APPENDIX S

Geotechnical Assessment

ILLAWARRA METALLURGICAL COAL

FEASIBILITY GEOTECHNICAL ASSESSMENT – DENDROBIUM MINE EXTENSION PROJECT

Dendrobium22- R1 Final FEBRUARY 2022

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EXECUTIVE SUMMARY

Illawarra Metallurgical Coal (IMC) are assessing the feasibility of mining the Bulli Seam in Area 5 at the Dendrobium Mine. In Area 5, the Bulli Seam considered in this geotechnical assessment is 2.0-3.3 metres (m) thick and occurs at depths of 345-395 m. Drift access to Area 5 is planned from the Wongawilli Seam workings in Area 3.

The main geotechnical issues identified for a longwall operation in the Bulli Seam in Area 5 are the alignment to the horizontal stress direction, geological structures, sandstone units in the overburden and silling in both the Bulli and Wongawilli Seams.

The consistent NE/SW horizontal stress trend indicates the longwalls are aligned at 0-45 degrees (^{o}) to this orientation. Concentration of the minor horizontal stress can be expected in the Maingate during the retreat of Longwalls 501-506. The Maingate of Longwall 510 can anticipate a concentration of the major horizontal stress and a super stress notch can be expected as LW502 retreats past the LW501 goaf. The Maingates of LW507-509 are aligned almost parallel with the major horizontal stress.

Faults and dykes have been identified in the Bulli Seam in Area 5. The dominant WNW fault/dyke trend is favourably aligned to the face lines of the east-west longwalls but the potential for carrying these features along the longwall panel should be considered. Longwall panels at other Bulli Seam mines have successfully negotiated similar geological features.

The spacing between potential bedding planes within the sandstone units in the Bulli Seam overburden is typically less than 10 m, indicating that weighting events can be readily controlled on the longwall face. A sandstone unit up to 15 m thick does occur in the central part of the area 15-20 m above the Bulli Seam and operational controls would be required whilst longwalling in this area. The favourable alignment of the east-west longwalls with respect to the jointing should assist in reducing the severity of any weighting events.

Sills have been identified in both the northern and south-eastern part of the area leading to the modification of the longwall layout. The location of the access drifts has also been optimised to reduce the potential intersection of both Bulli and Wongawilli Seam sill material. The sills in the Bulli Seam also exhibit variability in strength and thickness and additional igneous intrusions not identified by exploration are considered a risk to the Dendrobium Mine Extension Project (the Project).

Due to the range in thickness of the Bulli Seam, varying levels of floor dilution are anticipated both in development and on the longwall face. Three mining zones have been defined to quantify the different levels of dilution.

The primary support patterns are based on either compressive failure or bedding plane delamination failure mechanisms and previous experience at other Bulli Seam mines. Routine secondary support is not anticipated during development but would be required for longwall retreat. Analysis of these mechanisms indicates 1.8 m long roof bolts should be suitable in the majority of Area 5.

The roof support for wide driveages should be based on deadweight suspension and designed on a case by case basis. Varying levels of secondary and standing support can be expected based on the conditions encountered at other Bulli Seam mines. Routine rib support should be required in the Bulli Seam workings in Area 5.

Code Orange cable support is recommended in the proposed access drifts based on the orientation of the drifts at 90° to the horizontal stress, the proximity to disturbed ground associated with the silling, excavation across laminated strata including the Balgownie, Cape Horn and Wongawilli Seams and associated weaker strata, the anticipated slow cutting rates and the required life of mine function of these drifts.

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1 INTRODUCTION

Gordon Geotechniques Pty Ltd (GGPL) has been requested to provide a geotechnical assessment of longwall mining the Bulli Seam in Area 5 for the Dendrobium Mine Extension Project (the Project) using the revised mine plan, for inclusion into the feasibility report (**Figure 1**).

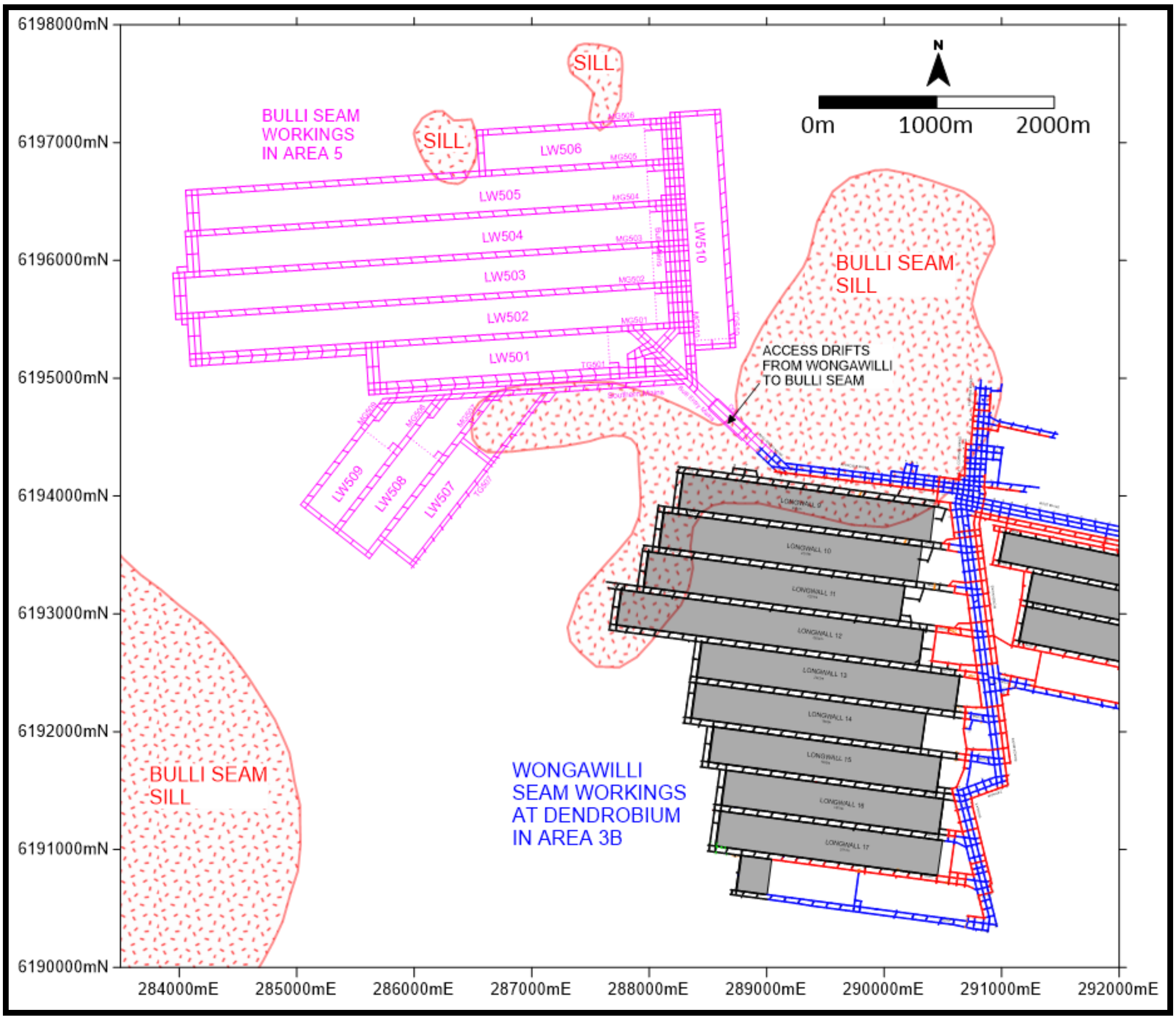

Figure 1. Dendrobium Mine Extension Project Layout.

Dendrobium Mine is currently mining Longwall 18 in the Wongawilli Seam in Area 3B (**Figure 1**). The Project proposes to access the Bulli Seam in Area 5 from the Wongawilli Seam through three access drifts (**Figure 1**).

Silling in the Bulli Seam in the northern part of the area has resulted in the shortening of Longwall 506 (**Figure 1**). The take-off location of Longwall 507 has also been moved inbye due to a predicted sill (**Figure 1**).

Since the pre-feasibility study in 2017, the majority of the longwall layout (LW501-506) has been rotated from a dominantly north-south orientation to east-west (**Figure 1**). Three shorter panels (LW507-509), to the south of LW501 are in a NE/SW orientation (**Figure 1**). The final panel to be mined, LW510, is in a north-south orientation (**Figure 1**). All longwalls will create a 305 metres (m) wide void and vary in length from 799 m (LW509) up to 3988 m (LW503) (**Figure 1**).

A number of neighbouring collieries have mined or are still mining the Bulli Seam in close proximity to the Project area (**Figure 2**). The Project is however located within a new mining area and would not interact with or impact on any historical workings.

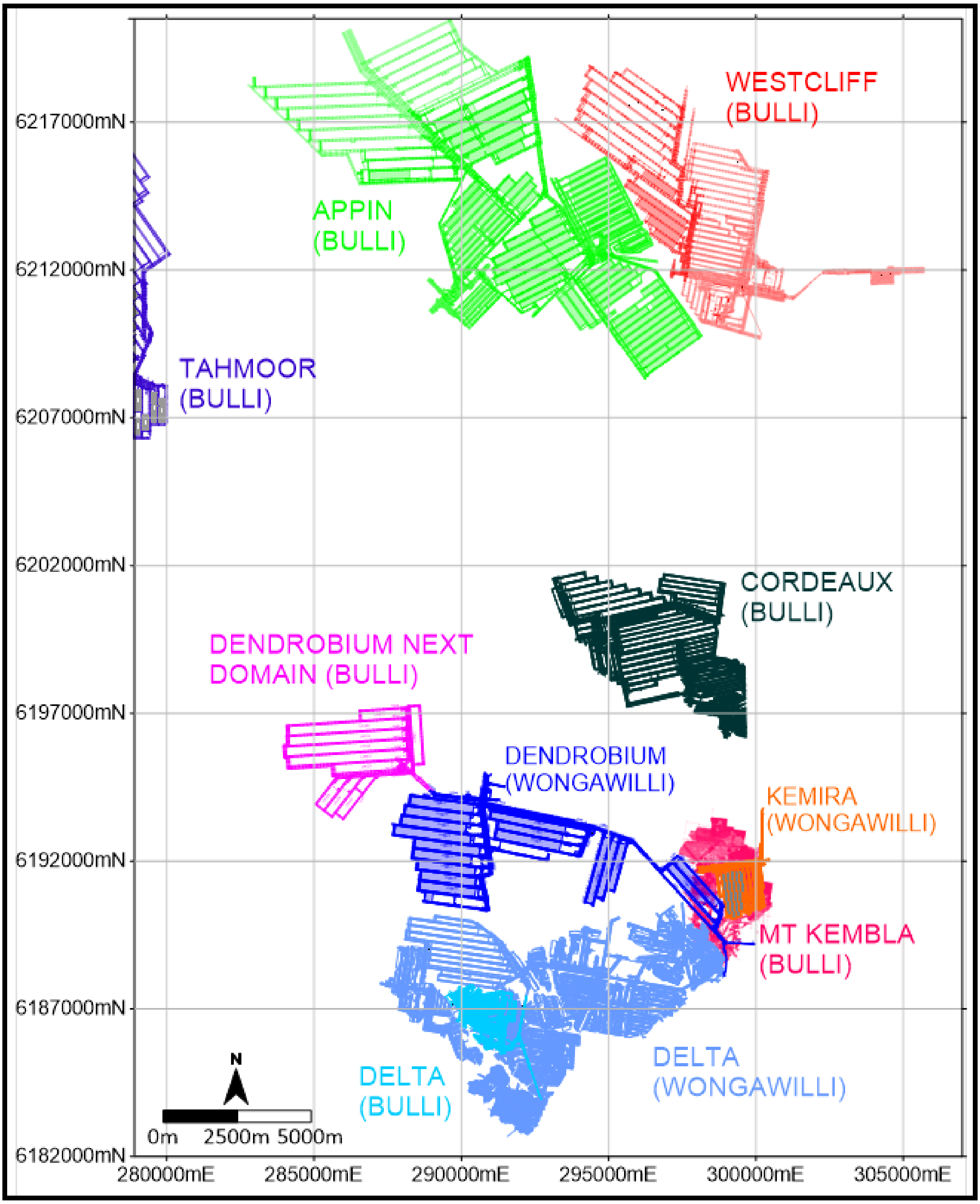

Figure 2. Neighbouring Workings in the Bulli and Wongawilli Seam.

1.1 Scope of Work

The Area 5 PFS geotechnical assessment study required an update to include the additional geological and geotechnical data collected since the study was completed in 2017. The scope of work for the update includes:

1. Geotechnical characterisation of Area 5 including:
    a. Roof and floor properties – strength, lithology, bedding thickness.
    b. Coal seam properties – strength, partings, plies.
    c. Geological features.
2. Assessment of working section ranges including stone brushing as required to maintain proposed minimum roadway heights (2.7 m in the gateroads and 3.0 m in the Mains) and minimum longwall cutting horizon of 2.4 m.
3. Review of PFS Reports (conducted by others) to make assessment of;
    a. Chain and barrier pillar sizes.
    b. Assessment of longwall conditions.
4. Detailed ground support design, including:
    a. Assessment support plans (primary, secondary, standing longwall tailgates, longer term perimeter road).
    b. Development support zones based on hazard plans.
    c. Zoned plans of expected secondary support levels.
    d. Monitoring arrangements.
5. Assessment of rock strength, ground conditions and support levels for the interseam drifts.
6. Coal Burst Assessment in line with recent ACARP studies.

The geotechnical assessment for the Bulli Seam for the Project follows the geotechnical design process of Bieniawski (1993)[1]. This process includes the compilation of the engineering geology, to allow an assessment of the mine design parameters such as panel orientation, roadway dimensions, pillar dimensions and ground support design.

A further update of the geotechnical assessment study was requested in January 2022, with the change to a reduced footprint mine plan and re-orientated southern panels.

1.2 Data Provided

The following geological and geotechnical data was provided to GGPL to assist in the updated assessment of Area 5:

- Mine plans for Bulli Seam Area 5 and Wongawilli Seam Area 3 as AutoCAD files.

[1] Bieniawski, Z.T. (1993). Design methodology for rock engineering: principles and practice. *Comprehensive Rock Engineering* (Eds J.A. Hudson, E.T. Brown, C. Fairhurst, and E. Hoek), **2**, 779-93. Pergamon: Oxford.

- ASCII files of all stratigraphic units for all boreholes including easting, northing, collar RL, thickness, structure roof, structure floor.
- Geological features including faults, dykes and sills as an AutoCAD file.
- Geotechnical reports on caveability, pillar design and panel width by Strata Control Technology in 2017.
- Drift cross sections.
- Appin Mine drift geotechnical reports and support patterns by Pitt and Sherry in 2015.
- English logs for the exploration boreholes up to S2490.
- Core photography and graphic lithology logs up to borehole S2498.
- LAS files for the exploration boreholes and SIS holes up to S2498.
- Acoustic scanner data and structural interpretation.
- Geotechnical test results of core samples up to borehole S2483.

1.3 Borehole Data

The exploration boreholes used for this investigation are shown in **Figure 3**. At the time of this study, completed geological and geotechnical data was provided up to borehole S2498. The Project area is also extensively covered by 2D seismic lines (**Figure 3**). Several SIS holes have been drilled as well (**Figure 3**).

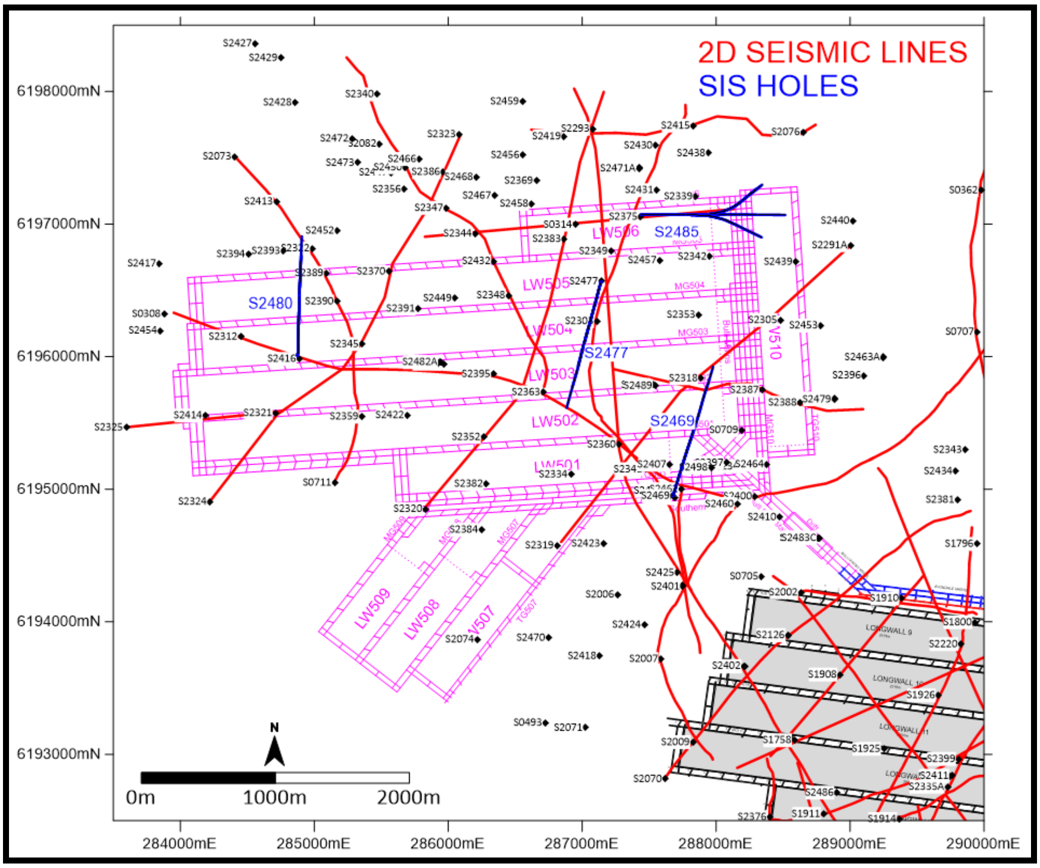

Figure 3. Exploration Boreholes and 2D Seismic Lines.

It is understood that additional infill boreholes have been recently drilled to further define structures with minimal change to the previously interpreted sill boundaries and dyke alignments.

1.4 Exploration Program

The exploration programs in Area 5 have collected a substantial amount of geological and geotechnical data. A summary of the geotechnical parameters required for an underground operation are listed in **Table 1**.

Geotechnical Parameters	Exploration in Area 5
Horizontal Stress Direction and Magnitude	Processing of acoustic scanner data.
Compressive Strength	Sonic velocity using the downhole geophysical logging tool and geotechnical rock testing of core samples.
Cohesion and Friction Angle	Triaxial compressive strength testing of selected samples.
Joint and Cleat Orientation	Processing of acoustic scanner data.
Geological Structures	Seismic survey, borehole drilling and core photography.
Roof and Floor Lithologies	Geological logging.
Bedding and Strength Characteristics	Geophysical and geological logging.
Caveability	Analysis of gamma geophysical logs and core photography.
Swelling Characteristics	Analysis of gamma geophysical logs.
Intrusions	Seismic and magnetic surveys and borehole drilling.

Table 1. Summary of Geotechnical Parameters Required During Exploration.

1.5 Geotechnical Framework for Classifying Mining Projects

Haile (2004)[2] proposed a geotechnical framework for classifying mining projects according to the level of the understanding of the geotechnical environment (**Table 2**). For the different levels of a mining project concept/scoping, pre-feasibility, feasibility and operational, Haile recommended geotechnical classifications of implied, qualified, justified and verified respectively.

The **qualified** category is defined as design recommendations, which are typically based on a combination of empirical guidelines and broad industry experience. In contrast, for **justified** design, recommendations are supported by rigorous analyses, which account for the measured intrinsic and/or extrinsic variability in the geotechnical characteristics.

The existing geological and geotechnical data suggests that the Project longwall mining area is at the justified level (**Table 2**). Based on **Table 3**, this is sufficient for the feasibility stage of any underground project.

[2] Haile, A. (2004). A Reporting Framework for Geotechnical Classification of Mining Projects. AUSIMM Bulletin September/October 2004, pp. 30-37.

DATA TYPE	IMPLIED	QUALIFIED	JUSTIFIED	VERIFIED
General Requirements and Geotechnical Model Reliability	No site-specific geotechnical data necessary	Project-specific data are broadly representative of the main geological units and inferred geotechnical domains, although local variability or continuity cannot be reliably accounted for.	Project-specific data are of sufficient distribution (density) to identify geotechnical domains and to demonstrate continuity and variability of geotechnical properties within each domain.	Site-specific data are derived from local in-situ rock mass
Geological Model				
Stratigraphic boundaries	Inferred from regional geology	Reasonable knowledge of major units and geometry	Well constrained in the vicinity of the mine excavations and infrastructure	Mapped in the field
Weathering/alteration boundaries	Inferred from regional geology	Based on geology model	Well defined grading of weathering and local variability	Mapped in the field
Major structural features	Inferred from regional geology	Major 'dislocations' interpreted	Drilling sufficient to be well constrained in continuity, dip and dip direction	Mapped in the field
Rock Mass Data				
Discontinuity	Based on general rock type characteristics	Estimates of RQD/FF and number of defect sets from resource data (will probably contain directional bias)	RQD/FF statistics and number of defect sets representative of all geotechnical domains and directions	Multi directional FF from in-situ mapping and visual count of defect sets
Intact material strength/deformation characteristics	Based on general rock type characteristics	Field estimates	Field and laboratory estimates and variability	Field and laboratory estimates
Defect Data				
Orientation	Inferred from regional geology	Orientation inferred from geological model	Dip and dip direction statistical data from drill holes	In-situ measurement of dip and dip direction from excavation mapping
Surface characteristics	Estimated on precedent experience	Estimated on precedent experience	Statistical estimates from core logging for all defect sets. Laboratory shear strength testing of critical defects	Statistical estimates from in-situ measurements. Laboratory shear strength testing of critical defects
Volumetric distribution (continuity and spacing)	Estimated on precedent experience	Estimated on precedent experience	Estimated on precedent experience	Persistence and spacing measurements
Stress Regime				
Principal stress field	Estimated on precedent experience	Mean regional trend	Local magnitude and orientation based on local experience or modelling	Measured or inferred from in-situ performance
Seismicity/earthquake	Based on general experience	Based on general experience	Based on regional trends	In-situ experience
Geotechnical Model/Domains	Based on geology model	Based on geology model	Based on geotechnical data	Based on in-situ data
Hydrogeological Model	Based on general experience	Based on general experience	Hydrogeological study	Local observations/measurements

Table 2. Categorisation of Geotechnical Data (Haile, 2004).

STUDY LEVELS	MINING METHOD AND ORE BODY GEOMETRY			
	Open Cut		Underground	
	Wide (shallow pit relative to pit floor area)	Narrow (deep pit relative to pit floor area)	Bulk mining methods	Selective mining methods e.g. bord and pillar
Concept/scoping	*Not applicable*	*Implied*	*Implied*	*Implied*
Pre-feasibility	*Not applicable/ Implied*	*Qualified*	*Qualified*	*Implied*
Feasibility	*Implied/Qualified*	*Justified*	*Justified*	*Qualified/Justified*
Operational	*Justified*	*Verified*	*Verified*	*Verified*

Table 3. Geotechnical Data and Analysis for Project Categorisation (Haile, 2004).

2 FUNCTIONAL REQUIREMENTS AND CONSTRAINTS

A number of constraints to the geotechnical design process, related to both the mine layout and the machinery to be used, were identified during this assessment of Area 5 including:

- The mine plan is constrained by existing Wongawilli Seam workings for the Dendrobium Mine and geological features such as sills, as well as surface features such as Avon Dam (**Figure 4**).

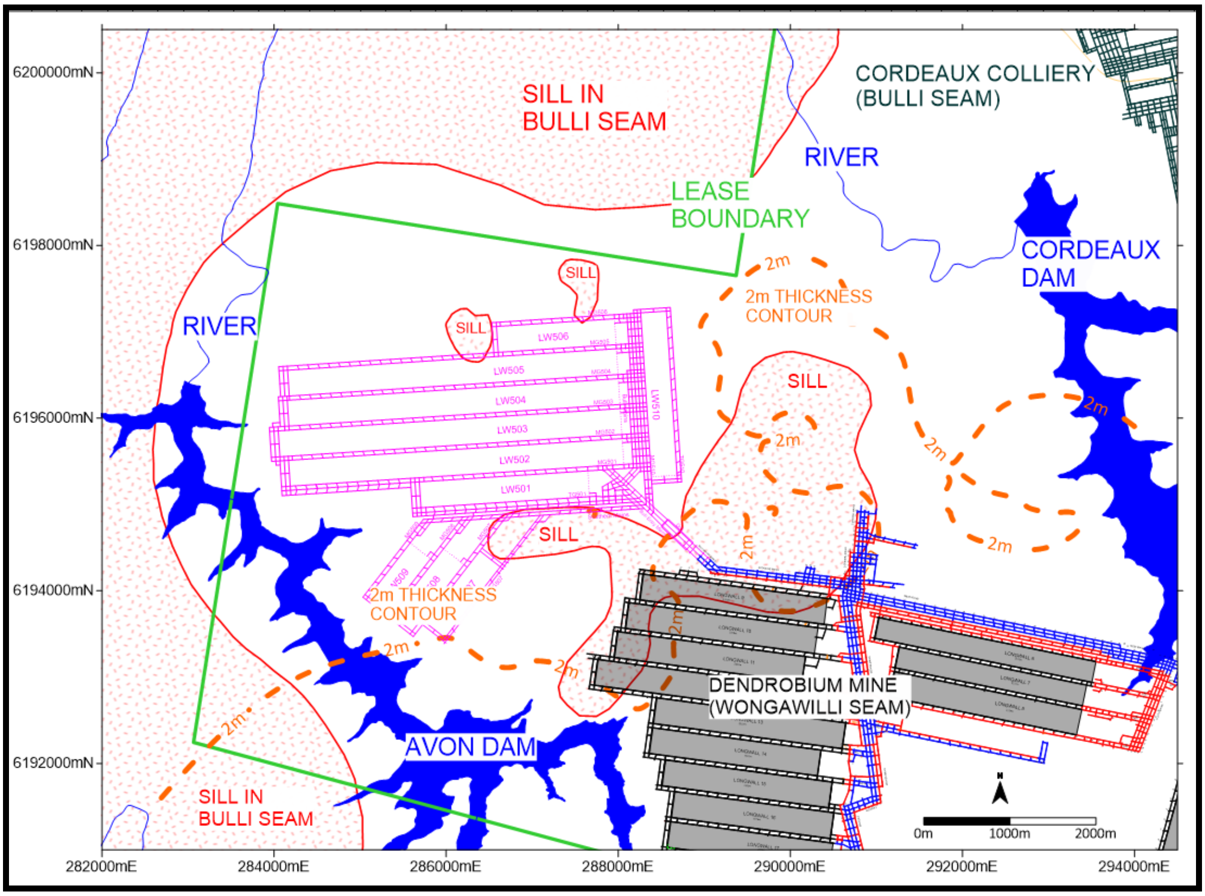

Figure 4. Constraints to the Area 5 Mine Plan.

- Bolter miners for development.
- 295 m wide longwall faces.
- Longwall panels up to 3.99 km long (**Figure 1**).
- Lease boundary to the north and west (**Figure 4**).
- 115 m long and 42 m wide chain pillars.
- Tailgate serviceability.
- Surface subsidence constraints.
- 5.2 m wide and 3.0 m high roadways in the Mains and minimum 2.7-3.3 m high in the gates.
- Seam thickness range of 2-3.3 m.
- Longwall operating range 2.4-3.3 m.
- Depth of cover range of 345-395 m.
- Requirement for wide and high driveages, such as installation roads, overcasts, transfer points, tripper drive excavations and driveheads.
- Access from the existing Wongawilli Seam workings for the Dendrobium Mine (**Figure 1**).

3 ENGINEERING GEOLOGY

GGPL considers that the understanding of the engineering geology of an underground deposit is fundamental in developing models to assist in the prediction of geotechnical conditions. This includes compiling the geotechnical characteristics of the seam, roof and floor units, as well as discussion on the geological features such as faults, joints, cleats and stress. This would assist in addressing macro design considerations such as panel orientation, panel width and pillar sizes.

During the course of the pre-feasibility study (GGPL, 2017), it was evident that the orientation of the horizontal stress, the thickness of the Bulli Seam, as well as the strength of the immediate stone roof and floor and location of the sills were key issues in the layout of the longwall panels and planned cutting horizons in Area 5.

With the additional geological and geotechnical data gathered in the feasibility stage of the Project, these parameters remain the focus of the mine planning considerations.

3.1 Stratigraphy

The Bulli Seam is located stratigraphically at the top of the Illawarra Coal Measures and is overlain by the Narrabeen Group (**Figure 5**). This group of sediments consists of a sequence of sandstone and shale/claystone units, which includes in ascending order the following formations (Area 3A Report, 2008)[3]:

- The **Coal Cliff Sandstone** - medium-grained sandstone, cross-bedded in places. This unit is not present in Area 5, except for a thin occurrence in the eastern part of the Project area.

[3] Illawarra Coal (2008). Geology of Dendrobium Area 3A.

- The **Wombarra Claystone** – mostly siltstones and claystones, with thin interbeds of fine-grained sandstone. This unit forms the immediate roof in the majority of the Project area.
- The **Scarborough Sandstone** – consists mainly of thickly bedded conglomeratic sandstone, with shale and sandy shale lenses up to several metres thick.
- The **Stanwell Park Claystone** – consists of greenish-grey mudstones and sandstones.
- The **Bulgo Sandstone** - consists of strong, thickly bedded, medium to coarse grained lithic sandstone, with occasional beds of conglomerate or shale.
- The **Bald Hill Claystone** – consists of brownish-red coloured shale.
- The **Garie Formation** - consists of cream to brown, massive, characteristically oolitic claystone.
- The **Newport Formation** - consists of interbedded grey shales and sandstones.

As shown in **Figure 5**, the Scarborough Sandstone, the Stanwell Park Claystone and the Bulgo Sandstone collectively form the Colo Vale Sandstone unit.

AGE	GROUP	SUB-GRP	CODE	FORMATIONS		MEMBERS
TERTIARY			CXCR		CORDEAUX CRINANITE	
					DENDROBIUM NEPHELINE SYENITE	
CRETACEOUS						
JURRASSIC						
TRIASSIC	WIANAMATTA GROUP		WMSH		BRINGELLY SHALE	
					MINCHINBURY SANDSTONE	
					ASHFIELD SHALE	
			MTFM		MITTAGONG FORMATION	
			HBSS		HAWKESBURY SANDSTONE	
	NARRABEEN GROUP	GOSFORD	NPFM		NEWPORT FORMATION	
			GRFM		GARIE FORMATION	
		CLIFTON	BACS		BALD HILL CLAYSTONE	
			BGSS	KANGALOON SANDSTONE; COLO VALE SANDSTONE	BULGO SANDSTONE	
			SPCS		STANWELL PARK CLAYSTONE	
			SBSS		SCARBOROUGH SANDSTONE	
			WBCS		WOMBARRA SHALE	
			CCSS		COAL CLIFF SANDSTONE	
PERMIAN	ILLAWARRA COAL MEASURES	SYDNEY	BUSM		BULLI COAL	
			LDSS		LODDON SANDSTONE	
			BASM		BALGOWNIE COAL	
			LRSS		LAWRENCE SANDSTONE	
			BNCS		BURRAGORANG CLAYSTONE	
			CHSM		ECKERSLEY FORMATION	CAPE HORN COAL
			UNM2			UNNAMED MEMBER 2 (inf.)
			HGSM			HARGRAVES COAL
			UNM2			UNNAMED MEMBER 3 (inf.)
			WNSM			WORONORA COAL
			NVSS			NOVICE SANDSTONE
			WWCO		WONGAWILLI COAL	FARMBOROUGH SANDSTONE
			ACFM		ALLANS CREEK FORMATION	AMERICAN CREEK COAL (ACSM)
			DFSS	APPIN FORMATION (APFM)	DARKES FOREST SANDSTONE	
			BGCS		BARGO CLAYSTONE	HUNTLEY CLAYSTONE MEMBER
						AUSTINMER SANDSTONE MEMBER
			TGSM		TONGARRA COAL	

Figure 5. Stratigraphic Section (Area 3A Report).

The thickness of these formations in Area 5 is presented in **Appendix 1**. The Bulli Seam has been extensively mined in the Southern Coalfield, due to its coking properties and low ash. A representative immediate roof and floor section for the Bulli Seam in Area 5 is shown in **Figure 6**.

LITHOLOGY		THICKNESS	STRENGTH
THICKER SANDSTONE UNITS INTERBEDDED WITH SILTSTONE		>20 m	60-70 MPa
LAMINATED SILTSTONE AND SANDSTONE		2-22 m	60-70 MPa
BULLI SEAM COAL		2.0-3.4 m	23-26 MPa
STONE BAND (WESTERN PART OF AREA)		<0.2 m	20-25 MPa
COAL (WESTERN PART OF AREA)		0.18-0.43 m	20-25 MPa
MUDSTONE GRADING INTO LAMINATED SILTSTONE AND SANDSTONE		2-4 m	35-70 MPa
SANDSTONE		3-11 m	55-80 MPa

Figure 6. Representative Bulli Seam Roof and Floor Lithology in Area 5.

3.2 Bulli Seam Characteristics

The bed resolution density responses from boreholes drilled in Area 5, illustrate the ply structure of the Bulli Seam (**Figure 7**). A distinct stone band overlying a 0.18-0.43 m thick ply of coal at the base of the seam is evident in the western part of the area (**Figure 7**). To the east and south, this basal ply appears to split away and shale out (**Figure 7**).

It is assessed that this characteristic of the Bulli Seam in Area 5 is not analogous to the false bottoms of Bellambi West, which were associated with a puggy claystone layer that caused major mining problems on development and longwall retreat.

The impact of the sill on the density profile is also evident in boreholes S2309, S2319 and S2344, where the Bulli Seam has been intruded (**Figure 7**).

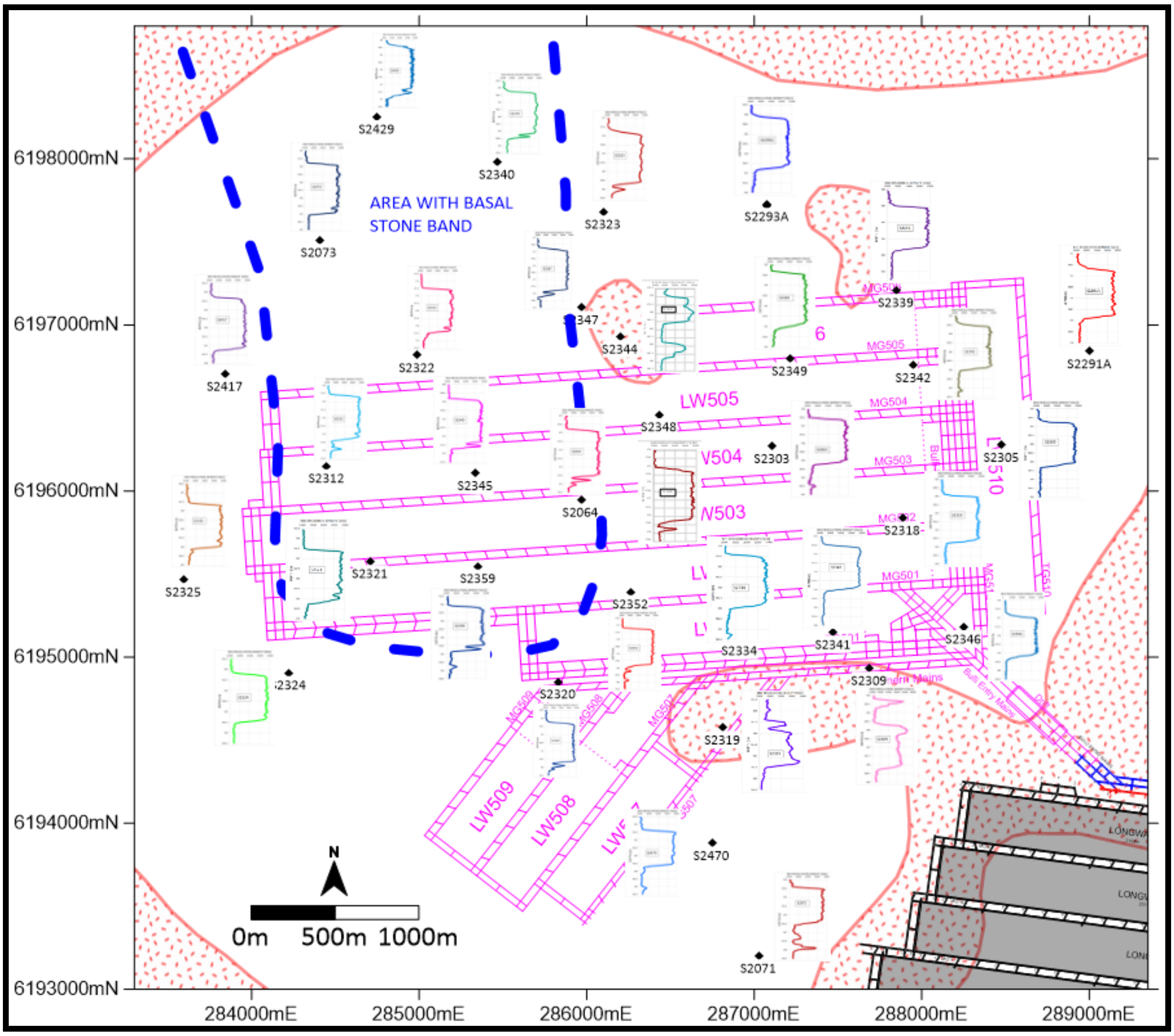

Figure 7. Bed Resolution Density Profiles.

3.3 Bulli Seam Thickness

In the proposed longwall area, the Bulli Seam is approximately 2.0-3.3 m thick (**Figure 8**). In the Longwall 501-506 area, the thickness is typically 2.4-3.3 m. In the southern Longwalls 507-509 and eastern Longwall 510, the Bulli Seam thickness decreases to 2-2.6 m (**Figure 8**).

For operational purposes, 2.4 m has been specified as the minimum cutting height on the longwall face in Area 5.

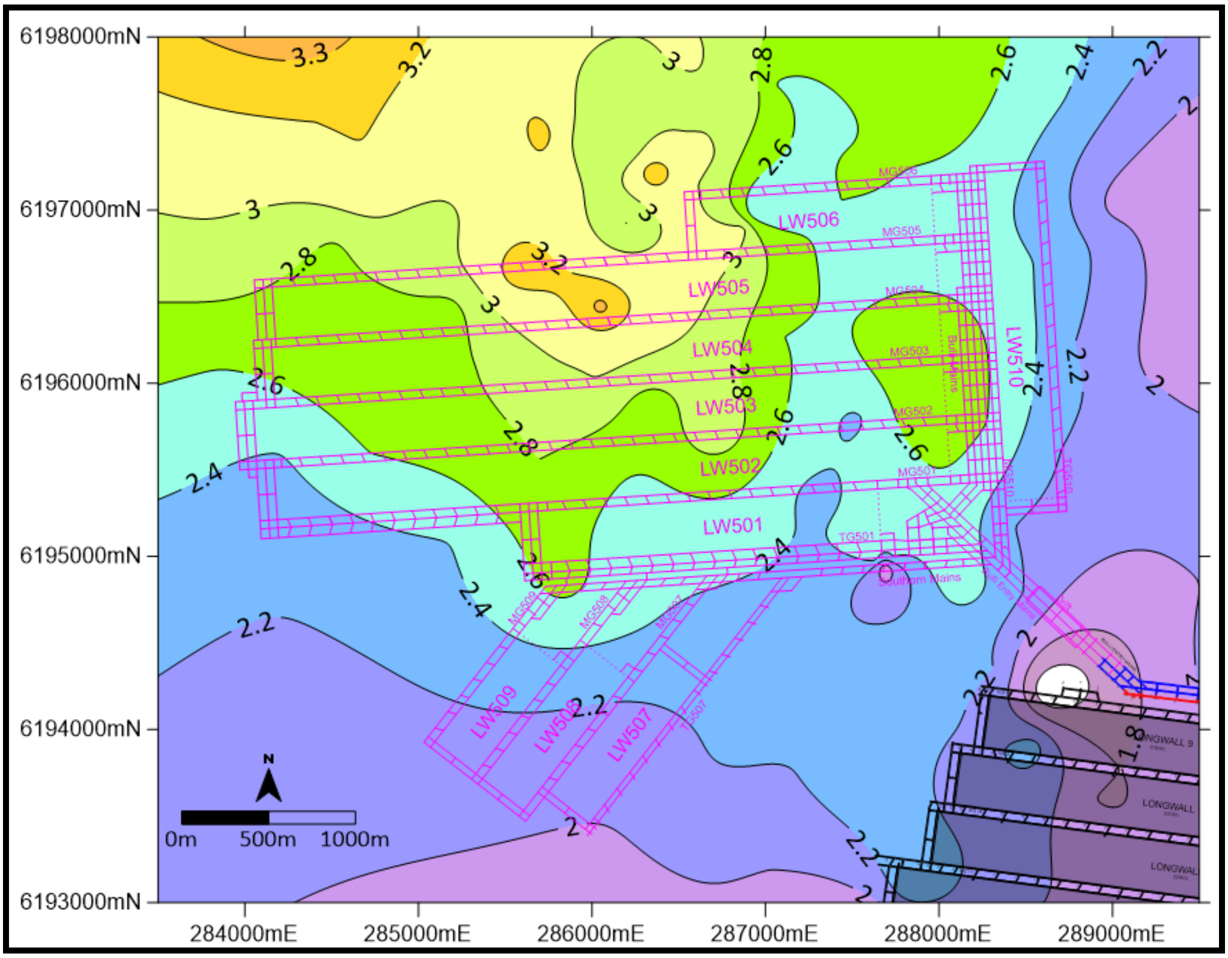

Figure 8. Bulli Seam Thickness (m).

