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# GEOTECHNICAL ROOF CLASSIFICATION FOR AN UNDERGROUND COAL MINE FROM BOREHOLE DATA

William Lawrence<sup>1</sup>, Jason Emery<sup>2</sup> and Ismet Canbulat<sup>2</sup>

**ABSTRACT:** It is standard and critical practice in the majority of geotechnical engineering applications to use a rock mass classification system to evaluate the condition of rock in mine planning and operations. The use of geotechnical classification schemes for rock mass characterisation in underground coal mines is well established. Several rock mass classification systems have been developed and used in civil engineering design and for underground mining operations. In the past, these rock mass classification systems were modified and used in the coal mining industry to quantify descriptive geological information for use in coal mine design and roof support selection. To facilitate geotechnical evaluations, mining companies in the Bowen Basin of central Queensland put considerable effort into obtaining geomechanical data from surface exploration boreholes and borecore. The advance or innovation in the proposed method is not in doing the characterisations, but the method of evaluating the required parameters from available borehole geophysics and geomechanical test data. Evaluating radial point-load strength from geophysical correlations is dependent on collating a large comprehensive database of actual point-load test data across the range of lithological types.

## INTRODUCTION

Effective and pre-emptive strata control in an underground coal mine is aided by an adequate definition of the geotechnical environment. Major components of the geotechnical environment are the lithological and geomechanical characteristics of the immediate roof. The geomechanics classification systems Rock Mass Rating (RMR) and the Norwegian Geotechnical Institute (NGI) Q-system are the most commonly used in civil and hard rock mining around the world. Both of these systems incorporate Rock Quality Designation (RQD) and are based on actual case histories. The RMR and Q systems have evolved over time to better reflect the perceived influence of various rock mass factors on excavation stability. The introduced modifications have arguably enhanced the applicability of these classification systems, but there are still areas of potential confusion.

The use of geotechnical classification schemes for rock mass characterisation of the immediate roof in underground coal mines is also well established. Simple single-parameter classifications may be derived directly from borehole geophysics. Both well-established and more complex multi-parameter classifications require additional direct testing of borecore or exposed roof strata to provide data for the calculation. Borehole geophysical data is obtained from all surface exploration holes; however, not all boreholes are cored. Where core is available and tested, there is usually insufficient data for each required immediate roof lithological unit; therefore, a method to derive multi-parameter geotechnical roof classifications using borehole geophysics correlated to rock-mass geomechanical properties is required.

Mining companies in the Bowen Basin of central Queensland, including Anglo American Metallurgical Coal's (AAMC) Capcoal operations, place considerable effort into obtaining geomechanical data from surface exploration boreholes. As well as standard geophysical data, core samples are routinely processed and geomechanically tested in laboratories. Point-load tests are conducted on available core in the field by exploration geologists; however, there are often more roof units present than can be tested in an appropriate time frame. Anglo American, through its Capcoal operations, has an extensive exploration database. All available data was not being effectively collated and used for mine design purposes, in particular borecore geomechanical data. A project was instigated to primarily provide geotechnical classification of the immediate roof for the Grasstree longwall mine. This objective required a database of correlated geomechanical properties.

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## GRASSTREE MINE

The Grasstree Mine is a longwall mine producing high quality coking coal as part of the German Creek complex, operating approximately 30 km west of Middlemount in the Bowen Basin (Figure 1). Underground development commenced in November 2003, eventually forming an extension to the adjacent Southern Colliery when the two mines were joined in 2005.

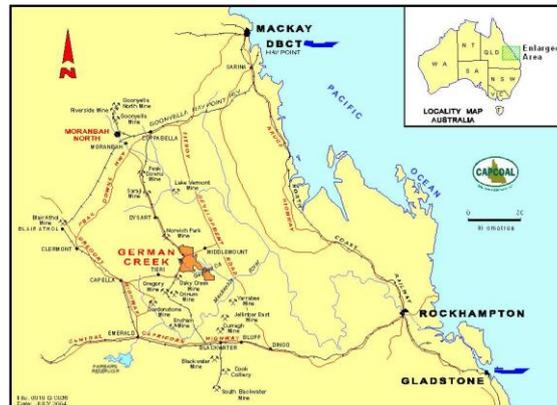


Figure 1 - German Creek mines complex, Queensland

Gateroads and main headings are developed with wide-head continuous miners, mining conventionally and supporting roof and rib with on-board drilling rigs. Grasstree longwall blocks are designed with three heading gate roads, two of which are utilised for ventilation due to the high gas content in the goaf, whereas the remaining heading is utilised for goaf sealing of the previous longwall block.

