APPENDIX 9

Blasting Impact Assessment

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UMWELT (AUSTRALIA) PTY LIMITED
on behalf of
CASTLEREAGH COAL PTY LTD

INVINCIBLE SOUTHERN EXTENSION PROJECT - BLASTING IMPACT ASSESSMENT

REPORT NO. UM-1606-150916

Thomas Lewandowski
15th September 2016

UMWELT (AUSTRALIA) PTY LIMITED
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1.0 INTRODUCTION

Enviro Strata Consulting Pty Limited (ESC) was engaged by Umwelt (Australia) Pty Limited (Umwelt), to undertake a Blast Impact Assessment for the Invincible Southern Extension Project (the Project) on behalf of Castlereagh Coal Pty Limited (CC).

The Southern Extension Project is located in the Western Coal Fields region of New South Wales (NSW); approximately 160 kilometres west of Sydney, 25 kilometres north west of Lithgow and 3.0 kilometres south-east of the township of Cullen Bullen.

The Project proposes open cut coal mining in the area to the south of the existing approved mining area of the Invincible Colliery (Invincible) which is currently being maintained under a Care and Maintenance program. This will extend the life of the mine by up to 8 years from date of approval.

This Blast Impact Assessment has been prepared by ESC on behalf of Umwelt as part of the Environmental Assessment (EA) for the Project. The EA has been developed to support an application to modify the existing Invincible project approval (07/0127) under Section 75W of the *Environmental Planning and Assessment Act 1979* (EP&A Act).

This report assesses the potential impacts of open cut blasting; including ground vibration, airblast / overpressure and flyrock, on the:

- local community;
- existing public infrastructure facilities;
- historic / heritage points of interest;
- sandstone pagodas and cliff line located in proximity to the Southern Extension Area.

The presented assessment is based on ground vibration and airblast overpressure modelling utilising parameters representative for the area. The results of the modelling are presented in the context of the relevant vibration and overpressure criteria for the local community, infrastructure, historical sites and sandstone pagodas.

An assessment to determine the condition of the closest sandstone pagodas and to evaluate the risk of potential blast impacts was undertaken in March 2016 and presented in Report UM-1509-150916 (ESC 2016). In addition, the assessment established appropriate vibration criteria to protect the pagodas from blast impacts.

2.0 PROJECT DETAILS

Invincible Southern Extension Project

The Invincible Southern Extension Project is a proposed extension of open cut mining operations to the south of the existing approved mining area at Invincible into an area known as the Southern Extension Area.

The Project includes:

- Extending the period in which mining can continue for a period of 8 years from approval of the modification application.
- Extending the open cut mining area immediately south of the existing mining disturbance area. Extraction of coal from all seams down to, and including the Lithgow seam. No highwall mining or open cut mining in any other areas of Invincible is proposed as part of the Project.
- Continued use of existing Invincible infrastructure (including operation of, and maintenance work on, the existing Coal Preparation Plant).
- Use of existing open cut voids and former underground workings for water storage.
- No change to currently approved mining production rates.
- No change to currently approved product coal transport arrangements with coal to be transported from the site by road truck to either the Shoalhaven Starches Plant or Mt Piper Power Station.
- Rehabilitation of the proposed Southern Extension Area and all existing disturbance areas at Invincible by reshaping mining areas to remove voids and revegetating the reshaped landform with locally endemic woodland and forest communities.

The Southern Extension Area is shown in **Figure 1** and key features of the Project are described in **Table 1**.

The Proponent, Castlereagh Coal, is part of the Manildra Group of companies. The purpose of the Project is to provide Manildra's Shoalhaven Starches with a reliable and cost effective source of specialty nut coal for its Bomaderry operations on the NSW South Coast. The proposed modification will provide access to an additional approximately 300 kt of nut coal from the Lithgow seam for use at the Shoalhaven Starches plant. Coal from the Lidsdale and Irondale seams which is unsuitable for use in Shoalhaven Starches plant will be sold to the Mt Piper Power Station.

The 8 year extension to the life of mining operations is to provide Shoalhaven Starches with flexibility of accessing nut coal from Invincible along with other suppliers or to source nut coal solely from Invincible. The eight year extension of mine life will also enable Castlereagh Coal and Shoalhaven Starches to fully investigate options of using coal from the Lidsdale and Irondale seams at the Shoalhaven Starches Plant. This assessment has assumed a conservative mining scenario of up to maximum limits of production to provide a conservative assessment of impacts over the life of the Project.

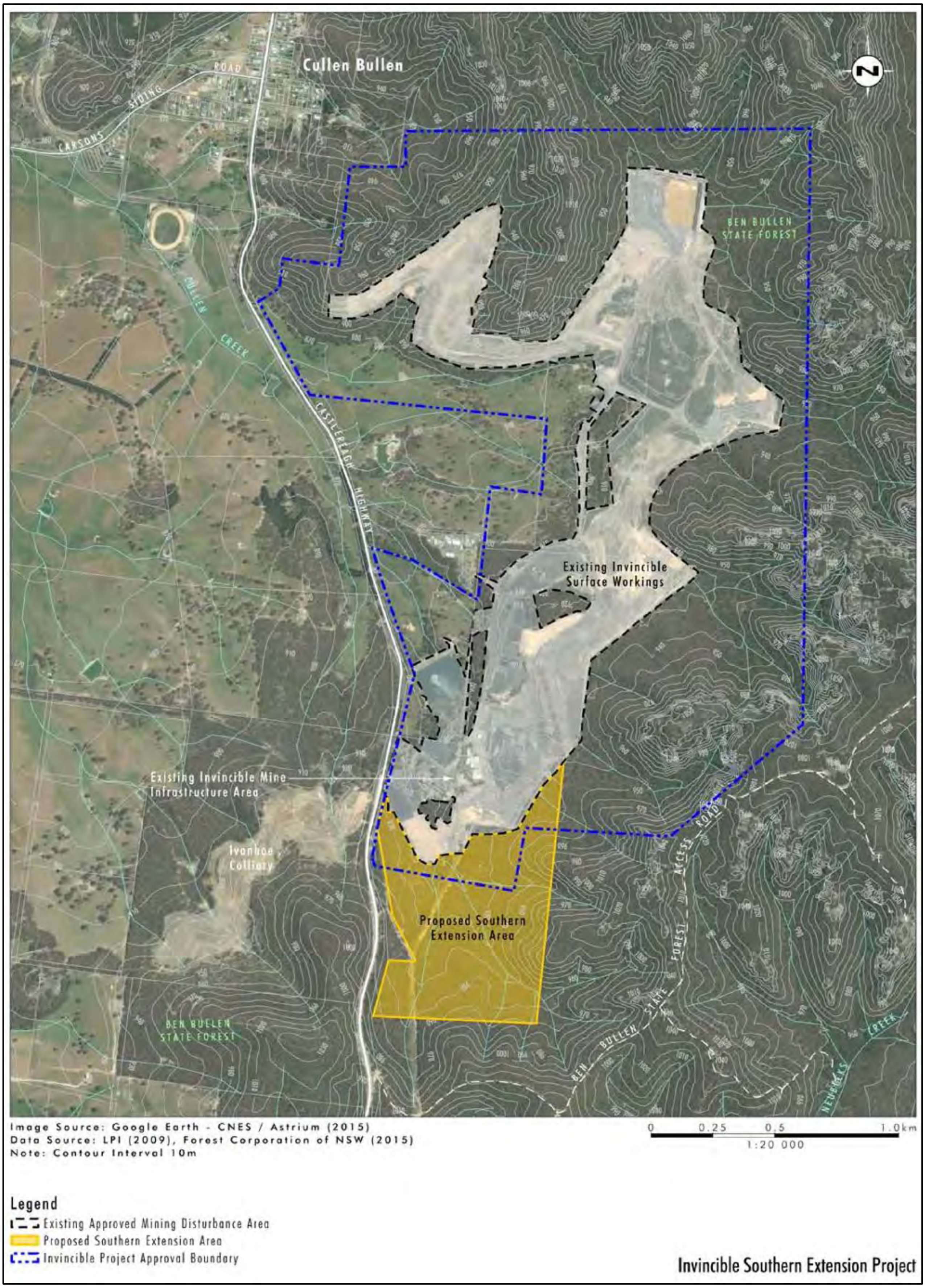

Figure 1 – Invincible Southern Extension Proposed Modification (Umwelt 2016)

Table 1: Comparison of Existing approved operations at Invincible and the Southern Extension Project (Umwelt 2016)

	Existing Approved Operations	Southern Extension Project
Resource Tonnes	Defined by existing footprint. Approved reserves have been mined.	Approximately 2.7Mt ROM coal, (including approximately 300kt of nut coal)
Mining Methods	Highwall and Open Cut	Open Cut only
Target Seams	All seams down to Lithgow Seam (Irondale, Lidsdale and Lithgow)	All seams down to Lithgow Seam (Irondale, Lidsdale and Lithgow)
Mining Rate	Up to 1.2 Mtpa ROM Coal	Up to 1.2 Mtpa ROM Coal
Production Rate	Up to 1.2 Mtpa Product Coal	Up to 1.2 Mtpa Product Coal
Mining Life	To December 2016 (8 years from date of approval)	Up to 8 years from date of approval
Open Cut Mining Area	152 hectares (ha).	Approximately 50 ha of additional disturbance
Operational Workforce	35 full time personnel.	Approximately 35 full time personnel.
Hours of operations	7.00 am – 10.00 pm Monday to Saturday (excl. public holidays). Mining in south pits not permitted between 6 pm and 10 pm.	7:00 am-10.00 pm Monday to Saturday (excl. public holidays). Mining and coal washery operations will not occur between 6 pm and 10 pm (operations limited to truck loading and maintenance activities only during this period).
Blasting	Blasting between 9:00 am and 5:00 pm Monday to Saturday, inclusive. No more than: • 2 blasts per day; or • 5 blasts per week averaged over a 12 month period.	Blasting between 9:00 am and 5:00 pm Monday to Saturday, inclusive. No more than: • 2 blasts per day; or • 5 blasts per week averaged over a 12 month period. Blasts sizes limited to manage potential risks to private residences, pagoda and cliffline formations and other infrastructure.

	Existing Approved Operations	Southern Extension Project
Transport	Road Transport 7 am – 9:30 pm Monday to Saturday, excluding Sundays and public holidays. No more than 146 laden coal truck movements from the site per day (averaged over a week). No more than 16 laden coal truck movements per hour.	Road Transport 7 am – 9:30 pm Monday to Saturday, excluding Sundays and public holidays. No more than 146 laden coal truck movements from the site per day (averaged over a week). No more than 16 laden coal truck movements per hour.
Tailings Management	Coarse tailings are co-disposed with overburden. Fine tailings are dried in drying ponds; dry tailings are then either mixed with product coal or co-disposed with overburden.	Coarse tailings are co-disposed with overburden. Fine tailings are dried in drying ponds; dry tailings are then either mixed with product coal or co-disposed with overburden.

Project Specifics

The Southern Extension Area as shown in **Figure 1** is rectangular in shape, with approximate dimensions of 0.65 x 0.9 km, with some shape irregularity in the northern section. This is due to the already extracted area of the existing approved Invincible Colliery surface workings. Maximum pit depth is approximately 40 metres below the existing ground surface.

The Project is to be located approximately 0.2 km to the south of the existing Invincible Mine infrastructure area (i.e. office area and CPP).

The parameters for the assessment of blasting impacts from the Southern Extension Project are similar to those used in the previous Invincible Open Cut Pit. The Project will utilise the same drill rig size and similar sized blasting benches. The primary focus of the drilling and blasting activities will be to blast the overburden and interburden materials allowing for extraction of three coal seams namely: Irondale, Lidsdale and Lithgow.

The Project will include the extraction of overburden and interburden material on a bench by bench basis, down to approximately 40 metres below the current surface level. Indicative rock strata in the Southern Extension Area is shown in **Figure 2A**. A cross-section of the rock strata is shown in **Figure 2B**. Due to the presence of the three coal seams the mine will undertake bench extractions at three different heights.

Both during and after completion of the Project the area will undergo a rehabilitation program.

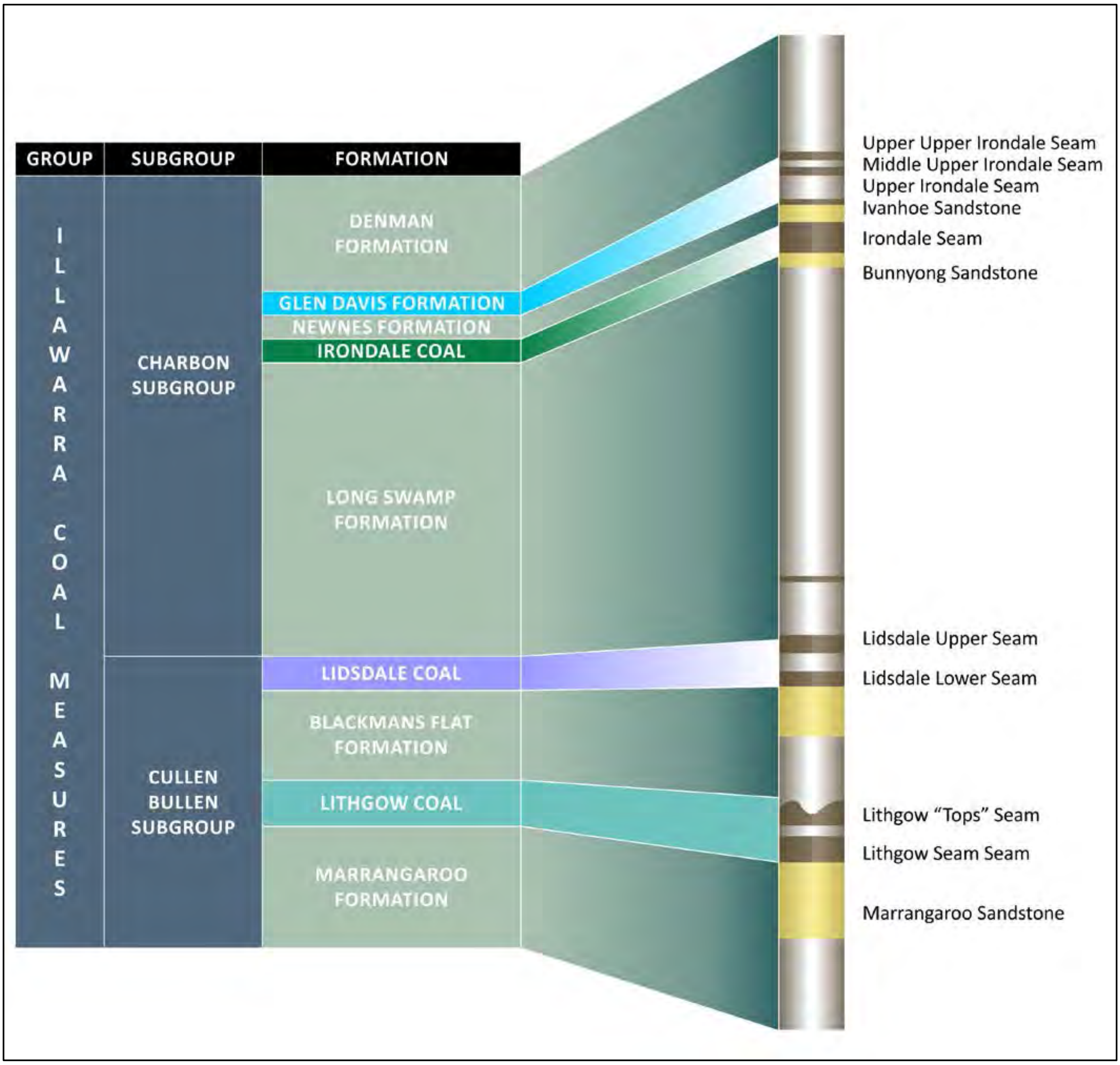

Figure 2A – Indicative Stratigraphic Column for the Southern Extension Area; (Umwelt 2016)

Figure 2B – A Cross-Section through the Invincible Mine Strata

3.0 CONCEPTUAL BLAST DESIGN

The coal extraction method to be employed in the Southern Extension Project will include a small scale drilling and blasting technique.

The blasting sequence commences with a bench survey and a blast design generated using dedicated blast design software.

Following bench preparation, a dozer is used for levelling and the bench is then drilled by means of a surface drill rig. Due to the proposed small scale of the Project a typical bench is rectangular in shape with no more than 100 holes and a uniform drilling pattern. The holes are loaded with explosive material (i.e. ANFO for dry holes or emulsion type for wet holes) and then the top part of the holes are filled with a gravel material (i.e. stemming) to contain the energy and thus to achieve a low airblast emission (i.e. lower environmental impact).

The loaded explosives are then initiated through a detonating cord, connected to each hole, which delivers a signal to the primer / booster, placed within each hole. The primer / booster then initiates the explosive column within each hole. To ensure single hole initiation there is a delay system incorporated on the surface of the blast area, allowing for a small delay between each blasted hole. This particular system (i.e. the NONEL system) controls the ground and air vibration impacts (i.e. facilitates lower environmental impact). Alternatively, pre-programmed electronic detonators can also be used with similar effect and increased accuracy.

To ensure the safety of personnel and potential onlookers a 500 metre area (i.e. exclusion zone) will be cordoned off using a number of sentries for the period of the blast duration. Blasts within 500 metres of any roads (Castlereagh Highway and the roads through Ben Bullen State Forest) will require the temporary closure of sections of roads with the exclusion area. Following firing of the blast, the blasted and fractured rock strata is then removed using a truck and shovel method for further rock strata stockpiling in another section of the mine.

Depending on the strength of the coal the same blasting process can be undertaken for coal strata blasting. Following this, the coal material is then removed, processed at the Invincible Coal Preparation Plant (CPP) and transported to its final destination.

The anticipated lifespan of the Southern Extension Project is in the order of 8 years. Based on the proposed mining plans, and an 8 year life of the mine, the following three stages are assigned to represent specified years of operation:

- Stage 1 – representing early stages of the Project with mining occurring immediately south of the existing Invincible disturbance area
- Stage 2 – representing a later stage of the Project with mining occurring in the southern extent of the Southern Extension Area
- Stage 3 – representing the conceptual final landform

The conceptual Invincible Southern Extension Project extraction stage plans (including Stages 1 to 3) were selected as the most representative of the proposed mine development activities as outlined below:

- **Stage 1**: The Invincible Southern Extension Project commences in the proposed new extraction section. The mining activities will commence in the northern most section of the Southern Extension Area. During this stage mining activities, including blasting, will be limited to approximately 40 % of the Southern Extension Area. At the end of this stage the remaining area will be squared off to allow for more efficient bench design, as shown in **Figure 3A**.
- **Stage 2**: The Project advances to the south reaching its southern pit boundary. As the entire mining activities advance in a southerly direction (i.e. away from the Cullen Bullen community) the impact in terms of ground vibration and airblast exposure for the local community is expected to lessen relative to earlier stages of the Project See **Figure 3B.**
- **Stage 3**: The Project has reached its southernmost extent and represents the final stage of the Project. Within this stage rehabilitation of the extracted area will be completed. See **Figure 3C**.

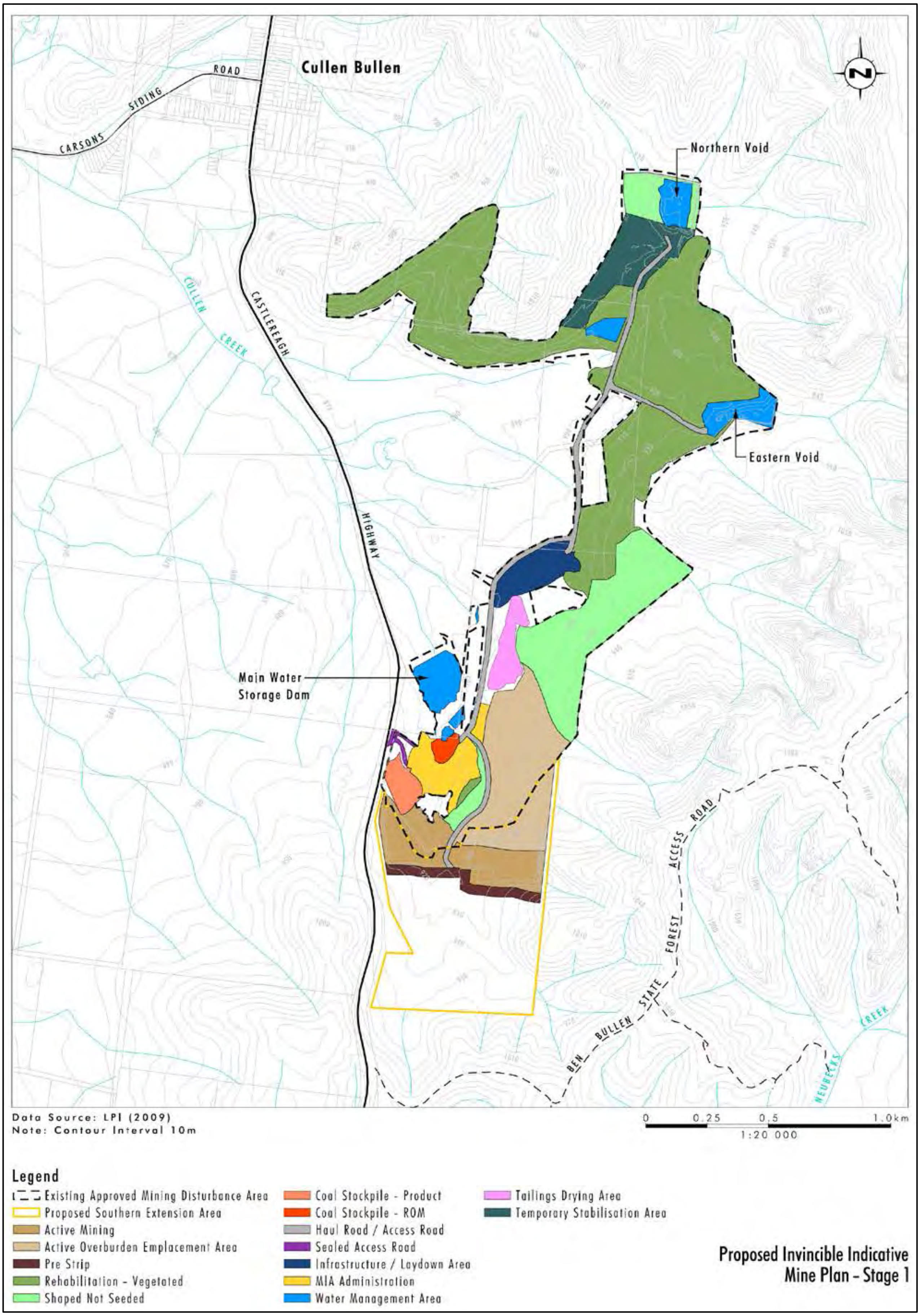

Figure 3A – The Project - Conceptual Mine Plan – Stage 1; (Umwelt 2016)

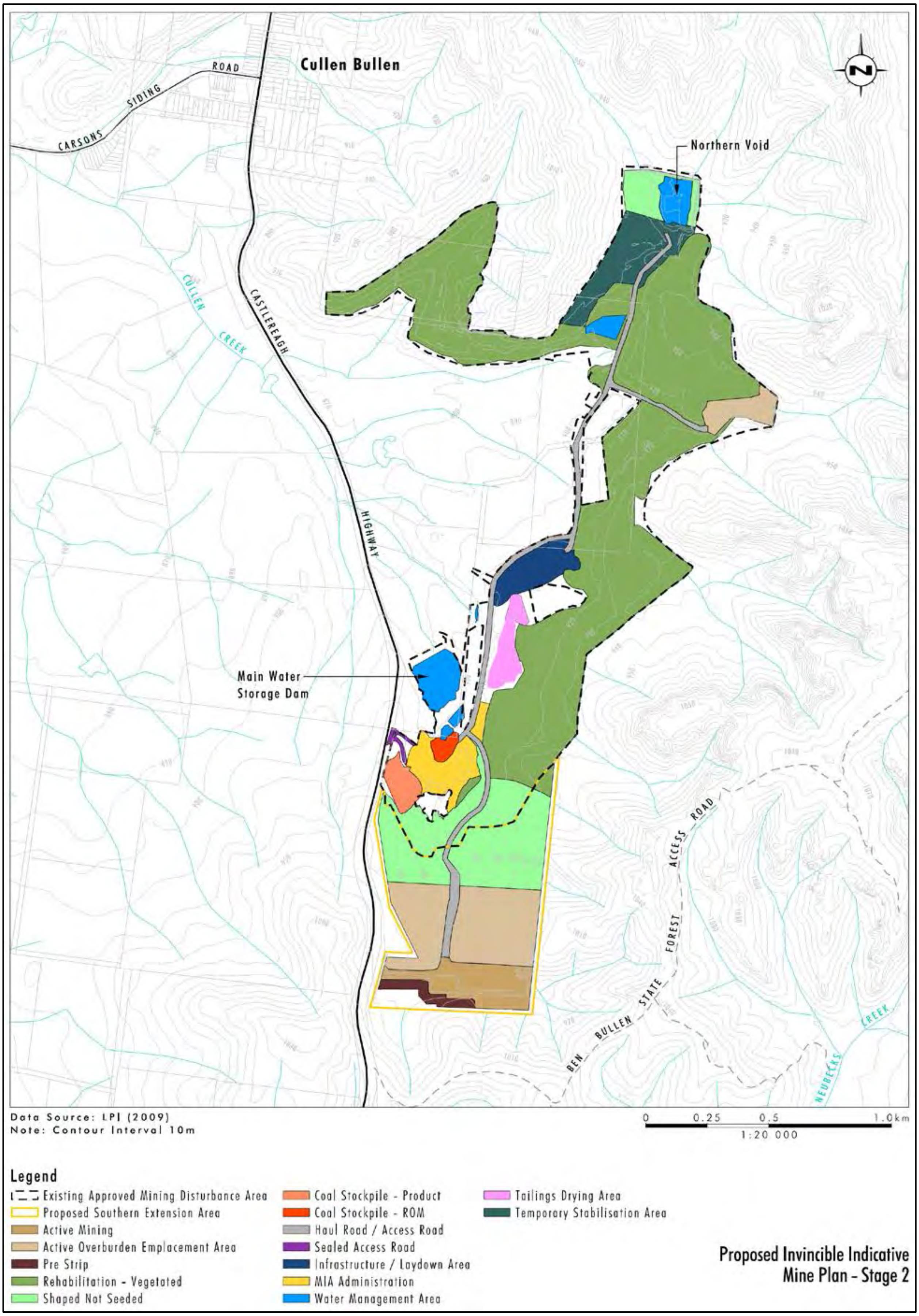

Figure 3B – The Project - Conceptual Mine Plan – Stage 2; (Umwelt 2016)