3.4 Depth of Cover

The depth of cover above the proposed longwalls ranges from 345 m in the southern part of the area at the inbye ends of LW507-509, increasing up to 395 m at the outbye end of Longwall 504 (**Figure 9**).

In comparison, Appin Mine has already developed to depths of 610 m in MG903, MG708A, TG708A and the Douglas Mains and longwall extraction has been carried out at the inbye end of LW707A at 600 m. At the Cordeaux Colliery, longwalls were also extracted at greater depths than Area 5, at typically between 400 m and 460 m.

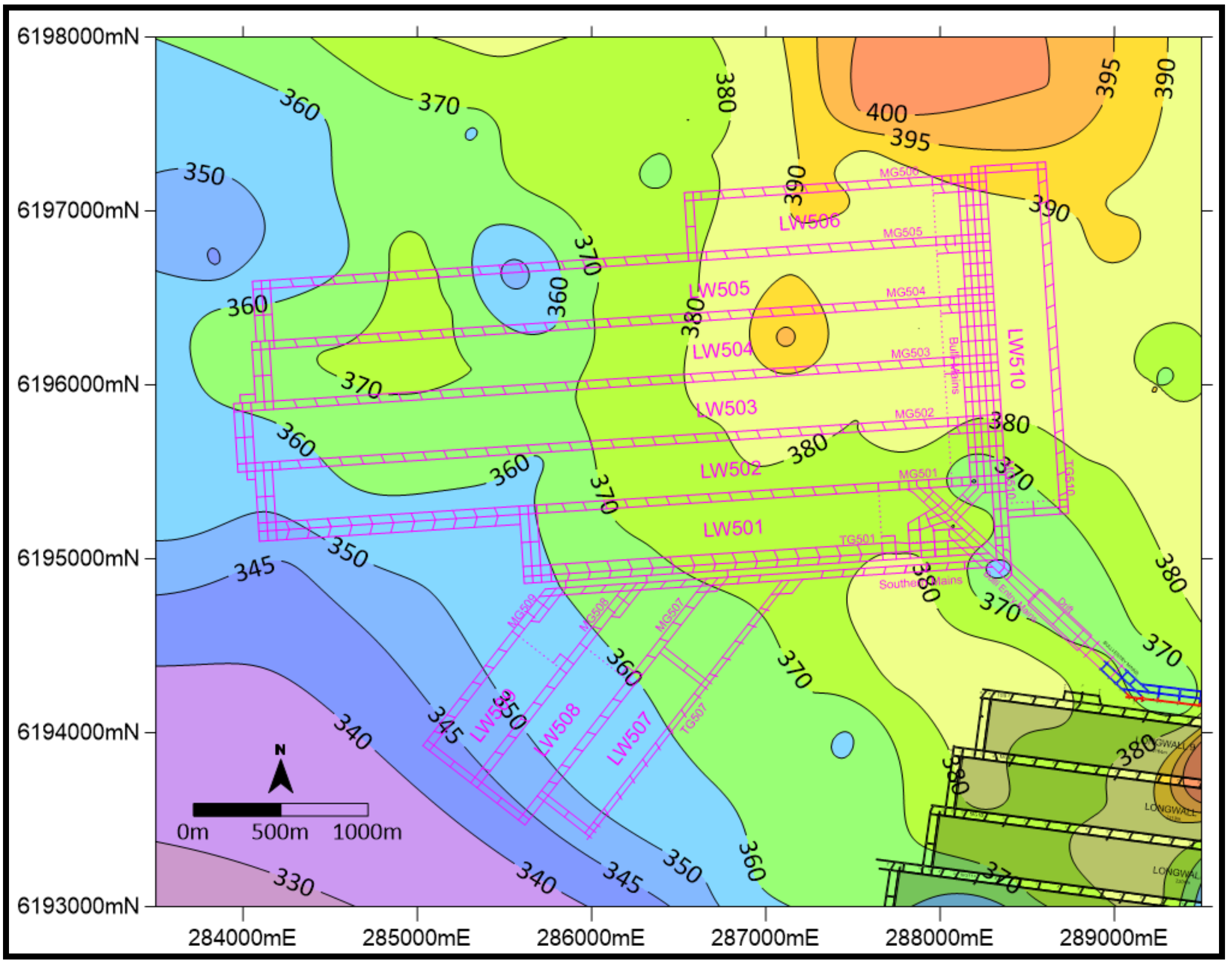

Figure 9. Depth of Cover to the Bulli Seam from Borehole Data (m).

3.5 Seam Levels

The Bulli Seam strikes consistently WNW across the western part of the area, (**Figure 10**). In the eastern part of the area, the strike swings into a north-south orientation associated with the regional synclinal structure (**Figure 10**).

Seam dips vary from more than 1 in 150 in the central-eastern part of the area, steepening up to 1 in 18 in south-western corner of Area 5 (**Figure 10**).

3.6 Standing Water Levels

GGPL has found at other mines that standing water levels in the exploration boreholes can be a useful method for determining the location of faults, particularly those with throws greater than the full seam thickness, as the water levels either side of these features may be substantially different.

The standing water level has been measured in the exploration boreholes as the depth at which the sonic velocity tool records meaningful values (**Figure 11**). Lower levels are evident in the north west and also in the east coincident with dykes and faults in these areas (**Figure 11**).

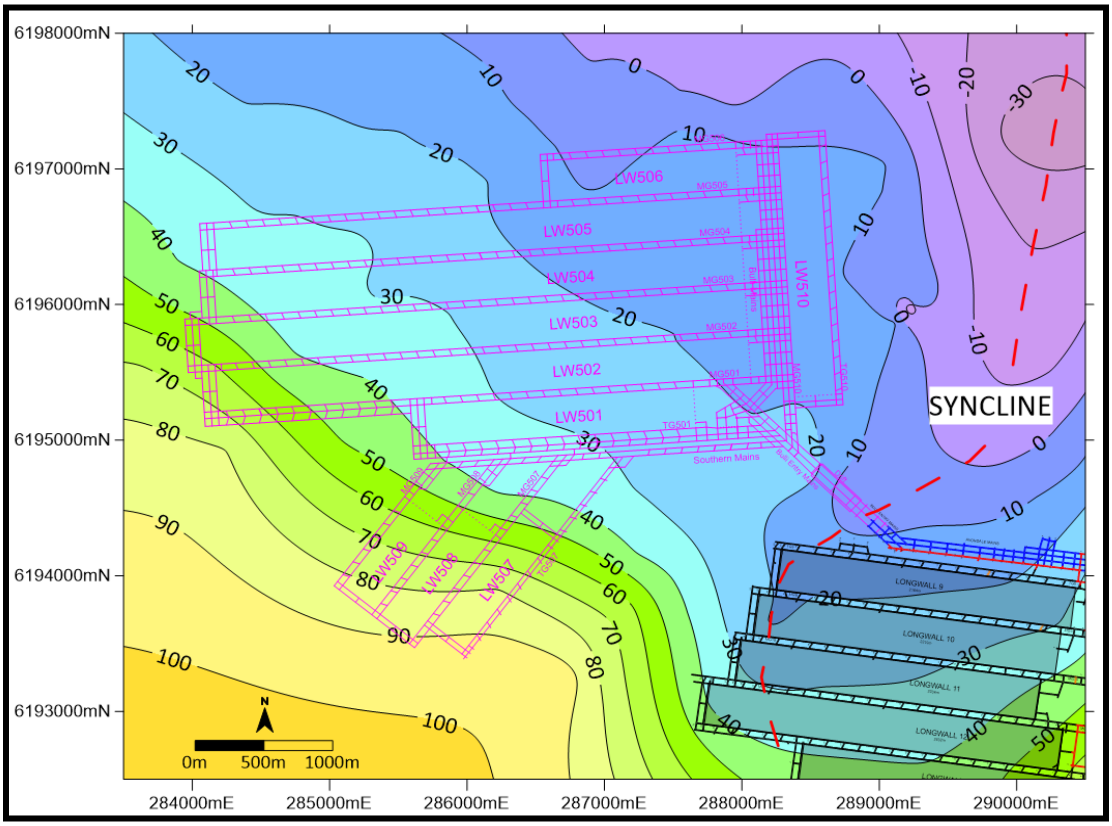

Figure 10. Bulli Seam Structure Floor (m ASL).

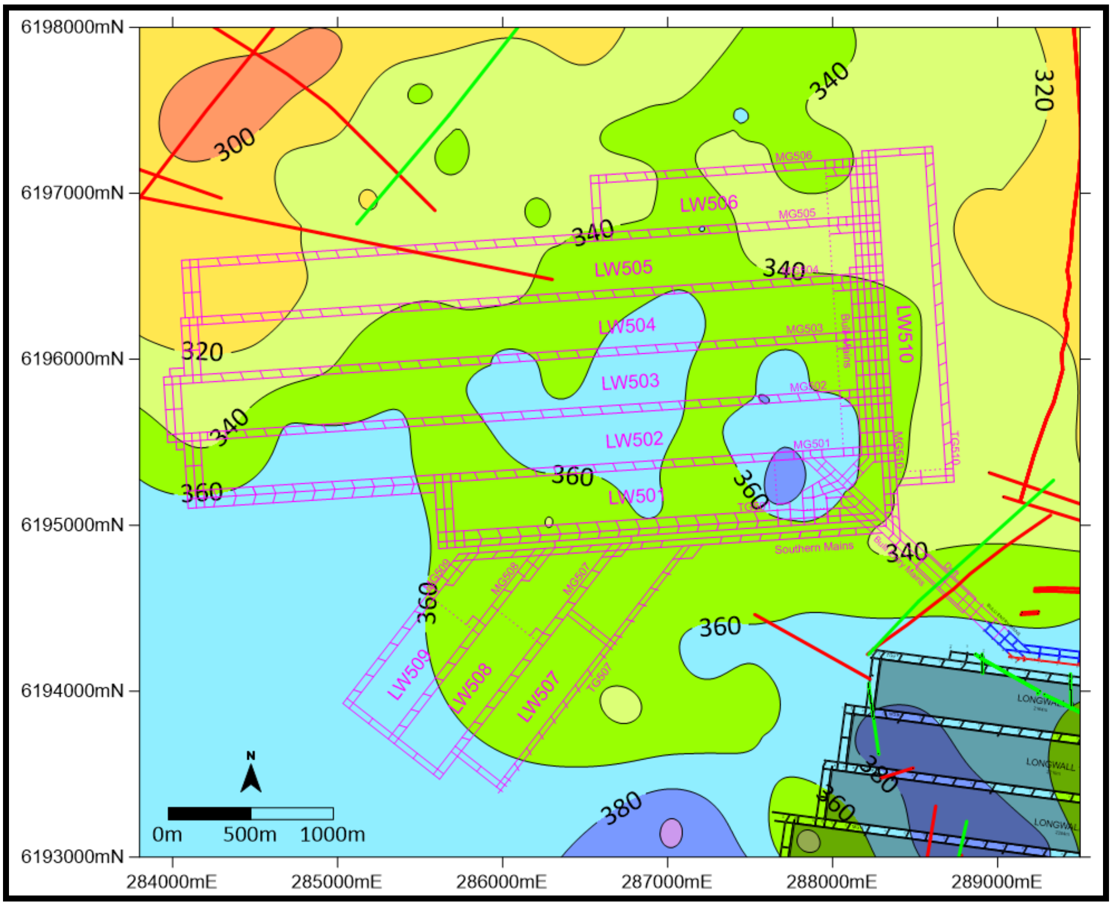

Figure 11. Standing Water Levels in Exploration Boreholes (m ASL).

3.7 Temperature Gradient

Ground temperatures measured in a selection of boreholes across the area, indicate a temperature range from 20°C to 27°C, at the planned mining depths in Area 5 (**Figure 12**).

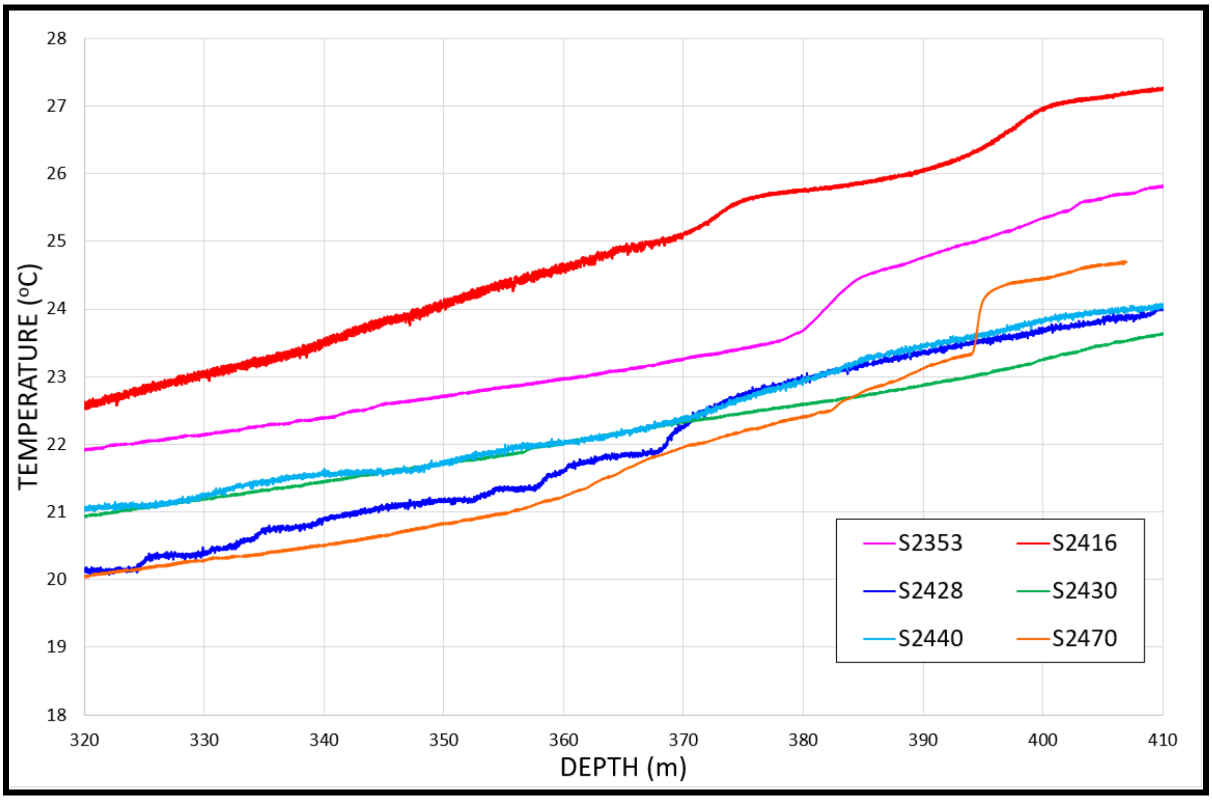

Figure 12. Temperature Gradient.

3.8 Lithologies

3.8.1 Bulli Seam Immediate Roof

The immediate Bulli Seam roof consists of a laminated sequence of interbedded sandstone, siltstone and mudstone (**Figure 13 and Figure 14**). This laminated immediate roof is typically 8-14 m thick over the majority of the proposed longwall area (**Figure 16**).

Where the immediate roof is stronger in the pit bottom area at the top of the Bulli Seam drifts, the laminite has a greater proportion of sandstone layers (**Figure 15 and Figure 41**).

Through the central part of Longwalls 503 to 505 and the inbye end of LW506, the laminite thins to 4-8 m (**Figure 16 and Figure 17**). Towards the west, this laminated roof strata thickens to more than 20 m (**Figure 16**).

Above the laminated immediate roof, thicker sandstone units are present within the upper section of the Wombarra Claystone Formation and are discussed in more detail in Section 3.8.3 (**Figure 18**).

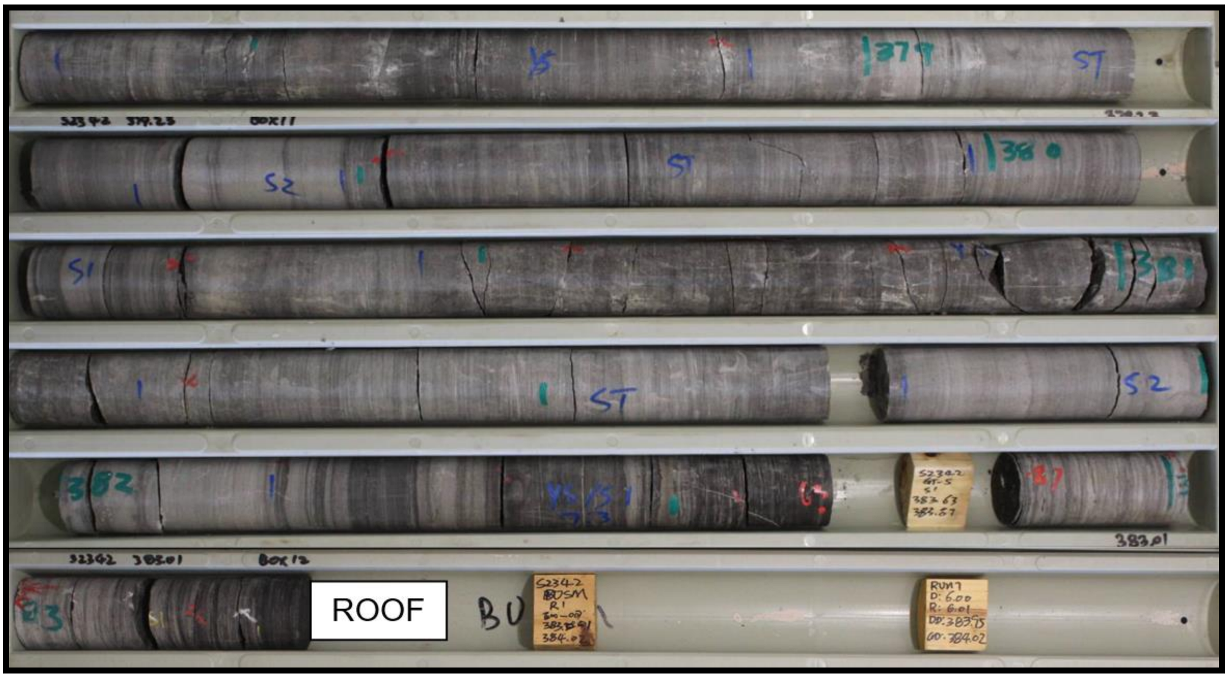

Figure 13. Bulli Seam Immediate Roof – Borehole S2342, outbye end of LW505.

Figure 14. Bulli Seam Immediate Roof – Borehole S2345, LW504.

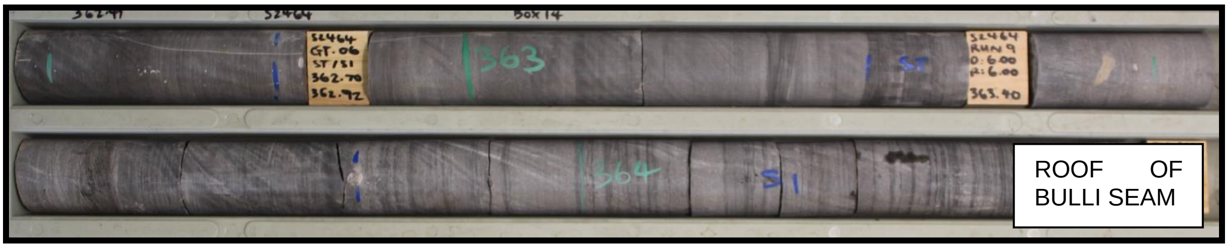

Figure 15. Bulli Seam Immediate Roof – Borehole S2464, Top of Drifts.

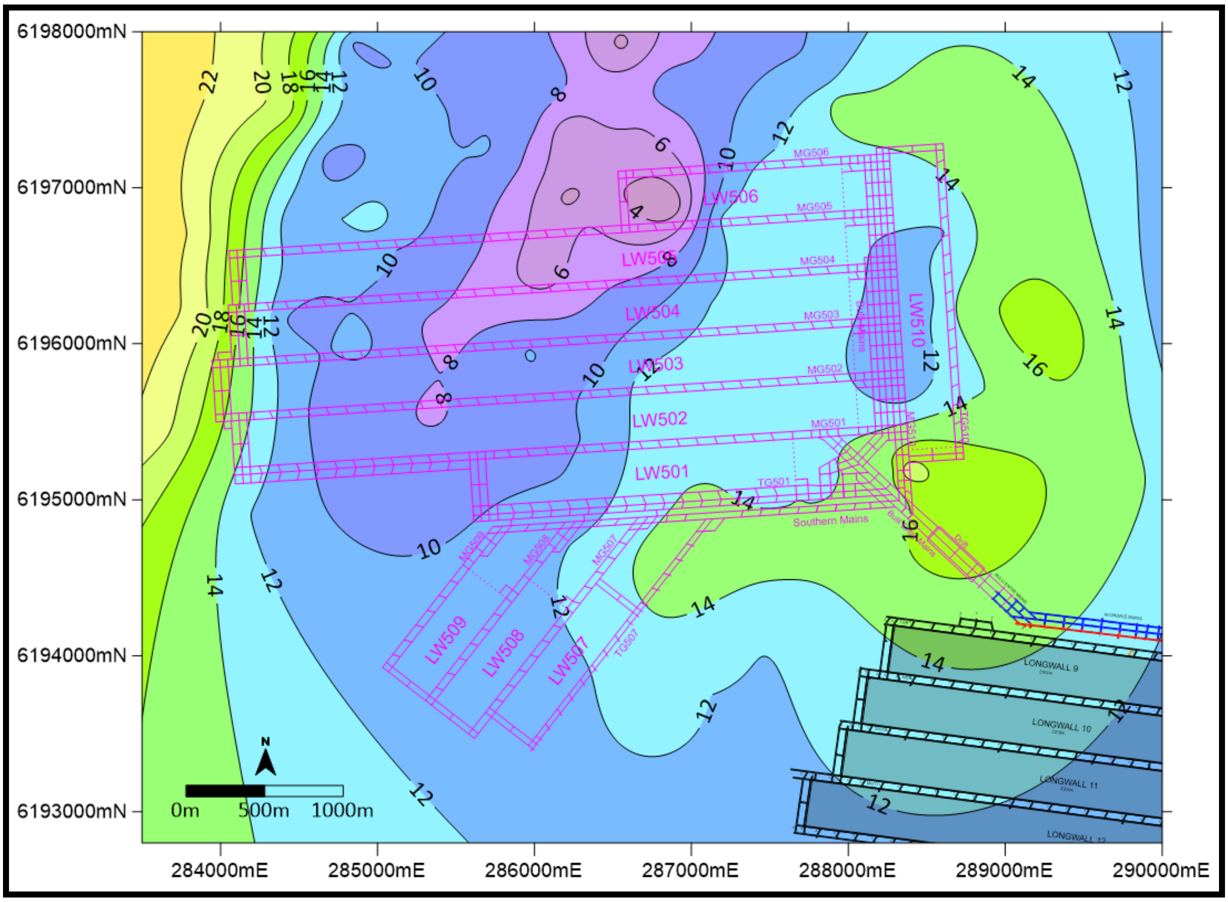

Figure 16. Thickness of the Laminated Immediate Roof (m).

Figure 17. Bulli Seam Immediate Roof – Borehole S2459, North of LW506.

Figure 18. Sandstone Strata – Borehole S2318 outbye end of LW503.

3.8.2 Bulli Seam Immediate Floor

The Bulli Seam floor typically consists of carbonaceous mudstone, grading into the coarser Loddon Sandstone sediments below, as shown in **Figure 19 and Figure 20**.

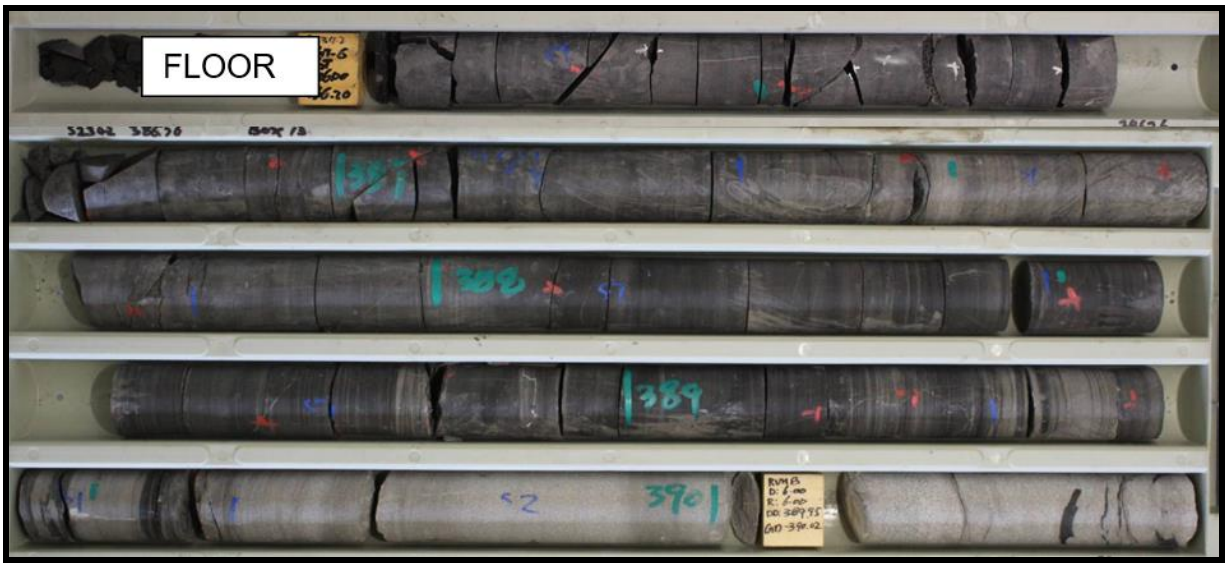

Figure 19. Bulli Seam Immediate Floor – Borehole S2342, outbye end of LW505.

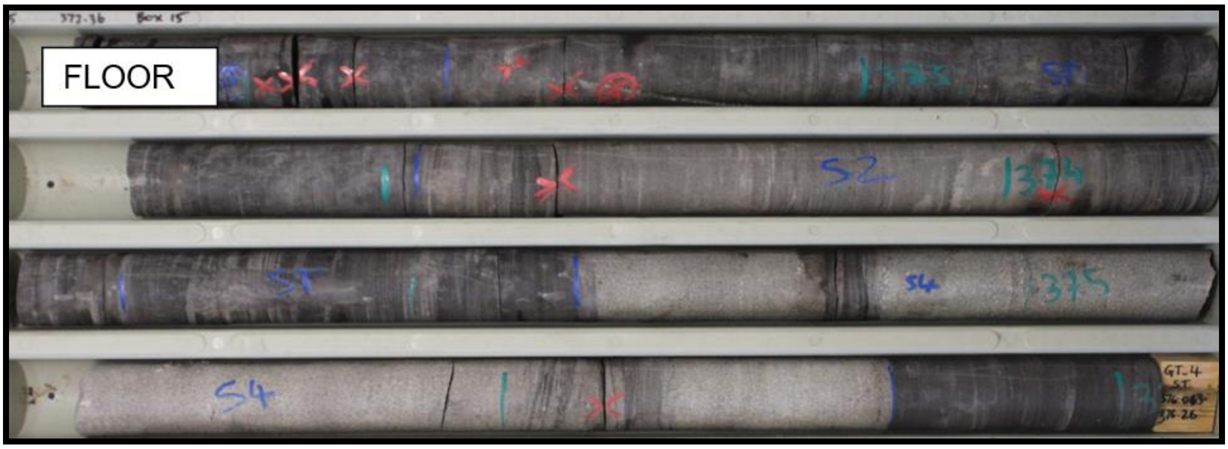

Figure 20. Bulli Seam Immediate Floor – Borehole S2345, LW504.

In the western part of the area, where the basal ply is coalesced with the Bulli Seam the immediate floor is sandier in composition (**Figure 21**).

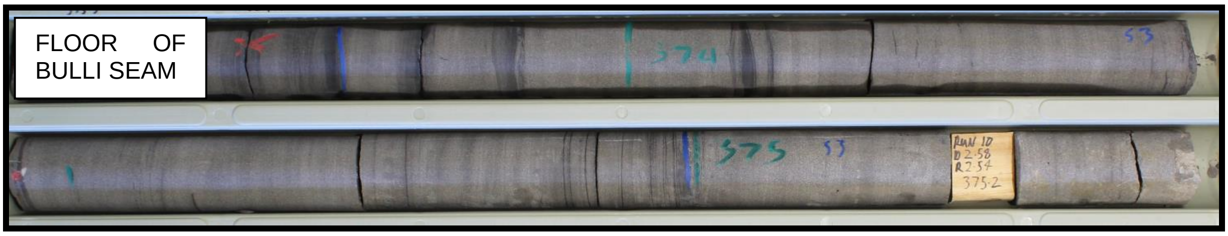

Figure 21. Bulli Seam Immediate Floor – Borehole S2416, LW504.

3.8.3 Massive Units in the Overburden

Above the Wombarra Claystone is the Colo Vale Sandstone, which is comprised of two sandstone units known as the Scarborough and Bulgo Sandstones, separated by the Stanwell Park Claystone (**Figure 5**). This sandstone formation is typically located 30-40 m above the Bulli Seam in Area 5 (**Figure 132**).

The geological log descriptions, core photography and geophysical logs have been used to identify massive sandstone units in the Bulli Seam overburden. Massive units do occur in the Wombarra Claystone but these are typically <10 m thick in the majority of the area (**Figure 22 and Figure 23**). There is a distinct thicker section above LW506 and the outbye ends of LW501-505, where the geotechnical thickness between potential bedding partings is 10-15 m (**Figure 23**). This zone extends into the outbye part of LW510 as well.

These sandstone units in the Wombarra Claystone are typically located more than 15 m above the Bulli Seam (**Figure 24**).

Similarly, the maximum geotechnical thickness between potential bedding partings in the overlying Colo Vale Sandstone is also typically <10 m (**Figure 25**). This compares to the total geological thickness of this unit in the range of 150-160 m (**Figure 131**).

In addition to the core photography and geological logs, an indication of the massiveness of sandstone units can be determined from the gamma geophysical log responses. To provide an indication of the likely behaviour of the sandstone roof above the Bulli Seam, a comparison with other seams in known mining conditions is required.

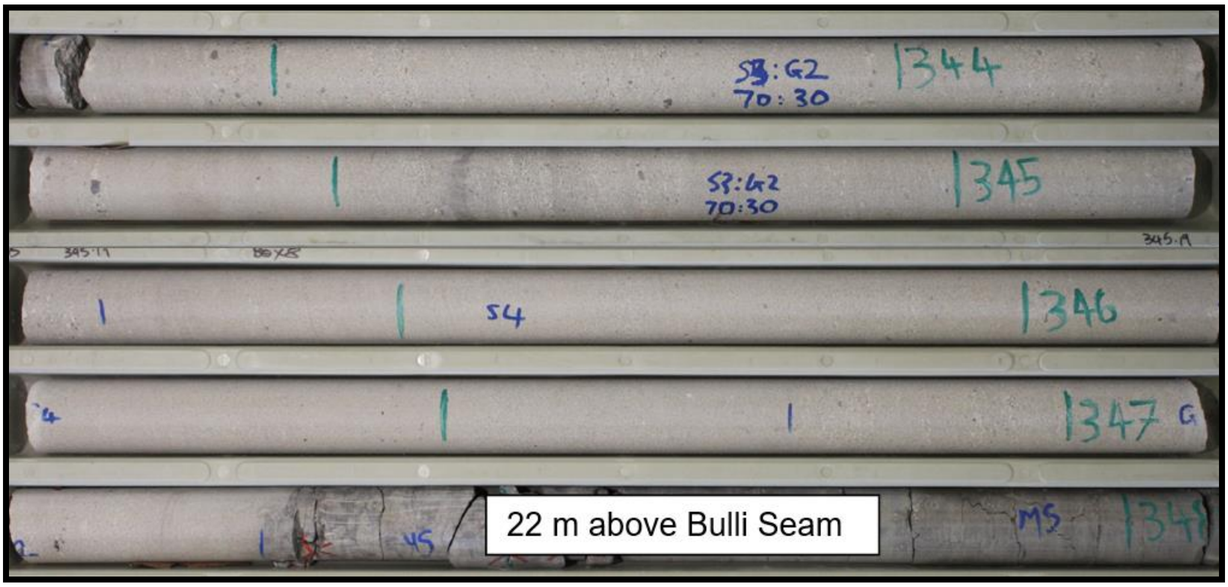

Figure 22. Sandstone in Wombarra Claystone – Borehole S2345, LW504.

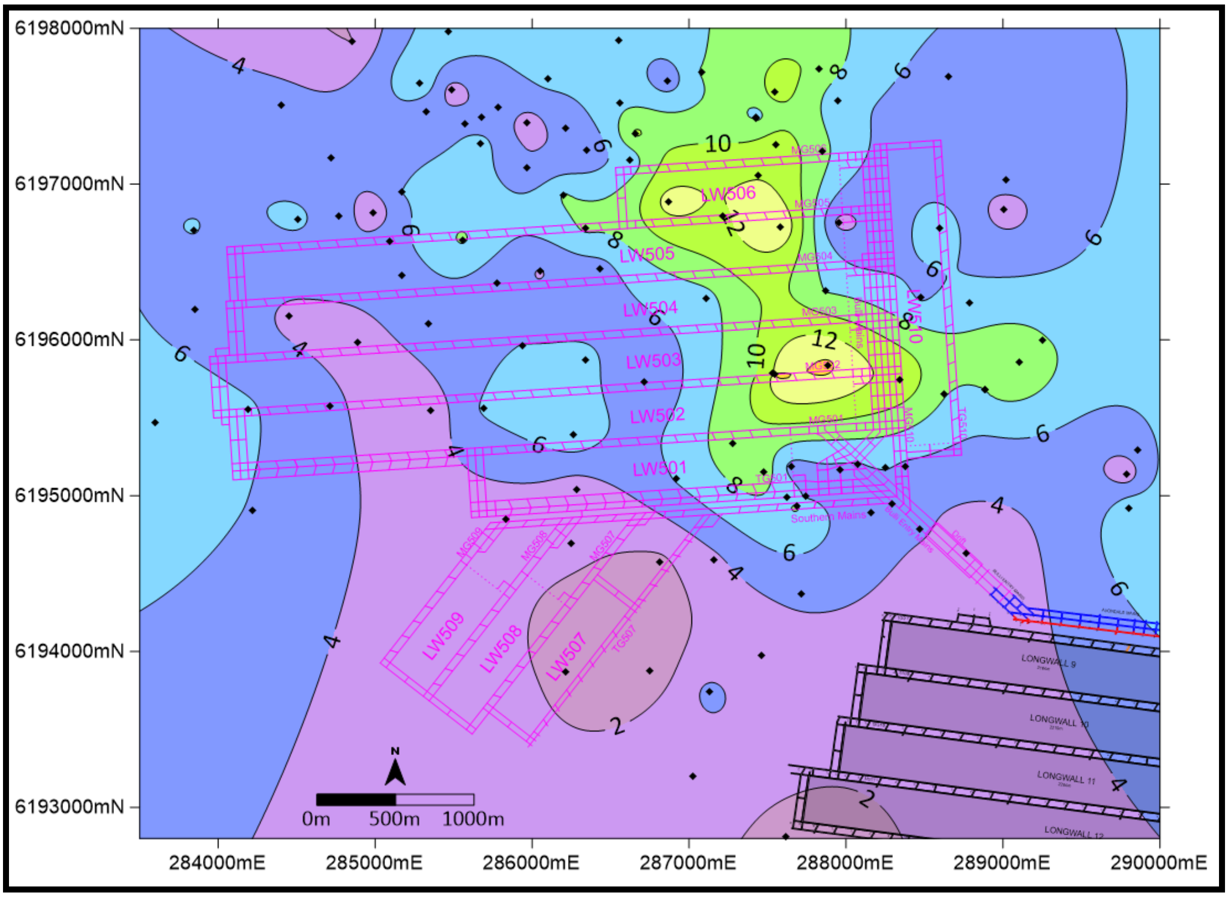

Figure 23. Geotechnical Thickness of Sandstone Units in the Wombarra Claystone (m).

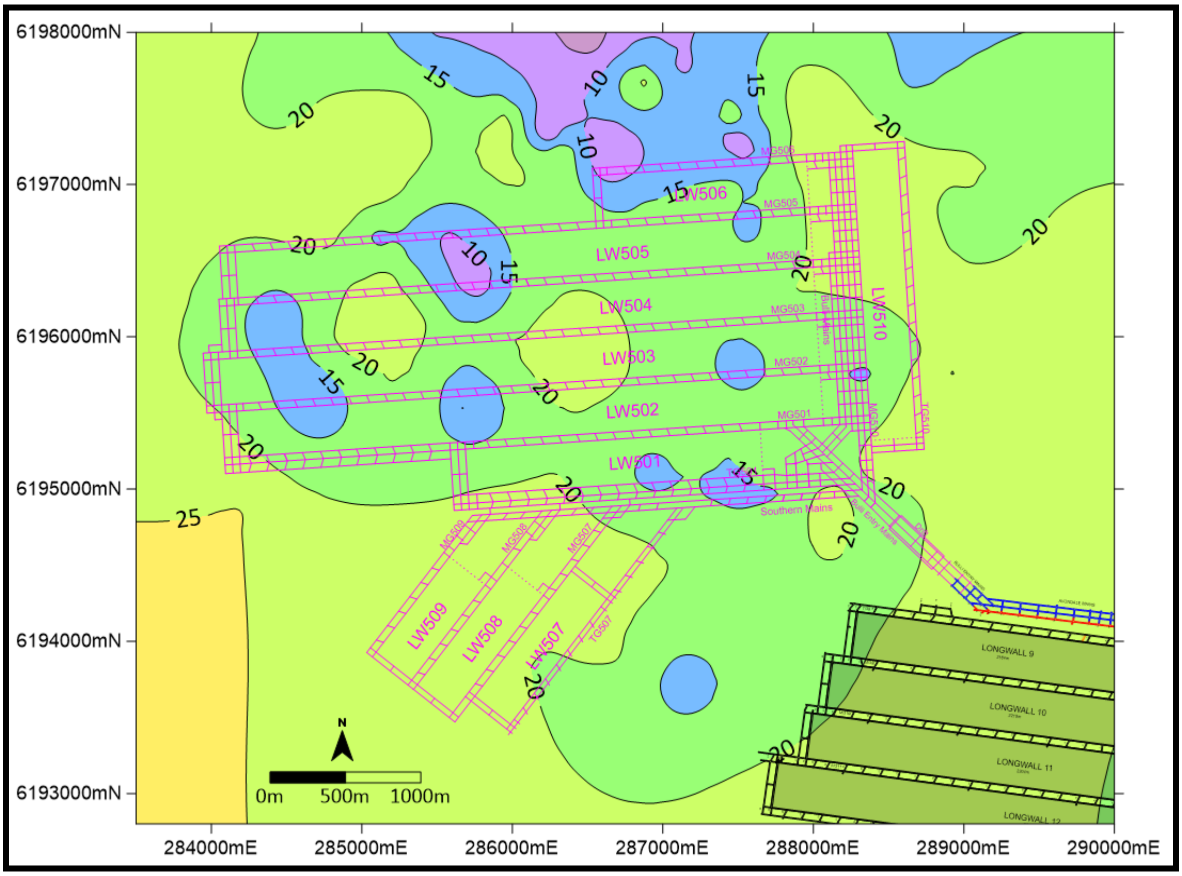

Figure 24. Height of the Sandstone Units above the Bulli Seam (m).

