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Mining Geomechanics and Materials Engineering

A.B.N. 40 056 752 606

18 February, 2013

Coalpac Pty Ltd
42 Morrow Street
Taringa
QLD 4068

Attention: Ian Follington, Bret Leisemann

Dear Ian & Bret,

RE: DEFINITION OF BARRIER PILLAR STABILITY

In response to your request of last Friday to address specific aspects referred to in the draft document entitled "Review of highwall mining component – Coalpac Consolidation Project" by Bruce Hebblewhite [1] this letter provides further discussion on the following two topics:

a) Definition of the actual Factor of Safety for each barrier pillar under worst case conditions, and
b) Effect of variable pillar width.

Barrier Pillar Factor of Safety (FoS)

In order to define the barrier pillar stability the same design method described in the GEONET report [2] to estimate the stability of highwall mining pillars has been modified. In this case the stability is calculated in relation to the width of the barrier pillar (Wp) and the span between barrier pillars (equivalent to the highwall mining opening dimension). This approach presents an absolute limiting condition in that it assumes that there are no highwall mining (web) pillars between barrier pillars. The calculation therefore is calculating the stability of the barrier pillar subject to loading induced by the overburden stress arch that would form between adjacent barrier pillars.

Using the appropriate variables for each coal seam, viz. overburden thickness (O/B), extraction height (Hp), pillar width (Wp) and span between barrier pillars (Sp) the limiting Factor of Safety is calculated. The results are presented as design charts in Figures 1(a), 2(a), 3(a) and 4(a) for each seam, respectively, and summarised for the recommended barrier pillar width in Table 1.

Table 1: Summary of barrier pillar dimensions and calculated limiting Factor of Safety.

Seam	O/B (m)	Hp (m)	Wp (m)	Sp (m)	Limit FoS
Katoomba	80 - 110	2.0	10.7	17.7	3.69 – 2.68
Moolarben	80 – 135	1.0	7.2	23.4	2.90 – 1.72
Irondale	100 – 165	0.9	7.8	27.0	2.57 – 1.56
Lithgow	150 - 185	2.2	12.7	19.7	2.17 – 1.76

These calculated limiting Factors of Safety present the absolute minimum and indeed artificially low values since the presence of the highwall mining web pillars will provide additional support to the overburden under the stress arch. In order to provide a more realistic estimate of the actual Factors of Safety that will be presented we have interrogated the original geotechnical model for stress conditions at the elevation of each seam.

The Factor of Safety (FoS) in any zone within the model may be calculated according to the local stress conditions and assigned shear strength properties using the following relationship:

$$FoS = (\sigma_{1critical} - \sigma_3) / (\sigma_1 - \sigma_3)$$

where

$$\sigma_{1critical} = [2c \cdot \cos\varphi / (1 + \sin\varphi)] + \sigma_3 \cdot [(1 + \sin\varphi) / (1 - \sin\varphi)]$$

where

φ is friction angle, *c* is cohesion,

σ_1 and σ_3 are the major and minor principal stresses, respectively.

The calculated Factor of Safety at the elevation of each coal seam, based on insitu stress conditions, is plotted in Figures 1(b), 2(b), 3(b) and 4(b) for each of the coal seams, respectively. On these plots the contour interval is 0.2 between the values 1<FoS<5. If the calculated FoS is greater than 5 then the contour is coloured white (appears grey in Figures). It can be seen that the range of FoS varies depending on overburden topography. Quite clearly the calculated FoS values are predominantly in excess of 5.0 with very small localisations of reduced values.

In the area of proposed highwall mining, Table 2 summarises the predicted upper bound principal stress magnitudes in each coal seam and tabulates the calculated representative Factor of Safety. If the average stress levels are considered then the FoS values are up around 10.

Table 2: Summary of barrier pillar stress conditions and calculated actual Factor of Safety.

Seam	**RL (m)**	**σ_1 (MPa)**	**σ_3 (MPa)**	**FoS**
Katoomba	960	4.73	1.74	4.83
Moolarben	940	6.18	2.53	5.00
Irondale	905	8.20	3.86	5.69
Lithgow	885	1.40	6.00	4.38

It is concluded that the proposed barrier pillar designs for each of the coal seams will provide more than adequate long term stability.

Effect of Variable Pillar Width

Highwall Mining Equipment manufacturers quote that the onboard directional monitoring controls should maintain accuracy of approximately 100mm either side of the target direction. This suggests that pillar dimensions should be accurate within 200mm of design width. The overall effect of a deviation from target direction may be either thinning or thickening of the immediate pillar depending on direction of deviation. However, accompanying this thinning or thickening of the pillar will be a corresponding thickening or thinning of the next pillar.

The number of web pillars which may be affected by directional offset will be limited by the barrier pillar spacing. It was shown in the previous section that the absolute limiting FoS of the barrier pillars will provide sufficient stability to arrest any instability that may arise from web pillar variations. This design precaution will provide more than sufficient pillar width to cope with a possible 200mm offset in pillar dimension.

These conclusions have been analysed in previous studies where pillar deviation and azimuth offset only impacted on the pillar strength once there was significant deviation from design layout. In this regard lateral deviations of 10% pillar width and vertical offsets of 30% opening height could be tolerated in a highwall mining panel layout.