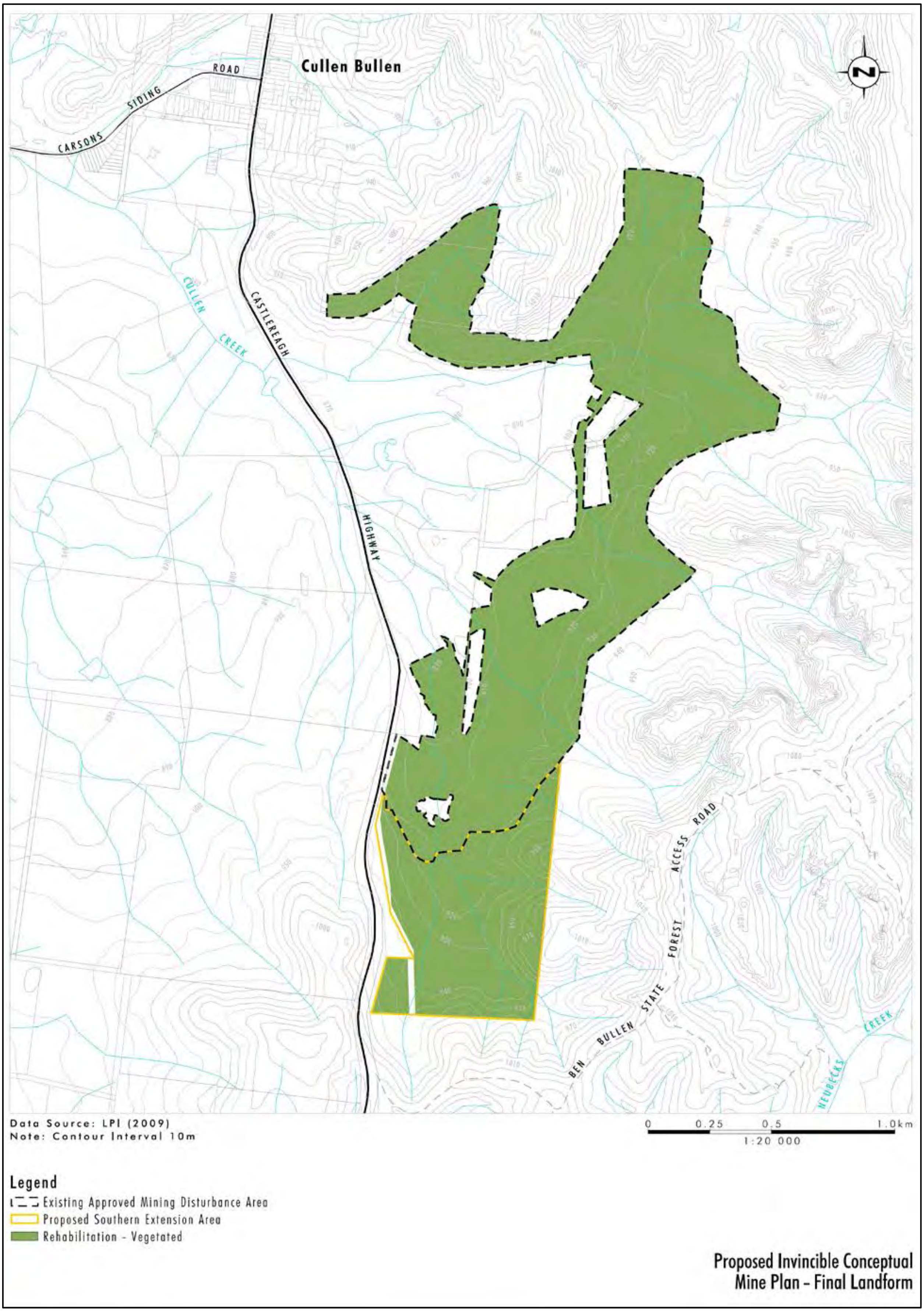

Figure 3C – The Project - Conceptual Mine Plan – Stage 3 / Final Landform; (Umwelt 2016)

Project Details

The primary focus of the drill and blasting activities will be to uncover coal material by blasting firstly the overburden and then interburden rock strata materials for further handling.

For the purpose of this assessment, it is reasonable to assume that the Project will utilise a 203 mm drill rig size. There is likely to be some variation in blasted benches ranging from 3 to 15 metres and hence in the charge masses used, ranging from approximately 26 to 466 kg. Maximum instantaneous charge masses ((MIC), (charge mass)) corresponding to wet product only (producing higher impacts than dry product) have been used for modelling the blast impacts; these charge masses are in the range 39 to 466 kg. The mine expects to use blasting products for both dry and wet strata conditions. These parameters are summarised in **Table 2** and were used in modelling the blast impacts of the Project (refer to section 5.0).

To ensure a low impact on the adjacent community and other blast sensitive sites, and that the imposed limits are not exceeded, the open cut mine will follow certain procedural requirements. This will enable an efficient design of each blast to minimise ground vibration, airblast overpressure and potential flyrock impacts on the surrounding environment thus ensuring compliance with the site specific blasting conditions.

Based on the provided plans, the Southern Extension Project will progress with bench by bench blasting and their subsequent extraction. The final pit void will be extracted to approximately 40 metres below the current R. L. level.

Table 2: Nominal Drilling and Blasting Design Parameters for the Project

Parameter	Value
Drilling Capacity	1 hydraulic rock drill
Drill Rig Hole Diameter (mm)	203
Number of Holes per Blast	< 100 (typically)
Drill Pattern	5 - 7 rows (typically)
Burden (m)	5 (typically)*
Spacing (m)	5.5 (typically)*
Bench Height (m)	3 – 15
MIC (kg)	26 – 466
Blast Size (BCM)	10,000 – 60,000
Operational Period	52 weeks / year
Blasting Frequency	2 blasts per day or 5 blasts per week, averaged over any 12 month period

* **-** *burden and spacing parameters depend on the bench depth; Typical range is around 3x3 for a 3 m depth and up to around 6x8 for a 15m depth.*

Times and Frequency of Blasting

The conditions of consent (PA 07_0127-2008) for the Invincible Coal Mine Extension Project specify that blasting is permitted during the hours of 9:00 am to 5:00 pm Monday to Saturday inclusive and blasting should not take place on Sundays or Public Holidays. Blasting would generally only be required on Saturday under exceptional circumstances, such as refiring misfires or extended sleep time due to rain or impending bad weather.

The blasting frequency in the conditions of consent is specified as 2 blasts per day or 5 blasts per week, averaged over any 12 month period.

No alteration to these conditions is proposed as part of the proposed modification.

4.0 PREDICTIVE MODELS AND BLAST EMISSION CRITERIA

4.1 PREDICTIVE MODELS

4.1.1 Ground Vibration Predictive Model for Surface Conditions

To provide an indication of potential vibration levels for a given point of concern, including residential receivers, infrastructure, historical sites and sandstone pagodas, a site law formula has to be developed. The site law formula recommended by the Australian Standard, Explosives – Storage and use, Part 2 – Use of explosives (AS 2187.2-2006) is accepted by relevant NSW Government agencies as being appropriate for mining blast assessments.

The site law formula equation is specified as follows:

$$\boldsymbol{PPV} = \boldsymbol{k}\left(\frac{D}{\sqrt{m}}\right)^{a}$$

where:

PPV	=	Ground Vibration as vector Peak Particle Velocity (mm/s)
D	=	Distance between charge and point of measurement (m)
m	=	Maximum Instantaneous Charge (MIC), effective charge mass per delay (kg)
a	=	Site exponent
k	=	Site constant

For ground vibration assessment the square-root scaled distance is more appropriate than a cube-root scaled distance and is widely used across the mining industry.

There is an absence of historical monitoring data available from the Invincible Mine that could be used in the development of the site law formula. Due to a discontinuation of operations there is no access to vibration data generated under the former operator, Coalpac Pty Ltd and Big Rim Pty Ltd (a contractor). The previous submission for the development of the area by Coalpac utilised only generic parameters based on the Australian Standard. To improve the accuracy of vibration estimates the ground vibration predictive model used in the assessment is based on vibration monitoring data collected from blasts undertaken in the adjacent open cut mine (i.e. Pine Dale Coal Mine), which is no longer operational. This particular mine is located approximately 3 kilometres to the south-east of the Project and is therefore considered representative of the vibration behaviour for the analysed area.

The developed ground vibration predictive model is based on vibration monitoring data collected from various blasts undertaken at Pine Dale open cut. The analysed sample is in the order of 50 readings collected over a number of years (i.e. 2008 - 2011). The data includes measurements from a single hole study as well as production blasts (including overburden and parting blasts) fired in the vicinity of the Castlereagh Highway, to the south-east of the Southern Extension Project.

These results were used to develop a site law formula, see **Figure 4**, which is generally site specific for the given strata conditions. The collected monitoring results were plotted using a standard log / log plot.

The parameters governing ground vibration behaviour derived through the site law analysis (corresponding to the 95% confidence level) are specified as follows:

The formula used for modelling purposes is therefore:

$$\boldsymbol{PPV\ (95\%)} = 921\left(\frac{D}{\sqrt{m}}\right)^{-1.46}$$

Where:	***PPV***	=	Ground Vibration as vector Peak Particle Velocity (mm/s)
	D	=	Distance between charge and point of measurement (m)
	m	=	MIC, effective charge mass per delay (kg)
	a	=	-1.46 (Site exponent)
	k	=	921 (Site constant)

The 95% confidence level, advocated by the Australian and New Zealand Environment and Conservation Council (ANZECC) Guidelines (1990), allows for an inherent variation in emission levels. This is by allowing for a 5% exceedance of general criterion.

Also, for completeness, the site law diagram includes a median level, that is, Peak Particle Velocity (PPV) 50% level. The parameters summarising the site law analysis for a 50% level are highlighted in **Figure 4** and show a site exponent of -1.46 and a site constant of 524.

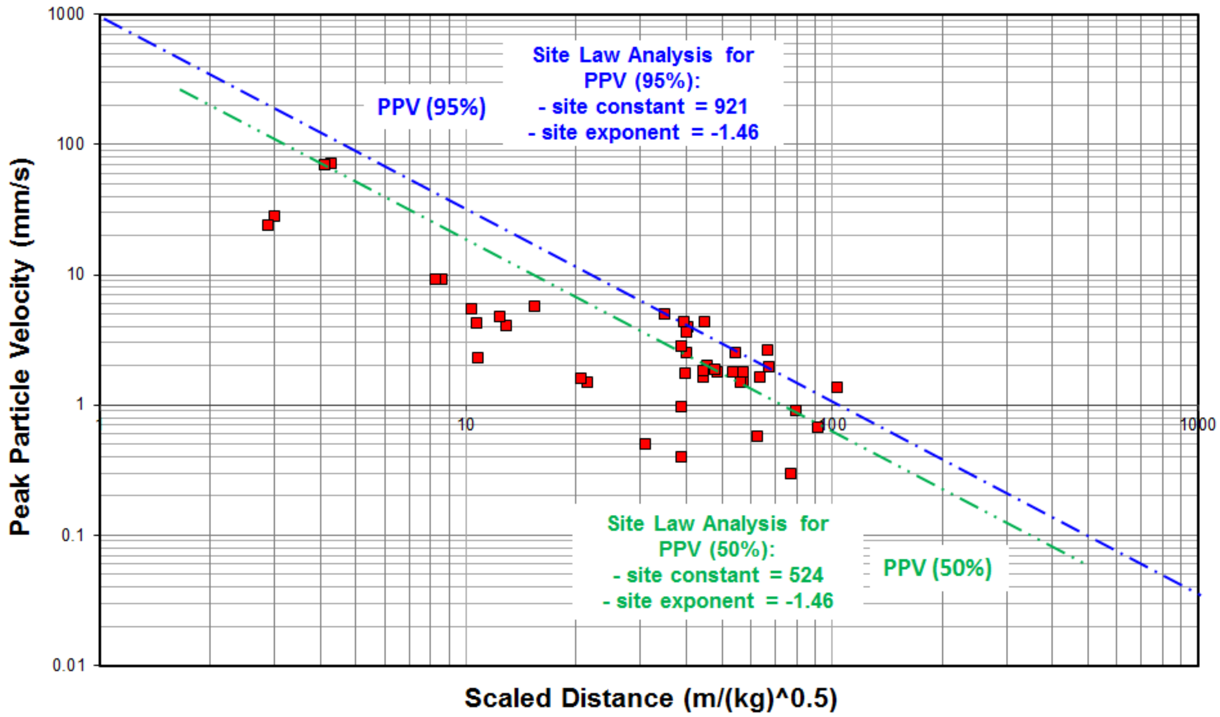

Figure 4– Site Law Analysis for Open Cut Blasting – Applicable to the Invincible Southern Extension Project

4.1.2 Airblast Overpressure Predictive Model

For the purpose of an evaluation of the potential air blast overpressure from the Project, a sonic decay law formula was developed. The sonic decay law formula recommended by Australian Standard AS 2187.2-2006 is accepted by relevant NSW Government agencies as being appropriate for mining blast assessments.

Similarly to the ground vibration model, to address the airblast overpressure impacts from the Project on the adjacent area, including residential receivers, infrastructure, historical sites and sandstone pagodas, an airblast predictive model has been developed. For that purpose actual monitoring data has been sought from the adjacent open cut Pine Dale Coal Mine. Pine Dale Coal Mine is considered to be representative for the area of interest as it is located only 3 km south-east from the Project.

The impact of the generated airblast levels from the source of the blast is generally guided by the sonic decay law recommended in Australian Standard AS 2187.2-2006. It should be noted that for the airblast impact assessment the cube-root scaled distance is more appropriate than the square root (used for ground vibration) as detailed in Australian Standard AS 2187.2-2006.

The sonic decay formula is specified as follows:

$$P = k\left(\frac{D}{\sqrt[3]{m}}\right)^{a}$$

Where:

Where:	P	=	Peak pressure (kPa)
	D	=	Distance between charge and point of measurement (m)
	m	=	MIC, effective charge mass per delay (kg)
	a	=	Site exponent
	k	=	Site constant

There are some limitations to this type of assessment as air vibrations are affected by a number of factors, for example topographical features, blast confinement and weather conditions, which are excluded from this calculation. This can generally be justified as the impact of some of these factors can be controlled or eliminated by an appropriate pre-blast check procedure which can, as an example, postpone blasting in adverse weather conditions.

Topographical features such as hills would generally have a suppressing impact on airblast levels. The model in this case would provide higher levels and does not account for potential noise suppression. Nevertheless, the model would account for the "worst case scenario'.

The predictive model has been derived from airblast monitoring data from the nearby Pine Dale Coal Mine. The monitoring sample corresponds to the 2008 – 2011 period and is based on approximately 50 monitoring points. The data includes measurements from a single hole study as well as production blasts (including overburden and parting blasts).

The developed model, which utilises a sonic decay law formula, was based on collated monitoring data which included measured airblast levels, MIC's and distances from the blasting areas.

The airblast monitoring measurements were plotted and, together with other parameters, gave rise to the models shown in **Figure 5.** The presented sonic decay law analysis features two lines corresponding to the median of the measured data set (marked as Sound Pressure Level (SPL) 50%) and SPL 95%, corresponding to 95% of the total population of data. Note that the 95% criteria is utilised following ANZECC guidelines which allow for an inherent variation in emission levels by allowing a 5% exceedance of general criterion.

To facilitate the accuracy of the assessment the forced exponent of - 1.45 has been used which corresponds to an attenuation rate of 8.6 dBL with a doubling of distance, as specified in Australian Standard AS 2187.2-2006.

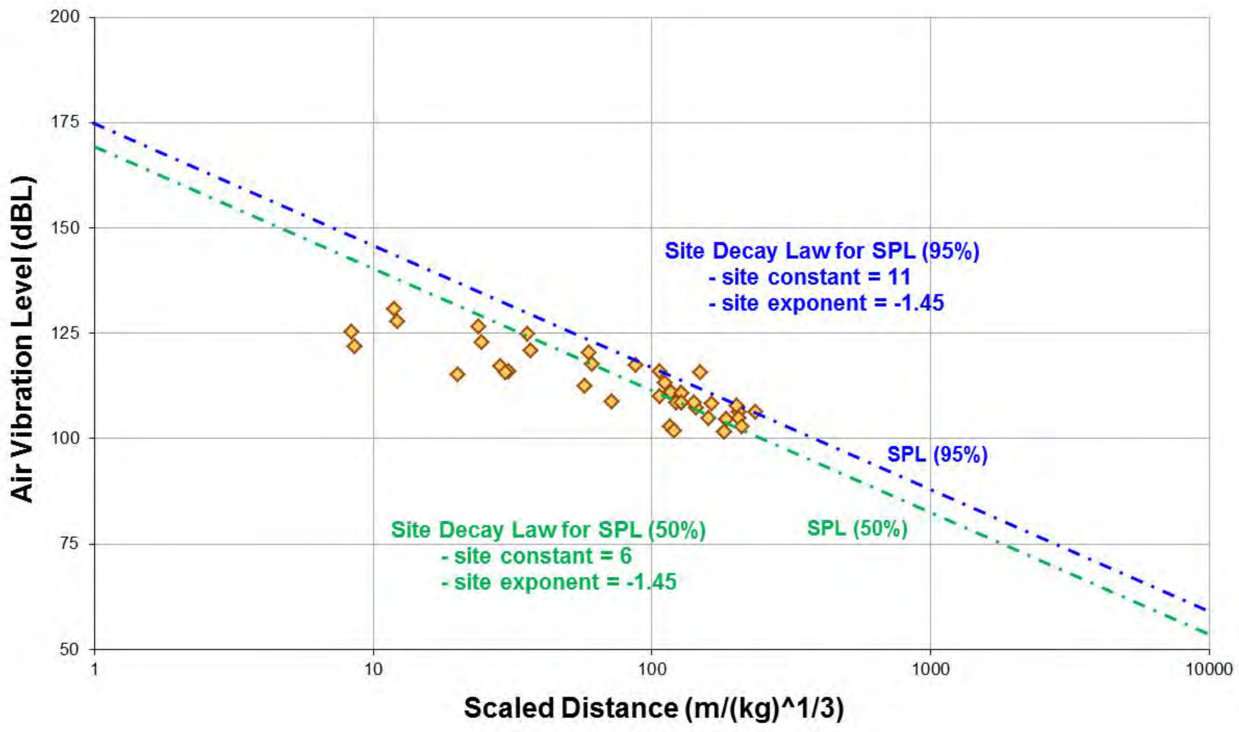

Figure 5 – Sonic Decay Law Analysis – Applicable to the Invincible Southern Extension Project

Based on the above assessment, the estimated sonic decay parameters (using the 95% confidence level) are as follows:

$$\boldsymbol{P\ (95\%)} = 11\left(\frac{D}{\sqrt[3]{m}}\right)^{-1.45}$$

Where:

	P	=	Peak pressure (kPa)
	D	=	Distance between charge and point of measurement (m)
	m	=	MIC, effective charge mass per delay (kg)
	a	=	-1.45 (Site exponent)
	k	=	11 (Site constant)

4.2 BLAST EMISSION CRITERIA

4.2.1 Criteria for Private Residences

Blast Emission Criteria for Human Comfort

To minimise the impact on residential receivers, the Office of Environment and Heritage (OEH) adopts the ANZECC (1990) guidelines "Technical Basis for Guidelines to Minimise

Annoyance due to Blasting Overpressure and Ground Vibration". The guidelines indicate the following:

- The general criterion for ground vibration is 5 mm/s, Peak Particle Velocity (PPV).
- The PPV of 5 mm/s may be exceeded up to 5% of the total number of blasts over a period of 12 months. The upper PPV level of 10 mm/s should not be exceeded at any time.
- The general airblast criterion is 115 dBL (decibel Linear).
- The level of 115 dBL may be exceeded up to 5% of the total number of blasts over a period of 12 months. The airblast level should not exceed 120 dBL at any time.

Therefore, the impacts of the Invincible Southern Extension Project have been assessed against these conditions.

Blast Damage Criteria – Ground Vibration

For blast damage criteria for residential structures the Australian Standard AS 2187-2:2006, refers to other available standards, such as British Standard BS 7385-2:1993 and American (USBM) RI8507.

The blast damage criteria are frequency dependant; based on the British Standard BS 7385-2:1993 these range from 15 mm/s for low frequencies up to 50 mm/s for high frequencies, see **Appendix 1**. Note that the lowest transient vibration value for cosmetic damage is estimated as 15 mm/s at 4 Hz. The cited range is well above the blast emission criteria for human comfort (i.e. 5 mm/s and 10 mm/s) as discussed above. It therefore follows that when vibration limits for human comfort are imposed, compliance with blast damage criteria for residential structures will be achieved.

Blast Damage Criteria – Airblast

The Australian Standard AS 2187-2:2006, specifies a conservative limit of 133 dBL as a safe level, implying no damage to the structure. AS 2187-2:2006 also specifies that damage to windows (regarded as the most fragile / sensitive material) is considered improbable for airblast exposures below 140 dBL.

Therefore, when vibration limits for human comfort are imposed (i.e. 115 and 120 dBL, as stated above), by default, the possibility of structural damage for the surrounding residential structures is eliminated.

4.2.2 Criteria for Infrastructure and Historical Sites

The proposed ground vibration and airblast emission criteria for the identified infrastructure, relevant historical sites and sandstone pagodas are discussed below.

A summary of blast emission criteria used in the assessment is presented in **Table 3.**

Bridges and Public Roads

The closest public roadway (Castlereagh Highway) is located approximately 50 metres to the west of the Southern Extension Project (with a minimum of 30 metres). There are also other public roadways located around Cullen Bullen village, located approximately 3 kilometres north-west of the Invincible mine infrastructure area. Boulder road and an overpass bridge are located approximately 1.6 and 1.7 km respectively to the south of the Southern Extension Area.

Australian Standard AS2187.2-2006 provides recommendations in regards to vibration exposure for concrete bridges. In addition, a comprehensive overview of the existing allowable vibration limits for various infrastructure (including public roads and related facilities) was presented in ACARP Report No. C14057. Vibration levels for roadways / concrete bridges were specified as follows:

- Public roads – 100 mm/s
- Concrete bridges – 100 mm/s (referenced in AS2187.2-2006)

These vibration limits are used as assessment criteria for the Project.

Power Transmission Lines

There is an 11 kV powerline and transmission towers, which are owned by Endeavour Energy (NSW electricity grid operator), located within and adjacent to the Southern Extension Area. It is noted that an additional 66 kV transmission line is located within the Southern Extension Area that is owned by Castlereagh Coal, which given this ownership has not been assessed as part of this study.

Generally a vibration limit of 100 mm/s is used for suspension towers. However, for tension towers (usually located at the corners / bends), lower vibration limits such as 50 mm/s apply. It is noted that blasting will be undertaken at a minimum distance of 20 metres from towers located within and adjacent to the Southern Extension Area.

It is proposed that the same criteria of 100 mm/s for suspension and 50 mm/s for tension and termination towers, be adopted for the Project. If further studies indicate that increased vibration limits can be achieved, an application to modify the approved limits will be made in consultation with the relevant authority.

Privately-owned Infrastructure – Storage Sheds

There is a range of buildings located to the north of the Project that have been occupied by a mining contractor in the past (Big Rim Pty Ltd). The complex is comprised of a variety of structures, mainly standard industrial storage sheds which are steel framed and clad buildings erected on concrete slabs.

