Kestrel Coal has undertaken a surface-to-seam consolidation program of faulted ground prior to longwall retreat in the 304 panel. Micro fine cement is used to improve the rock mass quality and therefore reduce the risk to personnel and equipment whilst increasing previously assumed sterilised reserves. The program is based on information attained from previously successful grouting campaigns in the Queensland coal area and follows the decision making process to ensure there is sufficient spatial permeation of cement across the faulted area. This data is used to assess the residual risk to the business in terms of health, safety and production.

**INTRODUCTION**

Kestrel Mine is located 50km northeast of Emerald and 354km by rail from the Port of Gladstone (Figure 1). The mine is managed by Kestrel Coal Pty Ltd, a wholly-owned subsidiary of Rio Tinto Coal Australia. Kestrel is currently longwalling in the 2.6-3.3m thick German Creek Seam, at depths between 220 and 270 metres. Run of mine production for 2007 is budgeted at 3.7Mt. Achieving these levels of production requires a good understanding of the geological and geotechnical environment particularly when longwalling through known poor ground conditions. Kestrel has an established geotechnical database maintained since about 1997. However this geotechnical understanding does not include faulted ground and only anecdotal data from previous observations is captured.

Fault consolidation with micro fine cement to stiffen the rock mass prior to longwall mining has been a practice with variable results. Consolidating known poor geological conditions can provide for a safer working environment, but the difficulty for the coal operator is reconciling the effectiveness of consolidation post completion of the programme. With assistance from AMC Consultants, Kestrel Coal has followed a design process to minimise the residual risk for the operation both in terms of safety of personnel and economics. Operations with successful consolidation histories can also maximise previously assumed sterilised reserves.

Ground conditions at Kestrel can vary significantly over several hundreds of metres. Previous monitoring and data capture from the 100 and 200 series proved invaluable for designing of roof reinforcement systems and because of this roof control is maintained very well in the 300 series. This data uses both near seam roof lithology and geophysical logs to build strength contours across the mine lease (Figure 2).
Overview of the Issue

The Corvus Fault ("Fault") is a reverse structure that has previously been mined through in the longwall 301 to 303 blocks (Figure 3). The Fault has a two metre throw and a wide zone of broken weak rock and coal resulting with difficult mining conditions such as roof falls, high longwall cross grades and redistribution of insitu stress. The Fault continues through the 304 block and in order to minimise the risk to personnel during coal winning, a proactive strengthening of the fault zone is required. This is done with a targeted drilling program of pressurised grout consolidation from in-seam or surface-to-seam. The grouting provides for improving the rock mass quality. Grout will permeate under pressure to fill voids and close joints while reducing water flow and providing for adhesive strengthening.

Given the time constraints and the difficulty to access the 304 drilling site from underground roadways Kestrel Mine has undertaken consolidation from surface boreholes to an average depth of 230 metres.

Risk Management Process

Successful, but localised consolidation has been trialed previously at Kestrel from drilling off the maingate in the 303 panel. Previous to this trial mining through the unconsolidated fault in 301-302 and part of 303 panels resulted in a combined downtime of eight weeks. Kestrel has decided on an engineering approach for consolidation in the 304 longwall panel and has followed the decision process defined in Figure 4.

EXPLORATION PHASE FOR FAULT CHARACTERISTICS

Overview and Aims

The Fault is a reverse fault aligned obliquely to the 300 panels. It enters the 304 tailgate road with a throw of 2m then exits the block at the maingate as two separate faults with throws of 0.6 and 0.5m. The Fault was intersected in the 301-304 gate roads during development and roof and rib conditions in these headings were generally poor for approximately 5m on either side of the fault plane. The roof was typically friable with highly interbedded sandstone and siltstone. Fault delineation data was attained on development, however this was deemed insufficient when designing the consolidation borehole pattern. To accurately design a drilling program to determine the geometry of the structure, a radio imaging survey V4 (RIM) was completed in March 2007. The primary aims of this program were to:

- provide for an estimate of the disturbed coal zone about the Corvus Fault;
- determine other geological anomalies through the panel;
- determine coal seam thickness and geometry; and
- provide background RIM data that can be correlated to mining history and subsequent confidence in the interpretation.
A secondary aim of this program was to assess the suitability of RIM as a central tenet of a future geological risk management process for Kestrel.

The RIM study was completed by Stolar Horizon Ltd, with assistance from Kestrel personnel over a two day period. An initial calibration survey was undertaken followed by a 90kHz tomography survey for a zone 0-450m from the LW304 takeoff line. A second 90kHz reconnaissance survey was undertaken of the entire 4km block to determine a background response for the panel.

Several RIM anomalies are measured through the targeted area and correlate with discrete high level attenuation rate increases. A trough in the signal profile across the block indicates a major in-seam discontinuity. There are also at least three minor troughs (low dips in signal) which are not associated with the faulting and may represent smaller anomalies in the seam or changing roof conditions. These three distinct signal drops appear as attenuation increases confined to local areas at chainage markers 40m, 310m, and 390m (Figure 5).

