figure7. Water moves more readily along bedding than across bedding.

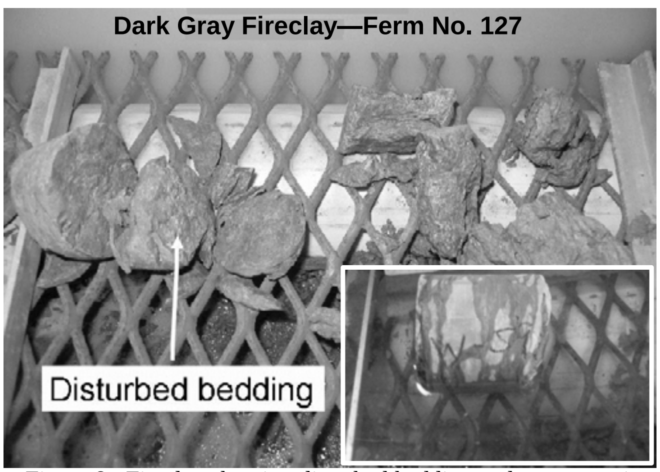

Figure 8. Fireclay showing disturbed bedding and water moving easily across bedding.

Figure 9. Water sensitive rock falls around bolts in an Illinois coal mine.

In addition, many of the water sensitive rock types we tested also have a sandy component. Unlike "mixed rocks" which have alternating layers of sandstone and shale to act as barriers to water infiltration, sandy shales have sand "floating" in a matrix of clay. This matrix is disturbed compared to fissile bedding.

The bedding of each rock sample was classified prior to the wet/dry cycling test. The bedding ranged from the flat fissile bedding of a quiet water lagoon deposit to the highly slickensided, chaotic bedding of a rooted underclay. Figure 10 shows that disturbed and massive unbedded rocks were the most water sensitive. The water sensitivity test utilizes a wet/dry cycling tank to simulate the seasonal change that roof rock may be subjected to from ventilation air. Fireclays can be over-compacted, and perhaps the repeated swelling and shrinking can have a cumulative effect that weakens the rock fabric. These rocks are often weak to begin with and cannot take much stress on the disoriented and disturbed rock fabric. This can result in a progressive failure leading to rock falls between bolts.

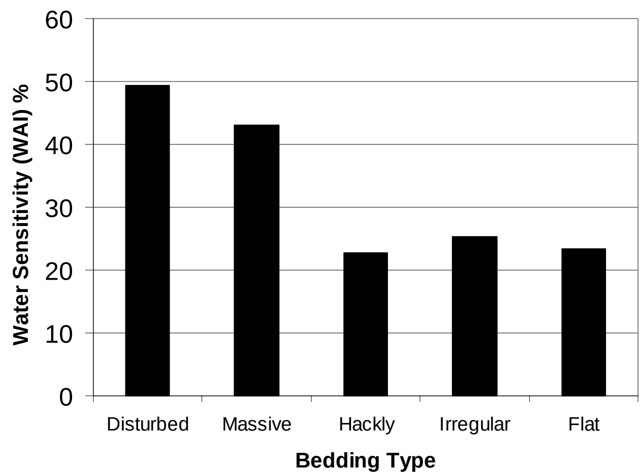

Figure 10. Disturbed and massive bedded rocks are the most water sensitive.

Sandstones and limestones are usually the least moisture reactive rocks due mainly to their inert mineralogy. Black shales and black fireclays are relatively non-reactive (figure 6). Holland (1956) cites data that show that rocks containing organic compounds like fatty amine acetate were less plastic, shrink and swell less, and are more resistant to swelling. Coal and bone coal are commonly used to protect moisture sensitive mudrocks in the roof above.

In order to identify the most reactive rock types, the proportion of samples tested of each rock type with a water sensitivity (WAI) greater than 75% was calculated. Figure 11 shows that the sandy fireclays, claystones, and sandy shales tested have 30-50% of their samples in the highest quartile of water sensitivity (>75% WAI). While showing some variability within a rock type, these data may suggest which rock types should be identified as likely to present problems with long term exposure to moisture. While data on the long term standup time of various rock types is not yet available, these test results may indicate that fireclays and sandy shales may deteriorate with long exposure to ventilation humidity.