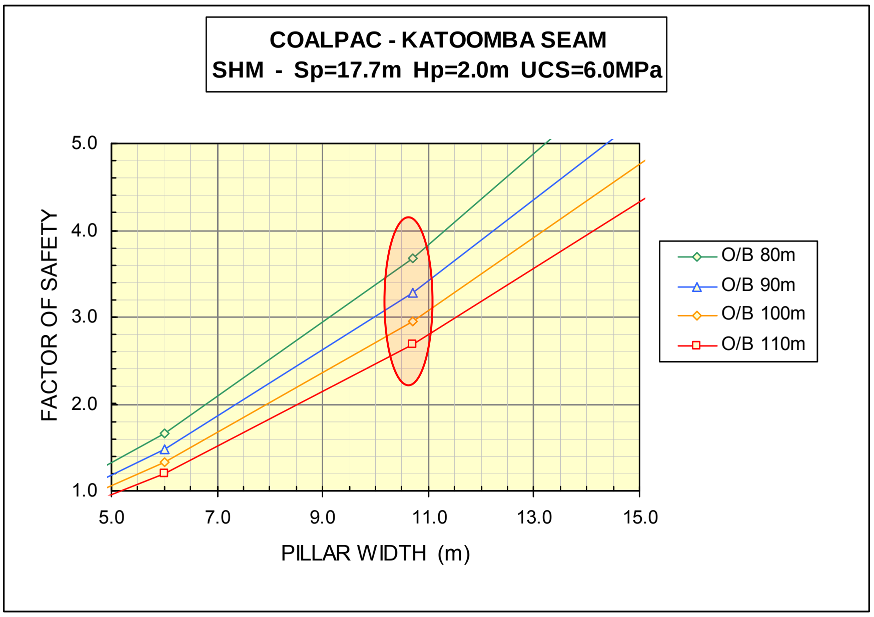

Figure 1(a): Limiting Factor of Safety in Katoomba seam highwall mining panels.

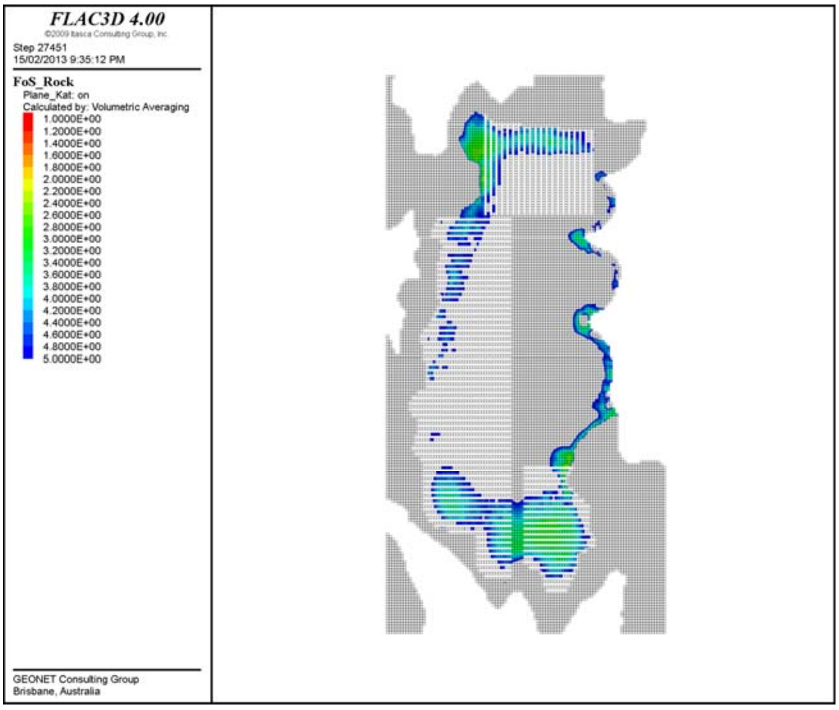

Figure 1(b): Simulated Factor of Safety in Katoomba seam highwall mining panels.

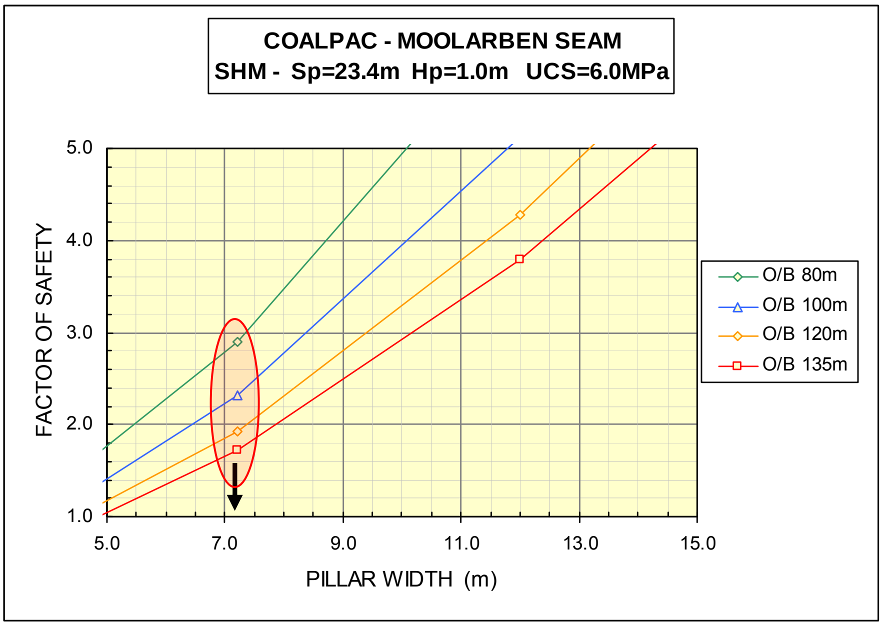

Figure 2(a): Limiting Factor of Safety in Moolarben seam highwall mining panels.

