Geology Roof Control and Mine Design

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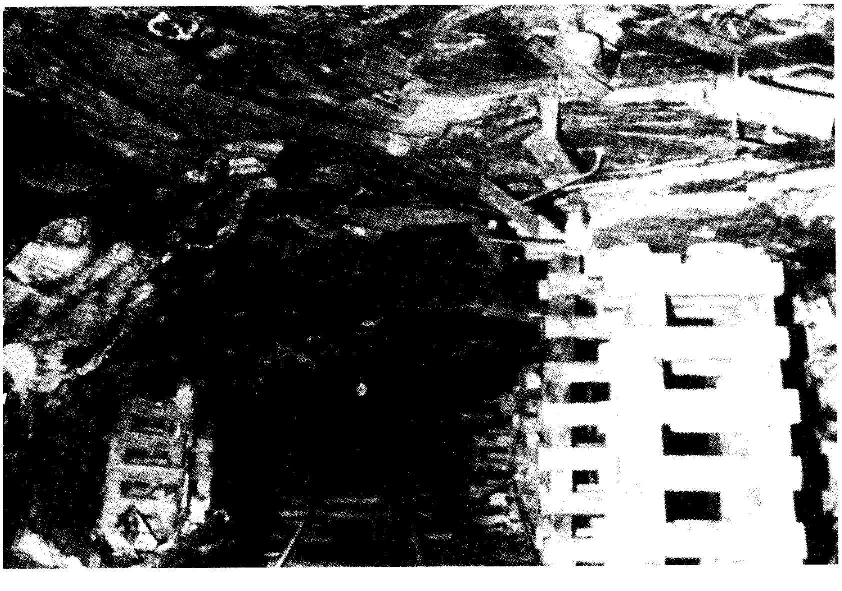
Geology is an integral part of roof control, mine design, and production operations. Yet, the importance of geology, coal/rock as an engineering construction material and its properties and behavior within the planned mine areas, in overall mine production operations has not been fully appreciated.

Of all of the engineering disciplines, mining engineers work with the most challenging construction materials. They must deal with rock materials as they exist in their natural states and design mine structures without well-known and defined properties. Further complicating the design process is the variability of the in-situ rock materials with rock types and rock properties varying widely from place-to-place. Predicting properties in advance of mining is difficult and oftentimes impossible. This is why some types of roof-control failures may suddenly occur in some areas when a single roof-control technique is consistently applied to an entire panel, section, or mine.

UNDERSTANDING THE NATURE OF ROOF GEOLOGY COULD EXPLAIN WHY ROOF CONTROL PLANS SOMETIMES FAIL

Many roof-control techniques are primarily applicable to the geological conditions that were assumed in the development of those techniques and variations of the rock or rock properties may require modification or significant redesign of the support technology.



A highly laminated roof rock weathers around the bolt's bearing plates.

A change in the geologic properties often results in significant variation of the rock behavior that is outside of the original design criteria limits assumed by the original authors in the development of the roof-control techniques. When this occurs, those techniques may not work, and in the worst case, the support system fails. Therefore, it is important to know as much as possible about geological conditions.

ROOF GEOLOGY

Sedimentary in nature, coal seam related rock strata include, in descending order of strength, limestone, sandstone, siltstone (or sandy shale), and shale. Mudstone or claystone are similar to shale without the laminations. The order of strength as stated above is true only when there are no discontinuous features such as bedding separations, fractures, or impurities in the rock strata.

The strength value as determined from standard laboratory testing only applies to the intact portion of the rock. From an engineering design viewpoint, the discontinuities are viewed as defects in the construction materials resulting in an adverse impact on the structural integrity of the system.

Limestones tend to be an extremely strong rock unit with unconfined compressive strengths usually exceeding 15,000 psi and many times approaching 30,000 psi. The consistency of the limestone strata is an important consideration. The strength value is oftentimes significantly reduced by bedding separations and other discontinuous features.