**Interpretation of tomography** - This major attenuation rate increase across the block is indicative of an in-seam feature localised in the centre of the panel (Duncan 2007). The dataset correlates well with observations made in the gate roads and the general geometry of the structure is commensurate with a regional en echelon type North-South primary and NE-SW secondary strike type faulting (Figure 6). The anomaly decreases in severity moving inbye. This attenuation anomaly results from the known faulting zone in this area. Its position near the tailgate and average strike, are shown as expected. However the shape near the centre of the fault, and moving towards the maingate rib is complex and discontinuous.

**DETERMINATION OF GROUND CONDITIONS**

Borehole geophysics to interpret geotechnical conditions follows that of Medhurst and Hatherly (2005). Five boreholes were sunk on each side of the fault structure to determine the mineability of the fault structure. The boreholes were sunk to understand the:

- geotechnical characterisation of the faulted area;
- inferred strength through measured sonic velocities;
- planar features in the immediate roof through acoustic scanner logs;
- permeability; and
- grout uptake.

Permeability and grout uptake are important when reconciling the effectiveness of post permeated pressure grouting and to decide on the location and spacing of boreholes.
Field testing program – the location of the five boreholes are shown in Figure 7. All boreholes were geophysically logged with gamma, density, and calipers. Sonic velocities were only attained for three boreholes (3239, 3241, 3242). All boreholes collapsed inwards hours after initial drilling. It became apparent that the overlying Corvus Seam was collapsing due to either poor ground conditions or abutment loading from nearby goafed panels. The first 10m of non-coal lithology was targeted for pressure grouting. Caliper results from all of the boreholes show that the German Creek Coal maintains a consistent borehole morphology.

Figure 7: Borehole locations for determination of ground conditions.

Geophysical results – Inferred UCS values attained from 3239-3242 drilling determine the 20cm velocity of the immediate two metre roof section of the faulted zone is in the order of 3300-3500ms\(^{-1}\) (85-92\(\mu\)s/ft). A site specific database has been established at Kestrel to characterise roof and floor strengths and typical values are indicated in Table 1. The lithology 6m immediately overlying the German Creek Seam has inferred composite UCS value of approximately 20-30MPa. This is moderately lower for interbedded sandstone/siltstone values from this coal area and indicative of weak shale type bands with the potential to fail with abutment loading as bedding plane shear.

Table 1: Typical sonic transit times and corresponding strength data at Kestrel after Gordon (2000) and Coffey Partners (1999).

<table>
<thead>
<tr>
<th>Depth into roof above German Creek Seam</th>
<th>Sonic Transit Times</th>
<th>Typical Strength (MPa)</th>
<th>Strength Range (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof (0-2m)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>85(\mu)s/ft ± 5(\mu)s/ft</td>
<td>30</td>
<td>21-38</td>
</tr>
<tr>
<td>2</td>
<td>90(\mu)s/ft ± 10(\mu)s/ft</td>
<td>20</td>
<td>11-38</td>
</tr>
<tr>
<td>3</td>
<td>90(\mu)s/ft ± &gt;15(\mu)s/ft</td>
<td>15</td>
<td>10-20</td>
</tr>
<tr>
<td>4</td>
<td>Average 95(\mu)s/ft ± 2 or more zones of &gt;15(\mu)s/ft departure</td>
<td>12</td>
<td>10-15</td>
</tr>
<tr>
<td>5</td>
<td>&gt;95(\mu)s/ft</td>
<td>7.5</td>
<td>2-12</td>
</tr>
<tr>
<td>Roof (2-6m)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0-0.5m &gt;100(\mu)s/ft</td>
<td>30</td>
<td>&gt;30</td>
</tr>
<tr>
<td>2</td>
<td>0.5-1.5m &gt;100(\mu)s/ft</td>
<td>25</td>
<td>20-30</td>
</tr>
<tr>
<td>3</td>
<td>1.5-2.5m &gt;100(\mu)s/ft</td>
<td>15</td>
<td>10-20</td>
</tr>
<tr>
<td>4</td>
<td>&gt;2.5m &gt;100(\mu)s/ft</td>
<td>10</td>
<td>&lt;10</td>
</tr>
<tr>
<td>FLOOR (0-2m)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>&lt;90(\mu)s/ft</td>
<td>20</td>
<td>&gt;20</td>
</tr>
<tr>
<td>2</td>
<td>90-100(\mu)s/ft</td>
<td>15</td>
<td>12-20</td>
</tr>
<tr>
<td>3</td>
<td>100-110(\mu)s/ft</td>
<td>10</td>
<td>10-12</td>
</tr>
<tr>
<td>4</td>
<td>110-125(\mu)s/ft</td>
<td>9</td>
<td>7.5-10</td>
</tr>
<tr>
<td>5</td>
<td>&gt;125(\mu)s/ft</td>
<td>5</td>
<td>&lt;7.5</td>
</tr>
</tbody>
</table>