Longwall panels are currently being developed in the 800 series on the southern side of the main headings. Current depth of mining operations range from 270-385 m in the 800 s series. Future longwall mining on the 900 s side is planned to follow on after the completion of LW807 with maximum depth to reach 450 m.

## GEOTECHNICAL ROOF CLASSIFICATION FOR COAL MINES

Numerous geotechnical rock classification schemes are utilised in the Bowen Basin coal mines. Most notable is the Coal Mine Roof Rating, CMRR (Mark and Molinda, 2005), an established coal industry standard. CMRR requires both intact compressive strength and discontinuity geomechanical data for each lithological unit of a mining horizon, typically equivalent to the length of installed support. Uniaxial compressive strength (UCS) (Payne, 2008), is used at several mines, and experience has shown that it can be a relatively good predictor of strata conditions. UCS is typically derived from a correlation to sonic velocity (transit time) from geophysical logs or from laboratory testing. An extension of UCS is the Roof Strength Index (RSI) (Gordon and Tembo, 2005), which incorporates depth of cover. RSI can be correlated to installed support, but is likely to be restricted to depth ranges and may not be sensitive to extremes of low strength. A recent and promising method under development is the Geophysical Strata Rating (GSR) (Hatherly, *et al.*, 2008), which estimates rock-mass competency by an analysis of geophysical logging data. Currently, this system is also being evaluated by AAMC.

### Database

As well as evaluating the immediate roof competency, the existing Grasstree geomechanical database is being updated with data from every hole assessed. Primarily, the roof classification project required the calculation of CMRR across current and proposed mining areas at Grasstree. Data points are acquired and collated from surface exploration holes with available electronic geophysical logs, i.e. sonic transit time. Slake durability, UCS, axial and radial point load data and fracture spacing. Sonic Transit Time (STT) or Sonic Velocity (SV) is evaluated for each rock sample to allow correlations between parameters to be developed. The geomechanical database should also have the capability to incorporate other CMRR data, e.g. information from underground exposures and borecore from underground drilling. CMRR has to be readily calculated for various roof horizons. The database needs to be able to calculate UCS and RSI for various roof horizons.

## Coal Mine Roof Rating (CMRR)

Mark (1990) integrated CMRR into support design programs like the USBM's Analysis of Longwall Pillar Stability (ALPS) program in the calculations of safety factors for given coal pillar sizes based on applied loads and pillar strength. It is also integrated into a similar design methodology in Australia by Colwell (1998) to determine the appropriate pillar sizes and required secondary support in tailgates. This design methodology is called the Analysis of Longwall Tailgate Serviceability (ALTS). In both cases, statistical analysis from case histories of CMRR values have been used in conjunction with existing pillar design formulae to develop a relationship (called Stability Factor) between the pillar Factor of Safety and CMRR.

Base unit CMRR is calculated from two components using the standard National Institute for Occupation Safety and Health (NIOSH) formulations (Mark and Molinda, 2005). One component uses UCS to characterise material strength. The second component characterises the strength and effect of discontinuities, and uses Radial Point Load Data (RPLD). Additional adjustments can be made to the base CMRR, including a strong bed adjustment, a multiple discontinuity adjustment and a surcharge deduction. Fracture Spacing (FS) and Axial Point Load Data (APLD) are also being collated, and may be correlated or incorporated in the future. UCS, axial and radial PLD and FS are available from the exploration database. No adjustments are made for water, as this should be done on a site-specific basis if water is present. Roof joints are usually not identified by standard borehole geophysics, and again may need to be considered on a site-specific basis. The advance or innovation in the method to calculate CMRR is to derive representative RPLD when explicit tests are not conducted.

CMRR is calculated for distinct individual lithological units. Units are chosen from assessment of geophysical logs (sonic and gamma). Units such as weak mudstone or strong sandstone may be as thin as 0.2 m. Composite roof CMRR can be readily calculated for any roof horizon. Typically, the roof bolt horizon is chosen, in this case 1.7 m (assuming 0.1 m of the standard 1.8 m is protruding from the roof). The composite CMRR is calculated from the cut-roof horizon; it is not calculated from top of seam (ToS). A standard excavation height of 2.8 m from base of seam (BoS) is used to calculate anticipated cut roof horizon.