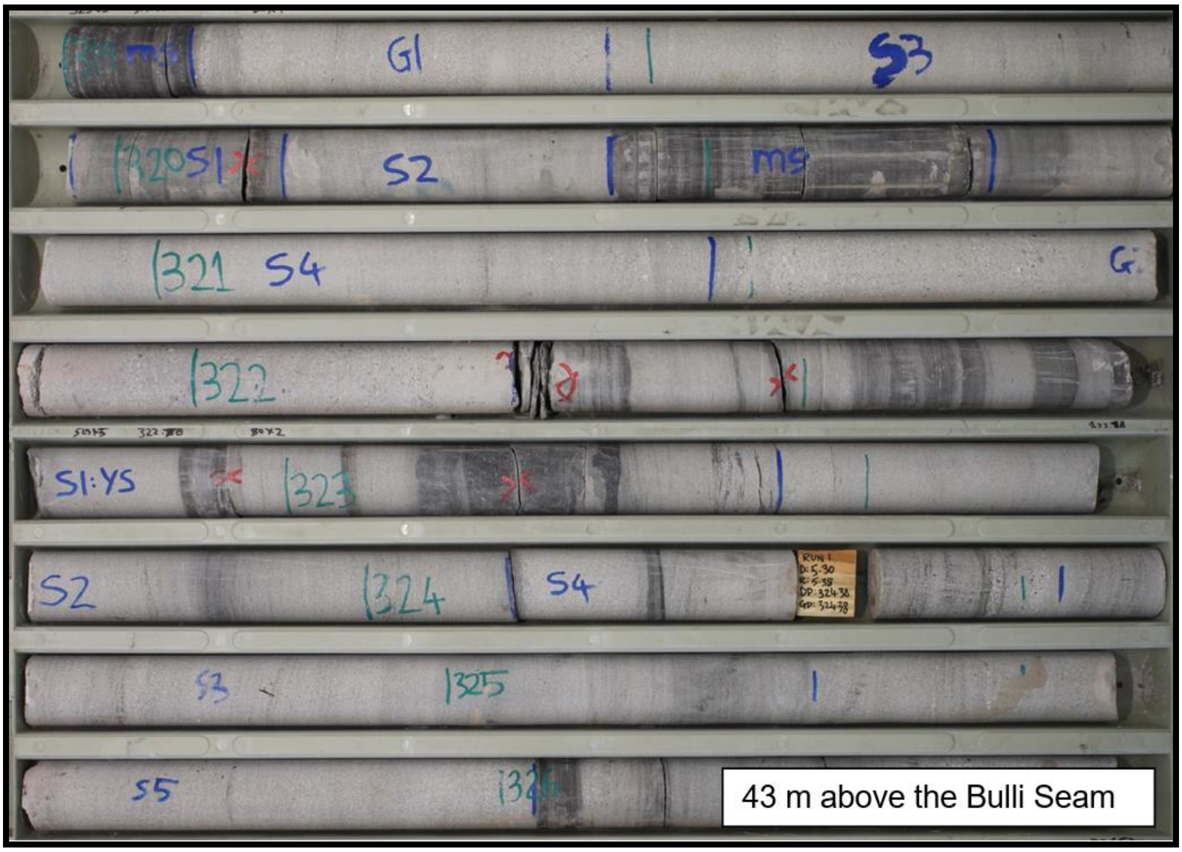

Figure 25. Sandstone in the Colo Vale Sandstone – Borehole S2345, LW504.

Away from the central thicker roof sandstone area, the sandstone typically shows different gamma response characteristics compared to the sandstone/conglomerate roof at another mine where weighting issues were experienced on the longwall face (**Figure 26**).

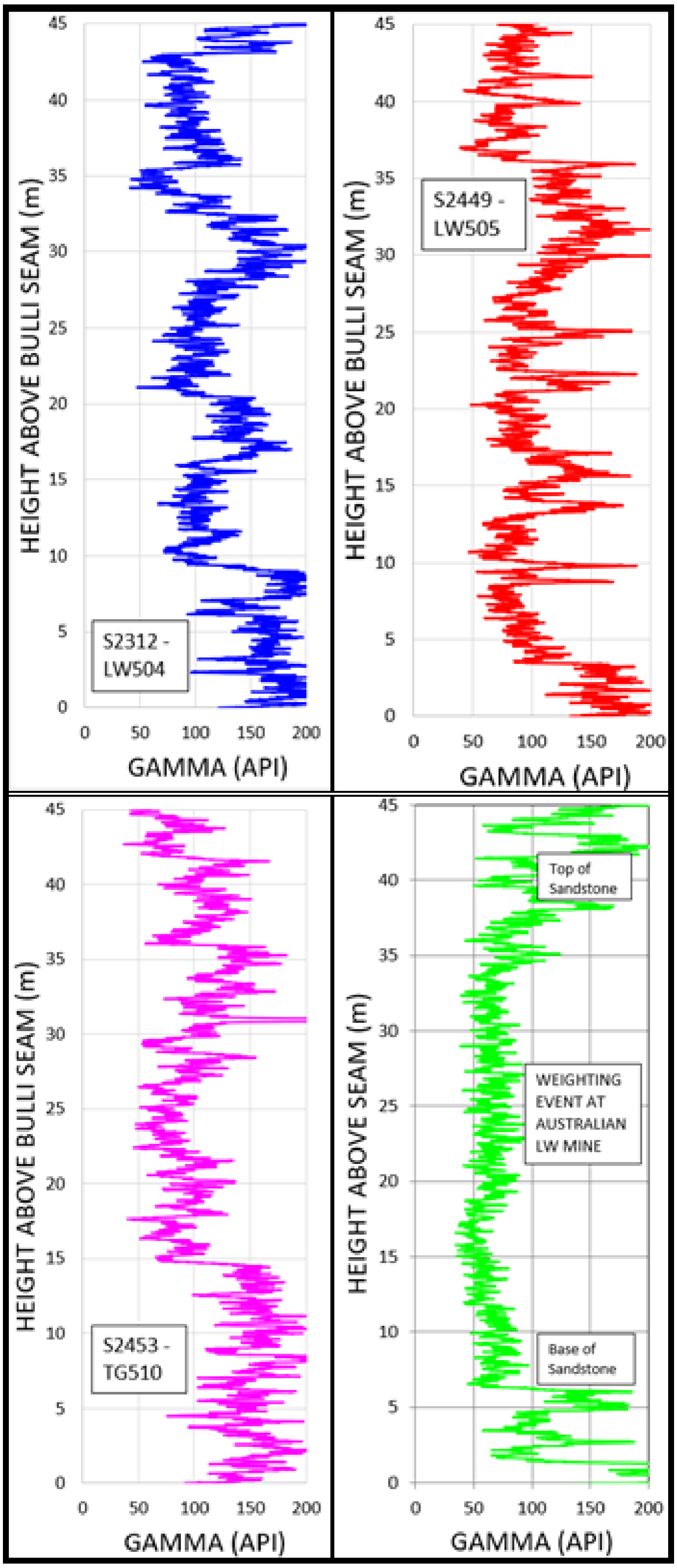

Figure 26. Comparison of the Gamma Response for the Bulli Seam Roof in the Western and Eastern Part of the Area.

Where the sandstone is thickest in the central part of the area, this unit shows similar gamma values of 50-80 API and a consistent trace to the known weighting event (**Figure 27**). As discussed in section 7.4, operational controls may be required when longwalling in this area.

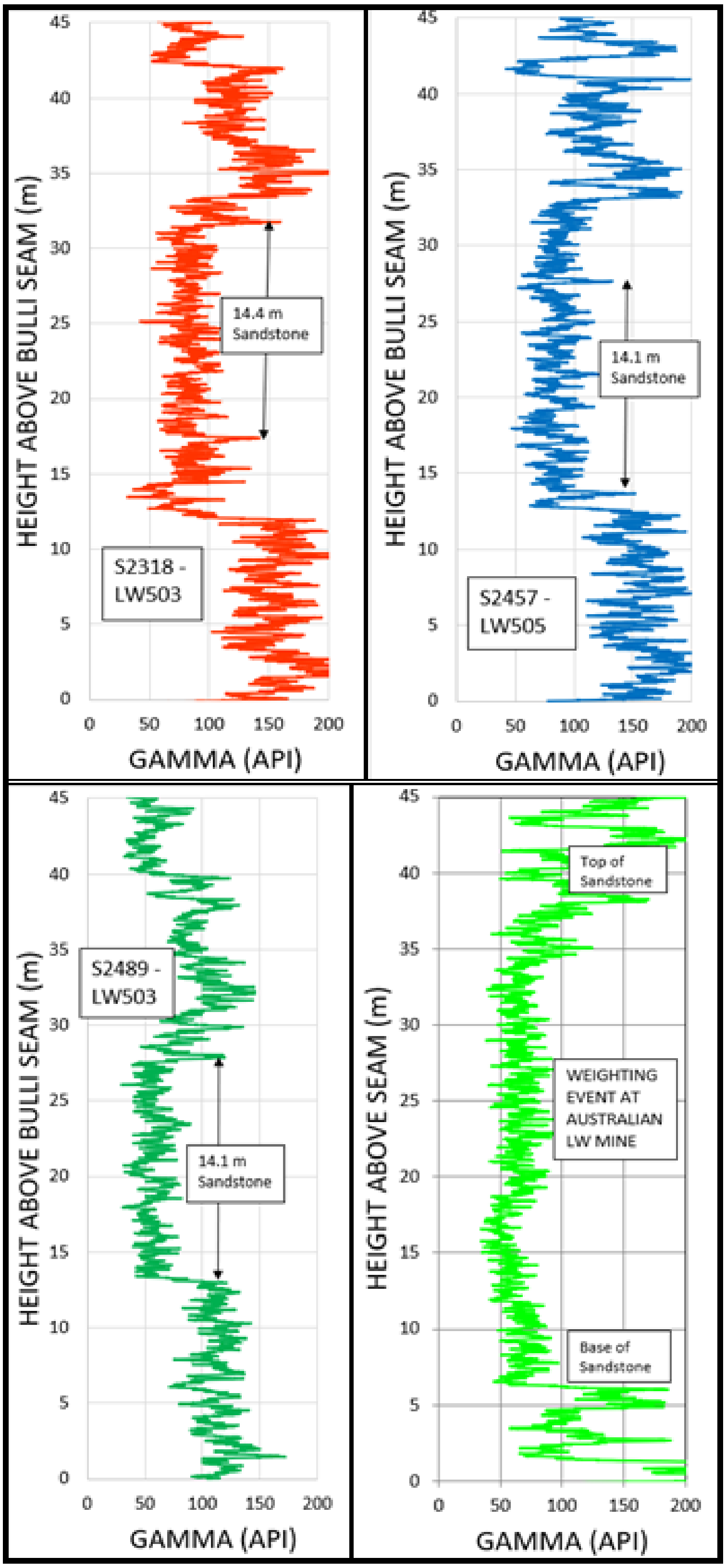

Figure 27. Gamma Response of the Sandstone in the Central Part of the Area.

The borehole gamma files can also be gridded to generate a cross section showing the variability in the thickness of the sandstone and laminite overburden units across the longwall area (**Figure 28**).

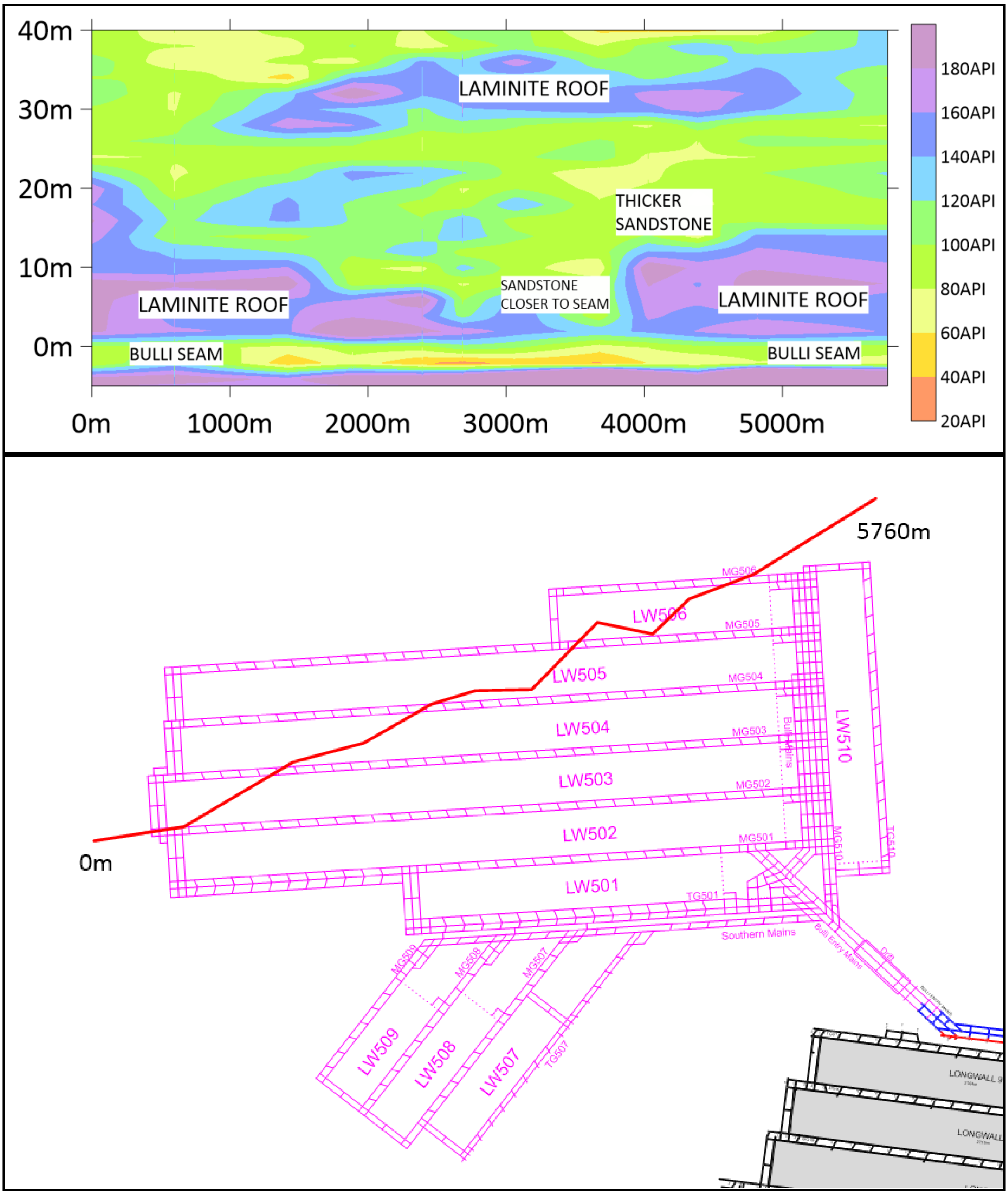

Figure 28. Gamma Cross Section across the Longwall Area.

3.9 Geotechnical Conditions

3.9.1 Geotechnical Testing

Geotechnical testing has been carried out on core samples from a number of exploration boreholes, in Area 5, including the five drift holes S2483 (vertical) and S2483A-S2483D (angled) (**Figure 29**).

The testing has measured the uniaxial compressive strength (UCS), Young's Modulus, Poisson's ratio, moisture content and density of selected core samples. Slake durability and triaxial strength testing has also been carried out on samples selected at various horizons in the exploration boreholes.

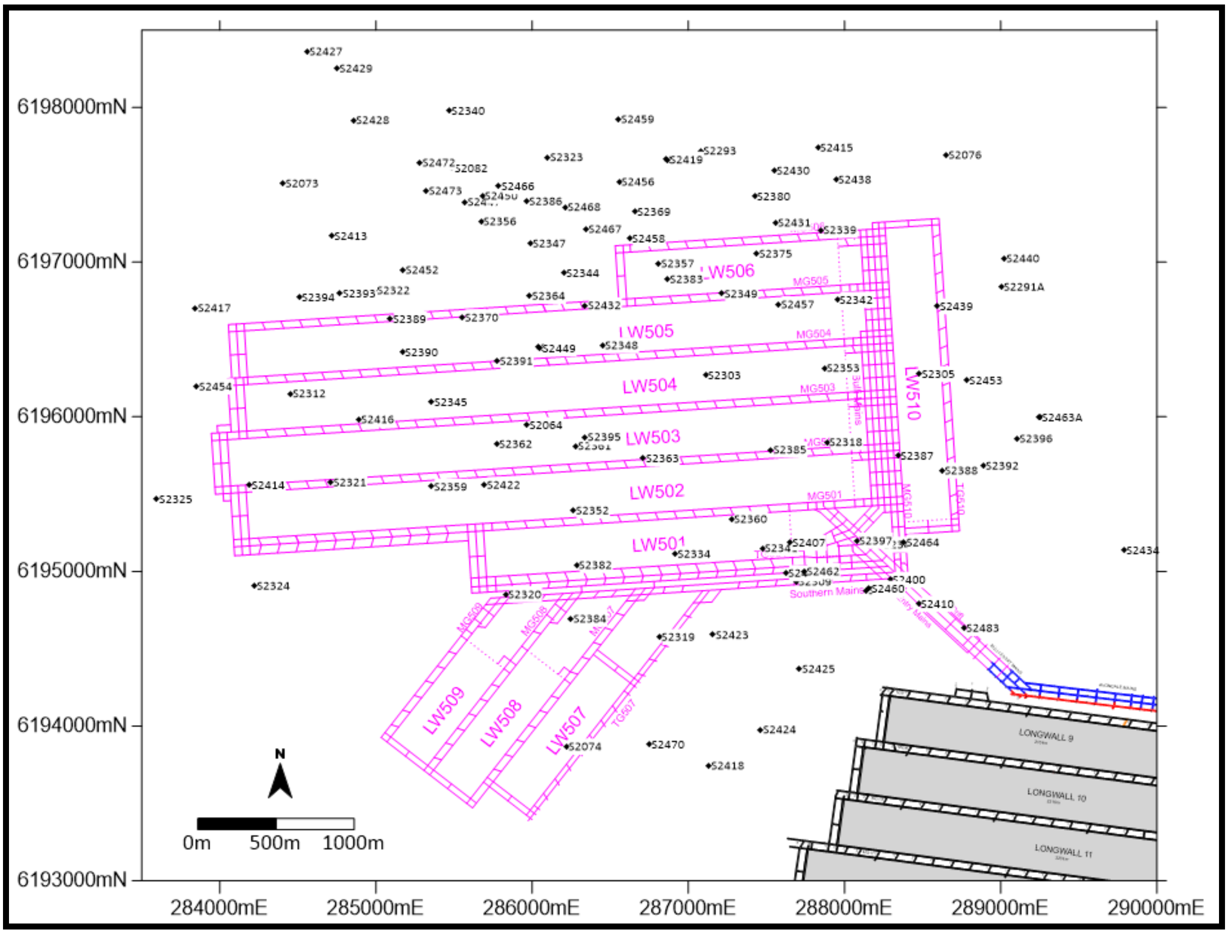

Figure 29. Location of Geotechnical Test Holes.

3.9.1.1 Uniaxial Compressive Strength

The strength and modulus data for individual lithologies has been plotted in **Figure 30**. The modulus: UCS ratio is similar for all lithologies ranging from 276 for sandstones, up to 360 for igneous material (**Figure 30**).

The range of strength values for individual lithologies, as well as the location with respect to the Bulli Seam is shown in **Figure 31** and **Figure 32** respectively.

Average strengths are typically 50-70 MPa for lithologies in Area 5 (**Figure 31**). The finer grained claystone and mudstone lithologies are slightly weaker than the coarser sediments (**Figure 31**).

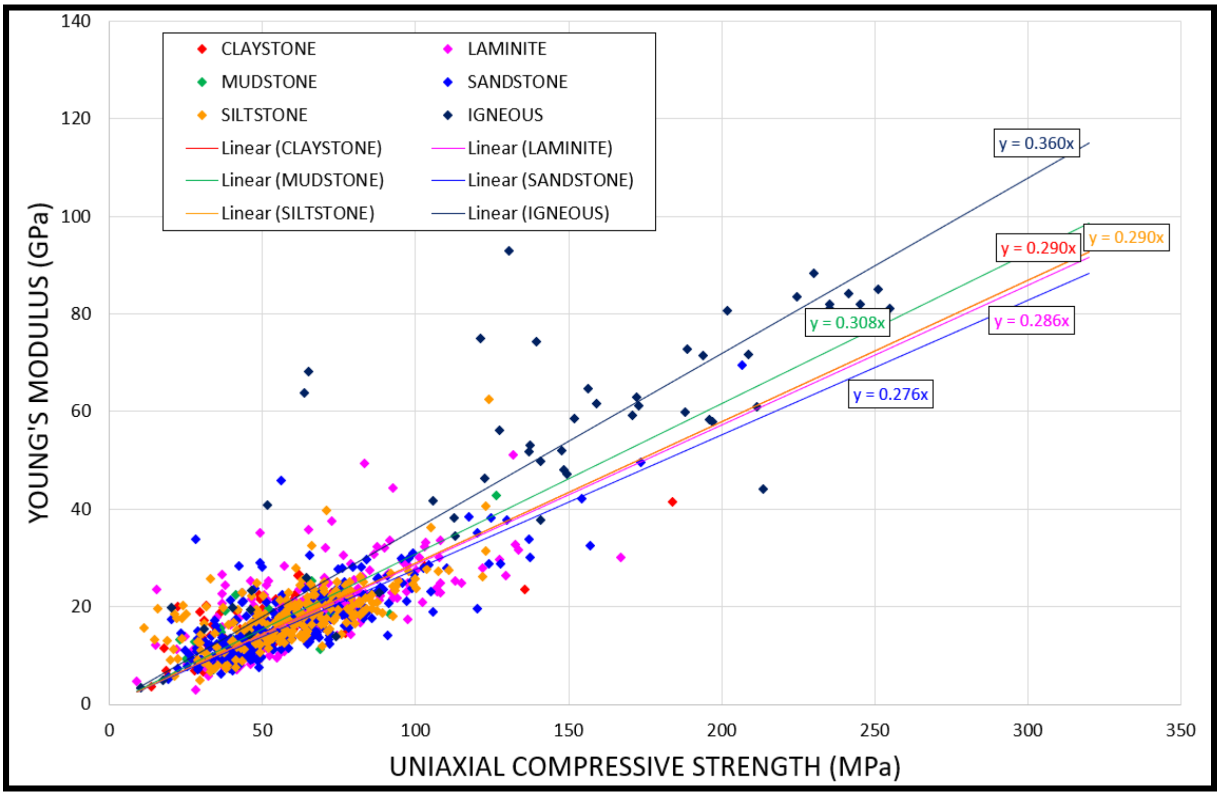

Figure 30. Elastic Modulus vs UCS.

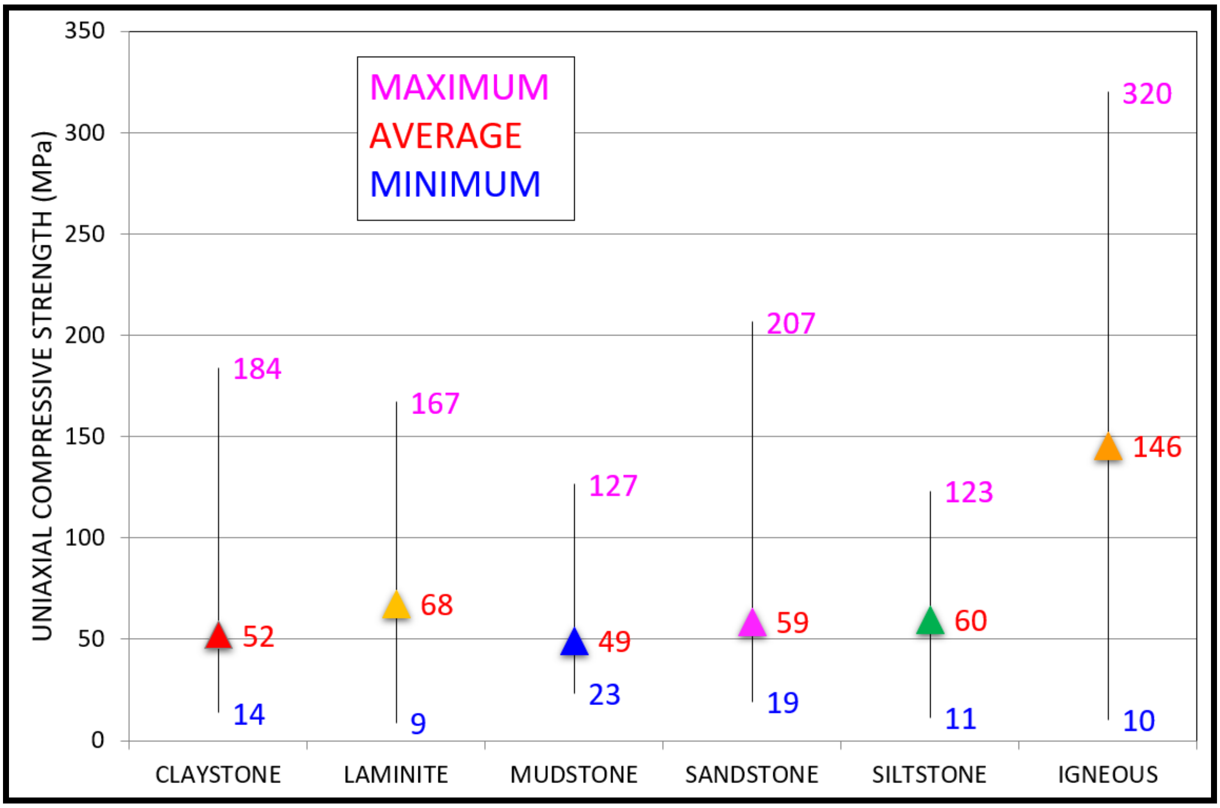

Figure 31. Strengths by Lithology.

Average strengths for the strata above and below the Bulli Seam are 59 MPa and 75 MPa respectively (**Figure 32**).

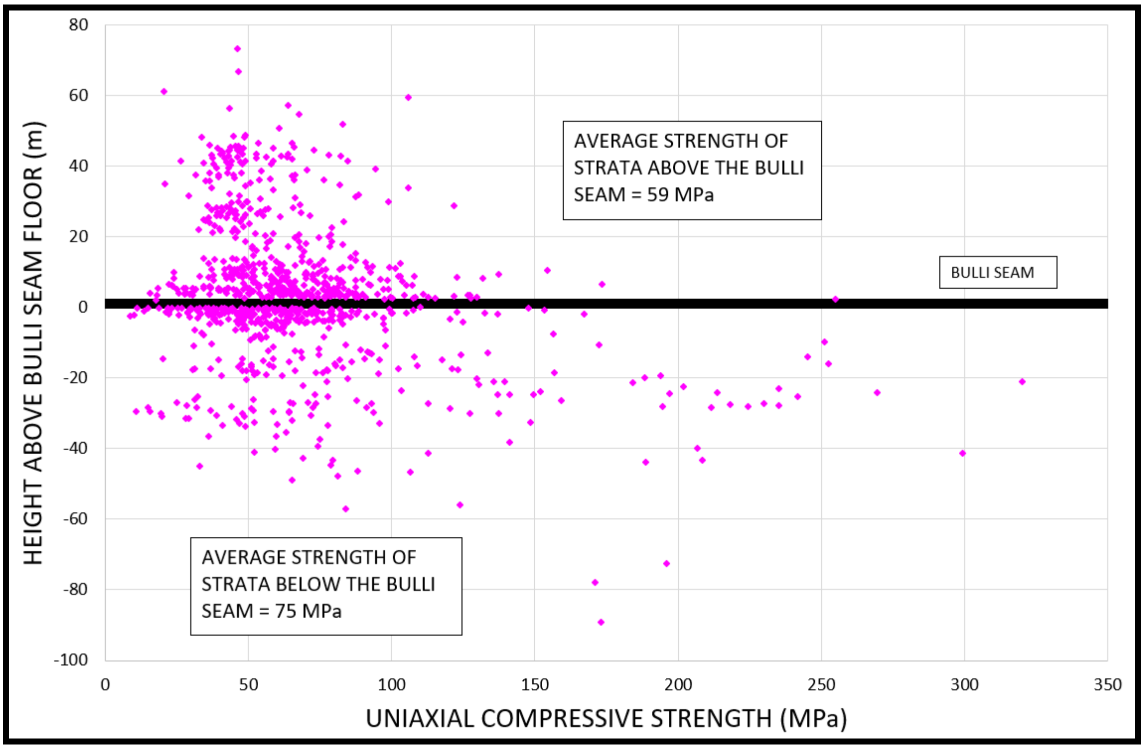

Figure 32. Strength w.r.t. Bulli Seam.

Closer analysis of the immediate roof and floor test results, indicates the majority of samples are greater than 40 MPa in uniaxial compression (**Figure 33**).

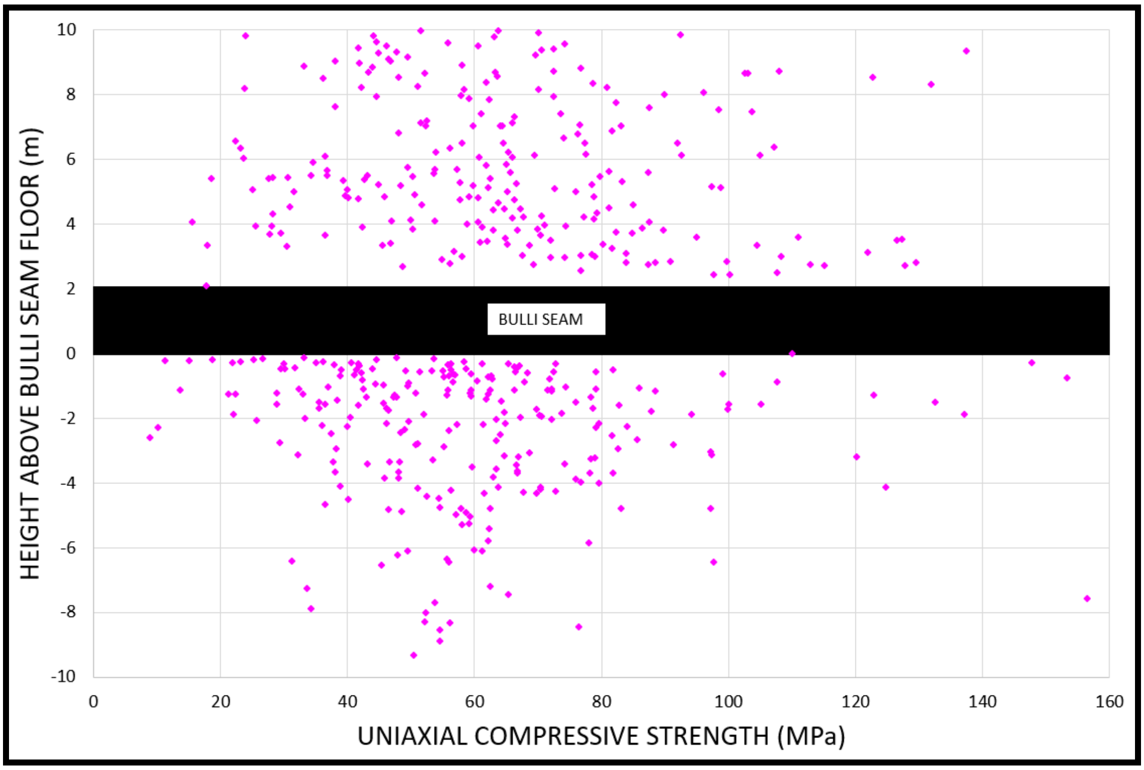

Figure 33. Immediate Roof and Floor Strength Test Results.

As expected, higher moisture content values were measured on weaker samples (**Figure 34**).

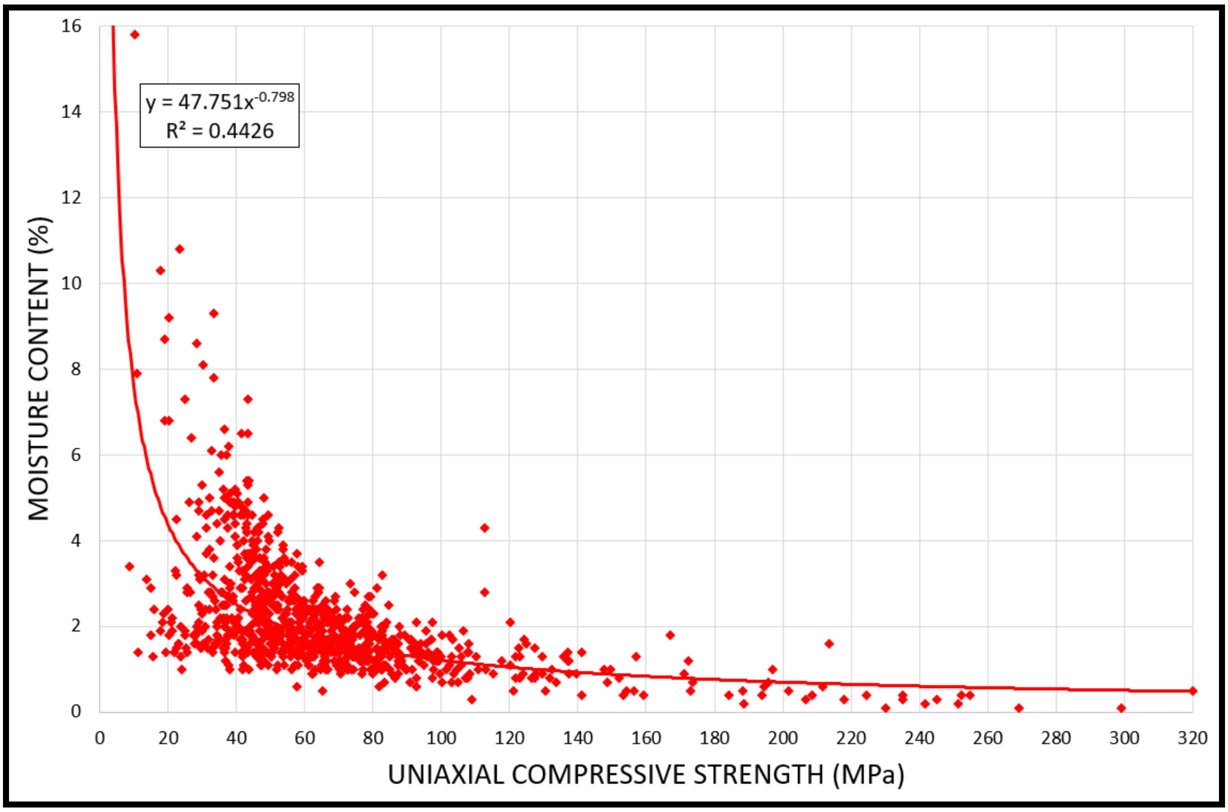

Figure 34. UCS vs Moisture Content.

3.9.1.2 Triaxial Strength

Triaxial testing allows the determination of how well a material can gain strength with confinement. Strata with higher friction angles, gain higher strength for the same amount of confinement.

The intact strength properties were determined from the triaxial strength testing of a large selection of 301 samples, using a Geological Strength Index (GSI) for sedimentary rock of 50. The majority of friction angle values, for failure through the rock substance, are between 25° and 35° (**Figure 35**). These values should be taken as upper bound values for the bedding planes.

As expected, lower cohesion values were measured on the finer grained samples (**Figure 36 and Figure 37**).

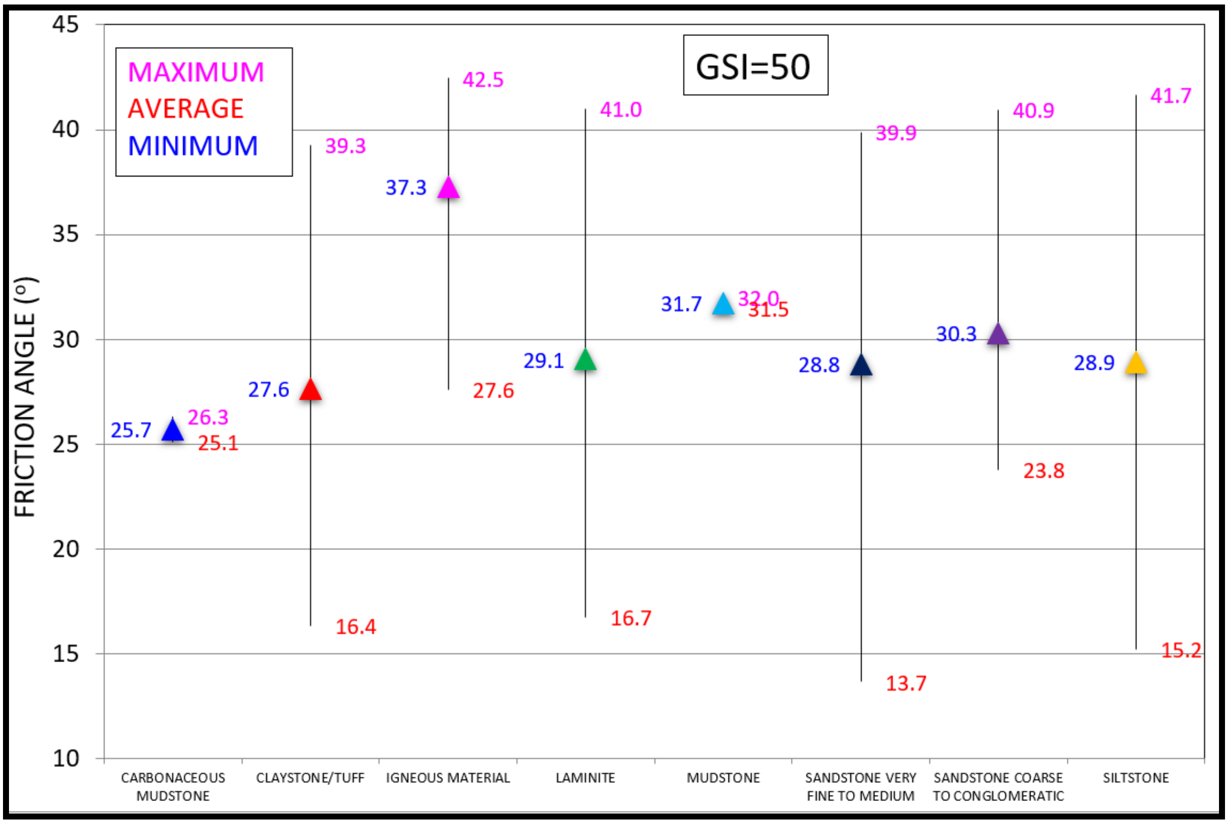

Figure 35. Friction Angle - Intact Strength Properties.

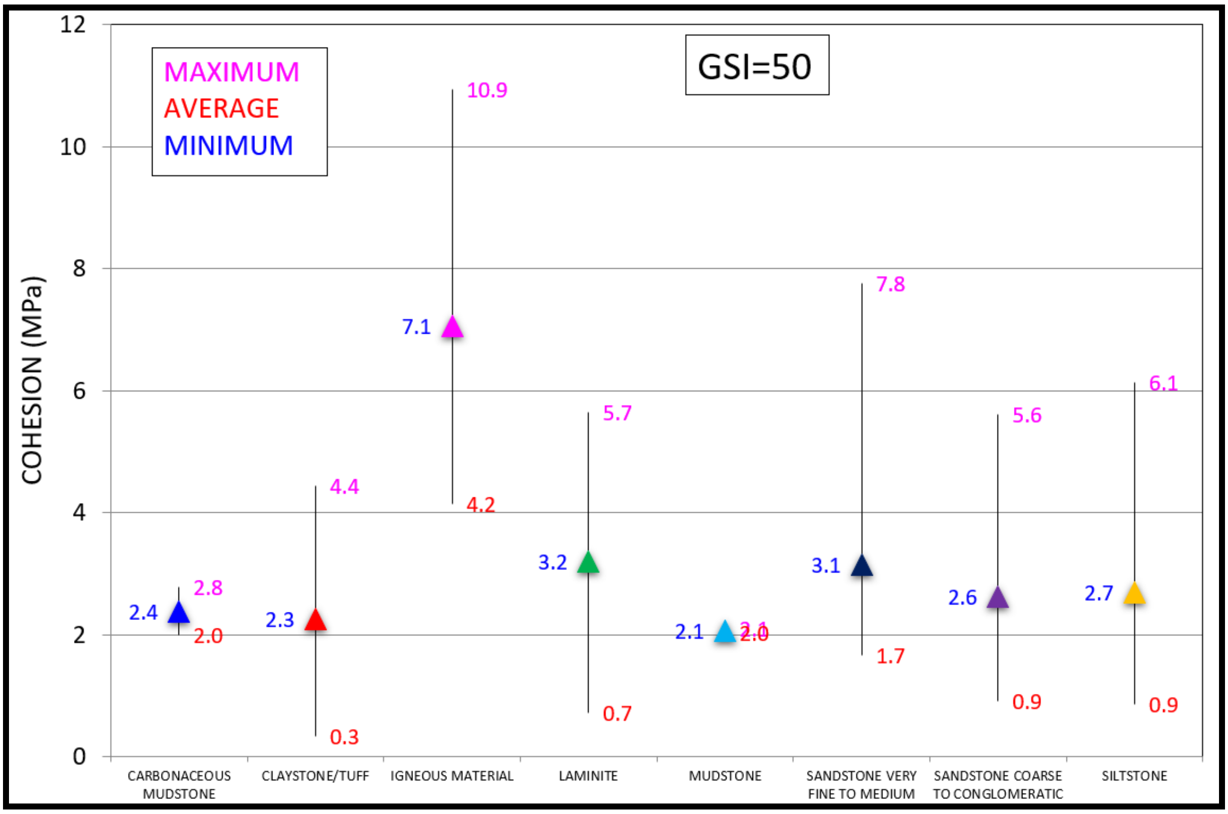

Figure 36. Cohesion - Intact Strength Properties.