A rock mass quality rating is derived from a Geophysics Strata Rating (GSR) where measured velocity, porosity and shale content are factored to determine a subsequent Coal Mine Roof Rating (Figure 8). Kestrel has a well defined data set and analysis of the three boreholes around the fault suggests a CMRR of between 42-50. Figure 9 shows a typical quantitative geophysical log with a distinctive offset in porosity and velocity and shale content at the 0.8m and 1.6-2m section above coal. This is evident in two of the three holes and suggests a weak, laminated shale immediately in the primary horizon, a key target for consolidation.

Figure 8: Geophysics strata rating (after Medhurst and Hatherly, 2005).

Figure 9: Geophysical Log analysis of borehole 3241
**Acoustic Scanner Results** – Inferred UCS values attained from 3239-3242 drilling determined the location and orientation of fractures in the immediate roof. The acoustic scanner log is used here as a replacement due to the loss of coring capability during the borehole program. Figure 10 is a typical profile for borehole 3241. The roof depth of the German Creek Seam is 231.7m and the immediate roof shows slumping at depth 229.6m correlating well with the sonic velocity. The rock quality in the primary roof horizon (2m above coal) is weak and subject to stress induced breakout. There is no significant reorientation of laminates above the coal.

**GEOTECHNICAL DISCUSSION**

The interburden between the Corvus Seam and the top of the German Creek Seam ranges from 15-20m. The Corvus Seam is typically weak broken coal with high permeability. Both the acoustic scanner and sonic velocity show that there is a moderate level of fracturing of weak shale with high porosity in the primary roof of the cutting horizon of the longwall. Therefore Kestrel Mine has targeted 10m above the immediate roof for consolidation and cable reinforcement. Cable reinforcement with either cuttable dowels or steel will provide some capacity to reduce the height of softening and large larger scale failures as the longwall retreats.

The Fault was observed to rotate and align parallel with the Longwall face in the 301-303 panels. This became problematic as in the centre of the block, tensile forces due to side abutments are maximised. In all three previous panels it was the centre of the block where roof control was lost. This reorientation is not evident about the Fault and this has been considered in the design of the 304 consolidation program.

**RISK MANAGEMENT**

The decision to consolidate faulted or poor ground conditions is a risk based assessment that requires determining a balance between several factors. These include:

- an understanding of the geometry of the fault and the ground conditions;
- the likelihood of grout take in the fault and potential for ground improvement;
- the cost of the pre-consolidation effort;
- assessment of alternatives such as relocating the longwall around the fault; and
- time constraints and associated impact on production continuity.

The latter of these factors can usually be readily quantified and form part of the assessment. The first two are more subjective, however the investigative effort described in this paper allows a comparative analysis of ground conditions near the fault against areas where successful mining has previously been undertaken.

The likelihood of grout take and potential for ground improvement is the most difficult question to answer. In this regard, comparison of ground conditions at Kestrel with other mines that have undertaken fault consolidation programs is the best available option. Medhurst and Barton (2007) provide results of a recent research project aimed to assess faulted areas to determine the need or otherwise for grouting and their likely impact on mining performance. This work provides an assessment of fault type and throw, fracture spacing and fault permeability as a guide to the need for grouting.

Using these guidelines, the Fault is classified as a complex fault system with at least two faults and maximum throw less than 2m. Fracture spacing is measured at less than 5m and permeability greater than 2 Lugeons. Under such conditions a comprehensive pre-consolidation and reinforcement program is recommended.

**CONCLUSIONS**

The geotechnical environment at Kestrel Mine is characterised by variable roof lithologies and associated range of roof strengths. Faulting at Kestrel is typically low to moderate with only a few faults projected spatially across the mine lease. However, the location of these faults are orientated in such a way that in order to maximise recovery and maintain an acceptable level of risk, some of these structures must be mined through.

The RIM study showed acceptable signal levels with an operating frequency of 90kHz. The study shows a geological anomaly consistent with the geological interpretation from development headings. Geophysics and acoustic scanner logs provided for fracture density and orientation and can provide for reconciliation with post consolidation boreholes. Inferred UCS values from sonic velocities and geophysical strata rating shows at least two weak shale horizons in the immediate roof. The acoustic scanner shows...
borehole breakout is evident at this depth but reorientation of the lithology is generally less than 4°.

A process to reduce the residual risk to personnel and equipment at Kestrel has provided information that will be used in consolidation design and reconciliation of that design.

ACKNOWLEDGEMENTS

The authors would like to thank Stolar Horizons Ltd and particularly Joe Duncan for their efforts during the RIM survey.

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