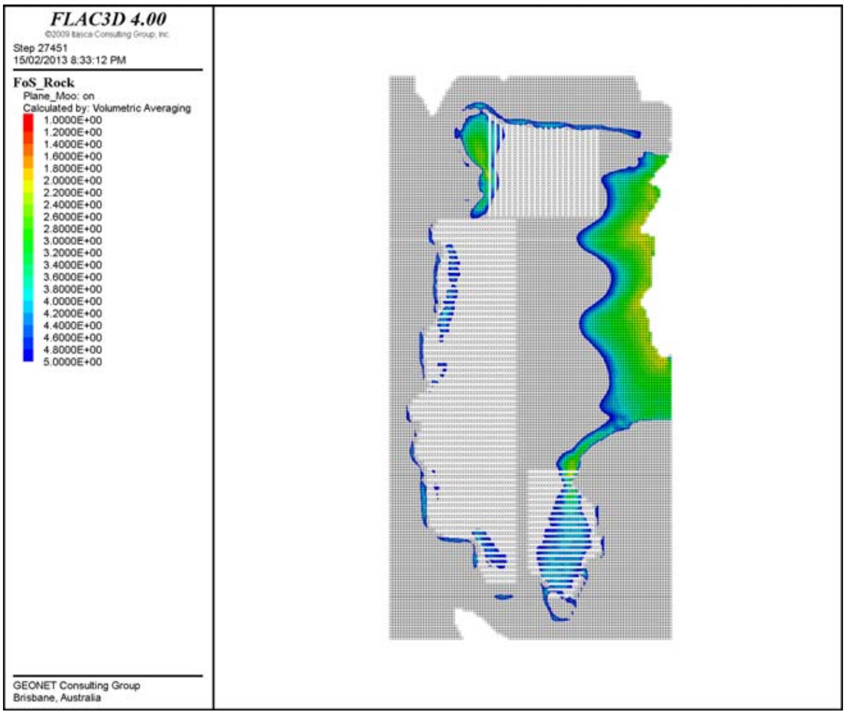

Figure 2(b): Simulated Factor of Safety in Moolarben seam highwall mining panels.

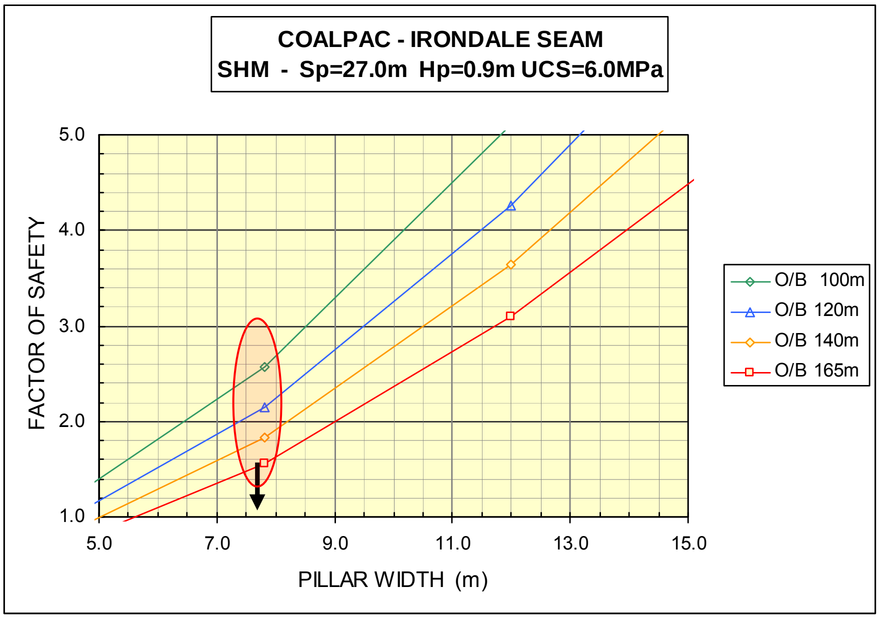

Figure 3(a): Limiting Factor of Safety in Irondale seam highwall mining panels.

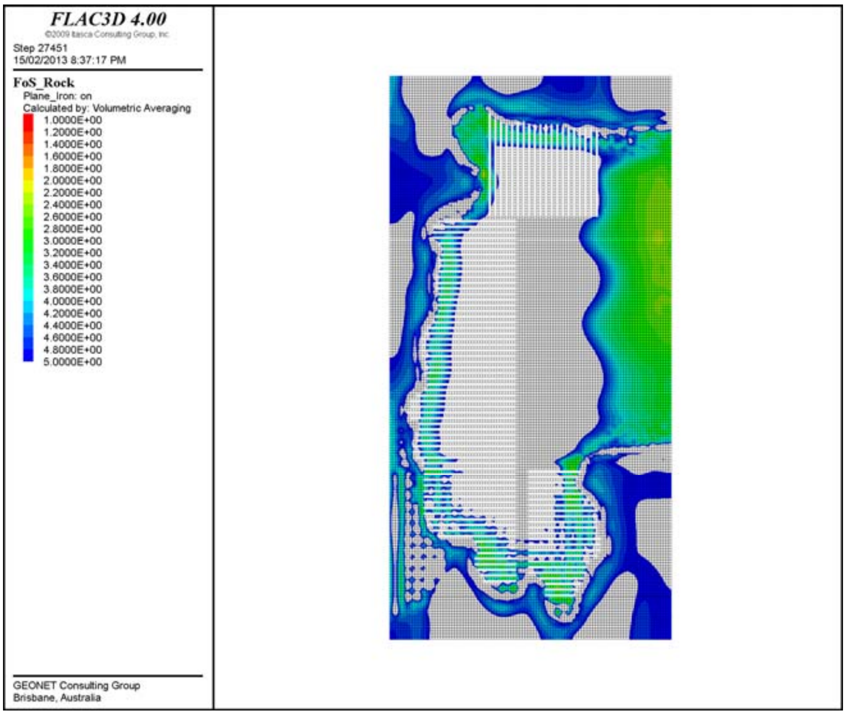

Figure 3(b): Simulated Factor of Safety in Irondale seam highwall mining panels.

