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3D GEOTECHNICAL MODELS FOR COAL AND CLASTIC ROCKS BASED ON THE GSR

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ABSTRACT: This paper provides the key outcomes and an example of Geophysical Strata Rating GSR analysis and modelling as undertaken in recently completed ACARP Project C17009. Various examples from the project demonstrate the use of GSR for overburden characterisation and hazard planning, tailgate stability and longwall face behaviour.

Borehole spacings of 200 m or thereabouts, which are typical of Bowen Basin underground operations, allow geologically meaningful 2D and 3D modelling of GSR and other parameters derived from the geophysical logs. Plots of clay content and porosity can be used, depending on their relevance to the given strata behaviour, and/or as alternative means of investigating geological features in the overburden sequence.

An approach for determining the GSR in coal and carbonaceous has been successfully developed material. In coal, the GSRi is inversely related to brightness as indicated by the ash content evident in density, natural gamma and sonic logs. GSR values are shown to relate to other existing classification schemes, but arguably with more sensitivity to the weaker materials than present in the manual logging methods.

INTRODUCTION

In most coal mining operations, there is a need for repeatable and quantifiable geotechnical assessment procedures that allow appropriate planning and responses to changing conditions. Many underground sites use the Coal Mine Roof Rating (CMRR) or similar classification systems. Others, both open cut and underground, use unconfined compressive strength (UCS) as an index to changing rock conditions. Where UCS is used, sonic logs have become the main data source to estimate UCS. Laboratory measurements are also included, where possible.

At the 2009 Underground Coal Operators Conference a new method for evaluating geotechnical conditions known as the Geophysical Strata Rating (GSR) was presented. A comparison between conventional UCS results at Crinum Mine and the new GSR determinations was provided. The GSR is based on the interpretation of sonic, density and natural gamma logs and is designed to provide a measure of strata properties on a linear scale similar to that used in the Coal Mine Roof Rating. The GSR allows coal bearing strata to be quantitatively assessed in every borehole that is geophysically logged, regardless of height above the working seam.

Through a series of ACARP funded projects C11037 (Hatherly *et.al,* 2003), C15019 (Hatherly *et.al*., 2008) and C17009 (Medhurst et al., 2009) we have made GSR determinations at mine sites throughout the Sydney and Bowen Basins. These have consistently provided useful insights into geotechnical conditions and provided a proven capability of distinguishing changes in strata properties. In the latest project we have had the opportunity to benchmark the GSR against actual mine performance. There was also a requirement to characterise coal and other carbonaceous materials. Through using sonic, density and gamma logs, we have been able to provide a complementary measure of GSR in these materials.

To make full use of the GSR assessment of ground conditions, it is necessary to estimate GSR values between boreholes, in three-dimensions. This requires geostatistical estimation using techniques that have received little attention in geotechnical engineering. The use of 2D and 3D geotechnical models using borehole interpolation from GSR estimates is demonstrated. 3D seismic data, if available, can also be used to constrain the boundaries of the main geological horizons (mainly coal seams) between boreholes.

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THE GEOPHYSICAL STRATA RATING

The full definition of the GSR is given in Hatherly *et.al* (2008). The components of the GSR are provided through the following scores, with the initial GSR (GSRi) being the sum of the first four scores:

1. strength score (5 to 55) depending on sonic velocity
2. porosity score (0 to -15) depending on porosity
3. moisture score (0 to -10) depending on porosity and clay content
4. cohesion score (10 to 25) depending on sonic velocity and quartz content
5. bed score (0 to 10) depending on the downhole variability of clay content.
6. fracture score depending on the downhole variability of the GSRi.

These terms have geomechanical significance. The first four can be added together to give an estimate of the quality of individual beds – the initial GSR (GSRi). The effects of the variability due to defects and changes in the bedding are captured by the last two terms. Comparison of the various scores indicates that sonic velocity is the main driver of the GSR. To ensure that the GSR is not depth dependent, the velocities are corrected for effective pressure. Compensation to the strength and cohesion scores is then made in consideration of the effects of porosity and clay content on rock strength. The bed score is designed to respond to bedding, as expressed by changes in the clay content. The effect of fracturing is assumed to be expressed within the variability present in the sonic log which, in-turn creates variability in the GSRi.