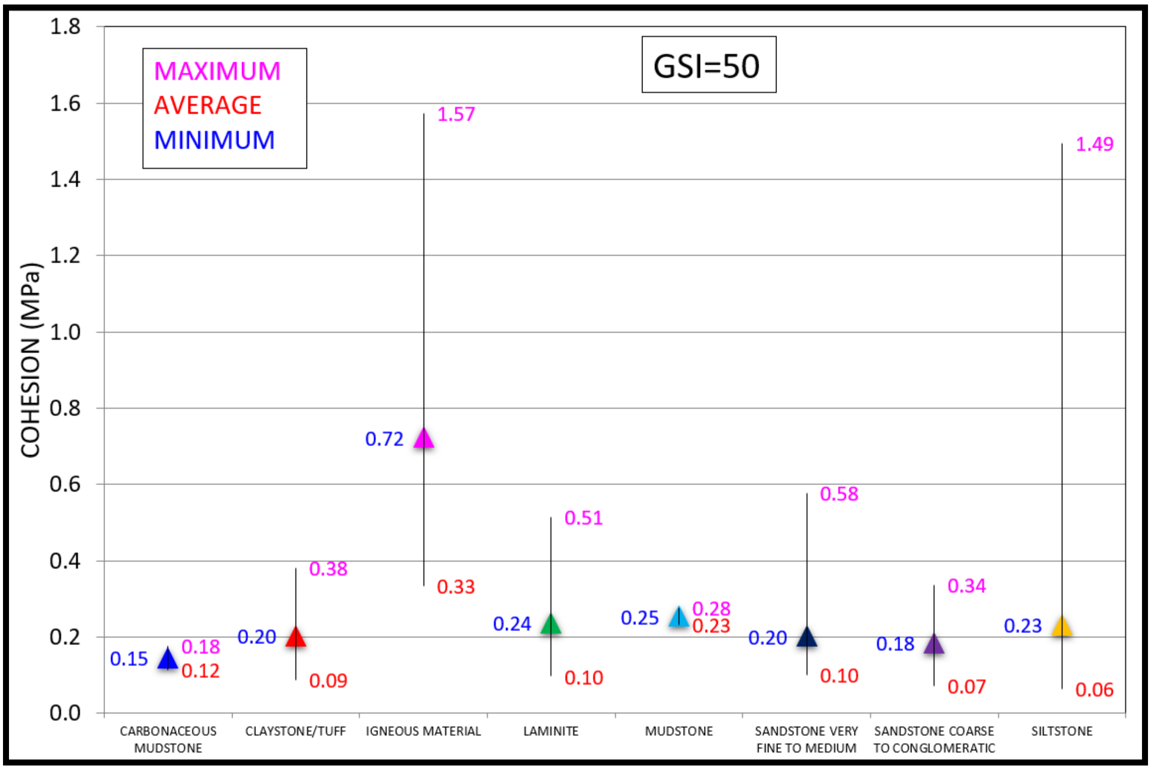

Figure 37. Cohesion - Residual Strength Properties.

3.9.1.3 Slake Durability

Slake durability testing indicates the Bulli Seam immediate stone floor exhibits typically high durability (**Figure 38**).

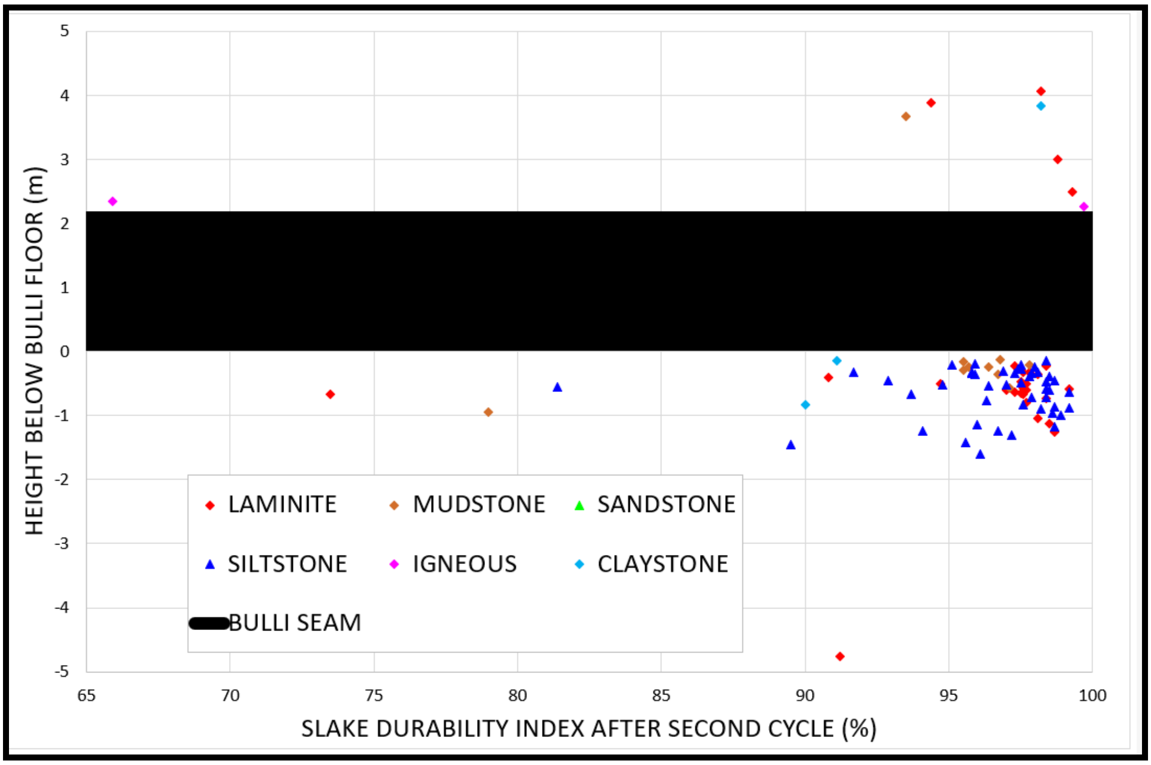

Figure 38. Slake Durability Index after Two Cycles.

3.10 Rock Mass Classification Systems

A number of rock mass classification systems including strength, strength index and Vshale ratio are detailed below to characterise the roof, floor and coal in the proposed longwall layout in Area 5.

3.10.1 Sonic/UCS Correlation

Geophysical sonic velocity logs are routinely used in the Australian coal industry to estimate the uniaxial compressive strength (UCS) of stone roof and floor strata. Contouring of this strength data derived from sonic velocity logs provides regional trends used by mine planners.

The standard South32 correlation from the Area 3C report[4] was used to manipulate the sonic velocity data in Area 5 as follows (**Figure 39**):

$$UCS = 2.7996e^{(0.0008*t)}$$

Where: UCS = Uniaxial Compressive Strength (MPa)
t = Sonic Transit Time (m/sec)

As shown in **Figure 39**, this correlation is similar to the previous correlation from the Area 3A report and a specific correlation generated by GGPL (2017) for Area 5 using 193 data points as follows:

$$UCS = 2.6988e^{(0.0008*t)}$$

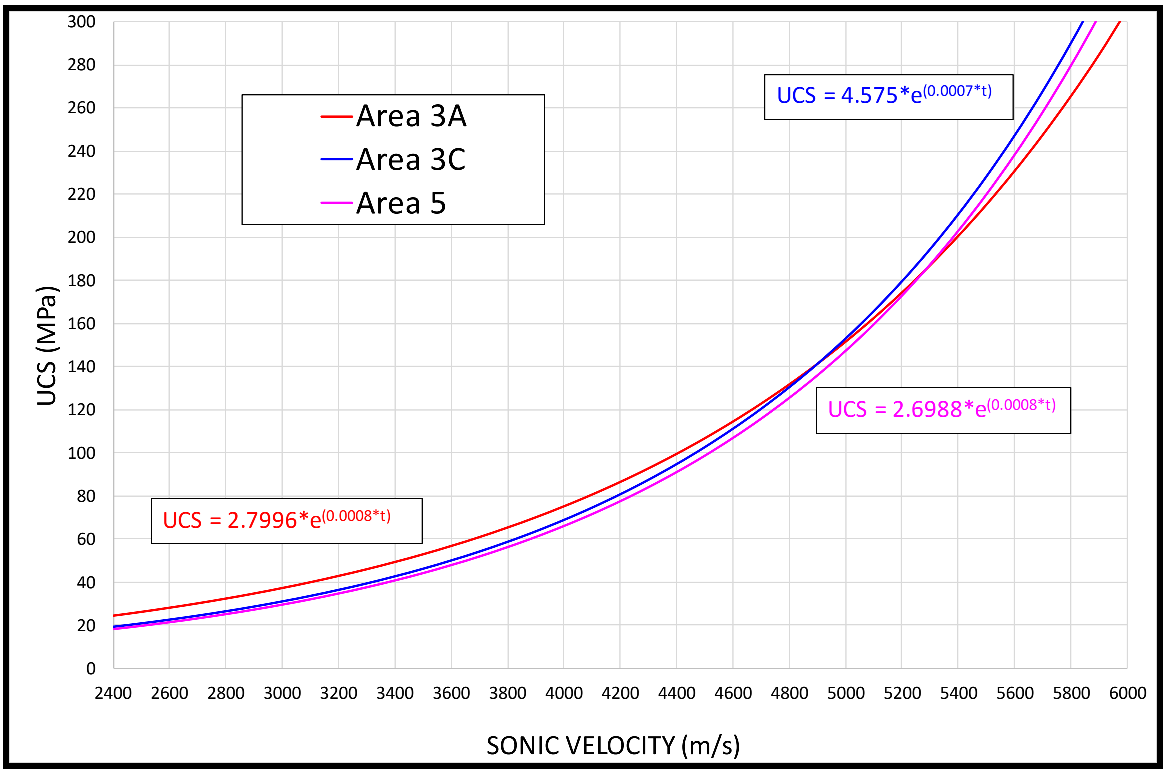

Figure 39. Sonic/UCS Correlations – Dendrobium.

[4] Illawarra Coal (2013). Dendrobium Area 3C - Preliminary Geology Report.

3.10.2 Stone Roof Strength

3.10.2.1 Bulli Seam Immediate Roof

In the proposed Bulli Seam longwall area, the immediate 0.5 m stone roof strength is typically in the range 50-80 MPa (**Figure 40**). There is a localised area of stronger immediate roof around the pit bottom area, at the top of the drifts (**Figure 40**). There is also a gradual weakening trend towards the north-west (**Figure 40**).

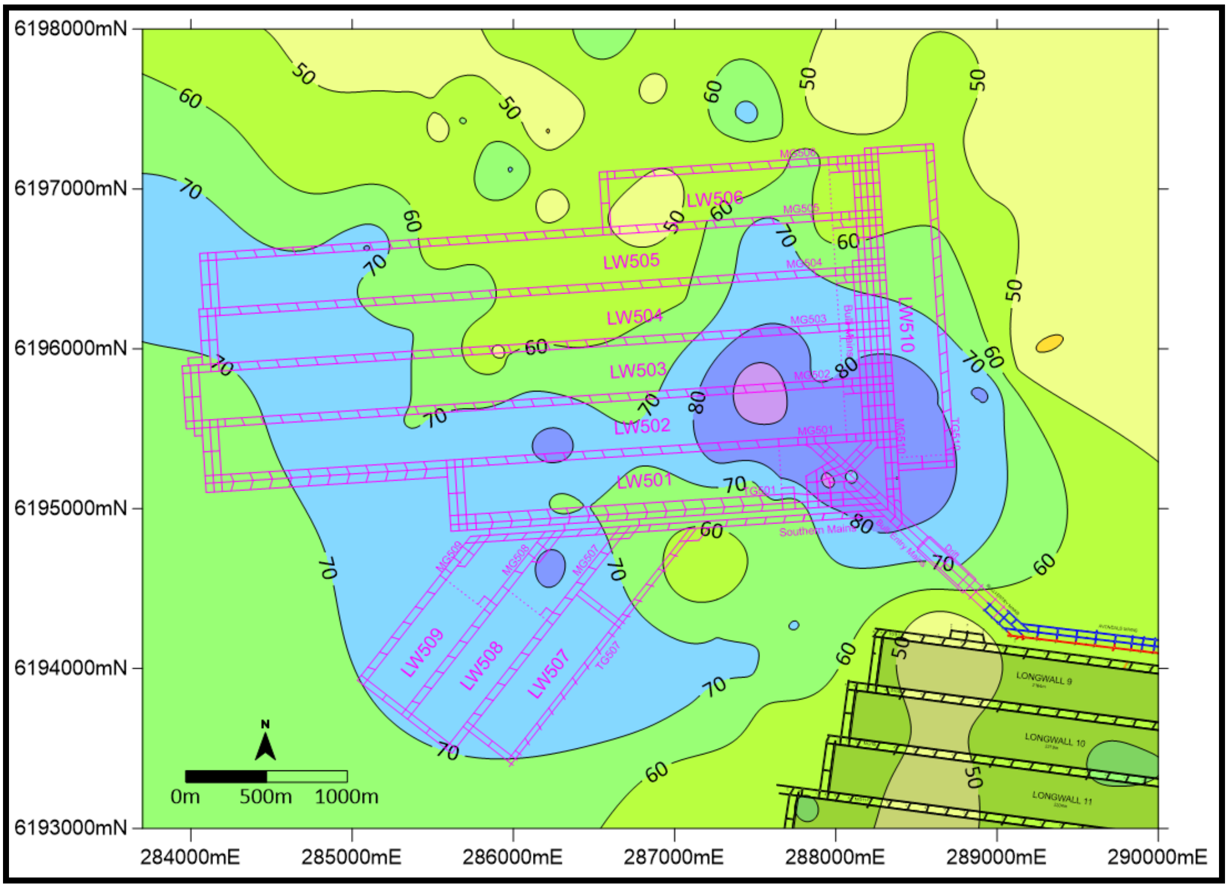

Figure 40. Average Strength of the 0-0.5 m Immediate Roof Interval (MPa).

The average strength of the 0-2 m stone roof horizon above the Bulli Seam is generally stronger, ranging between 60 MPa and 80 MPa (**Figure 41**). The secondary 2-6 m roof horizon is of similar strength, ranging from 65-75 MPa (**Figure 42**).

Similar strengths for the Bulli Seam immediate stone roof are indicated at Appin Mine and West Cliff, at greater depths of cover. Discussion on the impact of the rock strength to mining is detailed further in Sections 6 and 7 of this report.

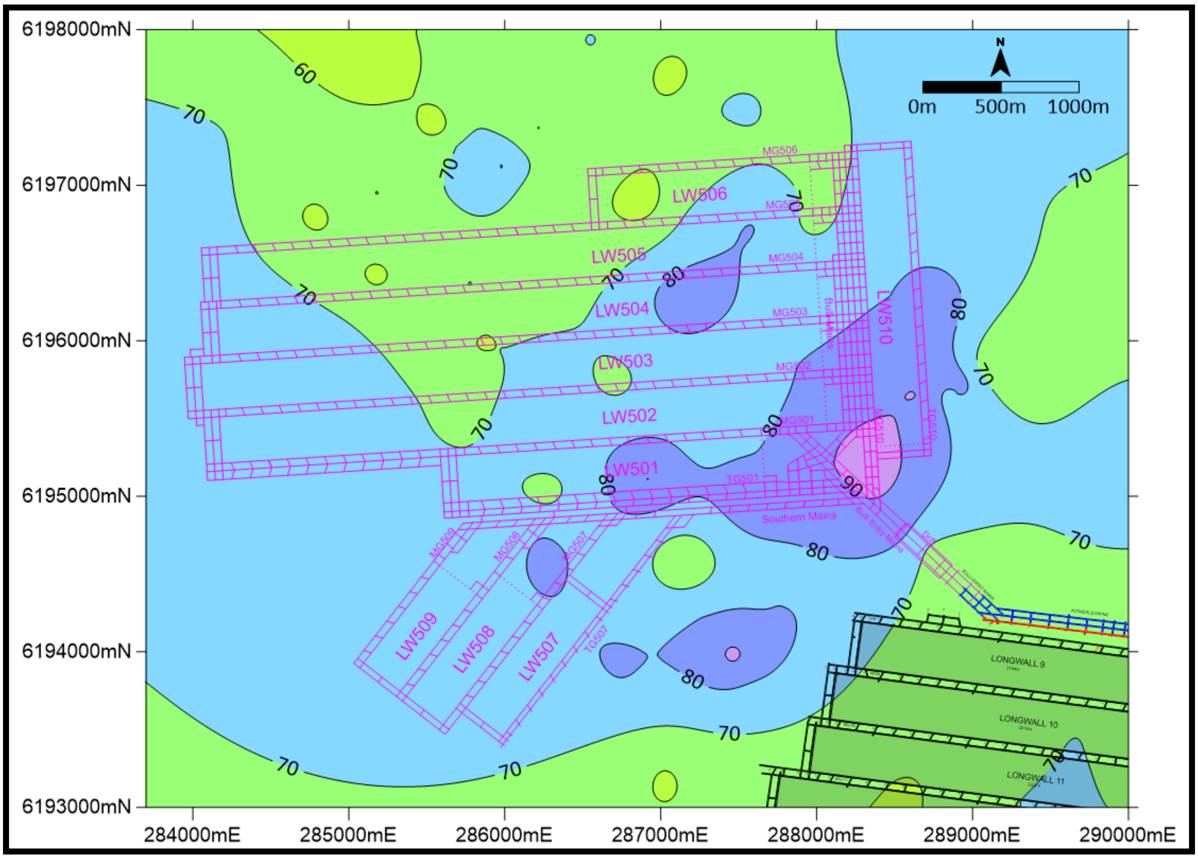

Figure 41. Average Strength of the 0-2 m Immediate Roof Interval (MPa).

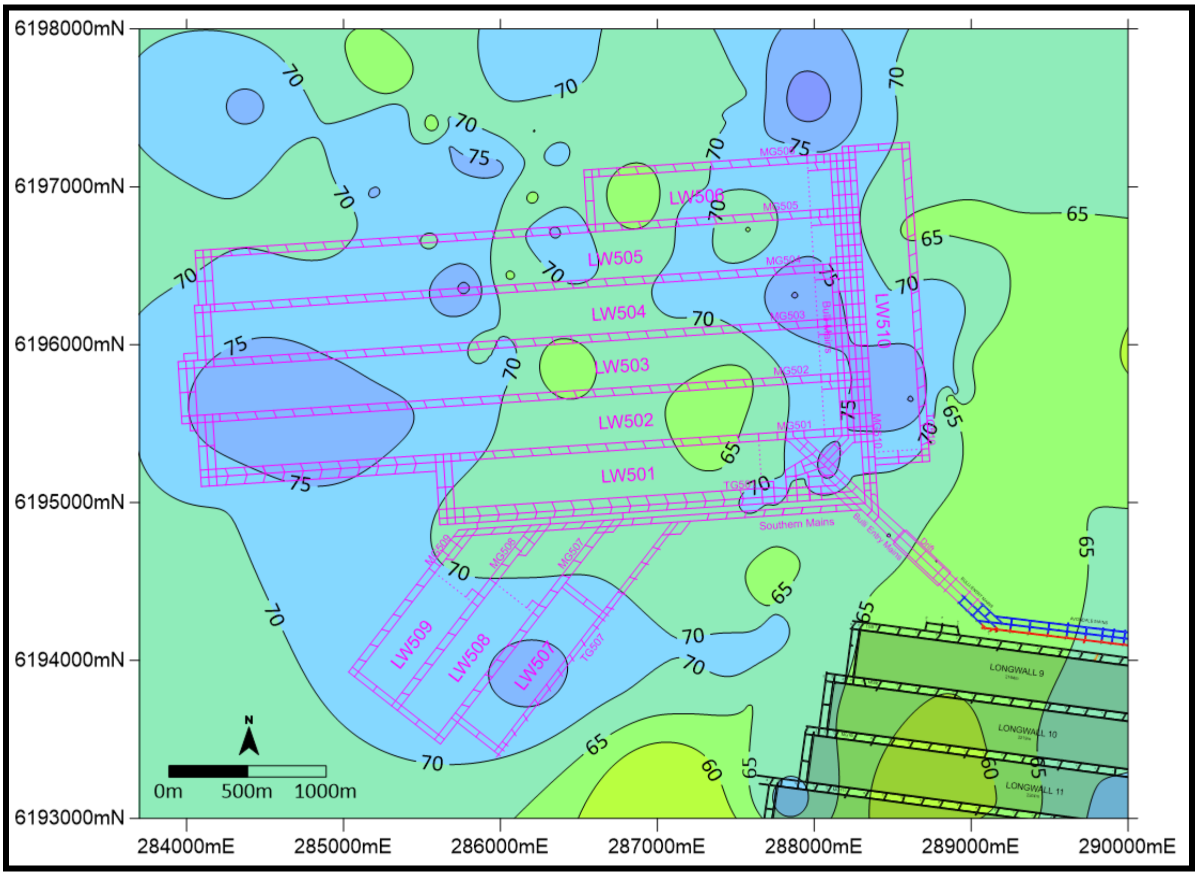

Figure 42. Average Strength of the 2-6 m Roof Interval (MPa).

3.10.2.2 Bulli Seam Overburden

Generally, the overburden for the 50 m of roof above the Bulli Seam averages 60-70 MPa in Area 5 (**Figure 43**). Where the sandstone roof units thicken to >10 m in the central part of the area, there is no appreciable increase in strength (**Figure 23 and Figure 43**). The strength of individual formations in the Bulli Seam overburden are presented in **Appendix 2**.

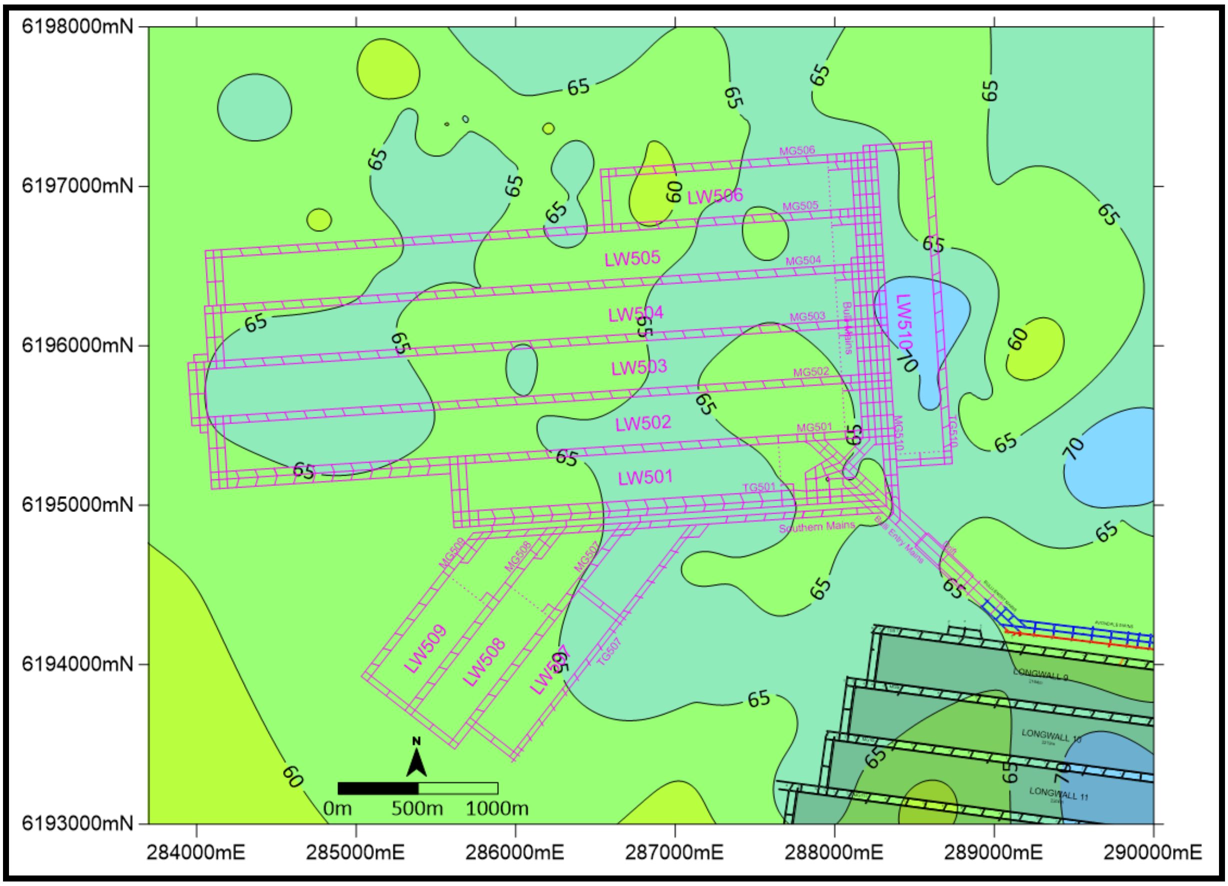

Figure 43. Average Strength of the 0-50 m Roof Interval (MPa).

3.10.3 Roof Strength Index

As well as strength, the Roof Strength Index or RSI rock mass classification system can be used to normalise strength against depth. This index is defined as the average strength of the roof over a specified interval, divided by the estimated vertical stress.

This method was originally developed at Kestrel Mine in Central Queensland by Gordon and Tembo (2005)[5] and has since been shown to work well in the workings at other mines, to identify the need for denser primary support and long tendon support, particularly as the depth of cover increases.

[5] Gordon, N., and Tembo, E (2005). The roof strength index – a simple index to one possible mode of roof collapse. Bowen Basin Symposium 2005 – The Future for Coal – Fuel for Thought. Pp. 347-352.

Where roadways are oriented unfavourably to the stress, a threshold RSI value of 8 is considered indicative of compressive failure or guttering. Where more favourably oriented, the threshold value reduces to about 4. RSI values of 6-9 are indicated for the stone roof above the Bulli Seam in Area 5, with the majority >7 (**Figure 44**).

The RSI has been calculated using an average density of 2.54 t/m^3, measured in each of the boreholes in Area 5.

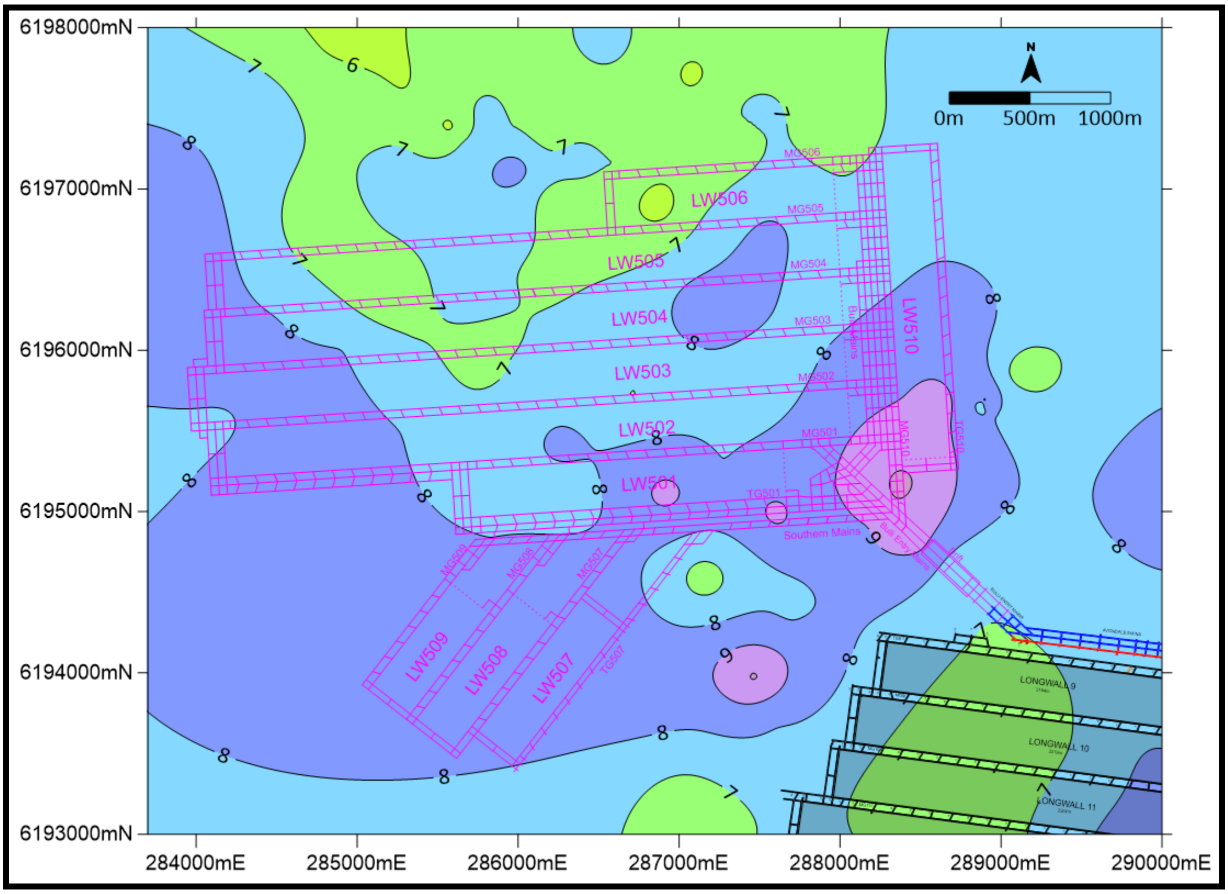

Figure 44. Roof Strength Index for the 0-2 m Immediate Roof Interval.

3.10.4 Stone Floor Strength

The average strength of the immediate 0.5 m of stone floor below the Bulli Seam is typically 40-50 MPa (**Figure 45**). Where the basal ply splits away there are localised areas of weaker floor <30 MPa, particularly in the northern part of the area (**Figure 45**).

Further below the Bulli Seam, the average floor strength increases to typically 50-70 MPa, with a stronger zone of >60 MPa in the central part of the area (**Figure 46**).

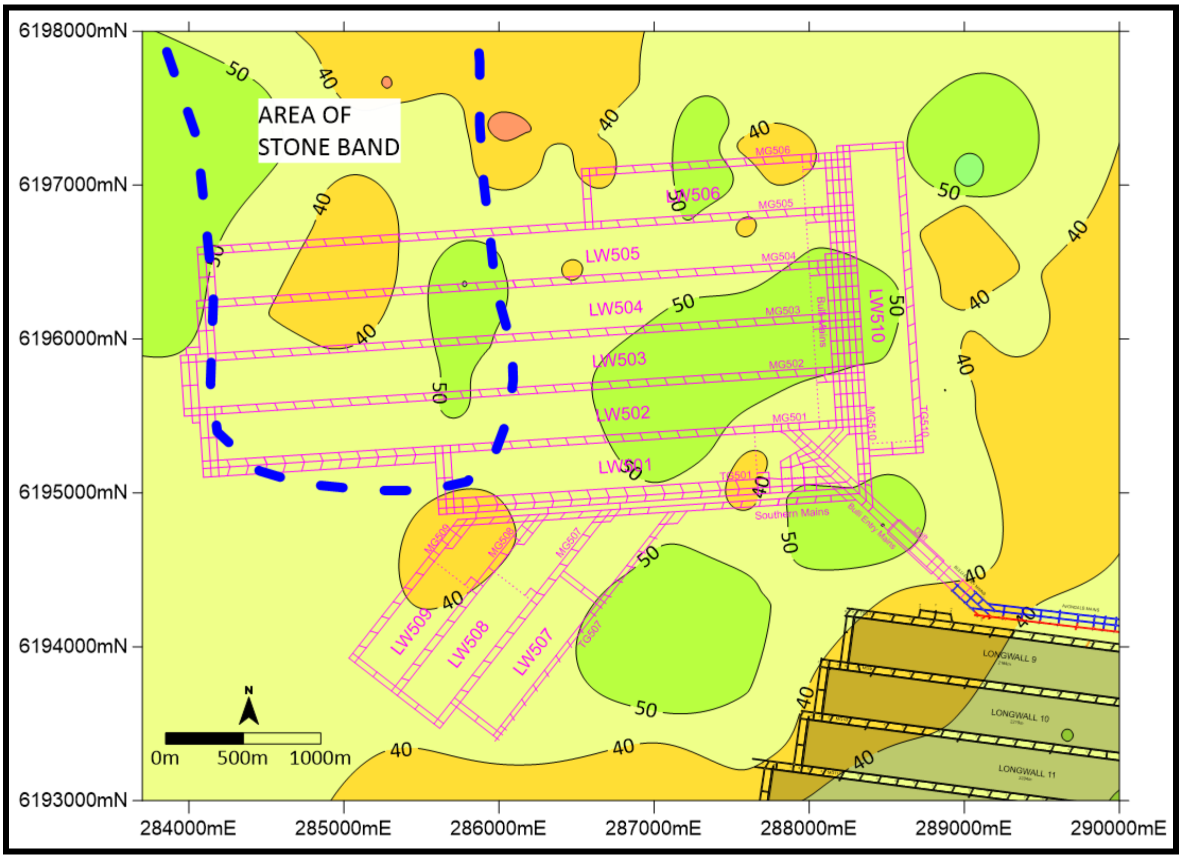

Figure 45. Average Strength of the 0-0.5 m Immediate Floor Interval (MPa).

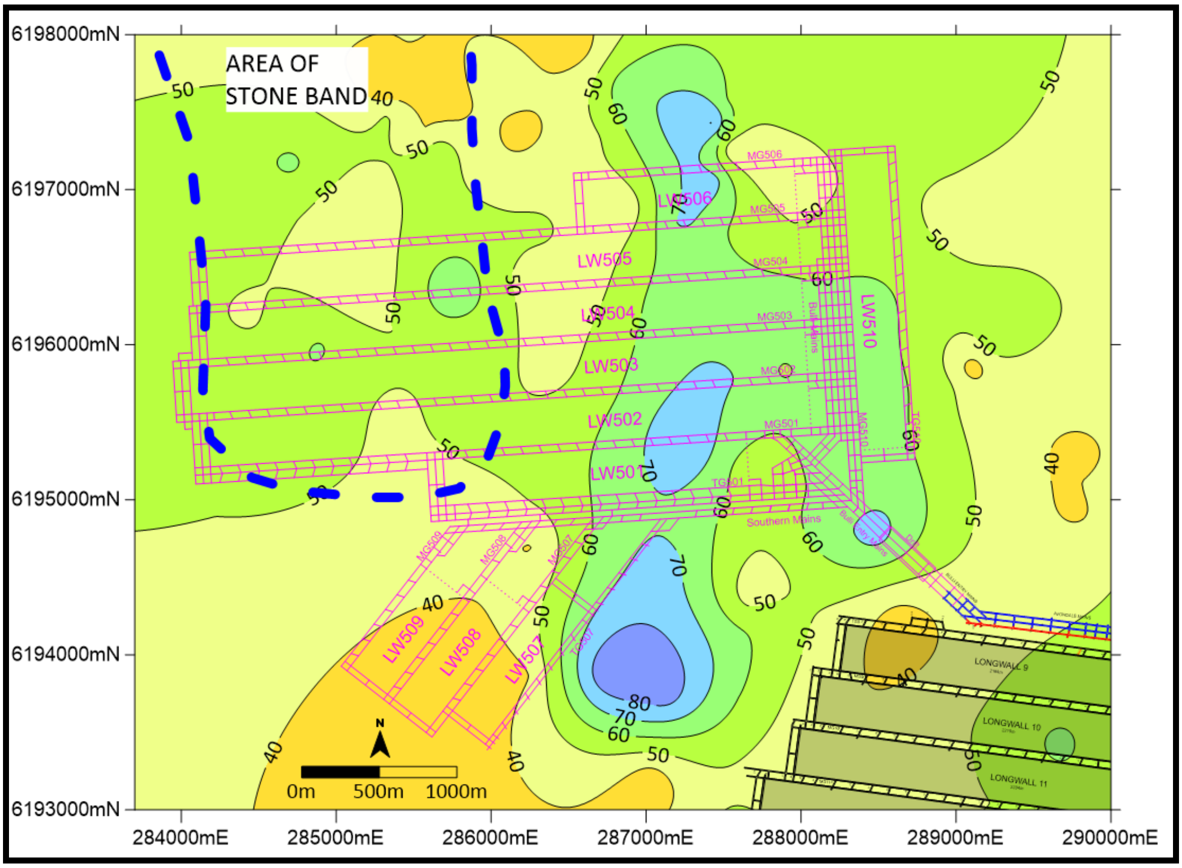

Figure 46. Average Strength of the 0.5-1 m Immediate Floor Interval (MPa).

3.10.5 Floor Strength Index

Similar to the RSI, the Floor Strength Index (FSI) can be used to characterise floor conditions. A threshold FSI value of <2 has been found to be typical of poor floor conditions at other mines.

For the immediate 0.5 m of stone floor below the Bulli Seam, the FSI values are typically 4-5, reducing locally to <3 where the basal ply splits away (**Figure 47**).

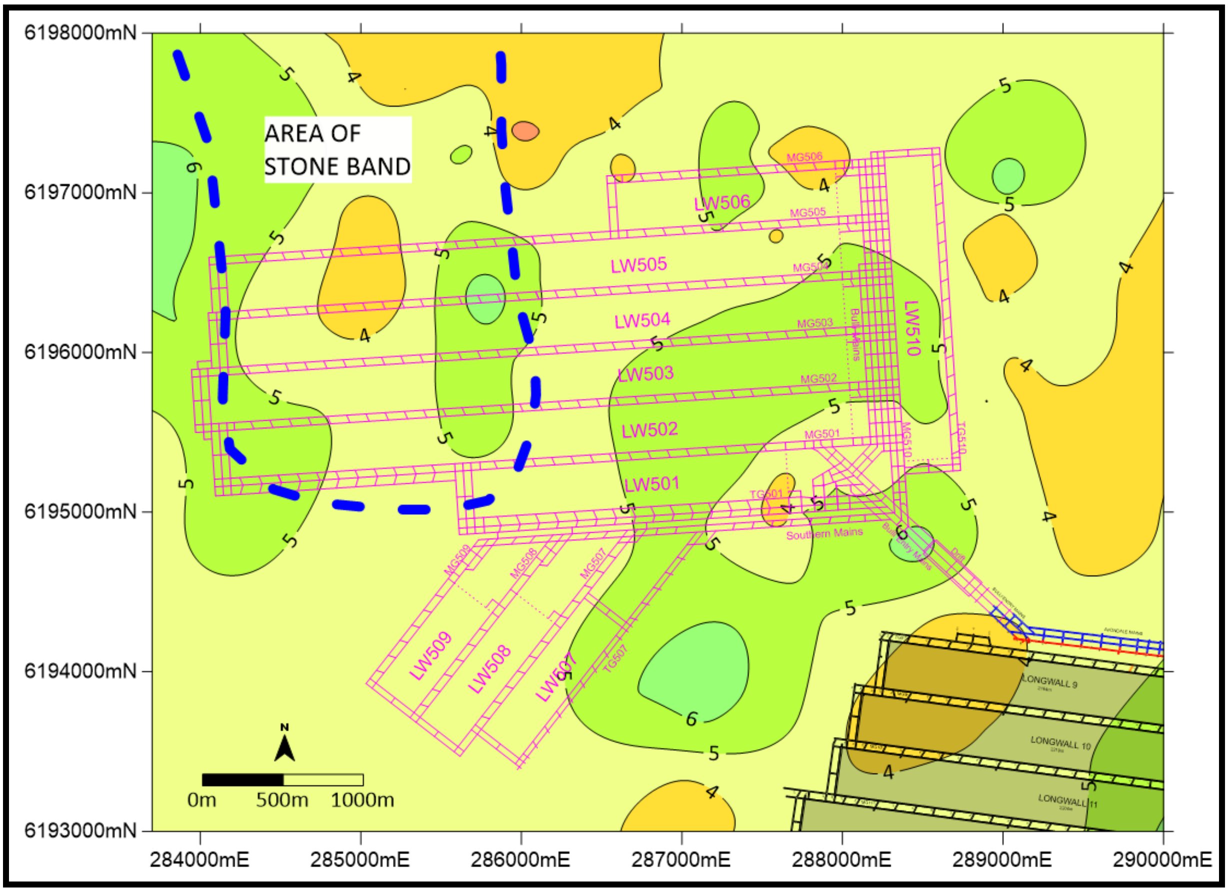

Figure 47. Floor Strength Index for the 0-0.5 m Immediate Floor Interval.

3.10.6 Coal Strength

There are a number of tools available to estimate coal strength including sonic velocity, geotechnical testing and back analysis of underground conditions. Where longwalling is proposed in Area 5, the average sonic velocities of the Bulli Seam are typically between 2450-2500 m/s (**Figure 48**).

Using the UCS/Sonic Velocity relationship presented in Seedsman et al (2009)[6] of:

$$UCS = 0.07 * \text{Sonic Velocity (m/s)} - 148.57$$

[6] Seedsman, R.W., Gordon, N. and Aziz, N (2009). Analytical Tools for Managing Rock Fall Hazards in Australian Coal Mine Roadways. ACARP Project C14029.

a laboratory strength range for the Bulli Seam of 23-26.4 MPa is indicated.

This is comparable to the 28.9 MPa quoted for the Bulli Seam by Seedsman et al (2009). It should be highlighted that these are laboratory strength values. The rock mass strength values would be lower due to the presence of cleats.