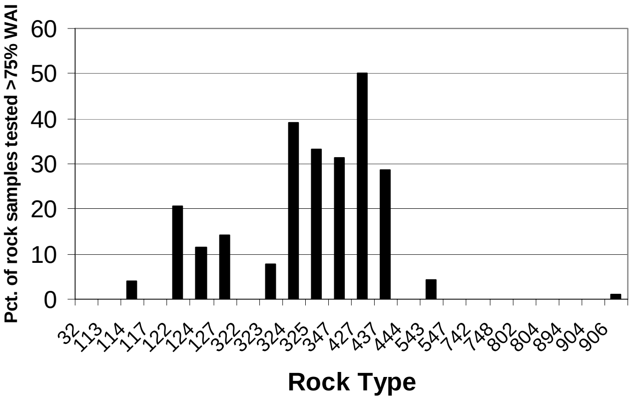

Figure 11. Proportion of rock samples tested for each rock type that had a water sensitivity (WAI) greater than 75%.

SWELLING PROPERTIES OF MUD ROCKS

The deterioration that occurs in the wet/dry water immersion cycling test as described above is primarily due to absorption of water by clay minerals making up the fabric of mudrocks. Water is absorbed into the platy clay minerals, causing swelling and disagregation of the minerals, and subsequent disintegration of the rock.

Swelling strain was measured on roof rock core that was immersed in water. Figure 12 shows sample swelling in strain versus time for four core samples fully immersed in water. The samples were all shales and laminated shales (Ferm 122, 124) from the roof of two coal mines, one in northern WV (A) and one in southern WV (B). These rock types are common to the roof of many coal mines. The data shown are typical for 10 of the 12 samples tested. Most samples showed rapid swelling during the first 8 to 24 hours, followed by either a much reduced swelling rate, or more commonly, a slow reduction in swelling strain over time. The peak strains for the typical samples ranged from -0.1 to .95%, averaging about 0.7%.

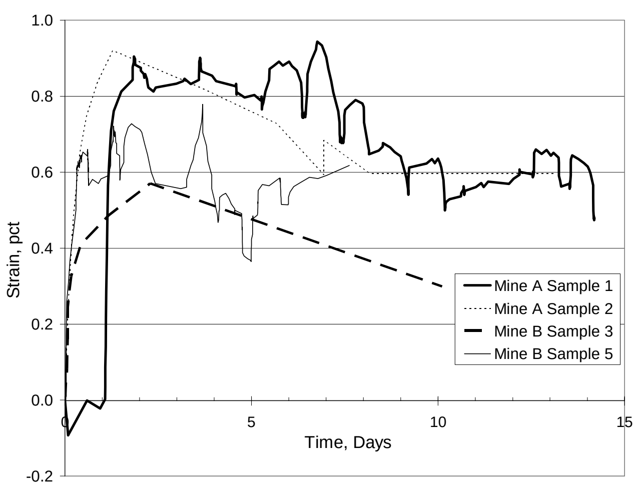

Figure 12. Strain profile of mudrocks shows most swelling occurs in the first 24-48 hours.

The implication is that sensitive rocks react quickly to moisture exposure and may result in scale formation at the face in the humid summer months. The long term implications relate to progressive upward unraveling of the roof. As roof members sag and delaminate with time, tensile fractures open, as well as relaxation on slickensides, and allows pathways for moisture access. Swelling occurs quickly causing more fractures and rock mass damage.

MOISTURE SENSITIVITY AND ROOF CONDITIONS

Samples of roof rocks were collected from 14 mines from various coal basins around the U.S. (figure 2). The wet/dry cycling test was conducted on samples from each mine. Figure 13 shows the distribution of the average moisture sensitivity (WAI) from each mine. Moisture sensitivities ranged from completely unreactive to roof rock which disintegrated to mud within 60 seconds of water immersion. Samples from six of the mines averaged nearly 50% or greater water sensitivity (WAI). All 6 of the mines had significant roof problems related to scaling and slaking. In response, all six mines were using some type of skin control to prevent injuries from rock falls. These controls included full and partial coverage of the roof with steel screen, cyclone fence, and the use of air conditioning to remove humidity from the air before it entered the mine. The mines below the 50% limit generally had less scaling and deterioration problems.