Guidelines in regards to vibration limits for infrastructure are provided in Australian Standard AS 2187.2-2006 "Explosives - Storage and Use - Part 2: Use of Explosives". The relevant vibration limits include:

- 25 mm/s - for ground vibration - for occupied non-sensitive sites, such as factories and commercial premises;

- 100 mm/s - for ground vibration - for unoccupied structures of reinforced concrete or steel construction; and
- 133 dBL - for airblast - recommended airblast limit for damage control; this limit is recommended as a safe level that will prevent structural / architectural damage from blasting.

These vibration limits are used as the assessment criteria for the Project.

Historical Sites

There are a number of European Heritage sites, in the vicinity of the Project, mainly within Cullen Bullen village, including:

- Miners Cottages – consisting of weatherboard and fibro cladding, brick foundation walling and gabled iron roofs. The cottages are typical of miner's cottages dating between 1890 and 1900.
- Royal Hotel – a Victorian styled building built in two stages. The first southern section was built in 1889 of ashlar render with double two pane windows and a parapet wall featuring dentil trim and decorative urns. The later northern addition is simpler in design erected with dry pressed brick with smaller single windows. An Edwardian verandah extends along the street facing façade.
- Cullen Bullen Public School – comprises three buildings. One constructed in 1875, another in the 1920's and the third is a modern demountable unit. The older two buildings are constructed of timber cladding with gabled roofs.
- Sandstone Building Footings – located to the south of the Project form a rectangular outline (approximately 9.8 by 8.5 metres) of the sandstone footings of a building. Sandstone blocks used are of irregular shapes and varying sizes with the largest blocks being approximately 70 cm long. The construction time of the footings is unknown but they certainly do not appear to be a modern / recent structure. There is no remnant sandstone or other material in the area that may have comprised walls, being either removed or not existent implying that the building has possibly never been completed.

Considering the variety of structures and building materials the applicable vibration assessment criteria are 5 mm/s and 133 dBL. It is noted however that the airblast limit is applicable to buildings / sheds only.

These criteria are well below the blast damage levels as discussed in section 4.2.1 (i.e. the lowest transient vibration value for cosmetic damage is estimated as 15 mm/s at 4 Hz). The recommended levels are in line with the ACARP Report (No. C14057) findings for Heritage Sites, which recommends 'safe' vibration limits such as those used by British Standard BS7385.

Sandstone Pagodas and Cliff Line

The sandstone pagodas and cliff line represent geological features consisting predominantly of sandstone material interlaced with ironstone bands. The formations were inspected and assessed in detail for structural integrity and deficiencies (ESC 2016). The rock strength values were also estimated. The study identified induced localised surface subsidence damage to the cliff line. The applicable vibration limits based on this study are:

- 50 mm/s – for the Northern, Central and Southern Pagodas, and
- 25 mm/s – for the cliff line.

Due to the detected damage within the cliff line the study also recommended additional monitoring surveys and vibration monitoring when blasting for the affected cliff area, see ESC report (2016).

Table 3: Summary of Blast Emission Assessment Criteria

Location	Vibration Criteria (mm/s)	Airblast Criteria (dBL)
Private residences[(1)]	5 / 10	115 / 120
Public roads	100	n/a
Concrete bridges	100	n/a
Power transmission lines[(2)]	50 / 100	n/a
Surface infrastructure - occupied	25	133
Surface infrastructure - unoccupied	100	133
Historical sites (Miners Cottages, Cullen Bullen Public School, Royal Hotel, Sandstone Building Footings)	5	133
Sandstone pagodas	50	n/a
Cliff line	25	n/a

(1) - Specified in the existing Project Approval PA 07_0127-2008;

(2) - 50 mm/s applies to tension towers, 100 mm/s applies to free standing towers.

5.0 BLAST IMPACT ASSESSMENT

Based on the expected size of the blasted benches (i.e. 3 to 15 metres), there is likely to be some variation in the charge masses used, ranging from approximately 26 to 466 kg, accounting for wet and dry product. Maximum instantaneous charge masses corresponding to wet product only (producing higher impacts than dry product) have been used for modelling the blast impacts; these charge masses range from 39 to 466 kg.

5.1 COMMUNITY

5.1.1 Introduction

The assessment is designed to address potential ground vibration and airblast exposure, as well as flyrock that will be generated when undertaking blasting as part of the Project. The estimated ground vibration and airblast exposure levels are discussed in the context of applicable air and ground vibration limits.

5.1.2 Location of Residential Receivers

The outline of the proposed extraction boundary for the project and the location of the adjacent residential receivers are highlighted in **Figure 6**. The residential receivers shown in the figure are all privately owned and exclude mine-owned residences. The private residences identified in yellow text on **Figure 6** have been assessed as part of this blast impact assessment as they provide representative locations of the surrounding area. It is noted that given blast related impacts are directly related to distance from blast, the assessment has been completed on private residences located on the southern extent of Cullen Bullen to provide an assessment of potential blast related impacts in this area.

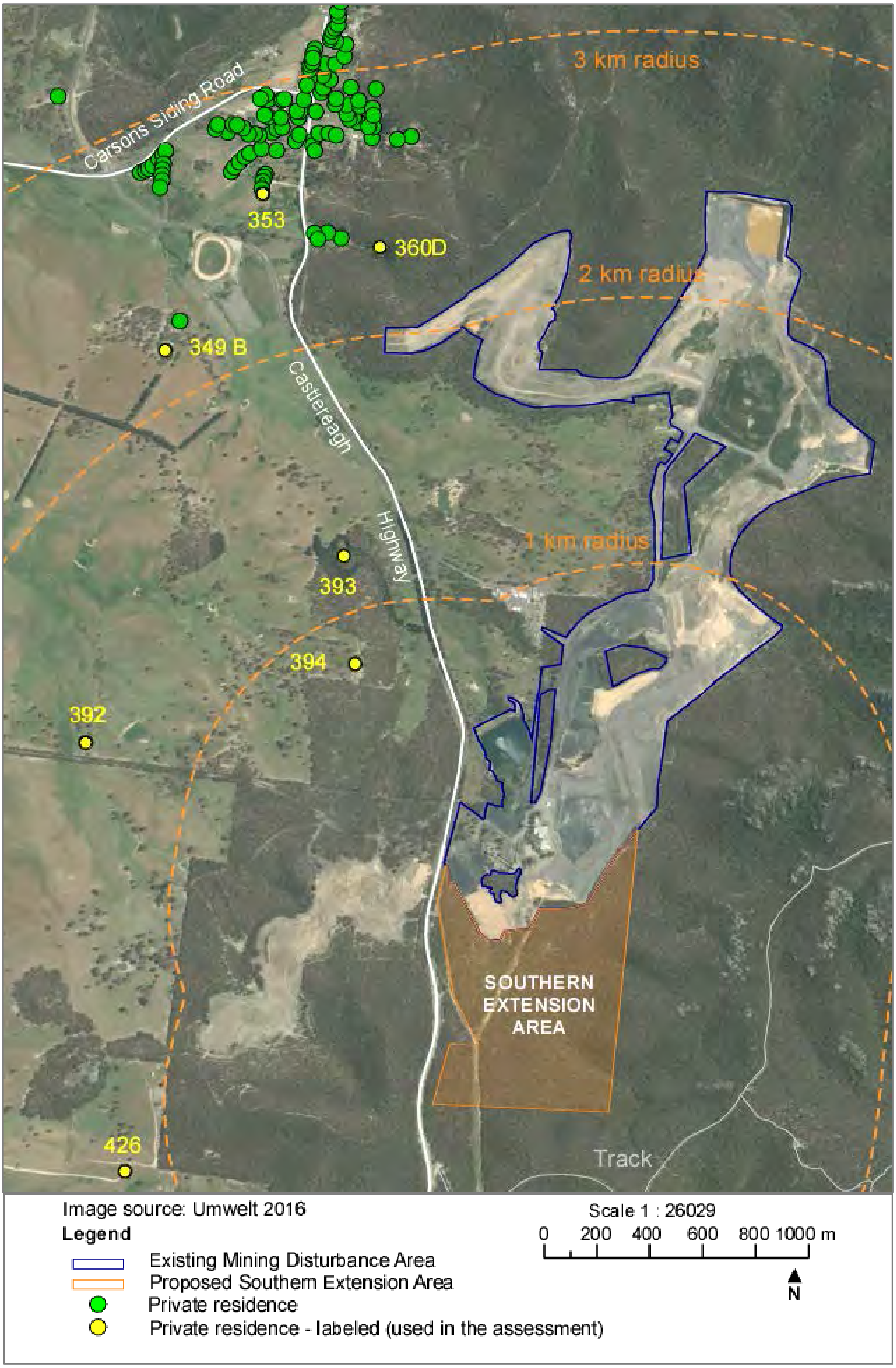

Figure 6 – Project Boundary and Locations of Private Residential Receivers

5.1.3 Assessment Results

5.1.3.1 Ground vibration

The potential impact of ground vibrations on private residential receivers was assessed using ground vibration modelling which utilised the site law formula as explained in section 4.1.1.

The ground vibration modelling covers ground vibration estimates for residential receivers located within a 3 km radius of the Project, see **Figure 6**. For the modelled parameters detailed predictions for the residential receivers located in excess of 3 km are not necessary as these receivers should generally be exposed to ground vibration levels less than 0.7 mm/s (well below the 5 mm/s ground vibration criteria, as explained in section 4.2). The 0.7 mm/s level is difficult to detect for most of the population and is used as a ‘cut off level’.

The modelling undertaken included three different bench sizes and involved three different charge masses, i.e. 39, 175 and 466 kg. The results were collated into a table of results and present the most extreme case of blasting from the proposed pit edge. Therefore, the table highlights the maximum vibration impacts that will be generated during the lifetime of the Project. The results affecting residential receivers within a 3 km radius are presented in **Appendix 2**; **Table 4** below presents an extract showing results for selected close-range private residences. The minimum distance stated in the table is based on the proposed boundary of the Project and represents the minimum distance for the lifetime of the Project.

Table 4: Results of Ground Vibration Modelling for selected close–range Private Residential Receivers – Maximum Vibration Estimates

Residential ID	Min. Distance[(1)] (m)	Estimated Max. Ground Vibration (mm/s)		
		3 m bench (2m stemming)	7 m bench (2.5m stemming)	15 m bench (3m stemming)
		MIC (kg)		
		HEAVY ANFO 39	HEAVY ANFO 175	HEAVY ANFO 466
394	820	0.7	2.2	4.6
426	1180	0.4	1.3	2.7
393	1210	0.4	1.3	2.6
392	1420	0.3	1.0	2.0
349B	2190	0.2	0.5	1.1
360D	2320	0.2	0.5	1.0
353	2600	0.1	0.4	0.8

(1) - Minimum distance over the lifetime of the project.

The results of the ground vibration modelling are summarised as follows:

- The estimated ground vibration exposure using three representative charge masses of 39, 175 and 466 kg for the three proposed bench sizes for the Project are in the order of 0.1 to 4.6 mm/s. This is for all residential receivers within a 3 km radius. The modelling confirmed that this is below the applicable vibration limits specified as 5 mm/s (for 95% of blasts) and 10 mm/s (not to be exceeded).

5.1.3.2 Airblast

The impacts of airblast overpressure to be generated by the Project were simulated using a sonic decay formula, as specified in section 4.1.2.

As for ground vibrations, the modelling undertaken included three different bench sizes and involved three different charge masses, i.e. 39, 175 and 466 kg. The results were collated into a table of results and present the most extreme case of blasting from the edge of the proposed pit. Therefore, the table captures the maximum airblast impacts that will be generated during the lifetime of the Project.

The results of the airblast modelling for private residential receivers located within a 3 km radius are shown in **Appendix 3; Table 5** presents an extract of results for selected close-range residences. Detailed predictions for the residential receivers located in excess of 3 km are not included as these receivers should generally be exposed to airblast levels less than 100 dBL (i.e. well below the 115 dBL airblast limit, as discussed in section 4.2) for the modelled parameters. The 100 dBL level is difficult to detect for most of the population and is used as a 'cut off level'.

Table 5: Results of Airblast Modelling for Selected Close–Range Private Residential Receivers – Maximum Airblast Estimates

Residential ID	Min. Distance(1) (m)	Estimated Max. Airblast Overpressure (dBL)		
		3 m bench (2m stemming)	7 m bench (2.5m stemming)	15 m bench (3m stemming)
		MIC (kg)		
		HEAVY ANFO 39	HEAVY ANFO 175	HEAVY ANFO 466
394	820	106	112	116*
426	1180	101	107	112
393	1210	101	107	111
392	1420	99	105	109
349B	2190	93	100	104
360D	2320	93	99	103
353	2600	91	97	102

(1) - Minimum distance over the lifetime of the project;

* - *Exceeds the applicable limit (115 dBL for 95% of blasts); however compliance is achievable through the application of an appropriate blast design and lower charge rates.*

The results of the airblast modelling are summarised as follows:

- The modelling revealed that the airblast impact for the closest private residence (ID 394) located within approximately 820 metres of the Project's northern boundary will be in the order of 106 to 116 dBL for the modelled charge masses. These overpressure levels apply only when blasting is undertaken in the northern-most corners of the pit area. Also, the modelling demonstrated that the airblast impact can be managed effectively via the application of lower charge masses and therefore can achieve the required criteria.
- The estimated airblast exposures using three representative charge masses of 39, 175 and 466 kg for the three proposed bench sizes are in the order of 89 to 112 dBL. This applies to all private residential receivers within a range of 1 to 3 km. The modelling confirmed that this is below the applicable vibration limits specified as 115 dBL (for 95% of blasts) and 120 dBL (not to be exceeded).
- The presented airblast modelling does not take into account the existing ridge between the Southern Extension Area and the Cullen Bullen village; it will provide some topographical shielding and a reduction in airblast levels.
- As the Southern Extension Project Pit reaches greater depths, some topographical shielding will emerge due to a change in the contours of the area. This will also assist to lessen the airblast impacts on the surrounding community.

5.1.3.3 Flyrock

The Project will operate using a standard 500 metre exclusion zone. This distance is considered appropriate for managing the risk of flyrock as it is used widely across the mining and quarry industries.

The closest private residence (residence ID 394) is located approximately 820 metres from the Project's pit shell. The issue of flyrock impact on adjacent residences is therefore considered to be fully managed and potential risks are considered negligible. A small area of cleared land on the southern extent of the Hillview property (residence ID 394) is located within 500 metres of the Southern Extension Area. This will be managed through consultation with the landholder including the implementation of temporary restriction of access to this area and relocation of stock (as required) during times of blasting within 500m of this property. This will be detailed in the updated Blast Management Plan.

5.2 INFRASTRUCTURE, HISTORICAL SITES AND SANDSTONE PAGODAS

5.2.1 Location of Points of Interest

The undertaken analysis includes an assessment of ground vibration and airblast overpressure exposures from the Southern Extension Project on adjacent infrastructure, identified historical sites, sandstone pagodas and the cliff line. The assessment is based on ground and air vibration modelling according to the applicable vibration predictive models. The vibration modelling results have been analysed, including references to relevant vibration limit criteria.

The items covered in this assessment include:

- Public infrastructure:
  - Public roadways including the immediately adjacent Castlereagh Highway, Boulder Road and an overpass bridge located approximately 1.6 and 1.7 km respectively to the south of the pit,
  - 11 kV powerlines and transmission towers,

- Private infrastructure:
  - Industrial storage sheds,

- Historical sites:
  - European heritage sites including a number of structures within Cullen Bullen village such as the Miners Cottages, the Royal Hotel and the Cullen Bullen Public School, and Sandstone Building Footings located to the south of the Project.
  - Indigenous heritage sites. A survey of the Southern Extension Area and surrounds has been undertaken and did not identify any Aboriginal heritage points to be assessed. It is noted that an existing sensitive Aboriginal archaeological site (rock shelter) has been previously identified approximately 1.1 km to the north-east of the Southern Extension Area. This site is located at a greater distance from the Southern Extension Area than the closest sandstone pagoda structures or cliff line as assessed in detail in Section 5.2.2 below.

- Sandstone pagodas and cliff line – includes the closest of these structures to the east of the Southern Extension Area.

The identified infrastructure (excluding the powerlines), historical sites and sandstone pagodas are located at highly variable distances ranging from 30 to 3,100 metres. The locations of the Project boundary and points of interest specified above are highlighted in **Figure 7**.

There are two power transmission lines (i.e. 11 and 66 kV) within close proximity of the Project. The 66 kV powerline is privately owned by the mine and it was not assessed in this report. The 11 kV powerline is public infrastructure and therefore assessed against the relevant vibration criteria.

There are a number of 11 kV power poles located very close to, or within, the proposed extraction area of the Project. A 20 metre offset is to be used for the power poles, leaving small pillars around the power poles and therefore sterilisation of some of the coal resources will take place.

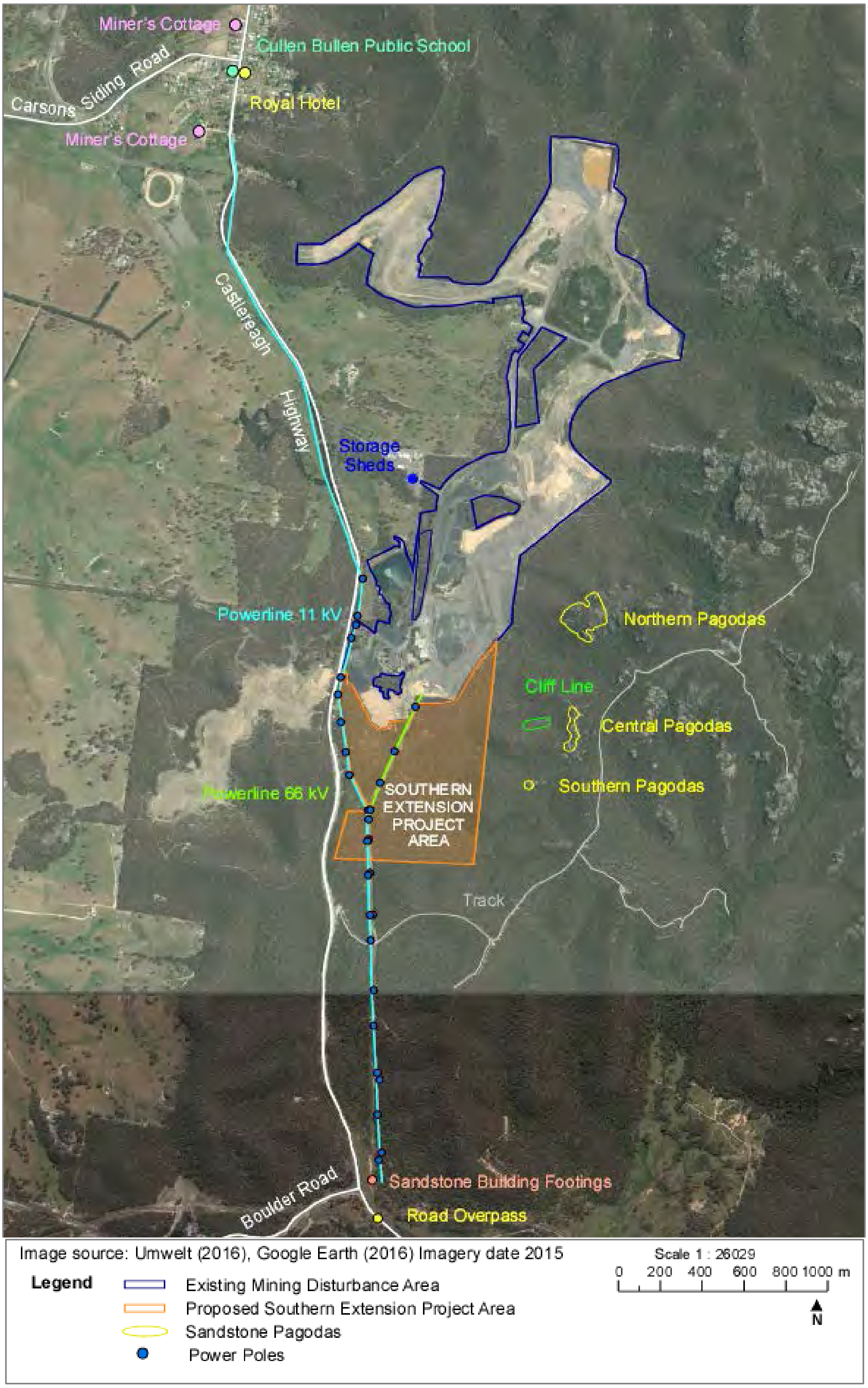

Figure 7 – Project Boundary and Points of Interest

5.2.2 Assessments Results

5.2.2.1 Ground Vibration

The undertaken assessment included three different simulations incorporating the proposed charge masses which could potentially be used in the Project. The results of the assessment are summarised in **Table 6**. The vibration modelling undertaken in this section has been performed according to the formulas specified in section 4.1.

The results of the assessment are summarised as follows:

- The closest public infrastructure is the existing Castlereagh Highway, which will be located approximately 30 metres from the pit boundary in the northern section and 50 metres or more in other sections of the open cut pit. Blasting will occur up to 30 metres from the Highway. The modelling showed that for the critical distance of 30 metres, lower charge masses (up to 42 kg) will be required to meet the vibration limit criteria. When blasting at further distances, i.e. in excess of 100 metres, no restriction will be necessary when using the modelled charge masses. The modelling confirmed that the vibration impact can be managed effectively below the applicable vibration limit of 100 mm/s.
- Boulder Road and the concrete overpass bridge located at 1,570 and 1,690 metres respectively from the pit will be exposed to vibrations below 2 mm/s. This is well below the vibration criteria for roadways and bridges of 100 mm/s.
- Ground vibration modelling for the 11 kV powerline, indicates that the ground vibration impact can be managed effectively to a level below the applicable vibration limit criteria (i.e. 50 and 100 mm/s for tension and transmission towers respectively) via the application of lower charge masses.

  If blasting was to take place as close as the 20 m offset then, based on the Pine Dale site law used in this assessment, the criteria can be satisfied by using a maximum charge size of 7 and 18.5 kg to conform to the 50 and 100 mm/s vibration limits for tension and freestanding power towers respectively.
- The privately owned industrial storage sheds located 870 metres to the north of the Project will be exposed to vibrations no higher than 5 mm/s. This is well below the applicable criteria of 25 and 100 mm/s (for occupied and unoccupied respectively) industrial structures.
- The vibration exposures for European heritage sites located within Cullen Bullen village (including Miners Cottages, the Royal Hotel and Cullen Bullen Public School) will be exposed to ground vibrations no higher than 0.8 mm/s. These sites are located at variable distances ranging from 2,650 to 3,100 metres. The Sandstone Building Footings in the South are 1,560 metres distant and the maximum predicted exposure is 1.8 mm/s. All estimates are below the applicable criteria of 5 mm/s.
- The closest sandstone pagoda is located 210 metres from the mining area of the Project. It will be exposed to ground vibration levels no higher than 36 mm/s. This is below the assessment criteria for sandstone pagodas of 50 mm/s. The Northern and Central Pagodas (320 and 370 metres distant respectively) will be exposed to vibration levels no higher than 18 and 15 mm/s respectively.

- Based on the modelling, the vibration exposure for the cliff line can be managed effectively to be below the applicable assessment criteria of 25 mm/s via the application of lower charge masses. For example, based on the Pine Dale site law, a charge mass of 175 kg fired at the edge of the pit is expected to generate no more than 22 mm/s.

Table 6: Results of Ground Vibration Modelling for Infrastructure, Historical Sites and Sandstone Pagodas

Item	Min. Distance(1) (m)	Estimated Max. Ground Vibration (mm/s)		
		3 m bench (2m stemming)	7 m bench (2.5m stemming)	15 m bench (3m stemming)
		MIC (kg)		
		HEAVY ANFO 39	HEAVY ANFO 175	HEAVY ANFO 466
PUBLIC INFRASTRUCTURE				
Castlereagh Highway	30(2)	93	279(3)	570(3)
Boulder Road	1,570	0.3	0.9	1.8
Overpass Bridge	1,690	0.3	0.8	1.6
11 kV Power Lines	20(2)	168(4)	504(4)	1030(4)
PRIVATE INFRASTRUCTURE				
Storage Sheds	870	0.7	2.0	4.2
HISTORICAL SITES				
Miners Cottages	2,650	0.1	0.4	0.8
	3,100	0.1	0.3	0.7
Royal Hotel	2,860	0.1	0.4	0.7
Cullen Bullen School	2,860	0.1	0.4	0.7
Sandstone Building Footings	1,560	0.3	0.9	1.8
SANDSTONE PAGODAS				
Northern Pagodas	320	2.9	8.8	18
Central Pagodas	370	2.4	7.1	15
Southern Pagodas	210	5.4	16	33
Cliff Line	170	7.4	22	45(5)

(1) - Minimum distance over the lifetime of the project;

(2) - Minimum distance from blasting (not always the same as from the edge of the pit);

(3) - Exceeds the applicable limit (100 mm/s); however compliance is achievable through the application of an appropriate blast design;

(4) - Exceeds the applicable limits (50 and 100 mm/s); however compliance is achievable through the application of an appropriate blast design (a maximum charge size of 7 and 18.5 kg will satisfy the 50 and 100 mm/s vibration criteria);

(5) - Exceeds the applicable assessment criteria (25 mm/s); however compliance is achievable through the application of an appropriate blast design.