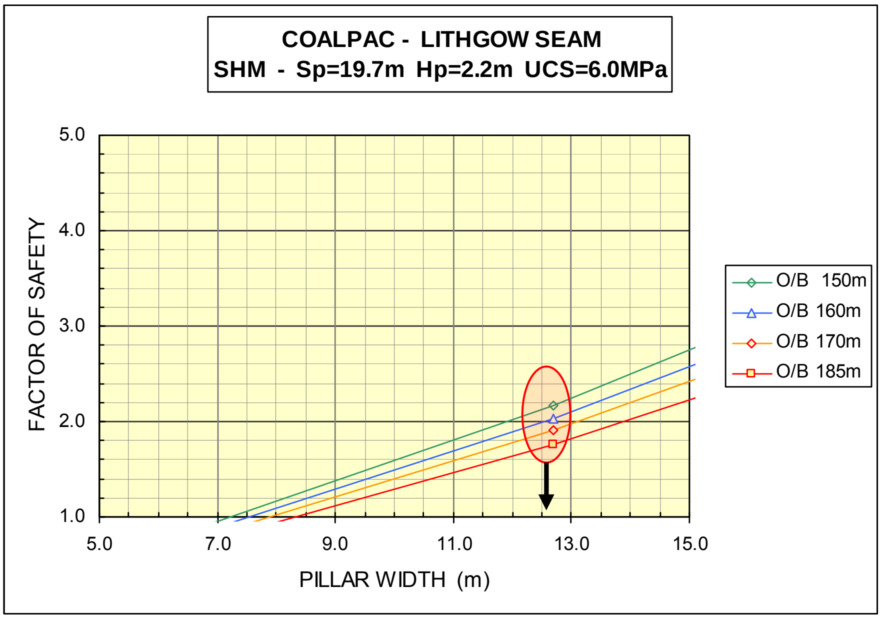

Figure 4(a): Limiting Factor of Safety in Lithgow seam highwall mining panels.

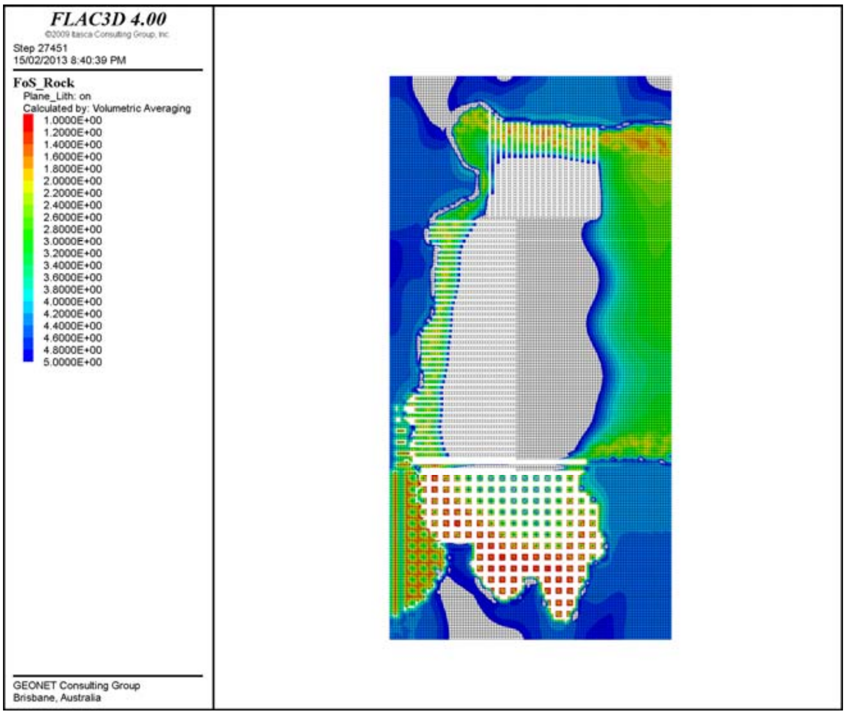

Figure 4(b): Simulated Factor of Safety in Lithgow seam highwall mining panels.

I trust that this brief review of the barrier pillar design stability provides you with the explanations called for to explain aspects of the original geotechnical modelling report.

Yours faithfully,

GEONET *Consulting Group*

Dr Ian H. Clark

Principal Consultant, Director

REFERENCES

1. Hebblewhite, Bruce K., 2013. Review of highwall mining component – Coalpac Consolidation Project. Draft report to Coalpac, 14 February 2013.

2. GEONET Consulting Group, 2011. Assessment of Stability and Subsidence SHM Highwall Mining, Coalpac Consolidation Project.

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27 February, 2013

Coalpac Pty Ltd
42 Morrow Street
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Attention: Ian Follington, Bret Leisemann

Dear Dr Follington and Mr Leisemann,

Slope Stability Assessment of Sandstone Cliffs Next to Proposed Open Cut Mining, Invincible and Cullen Valley Mines

1 Introduction

This report presents an assessment of the slope stability of the sandstone cliffs next to proposed open cut mining to be carried out as part of the Coalpac Consolidation Project (CCP), and a suggested method for monitoring the cliffs that may form part of the mine's Slope Stability Management Plan.