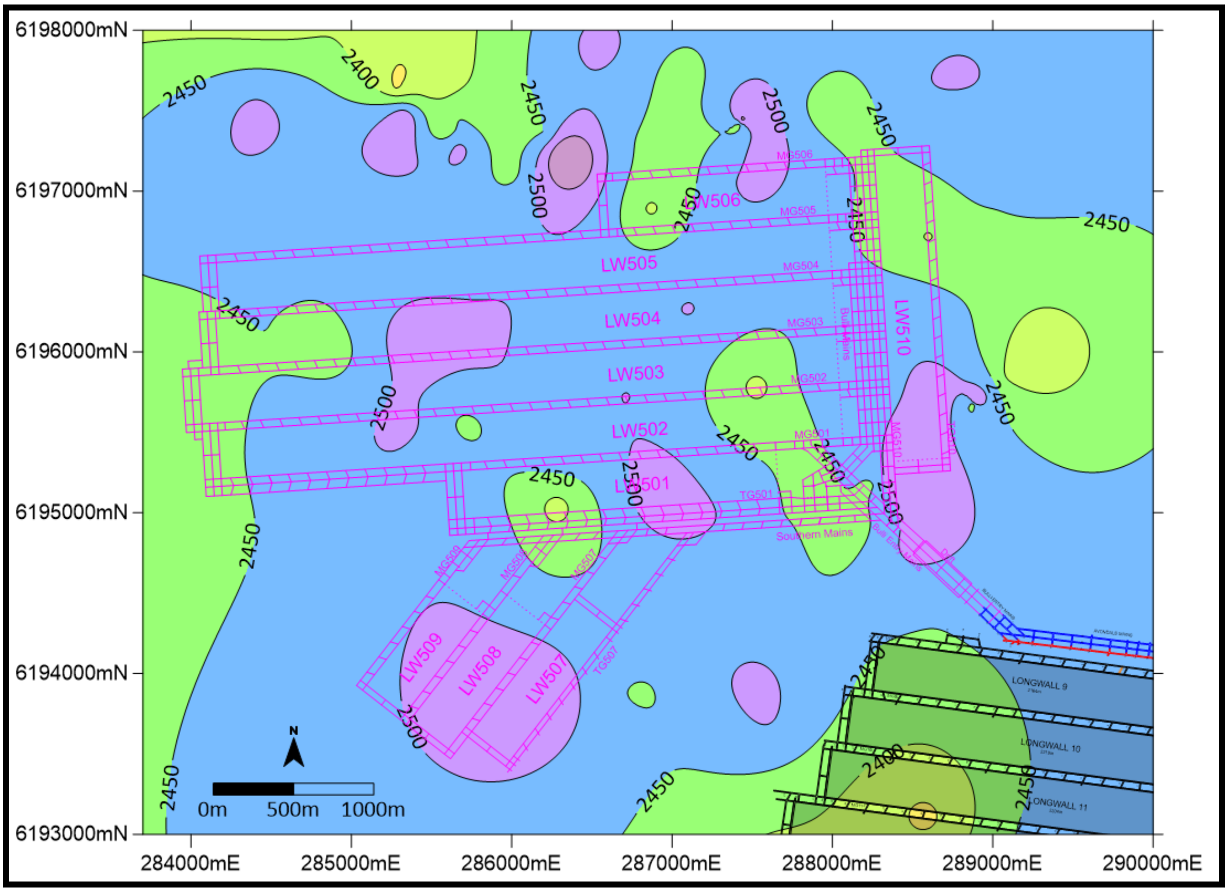

Figure 48. Average Sonic Velocity of the Bulli Seam (m/s).

3.10.7 Vshale

The Vshale ratio is used to provide an indication of the lithological composition of the strata around coal seams. This ratio is calculated from the geophysical gamma logs as follows:

$$(\gamma_{avg}-\gamma_{sand})/(\gamma_{clay}-\gamma_{sand})$$

Where: γ_{avg} = average gamma value
γ_{sand} = sandstone gamma value
γ_{clay} = claystone gamma value

Based on cross plots of the gamma and density logs, representative gamma values for sand and clay in the Narrabeen Group above the Bulli Seam in Area 5 are 40 and 220 respectively (**Figure 49**). This increases to 100 and 320 for the floor below the Bulli Seam (**Figure 50**). The Vshale ratio ranges from 0 for sandstone, up to 1 for claystone.

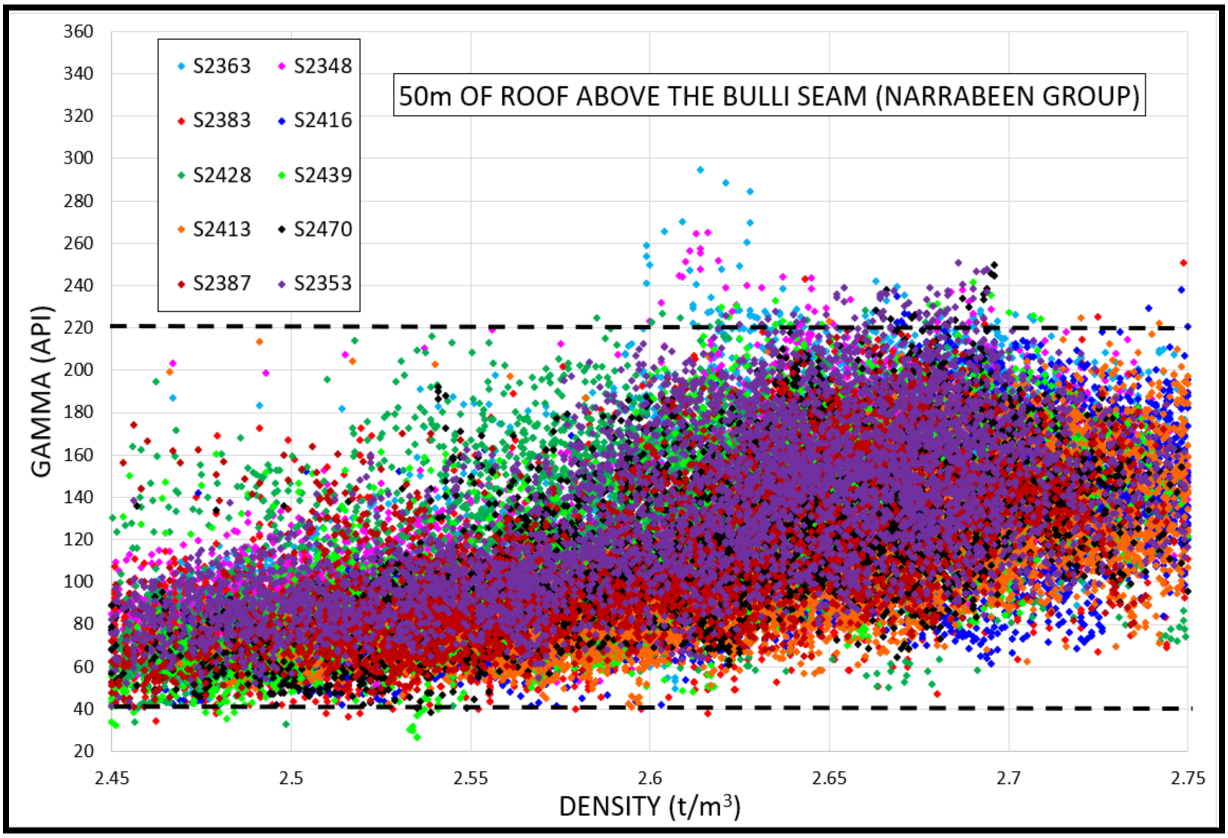

Figure 49. Gamma and Density Cross Plot – 50 m of Roof above the Bulli Seam (Narrabeen Group).

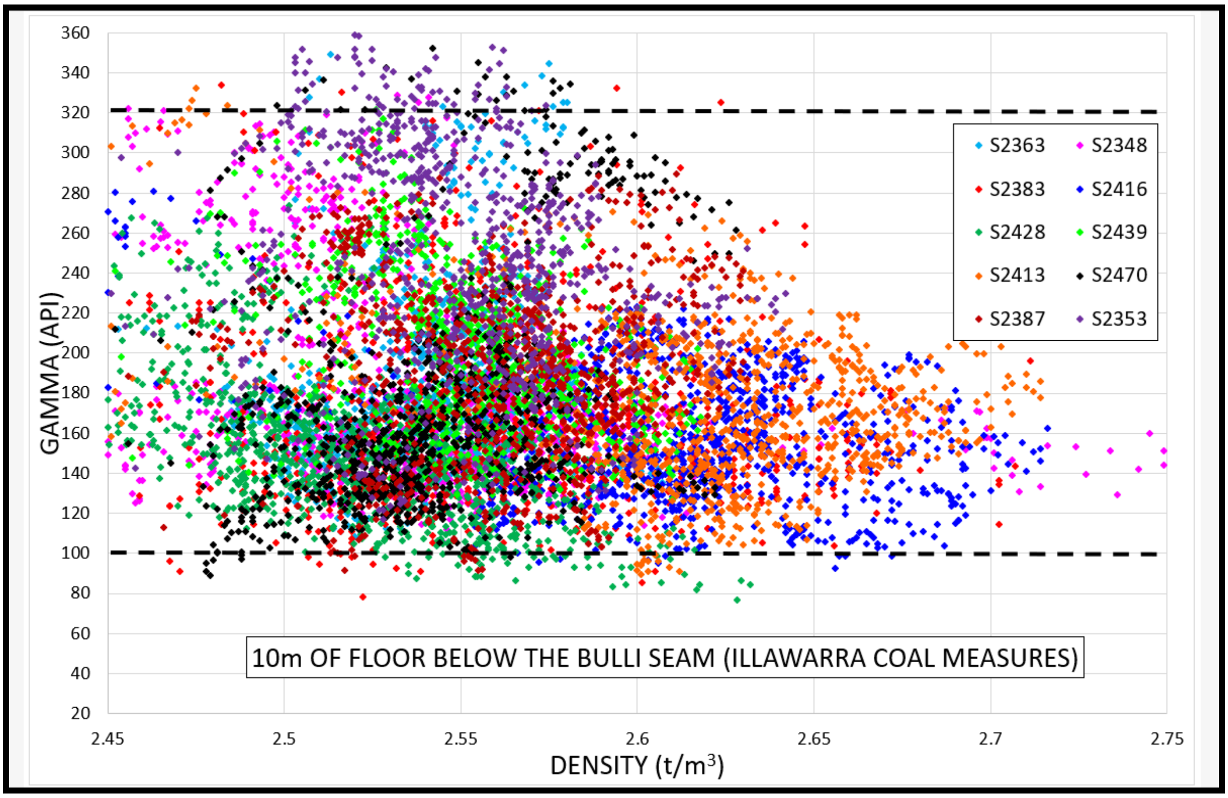

Figure 50. Gamma and Density Cross Plot – 10 m of Floor below the Bulli Seam (Illawarra Coal Measures).

The location of the holes used to calibrate the Vshale values are shown in **Figure 51**.

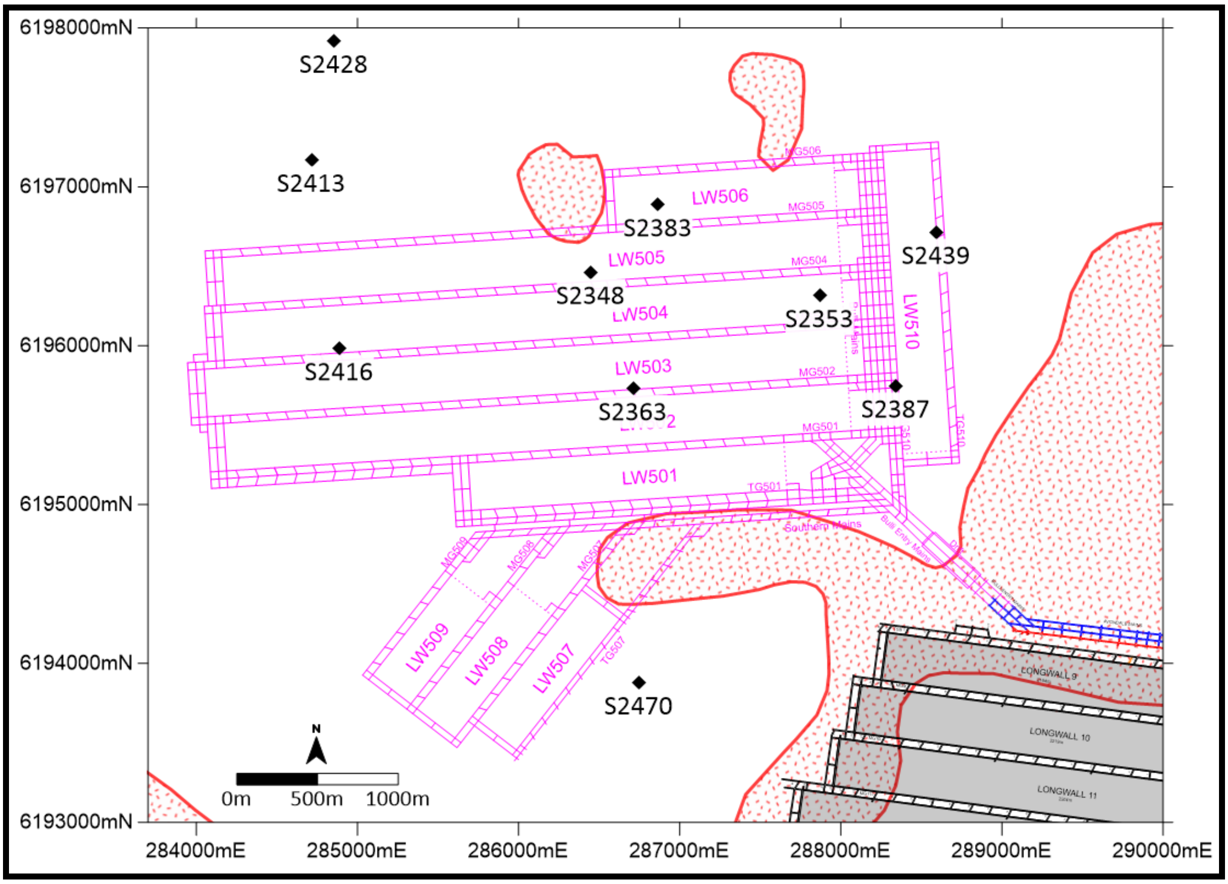

Figure 51. Location of Calibration Holes for the Vshale Analysis.

3.10.7.1 Stone Roof

The average Vshale ratios of typically >0.6 for the immediate 0-0.5 m and 0-2 m of stone roof respectively are consistent with the laminated nature of the immediate roof (**Figure 52 and Figure 53**). Lower ratios are indicated in the pit bottom area at the top of drifts, where higher strength roof is indicated.

The laminated characteristics continue into the 2-6 m horizon as well, with typical Vshale ratios of 0.6-0.7, indicating a significant proportion of finer grained mudstone/siltstone layers (**Figure 54**). Where the sandstone is closer to the Bulli Seam in the northern-central part of the area, lower Vshale ratios are evident as expected in this horizon (**Figure 54**).

Bullseyes in the Vshale data may also be related to silling.

As anticipated by the dominant sandstone lithology above the laminite, the 50 m of overburden is characterised by lower Vshale ratios (**Figure 55**). Similar to the average roof strength, the thicker sandstone unit in the central part of the area is not apparent on the Vshale 50 m overburden plot (**Figure 55**).

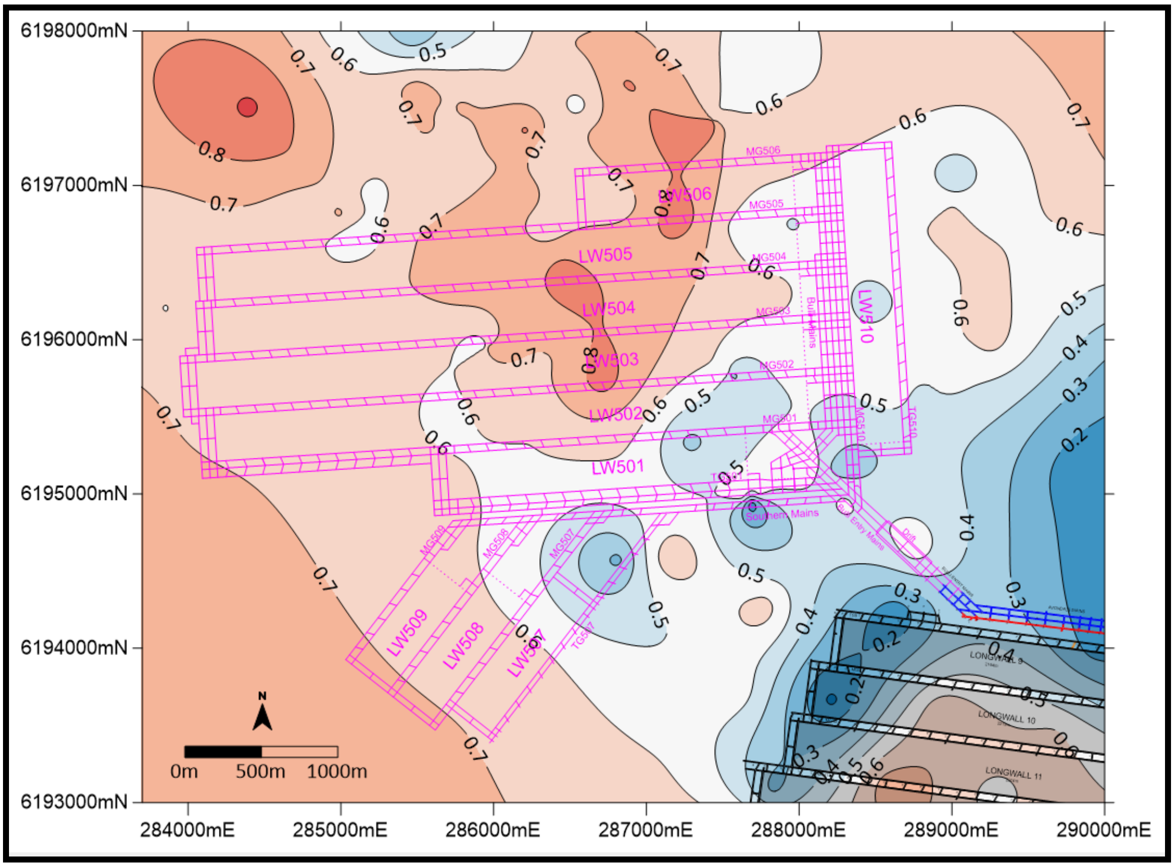

Figure 52. Vshale Ratio for the 0-0.5 m Immediate Roof Interval.

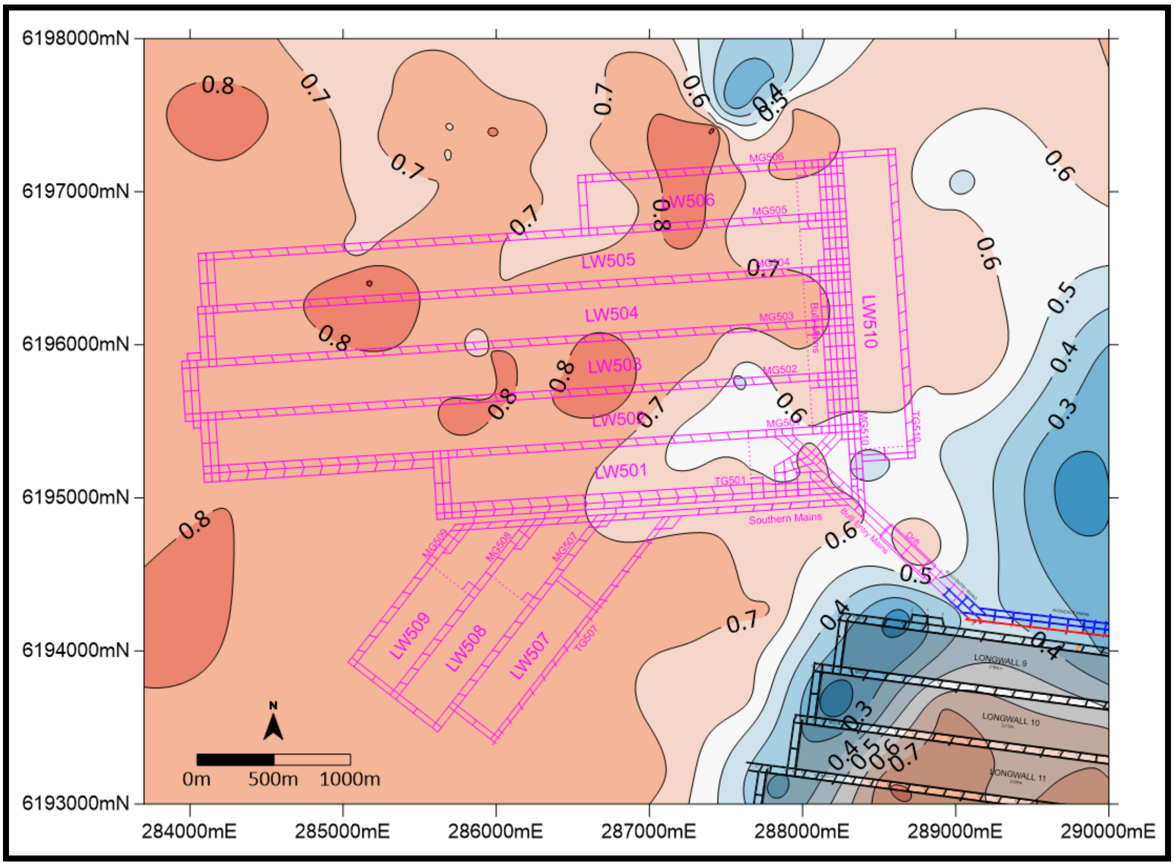

Figure 53. Vshale Ratio for the 0-2 m Immediate Roof Interval.

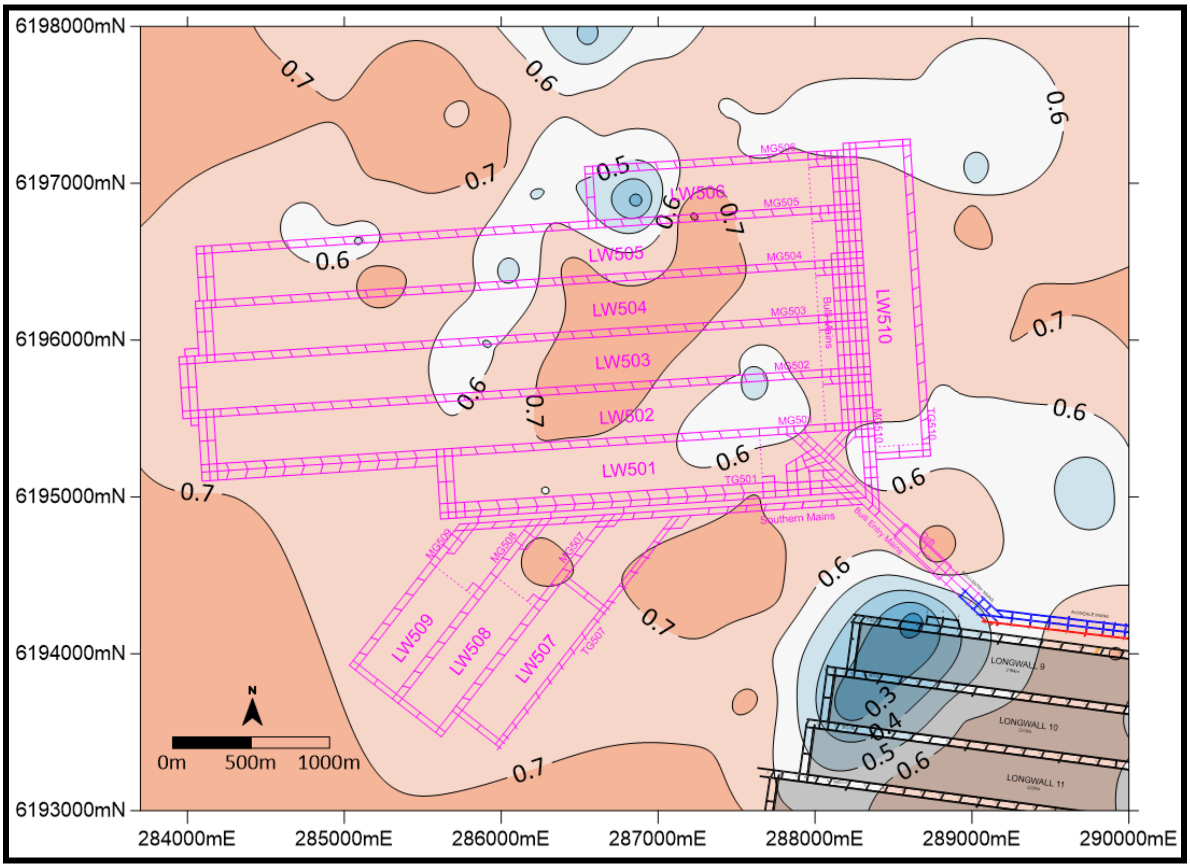

Figure 54. Vshale Ratio for the 2-6 m Immediate Roof Interval.

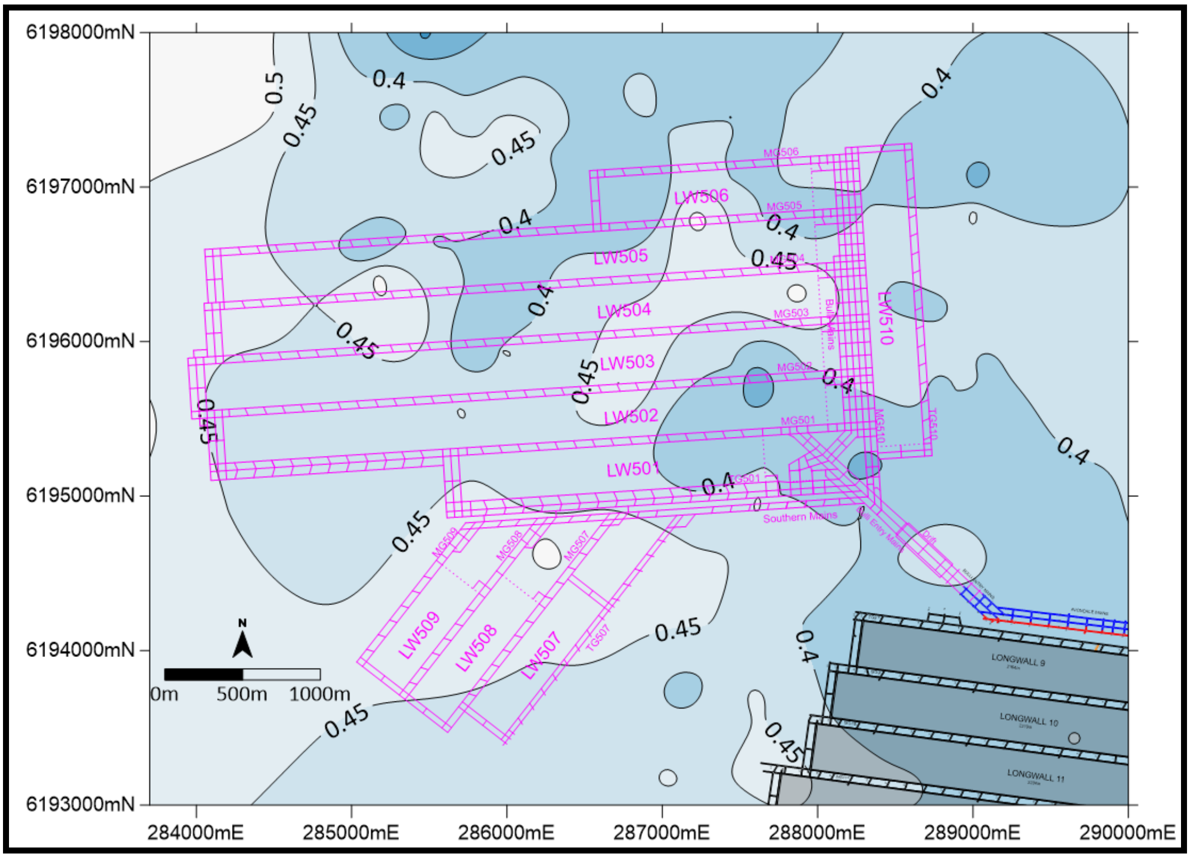

Figure 55. Vshale Ratio for the 0-50 m Overburden Interval.

3.10.7.2 Stone Floor

The Vshale ratios for the immediate stone floor below the Bulli Seam clearly show the increase in dominantly shale/mudstone strata where the basal ply splits away (**Figure 56**).

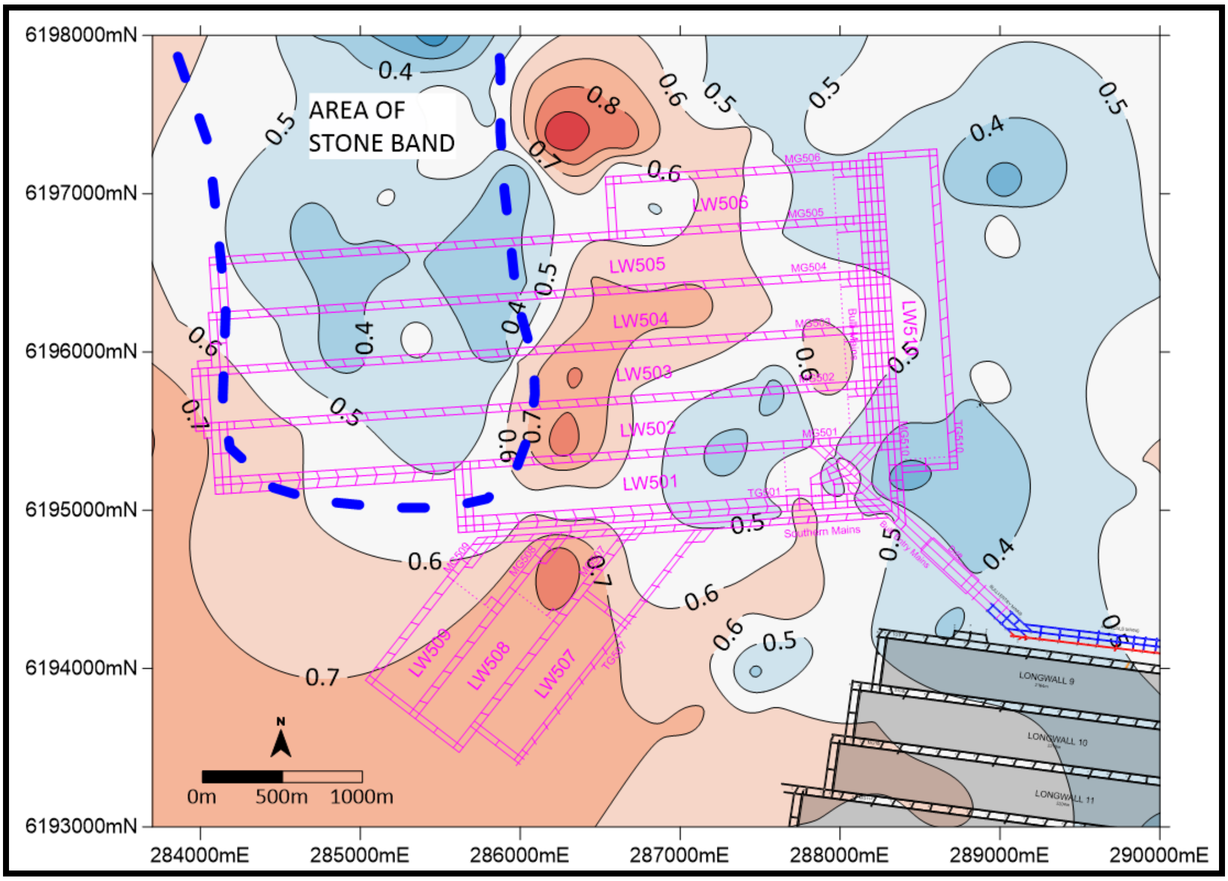

Figure 56. Vshale Ratio for the 0-0.5 m Immediate Floor Interval.

4 GEOLOGICAL FEATURES

4.1 Structures

As shown in **Figure 57,** a range of geological features, including faults, dykes and sills have been predicted in the Bulli Seam in this area. Boreholes with distinct fracture zones, potentially indicative of faulting or intrusive activity, are also shown on this figure (**Figure 57**).

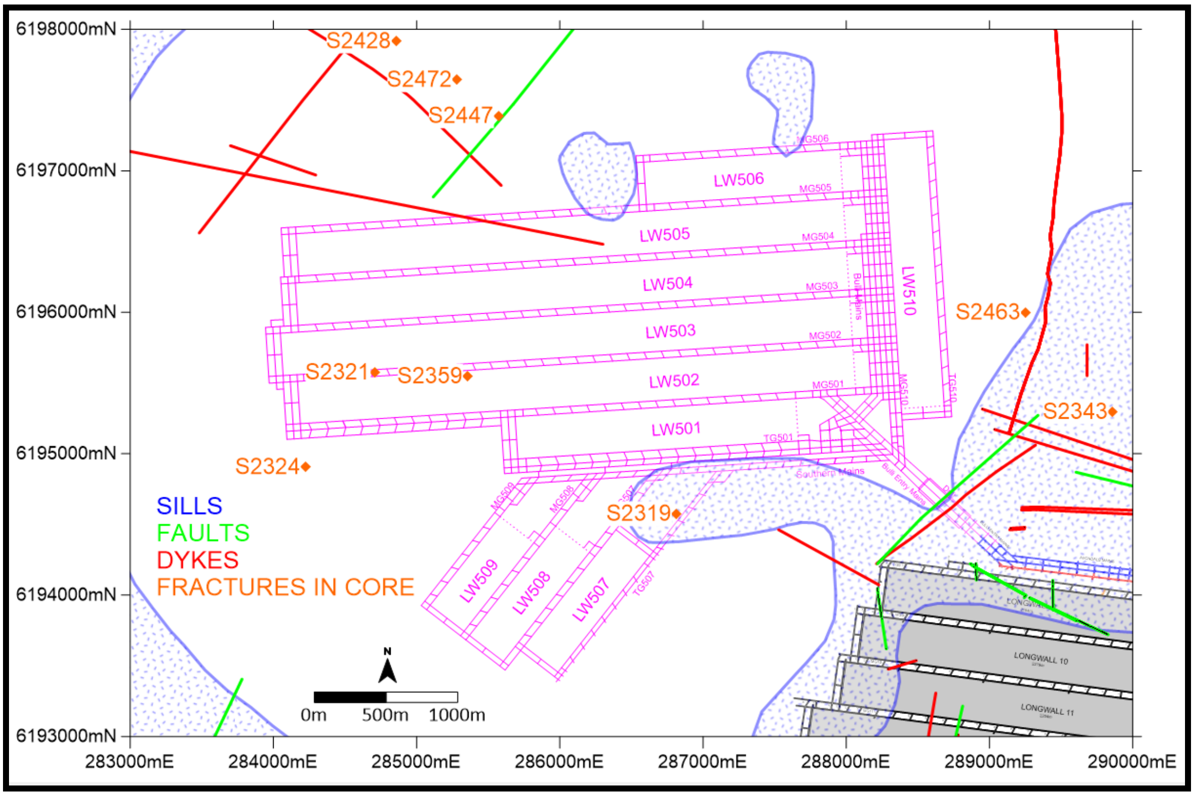

Figure 57. Summary of Geological Features in the Bulli Seam.

4.1.1 Dykes

Dykes have been encountered in the Dendrobium Mine area. The trend of these dykes is dominantly WNW/ESE (**Figure 58**). There is a secondary NE/SW set and a less dominant north/south trend as well (**Figure 58**).

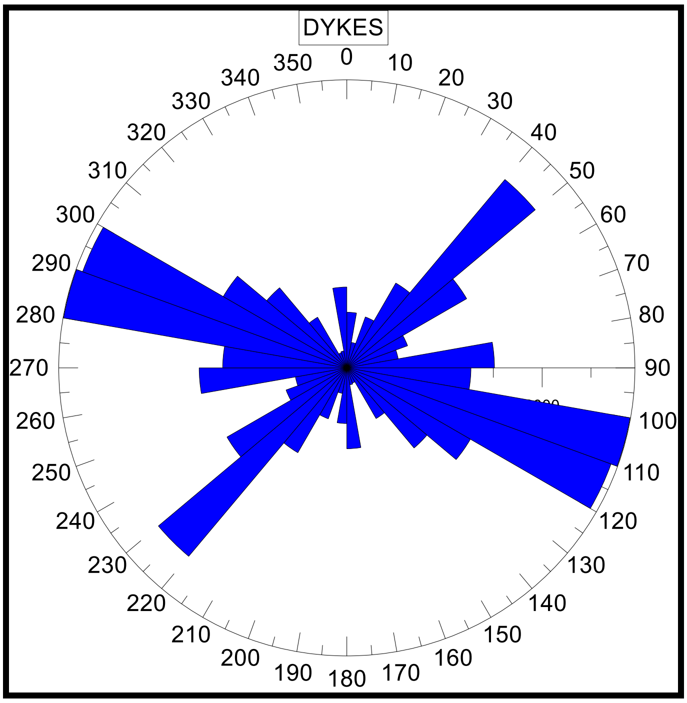

Figure 58. Strike of the Dykes in the Dendrobium Mine Area.

4.1.2 Faults

Normal, reverse and strike slip faults have been intersected in the Wongawilli Seam workings at Dendrobium Mine. Regional trends indicate a dominant WNW/ESE to NW/SE trend and less dominant N/S to NE/SW trends for the faulting in this area (**Figure 59**).

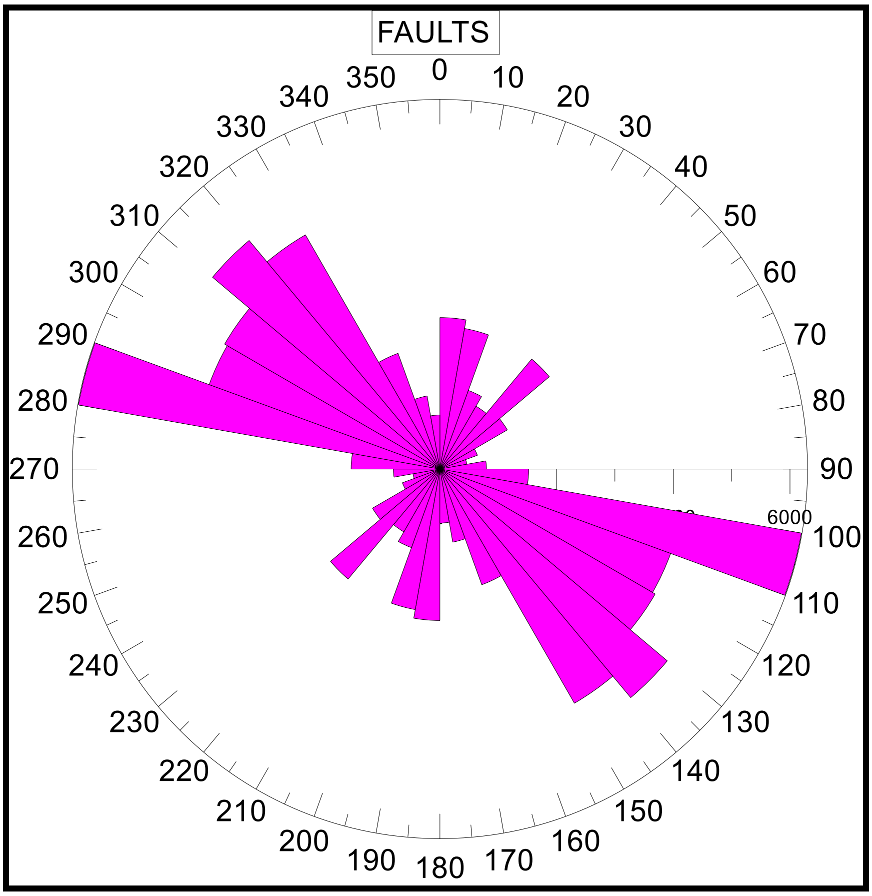

Figure 59. Strike of the Faults in the Dendrobium Area.

The core photography in Area 5 was also reviewed to identify potential faulting indicated by fracturing of the core samples (**Figure 57**). A summary of the zones identified is included in **Table 4**. Photographic examples of the zones identified are shown in **Figure 60**.

It is recommended that these observations are considered, prior to finalising the geological model in Area 5. In particular, fracturing was evident in two boreholes at the inbye end of LW502 (**Figure 57**).

HOLE	LOCATION	PANEL NAME	COMMENT
S2319	18.47-42.02 m above the Bulli Seam	Outbye end of LW507	Mid-angled shear fractures (**Figure 60**).
S2321	46.99-47.69 m above the Bulli Seam	Inbye end of LW502	Mid-angled shear fractures (**Figure 60**).
S2324	1.72-2.42 m above the Bulli Seam	South of LW502	Two 60º shear fractures.
S2343	19.33-20.33 m above the Bulli Seam	East of LW510	Mid-angled shear fractures.
S2359	1.2-5 m below Bulli Seam	Inbye end of LW502	Mid-angled shear fractures.
S2428	0.15-1.55 m and 7.55-9.45 m above the Bulli Seam	North of LW505	Zones of shear fractures with calcite infilling (**Figure 60**).
S2447	0.8-2.7 m above the Bulli Seam	North of LW505	Increased level of fracturing.
S2463	Immediate roof and floor of Bulli Seam	East of LW510	Microfaults (**Figure 60**).
S2472	Most prominent at 44.5-47.5 m and 51-53 m above the Bulli Seam. Other less distinct zones within the 150 m of Bulli Seam overburden.	North of LW505	Zones of shear fractures (**Figure 60**).

Table 4. Summary of Fracturing Identified in the Exploration Boreholes.