5.2.2.2 Airblast

Generally infrastructure facilities and geological features such as sandstone pagodas are not assessed in terms of airblast exposure as levels required to inflict damage are not applicable and / or not reached (as stated above in section 4.2).Therefore, the impact of airblast on the analysed infrastructure and Sandstone Pagodas is anticipated to be low / negligible.

The maximum expected airblast exposure for the industrial storage sheds is 115 dBL. This is well below the applicable criteria of 133 dBL

The airblast exposure for the relevant historical sites (including the Miners Cottages, Royal Hotel, Cullen Bullen Public School and Sandstone Building Footings) is 108 dBL or less, which is below the applicable criteria of 133 dBL.

5.2.2.3 Flyrock

As indicated above, the Project will operate using a standard 500 metre exclusion zone. This distance is considered appropriate for managing the risk of flyrock as it is used widely across the mining and quarry industries.

The impact on public roads and adjacent powerlines will be managed in accordance with a road closure protocol and Blast Management Plan to be developed in consultation with the relevant infrastructure owners as part of the Project, as specified below in section 6.

The storage sheds will be 870 metres from the boundary and the closest historical site (i.e. sandstone building footings) will be in excess of 1,500 metres from the Project’s mining area. Therefore, the storage sheds and historical sites are located at distances in excess of 500 metres from the Southern Extension Project and as such the potential risks are considered negligible.

The impact of flyrock on sandstone pagodas will be managed in accordance with the Blast Management Plan to be developed for the Project, see section 6.

6.0 MANAGEMENT AND MITIGATION MEASURES

A number of blast control measures and technologies have been proposed which can minimise blast impacts (including ground vibration, airblast and flyrock) on the surrounding environment and enable blasts to be designed not to exceed relevant criteria. Specifically, Castlereagh Coal commit to meeting all relevant criteria over the life of the Project through appropriate blast design. The modelling completed as part of the assessment (refer to Section 5.0) demonstrate that all criteria can be met over the life of the Project with appropriate blast design, drilling, and blasting procedures.

The blast emission control measures for the Southern Extension Project are specified below:

Ground vibration:

- Use of appropriate charge mass design, i.e. avoid overcharging holes;
- Use of an appropriate initiation sequence to minimise the possibility of hole interactions thus avoiding a build-up in wavefront reinforcement.

Airblast:

- Use of appropriate charge mass design, i.e. avoid overcharging holes and the use of insufficient stemming column;
- Use of an appropriate initiation sequence to minimise the possibility of hole interactions thus avoiding a build-up in wavefront reinforcement;
- Ensure appropriate blast design around identified geological features to avoid face burst;
- Application of an appropriate quality stemming material and stemming height to enable correct confinement of explosives to minimise airblast emission;
- Maintain appropriate burden specification for the front row holes (to avoid face burst);
- Use pre-blast procedure (including meteorological conditions review) to avoid blasting in unfavourable weather conditions.

Flyrock:

- Ensure appropriate blast design around identified geological features to avoid face bursts and potential flyrock incidents;
- Application of an appropriate quality stemming material and stemming height to enable correct confinement of explosives to minimise the possibility of stemming ejection / flyrock incidents;
- Maintain appropriate burden specifications for the front row holes (to avoid face bursts and related flyrock incidents).

Based on the undertaken modelling all blasts will be managed to meet the specified criteria by following appropriate design methodology and drill and blast procedures.

The assessment also identified the following mitigation and management measures which are recommended for the Project.

Blast Monitoring System

The assessment identified the exact locations of various private residences, located mainly to the north-west and west of the Project.

With respect to the Project it is therefore recommended that the monitoring system for private residences should consist of two permanent monitoring stations. The first station should be located at the closest residence to the north-west (i.e. ID 394 or 393) to represent the Cullen Bullen community.

Considering the Project footprint and the wide spread of residences to the west, an additional monitoring station will be required to provide adequate and representative coverage for the area. The recommended location for the monitor is either of the residences ID 392 or 426.

Castlereagh Coal will investigate the location of a blast monitor within the southern extent of Cullen Bullen village during the early stages of proposed mining.

In addition to the detailed assessment of structural integrity of the closest pagoda structures (ESC 2016), prior to blasting within 500 metres of these structures, Castlereagh Coal will undertake a detailed structural integrity assessment of all pagoda structures within 500m of the Southern Extension Area. This is to provide a baseline reference for ongoing monitoring and inspection of these sites over the life of the Southern Extension Project.

Castlereagh Coal will commit to the ongoing monitoring of blast vibration levels at the closest pagoda sites and regular inspections to provide an ongoing assessment of structural integrity and condition over the life of the Project. The monitoring schedule and methodology will be specified in the Blast Management Plan.

This includes periodic vibration monitoring of the Sandstone Pagodas and Cliff Line, including crack behaviour monitoring and surveys of the area, in particular of the damaged section of the Cliff Line (caused by inferred surface subsidence) which will be required when blasting is within a 500 metre radius of these sites.

In addition, periodic monitoring of infrastructure, including the transmission towers and Castlereagh Highway, will be required when blasting within 250 metres with a charge mass in excess of 130kg, that is when vibrations are expected to be 10 mm/s or above, or when blasting within 100 metres irrespective of the charge mass. The monitoring schedule and methodology will be specified in the Blast Management Plan.

Pre-Blast Assessment Protocol

A pre-blast assessment protocol is essential in mitigating blast impacts. It is important to develop an appropriate protocol that minimises the impacts on the surrounding area. It is recommended that this is developed and included in the Blast Management Plan for the Project.

Weather Monitoring System

Assessment of the environmental conditions prior to blasting plays a vital role in the pre-blast assessment protocol. The weather conditions can influence the blast impact outcome; especially airblast level, as well as dust distribution. The weather monitoring station for the Invincible Mine has already been established and can therefore be utilised for the assessment of environmental conditions prior to blasting. This needs to be incorporated into the pre-blast assessment protocol.

Road Closure Protocol

Blasting activities for the Project will be undertaken within close proximity of Castlereagh Highway. This will require the development of a Road Closure Protocol in consultation with the relevant road authorities to be prepared for the Project.

Power Transmission Lines Management

Blasting activities will be undertaken within close proximity of the 11 kV powerline. The management measures related to the protection of this infrastructure will be developed in consultation with the infrastructure owner/operator and be incorporated into the Blast Management Plan. The Blast Management Plan will also include flyrock management controls which consider potential impacts to poles and wires. Additional measures such as the application of blasting mats and power isolation for critical blasts can also be incorporated to minimise the risks.

Residence ID 394 - Flyrock Management

Management measures in relation to a small area on the southern boundary of the Hillview property (residence ID 394), located within 500 metres of the Southern Extension Area, will be developed through consultation with the landholder and included in the Blast Management Plan. Measures will include the implementation of temporary access restrictions to this area and the relocation of stock (as required) during times of blasting within 500m of this property.

Sandstone Pagodas Flyrock Management

Under the effective Blast Management Plan the flyrock impact can be controlled to approximately 50 metre distance. This will require the development of an appropriate system of flyrock modelling, implementation of strict quality control measures during blast design and loading stages and adequate procedural requirements.

7.0 CONCLUSIONS

The presented report includes an assessment of the impacts of blasting activities associated with the proposed Invincible Southern Extension Project on the surrounding environment, including private residences, public infrastructure, historical sites and sandstone pagodas.

The outcomes of the assessment are summarised as follows:

- The Southern Extension Area is to be located to the south of the previous Invincible Mine operation, extending away from the Cullen Bullen community. The blasting parameters were reviewed based on the geological model of the area. Typical blasting benches will be in the order of 3 to 15 metres for the Southern Extension Project Pit area. Charge masses were identified and are in the order of 26 to 466 kg (accounting for dry and wet products).
- The blast impact assessment utilised two models representative for the area, including airblast and ground vibration predictive models. This allowed for a detailed assessment of expected air and ground vibration levels on the surrounding residences, infrastructure, historical sites and sandstone pagodas.

- IMPACT ON PRIVATE RESIDENTIAL RECEIVERS:
  - The blast emissions and damage criteria for residential receivers are specified in section 4.2 of this report. The operational vibration limits for the Invincible Coal Mine Extension are specified as 5 mm/s allowed for 95% of blasts and 10 mm/s not to be exceeded. The operational airblast limits are 115 dBL allowed for 95% of blasts and 120 dBL not to be exceeded. The same criteria were utilised in the presented assessment.
  - The overall impact on the community will be highly variable due to the wide spread of residential receivers around the Southern Extension Project. The closest privately owned residence (ID 394) will be located approximately 820 metres from the Project boundary.
  - Modelling of the ground vibration impacts for the residential receivers confirmed that vibration impacts can be managed effectively within the specified blasting parameters. The estimated vibration exposure for all residential receivers within a 3 km radius (for the specified blast design parameters) is predicted to be in the range of 0.1 to 4.6 mm/s, which is below the applicable vibration limit of 5 mm/s. Impacts beyond the 3 km radius are considered negligible (i.e. below 0.7 mm/s).
  - The airblast modelling for the private residential receivers within a 1 km radius (ID 394 at 820m) identified that airblast impacts can be managed effectively below the applicable limits of 115 dBL (for 95% of blasts) and 120 dBL (not to be exceeded) by the application of lower charge masses. The estimated airblast exposure within a 1 to 3 km radius (for the specified blast design parameters) is predicted to be in the range of 89 to 112 dBL. Impacts beyond the 3 km radius are considered negligible (i.e. below 100 dBL).

- IMPACT ON PUBLIC INFRASTRUCTURE:
  - The modelling confirmed that vibration impact on the closest public roadway, Castlereagh Highway (located between 30 to 150 metres along the boundary), can be managed effectively below the applicable vibration limit of 100 mm/s via the application of lower charge masses.
  - Boulder Road and the concrete overpass bridge will be exposed to vibration levels no higher than 2 mm/s. This is well below the vibration criteria for public roads and bridges of 100 mm/s.
  - Ground vibration modelling for the 11 kV powerline revealed that the ground vibration impact can be managed effectively below the applicable vibration limit

criteria of 50 and 100 mm/s (for tension and transmission towers respectively) via the application of lower charge masses.

- IMPACT ON PRIVATE INFRASTRUCTURE:
    - The maximum vibration impact on the privately-owned industrial storage sheds will be no higher than 5 mm/s and 115 dBL. This is well below the ground vibration criteria for occupied / unoccupied industrial infrastructure of 25 and 100 mm/s respectively and 133 dBL for the airblast criteria.

- IMPACT ON HISTORICAL SITES:
    - Ground vibration exposures for the European heritage sites (located at variable distances ranging from 1,560 to 3,100 metres) are no higher than 1.8 mm/s which is below the applicable criteria of 5 mm/s.
    - The airblast exposures for the relevant European heritage sites are all below 108 dBL, which is below the applicable criteria of 133 dBL.

- IMPACT ON SANDSTONE PAGODAS:
    - The expected vibration exposure for the Sandstone Pagodas located between 210 and 370 metres is no higher than 33 mm/s. This is below the assessment criteria of 50 mm/s.
    - The modelling confirmed that the vibration exposure for the Cliff Line can be managed effectively below the applicable assessment criteria of 25 mm/s via the application of lower charge masses.

- FLYROCK:
    - The Project will operate using a standard 500 metre exclusion zone for flyrock management. This distance is considered appropriate for managing the risk of flyrock and it is widely used across the mining and quarry industries. The closest private residence (ID 394) will be located in excess of 820 metres. The issue of flyrock impact with respect to private residences is therefore considered to be fully managed and the potential risks are considered negligible.
    - The impact on public roads and adjacent powerlines will be managed in accordance with a road closure protocol and Blast Management Plan to be developed in consultation with the relevant infrastructure owners as part of the Project, as specified in section 6
    - The impact of flyrock on sandstone pagodas will be managed in accordance with the Blast Management Plan to be developed for the Project, as specified in section 6.

- BLAST MONITORING SYSTEM:
    - To ensure that the mine complies with applicable vibration limits it is recommended that an ongoing vibration monitoring program is implemented. Detailed recommendations in regards to the number and approximate locations for the permanent monitoring stations were provided in section 6.

REFERENCES

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2. Australian & New Zealand Environment and Conservation Council (ANZECC) 'Guidelines Technical Basis for Guidelines to Minimise Annoyance due to Blasting Overpressure and Ground Vibration' September 1990.
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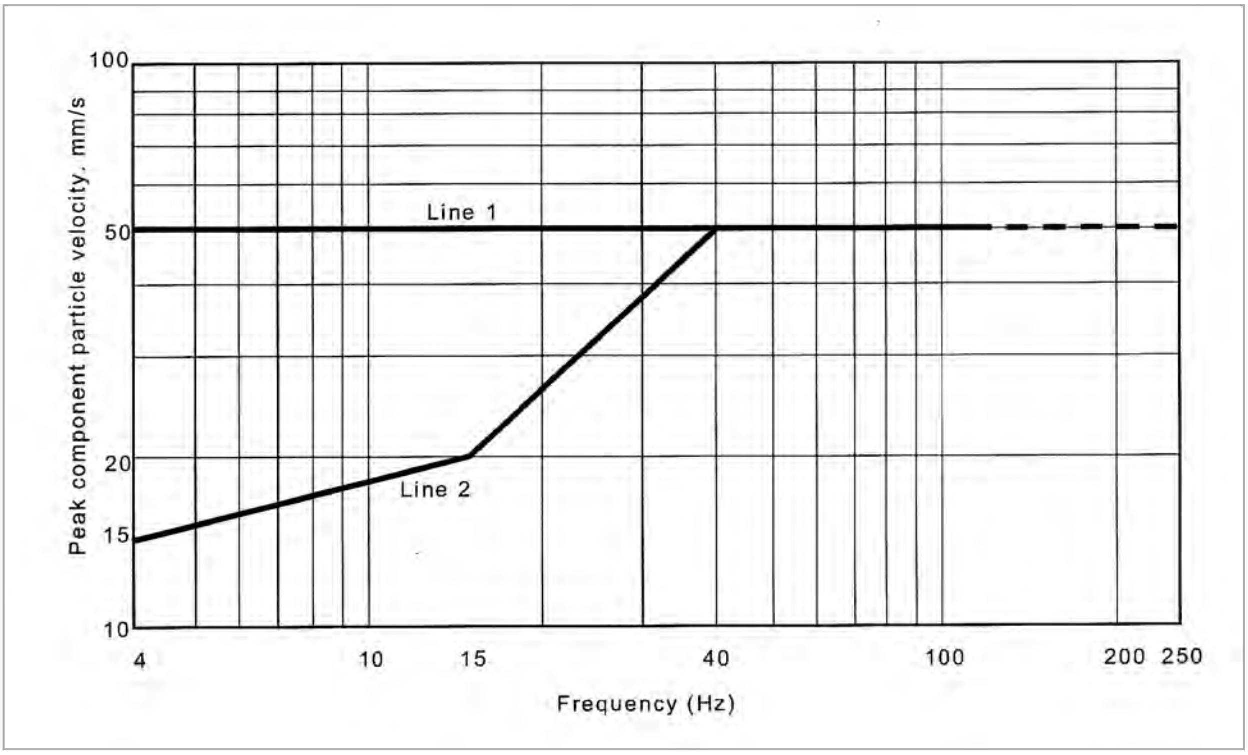
4. British Standard BS 7385-2:1993, Evaluation and measurement for Vibration in Buildings – Part 2: Guide to Damage Levels from Ground Borne Vibration.
5. Invincible Coal Mine Extension Project Approval, 2008. PA 07_0127-2008.
6. ESC 2016. Blasting Impacts and the Stability of Sandstone Pagodas in the Vicinity of the Invincible Southern Extension Project. Report no. UM-1509-150916.
7. US Bureau of Mines, USBM RI8507.

Thomas Lewandowski
15th September 2016
Enviro Strata Consulting

APPENDICES

Appendix 1 – Transient Vibration Guide Values for Cosmetic Damage - British Standard (BS 7385-2:1993)



Appendix 2 – Results of Ground Vibration Modelling for Private Residential Receivers within a 3 km Radius – Maximum Vibration Estimates

Residential ID	Min. Distance* (m)	Estimated Max. Ground Vibration (mm/s)		
		3 m bench (2m stemming)	7 m bench (2.5m stemming)	15 m bench (3m stemming)
		MIC (kg)		
		HEAVY ANFO 39	HEAVY ANFO 175	HEAVY ANFO 466
394	820	0.7	2.2	4.6
426	1180	0.4	1.3	2.7
393	1210	0.4	1.3	2.6
392	1420	0.3	1.0	2.0
414	1820	0.2	0.7	1.4
421	2130	0.2	0.6	1.1
349B	2190	0.2	0.5	1.1
349A	2260	0.2	0.5	1.0
360D	2320	0.2	0.5	1.0
360C	2380	0.2	0.5	1.0
360A	2390	0.2	0.5	1.0
360B	2410	0.2	0.5	0.9
361	2410	0.2	0.5	0.9
454	2510	0.1	0.4	0.9
419	2530	0.1	0.4	0.9
353	2600	0.1	0.4	0.8
354	2620	0.1	0.4	0.8
391	2620	0.1	0.4	0.8
355	2630	0.1	0.4	0.8
356	2650	0.1	0.4	0.8
357	2660	0.1	0.4	0.8
388	2670	0.1	0.4	0.8
358	2670	0.1	0.4	0.8
350E	2710	0.1	0.4	0.8
317	2720	0.1	0.4	0.8
327B	2720	0.1	0.4	0.8
412	2720	0.1	0.4	0.8
350D	2730	0.1	0.4	0.8
327A	2730	0.1	0.4	0.8
325	2730	0.1	0.4	0.8
318	2740	0.1	0.4	0.8
373	2740	0.1	0.4	0.8
350C	2740	0.1	0.4	0.8
352B	2750	0.1	0.4	0.8

Residential ID	Min. Distance* (m)	Estimated Max. Ground Vibration (mm/s)		
		3 m bench (2m stemming)	7 m bench (2.5m stemming)	15 m bench (3m stemming)
		MIC (kg)		
		HEAVY ANFO 39	HEAVY ANFO 175	HEAVY ANFO 466
345	2750	0.1	0.4	0.8
350B	2750	0.1	0.4	0.8
319	2760	0.1	0.4	0.8
321	2760	0.1	0.4	0.8
350A	2760	0.1	0.4	0.8
287	2770	0.1	0.4	0.8
352A	2770	0.1	0.4	0.8
320B	2770	0.1	0.4	0.8
343	2770	0.1	0.4	0.8
310	2770	0.1	0.4	0.8
311	2780	0.1	0.4	0.8
320A	2780	0.1	0.4	0.8
288	2790	0.1	0.4	0.8
342	2790	0.1	0.4	0.8
308	2800	0.1	0.4	0.8
341	2810	0.1	0.4	0.8
300	2810	0.1	0.4	0.8
283	2820	0.1	0.4	0.8
309	2820	0.1	0.4	0.8
281	2820	0.1	0.4	0.8
312	2820	0.1	0.4	0.8
284	2820	0.1	0.4	0.7
285	2830	0.1	0.4	0.7
280	2830	0.1	0.4	0.7
340	2830	0.1	0.4	0.7
334	2830	0.1	0.4	0.7
333	2830	0.1	0.4	0.7
279	2830	0.1	0.4	0.7
302	2830	0.1	0.4	0.7
335	2830	0.1	0.4	0.7
336	2840	0.1	0.4	0.7
313	2840	0.1	0.4	0.7
337	2850	0.1	0.4	0.7
272D	2850	0.1	0.4	0.7
306	2860	0.1	0.4	0.7
375	2860	0.1	0.4	0.7
278	2860	0.1	0.4	0.7

Residential ID	Min. Distance* (m)	Estimated Max. Ground Vibration (mm/s)		
		3 m bench (2m stemming)	7 m bench (2.5m stemming)	15 m bench (3m stemming)
		MIC (kg)		
		HEAVY ANFO 39	HEAVY ANFO 175	HEAVY ANFO 466
291	2860	0.1	0.4	0.7
338	2860	0.1	0.4	0.7
271	2860	0.1	0.4	0.7
303	2870	0.1	0.4	0.7
339	2870	0.1	0.4	0.7
272C	2870	0.1	0.4	0.7
272B	2880	0.1	0.4	0.7
296	2880	0.1	0.4	0.7
269A	2880	0.1	0.4	0.7
277	2880	0.1	0.4	0.7
305	2880	0.1	0.4	0.7
276	2880	0.1	0.4	0.7
273A	2880	0.1	0.4	0.7
269B	2890	0.1	0.4	0.7
295	2900	0.1	0.4	0.7
273B	2900	0.1	0.4	0.7
456	2900	0.1	0.4	0.7
272A	2910	0.1	0.4	0.7
258	2910	0.1	0.3	0.7
453	2930	0.1	0.3	0.7
267	2930	0.1	0.3	0.7
247	2930	0.1	0.3	0.7
268	2930	0.1	0.3	0.7
257	2930	0.1	0.3	0.7
264	2940	0.1	0.3	0.7
248	2940	0.1	0.3	0.7
262	2950	0.1	0.3	0.7
263	2960	0.1	0.3	0.7
223	2960	0.1	0.3	0.7
250	2970	0.1	0.3	0.7
225	2990	0.1	0.3	0.7
251	2990	0.1	0.3	0.7
452	3000	0.1	0.3	0.7

* *Minimum distance over the lifetime of the project.*

Appendix 3 – Results of Airblast Modelling for Private Residential Receivers within a 3 km Radius – Maximum Airblast Estimates

Residential ID	Min. Distance* (m)	Estimated Max. Airblast Overpressure (dBL)		
		3 m bench (2m stemming)	7 m bench (2.5m stemming)	15 m bench (3m stemming)
		MIC (kg)		
		HEAVY ANFO 39	HEAVY ANFO 175	HEAVY ANFO 466
394	820	106	112	116
426	1180	101	107	112
393	1210	101	107	111
392	1420	99	105	109
414	1820	96	102	106
421	2130	94	100	104
349B	2190	93	100	104
349A	2260	93	99	103
360D	2320	93	99	103
360C	2380	92	99	103
360A	2390	92	99	103
360B	2410	92	98	103
361	2410	92	98	103
454	2510	92	98	102
419	2530	91	98	102
353	2600	91	97	102
354	2620	91	97	101
391	2620	91	97	101
355	2630	91	97	101
356	2650	91	97	101
357	2660	91	97	101
388	2670	91	97	101
358	2670	91	97	101
350E	2710	91	97	101
317	2720	91	97	101
327B	2720	91	97	101
412	2720	91	97	101
350D	2730	91	97	101
327A	2730	91	97	101
325	2730	91	97	101
318	2740	91	97	101
373	2740	91	97	101
350C	2740	90	97	101
352B	2750	90	97	101

Residential ID	Min. Distance* (m)	Estimated Max. Airblast Overpressure (dBL)		
		3 m bench (2m stemming)	7 m bench (2.5m stemming)	15 m bench (3m stemming)
		MIC (kg)		
		HEAVY ANFO 39	HEAVY ANFO 175	HEAVY ANFO 466
345	2750	90	97	101
350B	2750	90	97	101
319	2760	90	97	101
321	2760	90	97	101
350A	2760	90	97	101
287	2770	90	97	101
352A	2770	90	97	101
320B	2770	90	97	101
343	2770	90	97	101
310	2770	90	97	101
311	2780	90	97	101
320A	2780	90	97	101
288	2790	90	97	101
342	2790	90	97	101
308	2800	90	97	101
341	2810	90	96	101
300	2810	90	96	101
283	2820	90	96	101
309	2820	90	96	101
281	2820	90	96	101
312	2820	90	96	101
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280	2830	90	96	101
340	2830	90	96	101
334	2830	90	96	100
333	2830	90	96	100
279	2830	90	96	100
302	2830	90	96	100
335	2830	90	96	100
336	2840	90	96	100
313	2840	90	96	100
337	2850	90	96	100
272D	2850	90	96	100
306	2860	90	96	100
375	2860	90	96	100
278	2860	90	96	100

Residential ID	Min. Distance* (m)	Estimated Max. Airblast Overpressure (dBL)		
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		MIC (kg)		
		HEAVY ANFO 39	HEAVY ANFO 175	HEAVY ANFO 466
291	2860	90	96	100
338	2860	90	96	100
271	2860	90	96	100
303	2870	90	96	100
339	2870	90	96	100
272C	2870	90	96	100
272B	2880	90	96	100
296	2880	90	96	100
269A	2880	90	96	100
277	2880	90	96	100
305	2880	90	96	100
276	2880	90	96	100
273A	2880	90	96	100
269B	2890	90	96	100
295	2900	90	96	100
273B	2900	90	96	100
456	2900	90	96	100
272A	2910	90	96	100
258	2910	90	96	100
453	2930	90	96	100
267	2930	90	96	100
247	2930	90	96	100
268	2930	90	96	100
257	2930	90	96	100
264	2940	90	96	100
248	2940	90	96	100
262	2950	90	96	100
263	2960	90	96	100
223	2960	90	96	100
250	2970	89	96	100
225	2990	89	96	100
251	2990	89	96	100
452	3000	89	96	100

* *Minimum distance over the lifetime of the project.*

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UMWELT (AUSTRALIA) PTY LIMITED
on behalf of
CASTLEREAGH COAL PTY LTD

BLASTING IMPACTS AND THE STABILITY OF SANDSTONE PAGODAS IN THE VICINITY OF THE INVINCIBLE SOUTHERN EXTENSION PROJECT

REPORT NO. UM-1509-150916

Thomas Lewandowski
15th September 2016

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1. INTRODUCTION

Enviro Strata Consulting Pty Limited (ESC) was engaged by Umwelt Australia Pty Limited (Umwelt), on behalf of Castlereagh Coal Pty Limited, to undertake an assessment of the potential blast impacts from the proposed Invincible Southern Extension Project (the Project) on the adjacent Sandstone Pagodas. The report provides an assessment of the risks related to blasting and comments on the allowable vibration exposures for the adjacent Sandstone Pagodas.