As shown in Figure 3, open cut mining may approach to within 60 m of the sandstone cliffs and create temporary mine highwall rock faces up to 100 m in height for short periods before they are backfilled and rehabilitated. This assessment has focussed on the stability of the open cut highwalls and the cliffs behind them while the highwalls are at their maximum exposure (i.e. a worst case scenario).

2 Qualification to Provide this Assessment

My qualification to carry out this assessment is based on:

- Formal qualifications
- Extensive geotechnical experience
- Specific involvement with the Invincible and Cullen Valley open cut mines since 2007.

My résumé is appended to this report.

My formal qualifications are:

- BSc in geology awarded by the UNSW
- MEngSc in geotechnical engineering awarded by UNSW

I am a member of the Institution of Engineers Australia, Australasian Institute of Mining and Metallurgy and a Chartered Professional Engineer.

My general geotechnical experience spans over 30 years. For the last 12 years I have been the owner of GeoTek Solutions Pty Ltd (GTS), a geotechnical consultancy that specialises in open cut mining slope stability. The greatest number of projects undertaken by GTS have been for open cut coal mines in NSW and Queensland.

Since 2007, I have been engaged by Coalpac to carry out routine inspections of the Invincible and Cullen Valley open cut mines. These inspections are part of Coalpac's Slope Stability Management Plan and have never been triggered by any untoward event.

The current geotechnical inspection regime is for an inspection to be carried out at approximately annual intervals. This interval has been selected because of the benign geological conditions that pertain to the Project. During these inspections the whole of the Project is inspected, usually over a two day period, with a particular emphasis on the condition of the pit highwalls and dumps. At the conclusion of the inspection a report is prepared.

3 Geology

The Project is located on the western margin of the Sydney Basin. The rocks exposed in the Project area comprise a variable thickness capping of Triassic age sandstone belonging to the Narrabeen Group. The Narrabeen Group unconformably overly interbedded sandstone and mudstone belonging to, in descending order, the Wallerawang, Charbon and Cullen Bullen Subgroups within the Illawarra Coal Measures of Permian age (Yoo et al, 2001)

The sandstone capping consists mostly of well-cemented, cross-bedded, medium and coarse grained sandstone composed mainly of quartz grains and subsidiary lithic fragments. The intact rock is generally of medium strength (estimated UCS typically 25 to 35 MPa). By way of comparison, the required strength for house-slab concrete is typically 20 to 25 MPa. The sandstone is usually dissected by very widely spaced, near-vertical joints and, because the rock is so strong, it forms cliffs rather than weathering to a much flatter slope like the underlying Permian strata. The cliff lines tend to follow the dominant joint directions. Where the sandstone is sufficiently thick, cliff faces are generally 40 to 60 m high but may, locally, be higher. A typical cliff is shown in Figure 1.

Figure 1 Typical cliff in Narrabeen Group sandstone.

The underlying, Permian age, coal measures rocks consist of sandstone, mudstone, tuff and coal seams. The estimated intact strength of the coal measures rocks vary with rock type but typically, range from 15 to 25 MPa.

The strength of the intact coal measures rocks is, on average, slightly less than that of the Narrabeen Group sandstone. However, as can be seen in Figure 2, the strength of the rock mass is more than adequate to support an 80 m high, sub-vertical highwall.

The two main structural features of the coal measures strata are:

- Bedding, which dips on average, at a gradient of about 1 in 80 in an easterly direction, consistent with the Project being located on the western margin of the Sydney Basin,
- Joints, predominantly orientated parallel and perpendicular to the strike of the coal seams but with other orientations in addition.

The joints are more frequent and more closely spaced in the weaker, less-brittle coal measures rocks than in the stronger, more-brittle Triassic sandstones. A consequence of this is that if a failure does occur on a joint plane in the coal measures, then it is likely to be of limited extent, as the failure surface quickly terminates against intact rock.

There are a few very small (<0.2 m in displacement) faults within the Permian strata at Cullen Valley Mine and Invincible Colliery, but generally the strata are undisturbed by geological structure.

Figure 2 Cullen Valley showing a stable, 80 m highwall face cut at an angle of approximately 80°.

When subject to weathering and erosion over geological time, the coal measures rocks are much less resistant than the Triassic sandstone and tend to break down to a soil that is transported downhill, thereby forming the gentle side slopes leading down into the valleys. In so doing, this undercuts the Triassic sandstone cliffs, eventually causing slabs of rock to break off, usually along pre-existing joints, to form piles of rubble in front of the cliff face. Initially, the rubble rests at angles of 30° to 35°. In the short term these slopes are stable but, in the long term, i.e. tens and hundreds of years, the colluvium slowly creeps downhill, as can be inferred from the frequent tilted trees that can be seen around the base of the cliffs. This process of slope development and valley retreat is occurring much more slowly now than during the geological, past when there were periods of much higher rainfall.

Apart from valley side slope retreat, there are a variety of other weathering and erosion processes at work that are degrading the in situ rock and transporting the resultant soils towards the valley floors. However, in the context of the current mining proposal, the key feature is that within the framework of our geological and engineering knowledge, and observationally, the Triassic sandstone cliffs are essentially stable, and properly excavated highwalls in the Permian strata are also stable.

In the following sections, the results of 2D limit equilibrium slope stability analyses are produced to further support the assertion that slopes are stable in the short term.