Significantly, the GSR does not attempt to map individual fractures nor their orientation. It is also unable to identify mineralogical factors such as the presence of water reactive clays. The GSR should be viewed as a scheme which provides bulk rock characterisation, independent of depth and mining considerations.

GSR FOR CARBONACEOUS MATERIAL

For the purposes of the analysis we have taken carbonaceous material to represent rock units containing enough organic components to affect the geophysical log responses but which are not coal[1]. Such material will have low density and low velocity. Unless it is explicitly identified in the GSR calculations, it will be assigned a very high porosity and be scored accordingly. Given that the carbonaceous material that is most commonly encountered is in the form of carbonaceous mudstone and siltstone both of which have low porosities, the score would not be correct.

We have chosen to automatically set the porosity to zero for any carbonaceous material found from a density log which is not identified as coal. The GSR determination then continues in the same manner as for clastic rocks.

GSR FOR COAL

To provide a rating for coal, a different approach has been developed. If we simply extended the approach for clastic and carbonaceous materials into coal, it would be the weakest rock type because it has the lowest sonic velocity. However, we know that coal, by virtue of its organic fabric and the absence of bedding planes, can have an intrinsic strength that is not present in other rock types with low sonic velocities.

Medhurst and Brown (1998) investigated factors affecting variations in coal strength and found that bright coals are weaker than dull coals. This was found to be due to the increased presence of cleats in the brighter coals. Brightness, per se, is not a parameter that can be expected to be associated with a geophysical log response. However, given that coal brightness can be related to coal strength, there is some merit in proposing that the ash profile may be also related to brightness and hence be related to the mechanical properties of the coal. Ash content (mineral matter) is a parameter that influences geophysical log responses. Density, natural gamma and sonic responses all become elevated when

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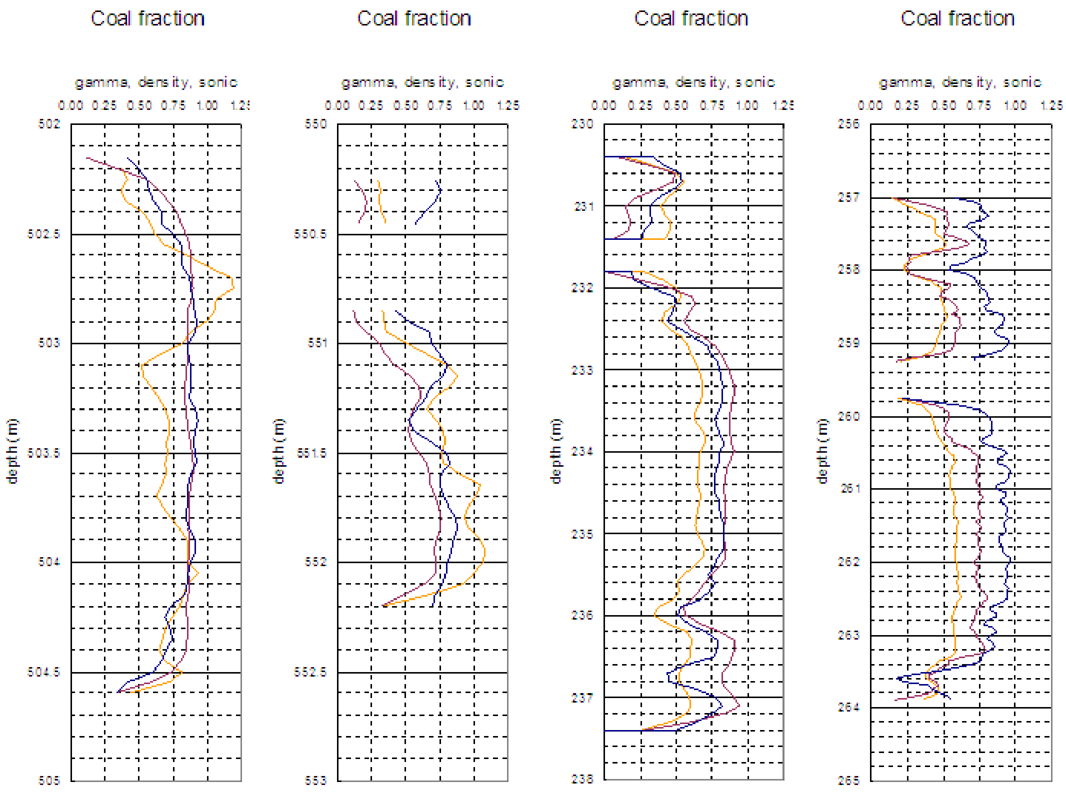
[1] The ASTM's definition for coal is that it is material containing more than 50% by weight and 70% by volume carbonaceous material. The carbonaceous material under discussion here has less than 50% organic material.

the ash content increases. (See for example, Zhou and Esterle (2007) who describe the use of density data to predict ash content.)