The Sandstone Pagodas are recognised as significant geological formations of important ecological and conservational value and their structural preservation is a key consideration for the Project.

The request was instigated by Castlereagh Coal's plans for a development of the Invincible Colliery's open cut mining operations to the south of the existing approved mining area (i.e. the Invincible Southern Extension Project) in the vicinity of the Sandstone Pagodas, see **Figure 1**.

The report presented below addresses the following points:

- Assessment of the rock strengths and structural integrity of the closest identified Sandstone Pagodas.
- Potential risks associated with structural damage due to blasting impacts.
- An estimation of allowable vibration exposures for the Sandstone Pagodas.

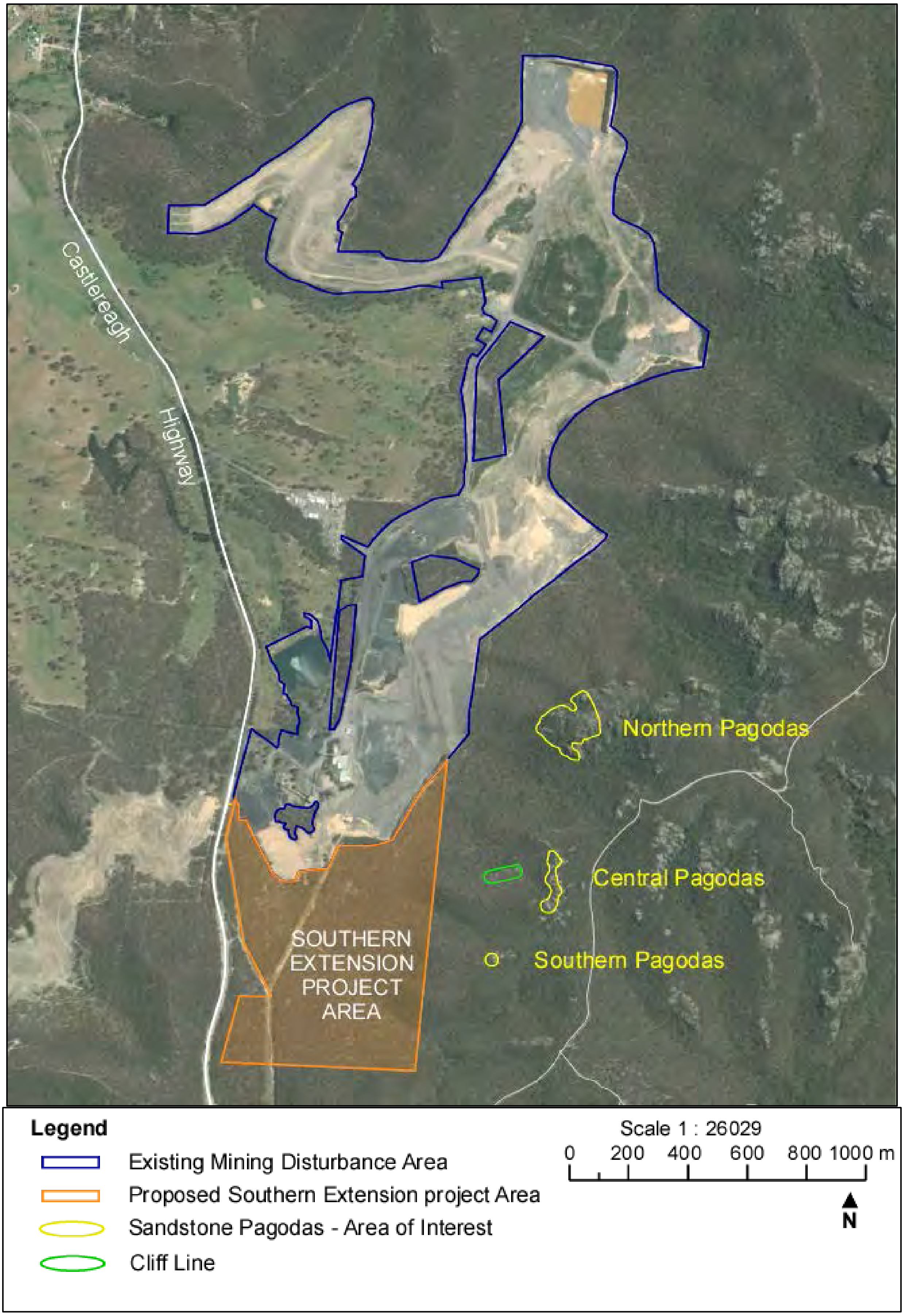

Figure 1 - Invincible Southern Extension Project and Closest Adjacent Sandstone Pagodas

2. PROJECT METHODOLOGY

The following project methodology was used in the presented assessment:

- Review of existing reports and available relevant information;
- Review of comparable Australian and international studies / reports and applicable information related to blast exposure of various rock strata formations and concerns associated with similar structures;
- A site assessment undertaken on the 21.03.16 and 22.03.16 which included site mapping, site testing (i.e. rock strength estimations), and a structural inspection of the conditions of the Sandstone Pagodas and dominant strata conditions;
- Collation of rock strength data for further assessment with comparable studies.

3. SANDSTONE PAGODAS

The Sandstone Pagodas in proximity to the Southern Extension Area are unique sandstone formations found the Lithgow / Blue Mountains region. The Sandstone Pagodas and the Project are located within the Ben Bullen State Forest.

There are two types of pagodas, including:

- Smooth pagodas, also known as beehives, and
- Platy pagodas, also known as step cones

Smooth pagodas are beehive like structures which form relatively regular and compact conical rock formations.

Platy pagodas are stepped and terraced cones reminiscent of Asian pagodas, often displaying spectacular eroded rock forms.

In terms of the Project, the closet Pagodas of interest are located to the east of the proposed mine extension and some distance away from the proposed Project's boundary, see **Figure 1**.

Detailed description of pagodas located in the area of Lithgow and Cullen Bullen can be found in the Keats and Fox's book 'The Gardens of Stone National Park and beyond' (2011, book 1).

The Sandstone Pagodas were formed by erosion of sandstone outcrops originating from the Triassic period. The predominant composite materials of these formations include sandstone and flat or coiled ironstone layers, with occasional siltstone or shale bands. The presence of ironstone bands creates and shapes the pagodas' hard surfaces of the terraces or the intricate features. The ironstone bands (iron-cemented sandstone) are up to several centimetres thick with the distance between the bands varying from 0.2 to 2 metres (Washington and Wray, 2011). The ironstone bands and the much softer sandstone are subject to differential weathering, which is weathering at different rates, this is due to their dissimilar erosional resistance.

The sandstone pagodas represent the visible section, the exposed top part of the eroded sandstone outcrops.

In these types of formations sandstone layers are generally not of uniform strength but vary from band to band. There could be significant strength differences in the sandstone bands for the considered Sandstone Pagoda structures. The variation in the size of the grains of the sandstone generally implies varying strength, with larger grains corresponding to weaker strata formations. There are also differences in sandstone material colours indicating the variation in mineral content and cement.

The presented study below focused on assessment of structural integrity as well as identification of potential deficiencies including: major cracks, overhangs, unstable top features, and other geological features.

Overhangs

Generally the formation of an overhang occurs over a significant period of time. The driving mechanism appears to be related to the presence of a recessing layer (consisting of a sandstone, and / or siltstone or shale band, see **Figure 2A**) and ongoing physical and / or chemical weathering processes including water action, freeze / thaw conditions (related to seasonal conditions) as well as wind action.

In the advanced stage of overhang formation it is possible that a large boulder is detached from the pagoda structure. Depending on the steepness of the hill and the thickness of the vegetation the released boulder can be displaced a significant distance away from the original overhang position, see **Figure 2B**.

Figure 2A - Recessive Band

Figure 2B – Overhang

Top Features

The top sections of the pagodas are the most exposed sections to the elements, and potential physical and chemical weathering. Similarly to the overhangs, these sections undergo severe weathering and with time potentially form unusual "sculptural" formations. Ultimately these top sections will fully erode and collapse with time. The process is irreversible, although it takes a long time before the top "sculpture" is formed and then tilted and destroyed.

According to Dr M. Wilkinson's study notes in Keats and Fox (2011) 'the measured erosion rates show that the tops of the pagodas erode more slowly than the valleys or slopes between them'.

The site inspection revealed that the majority of the formations in the top section are smooth dome shaped forms, showing an almost conical shape, which allows for immediate water dispersion, see **Figure 2C**.

Occasionally, however, the top sections of the pagodas include well-formed "sculptural" elements, characteristic of the platy pagodas, indicating the presence of an undulating 3-dimentionl ironstone band, see **Figure 2D**.

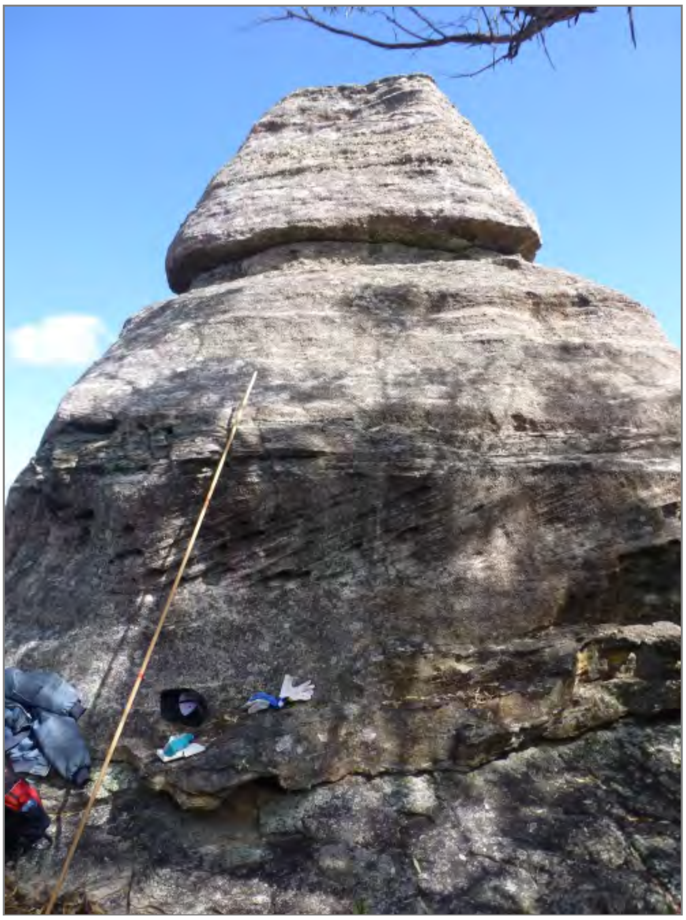

Figure 2C - Top Feature – Dome

Figure 2D - Top Feature

Major Cracks

The origin of some of the cracks appears to be related to the action of water runoff in-between the pagoda formations. The site observations identified that some of the cracks occur in the niches / spaces between two adjacent pagoda forms. These areas serve as a water catchment area collecting water from the top of the pagodas and usually diverting it away to a lower section in the valley or to the adjacent streams. The site examination confirmed some significant leaf and other post rain debris often deposited at the base of the identified cracks. Other cracks were located within the pagoda structures themselves, see **Figure 2E**. Major cracks for the purpose of this assessment are defined as any cracks that are at least 5 centimetres wide and/or 3 metres long.

The man-induced cracks, such as those due to surface subsidence, usually exhibit a certain pattern, such as a number of parallel cracks or a semi-circular pattern due to, for example, the sliding motion of the slope.

Overall, see Lewandowski (1996), it should be noted that one-off crack occurrences within a pagoda structure do not have any significant influence on the overall stability of the structure. Also, it is concluded that due to the limited number of these cracks the impact of blasting should not have a significant effect, nor provide any additional risks (besides the ongoing natural erosion factors), to the pagodas when exposed to controlled blasting from the adjacent mine.

Figure 2E - Major Crack – 8 cm wide

Unusual Features

There are a number of unusual features including various formations such as “windows”, geological intrusions, honeycombing, dyke intrusion and others, see **Figures 2F** and **2G**.

Figure 2F –‘Window’ Feature

Figure 2G – ‘Honeycomb’ Feature

4. SANDSTONE PAGODA STUDIES AND OTHER COMPARATIVE STUDIES

Presented below are a number of relevant overseas and local studies which can be used as an indicative measure of blast damage criteria and allowable vibration exposures for comparable geological structures to the considered Sandstone Pagodas. There are seven cases presented, studies numbered 6 and 7 – represent studies in the proximity of Invincible Mine.

Study 1

Oriard (2005a) summarised a study related to vibration impacts on friable structures including stalactite formations. A study was conducted with regards to soda straw stalactites suspended from a tunnel arch. These stalactites were up to 760 mm in length and 4.8 mm in diameter at the base. They were observed to be “very delicately suspended”. The study found that none of the stalactites fell during blasting where the vibrations reached peak particle velocities of around 19 mm/s. In view of the fragility of the stalactite structures, relatively high vibration levels were achieved without a negative impact.

Study 2

Oriard (2005b) summarised a study which was conducted with regards to blasting effects on delicate pinnacles located in Bryce Canyon National Park in Utah USA. The pinnacles were made of limestone, sandstone, claystone, cemented gravels and other remnants of sedimentary materials. These structures were originally formed underwater then lifted by the shifting of the earth’s crust. The process of erosion followed which predominantly impacted the softer formations with limited impact on the top, harder rock layer, leaving a hard cap.

Two blasts at a distance of 7.3 km from the test pinnacle were detonated. Each blast was in a hole approximately 24 m deep and consisted of a single 791 kg charge of the blasting agent ANFO. The following measurements resulted: the strongest motion found at the top of the pinnacle had a displacement of 0.0033 mm at a frequency of 10 Hz and 0.005 mm at a frequency of 3 Hz. The motion at the base of the pinnacle was measured to be 0.25 mm/s at 10 Hz, with a displacement of 0.004 mm.

A fatigue test was also conducted, making use of a large mechanical shaker located at the base of the pinnacles. It introduced 78,000 cycles of motion into the pinnacle’s base in order to simulate the blasting activities conducted during the life of a mine. No damage occurred during this test and there were no changes in the physical properties of the pinnacle. The study concluded that the proposed mining operation and related blasting activities would have no effect on the pinnacles.

The induced vibrations were not measured, however it can be assumed that the use of a large mechanical shaker would generate substantial vibration levels at the base of the pinnacles.

Study 3

Dobrilovic (2009) described works undertaken during excavation of the Brzet tunnel in Croatia. The blasting was undertaken immediately adjacent to a fault line at the tunnel portal and unstable boulders on the surface over the tunnel. To manage these issues a controlled blasting technique with the imposed vibration limit of 18 mm/s for all unstable boulders was introduced. The imposed limit sufficiently prevented any boulder movement.

Study 4

Blair and Kearney (2011) summarised a study related to blasting effects on the integrity of an Aboriginal rock shelter. For the purpose of the investigation a number of single hole blasts were undertaken. These single hole blasts generated signature vibrations, typical of vibration impacts when blasting with a significant delay between holes. The seed wave holes were placed at various distances (i.e. within 100 – 300 metres) from the Aboriginal rock shelter with each containing a different amount of charge explosives (i.e. 57 – 289 kg range). Vibration data was collected both inside and outside the Aboriginal shelter, noting Peak Particle Velocity (PPV) for each seed hole blast. The generated vibration impact was in the order of 0.5 – 6.0 mm/s, and did not induce any negative impacts on the Aboriginal rock shelter.

The study concluded that electronic delay systems should be used to purposely scramble the delay sequence in order to avoid producing any sinusoidal motion that may generate large peak levels of vibration. The vibration criterion used for the cave was 25 mm/s.

Study 5

Oriard (2005c) summarised a study related to vibration impacts on stalactite formations within the scenic Kartchner Caverns in Arizona USA (work undertaken in 1999). The stalactites in focus were delicate soda straws of small diameter and variable lengths. This included one of the longest in the world hanging at over 6.4 m and less than 0.02 m in diameter.

Tests were conducted in order to calculate what PPV could be achieved without damaging the stalactites. "In one test area, it was thought that one or more sensitive soda straws fell at a peak particle velocity of about 15 mm/s, although there was no observed increase in falling soda straws as the particle velocity increased to 50 mm/s." In a different test area, observations were made that several small blocks of material fell at particle velocities ranging from 28 to 48 mm/s. In addition to this a ringing sound was believed to have occurred after one of the blasts.

The results could be compared to many previous projects where observations were made of the fall of loose, unscaled rock particles in tunnels. The findings in this project were similar to those commonly experienced amongst other projects; the already loosened particles fall at a low level of vibration, and then there are no more falling particles observed even though vibrations rise to levels many times higher.

Study 6 - Study in the Proximity of Invincible Mine – Aboriginal Rock Shelters

Strata Control Technology - SCT (2012) undertook a detailed geotechnical review of the stability of five Aboriginal Rock Shelters in the vicinity of the previously proposed Invincible mine expansion area by Coalpac in 2012. This area is located within the Ben Bullen State Forest to the east and north east of Invincible. It is noted that the closest Aboriginal Rock Shelter to the Southern Extension Area is located approximately 1.1 km to the north east. It was indicated that the sites / overhangs were found to have a varying degree of natural instability associated with the inherent unstable geometry of the rock overhang formations. The review included the assessment of risks in regards to the level of instability. The adopted vibration limit criteria varied and were specified as follows:

- 20 mm/s for sites CV-RCK1-10 (located 1.1 km from Southern Extension Area) and CV-RCK2-10
- 50 mm/s for site CV-RCKPAD1-10
- 100 mm/s for CV-RCKPAD2-10

The risk analysis for these five sites took into consideration the overall geometry, geological character, the degree of incipient instability and the immediate risk to each site. Disturbance of each site due to proposed open cut mining was risk ranked as a function of distance from the open cut edge to the overhang structure.

In summary, for the considered blasting parameters, the following distances were estimated to be a low risk;

- Site CV-RCK1-10 >250 m – low risk
- Site CV-RKPAD1-10 >250 m – low risk
- Site CV-RCKPAD2-10 >100 m – low risk
- Site C-S-1 >250 m – low risk
- Site CV-RCK2-10 100 to >250 m – moderate risk
  Note: as collapse of this site is considered highly likely in any condition, no low risk distance was suggested.

For the considered sandstone features, the study showed that generally, distances in excess of 250 metres should produce a low risk from the adjacent mine blasting. There was an exception of one shelter, this however is being described as being in an unstable state with active slabbing and considered highly likely to collapse regardless of the mining activities.

Study 7 - Study in the Proximity of Invincible Mine – C-S-1 site

Holt and Associates (2004) dealt with the impact of open cut extraction at Cullen Valley Mine on C-S-1 site. To mitigate the risks of vibration impact on the site the following recommendations were made.

- For a distance of 70 – 100 m – a maximum charge weight of 150 kg
- For a distance of 100 – 150 m – a maximum charge weight of 200 kg
- For a distance > 150 metres – no charge weight limit

Generally, the study showed that, for the considered sandstone features, distances in excess of 150 metres should produce a low risk from the adjacent mine blasting.

For a summary of the presented studies refer to **Table 1**.

Table 1: Summary of Blast Impact Studies on Fragile Geological Structures

Type of Structure / Composition	Max. Vibration (mm/s)	Max. Displacement (mm)	Detected Impact / Comments
(Study 1) Stalactites / soda straw stalactites	19	-	No damage observed
(Study 2) Pinnacles / limestone sandstone, claystone, cemented gravels	0.25	0.0033 0.004	No damage observed
	fatigue test / vibration unknown	-	No damage observed from large mechanical shaker located at the base of the pinnacles
(Study 3) Unstable boulders	18 – limit	-	Blasting with imposed limit of 18 mm/s prevented any movement of unstable boulders.
(Study 4) Aboriginal rock shelter	0.5 to 6.0 (25 - limit)	-	No damage observed
(Study 5) Stalactite formations, small diameter soda straws of variable lengths	15 28 to 48		One or more sensitive soda straws fell – possibly already loosened material Several small blocks of material fell
(Study 6) Aboriginal rock shelters – sandstone overhangs	Limits: 20 50 100	-	Generally, distances in excess of 250 metres should produce a low risk for the shelters from the adjacent mine blasting
(Study 7) Rock overhang	-	-	Generally, distances in excess of 150 metres should produce a low risk for the feature from the adjacent mine blasting

5. COMPARATIVE STUDIES BASED ON ESC'S EXPERIENCE

The following case studies are the experiences from other open cut operations that have encountered comparative issues. Each of these cases involved ESC's participation and investigation of the issue.

STUDY MINE A – Underground sandstone roof / coal pillar behaviour

The results of this study were published by the author, Lewandowski et al (2006) and include a detailed assessment of roof / rib behaviour when exposed to ongoing blasting from an open cut mine located directly above underground workings. The large scale open cut blasting (typical for Hunter Valley mines) was undertaken 160 metres (or less) above the underground workings.

The study was conducted from 2004 - 2006 between Wambo Open Cut and United Collieries (Underground Mine) and covered:

- Detailed geotechnical assessment of strata conditions
- Underground vibration monitoring
- Underground site observations and mapping, following blast exposure
- Supplementary extensometer monitoring to detect strata movement
- Assessment of allowable vibration limit for underground personnel

The underground strata were assessed to be in the order of 12 - 21 MPa for the coal material (i.e. rib strata) and 25 – 110 MPa for the dominant sandstone / shale material (i.e. roof strata) tested. The strength of the strata is considered comparable to the discussed Sandstone Pagodas.

The study included a detailed assessment of the impacts of blasting on underground mine strata conditions. Special emphasis was put on the assessment of roof and pillar behaviour when exposed to the repetitive impacts of blasting, including ground vibration exposure. The studied rock strata included laminated rock strata from the roof (including variable materials such as sandstone / shale and others) and coal material located in the mine pillars.

Following any major open cut blasting (over 50 blasts measured with vibration exposures between 2 and 96 mm/s) the roof and rib conditions were inspected for vibration damage. The assessment methods involved site observations and mapping supported by vibration monitoring and extensometer monitoring.

The study revealed the following:

- A 10 mm/s vibration limit is appropriate for personnel presence. At this level there is no risk to personnel underground, concluding no risk of rock strata damage.
- Generally, for vibration levels between 0 and 20-30 mm/s, there were neither visual signs nor any measured signs of vibration impacts on the described rock strata. These were also confirmed by extensometer measurements, which did not register any roof deflection. The study concluded that at these levels the roof and rib behaved in an elastic manner.
- For levels between 20-30 up to 96 mm/s of vibration exposure the roof and rib still displayed elastic characteristics. However, there were signs of stone dust on the floor. Occasionally, small loose particles (previously trapped in the roof or rib crevices / edges, or wire mesh), were dropped on the floor. It appears that at these levels any loose particles will fall due to the shaking motion from blasting. For the measured range there was a lack of any significant roof / rib movement. The inferred potential vibration impacts at these and higher levels are also summarised in **Table 2**.

- The estimated structural damage level for the described strata conditions was in the order of approximately 250 mm/s (i.e. UCS (Uniaxial Compressive Strength) 12 - 21 MPa for the coal - rib strata and 25 – 110 MPa for sandstone – roof strata).

Table 2: Impact of vibration - indicative roof and rib behaviour for underground coal mines (after Lewandowski at al 2006)

Vibration Level (mm/s)	Description	Symptoms
0 – 20/30	- elastic roof behaviour - no impact on roof and ribs	- loose pieces of coal / rock can possibly fall due to vibration - acceptable vibration level by personnel
20/30 – 40	- elastic roof behaviour - no damage to the rock strata	- some pieces of coal dust fall on the floor - unpleasant/intolerable vibration level by personnel - loose pieces of coal / rock can possibly fall due to vibration
40 – 150/180	- elastic roof behaviour - no damage to the rock strata	- large amount of stone dust on the floor - loose pieces of coal / rock can possibly fall due to vibration
150/180 – 250	- minor damage stage	- minor roof fretting - minor damage to the roof corners - minor damage to the ribs - large amount of stone dust on the floor
250 – 350	- deterioration stage (more pronounced damage stage)	- development of roof cracks - pronounced damage to the ribs - roof corner deterioration - possible damage in the vicinity of geological features
>350 level unknown	- failure stage (possible roof fall stage – this stage is highly dependent upon roof and rib bolting density)	- substantial number of new cracks in the roof - possibility of joints opening - possibility of roof fall highly dependent upon roof bolting density - possible delimitation of the roof - substantial damage to coal ribs

In summary, the most relevant part of this study applicable to the Sandstone Pagodas is that there were neither visual nor measured changes to the analysed underground rock strata (including the coal ribs which were the weakest element) for vibration levels up to 20 - 30 mm/s. However, above the 20 - 30 mm/s vibration level, the first signs of potential vibration impacts could be observed by the presence of stone dust on the floor (due to the shaking motion of the rock strata). In addition, the 10 mm/s vibration level was chosen as a safe vibration level that personnel can be exposed to underground (i.e. human comfort level), implying no impact on rock strata.