The current Grasree UCS to STT correlation is shown in Figure 2, and comprises about 300 data points. The average unit STT is used to calculate the unit UCS. The discontinuity CMRR component could be calculated for each hole using that hole's data, but this would only be possible for cored holes. In addition, RPLD and FS may not be taken for each individual lithological unit, which means that a composite CMRR may not be possible even with cored holes. In the Bowen Basin, discontinuity strength and stiffness broadly varies with lithology, in particular clay content. Infill and faulting also define discontinuity characteristics. Weaker discontinuity strength is evident in siltstones and mudstones and siltstone interbeds. Choosing representative RPLD for each lithology could be possible, but would not represent the likely strength variability within standard lithological units.

The new approach taken is to define a RPLD-to-STT correlation, similar to UCS. Unlike UCS, where an average unit STT is used, for RPLD a maximum STT (minimum SV) is used that corresponds to the low strength "spikes" (Figure 3). The sonic geophysics tool does not have the resolution of a lamination; the low strength spikes are assumed representative of the weakest partings. This method may not be ideal, but there is no other available parameter that could be used instead of STT. The current RPLD-to-STT correlation is shown in Figure 4, and currently comprises about 200 data points. With a larger database and analysis, it may be possible to derive an alternate RPLD correlation to unit UCS, and include parameters such as clay content (gamma) and signal spikiness.

Unlike the unit average value of STT to derive UCS, there is an issue about what RPLD correlation to use. As an example, refer to representative borehole geophysics shown in Figure 5. The average Unit A STT is about 75  $\mu\text{s}/\text{ft}$ , with a lower-bound STT of about 80  $\mu\text{s}/\text{ft}$ . The average Unit B STT is about 74  $\mu\text{s}/\text{ft}$  with a lower-bound STT of about 77  $\mu\text{s}/\text{ft}$ . If the average (black) correlation of Figure 4 is used to derive radial point-load strengths, the resultant unit CMRRs are 46 and 52 for Unit A and B, respectively. However, the average correlation of Figure 4 does not consider the presence of weak laminations, which will predominantly affect roof integrity in a laminated stone roof such as Grasree given the relatively high ratios of horizontal to vertical stress (2:1) in the Bowen Basin.

From the wide data spread there are considerable data points with minimal radial  $I_{s50}$ , indicating occasional weak laminations even in a relatively strong unit. Using the red or lower-bound correlation gives unit CMRRs of 40 and 41 for Unit A and B, respectively. While weak laminations do occur in stronger strata units they are not pervasive, and their effects do not predominate considering relatively

high material strength. The green or proposed correlation is midway between, and gives unit CMRRs of 42 and 46 for Unit A and B, respectively. Other correlations and justifications may be possible. If the green correlation is used, the red and black correlations then provide limits of uncertainty that may be used in a risk-based assessment, if required. The CMRR with strong bed adjustment assessment for a portion of Grasree workings is shown in Figure 6. The assessment is done for the primary support roof horizon, i.e. 0 m to 1.7 m above cut roof horizon.