From a given log response and estimated values for density, natural gamma and transit times it is possible to estimate a parameter that relates to the overall ash content. A simple model for these associations utilises linear mixing laws to estimate the relative proportions of the organic coal and ash constituents that are present. Logs showing coal volume profiles within four different coal seams are presented in Figure 1. For each of these seams, the three different logs provide similar estimates, thus suggesting that the linear mixing laws are appropriate[1].



Bulli seam Wongawilli seam Moranbah North Hunter Valley

Figure 1 - Fraction of organic matter in coal seams from a range of locations. Gamma log results in blue, density in plum and sonic in god

The average of these three coal/ash indicators can therefore be calculated to provide an indication of the fraction of coal present and the apparent ash profile in the coal seam. Given that coal brightness may also be related to the ash profile, we propose the following simple relationship to provide an estimate of GSRi:

$$\text{GSRi} = 5 + 45*(1 - \text{CoalFraction})$$

where the coal fraction it is set to 0.3 if the average apparent ash value is less than 0.3.

In the normal GSR calculations, the defect score (the combined bed and fracture scores) is between 0 and 20. In the case of coal, adding defect scores between 0 and 20 provides too much emphasis to the defects and creates 'noisy' GSR estimates. We have therefore decided to halve the values of the defect scores in coal (i.e. the total defect score is between 0 and 10). This is further supported by the observation that horizontal weakness planes are often less well developed in pure coal seams and hence less dominant in their failure behaviour. Cleating normally plays the dominant role. Distinct non-coal weakness planes such as penny bands are picked up via the normal GSR analysis.

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[1] *There is the greatest difference for the Hunter Valley example. In this case the difference may be due to problems in the calibration of the geophysical logs.*

Figure 2 shows a comparison between GSRi and average brightness for data from Moranbah North. Although both parameters are based on averages over the given seam interval, the results still show the trend of GSRi increasing with duller coals. Figure 3 investigates the relationship between GSR and CMRR where coal roof, carbonaceous and non-coal materials are present. There is a weak but positive correlation. Note also the relatively small range of CMRR values (40 – 45) compared to GSR (20 – 30). This suggests that the GSR analysis is more sensitive to variations in coal strength.

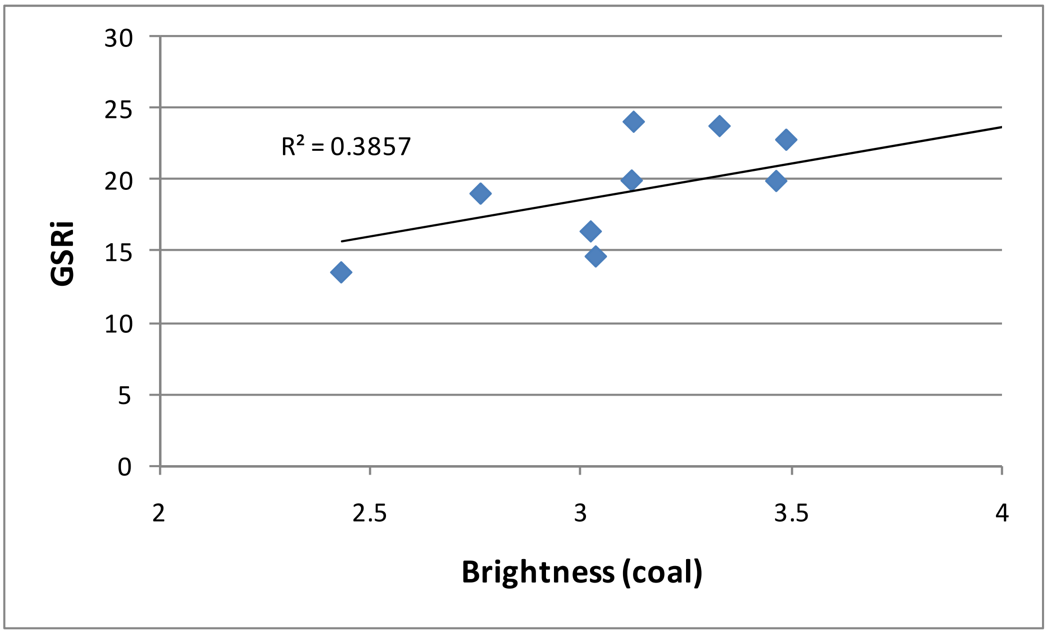

Figure 2 - Comparison of GSRi and average brightness in coal roof holes from Moranbah North