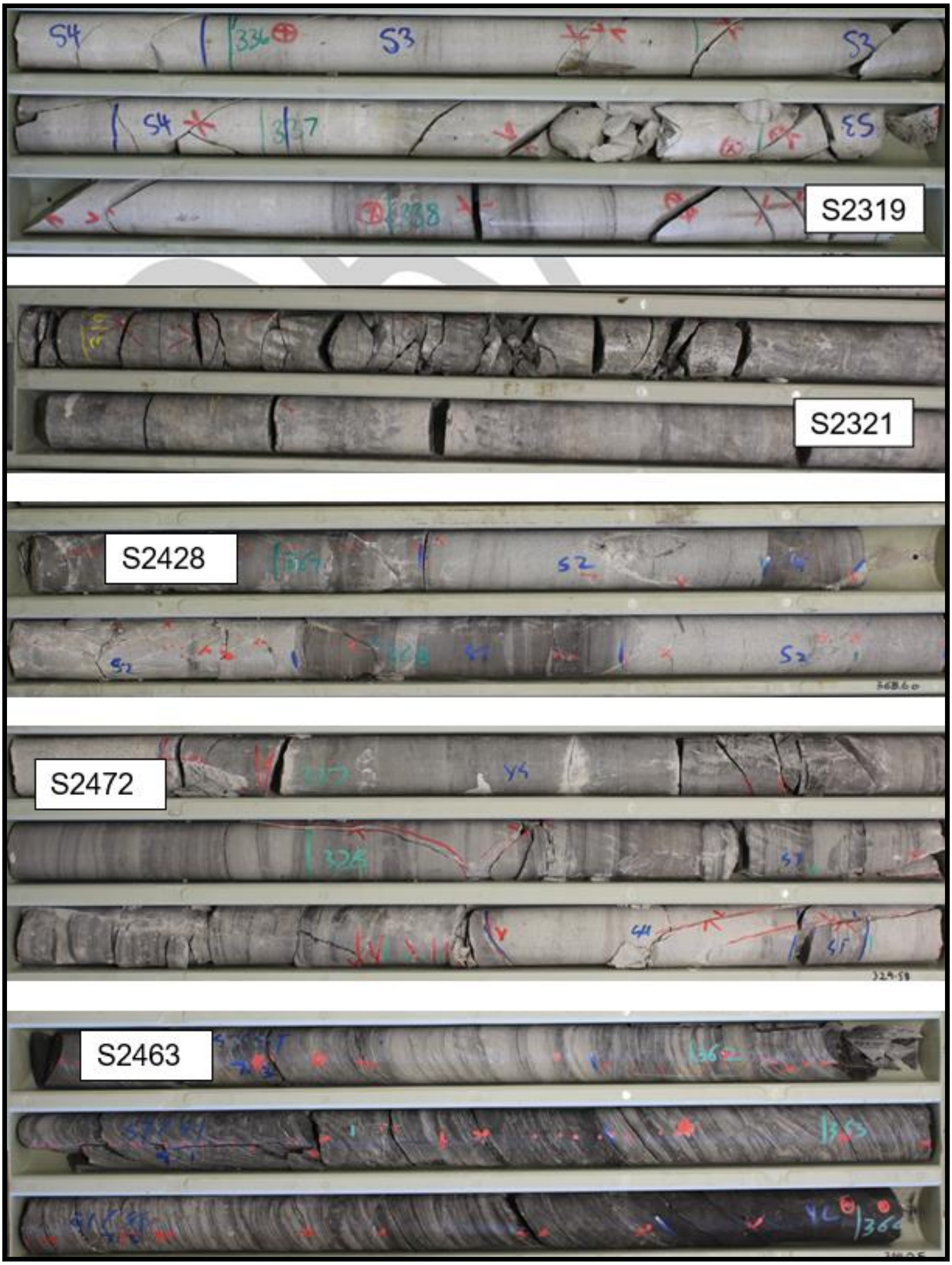

Figure 60. Fracturing in Core Samples.

4.1.3 Geological Features in Core Samples

As well as the fracturing, a range of geological features have been observed in the core samples drilled in the exploration boreholes in the proposed underground area including joints, micro-faults, intrusions and bedding (**Figure 61**).

Figure 61. Examples of Geological Features Observed in the Core Samples.

4.1.4 Sills

The Dendrobium lease area is characterised by silling throughout the coal measure sequence. In particular, igneous material and associated heat affected Bulli Seam coal has been identified in a number of holes in Area 5 (**Figure 62 and Figure 63**).

The characteristics of the silling in southern and eastern part of the area, compared to the northern sills is detailed in the following sections.

The cumulative thickness of igneous material in the sedimentary sequence increases towards the NE and NW of Area 5 (**Figure 64**).

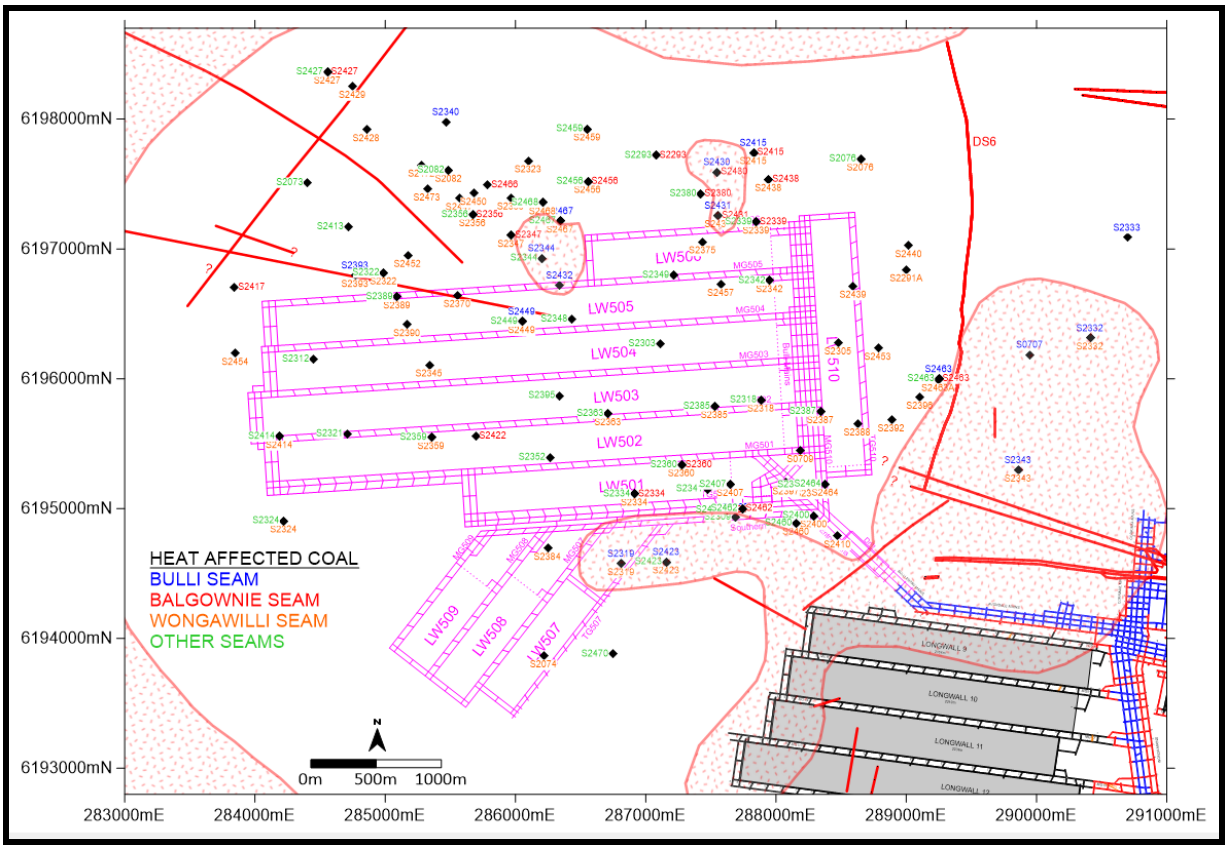

Figure 62. Heat Affected Coal.

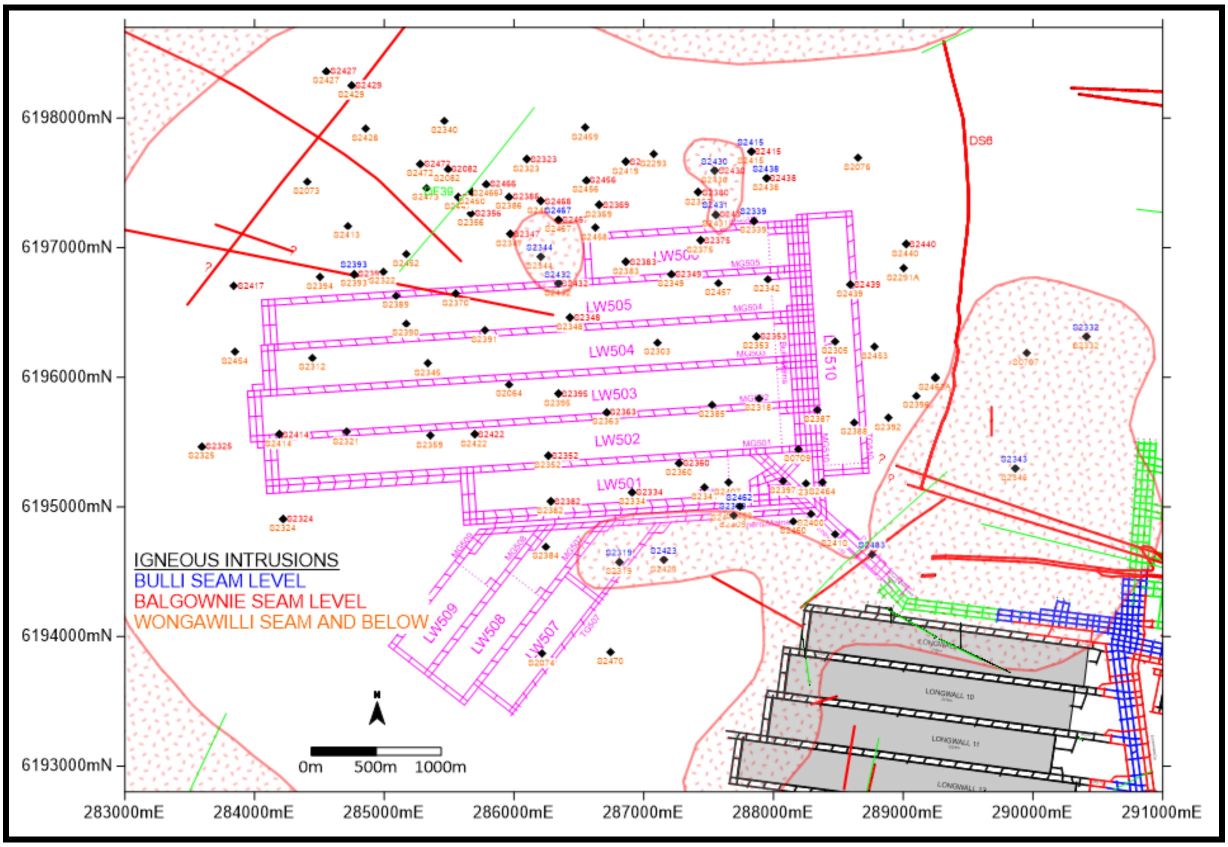

Figure 63. Igneous Intrusions.

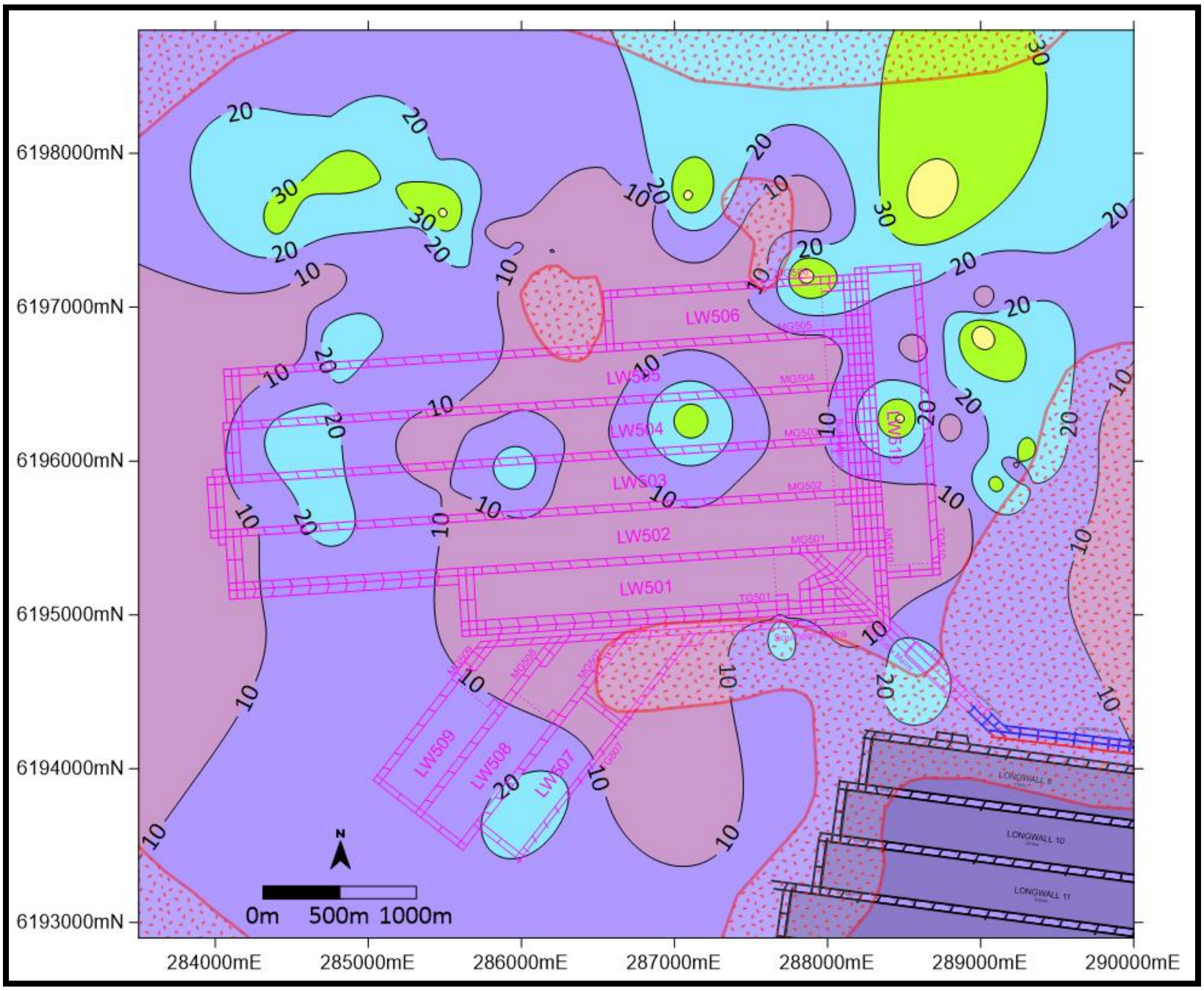

Figure 64. Cumulative Thickness of Igneous Intrusions.

4.1.4.1 Silling in the Southern and Eastern Part of the Area

In borehole S2309, located at the outbye end of TG501, the silling in the Bulli Seam immediate roof is >2 m thick and has affected the majority of the seam (**Figure 65**). There is also a thin, low strength intrusion in the floor below the Bulli Seam in this borehole (**Figure 65**).

In comparison, in borehole S2462, approximately 90 m to the north-east of S2309 the impact of silling has diminished rapidly with the intrusion in the roof reduced to 5 cm thick.

The sill material in this southern part of the area is also variable in strength. Sonic velocities for the sill material around the Bulli Seam between Longwalls 501 and 507 are typically <3000 m/s (<30 MPa), with occasional stronger, thinner layers >5000 m/s (>150 MPa) (**Figure 65**). Conversely, in the main part of the sill to the east, high sonic velocities of 5000 to >6000 m/s (>340 MPa) are evident (**Figure 66**).

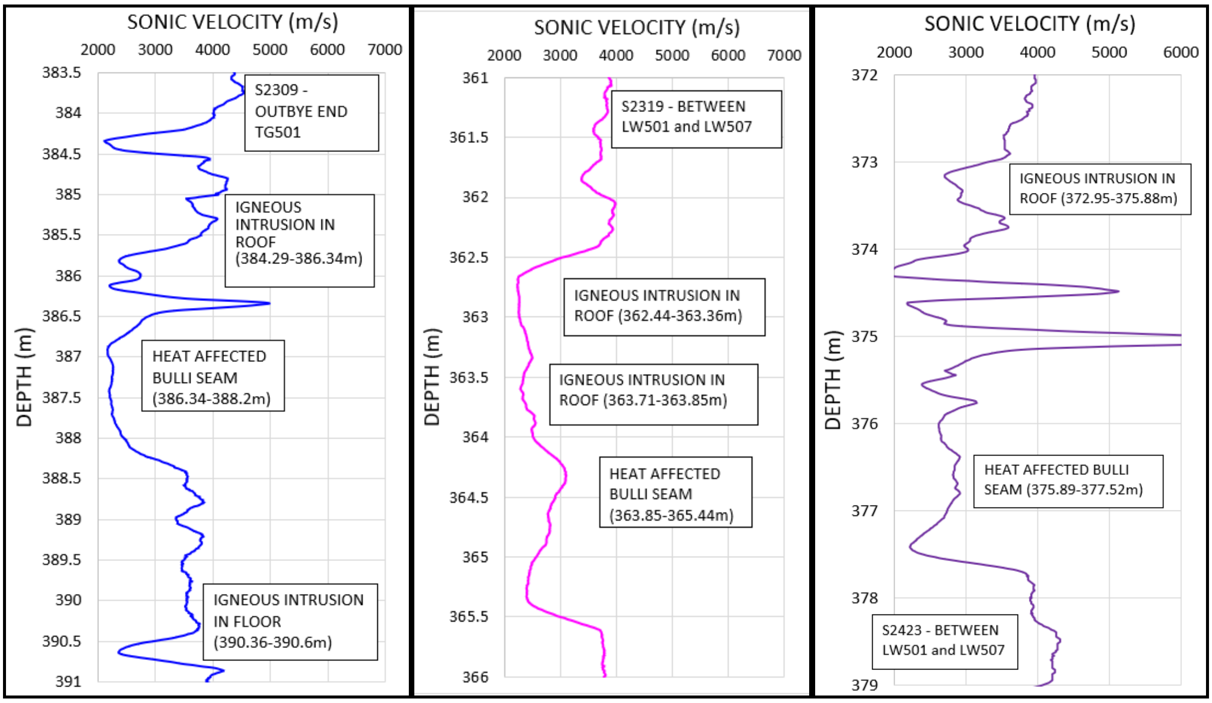

Figure 65. Sonic Velocity Logs of Igneous Intrusions near the Bulli Seam – Between LW501 and LW507.

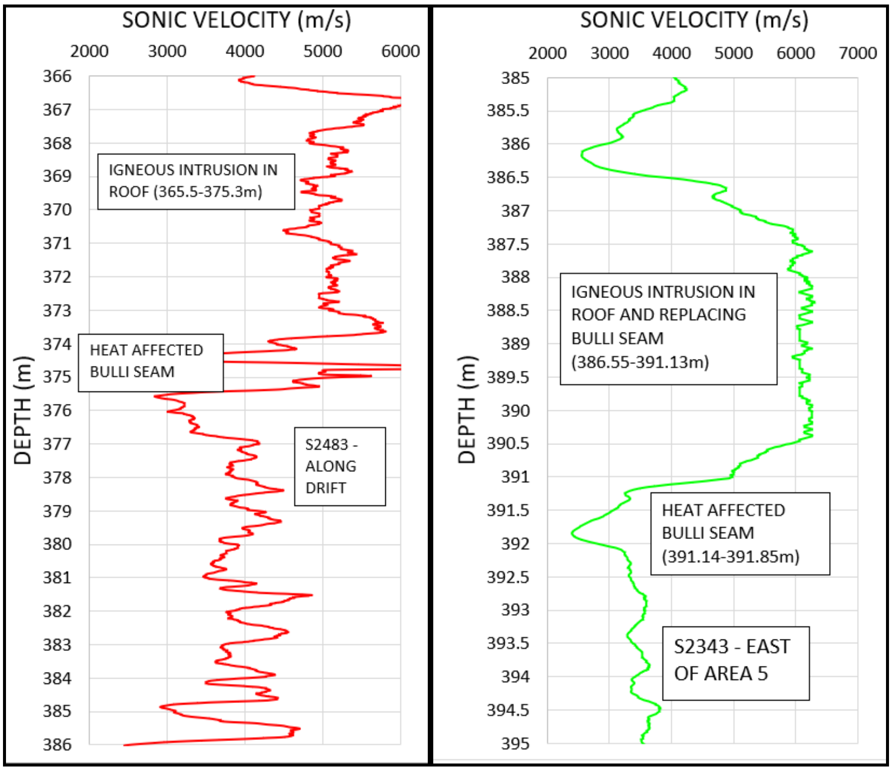

Figure 66. Sonic Velocity Logs of Igneous Intrusions near the Bulli Seam – Eastern Part of the Area.

This variability in the characteristics of the silling is evident in the results of the detailed drilling along the access drifts using four angled holes and one vertical hole (S2483-S2483D). For example, the 9.8 m thick sill in the roof of the Bulli Seam in borehole S2483 continues into S2483B, 60 m away but is absent in S2483A a further

30 m along the drift alignment (**Figure 67 and Figure 68**). The Bulli Seam Sill was also intersected in S2483D but was not encountered in S2483C (**Figure 69**).

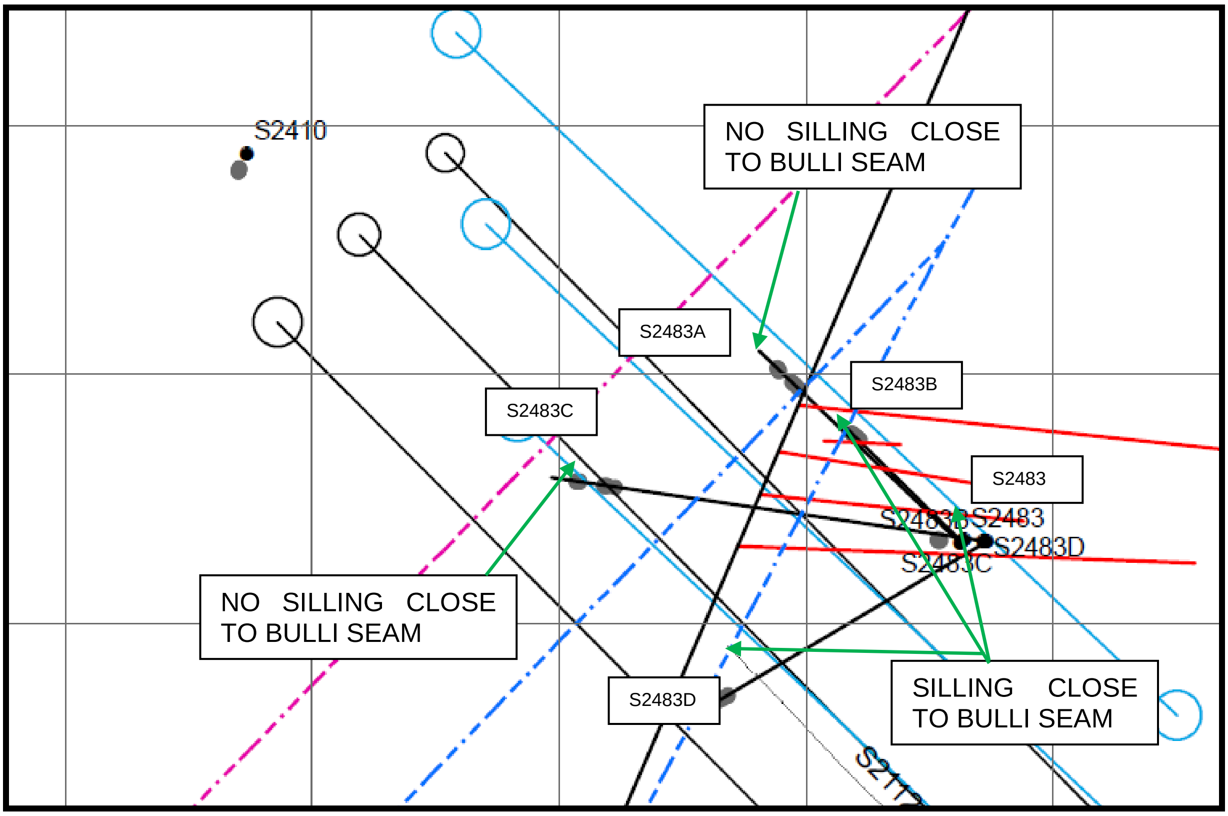

Figure 67. Location of Drift Holes.

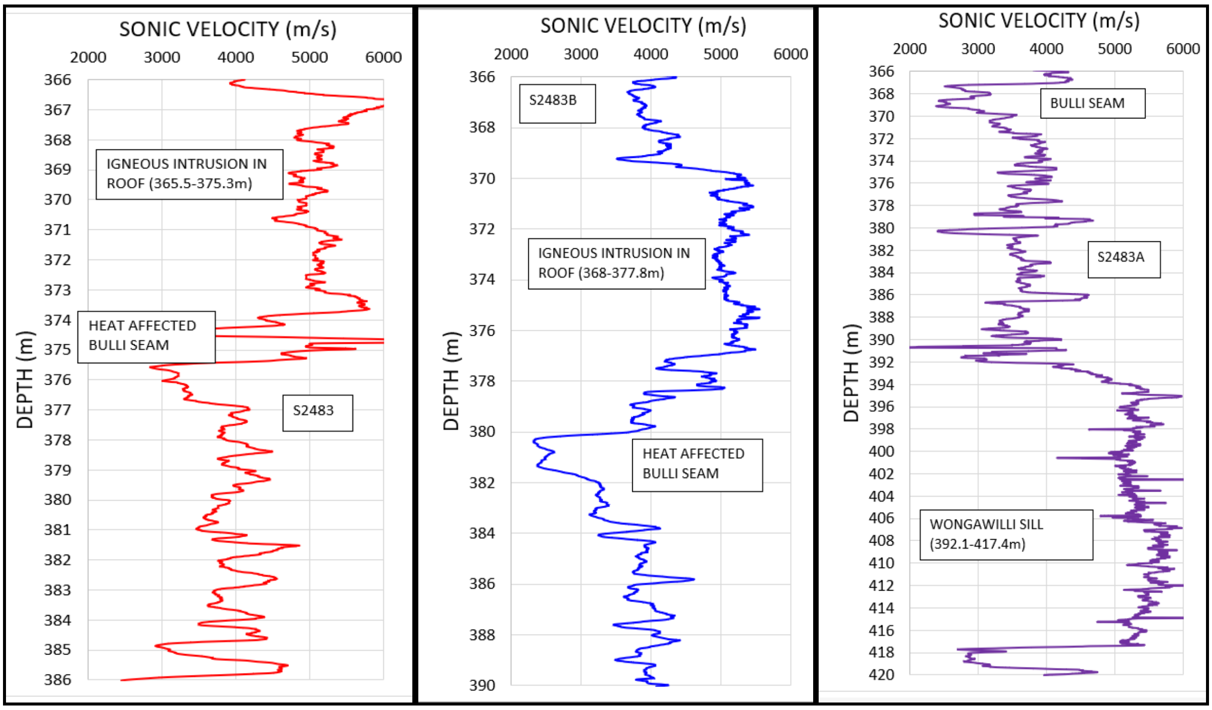

Figure 68. Sonic Velocity Logs of the Drift Holes North of C Heading.

At the top of the drifts, silling was not encountered in the roof and floor of the Bulli Seam in borehole S2410, indicating a corridor in this area for access to the Bulli Seam.

The Wongawilli Seam sill also occurs in this area and was encountered in holes S2410, S2483A and S2483C but not S2483, S2483B and S2483D, indicating that the outbye drift drivage should be located to avoid this very hard sill material (**Figure 68 and Figure 69**). This is to be confirmed with in seam drilling prior to determining the final start position of the drifts (**Figure 70**).

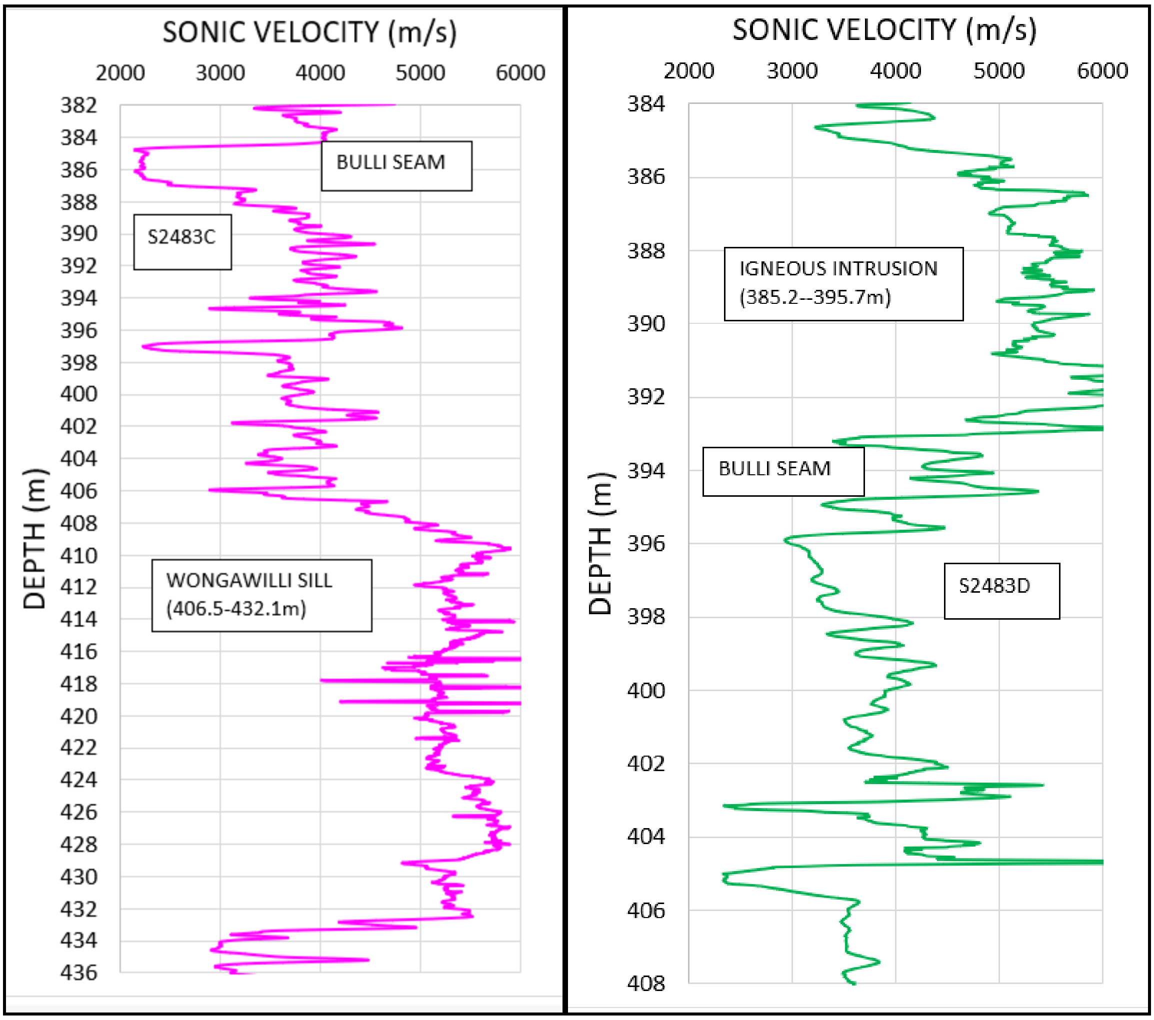

Figure 69. Sonic Velocity Logs of the Drift Holes near A and B Headings.

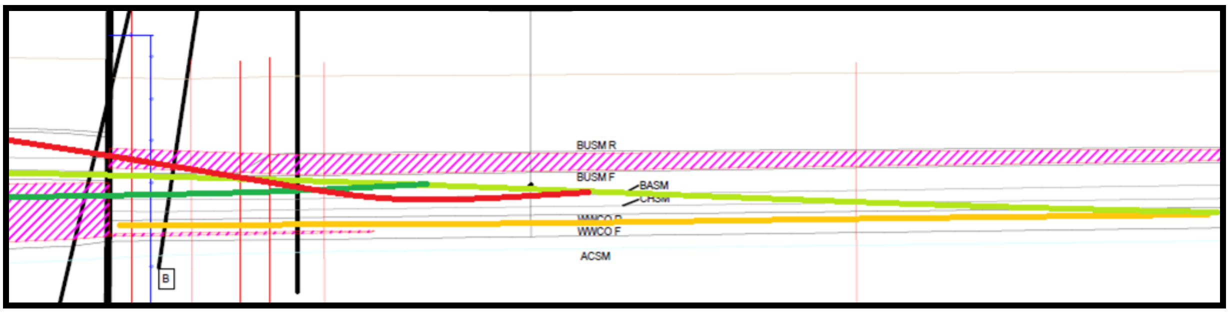

Figure 70. Proposed In-Seam Drilling along the Drifts.

4.1.4.2 Silling in the Northern Part of the Area

The two sills interpreted in the northern part of Area 5 have restricted longwall extraction and shortened LW506 (**Figure 63**).

The intrusion at the inbye end of LW506 appears to be thickest and strongest adjacent to MG505 (**Figure 71**). Towards the north the thickness of this sill intruding the Bulli Seam thins and decreases in strength. The full extent of this silling would be exposed by development drivage and the optimum location for the Longwall 506 install road in this area can then be assessed.

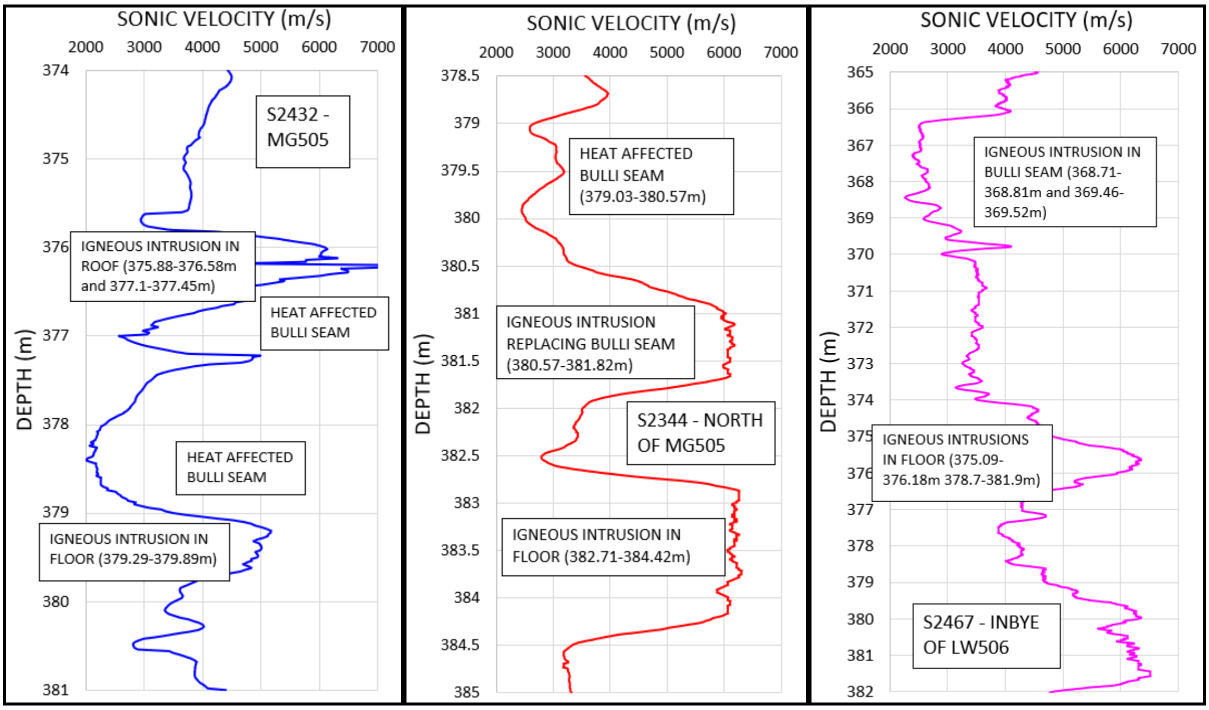

Figure 71. Sonic Velocity Logs of Igneous Intrusion near the Bulli Seam – Longwalls 505 and 506.

The sill north of LW506 appears to be thinner and weaker adjacent to MG506 (**Figure 72**). In this area, the silling is mostly confined to the roof of the Bulli Seam and thins and weakens southwards (**Figure 72**). A hard 0.63 m thick intrusion was also encountered in borehole S2430 immediately below the Bulli Seam (**Figure 72**).

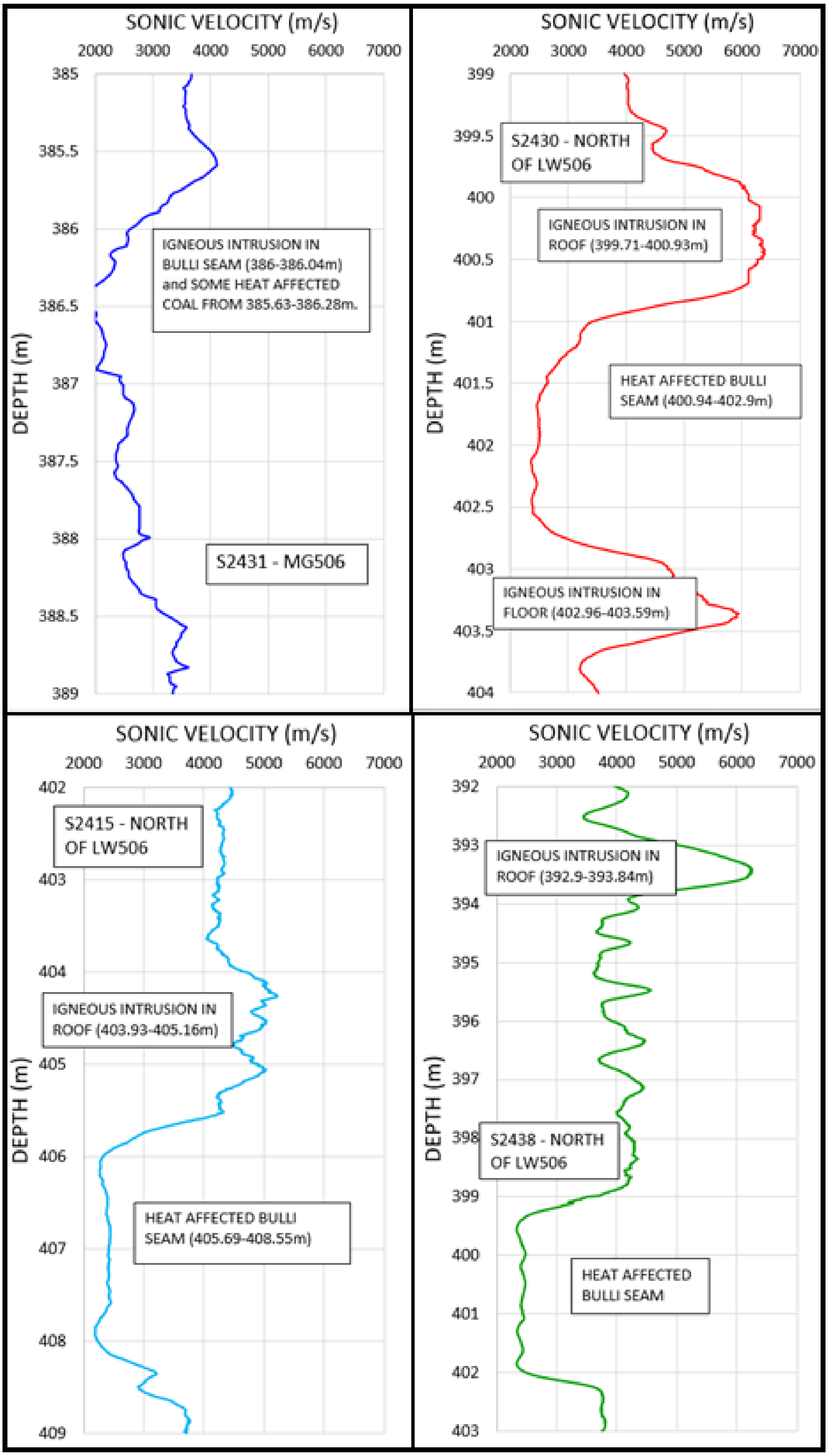

Figure 72. Sonic Velocity Logs of Igneous Intrusion near the Bulli Seam – Outbye End of Longwalls 507 and 508.

There is also evidence of igneous activity around borehole S2393 north of the inbye end of LW505 (**Figure 73**).

Intrusive material was intersected in this borehole in the roof, floor and in the Bulli Seam, however nothing was intersected at seam level in the wedge borehole S2393W, suggesting a dyke feature (**Figure 62**). Where this dyke is encountered within the Bulli Seam, relatively low strengths of 30 MPa (sonic velocity of 3000 m/s) are indicated (**Figure 62**).