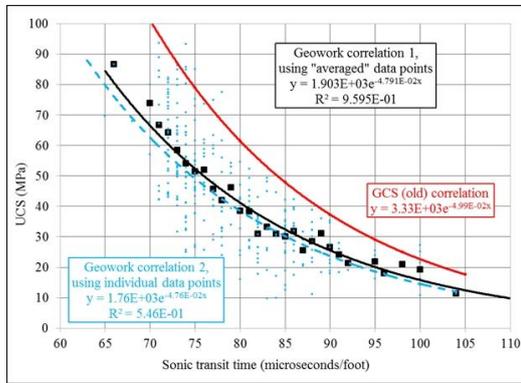


Figure 2 - The current UCS and STT correlation at Grasree Mine

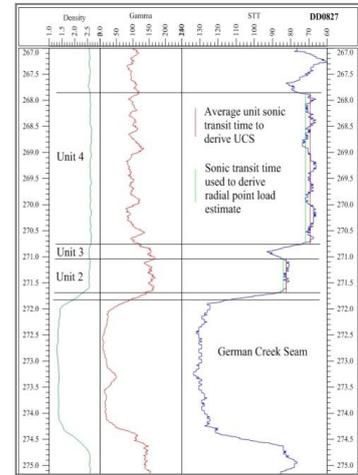


Figure 3 - Geophysical log showing roof units and STT used to derive UCS and RPL

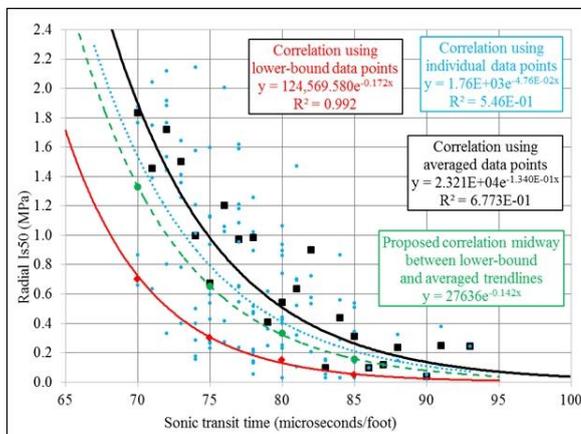


Figure 4 - RPL and STT Correlation at Grasree Mine

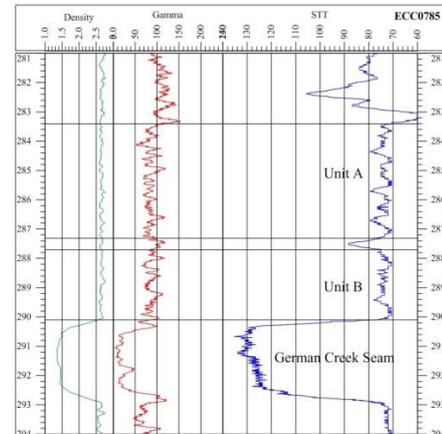


Figure 5 - Example sonic trace

**UCS and RSI**

UCS is calculated for each lithological unit using the correlation shown in Figure 2. RSI is defined as the UCS (MPa) divided by the in-situ vertical stress (MPa) (Gordon and Tembo, 2005) and is unitless. Vertical stress may be calculated from depth of cover. The UCS and RSI assessments for a portion of the Grasree workings are shown in Figures 7 and 8, respectively.

**CONCLUSIONS**

Characterisation of the rock mass across proposed workings is a critical component of mine planning. The advance or innovation outlined above is not in doing the characterisations, which are standard industry assessments, but in the method of evaluating required data from available borehole geophysics. Based on underground observations the utilisation of this technique, specifically the use of low strength spikes in STT to estimate RPLD data, is deemed appropriate for Grasree Mine. It is acknowledged that this technique is likely limited to a laminated stone roof for which it has been developed. Evaluating radial point-load strength for a lithological unit from geophysical correlations is dependent on first collating a

large comprehensive database of actual point-load test data, across the range of lithological types, whilst also having abundant geophysical data. It is appreciated that different and improved methods of calculated geomechanical data from borehole geophysics may be proposed and developed.

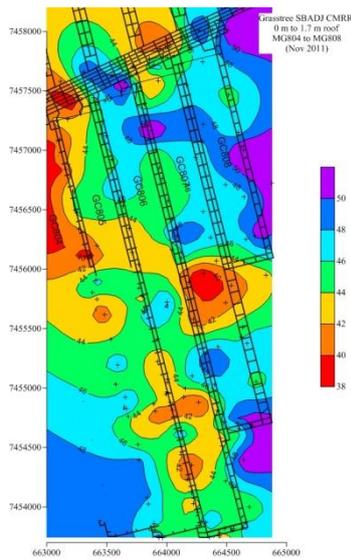


Figure 6 - CMRR MG804 to MG808

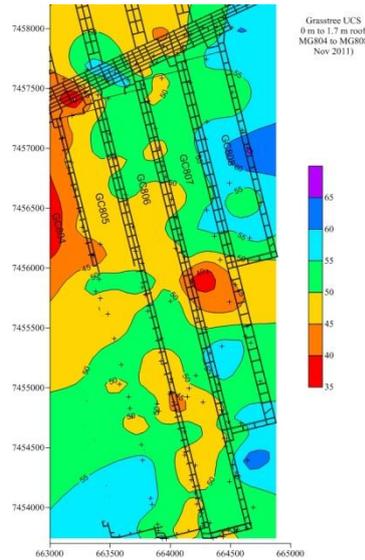


Figure 7 - UCS MG804 to MG808

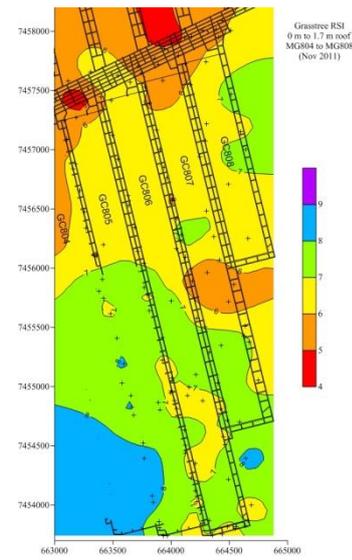


Figure 8 - RSI MG804 to MG808

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