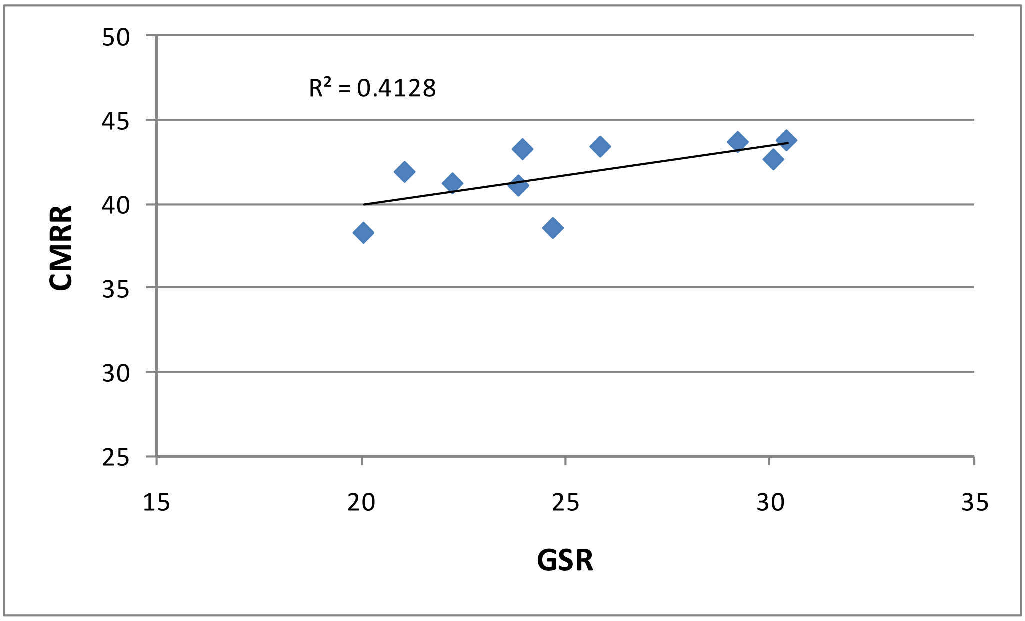

Figure 3 - Comparison of CMRR and GSR within 2m roof coal sections at Moranbah North Mine

MODELLING THE GSR

In order to make full use of GSR determinations, it is desirable to extend the results between boreholes to form 2D and 3D models. From these models sections and plans showing vertical and lateral variations can be constructed to enable further geotechnical evaluation.

There are a number of large modelling packages utilised by mining companies. For this project, we did not seek access to any of these packages nor undertake the training required to operate them. Instead, we chose to utilise the low-cost Surfer program to undertake our initial 2D modelling while at the same time developing a 3D modelling capability that would allow us to develop 3D models. The algorithm was to be based on estimation procedures we had already developed in a previous ACARP project for converting seismic reflection data from travel times to depths (Zhou *et al.,* 2004).

Inputs for the 2D and 3D modelling were simple Excel and text files detailing the locations of the boreholes, the GSR data tabulated against down-hole depth and, for our own modelling program, the depths of the control surfaces in each of the boreholes. Our algorithm allows for seam splitting but not faulting in situations where layers replicate themselves (reverse faulting) or are absent (normal faulting).

The outputs from the modelling are grid files showing grid point coordinates and the estimated value of GSR. 2D grid files can be displayed using Surfer. For our 3D modelling, there is the option of generating a series of grid files which Surfer can display, or alternatively organising the results into the same data structures used for 3D seismic data. With the data in this format, we are able to interrogate the model using SeisWin, our interactive 3D seismic interpretation program. A useful feature of Surfer and SeisWin is that they allow dxf files showing mine plans and other map data to be imported and displayed together with the model results.