Minor heat affected ply of Bulli Coal in borehole S2449 also provides evidence for the continuation of this dyke into LW505 (**Figure 62**).

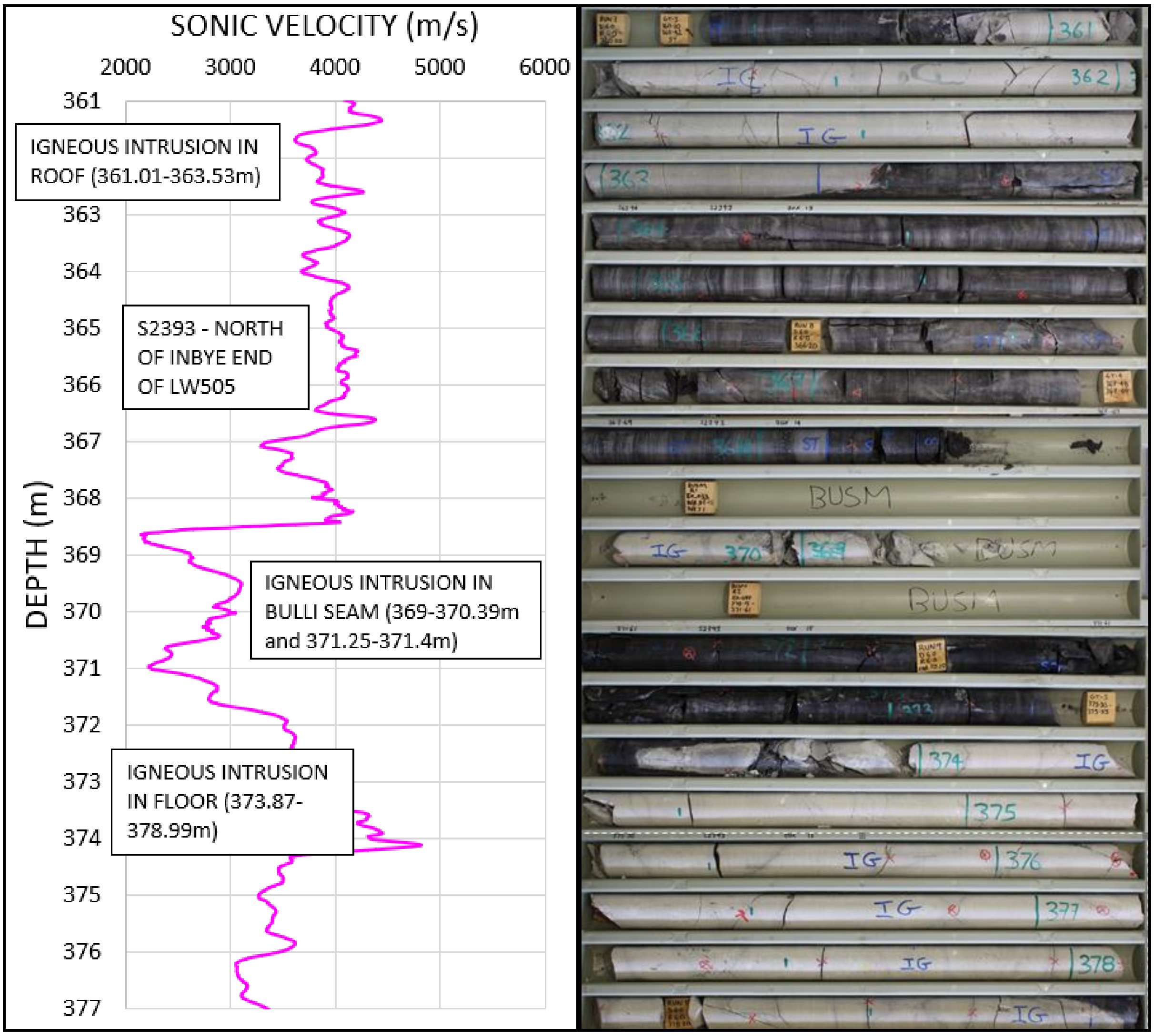

Figure 73. Sonic Velocity Log and Core Photography of Igneous Activity – Borehole S2393, North of Inbye End of LW505.

Further north, there may also be intrusive activity due to evidence of heat affected coal recovered in borehole S2340 (**Figure 62**).

In the eastern part of the area, heat affected Bulli Seam coal in borehole S2463, east of LW510, indicates the close proximity of the Bulli Sill (**Figure 62**).

4.1.4.3 Underlying Intrusions

The intrusions further down the sedimentary sequence below the Bulli Seam, including the Wongawilli Seam sill appear to be typically hard, with sonic velocities >5000 m/s, indicating strengths >150 MPa (**Figure 39 and Figure 74**).

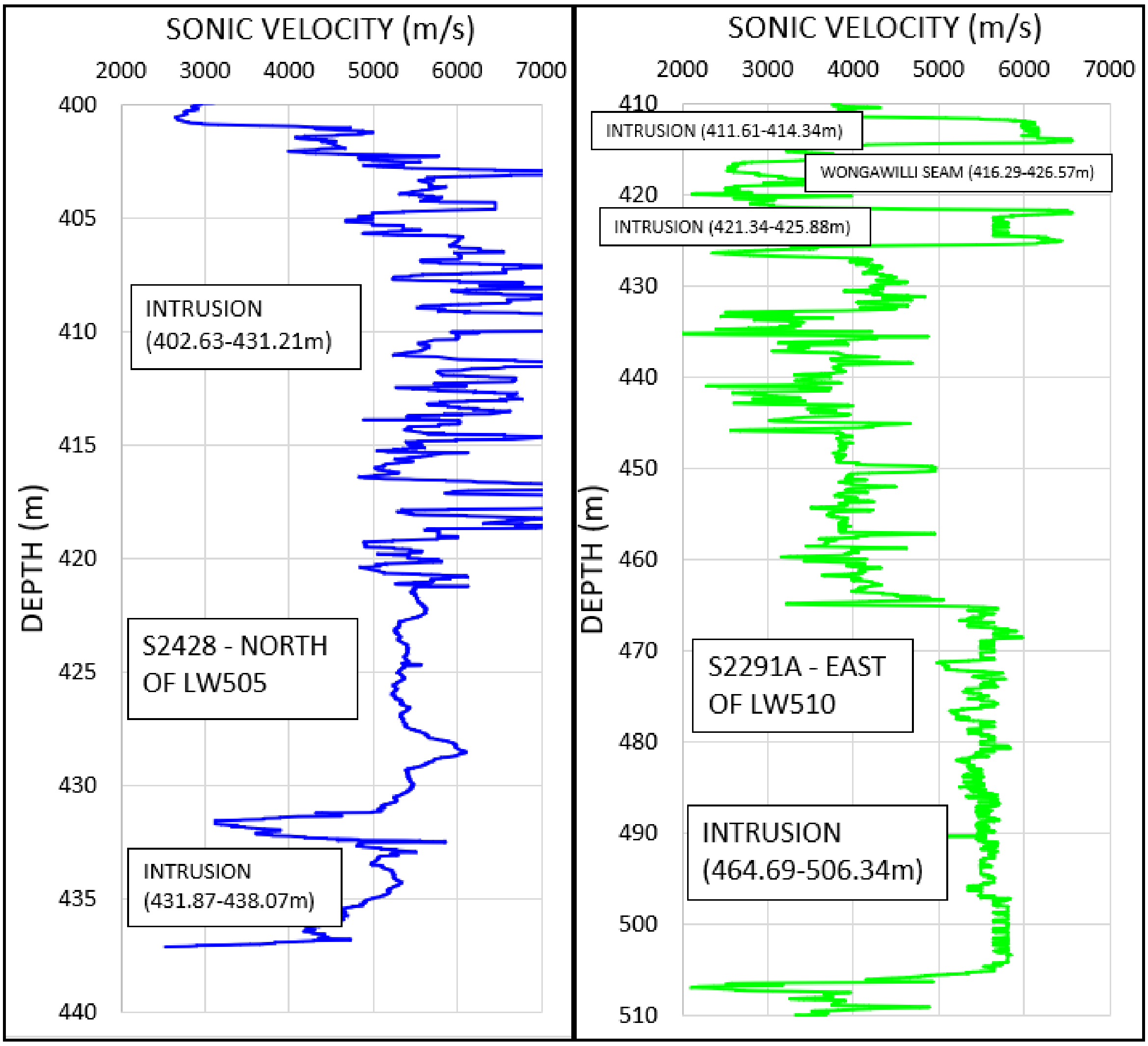

Figure 74. Sonic Velocity Logs of Igneous Intrusions below the Bulli Seam.

4.2 Acoustic Scanner Analysis

The analysis of the acoustic scanner borehole data has been completed, by both Strata Control Technology (SCT) and ASIMS, on a number of holes in Area 5 (**Figure 75**). Both consultancies processed the scanner file from borehole S2305 over Longwall 510 (**Figure 75**).

More recently, the scanner holes have been processed in house by South32 technical personnel (**Figure 75**). It is noted that several scanner holes have not been processed and should be completed in due course. These are also shown on **Figure 75**.

The structural interpretation carried out on these holes has delineated defects including joints, cleats, bedding and other structures from the acoustic scanner image file over the cored intervals of the boreholes. The horizontal stress orientation was also measured where borehole breakout had occurred. During the processing, the orientation data was converted to Grid North.

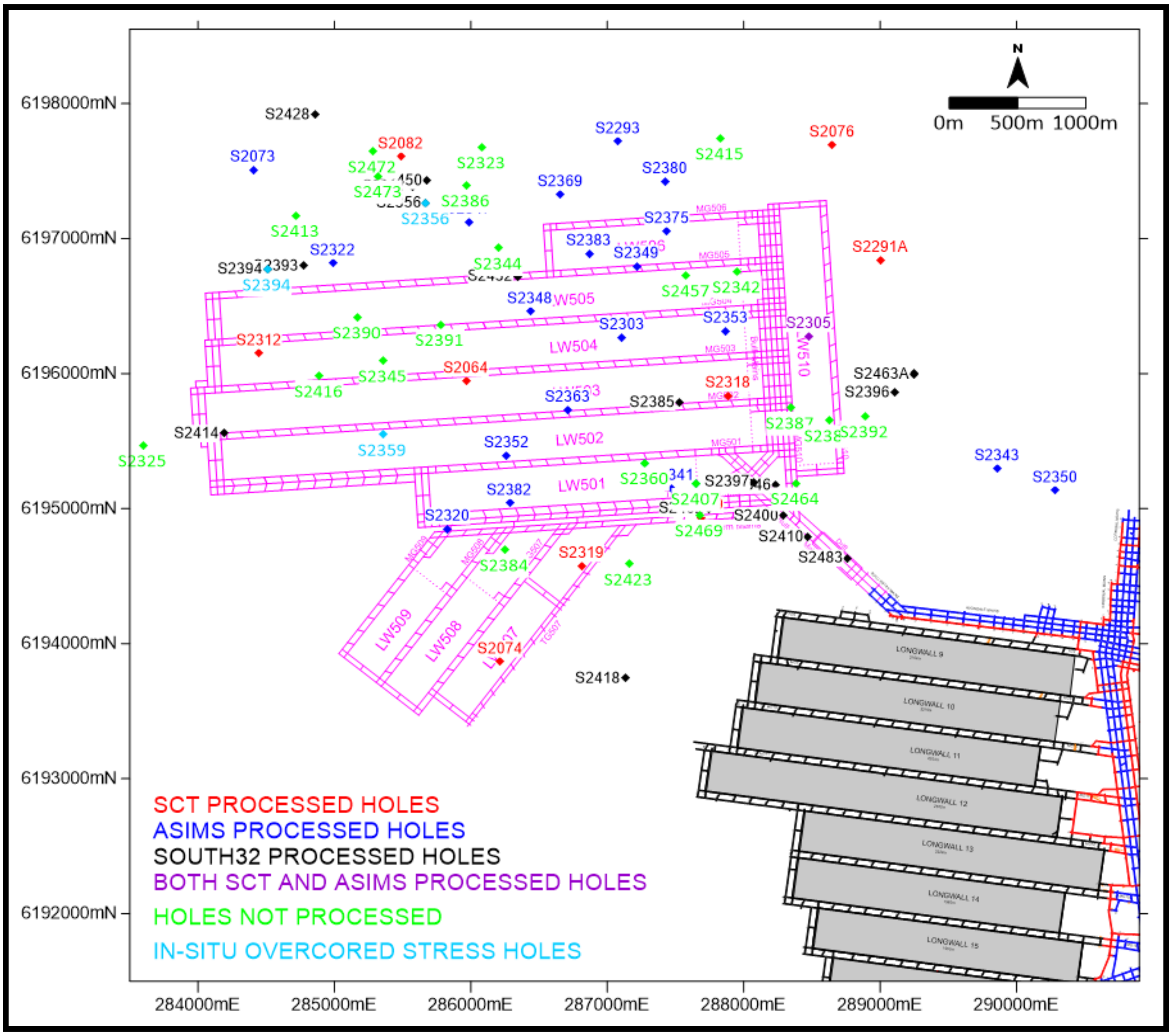

Figure 75. Location of Acoustic Scanner Holes.

4.2.1 Joints in Stone

The dominant joint set in Area 5 trends NW/SE (**Figure 76**). Another less dominant NNE/SSW set is evident in the scanner data (**Figure 76**). The majority of the joints dip at >70º.

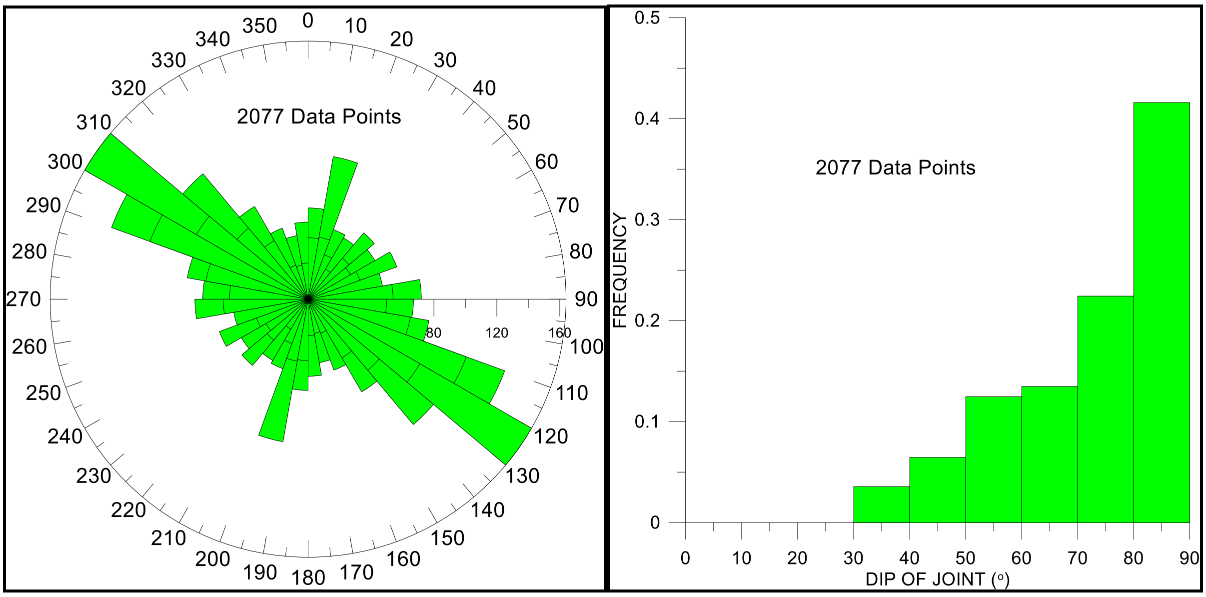

Figure 76. Strike and Dip of Stone Joints from Acoustic Scanner Holes.

4.2.2 Coal Cleats

Acoustic scanner measurements in the Bulli Seam indicate a dominant NNE/SSW cleat trend and less dominant WNW/ESE orientation (**Figure 77**). The WNW orientation is more dominant in SIS borehole S2469 (**Figure 3**). In terms of dip, 85% of these coal cleats are steeper than 70°.

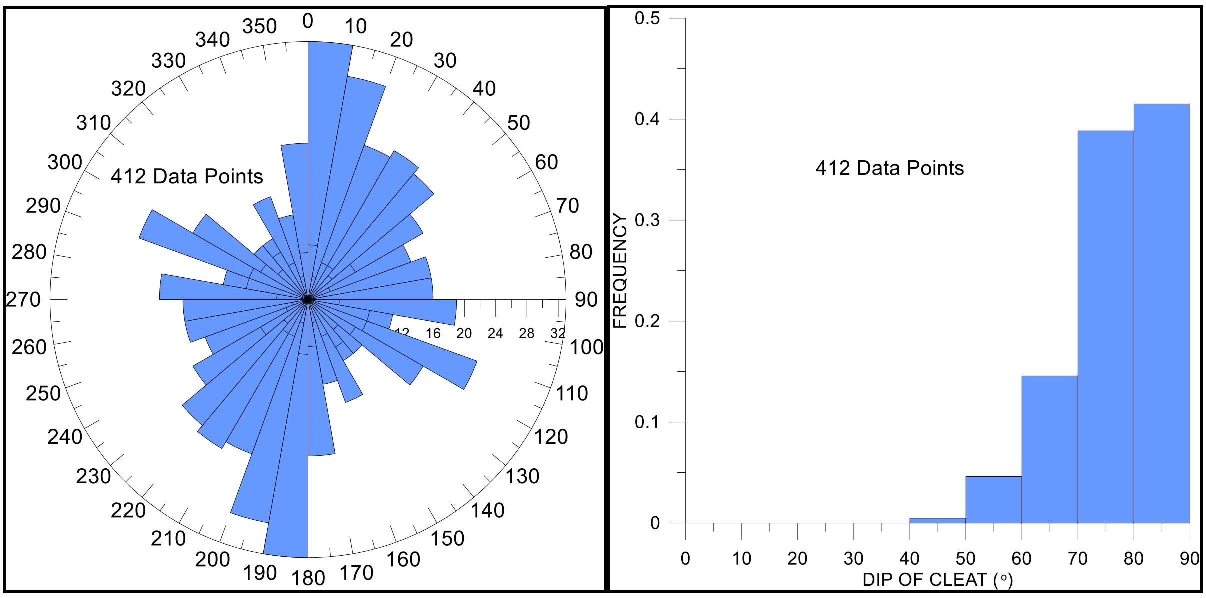

Figure 77. Strike and Dip of Cleats from the Bulli Seam.

The strike of the cleat in the Wongawilli Seam is not as clearly defined as in the Bulli Seam but the NNE/SSW and WNW/ESE trends appear to be apparent (**Figure 78**). These orientations are consistent with those mapped underground at the

Dendrobium Mine (GGPL, 2018[7]). The dip of the cleats is also typically >70º (**Figure 78**).

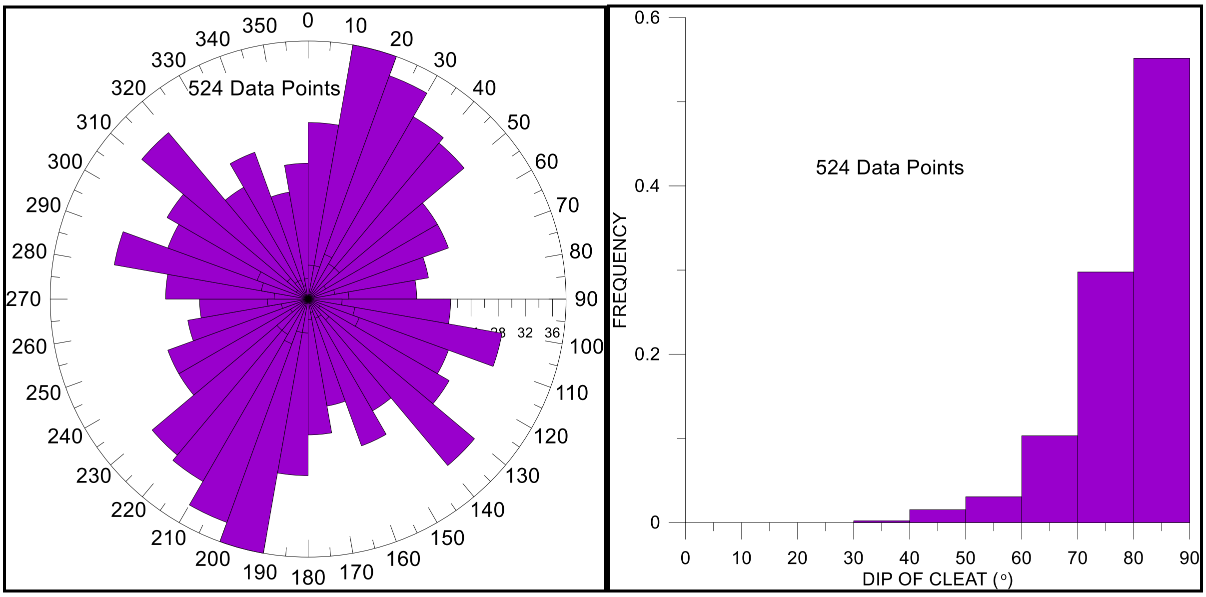

Figure 78. Strike and Dip of Cleats from the Wongawilli Seam.

4.2.3 Other Structures

There are two broad trends in the other structure data identified in the acoustic scanner holes, of NW/SE and NNE/SSW (**Figure 79**). The majority of these features dip at <30º.

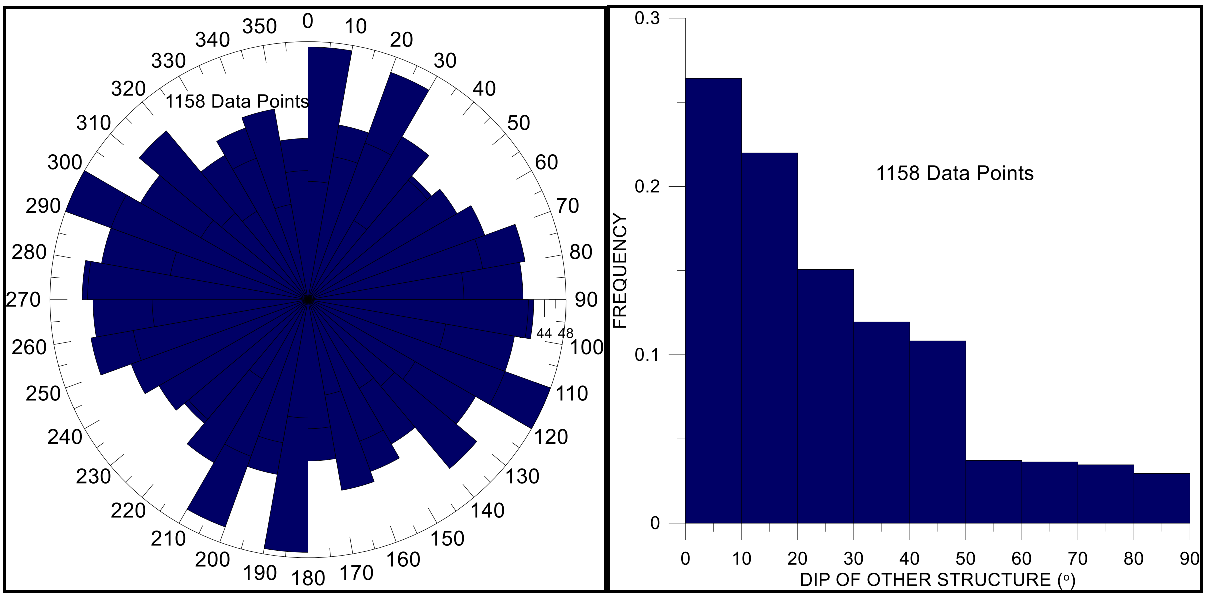

Figure 79. Strike and Dip of Open Fractures and Shears.

[7] GGPL (2018). Geotechnical Assessment of Longwalls 20 and 21 at Dendrobium. Report No. Dendrobium18-R1.

4.2.4 Bedding

A range of bedding strikes is evident in the acoustic scanner data, consistent with the variability in the Project area (**Figure 80**). More than 70% of the measurements indicate dips <10º (**Figure 80**).

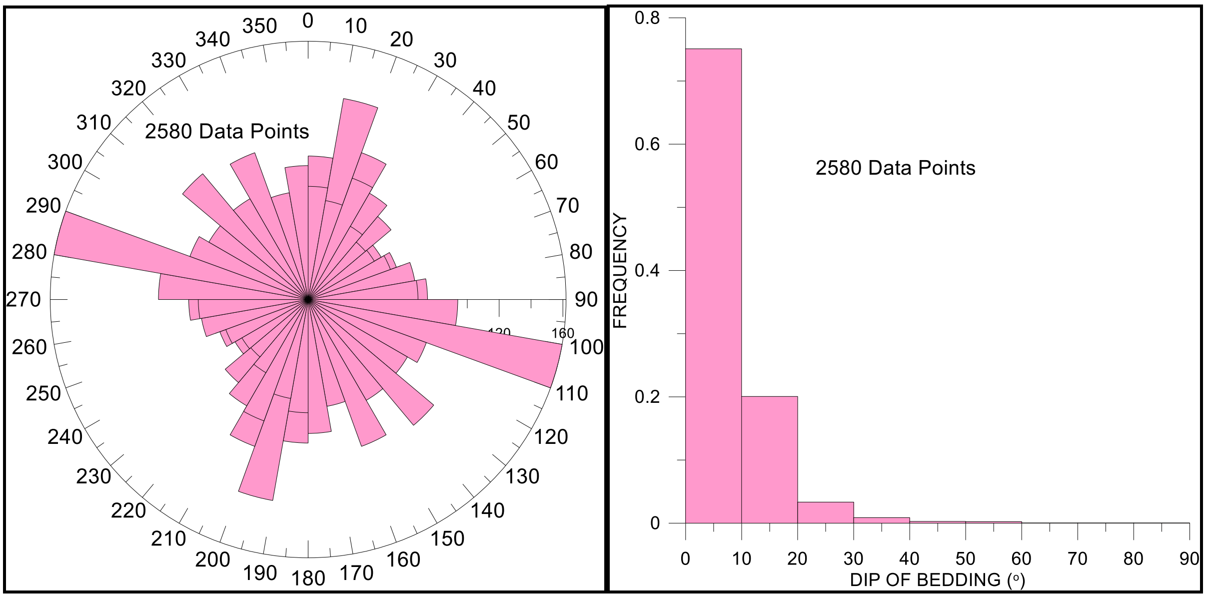

Figure 80. Strike and Dip of Bedding.

4.2.5 Ground Stresses

Acoustic scanner plots of the horizontal stress orientation determined from borehole breakout in Area 5 are shown in **Figure 81**. The consistent NE/SW orientation of the horizontal stress is evident in both **Figure 81 and Figure 82**.

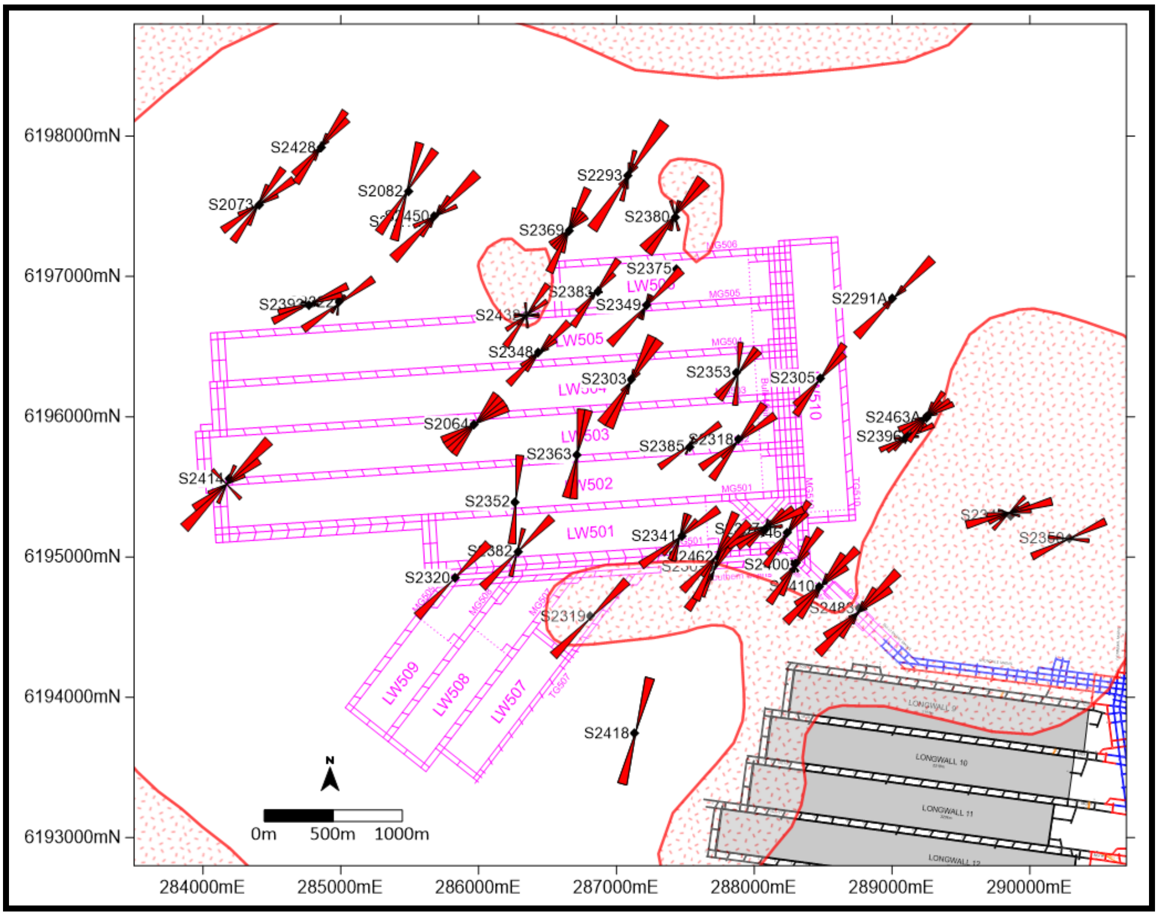

Figure 81. Summary of Horizontal Stress Direction from Acoustic Scanner.

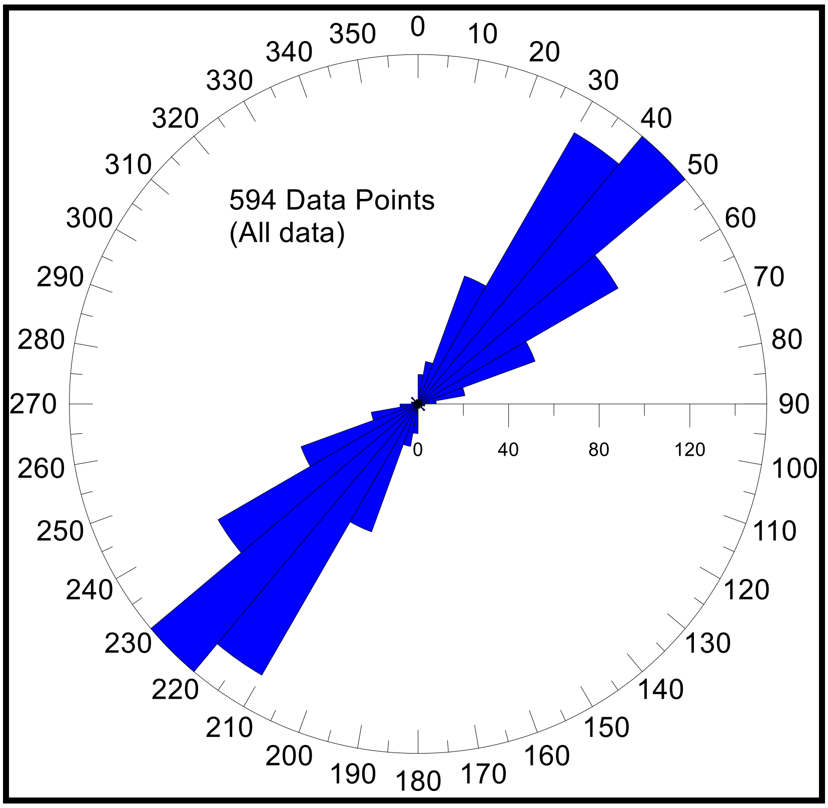

Figure 82. Horizontal Stress Direction – all boreholes.

When the breakout data is filtered to within 20 m of the Bulli Seam, a similar consistent NE/SW trend is evident (**Figure 83**).

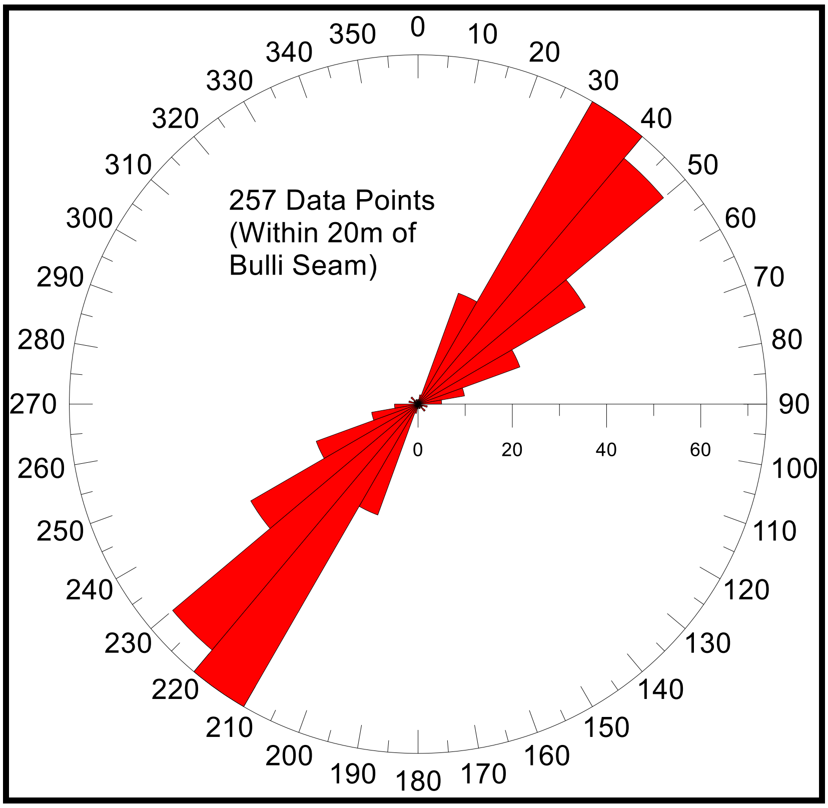

Figure 83. Horizontal Stress Direction within 20 m of the Bulli Seam.

The similar trends above and below the Bulli Seam, suggests that the Wongawilli Seam goaf at the Dendrobium Mine has not significantly affected the stress field in Area 5 (**Figure 84**). There may however be some localised re-orientation in borehole S2418, located close to Longwalls 10 and 11 in the Wongawilli Seam (**Figure 81**).

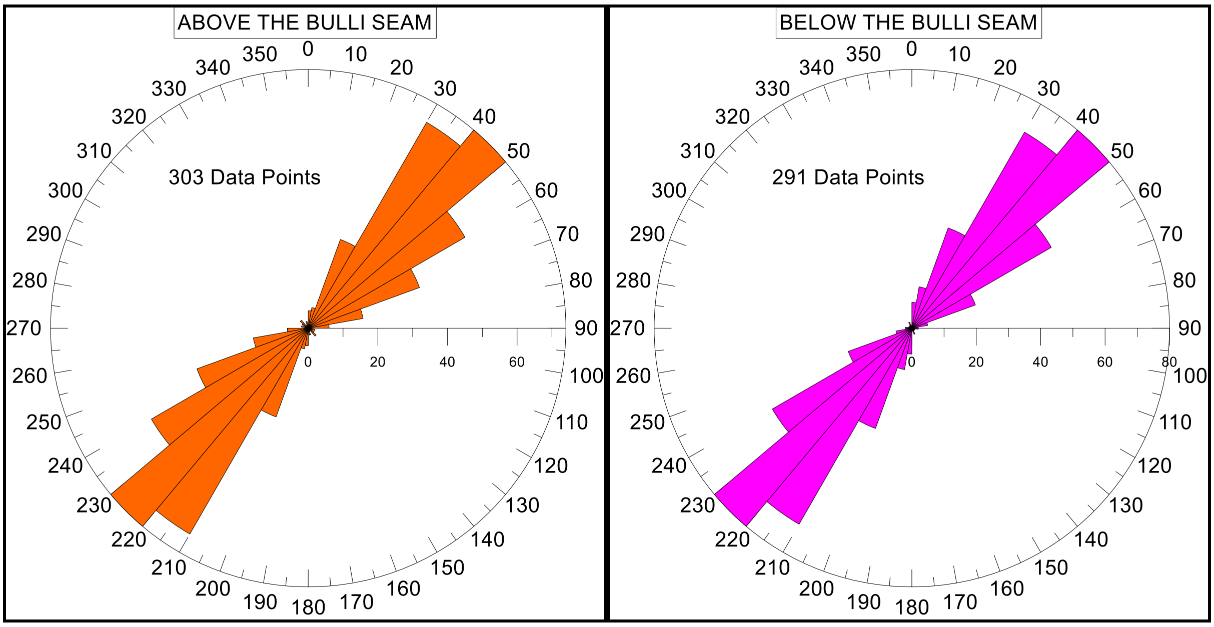

Figure 84. Horizontal Stress Direction Above and Below the Bulli Seam.

SCT (2018[8]) document the in-situ stress overcoring measurements that have been carried out in Area 5. The location of these holes is shown in **Figure 75**. The NE/SW major horizontal stress direction measured in the overcore holes is also consistent with the acoustic scanner measurements (**Table 5**).

The ratio of the major horizontal stress: vertical stress averages 1.76, with a standard deviation of 0.42 (**Table 5**). Similarly, the major to minor horizontal stress ratio averages 1.41 (**Table 5**).

Borehole	Depth (m)	Modulus (GPa)	σ_H (MPa)	Bearing (ºGN)	σ_h (MPa)	Bearing (ºGN)	σ_V (MPa)	σ_H:σ_h	σ_H:σ_V
S2356	369.2	18	11.2	54	8.3	146	6.9	1.35	1.62
S2359	354.3	18	9.4	62	7.7	147	6.8	1.22	1.38
S2360	151.7	23	7.4	62	4.5	153	3.5	1.64	2.11
S2360	214.7	15	9.7	61	8.1	151	4.6	1.20	2.11
S2360	318.8	22	6.6	66	5.1	132	6.6	1.29	1.00
S2360	358	15	11.6	56	8.8	146	7.3	1.32	1.59
S2394	314.2	18	11.8	53	8.1	143	6.6	1.46	1.79
S2394	361.2	16	13.2	167	9.5	77	7.6	1.39	1.74
S2407	240.5	23	13.6	44	9.7	133	5.2	1.40	2.62
S2407	352.7	24	12.7	31	8.9	122	7.3	1.43	1.74
S2407	381.7	22	12.9	42	7.2	136	7.9	1.79	1.63

Table 5. Summary of In-Situ Stress Measurements in Area 5 (SCT, 2018).

Pitt and Sherry (2015[9]) also report a similar major horizontal: vertical stress ratio of 1.8 used in design studies at the Appin Mine.

5 PILLAR DESIGN

5.1 Chain Pillars

The chain pillars in the Bulli Seam for Area 5 have been designed for this stage of the Project at 42 m wide (rib to rib) and 115 m long (rib to rib), at depths of 345 m to 395 m (**Figure 85**). For a 2.7 m mining height, these pillars have a width to height ratio >10, so would strain harden rather than fail.

Appin Mine have successfully used similar size pillars at depths approaching 600 m. The roof strengths at Appin Mine are also similar to Area 5, albeit at an increased depth of cover (GGPL, 2019[10]). It is more a question of Tailgate serviceability.

[8] SCT (2018). In Situ Stress Measurements in Exploration Borehole S2407. Report No. STH324664C.

[9] Pitt and Sherry (2015). Appin Coal Clearance Project Report on Interseam Drift Strata Support Assessment.

[10] GGPL (2019). Assessment of Mining Conditions at 700 m. Report No. South32-R2.

Based on the chain pillar sizes used at other Bulli Seam operations, the proposed pillar width in the Project area should result in adequately serviceable roadways (**Figure 85**).