STUDY MINES B, C, D and E – Underground roof / coal pillars behaviour

The results of this study covered a broad range of underground conditions and were published by the author Lewandowski et al (2007). The study covered four different underground mines where a uniform blast management system was implemented. The study was supported by vibration monitoring, geotechnical assessment and site observations. This included detailed assessments of roof / rib behaviours when exposed to ongoing blast vibrations.

In each case geological / geotechnical data (including UCS values) were used to assess the potential damage level for the dominant rock strata conditions. Generally, very high vibration levels are required to induce strata damage; this could be in the order of few hundred mm/s. For example, the rock strata as shown in **Appendices 1A and 1B**, would require vibration exposure in the order of 250 mm/s (for the mudstone band) and 350 mm/s (for the sandstone/siltstone band) for the structural vibration limit to be exceeded. The indicative rock strength values for the assessed roof varied between 10 and 40 MPa for the mudstone band and 30 and 90 MPa for the sandstone / siltstone band.

Each of the mines implemented the same system of personnel management where 10 mm/s was used as a cut off level for personnel presence. This also implied no risk of damage to roof / rib conditions and therefore no danger for underground personnel. The site observations also confirmed that any visual signs of blast vibration exposure (i.e. stone dust on the floor) is only expected at higher levels such as the previously mentioned 20 - 30 mm/s level.

In summary, the most relevant part of these studies applicable to the Sandstone Pagodas is that there are various structural damage levels that are highly dependent upon the dominant rock strength data and structural integrity. The structural damage levels for the rock strata are quite high and in the order of a few hundred mm/s for the analysed dominant sandstone / mudstone layers. Also, in each case the 10 mm/s vibration level was chosen as a safe vibration level that the personnel can be exposed to underground (i.e. human comfort level), implying no impact to the rock strata.

STUDY MINE F – Impact of faults and joints on final high-wall stability

The subject of this study covered the assessment of geological features (including faults and joints) on high-wall stability and the final high-wall quality following open cut blasting. The study was published by the author, Lewandowski et al (1996). The study assessed two parameters, including intensity of joints (and faults) and the angle of geological features (in relation to the wall) and their impact on the final wall quality. More specifically, how the intensity and the angle of geological features influence the stability of the wall after presplit blasting.

The study featured six open cut mines in Queensland and concluded that the intensity of one or two joints (faults) per metre produced limited impact on the wall stability. A significantly higher number of joints (or cracks) is required to impact on the wall stability (quality).

The study also highlighted the impact of joint angle in relation to the wall, which can influence the type of failure.

The results of the study are directly applicable to the Cliff Line and the Sandstone Pagoda walls, which are affected by cracks, joints and faults.

STUDY MINE G – Sandstone remnants including Aboriginal shelters and caves

This study, undertaken by ESC, involved a blast impact assessment on sandstone remnants including aboriginal shelters and caves. The study included monitoring of vibration impacts from an adjacent open cut mine (during the initial stage of mine operations including blasting in a new area) and the assessment of vibration impacts on sandstone remnants and aboriginal caves in the Mudgee area in 2012.

The monitored structures consisted predominantly of sandstone remnants and caves with various sized overhangs (see **Appendices 2A-C);** and are therefore similar to that of the discussed Sandstone Pagodas.

The study incorporated a blast impact assessment, collection of vibration measurements, and an assessment of the state of the structures when exposed to blast vibrations.

There were a total of six blasts monitored at three different locations. The vibration exposure was in the range of 0.9 – 12.3 mm/s.

The post blast inspections did not reveal any fresh dust or rock (sandstone) fragments on the ground, which could indicate initial vibration impacts on the rock structure itself. This initial study concluded that there was no damage to the monitored sandstone remnants and rock shelters nor was there any deterioration caused by the adjacent open cut blasting.

After this initial study (following the commencement of mine blasting) the mine continued with open cut blasting. The study served to confirm the lack of any impact from the initial phase of the adjacent mine's blasting on the considered structures.

STUDY MINE H – Vibration and dam wall behaviour including geological weaknesses

This study, also undertaken by ESC, involved long term monitoring of the behaviour of a dam wall affected by significant geological weaknesses, when exposed to blast vibrations. The dam wall consisted predominantly of two rock types, sandstone and coal. Also, the top part of the dam wall included very friable sandstone material, i.e. weathered sandstone.

The study was supported by continuous vibration monitoring and dam observations from 2008 to 2014 as this is the period when the dam was filled with water.

As indicated, the state of the monitored dam wall was a key concern as it included major dam wall weaknesses such as a geological fault line in one section of the wall. There was also periodic water seepage through the described geological weakness. The dam wall consisted of sandstone materials similar to that of the discussed Sandstone Pagodas, see

Appendices 3A-C. The other materials, such as the coal, are considered even more friable than the sandstone material.

The collated data revealed that the vibration exposure for the dam wall varied significantly from 0 to 22 mm/s, while the majority of the readings were in the range of 0 to 10 mm/s.

The vibration impact, if significant, would potentially cause some deterioration to the weakest part of the structure, i.e. the fault line. The observations of the dam wall behaviour pointed to there being a periodic increase in water seepage. This was, however, related to an increase in the dam water level following any significant rainfall. As observed, the water level fluctuation was the main factor behind the increased / periodic dam seepage.

In summary, the study concluded the absence of any negative impacts of ground vibration (being in the order of 0 – 22 mm/s) from open cut blasting on the dam wall conditions (including the fault line).

6. ASSESSMENT OF THE INTEGRITY OF THE SANDSTONE PAGODAS

The boundary of the proposed Invincible Southern Extension Project and the locations of the Sandstone Pagodas of interest, as well as an identified Cliff Line, are highlighted in **Figure 1**. Mining within the planned Project area will advance to the South. The estimated minimum distances from the proposed blasting area to the Sandstone Pagodas will vary and are estimated as follows:

- Northern Pagodas – approximately 320 m
- Central Pagodas – approximately 370 m
- Southern Pagodas – approximately 210 m
- Cliff Line – approximately 170 m

Assessment of the integrity of the Sandstone Pagodas included:

- Rock strength estimations, and
- Structural integrity assessments

6.1 ROCK STRENGTH ESTIMATIONS

METHODOLOGY – NON-DESTRUCTIVE TESTING

The most reliable method of rock strength estimation is rock strength testing undertaken in a laboratory and includes Uniaxial Compressive Strength (UCS) testing on rock core samples. Rock core samples are obtained in field using an invasive method of rock core drilling requiring drill rig access.

Due to the sensitivity of the Sandstone Pagodas this method was not suitable. Therefore, an alternative rock strength testing method using a non-destructive type of testing was employed.

To provide some indication about the rock strength of the sandstone strata, USC measurements were undertaken by ESC's engineer using the Silver Schmidt Hammer, which is a non-destructive type test, see **Figure 3**. The measurements are taken using a piston type device and rely on the rebound of a spring showing higher values of rebound (R value) for stronger rock and lower rebound values for lower strength rocks. The Silver Schmidt Hammer is an advanced device, which eliminates potential errors due to the effects of gravity and friction, and produces rebound results in Q-value. The Q-value is then converted to a compressive strength value expressed in Megapascals (MPa).

Figure 3 - In-field Rock Testing

The results are summarised in **Table 3**. This is an indicative test only however it provides a valid assessment, especially when a large statistical sample is to be obtained.

The measurements were obtained using an averaging mode of mean outliers. This implies that a sample of at least 10 results was obtained from a given strata layer. The method truncates the two outliers, including the minimum and maximum readings, see **Figure 4A**. An average value is then calculated from the remaining measurements. The validity of this approach is supported by the observations made during the Pagoda testing, where an occasional measurement taken on a larger fragment of quartz (embedded within the sandstone material) produced an elevated (spurious) reading in comparison to other measurements from the same sandstone band. Therefore, the elevated measurement from the quartz rock is excluded from the calculations as it is not representative of the monitored sandstone sample.

The method included testing of various Sandstone Pagoda layers. It is noted that these layers usually varied in appearance. For example, for one pagoda formation there were five different layers identified (i.e. requiring 50 tests) which exhibited different colours between each layer and sometimes different structural compositions such as larger grains or other variations.

Where the pagoda formation appeared to have relatively uniform characteristics one set of measurements (i.e. 10 tests) with a calculated average value appears to be sufficient to determine the likely rock strength value for that pagoda.

For samples of the measurements taken at the Sandstone Pagodas, refer to **Figures 4A** and **4B**. In both cases there were 11 measurements taken. After truncation of the extreme values an average value based on the remaining 9 readings was calculated. The average rock strength measurements for each sample are 11.5 and 25.5 MPa respectively.

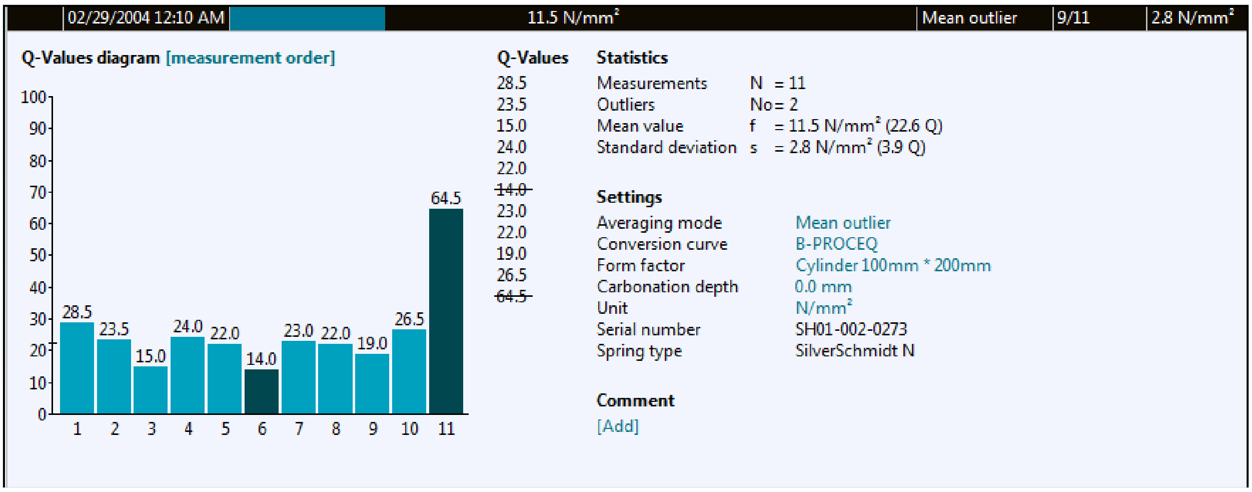

Figure 4A - Sample of Rock Strength Estimation - Low Strength Sandstone, i.e. 11.5 MPa

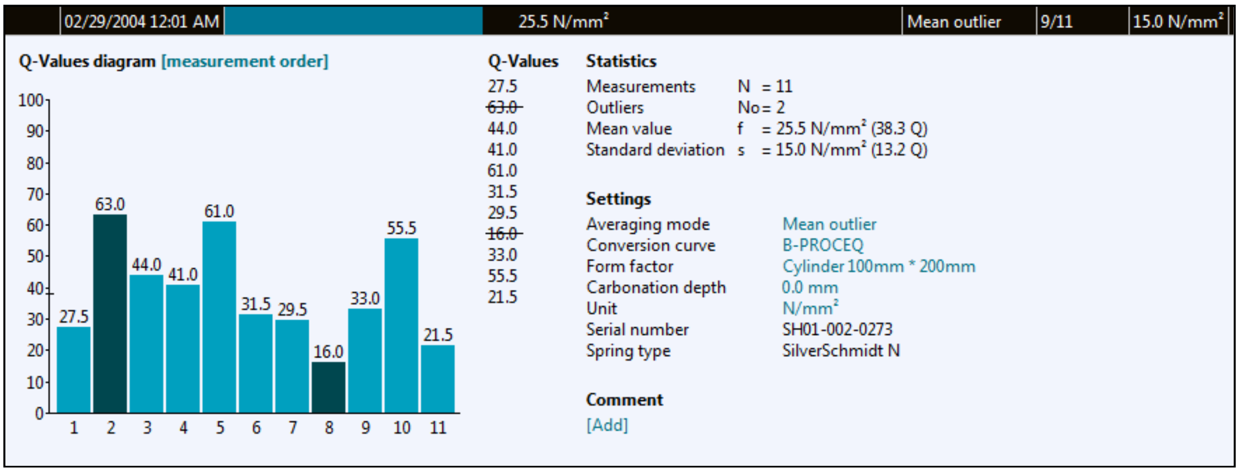

Figure 4B - Sample of Rock Strength Estimation - Medium Strength Sandstone, i.e. 25.5 MPa

Northern Pagodas

There were a number of different layers identified within an exposed western section of the Northern Pagoda. Out of these, six different layers were identified and targeted for testing. The sandstone layers varied in colour (reflecting the variation in mineral content) and visual appearance. The last, seventh layer corresponded to the top of the pagodas. In addition to the layering of the strata, in the most western section some honeycomb features were observed. The rock strength testing revealed rock strengths for the Northern Pagodas in the range of 9 to 26.5 MPa.

Generally, adequate rock strength was measured, with only one softer layer detected (estimated strength for this layer is between 5 and 9 MPa, as explained below). The majority of the rock strength was estimated to be in the order of 11.5 MPa or above.

Central Pagodas

The rock strength estimates for the tested Central Pagoda are in the range of 11.5 to 24.5 MPa. The majority of the readings are around 16 MPa. The sandstone material appears well compacted and uniform with a high amount of larger grain sized quartz.

Southern Pagodas

The observed sandstone material appeared relatively uniform, without significant visible layering within the Southern Pagodas. Therefore, only spot measurements around the perimeter of the Southern Pagodas section, including the inner passages and topmost surfaces, were undertaken (without particular attention to layers). The estimated rock strength was in the range of 9 to 13 MPa. There were some sections showing strength values lower than 9 MPa (these sections would most likely be in the range of 5 to 9 MPa, as explained below).

In summary, the Southern Pagodas appear to have the lowest rock strength in comparison to the other three landforms tested as part of this study. Nonetheless, there is sufficient strength in the whole structure, without the presence of strongly (actively) weathering layers.

Cliff Line

There were a number of layers identified within the exposed Cliff Line. Out of these, five different layers were selected and targeted for testing. The rock strength testing revealed the rock strength varied between 11 and 23.5 MPa for the whole cliff area. The second top layer appears to be the weakest showing strength values of less than 9 MPa (most likely being in the range of 5 to 9 MPa, as explained below). This layer is above 8 metres from the ground (approximately where the wedge failure and block detachment occurred).

Generally, an adequate rock strength was measured. There was, however, one section where most of the damage was located, i.e. the measurements in this section confirmed lower strength material.

Table 3: Summary of Rock Strength Estimations of Sandstone Pagodas

Reading ID (time)	Rock Strength (MPa - mean value)	Q Value (mean value)	Standard Deviation (MPa)	No. of Readings
21/03/16				
Northern Pagoda				
11:06	23.0	35.5	9.3	9/11
11:09	26.5	39.0	9.8	9/11
11:12	15.5	28.0	7.5	10/12
11:15	11.0	22.0	2.5	9/11
11:18	18.5	31.5	7.5	9/11
11:21	11.0	22.0	4.0	11/15
11:37	10.0	20.0	4.3	10/12
11:59	13.5	25.5	4.5	10/14
12:01	17.0	19.5	4.8	11/15
12:02	20.5	33.5	7.0	9/13
12:08	12.5	24.0	4.0	9/11
12:28	18.0	31.0	9.0	10/12
12:01/12:31	25.5	38.5	15.0	9/11
12:06/12:36	9.0	19.0	3.0	8/10
12:09/12:39	12.5	24.0	4.0	8/10
12:10/12:40	11.5	22.5	2.8	9/11
12:14/12:44	11.5	22.5	5.8	8/10
Cliff Line				
12:55/1:25	23.5	36.0	16.5	10/12
12:57/1:27	11.5	22.5	3.8	10/12
1:02/1:32	20.0	33.0	14.8	9/11
1:04/1:34	<9	17.5	-	8/10
1:06/1:36	11.0	21.5	3.8	7/7
1:13/1:43	13.0	25.0	5.3	9/11
1:22/1:52	16.0	28.5	6.0	8/10
1:33/2:03	21.0	33.5	6.5	9/11
1:46/2:16	19.0	32.0	9.5	10/12
2:09/2:39	18.5	31.0	7.3	9/11
22/03/16				
Central Pagodas				
9:55	17.0	30.0	6.5	9/11

Reading ID (time)	Rock Strength (MPa - mean value)	Q Value (mean value)	Standard Deviation (MPa)	No. of Readings
10:01	16.5	29.0	4.8	8/10
10:02	19.0	31.5	8.8	8/10
10:12	11.5	22.5	7.3	9/11
10:21	16.0	28.5	9.8	10/12
10:28	17.5	30.0	6.8	8/10
10:48	13.5	25.0	5.5	10/12
11:00	13.5	25.5	4.0	8/10
11:28	21.0	34.0	11.3	9/11
11:39	15.0	27.5	5.0	8/10
11:49	11.5	22.5	1.8	8/10
12:13	14.0	26.0	4.5	8/10
12:15	24.5	37.5	8.3	8/10
Southern Pagodas				
1:02	13.0	24.5	3.8	10/12
2:21	<9	18.5	-	9/9
2:22	<9	15.0	-	8/10
2:24	11.0	21.5	3.0	8/10
2:25	<9	15.5	-	8/10
2:27	9.0	19.0	-	8/10
2:31	11.0	21.5	5.8	8/10
2:32	12.5	24.0	2.3	9/11
2:42	9.5	19.5	2.0	8/10
2:46	9.0	19.0	-	8/10

Alternative Method of Rock Strength Estimations

As explained above, the in-field rock strength estimation method presented relies on a high volume of collected in-field data. However, there is a certain instrument limitation due to the instruments operational range, which does not allow for assessment of very low strength rocks.

The instrument’s lower limit of rock strength estimations is around the 9 to 10 MPa level, while the upper limit is around 70 MPa. Therefore, as there were the occasional low strength bands identified during the site assessment (i.e. rock strengths below 9 MPa level), an alternative in-field rock strength assessment method was required.

The method is a ‘Simple Means’ Intact Rock Strength Field Estimate. The method has been discussed in detail by **Hack and Huisman (2002).** In addition, the method has been compared to a standard laboratory testing method of UCS, which has also been identified to have a number of weak points, and therefore not always is fully representative of the actual in-field rock strength values, e.g. samples tested in a laboratory tend to be of better quality as poor rock is usually discarded.

The authors postulate that the ‘Simple Means’ Intact Rock Strength Field Estimate could provide an alternative means of rock strength assessment. The method is summarized in **Table 4** and relies on the observation of rock behavior via applying simple means of assessment during in-field testing.

Table 4: Estimation of intact rock strength (after Hack and Huisman (2002))

Intact Rock Strength (MPa)	**‘Simple Means’ Test** (using standard geological hammer of about 1 kg)
< 1.25	Crumbles in hand
1.25 – 5	Thin slabs break easily in hand
5 – 12.5	Thin slabs break by heavy hand pressure
12.5 – 50	Lumps broken by light hammer blows
50 – 100	Lumps broken by heavy hammer blows
100 – 200	Lumps only chip by heavy hammer blows
>200	Rocks ring on hammer blows. Sparks fly.

Therefore, applying the ‘Simple Means’ test principles to the low strength bands identified during the site testing (i.e. bands measured to be below 9 MPa), the bands were assessed to have a rock strength in the order of 5 – 12.5 MPa. Accounting for the Silver Schmidt Hammer test range (i.e. the lower bound being 9 MPa), the rock strength of the considered bands is most likely in the order of 5 to 9 MPa.

6.2 Structural Integrity Assessments

In addition to the described rock strength testing, each of the Sandstone Pagodas and the Cliff Line was assessed for their integrity during site visits on the 21.03.16 and 22.03.16. This included site inspections, detailed site mapping and identification of geological features, existing cracks and overhangs, documented by the means of GPS mapping (selected points) and area photography. This approach would assist in the identification of risks and potential hazards when exposed to the adjacent (proposed) open cut blasting.

It is acknowledged that there are certain limitations of the site inspections, which were restricted to accessible areas only. Nevertheless, the inspections generally covered the sections around the pagodas of interest and access to the top of the pagodas wherever possible.

Northern Pagodas, (see Appendices 4A-Q)

The Northern Pagodas represent a platy pagoda formation. The identified area of the Northern Pagodas extends for approximately 200 metres in length and up to 150 metres in width. Due to the extent of this area the focus of this investigation was limited to the western section only. This represents the closest section to the mine located at its closest at approximately 320 metres.

The area represents a massive single pagoda formation. The height of the structure varies and in places is in excess of 20 metres (where inspected). There is no access to the top of the pagoda from the western side, the top of the formation was reached from the southern end. The surrounding area, together with the accessed top section, was inspected for major deficiencies in the structure. The structure had limited cracks / deficiencies / geological features with relatively limited deterioration.

Major Cracks / Defects

The site inspection revealed only a limited number of cracks. These are highlighted in **Figure 5**. The cracks are generally a few metres long (few centimetres wide) and have a north–west / south-east orientation. There were a total of five major cracks identified within the inspected section of the Northern Pagodas area. Accounting for the extent of the area (i.e. an 80 x 40 m approximately triangular section) the number of cracks is not considered significant in terms of stability impact (i.e. ground vibration from open cut mining).

The origin of some of the cracks appears to be related to the action of water runoff in the pagodas area. The site observation confirmed some significant leaf and other post-rain debris deposits usually adjacent to the identified cracks. Other cracks were located within the pagoda structures themselves.

Overhangs

The extent of each overhang (including dimensions) was measured, wherever possible. However, for higher and not accessible formations only visual estimates were made. Only 3 overhangs with limited depths were identified within this section of the Northern Pagoda.

Top Sections

Due to the difficult access to many areas of the top sections only one pagoda top was reached and examined. The damage was relatively limited and the presence of stronger, mainly horizontal ironstone bands was observed, see **Appendices 4K, 4L** and **4M.** Other, inaccessible surrounding top sections, were observed for significant deficiencies. There were only two top sections that showed limited erosion.

General Summary for Northern Pagodas

Overall, it has been concluded that due to the limited number of cracks / defects the impact of blasting should not have a significant effect, nor provide any additional risks (besides the ongoing natural erosion factors), to the pagodas when exposed to controlled blasting from the adjacent mine.

The assessed section of the Northern Pagodas formation appears to be structurally sound with a limited number of defects identified (as specified above).