MORANBAH NORTH EXAMPLE

During extraction of LW105 at Moranbah North, longwall face cavities and uncharacteristic tailgate instability developed at the inbye end of the panel, which required relocation of the face. One aspect of the overburden conditions which was considered to contribute to the instability was the presence of a rider seam/stone interface in the roof.

Detailed discussion of field monitoring and 3D modelling of gateroad behaviour at Moranbah North is provided by Tarrant (2006). As a result of this study, a deformation mechanism termed 'skew roof deformation mechanism' was identified, which related the regional differential horizontal movements to the shear behaviour about gateroads. Tarrant suggests the key factors driving the skew roof mechanism are:

- the magnitude of the vertical and horizontal stresses;
- the shear modulus of the strata pile (shear deformability); and
- the extent of overburden bridging.

The relative location of weak interfaces in the roof and the character of the overburden strata, particularly massive strata, can have a significant effect on roadway support and chain pillar sizing. Interestingly, the influence of massive strata movements and its impact on maingate roof behaviour was previously identified via microseismic monitoring and analysis of surface to seam extensometer data at Southern Colliery (Hatherly *et.al*., 2003). This was attributed to a thickening of an overlying sandstone channel and a weak interface high into the strata, which allowed strata movements towards the goaf. It was therefore considered useful demonstration of the GSR analysis to investigate the 3D variations in overburden strata characteristics in the vicinity of the LW105 fall zone.

The general area investigated showing relevant boreholes is shown in Figure 4. Two-dimensional analyses of borehole data along the gateroads were initially undertaken. Figures 5 and 6 show detailed sections from the 2D analysis along the tailgate and maingate, respectively. The upper and lower white lines show the bounding surfaces. Within the GM seam, the boundaries of the working section are also shown. The plots also show the presence of the rider seam at the lower right edge of the plot and the associated seam split. There is also a split present in the overlying P seam which is associated with the development of an upper sandstone channel.