The strength of sandstone formations vary considerably. The composition, size, and shape of the sand particles and the type and characteristics of the cementing agent and matrix all have significant influence on the ultimate strength of the formation. Unconfined compressive strengths may vary from several thousand to in excess of 20,000 psi. Bedding planes, such as cross bedding, inclined bedding, and horizontal bedding, often weaken a sandstone formation. These bedding types are governed by the characteristics of the depositional environment.

Siltstones or sandy shales are similar in strength to sandstones and the ultimate strength depends upon the nature of the composition and presence of discontinuities. Siltstones and shales tend to be more prone to having laminations which are more

Table 1—Representative UCS* data for the four major rock types

Rock Type	Minimum UCS, psi	Median UCS, psi	Maximum UCS, psi
Limestone	6,000	19,000	32,000
Sandstone	2,000	11,000	21,000
Siltstone	2,000	6,000	19,000
Shale	<1,000	4,000	16,000

Uniaxial or unconfined compressive strength

characteristic of the finer-grained sediments. Laminations do not necessarily mean the strength of the rock unit is reduced although in many rock units this is the case.

Shale tends to be the weakest of the four general rock types of interest and is defined by either the materials of the rock itself (predomiantly clay minerals) or the size of the particles composing the rock. While some shales have been found to have unconfined compressive strengths above 15,000 psi, the majority tend to be less than 5,000 psi. A weaker rock than the other three, shales degrade from moisture in the mine air.

The variability of the strength of limestones, sandstones, siltstones, and shales is significant and the range of strengths from one rock type to another overlaps (See Table I). Given this much variability, the mine engineer is faced with the daunting challenge of developing an appropriate design for ensuring the stability of the mine structure without yet considering other important factors.

Identifying these rock types underground is not always easy since the majority of sedimentary sequences tend to grade from one rock type to another. Limestones grade from shaley or sandy to pure limestones and it is difficult to distinguish between the exact classification without laboratory testing. Purer limestones tend to be stronger and when broken have a clean sharp break that is glassy in appearance. The less pure limestones tend to break along planes of laminations. Sandstones are usually fairly easy to identify because of the surface texture and are best described as grainy to the touch. Individual grains can be easily observed and are apparent when handled. Some of the strongest sandstones are crystalline in nature and have a smooth glassy appearance. Siltstones are a gradation between sandstone and shale and in many cases exhibit an identifiable surface texture and the laminations usually found in shales. Siltstone grains are smaller than sandstone grains and the composition of the two rock types may be identical. Shales are composed of grains that are too small to be seen with the naked eye as most are in the size range of silt and clay particles. Many of the shales are soft enough to be easily broken by hand.

FACTORS AFFECTING STRENGTH

Discontinuities such as impurities, fractures, and separations weaken the strata's strength as a structural element. These impurities include weakened zones of mineralization (mica, clay, or calcite surfaces) while the fracture or separation systems include bedding planes, laminations, cleats, slickensides, joints, and faults.

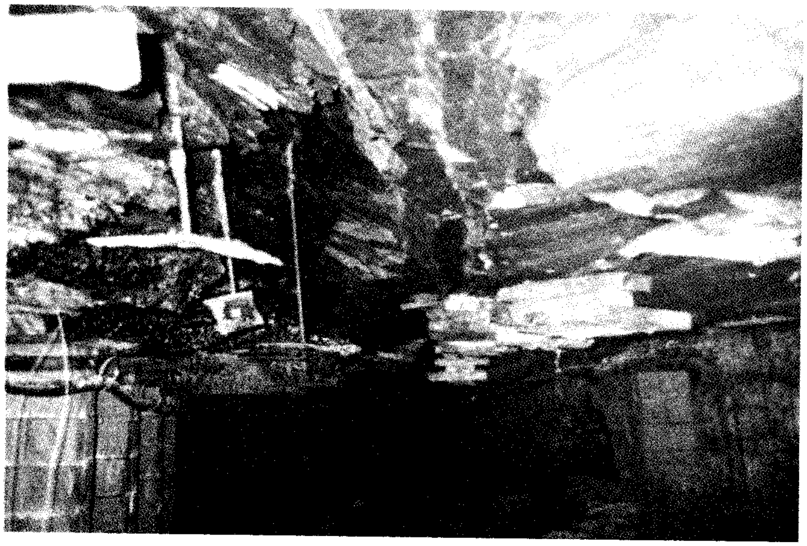
Mica, calcite, clay, and fossils tend to be deposited more or less on surfaces parallel to the bedding planes and laminations and form a plane of weakness along which rock strata can easily separate. These discontinuous surfaces oftentimes have extremely low cohesive properties and the presence of these features is an important consideration for determining the overall strength of the rock mass.