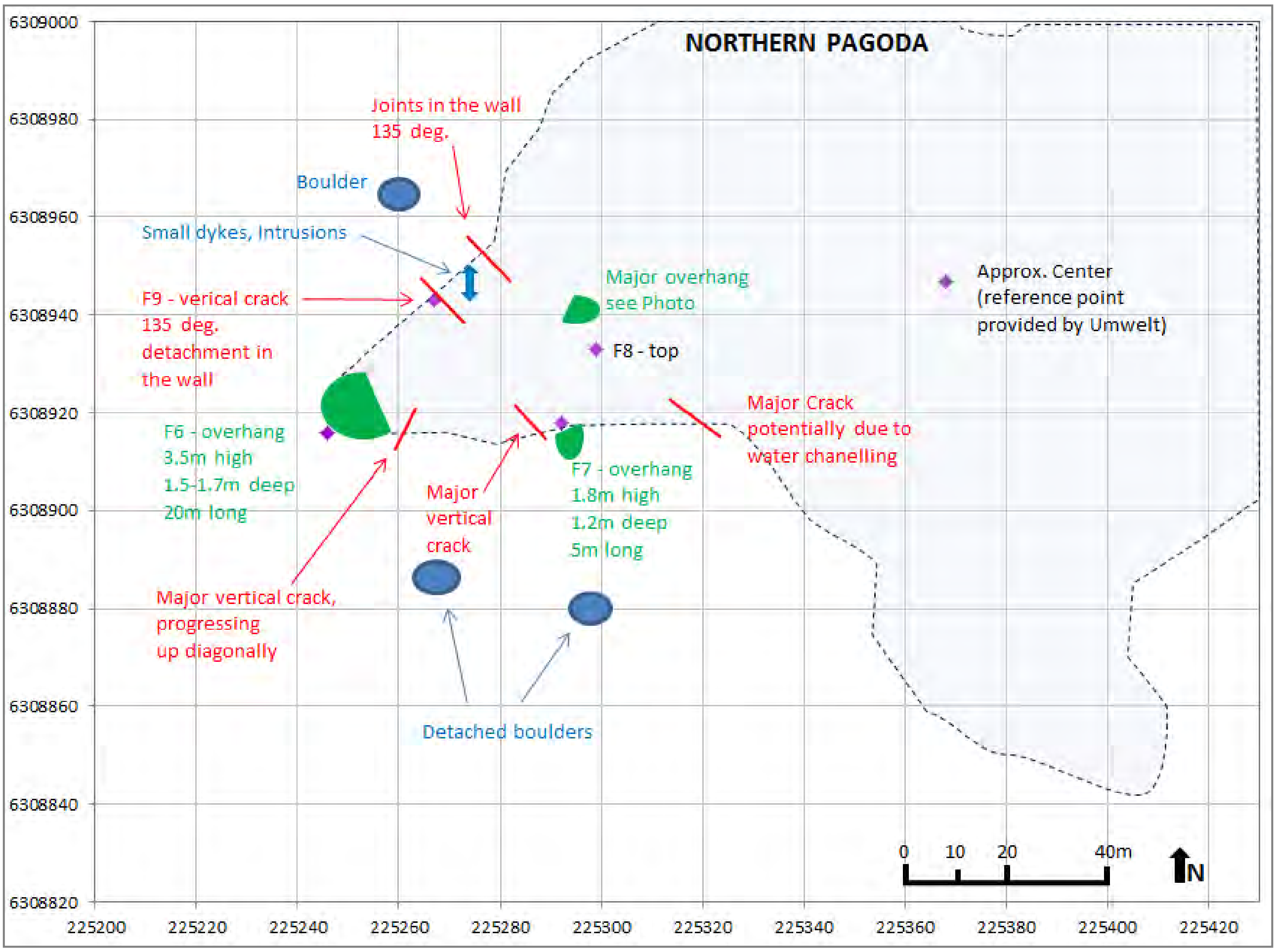

Figure 5 – Survey of the Northern Pagoda

Central Pagodas, (see Appendices 5A-P)

The Central Pagodas represent platy pagodas with a mix of intricately sculptured and smooth surfaces. The identified area of the Central Pagodas extends for approximately 250 metres in length and up to 75 metres in width. The area consists of a high number of closely spaced sandstone pagodas with small separations, soil covered lightly wooded scree between them. Occasionally however, two or three pagodas show connection at the base forming a single unit. It is noted that often such features include two or three separate mounts specific for each pagoda.

There were a number of thinly bedded sandstone and siltstone / shale bands located mainly in the western and eastern sections of the inspected pagodas. These bands are prone to recessive action and with time are responsible for the formation of a number of overhangs, see **Figure 6**.

Such recessive material appears relatively strong (no different and occasionally higher strength than adjacent sandstone strata) although under the influence of water the ply structure disintegrates (via water ingress into fissures) and results in the formation of overhangs. Note that some fresh overhang damage was observed in the eastern sector of the tested Central Pagoda section. In addition, in the eastern section an active slabbing and spalling of the recessive layer was observed, see **Figure 2A**.

Major Cracks / Defects

The site inspection revealed only a limited number of cracks. These are highlighted in **Figure 6**. The cracks are generally a few metres long (few centimetres wide) and are either a north / south or north-east / south-west orientation. There were a total of 7 major cracks identified within the Central Pagodas area. Accounting for the extent of the area (i.e. 250 x 50 m rectangular section on average) the number of cracks is not considered significant in terms of stability impact.

Overhangs

The common feature of the Sandstone Pagodas are the overhangs. The extent of each overhang (including dimensions) were measured wherever possible, see **Figure 6**. However, for higher and not accessible formations only visual estimates were made.

Top Sections

The site inspection revealed that the majority of the formations in the top section are smooth and dome shaped, showing an almost conical shape, resembling a smooth pagoda type. Such shapes allow for immediate water dispersion, see **Appendix 5A** and **5B**. There were only few sections of pagodas with well-formed "sculptural" elements on top, characteristic of platy pagoda type, indicating the presence of a stronger undulating-shape ironstone band, see **Appendices 5C, 5O** and **5P**.

General Summary for the Central Pagodas

The assessed Central Pagodas formation appears to be structurally sound with a limited number of defects identified (as specified above).

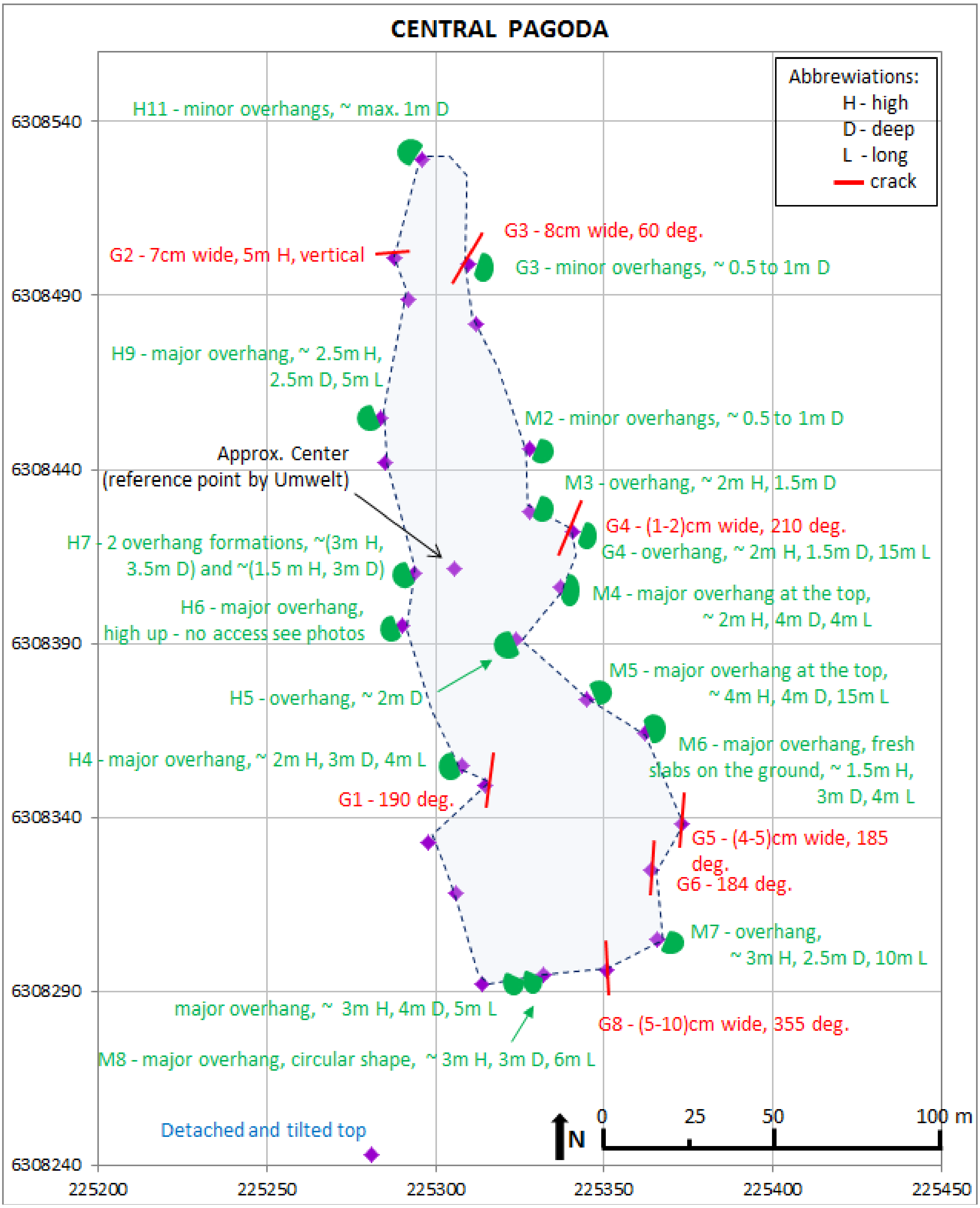

Figure 6 – Survey of the Central Pagoda

Isolated Degraded Sandstone Formation, (see Appendices 5Q and R)

The site inspection revealed an unusual case of a degraded sandstone formation. This particular formation is a stand-alone structure and is located some distance away from the other Sandstone Pagodas, in a south-west direction from the Central Pagodas (approximately 390 metres from the proposed pit boundary), see **Figure 6**.

It appears that the damage was most likely induced by a chemical or physical weathering of the strata layer over a long period of time. The damage occurred at approximately two-thirds of the height of the structure. Consequently the top dome has tilted as it has slid from the sandstone pagoda sub-base and appears to crack in some places. The site is located on sloping terrain; therefore the top dome will continue to slide due to gravitational forces. The displacement of the top of the pagoda will continue to accelerate during extreme weather conditions such as heavy rain, or the buildup of ice or others. The water in this case will act as a lubricant for the deteriorated strata layer. Subsequently the top dome will continue to move with periods of acceleration and static periods between.

To assess the overall stability of the detached sandstone pagoda an estimation on the location of the centre of gravity (for the detached element) has been made. For that purpose it is assumed that the detached element is a conceptual cone.

The centre of mass for a cone lies along the axes of symmetry, at a distance three quarters of the height from the tip (i.e. 1/4 from the base).

Centre of mass = 1/4 * Height = 0.75 metres (from the base)

where
Height – is a height of cone, which is approximately 3 metres

Therefore, the centre of mass of the pagoda is located approximately 0.75 metres from the base of the pagoda, as marked in **Figures 7A-C.** Based on this assessment the centre of gravity still lies some distance from the edge of the pagoda base (i.e. in excess of 0.5 metre).

Taking into consideration blasting impacts such as those generated by 25 mm/s or even 50 mm/s, the induced displacement is no higher than 1 to 2 mm (i.e. dynamic displacement). Therefore, the detached cone will not be sufficiently displaced to shift the cone to be in the danger zone (i.e. to be on the edge of the base), that it can tilt over.

In addition, the analysis assumes the “worst case scenario” that during the moment of actual vibration the resistance force is almost minimal and all induced displacement by the vibration forces is transferred directly to the detached cone. In reality however this is not the case.

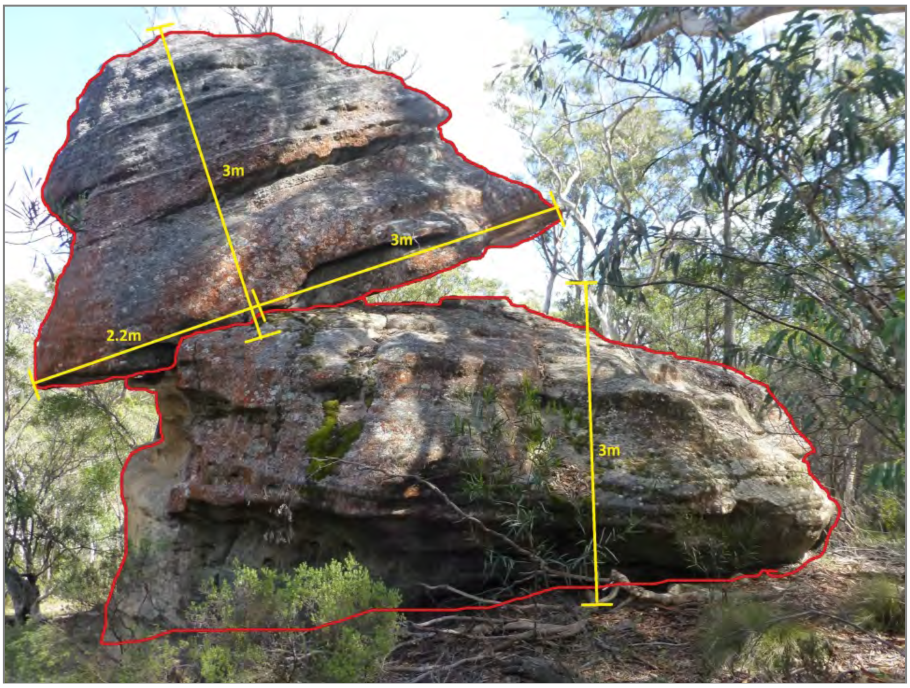

Figure 7A – Degraded Pagoda

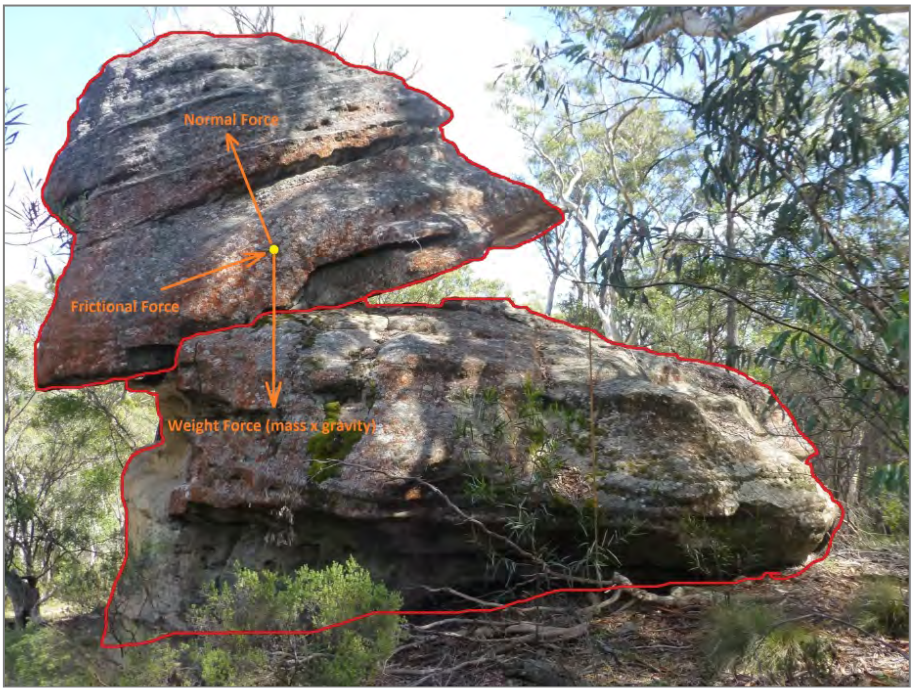

Figure 7B – Degraded Pagoda

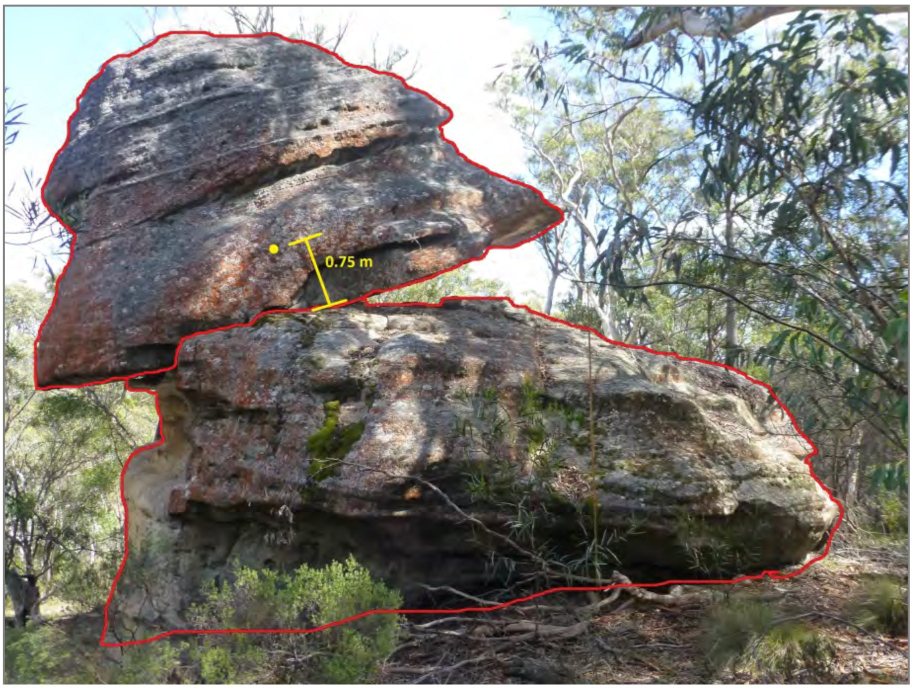

Figure 7C – Degraded Pagoda

Southern Pagodas, (see Appendix 6A-I)

The Southern Pagodas represent a platy pagoda type. Differential weathering of sandstone and ironstone bands is not as pronounced in this section and as a result the formations appear smoother than the other investigated Pagodas. The identified area of the Southern Pagodas is an irregular shape approximately 80 metres in length and up to 50 metres in width. The grouping can be described as one single unit with a number of sandstone pagoda peaks. The area is similar to the Central Pagodas, although it appears to be more compact with steep angled walls on the eastern and western sides. The individual formations of the Southern Pagodas seem to originate from the same sub-base. The majority of the top sections were easily accessible and were inspected for major deficiencies and geological features.

Major Cracks

The site inspection revealed only a limited number of cracks. These are highlighted in **Figure 8**. The cracks are generally a few metres long (few centimetres wide) and are a north-east / south-west orientation. There were a total of 9 major cracks identified within the Southern Pagodas area. Accounting for the extent of the area (i.e. approximately 80 x 50 m), the number of cracks is not considered significant in terms of stability impact.

The origin of some of the cracks appears to be related to the action of water runoff in the pagodas lee (i.e. lowest sections between pagoda tops). Collected leaf and other post-rain debris deposits were found at the base of some of the identified cracks. There were also other cracks located within the pagoda structures themselves.

In addition to the above, there were two damaged sections identified, including the south-west corner of the pagodas and the cracked and dislodged western ledge.

The south-west corner appears to be affected by corner cracking. The cracks were mapped and are most likely related to the movement of the pagoda corner in this section. In the top section there was a detached boulder (approximately 1 x 2 m in size) from the pagoda, most likely caused by the local instability in this section, i.e. cracking and localised movement, see **Appendix 6C** and **6F.**

On the western side a ledge showing an approximately 15 metre long crack (10 - 15 cm wide) was found. Due to the crack the semicircular ledge (approximately 10 metre radius) appears detached from the body of the pagoda. As the ledge is located on a steep slope the most likely cause appears to be related to localised slope sliding, see **Appendix 6G** and **6H.**

Both of these identified defects appear to be related to localised instabilities, more likely caused by either water, gravitational effect or local slope movement rather than underground subsidence within this area. This, however, should be further verified, if possible.

<u>Overhangs</u>

The extent of the overhangs (including dimensions) were measured / estimated wherever possible. However, for higher and not accessible formations only visual estimates were made. Only 5 overhangs with limited depths (i.e. 1 – 1.5m) were identified within this section of the Southern Pagodas.

<u>Top Sections</u>

The south-west corner of the pagoda appears to have an affected section and revealed one detached boulder. Also some cracks were identified in this section. Note that the south-west corner was not accessed due to the limited accessible space and safety reasons.

The southern and central parts of the top sections appear to have limited erosion and damage observed. These appear relatively stable. The top sections in the northern area include a number of detached, but stable, boulders.

<u>General Summary for the Southern Pagodas</u>

In summary, the structure is described as a single formation with limited cracks / deficiencies / geological features and relatively limited deterioration

The inspection identified two sections with some defects / damage. This included the south-west corner with a detached boulder on top and a cracked corner section. There is also a detached ledge on the western side with a major crack splitting it from the pagoda section. The detached ledge appears to be displaced by localised ground instability. It is unlikely that this was caused by underground subsidence, but more likely by a localised issue.

The extent of the damage in both cases appears to be limited. The damage does not seem to be recent and does not appear to be continuing. The other sectors appear structurally sound.

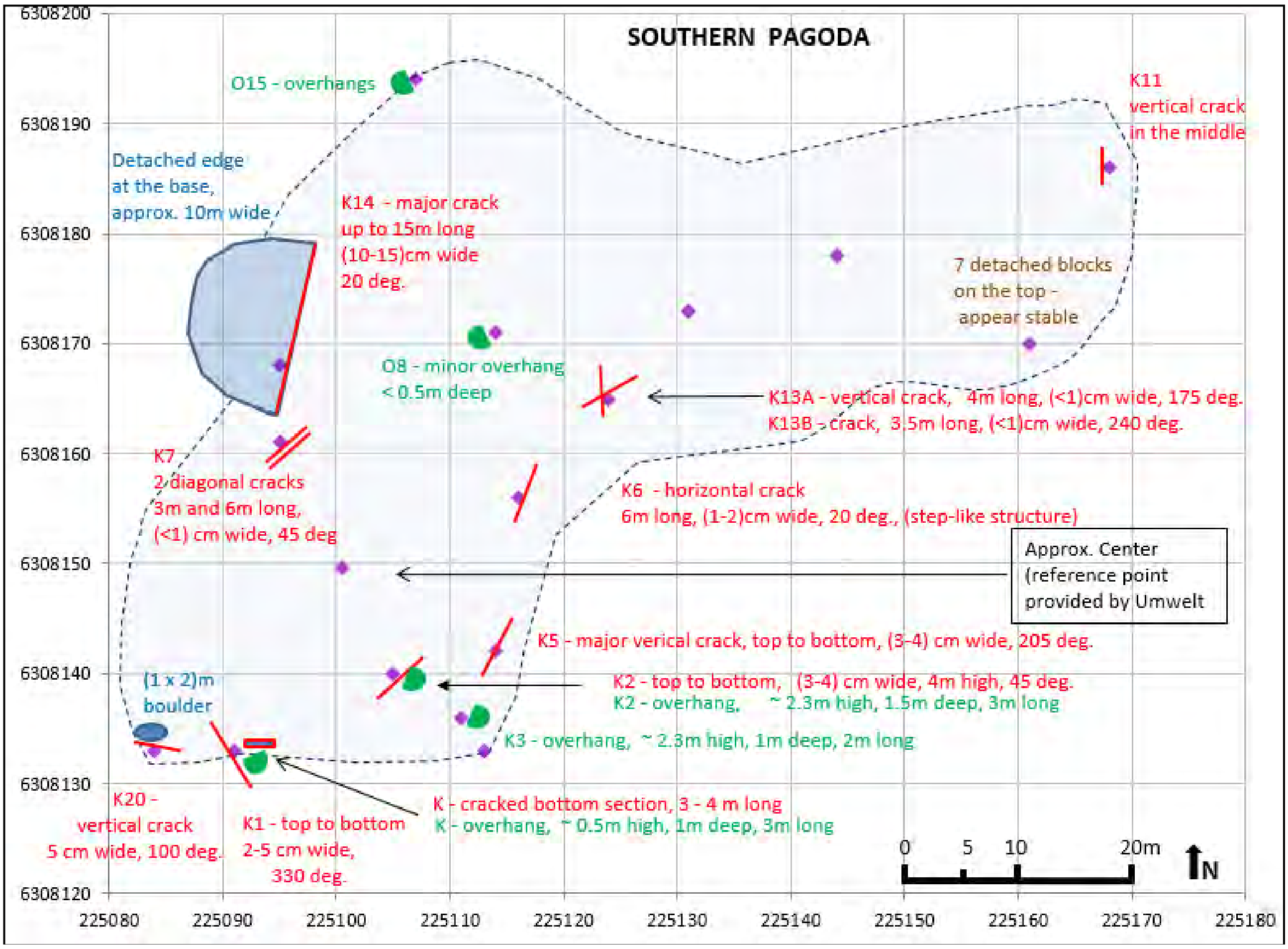

Figure 8 – Survey of the Southern Pagoda

Cliff Line, (see Appendices 7A-P)

The identified area of the Cliff Line extends for approximately 100 metres in length and varies between 8 and 14 metres in height. The Cliff Line is of northeast / southwest orientation, see **Figure 9A**. The area is accessible from the south-west corner and the inspection of the Cliff Line identified at least 5 different strata layers, which varied in appearance / colour and strength (see rock strength estimation section).

Major Cracks / Defects

The site inspection revealed major damage to the south west section of the Cliff Line. There are signs of a major slope sliding failure and related damage. On the top surface of the Cliff Line there is one pronounced semi-circular (major) crack, see **Appendices 7H-L**. Other, moderate cracks generally follow the pattern of the slope sliding failure line, i.e. generally parallel to the main crack. These are highlighted in **Figure 9B.**

The major crack is approximately 60 metres long and up to 40 cm in width. The crack appears to be very deep (upon testing by the dropping of a stone). It is suspected that the crack is related to surface subsidence and extends all the way to the old underground workings.

In addition to the major cracking on top of the Cliff Line there was related damage within the face of the Cliff Line. This included substantial vertical cracks as well as “inverted” wedge failures in the top section of the Cliff Line. The observed wedge failure resulted in boulder detachments of substantial sizes from the top section of the Cliff Line.

The extent of the damage is quite significant and appears to be related to surface subsidence caused by previous underground operations in this area, see **Appendices 7C-F**.

The remaining section of the Cliff Line is in relatively good condition with limited deficiencies and defects.

The identified damaged section appears to have occurred quite some time in the past (there were no fresh signs of further deterioration observed) and has most likely stabilised, as strata is interlocked and appears to be in equilibrium.

Overhangs

Only 2 overhangs (excluding the damaged wedge section), with limited depth were identified.

Top Sections

The top section of the Cliff Line forms a gently inclined rising slope and is easy to walk (with the exception of the steeply inclined slope immediately adjacent to the Cliff Line) and shows no significant top features.