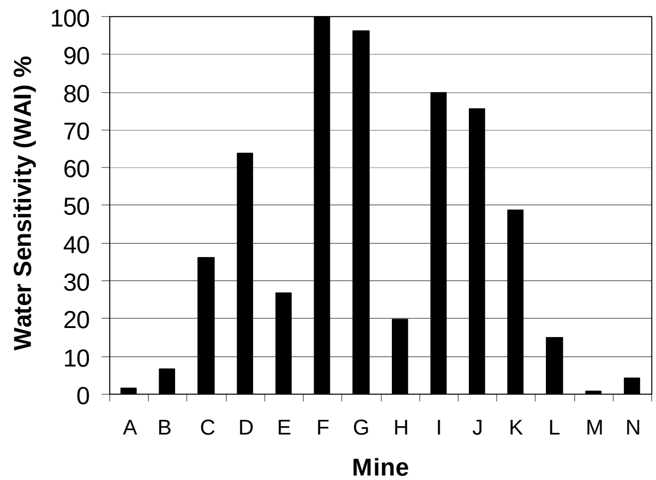

Figure 13. Average water sensitivity (WAI) for roof rocks sampled from selected U.S. mines.

SUMMARY

MSHA accident statistics show an increase in roof falls as well as rock fall injuries in the summer and early fall (MSHA, 2004). NIOSH has also reported significant seasonal deterioration of roof requiring the installation of skin controls

NIOSH has begun a rock testing program aimed at identifying the most moisture sensitive rocks. Moisture sensitivity has been measured using the Unrug weatherability apparatus. This index test simulates the wet and dry cycling which occurs with seasonal changes in humidity. Testing of nearly 400 samples of common roof rocks found that those rocks with disturbed or non-fissile bedding are the most moisture sensitive. These include: sandy shale (324), dark gray sandy fireclay (327), green sandy claystone (347), sandy fireclay with limestone nodules (437), dark gray sandy fireclay with limestone nodules (427), and gray fireclay (127). These data suggest that the mechanism of rock deterioration is at least somewhat related to internal rock discontinuities rather than solely due to the presence of swelling clays. Disrupted bedding allows moisture to move across bedding, finding access to slickensides. More surface area becomes available for wetting and subsequent swelling can break apart weak rocks. Additionally, disrupted bedding does not provide the benefit of lamination beaming and the rock is more easily disaggregated by swelling.

Moisture sensitivity testing of rocks from 14 mines showed that all 6 mines with WAI at or over 50% had poor roof conditions and rock slaking. All these mines were using some type of supplemental support or other remedy to control rock falls. Swelling strains were measured in 12 core samples from two mines in WV. The profiles showed that most of the strain occurred in the first day after water immersion, with rock swelling subsiding quickly afterward. This may suggest that highly moisture sensitive rocks may need to have surface control installed quickly after mining in order to catch falling rock. NIOSH data has shown that installing steel screen on cycle with primary support can significantly reduce rock fall injuries. Roof bolters and CM operators suffer the most rock fall injuries (Molinda et al., 2003). When highly moisture sensitive rocks (fireclay and sandy shale) are encountered, on-cycle surface control provides the most protection for these miners.

The Unrug weatherability apparatus provides a good index test for the deterioration of mudrocks. It correctly simulates the wet and dry cycling which can damage roof rocks.

Remedies to prevent the fall of moisture sensitive roof rock include: covering the strata by leaving head coal, removing the hazardous draw rock, sealing the strata with chemical sealants, conditioning the ventilation air to remove humidity, or using high coverage surface control like straps, pans, or screens. Planning for these controls can best be accomplished when the occurrence of moisture sensitive roof rocks can be projected in advance through routine rock testing.

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APPENDIX

Ferm No.	Rock Description	Ferm No.	Rock Description
32	Bone Coal	427	Dark gray sandy fireclay with limestone nodules
113	Black shale with coal streaks	437	Light gray green sandy fireclay with limestone nodules
114	Black shale	444	Green sandy shale with limestone nodules
117	Black fireclay	543	Gray sandstone with shale steaks, rippled
122	Dark gray layered shale	547	Gray rooted sandstone
124	Dark gray shale	564	Hard massive sandstone
127	Dark gray fireclay	742	Gray shale pebble conglomerate
322	Dark gray shale and interbedded sandstone	748	Gray sandstone with coal spars
323	Dark gray shale with sandstone streaks	802	Layered fine grained shaly limestone
324	Dark gray massive sandy shale	804	Massive fine grained shaley limestone
325	Dark gray massive churned sandy shale	894	Massive fine grained shaley limestone with fossil shells
327	Dark gray sandy fireclay	904	Massive fine grained limestone
347	Green sandy claystone	906	Nodular fine grained limestone