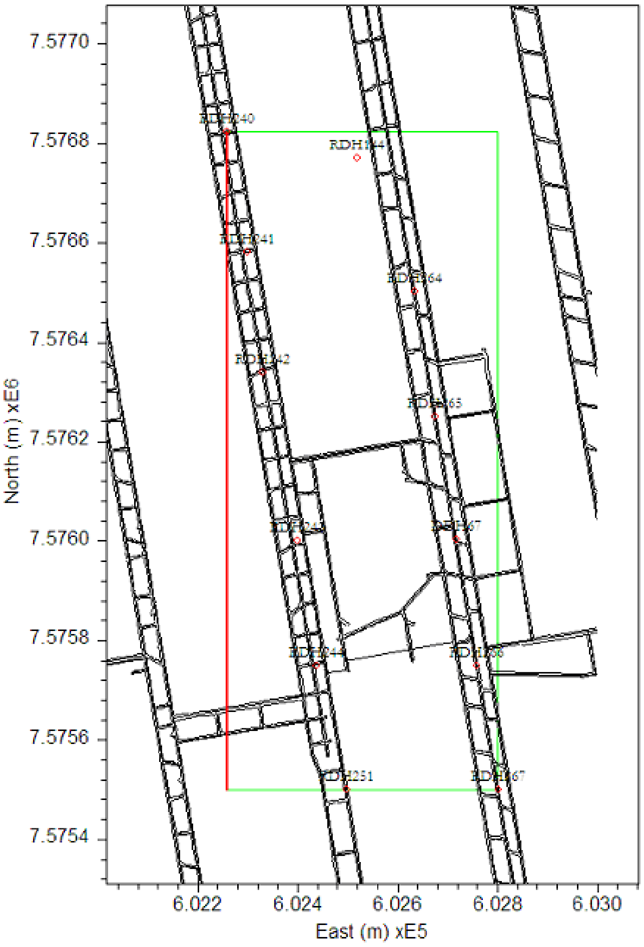

Figure 4m - Zone used for Moranbah North GSR analysis

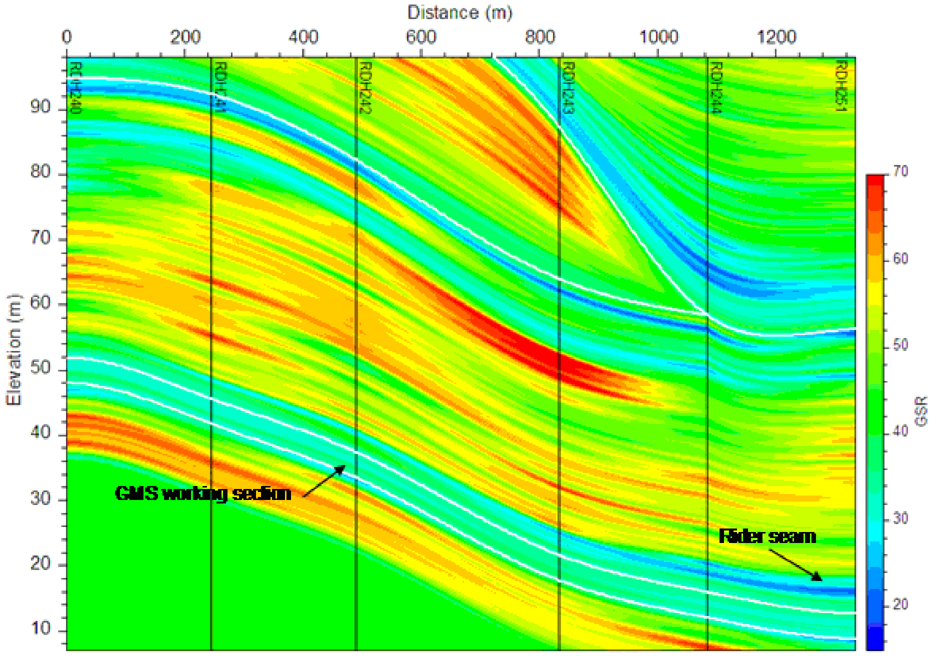

Figure 5 - Detailed section along tailgate

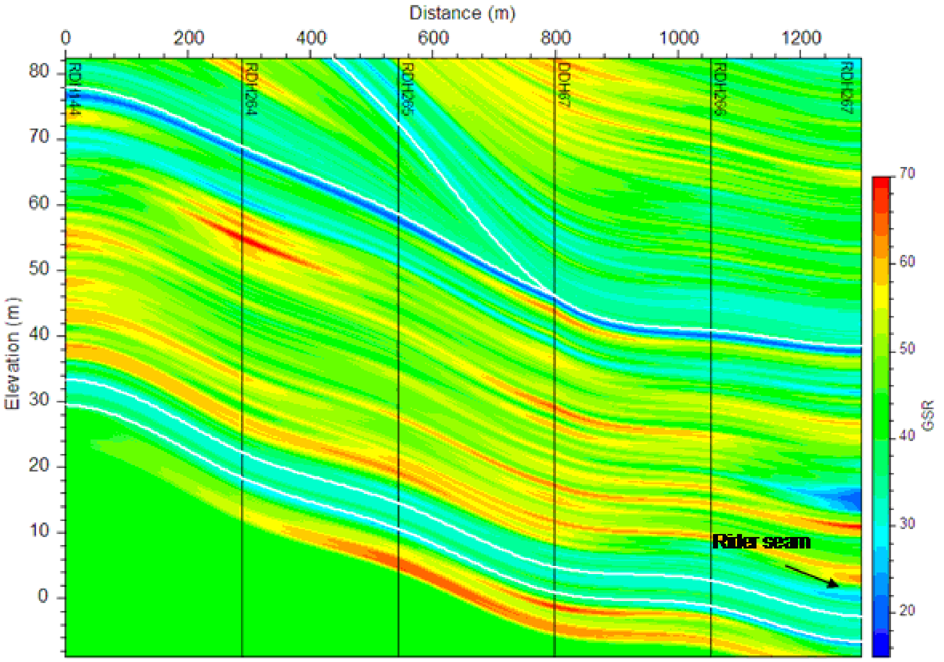

Figure 6 - Detailed section along maingate

Comparison of the two sections indicates a stark contrast in overburden conditions. In particular, the presence of thick sandstones (high GSR values) immediately above the seam and higher up into the strata over the tailgate can be observed. In addition at the location of RDH244, the rider seam is present and is immediately overlain by heavy sandstone strata that also coincide with the edge of the upper sandstone channel. This is the location where the longwall had to be relocated. This clearly shows the benefit of developing detailed overburden sections, as such information could be difficult to determine from analysis of RDH244 in isolation; or from manual analysis of gamma or sonic velocity data.