4 Highwall Design for CCP

Figure 3 shows a cross section when the mining highwall under the proposed CCP is at its closest to the sandstone cliffs.

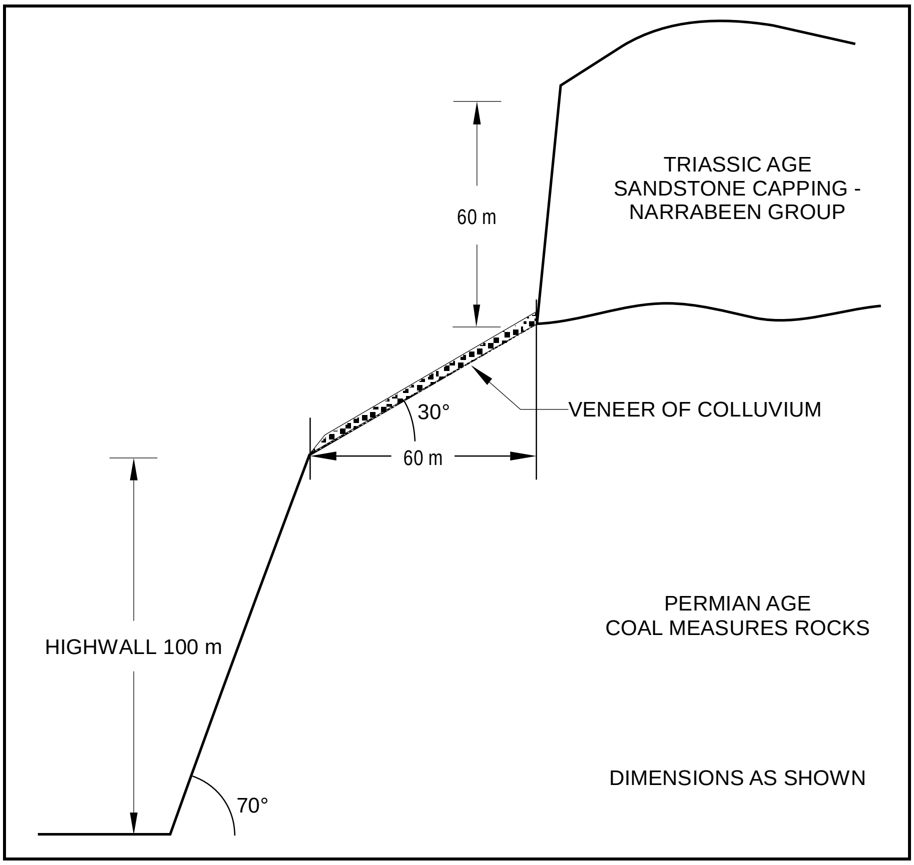

Figure 3 Cross section showing relationship between cliff-forming sandstone, coal measures rock and mining highwall under the proposed CCP.

Key features shown in the cross section are:

- The Triassic sandstone cliff face is 60 m distant from the highwall crest
- The colluvium slope has a maximum angle of 30°
- The highwall slope angle is 70°. (Note, while slopes between bench levels are 80°, the overall slope becomes 70° once catch-benches are included). It is excavated wholly within the coal measures rocks and, as shown in Figure 2, these are perfectly capable of standing upright to heights in excess of 100 m, provided that they do not contain any unfavourable geological structures, which is the normal situation.)

5 Slope Stability Analyses

A number of slope stability analyses were undertaken using the program Slide (Rocscience, 2013). The General Limit Equilibrium (GLE) method was used as the primary method of analysis and results were checked for reasonableness by also running the analysis using the Bishop Simplified method. The results are shown in the output plot in Figure 4 below.