Laminations (or planes of separation) may result in changes in the characteristics of the formation including chemical composition, type and characteristics of clastic materials, and the presence and degree of cementation. Since laminations are generally found in finer-grained sedimentary rocks, these rocks in many cases have larger amounts of clay minerals. The clay minerals are subject to weathering in the presence of moisture.

Slickensides are smooth and glossy slip surfaces that are randomly oriented and may be found in various sizes. These surfaces are highly polished, have no cohesion, and once undermined, rocks containing slickensides will separate along the slick surfaces and fall off with little warning. The presence of water is particularly detrimental to cohesion of the slick surfaces and generally weakens the strength of all sedimentary rocks.

Joints and faults also weaken the overall strength of the unit. Faults have displaced rock strata while joints do not. Either type of fracture may be found with other materials or minerals filling in the voids between the free surfaces. In both cases, the rock strata surrounding these features may be weaker than the intact rock and additional support may be necessary.

Finally, the strength of a rock unit as a whole is proportional to its thickness. A thin sandstone layer is definitely weaker than a thick layer of shale even if the sandstone is much higher in strength than the shale when tested in the laboratory. The thickness of the formation is very important in determining the self-supporting capacity for roof-bolting design in entry support. It is even more important when it comes to determining the abutment pressures in and around the longwall faces and the pillar lines in room-and-pillar mining with pillar extraction. With everything being equal, a thicker shale stratum will overhang longer than a thinner sandstone stratum, thereby creating larger abutment pressures that may generate more intense roof-control problems.



Roof failed due to break up of roof strata along randomly oriented slickensides.

DETECTING GEOLOGICAL ANOMALIES IN ADVANCE

There are several geophysical methods that have been developed for identifying large-scale geological anomalies such as sand channels and faults. These include electrical resistivity, ground penetrating radar, seismic, and radio imaging methods (RIM).

Seismic tomographic imaging and improved RIM technology looks promising. With research continuing on improving accuracy and speed of the algorithms used in these systems and enhanced data processing techniques, the application and usefulness of these systems should improve significantly.

The smaller-scale features such as fracture patterns and bedding separations are more difficult to detect but some recent research programs hold promise. Drill-monitoring systems for underground roof bolters and portable handheld acoustic energy meters are two recent developments that have been used to identify smaller-scale geologic features. Monitoring the drilling parameters during roof-bolt installation appears to have application for determining both rock properties and fractures or bedding separations in the roof. Studies on the acoustic energy meter have detected bed separations, roof slips, and changes in the physical characters of the roof rocks such as weakening over time from weathering. Additional studies on those two technologies are continuing.

GEOLOGICALLY CONTROLLED MINE STABILITY PROBLEMS

There have been many studies performed and papers published in the past regarding how various geological anomalies or defects have caused entry stability problems (roof falls, rib rolls, and floor heave). The anomalies, such as clay veins/dikes, coal seam rolls, hillseams/mountain seams, joints/faults, kettle bottoms, and sandstone channels, are larger in size and oftentimes easily recognizable. A series of reports were developed to help identify these features and recommend preventive measures to reduce their impacts.

However, other features involving minor or gradual and subtle changes in geology that are not easily identifiable or observable have been responsible for major roof-control failures.