Detailed 3D analysis was also undertaken using the borehole data. The 3D plots compare well with the 2D sections along the gateroads. Figures 7 and 8 shows plan views of the average GSR over intervals of interest. Figure 7 shows the immediate roof zone. The influence of the rider seam resulting in low GSR values south of RDH243 can be seen. Figure 8 shows a similar plot for the intermediate roof. This highlights the influence of the overlying sandstones and the zone where the heavy roof overlaps the seam split zone.

In summary, the analysis shows the location of heavy roof and how it coincides with the fall area along the LW105 tailgate. Previous analysis had also indicated that the presence of the rider seam under these conditions can lead to particularly challenging roof conditions that require specific ground support requirements. The GSR analysis provides a detailed representation of the ground conditions that would have contributed to the falls and accurately corresponds to the zones in which such roof behaviour would have been triggered.

The analysis provided here was undertaken using data that was available prior to the instability. Whilst roof monitoring alone could not be used to verify the proposed roof failure mechanisms, the geophysics based analysis provides ample evidence to support the proposed roof failure mechanism. With such information available prior to extraction, the mine may have been able to identify hazards, improve monitoring strategies and if necessary undertake additional analysis to incorporate into the strata management plan.

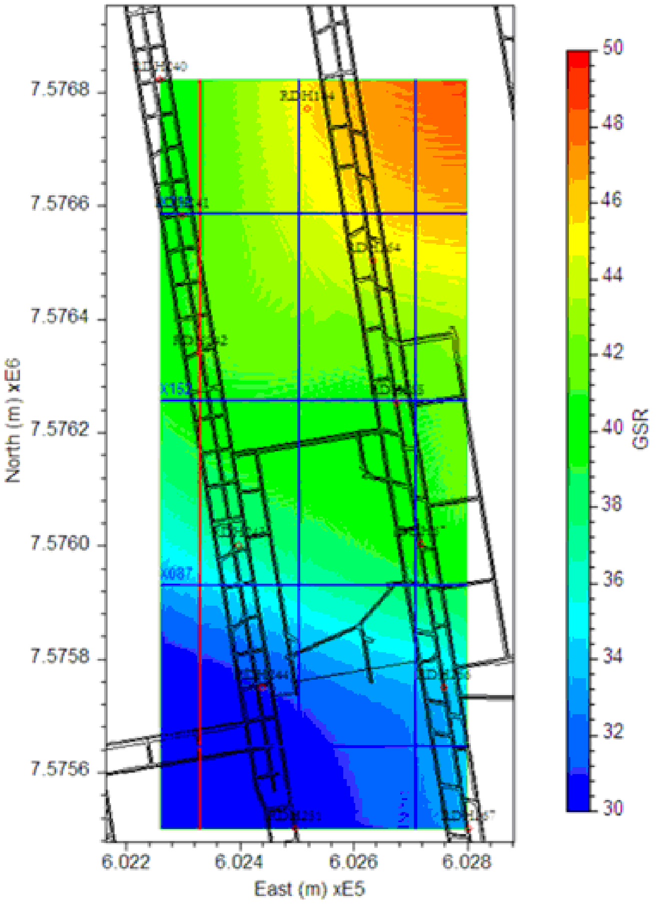

Figure 7 - Average GSR for 5 m interval above GMS working roof

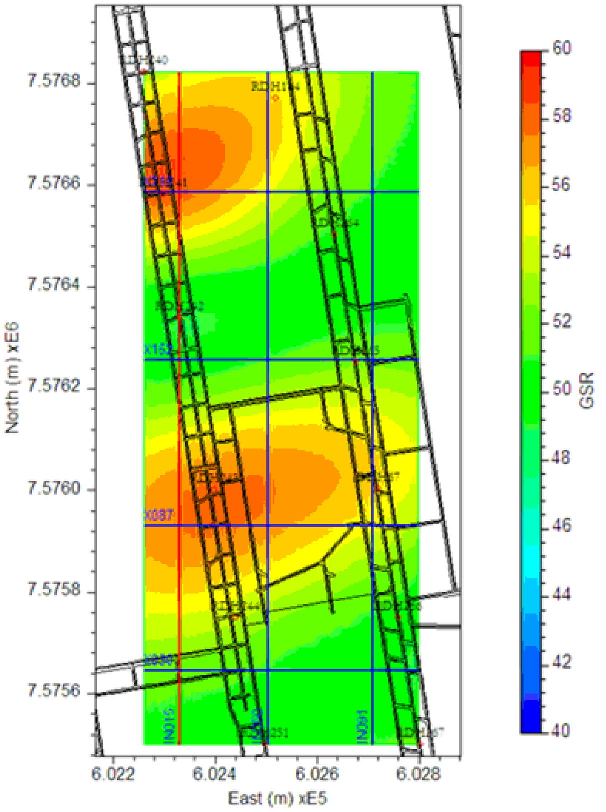

Figure 8 - Average GSR for 4 m to 14 m interval above GMS working roof

DISCUSSION AND CONCLUSIONS

This paper provides the key outcomes and an example of GSR analysis and modelling as undertaken in recently completed ACARP Project C17009. Further examples from GSR modelling from Newlands and Crinum mines are provided in the final report. At our three main investigation sites, our approach for determining the GSR provided a means to identify key strata characteristics that were known to have influenced mining performance. In each case the data used for the analysis was available and could have been used prior to mining.

The examples demonstrated highlight the use of GSR for overburden characterisation and hazard planning, tailgate stability and longwall face behaviour. Previous experience at other operations also shows that a GSR analysis is able to identify subtle changes in strata characteristics that can often be associated with strata control management issues.

The results show that borehole spacings of 200 m or thereabouts, which are typical of Bowen Basin underground operations, allow geologically meaningful 2D and 3D modelling of GSR and other parameters derived from the geophysical logs. Plots of clay content and porosity can be used, depending on their relevance to the given strata behaviour, and/or as alternative means of investigating geological features in the overburden sequence.