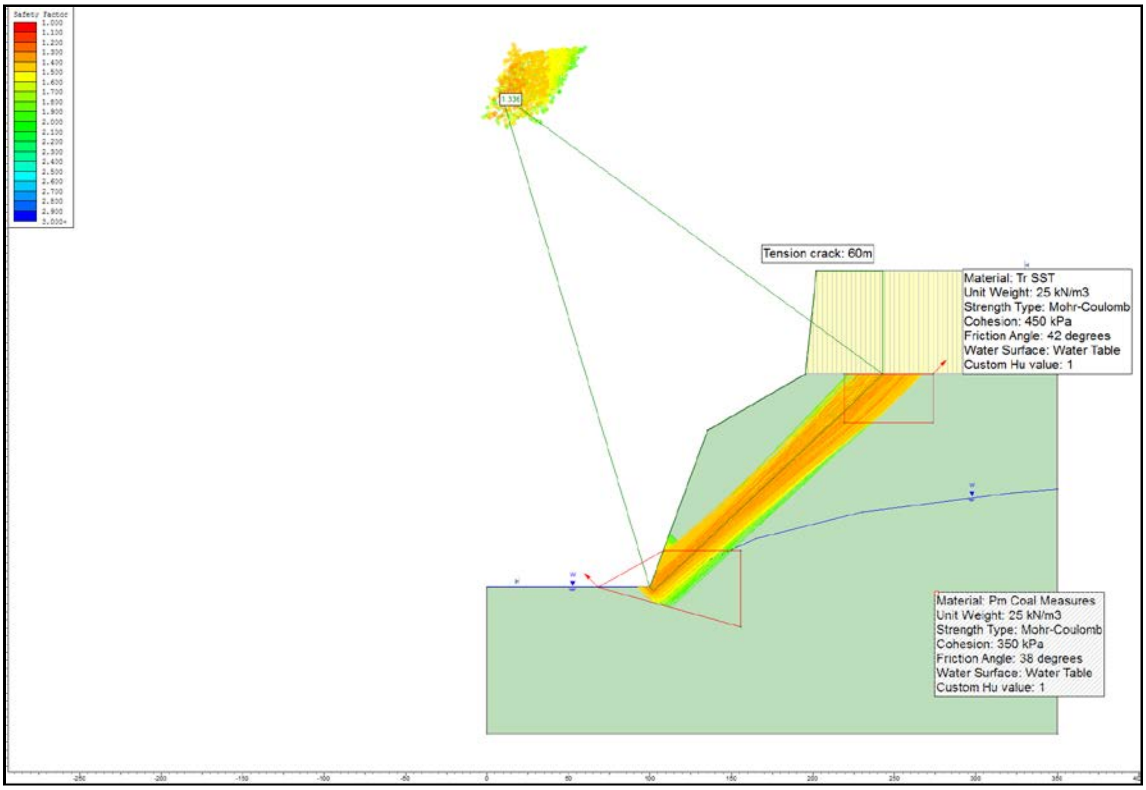

Figure 4 Output from slope stability analysis.

The GLE method was used to analyse randomly generated non-circular failure paths using blocks, which are shown in Figure 4, to define broad zones for the crests and toes of the failure paths.

An anisotropic strength model was trialled because the coal measures rocks are so well bedded. However, this made little difference to the calculated factor of safety (FOS) because the bedding is so flat within the Project area.

The results show that the minimum global factor of safety for the selected profile is 1.36. To put this in context, the normally accepted FOS for a short-term mining slope under which people will work is 1.2, and for a slope carrying critical infrastructure required for the life of mine the design FOS would be about 1.3. Given that the final mining highwall proximal to the cliff line is expected to be fully exposed for periods on the order of 8 to 12 weeks before backfilling begins, it is considered that the temporary highwall design, as shown in Figure 3 and Figure 4, is appropriate and will not cause a failure of the overlying cliffs. Backfilling the highwalls is part of the normal excavation and dumping sequence that has been utilised for over 10 years at these mines. Backfilling ensures the stability of the excavated highwall face by acting as a buttress, effectively and proactively supporting the newly created excavation, and increasing the FOS on the highwall slope.

As in all mining operations, regular checks for conformance of field conditions with design assumptions is a necessary and routine requirement. Excavation of these highwalls is no exception and the following section provides guidelines for monitoring the highwalls and the cliff faces.

6 Impact of Existing Underground Workings

Before Coalpac commenced open cut mining at the Invincible Colliery extensive underground mining had been carried out using bord and pillar methods within the Lithgow Seam. These historical underground mine workings extend on the order of 2 km beyond the Triassic sandstone cliff line in places. The recovery from this method of mining is relatively low and the width of the pillars left behind ensures the stability of the workings. I have inspected sections of the Triassic Cliffs on two occasions on foot, in 2008 and in 2012. On those occasions I observed no evidence mining induced rockfalls.

The observed cliff behaviour is consistent with my observations during routine geotechnical inspections that the damage to the strata above the old bords (tunnels) rarely extends more than 3 or 4 times the height of the bord, as shown, for example in Figure 5. There may be some immediate roof collapse as shown in the LHS of Figure 5 but not above the old bord on the RHS of the figure. Within a short distance above the roof, arching has occurred, and no further deformation of the roof strata occurs.

Figure 5 View of highwall intersecting old coal mine workings.

The strength and arching behaviour of the roof strata and the relatively low coal recovery from the historical workings, together with the benign structural geological conditions within the Project area also explain why there has never been a recorded failure caused by a highwall intercepting old workings.

7 Monitoring Guidelines

7.1 Highwall Monitoring

Three principal recommendations are made for monitoring the highwalls.

1. The mine geologist should carry out a detailed inspection of the highwall on a minimum weekly basis and record their observations in a permanent record once a highwall is within 150 m of a sandstone cliff. This record would be in addition to the current inspection reports provided by the OCE and would focus specifically on the geological and geotechnical conditions that were being exposed in the advancing highwall, including:
    - Rock strength
    - Bedding orientation and spacing
    - Joint orientation and spacing
    - Whether any faults are present and if so, their orientation
    - Groundwater seepage
    - The nature and significance of any rockfalls in the advancing highwall.
2. Develop a site-specific check list with objective parameters and criteria that would trigger specified action responses. The responses would range from “do nothing” to “obtain specialist external advice on-site within one week”.
3. Increase the routine geotechnical inspections from the current annual interval to quarterly. Additional inspections would be carried out should a response to a trigger action, referred to above, require it.

7.2 Sandstone Cliff Monitoring

It is recommended to create a cliff line condition geographical information system (GIS). The GIS would facilitate the recording, managing, analysing and displaying of the condition of the sandstone cliffs proximal to the CCP. To generate the data required by such a GIS it will be necessary to record the location and condition of each element of the cliff line in sufficient detail that the condition survey can be replicated. A combination of a handheld GPS, a photographic record, inspection check lists and appropriate maps should be sufficient to build up the cliff line condition GIS.

Initially the cliff line condition should be assessed annually. As mining approaches to within 200 m of a section of cliff line, that section of the cliff line should be assessed every 3 months. Once mining has moved away from a section of cliff line and the highwall has been backfilled, the inspections should revert to annual assessment.

Two years from the completion of final rehabilitation of an affected section of cliff line, provided no damage has been observed, the inspection frequency can be reduced to every two years.