Thick sequences of thinly bedded sandstones, siltstones, and shales (most commonly called "stack rock") are often difficult to support given the tendency to delaminate following displacement after mining or horizontal stress concentrations. While the compressive strength of the individual rock units is high, the stability of the strata is very low. The laminations weaken the rock sequence to the point that even after roof bolting the rocks are not structurally sound enough to remain stable. This type of roof has been found to be responsible for massive high roof falls covering many pillar blocks.

Recently a type of coal mine roof rock was observed to be extremely unstable and virtually impossible to support prior to complete failure. This rock interval appeared to be highly fractured in an orthogonal pattern with the fracture pattern being extremely closed-spaced (less than 1/16 inch). The rock interval failed immediately following mining and failed in a near-flowing motion as one would expect unconsolidated sand grains to displace. The close spacing of the fractures, the calcite coating on the plane surfaces, and the degree the fractures were interconnected resulted in a rock unit that essentially was unconsolidated. This rock unit appeared within the mine roof suddenly and required a significant effort for mining in the area.

Partings in coal seams are important features for coal mining operations and they are frequently used for cutting horizon control. Partings also play a very important role in entry stability, especially in high coals and/or under deeper overburdens. A stronger parting normally enhances the stability of the pillars although it is more difficult to cut during the mining operation. On the other hand, a much weaker parting, depending on its location and thickness, could be the deciding factor in pillar stability in thick coals and/or under high cover, rather than the strength of the coal itself.

All conventional pillar design formulas do not consider the fact that coal seams usually contain one or more partings at various elevations and the role of the partings in pillar and entry stability. Most partings found in coal seams are weaker than the host coal and normally contain varying amounts of clay minerals.

The clay minerals are subject to weathering and deteriorate once in contact with the wet/dry cyclic nature of the ventilation air. These weathered partings tend to promote rib rolls and sloughages over time, particularly under the influence of abutment pressures. In high coals and/or under high overburdens, the deterioration could be so severe that it seriously threatens mining operations.

Since mining engineers do not and cannot select the rock materials to build the mine structures and the in-situ rock materials are known to vary considerably from place-to-place, it is extremely important to be aware of the geological character of the roof and coal seam.

Obviously the key is the timely identification and recognition of subtle or sudden changes in rock strata, the impact of the changes on structural stability within the mine, and the development of an approach for minimizing the impact if the conditions signify a shift from stable to unstable.

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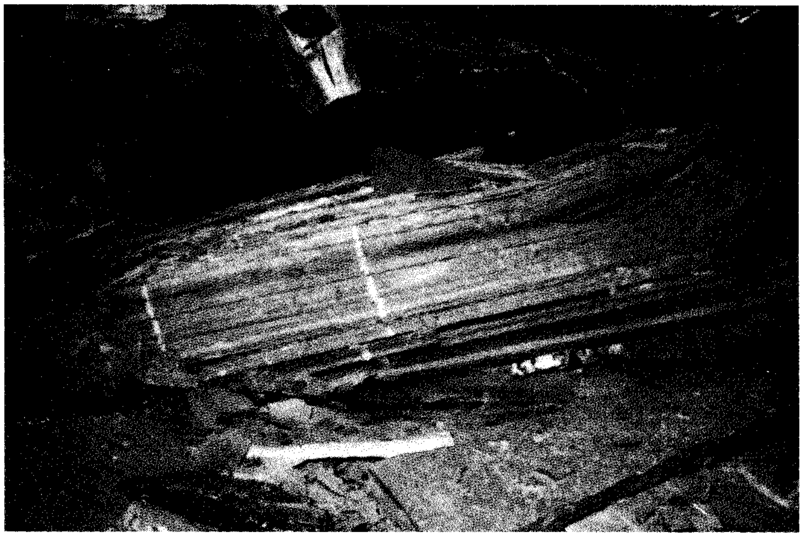

Thinly laminated stack rock can create challenging mining conditions.