An approach for determining the GSR in coal and carbonaceous material has been successfully developed. In coal, the GSRi is inversely related to brightness as indicated by the ash content evident in density, natural gamma and sonic logs. GSR values were also shown to relate to other existing classification schemes, but arguably with more sensitivity to the weaker materials than present in the manual logging methods.

It is accepted that all strata characterisation schemes will have their strengths and weaknesses with regard to capturing key detail. However GSR analysis has several advantages over manual methods, which include

- Utilises large datasets of borehole geophysics data that exist at some sites
- Quantitative, repeatable analysis
- Provides a continuous record of strata conditions over the entire borehole column
- Complimentary assessment of both geological and geotechnical strata characteristics
- Information available in digital format
- Data suited to 2D and 3D modelling of overburden conditions
- Can be used to re-analysis old datasets
- Easy to update as new information becomes available
- Potential to enhance existing seismic datasets
- Compliments traditional borehole, sampling and testing programs

In general, the ability to capture the spatial variability in strata conditions is the key feature of GSR analysis. Such an approach is necessary to support current trends in resource development from initial scoping and project definition through to mine planning and production management. Different implementation strategies may therefore be required to incorporate GSR analyses depending on project requirements. In this regard factors such as data quality, borehole density and modelling technique have to be considered.

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REFERENCES

Hatherly, P, Sliwa, R. Turner, R. and Medhurst, T, 2003. Quantitative geophysical log interpretation for rock mass characterisation. *End of Grant Report*, ACARP Project C11037.

Hatherly, P, Medhurst, T. and MacGregor, S, 2008. Geophysical Strata Rating. *End of Grant Report*, ACARP Project C15019.

Hatherly, P, Gale, W, Medhurst, T, King, A, Craig, S, Poulson, B, and Luo, X, 2003. 3D stress effects, rock damage and longwall caving as revealed by microseismic monitoring. *End of Grant Report*, ACARP Project C9012.

Medhurst, T P and Brown, E T, 1998. A study of the mechanical behaviour of coal for pillar design. *Int. J. Rock Mech. Min. Sci*., Vol. 35, pp1087-1105.

Medhurst, T, Hatherly, P, Zhou, B. and Ye, G. 2009. Application of the Geophysical Strata Rating in Production Settings. *End of Grant Report*, ACARP Project C17009.

Tarrant, G. 2006. New Concepts in Tailgate Strata Behaviour and Implications for Support Design, PhD Thesis, unpublished, University of New South Wales.

Zhou, B. and Esterle, J., 2007. Improving the reliability of density and grade estimation from borehole geophysical log suites. *End of Grant Report*, ACARP Project C15036.

Zhou, B, Hatherly, P. and Sliwa, R, 2004. Integration of seismic data for mine planning. *End of Grant Report*, ACARP Project C11038.