8 Conclusions

I have concluded, on the basis of geological engineering principles and 5 years direct experience with the Cullen Valley Mine and Invincible Colliery, that the proposed highwall designs are adequate to prevent mining induced damage of the Triassic sandstone cliffs.

A limit equilibrium slope stability analysis has been carried out of the worst-case mining scenario and this calculated a minimum global factor of safety equal to 1.36, which is more than acceptable for a temporary mining slope with people working below it.

A highwall monitoring procedure has been recommended requiring weekly inspections when a highwall is within 150 m of sandstone cliffs, the development of site specific trigger action responses, and an increase in the frequency of inspection by a geotechnical expert from the current level of annual inspections to quarterly inspections.

A cliff line condition monitoring procedure has been recommended that involves regular, documented surveys of the condition of the Triassic sandstone cliffs and recording those observations in a geographical information system (GIS).

BSc MEngSc MIEAust CPEng
Principal, GeoTek Solutions Pty Ltd

9 References

1. Yoo, E.K., Tadros, N.Z., Bayly, K.W., 2001. A Compilation of the geology of the Western Coalfield. Notes to accompany the Western Coalfield Geology maps. NSW Department of Primary Industries.

2. Rocscience, 2013. Slide v6.02.

Résumé for Paul Maconochie
Highlighting Open Pit Coal Mining Projects

1 QUALIFICATIONS

1984 Master of Engineering Science (UNSW)
1976 Bachelor of Science (UNSW)

2 PROFESSIONAL REGISTRATIONS

2000 Registered Professional Engineer of Queensland
1988 Chartered Professional Engineer

3 AFFILIATIONS

1977 Member, Australian Geomechanics Society
1977 Member, International Society of Rock Mechanics
1977 Member, International Association of Engineering Geologists
1988 Member, Institution of Engineers, Australia
1992 Member, Australasian Institute of Mining and Metallurgy

4 EMPLOYMENT

1999 – Present
Director GeoTek Solutions Pty Ltd, Brisbane

GeoTek Solutions (GTS) provides geotechnical and engineering geology consulting services to mining and civil engineering projects. Paul Maconochie's core competency is in geotechnical engineering for open pit mining. In his role at GeoTek Solutions, Paul has carried out projects at hard and soft rock mines in Australia, Papua New Guinea, Fiji, the Solomon Islands, the Philippines, Indonesia and Brazil.

Before starting GeoTek Solutions in 1999, Paul held the following positions:

1998 – 1999	Senior Geotechnical Engineer, Cutting Edge Technology Pty Ltd
1996 – 1998	Manager, CSIRO Minesite Rehabilitation Research Program
1996 – 1998	Manager Mining Science CSIRO Division of Exploration and Mining,
1995 – 1996	Acting Manager, Coal Mining CSIRO Division of Exploration and Mining,
1993 – 1995	Research Engineer and Group Research Manager CSIRO Division of Exploration and Mining,
1992 – 1993	Acting and Registered Mine Manager, Ok Tedi Mining Ltd, PNG
1987 – 1993	Senior Geotechnical Engineer and Geotechnical Superintendent, Ok Tedi Mining Ltd, PNG
1976 – 1987	Engineering Geologist/Senior Engineering Geologist, Douglas Partners Geotechnical Consultants, Sydney.

Selected coal projects in which Paul has been the sole or lead geotechnical engineer are listed and described briefly below.

Year	Project	Client	Description
2009-2012	Alpha	Hancock Prospecting	Geotechnical analysis and design for 30 Mtpa mine
2009-2013	Commodore	Downer Edi	Ongoing review of Commodore mine
2008-2013	Sonoma	Leighton	Ongoing review of Sonoma mine
2001-2011	Foxleigh	Foxleigh Mining, Anglo Coal	Ongoing design and review of Foxleigh mine
2000-2011	Coppabella	Thiess, Roche and Macarthur	Ongoing design and review of Coppabella mine
2000-2011	Moorvale	Leighton and Macarthur Coal	Ongoing design and review of Moorvale mine
2010-2011	Kevin's Corner	Hancock Prospecting	Commenced geotechnical analysis and design
2010	Maryborough	Northern Energy Corp.	Geotechnical design for Maryborough mine
2010-2011	Minerva	Felix Resources	Review of mine and analysis of proposed new highwall
2009	Cameby Downs	Thiess	Geotechnical review for preparation of tender
2007	Anvil Hill	Thiess	Geotechnical review
2007	Hail Creek	RTCA	Site investigation for Hail Creek East geotechnical investigation
2007	Kestrel	RTCA	Field work for Kestrel 400 Series Extension
2007	Millenium	Thiess	Third party review of geotechnical baseline report
2007	Mt Pleasant	RTCA	Site investigation for Mt Pleasant coal mine
2007	Pakri Barwadih, India	Thiess	Geotechnical review
2006	Isaac Plains South	Isaac Plains Coal	Geotechnical design for Isaac Plains open pit mine
2005	Clermont	RTCA	Site investigation for 2005 supplementary geotechnical investigation
2005	KPC, Indonesia	PT Thiess	Review of geotechnical procedures and data relating to mining of Melawan and J Pits.
2005	Suttor Creek	Xstrata	Geotechnical design for new mining area at Newlands
2004	Hail Creek	RTCA	Site investigation for Elphinstone geotechnical investigation
2004	Lake Vermont	Thiess	Geotechnical assessment
2003	Mt Thorley	RTCA	Investigation of geotechnical aspects of a mine accident
2002	Rolleston	MIM	Final geotech review prior to board submission for approval
2001	Blackwater	BHP	Investigation of large dragline spoil dump failure

5 PUBLICATIONS

5.1 Papers

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