General Summary for the Cliff Line

In summary, the structure is described as a major vertical wall of 8 – 14 m high. One section of the Cliff Line appears to be heavily damaged by inferred surface subsidence from previous underground operations. The extent of the damage for the affected area is classified as significant, showing signs of slope sliding. The damage occurred at some time in the past and does not appear to be actively continuing. The remaining section appears structurally sound.

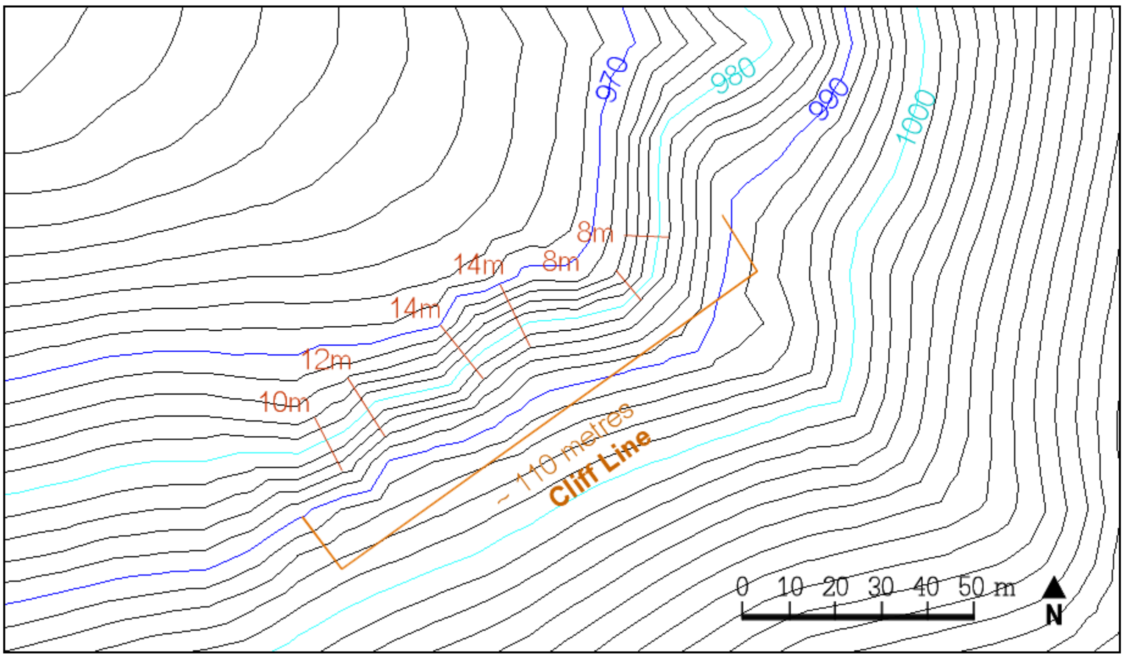

Figure 9A – Heights and Extent of the Cliff Line; (2 metre contour line)

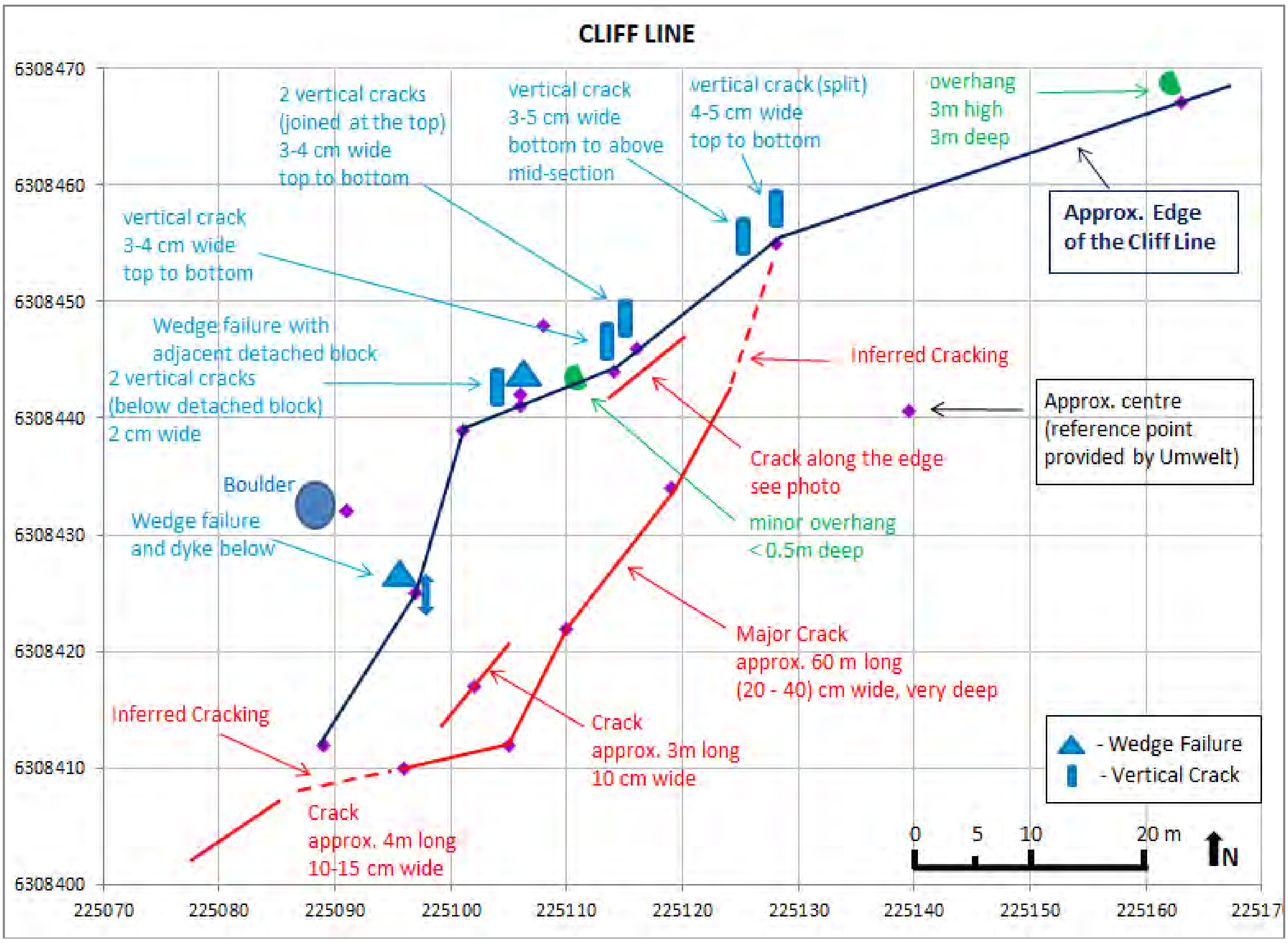

Figure 9B – Survey of the Cliff Line

7. DISCUSSION

The study presented above included a detailed assessment of the state of the Sandstone Pagodas and Cliff Line using various assessment techniques, including:

- rock strength estimations,
- site mapping,
- structural assessment, including cracks and geological defect identification.

These assessment methods were utilised to assist in addressing risks for the identified structures when exposed to the effects of the proposed open cut blasting.

Summary of Rock Strength Testing

The majority of the obtained rock strength values were above 10 MPa with a typical range of 10 to 26.5 MPa, therefore representing a medium strength material in terms of exposure to vibrations. There was only a small percentage of rock strata around 9 MPa or lower (i.e. between 5 and 9 MPa). Usually low strength strata is prone to increased weathering or increased damage due to water ingress and chemical weathering, as discussed above. The study did not identify rock strata layers below 5 MPa. Overall, the rock strength study confirmed adequate rock strength for the sandstone structures to be exposed to moderate, and in some cases, high vibration levels.

Summary of Structural Assessment

From a blasting viewpoint, the outcropping sandstone rocks, such as the described Sandstone Pagodas, are substantially sized structures supported by a significant sandstone sub-base. In many cases, the base of the sandstone outcrop is at an approximate angle of 40 degrees or more, without any signs of deterioration of the base. As a whole therefore, the inspected arrangement is classified as a massive formation and considered to be well protected (due to the massive sub-base) from the forces of blast vibration and/or earthquake tremor.

From a blasting perspective, when dealing with structural damage for massive structures, damage is relatively difficult to induce. This is due to the fact that the structure responds to vibrations as a whole and induced stresses are generally distributed uniformly.

An additional point to consider is the presence of the existing weaknesses within the Sandstone Pagoda structures, such as cracks and geological features. The assessment revealed a limited number of cracks and geological intrusions / weaknesses within the Sandstone Pagoda structures.

Considering the state of the Sandstone Pagodas, and the identified damage / deficiencies, the risks for the Pagodas are negligible / low. This is applicable for the proposed blasting distances and proposed blasting parameters (max MIC 466 kg). The 50 mm/s target ground vibration limit should provide a sufficiently low limit (including adequate Factor of Safety) for these structures to be exposed to. This is also supported by low dynamic displacement estimates for typical blasting frequencies of 4 – 25 Hz, see **Table 5**. It is stressed that the damage level is substantially higher than the 50 mm/s level quoted here.

In view of the undertaken study the target ground vibration limit of 25 mm/s for the Cliff Line is acceptable for this structure, taking into consideration the detected major rock strata deterioration. This is also supported by low dynamic displacement estimates for typical blasting frequencies of 4 – 25 Hz, see **Table 5**. As reported, the southern part of the Cliff Line was previously damaged by (inferred) underground subsidence. Therefore, there is a need for additional monitoring around the Cliff Line when undertaking blasting for the proposed Project. The vibration limit of 25 mm/s is proposed with the proviso that the site will be monitored, including vibration and crack monitoring behavior. In addition to vibration monitoring, a periodic survey of target points is to be introduced.

Blasting at these levels (i.e. 25 mm/s and below) should not have any detrimental impact on strata behavior. Based on the experience from similar projects the subsided rock strata usually behaves in a static manner, i.e. for a well subsided area, when the movement occurred a long time ago. As such, the strata can sustain low vibration impacts without damage such as rock strata movement and further cliff deterioration occurring.

It should be noted however, that the affected Cliff Line can still undergo further strata damage / deterioration when exposed to extreme weather conditions such as, for example, deluge or an extreme heavy rain event (i.e. continuing for a number of days). The water intake / inrush into identified major cracks will initially promote further strata damage and with time will act as a lubricant between the damaged strata layers, which would most likely cause further slope slippage and subsequent Cliff Line deterioration.

The monitoring program will therefore provide an additional tool in assessing the long term Cliff Line behaviour.

The results of the undertaken assessments are summarised in **Table 5**.

Based on the undertaken assessments the risks are classified as follows:

- Negligible / low for the Sandstone Pagodas, and
- Low / moderate for the Cliff Line.

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Table 5: Summary of Risk Assessment

Structure	Strength	Defects	Vibration Limit (mm/s)	Dynamic Displacement (mm)	Comments	Risks
Northern Pagodas	9 - 26.5 MPa, 5 - 9 MPa – one weaker section	Single cracks observed. Intensity low i.e. approximately 1 per 10 m	50 mm/s Limit	4 Hz – 2.0 mm 25 Hz – 0.32mm	Northern Pagodas appear to be structurally sound with a limited number of defects identified.	negligible / low
Central Pagodas	11.5 – 24.5MPa, Majority around 16 MPa	Single cracks observed. Intensity low i.e. approximately 1 per 12 m	50 mm/s Limit	4 Hz – 2.0 mm 25 Hz – 0.32mm	Central Pagodas appears to be structurally sound with a limited number of defects identified.	negligible / low
Southern Pagodas	9 - 13 MPa 5 - 9 MPa – few weaker sections	Single cracks observed. Intensity low i.e. approximately 1 per 10 m	50 mm/s Limit	4 Hz – 2.0 mm 25 Hz – 0.32mm	Generally Southern Pagoda appear to be structurally sound. Two sections with some defects/damage were identified i.e. south-west corner with a detached boulder and a cracked corner section. The second area included a detached ledge with a major crack splitting it from the body of the pagoda.	negligible / low
Cliff Line	11 - 23.5 MPa 5 - 9 MPa – single layer	Single cracks observed. Intensity low i.e. approximately 1 per 3 m	25 mm/s Limit	4 Hz – 1.0 mm 25 Hz – 0.16mm	One section affected by (inferred) surface subsidence, major damage due to slope failure observed.	low / moderate

8. CONCLUSIONS AND RECOMMENDATIONS

The assessment forms part of the Blasting Impact Assessment and will be used to obtain approval to undertake coal extraction for the Invincible Southern Extension Project. The Sandstone Pagodas and Cliff Line were inspected and assessed for potential risks, including damage from blasting (that is ground vibration exposure).

The study is supported by a review of proposed extraction plans, comparable studies and a review of the ESC's professional experience related to similar structures. The study also included rock strength testing and structural integrity assessment undertaken on the 21st and 22nd of March 2016 during site inspections. The investigation is summarised as follows.

ROCK STRENGTH ESTIMATIONS

- The study included in-field rock strength testing. The methodology behind the in-field rock strength estimations was presented in section 6.1. For all of the tested structures the rock strength was generally found to be adequate when measured without the presence of dilapidated layers, i.e.
- The rock strength estimates for the Northern Pagodas are in the range of 9 to 26.5 MPA, with one weaker strength section (i.e. between 5 and 9 MPa). The majority of the rock strength was estimated to be in the order of 11.5 MPa or more.
- The rock strength estimates for the tested Central Pagoda are in the range of 11.5 to 24.5 MPa. The majority of the readings are around 16 MPa.
- The rock strength estimates for the Southern Pagodas are in the range of 9 to 13 MPa. There were some sections showing strength values between 5 and 9 MPa.
- The testing for the Cliff Line revealed the rock strength generally varied between 11 and 23.5 MPa, with one weaker layer with strength values in the range of 5 and 9 MPa.

STRUCTURAL INTEGRITY

- The sandstone formations have been inspected and assessed in detail. The Sandstone Pagodas are of substantial size located on a significant sub-base and are affected in places by ongoing rock weathering. The sandstone material was determined to be of an acceptable strength (in terms of vibration impact). The assessment revealed a limited number of cracks and geological intrusions / weaknesses within the Sandstone Pagoda structures, all of these were mapped and presented for future reference.
- Considering the distances and estimated vibration exposures, the study did not identify any major risks related to structural damage for the Sandstone Pagodas. This is taking into consideration the current state of these structures, their substantial base and limited number of weaknesses.

- Based on the undertaken assessments and using recommended vibration limits, see **Table 5**, the risks are classified as follows:
  - Negligible / low for the Sandstone Pagodas, and
  - Low / moderate for the Cliff Line.

VIBRATION LIMITS

- The vibration limit for the Sandstone Pagodas (including the Northern, Central and Southern Pagodas) were identified as 50 mm/s. As discussed in the report, the specified level is conservative when considering inducing damage to rock strata layers. The proposed limit is also well below the damage criteria for the assessed sandstone material.
- Considering the distances and estimated vibration exposures, the study did not identify any major risks related to structural damage for the Sandstone Pagodas. This is taking into consideration the current state of these structures, their substantial base and lack of significant weaknesses.
- The vibration limit for the Cliff Line was identified as 25 mm/s. Part of the Cliff Line appears to be affected by surface subsidence induced by previous underground extraction in this area. Due to the detected damage additional vibration and crack monitoring is to be introduced when commencing blasting for the Project. In addition, periodic surveys of target points is also to be introduced.
- The recommended allowable vibration limits are in agreement with the ESC's studies of comparable rock strata materials as well as other published studies of a similar nature as presented in sections 4 and 5.
- There are no airblast overpressure criteria for the considered structures as airblast overpressure would have negligible impact for the considered Sandstone Pagodas and Cliff Line.

Thomas Lewandowski
15th September 2016

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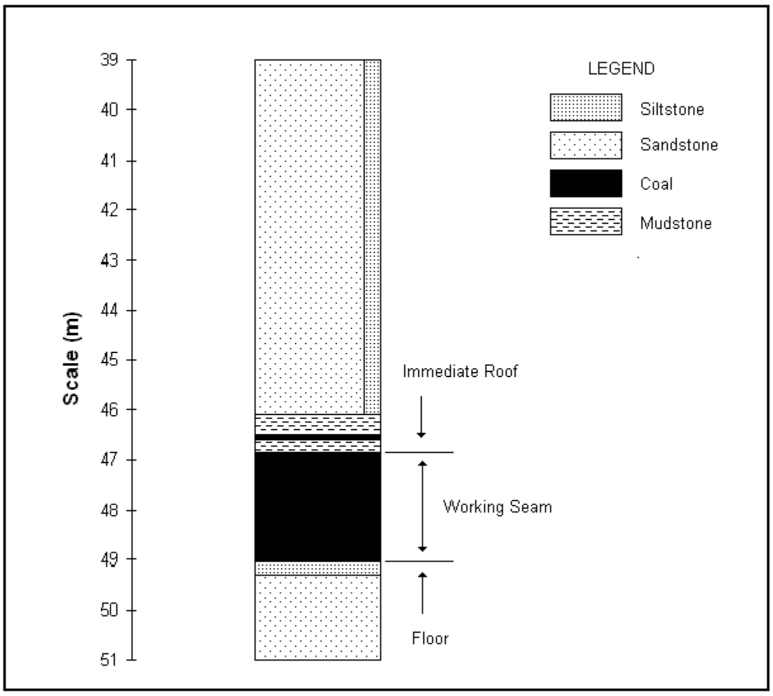
APPENDICES

Appendix 1A – Rock strata cross-section – North Wambo Underground mine (after Lewandowski et al 2007)



Appendix 1B – Summary of UCS values for immediate roof – based on sonic velocity data (after Lewandowski et al 2007)

Hole No.	Sample Description/Depth	Inferred UCS (MPa) (based on sonic velocity)
WML 009	Sandstone / Siltstone / Mudstone (seam at 143 m)	30 – 90 MPa – sandstone 10 – 20 MPa – mudstone
WML 013	Sandstone / Siltstone (seam at 127.5m)	40 – 87 MPa – sandstone
WML 004	Sandstone / Siltstone / Mudstone (seam at 84.2m)	40 – 70 MPa – sandstone 10 – 40 MPA – mudstone
WML 82	Sandstone / Siltstone (seam at 64m)	60 – 90 MPa – sandstone

Appendix 2A – Sandstone Remnants Study (by ESC); Showing Rock Strata Features

Appendix 2B - Sandstone Remnants Study (by ESC); Showing Rock Strata Features

Appendix 2C - Sandstone Remnants Study (by ESC); Rock Strata Features and Monitoring Equipment

Appendix 3A – Dam Wall Study (by ESC); Top of the Dam Wall Features and Monitoring Equipment

Appendix 3B – Dam Wall Study (by ESC); View of the Dam Wall and the Fault Line

Appendix 3C – Dam Wall Study (by ESC); Showing Dam Wall Features

Appendix 4 – Northern Pagodas as Inspected on 21.03.16

Appendix 4A

Appendix 4B

Appendix 4C

Appendix 4D

Appendix 4E

Appendix 4F

Appendix 4G

Appendix 4H

Appendix 4I

Appendix 4J

Appendix 4K

Appendix 4L

Appendix 4M

Appendix 4N

Appendix 4O

Appendix 4P

Appendix 4Q

Appendix 5 – Central Pagodas as Inspected on 22.03.16

Appendix 5A

Appendix 5B

Appendix 5C

Appendix 5D

Appendix 5E

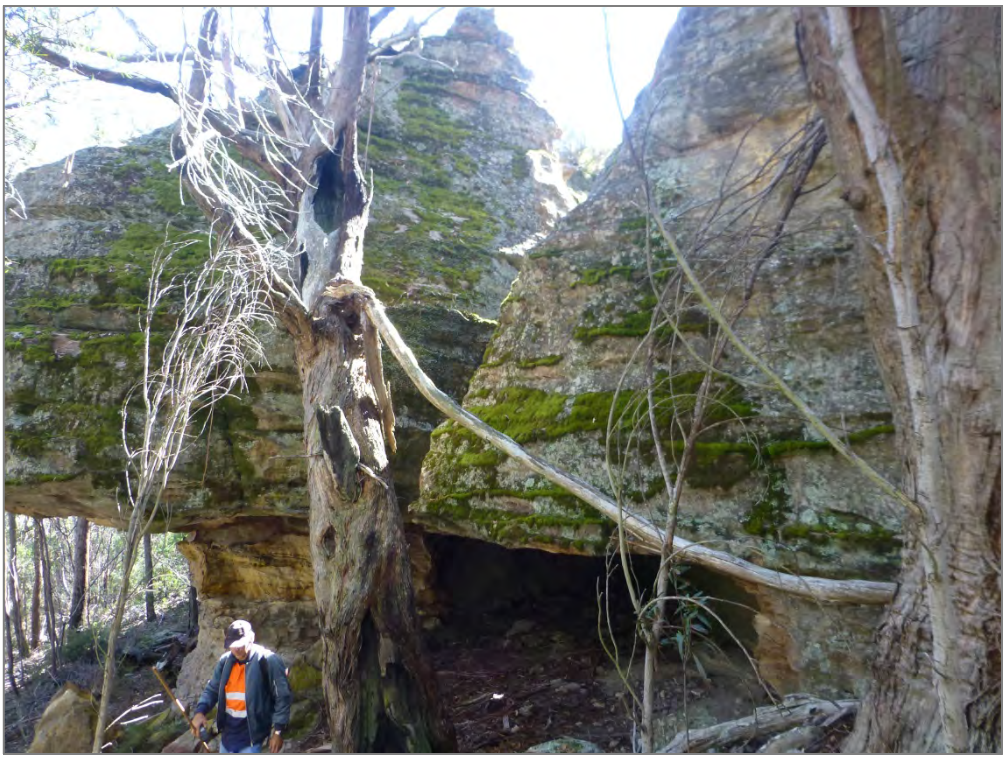
Appendix 5F

Appendix 5G

Appendix 5H

Appendix 5I

Appendix 5J



Appendix 5K

Appendix 5L

Appendix 5M

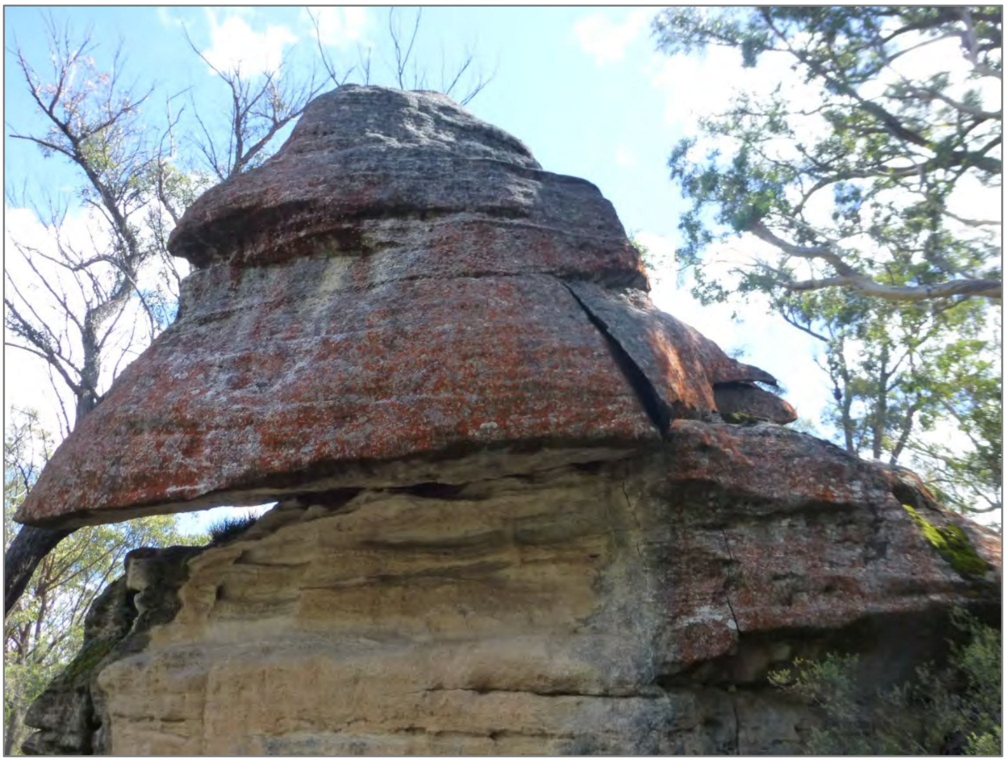
Appendix 5N

Appendix 5O

Appendix 5P

Appendix 5Q - Isolated Degraded Sandstone Formation

Appendix 5R - Isolated Degraded Sandstone Formation



Appendix 6 – Southern Pagodas as Inspected on 22.03.16

Appendix 6A

Appendix 6B

Appendix 6C

Appendix 6D

Appendix 6E

Appendix 6F

Appendix 6G

Appendix 6H

Appendix 6I

Appendix 7 – Cliff Line as Inspected on 21.03.16

Appendix 7A

Appendix 7B

Appendix 7C

Appendix 7D

Appendix 7E

Appendix 7F

Appendix 7G

Appendix 7H

Appendix 7I

Appendix 7J

Appendix 7K

Appendix 7L

Appendix 7M

Appendix 7N

Appendix 7O

Appendix 7P