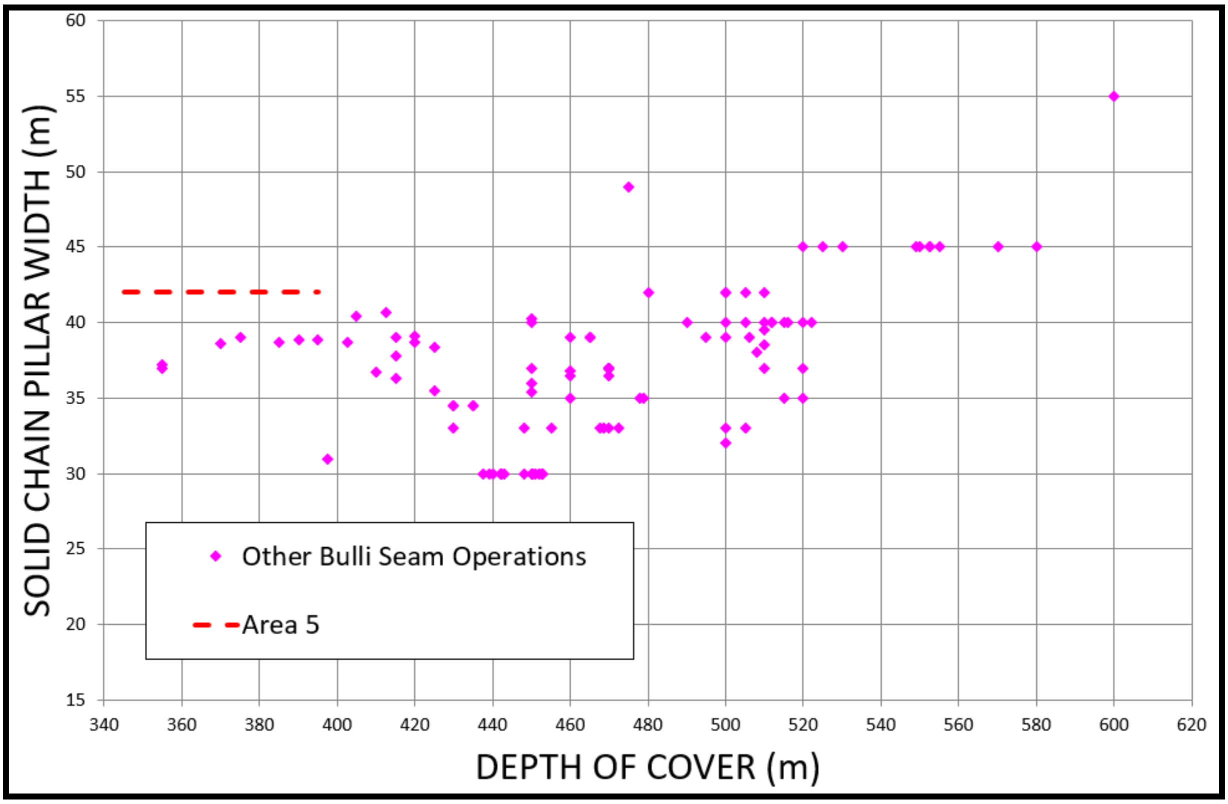

Figure 85. Chain Pillar Widths (Solid) at Bulli Seam Operations.

Using the UNSW pillar design methodology and factors of safety for single abutment, tailgate corner and double abutment conditions of 1.8, 1.5 and 1.3 respectively indicates there is some room for optimisation of the Area 5 chain pillar sizes in terms of geotechnical stability (**Figure 86**). It is noted that a conservative abutment angle of 21^{o} has been used in the analysis in **Figure 86**, whereas a 10^{o} angle may be more appropriate (L. Brown pers. comm.).

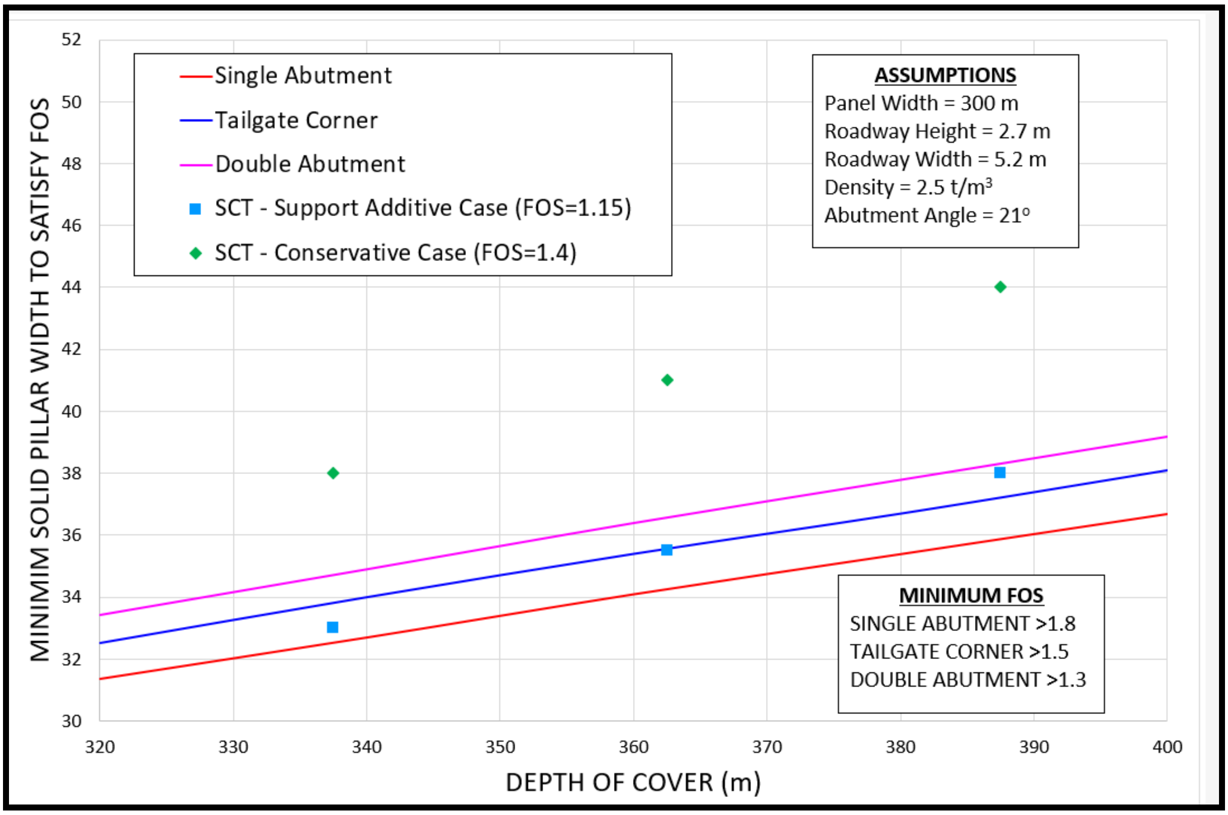

Figure 86. Chain Pillar Widths – UNSW Pillar Design Methodology.

5.1.1 SCT Recommended Chain Pillar Size

SCT (2017[11]) also made recommendations on the pillar sizes, as well as assessing the panel width. SCT used a combination of empirical design assessment to determine pillar strengths and numerical simulation to determine abutment load characteristics in Area 5.

SCT highlighted that the moderate to high strength Bulli Seam roof and floor strata and low seam height provide for an overall stronger pillar system. They detail that the main design requirement is to provide acceptable roadway serviceability conditions in the tailgate. SCT also indicated that there is potential to optimise the chain pillar design. This is consistent with the UNSW analysis presented above (**Figure 86**).

SCT used the Mark-Bieniawski pillar strength equation and modified the abutment angle using the method of Tulu and Heasley (2012[12]). They provided recommended pillar widths for a support additive case (FOS =1.15) and a conservative design case (FOS=1.4) as shown in **Figure 87**.

These results are also shown on **Figure 86**, as a comparison with the UNSW pillar design results.

[11] SCT (2017). Dendrobium Area 5 Bulli Seam Studies – Pillar Design and Panel Width Assessment. Report No. STH324670.
[12] Tulu, I.B. and Heasley, K.A. (2012). Investigating Abutment Load. In Proceedings 31st International Conference on Ground Control, Morgant

Height (m)	Depth Range	Pillar Solid (m)
Support Additive (FOS 1.15)		
2.7	300m to 325m	30.5
2.7	325m to 350m	33
2.7	350m to 375m	35.5
2.7	375m to 400m	38
2.7	400m to 425m	40.5
3	300m to 325m	32.5
3	325m to 350m	35
3	350m to 375m	38
3	375m to 400m	40.5
3	400m to 425m	43.5
Conservative (FOS 1.4)		
2.7	300m to 325m	35
2.7	325m to 350m	38
2.7	350m to 375m	41
2.7	375m to 400m	44
2.7	400m to 425m	47
3	300m to 325m	37
3	325m to 350m	40
3	350m to 375m	43
3	375m to 400m	46
3	400m to 425m	49

Figure 87. Chain Pillar Solid Widths based on Tailgate Corner Load Assessment (SCT, 2017).

5.2 Mains Pillars

The Mains pillars in Area 5 have solid dimensions of 35 m at depths of 360-390 m. For a 3 m mining height, 35 m x 35 m (solid) pillars have factors of safety >2.77 (using the UNSW power formula for squat pillars).

As detailed by SCT (2017), the Factors of Safety and the width: height ratios of the Mains pillars provide a robust pillar system. Due to the high FOS values, there is potential to reduce the minimum width of the Mains pillars in the shallower part of Area 5.

5.3 Barrier Pillars

The width of barrier pillars can be analysed using the method of Peng and Chiang (1984)[13], which estimates the width of the front abutment vertical stress zone based on monitoring data from the USA (**Equation 1**).

$$D = 5.13 \times H^{1/2} \qquad \text{Equation 1}$$

Where D is width and H is depth (both in metres).

As shown in **Figure 88**, significant front abutment effects on the Mains roadways are not expected in the proposed Area 5 longwall layout.

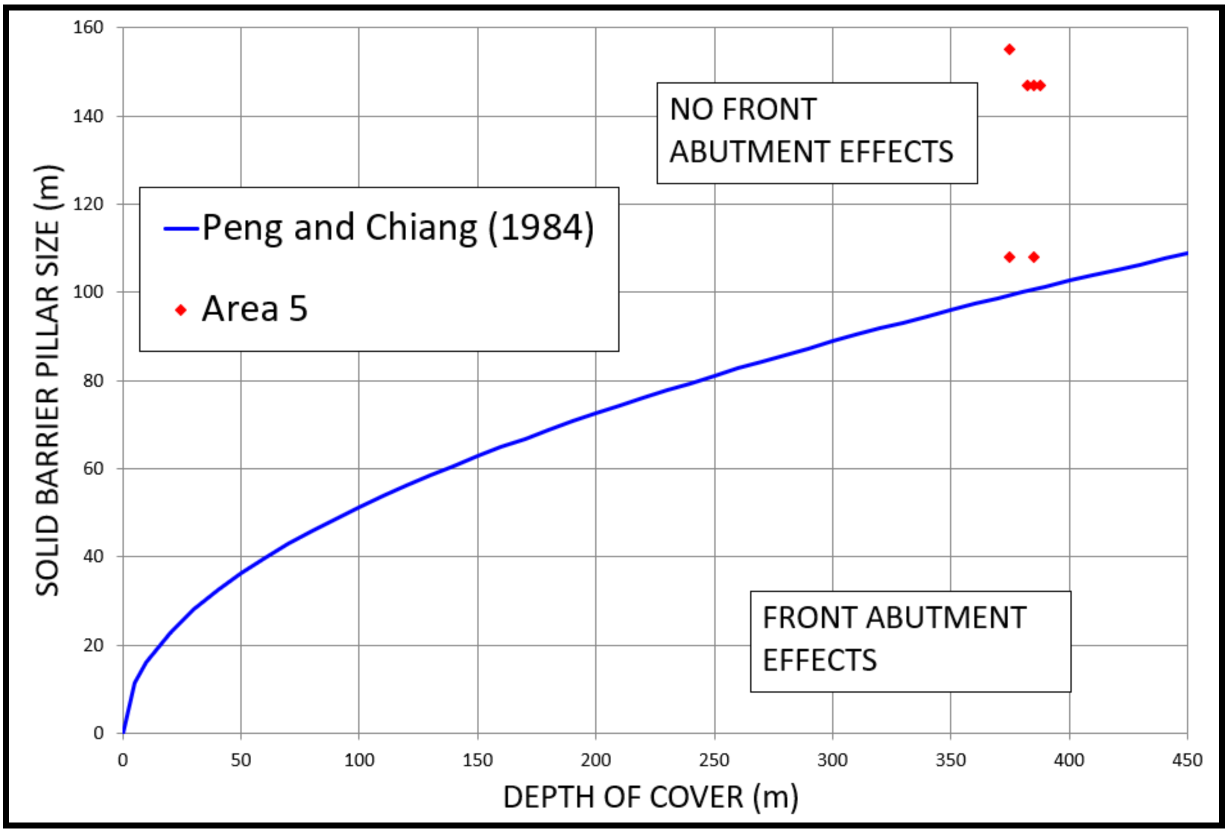

Figure 88. Analysis of Barrier Pillars (after Peng and Chiang, 1984).

5.4 Shaft Pillars

The proposed upcast and downcast shafts in the pit bottom area are located between angle of draw values of 30.5-38.7°. These are within the angle of draw requirements of 26.5° used for shaft pillars in the United Kingdom. As such the shafts would be expected to experience low levels of ground movement (SCT, 2017).

[13] Peng, S.S. and Chiang, H.S. (1984). Longwall Mining. Wiley, 1984. Pp. 708.

5.5 Coal Bursts

A pressure (or coal) burst is a pressure bump that actually causes consequent dynamic rock/coal failure in the vicinity of a mine opening, resulting in high velocity expulsion of this broken/failed material into the mine opening (ACARP, 2018[14]). The dominant energy source in coal or pressure bursts is stress. The energy levels, and hence velocities involved in pressure/coal burst can cause significant damage to, or destruction of conventional installed ground support elements such as bolts and mesh.

In comparison, an outburst is also a dynamic energy release leading to some form of rock failure but the source of energy is primarily associated with in situ gas pressure (ACARP, 2018).

The most common occurrences of coal bursts have been recorded during longwall retreat (**Figure 89**).

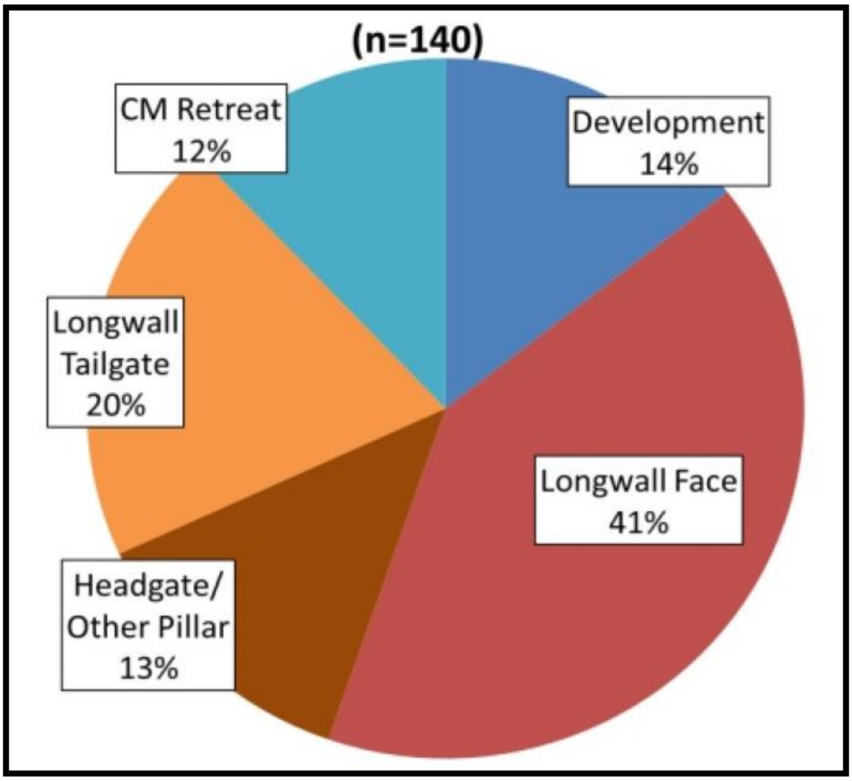

Figure 89. Percentage of Coal Bursts by Location (Mark 2014).

Recent research in ACARP Project C25004 (2018), identified nine critical risk factors that influence the risk of a coal burst. Using these factors a coal burst risk classification system (BurstRisk System) was developed, based on the back analysis of coal burst cases from Australia, China and USA.

Two separate matrices have been developed for both development and longwall mining in Area 5. It is anticipated that during development in normal gas conditions

[14] ACARP Project C25004 (2018). Review of Australian and International Coal Burst Experience and Control Technologies.

(<8m^3/tonne) and away from geological structure, the risk of a coal burst is low in Area 5 (**Table 6**). In areas close to geological structure and with gas contents >8m^3/tonne, the risk increases to medium (**Table 6**).

	DEVELOPMENT			
Weighting	Risk Factor	Rating	Dendrobium Area 5 (near geological structure and >8m^3/t)	Dendrobium Area 5 (away from geological structure and <8m^3/t)
30	**Depth of Cover**			
	<350m	1	5	5
	351-450 m	5		
	450-700 m	15		
	>700 m	20		
5	**Topography**			
	Flat	1	5	5
	Average	3		
	Steep	5		
30	**Geological Structure**			
	No significant geological features	1	10	1
	>20 m proximity to the excavation	3		
	<20 m proximity to the excavation	10		
30	**Seismic Activity**			
	No recorded seismic activity	1	5	5
	Isolated minor seismic events in mine	5		
	Semi-regular seismic events	10		
	Persistent seismic events	20		
5	**Cleating**			
	High density	1	1	1
	Low density	5		
20	**Abutment Stresses**			
	Abutment >500 m away	1	5	5
	Abutment 150-500 m away	5		
	Abutment <150 m away	10		
5	**Multi-seam Mining**			
	No mining below or above	0	0	0
	Workings >100 m apart	3		
	Workings 50-100 m apart	5		
	Workings <50 m apart	10		
10	**Gas Content**			
	<3m^3	1	10	5
	3-8m^3	5		
	>8m^3	10		
	Likelihood		0.46	0.30
	Propensity		0.44	0.27
	Risk Classification		0.83	0.54
	LOW	<0.8		
	MEDIUM	0.8-1		
	HIGH	>1		

Table 6. Development Risk Classification Table.

During longwall retreat, in areas away from geological structure, in normal gas conditions (<8m^3/tonne) and with massive units in the overburden <10 m thick, the risk of a coal burst is low (**Table 7**). When the worst case geological structure, gas and massive unit conditions are encountered the risk increases to medium (**Table 7**).

	LONGWALL			
Weighting	Risk Factor	Rating	Dendrobium Area 5 (near geological structure, >8m^3/t and massive units >10m)	Dendrobium Area 5 (away from geological structure, <8m^3/t and massive units <10m)
	Depth of Cover			
30	<350m	1	5	5
	351-450 m	5		
	450-700 m	15		
	>700 m	20		
	Topography			
1	Flat	1	5	5
	Average	3		
	Steep	5		
	Massive Units			
15	None	1	10	5
	<5m thick	3		
	5-10 m thick	5		
	>10 m thick	10		
	Geological Structure			
15	No significant geological features	1	10	1
	>20 m proximity to the excavation	3		
	<20 m proximity to the excavation	10		
	Seismic Activity			
30	No recorded seismic activity	1	5	5
	Isolated minor seismic events in mine	5		
	Semi-regular seismic events	10		
	Persistent seismic events	20		
	Cleating			
5	High density	1	1	1
	Low density	5		
	Abutment Stresses			
15	MG	1	5	5
	Face	3		
	TG	5		
	Multi-seam Mining			
5	No mining below or above	0	0	0
	Workings >100 m apart	3		
	Workings 50-100 m apart	5		
	Workings <50 m apart	10		
	Gas Content			
1	<3m^3	1	10	5
	3-8m^3	5		
	>8m^3	10		
	Likelihood		0.54	0.34
	Propensity		0.42	0.29
	Risk Classification		0.93	0.60
	LOW	<0.8		
	MEDIUM	0.8-1		
	HIGH	>1		

Table 7. Longwall Risk Classification Table.

It should be highlighted that the assessment of coal burst potential in Australia is relatively new and the conclusions from the BurstRisk System analysis should be considered as a guideline only. It is noted that several coal bursts and shakedown events have occurred at various locations on LW903 at the Appin Mine whilst mining into the hard dyke, at depths of 600m and greater and also in the transitional immediate roof lithology zone from siltstone to sandstone. During development mining, the risk of coal bursts at the Appin Mine is considered low away from geological structures (L. Brown pers. comm.)

Based on the recent experiences at the Appin Mine and the development and longwall risk classifications in **Table 6 and Table 7**, a coal burst Trigger Action Response Plan (TARP) and management plan are recommended for Area 5.

A method for determining whether the risk of a coal burst is significant or not is the coal cuttings test. This test requires holes to be drilled into the coal, since it has been well documented that the amount of coal fines produced increases in direct proportion to the magnitude of stress and assessed against its proximity to the edge of the mine opening.

There are also a number of mitigating controls for the risk of coal bursts that can be implemented such as remote mining and reducing production rates.

6 GROUND SUPPORT

6.1 Introduction

The ground support issues in Area 5 have been analysed using a number of design methods. Seedsman (2008)[15] recognises five different approaches to the formulation of a geotechnical model and the subsequent analyses (**Figure 90**). For completeness, an additional design by measurement approach is included.

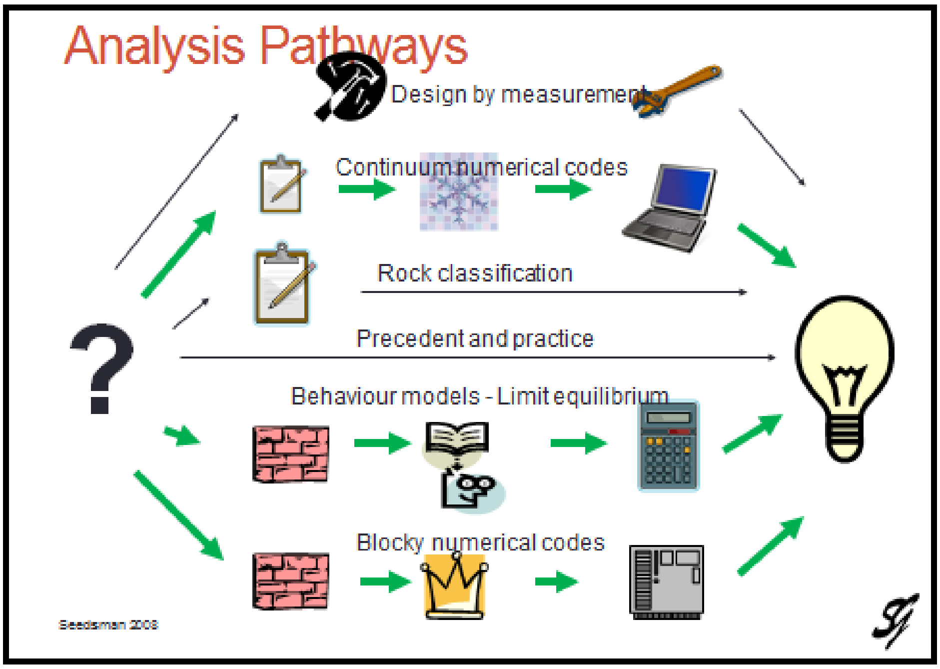

Figure 90. Analysis Pathways (Seedsman, 2008).

[15] Seedsman, R.W. (2008). Limitations of the observational method and monitoring programs for high production longwalls and an alternative framework. COAL 2008 – 8th Underground Coal Operators Conference, Wollongong, pp. 67-74.

Due to the strengths and weaknesses of all these approaches it is recommended to always use at least two. Precedent and practice is an extremely strong design tool when used in combination with other methods.

6.2 Bulli Seam Experience

6.2.1 Roof Conditions

Away from geological structures, typically good roof conditions are encountered during development in the Bulli Seam workings at other mines in the Southern Coalfield. Significantly poorer conditions are experienced near geological structures such as faults and dykes.

Roof failure modes such as roof guttering, sagging, centre cracking and bolt plates taking weight are referenced in the Development TARP for the Appin Mine (**Figure 91**).

	NORMAL	LEVEL 1	LEVEL 2
Roof condition Triggers	• Gutter height < 0.1m • Cavities < 0.3m • Sag < 0.1m • Tell-Tale movement T < 30mm • No fresh deterioration outbye of miner	• 0.1m < Gutter height < 0.5m • 0.3m < Cavities < 1.0m • 0.1m < Sag < 0.3m • Significant cupping of plates • Tell-Tale movement 30mm < T < 120mm • Tensile Crack < 10mm • Duration (every 20 seconds) noise/bumping coming from roof and ribs for periods < 2 minutes	• Gutter height > 0.5m • Cavities > 1.0m • Sag > 0.3m • Presence of geological structure - Fault, Dyke, Joint zone or Shear zone • Tell-Tale movement T > 120mm • Tensile Crack > 10mm • Duration (every 20 seconds) noise/bumping coming from roof and ribs for periods > 2 minutes
Rib condition Triggers	• Vertical Rib with moderate rib spall < 0.4m	• Significant rib spall and/or small amount of rib failure > 0.4m but < 0.6m	• Bulging Ribs with Significant rib spall and/or significant rib failure > 0.6m • Intersecting joints with potential to cause wedge failure

Figure 91. Triggers in Development at the Appin Mine.

Similar roof triggers were used in development drivage at West Cliff (**Figure 92**). These types of failure modes and geological features are also anticipated in Area 5.

GREEN

- *"Leaners"* in ribs but not in roof
- *Roof guttering* less than 100mm over 3m of roadway advance
- Cavities: Less than 300mm

ORANGE

- *"Leaners"* or closely spaced jointing in **Rib** <u>and</u> **Roof**.
- A single shear, open and/or in-filled vertical joint
- *Roof guttering* 100mm to less than 300mm over 3m of roadway advance
- Cavities: 300mm to 600mm

RED

- Multiple shears, open and/or in-filled vertical joints across a single support row (i.e. mesh module)
- Fault(s)
- *Roof guttering* 300m or more over 3m of roadway advance
- Cavaties: Greater than 600mm.

Figure 92. Roof Triggers in Development at West Cliff.

6.2.2 Roof Monitoring

Specific roof movement triggers would need to be implemented for the proposed development and longwall retreat in Area 5. At other Bulli Seam mines, the Level 1 threshold in development is between 30 and 50 mm (**Figure 93**).

At the Appin Mine, when the Level 2 trigger of 120 mm is reached in development, cables are installed. Once the Level 3 trigger of 200 mm is exceeded, the cable pattern is infilled to double the density.

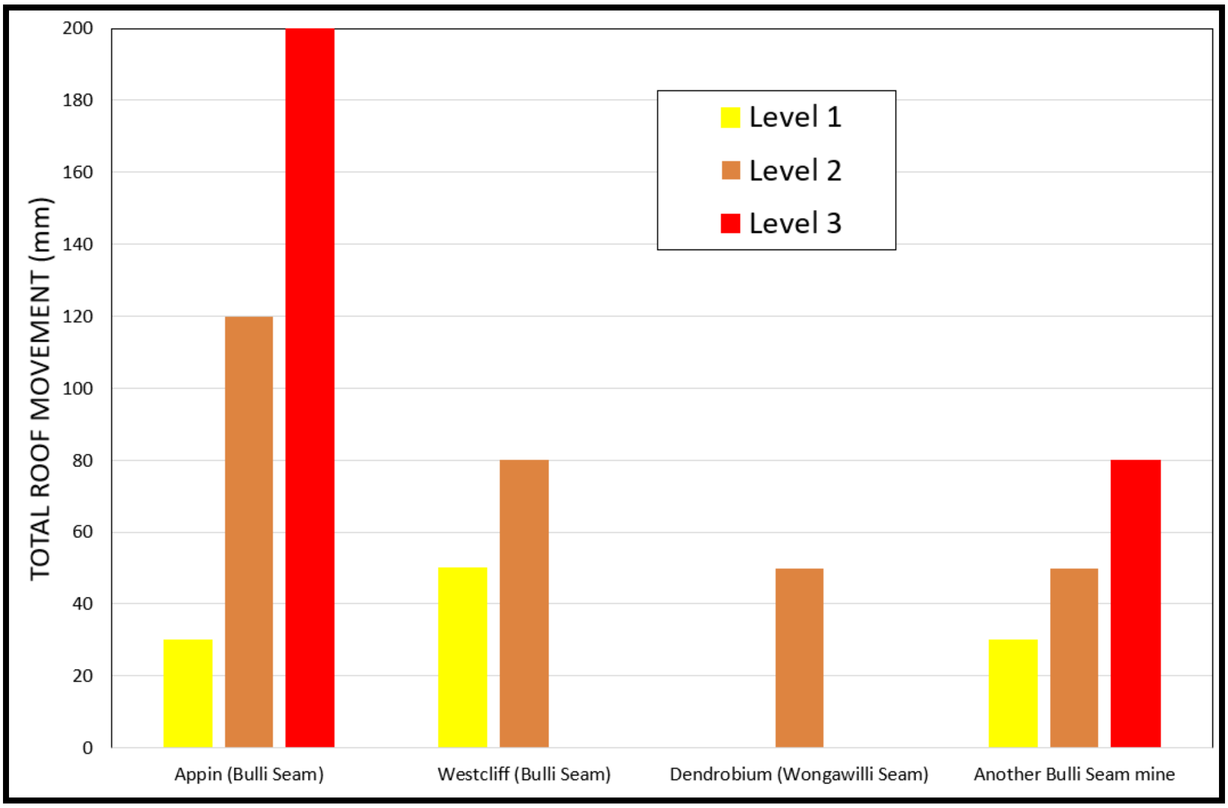

Figure 93. Comparison of Roof Movement Triggers.

6.2.3 Rib Conditions

Poor rib conditions are typical in the Bulli Seam and the ribs are routinely supported with 2 bolts/m (**Figure 94**). Mesh is installed on all non-longwall ribs and is joined with the roof mesh at a number of Bulli Seam mines, including Appin Mine.

As detailed in the Development TARP for the Appin Mine, additional rib support is triggered by the severity of the spall and the number of joint sets (**Figure 91**). The minimum rib bolt length used at Appin Mine is 1.5 m. With the current drill rig set up, these 1.5 m bolts are installed in a single pass on the Joy continuous miners, however double pass drilling is required on the ABM machines.

In poorer ground conditions, long cable/dowel support may be installed for longwall retreat at Appin Mine.

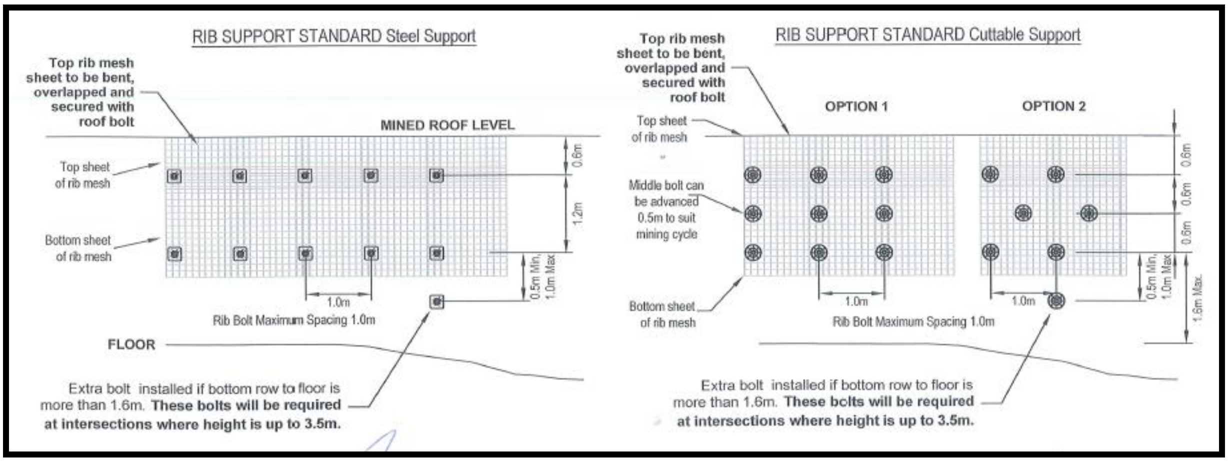

Figure 94. Rib Support Patterns at the Appin Mine.

6.2.4 Floor Conditions

Floor heave has been an issue in the deeper Bulli Seam workings at other mines in the Southern Coalfield. In development, some areas require brushing before the belt is advanced. Similar heave issues are experienced in the Maingate during longwall retreat.

Where major stress notch conditions are experienced in the Maingate at the Appin Mine, floor brushing to 3.5 m in the mid-pillar area, increased to 4 m through the intersections is required (L. Brown pers. comm.).

6.2.5 Longwall Conditions

Typically, good conditions are encountered on the Bulli Seam longwall faces in geologically unstructured areas. Strata control issues are more commonly experienced at the gate ends.

In areas of thicker and more massive sandstone overburden, weighting events may occur and are exacerbated by slower retreat rates.

Other hazards around the longwall panel include water pooling along the gateroads and on the longwall face, large cross grades across the face, thinner seam areas and geological features such as faults and dykes. These types of hazards also apply to Area 5. Cross block pumping was required in the synclinal area at the Appin Mine to prevent water ponding in the tailgate.

Due to the laminated immediate roof in Area 5, it is anticipated that goafing would be directly behind the shields.

Longwall TARPs from other Bulli Seam mines are a good indicator of the conditions likely to be encountered on the Area 5 longwall face and in the gates. Triggers on the face include:

- Increase in tip to face distance.
- Cavities developing.

- Reduced shearer clearance.
- Roll and geological structure on the face.
- Support canopies away from the roof.
- Poor creep and pontoons sinking into the floor.

Triggers in the gates include:

- Reduced clearance at the crusher.
- Buckling, guttering and sagging of roof.
- Roof bumping, floor heave and rib spall.
- Cable bolt plates showing signs of weight.

6.3 Geotechnical Models

Prior to making recommendations on the roof and rib support patterns, it is important to detail a number of models for the likely geotechnical conditions in Area 5. These models form the basis of the analyses and hazard recognition in the next stage of the geotechnical design process proposed by Bieniawski (1993) in **Figure 95**.

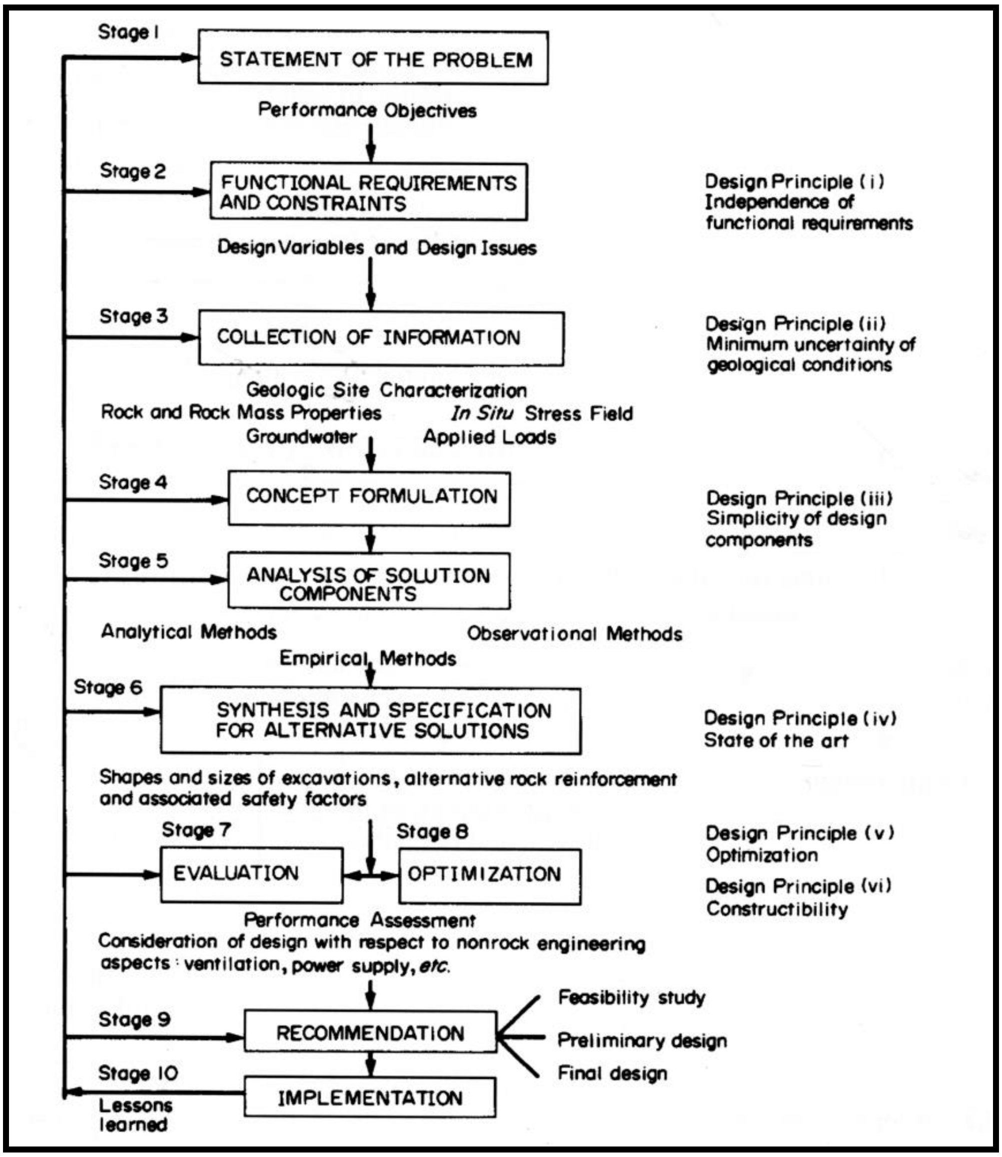

Figure 95. Flow Chart for the Geotechnical Design Process (Bieniawski, 1993).

The key feature in Area 5 is that the working section of the Bulli Seam would be to **stone** roof and **stone** floor. It should also be highlighted that experience from conditions encountered in the workings at other Bulli Seam mines provides the best analogue to the likely conditions in Area 5.

With the additional geological and geotechnical data collected since the 2017 pre-feasibility study, there is greater confidence in the geotechnical models at this feasibility stage of the Project.

It should be highlighted that at the Appin Mine there is large variability in the roof strata between surface exploration boreholes. Therefore underground roof coring and borescoping programs are typically required for roof characterisation and support optimisation. Similar programs are anticipated in Area 5, based on the variability in the thickness of the laminite roof identified from the exploration drilling (**Figure 16**).

6.3.1 Stress Redistribution in Stone

6.3.1.1 About a Development Roadway

In a Bulli Seam development roadway, mining to a stone roof with a K ratio of 2 (ratio of horizontal to vertical stress), there is an increase in compressive horizontal stresses. The deviatoric stress (σ_1-σ_3) is the driver for compressive/shear failure and as shown in **Figure 96,** high deviatoric stresses are concentrated at the roof/rib corners. GGPL has used the Examine 2D software package from Rocscience[16] to illustrate these features of the stress field at 400 m.

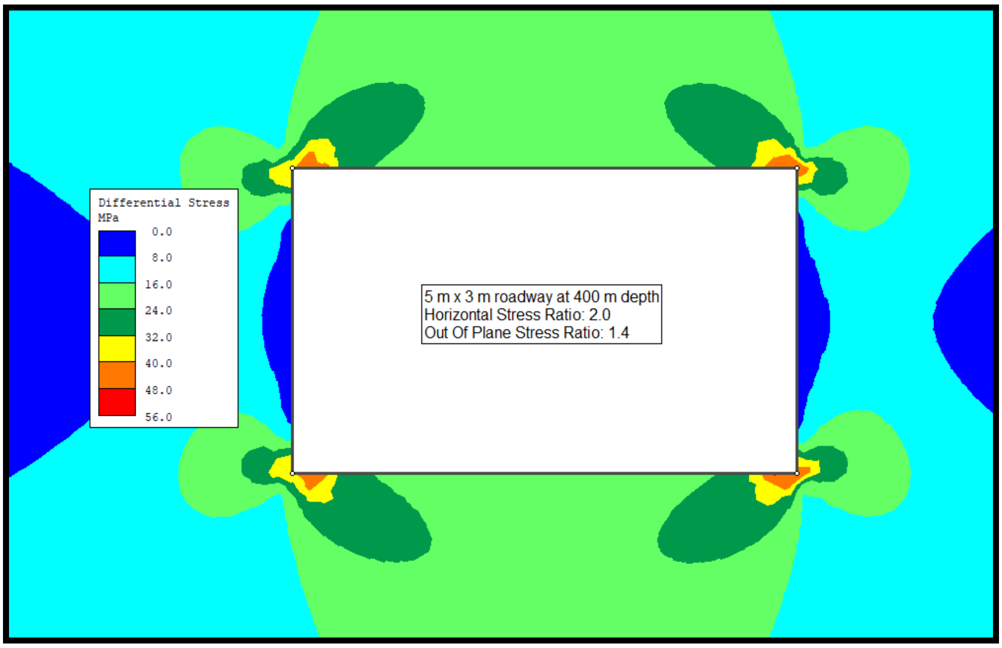

Figure 96. Distribution of Deviatoric Stresses for K=2 at 400 m.

It is noted that the average K ratio measured in the overcore boreholes is 1.76 (**Table 5**), suggesting that the magnitude of the guttering may not be as severe as shown in **Figure 96**.

[16] www.rocscience.com

When using Examine 2D it should be remembered that the modelling assumes the material is homogeneous, isotropic and linearly elastic and hence an oversimplification of the real world. Most rock masses do not possess all these properties. The degree to which the actual rock mass deviates from these assumed properties when modelled should be kept in mind.

In summary, Examine 2D like all numerical models should be used to enhance and supplement but never replace common sense and good engineering judgement (Examine 2D Program Overview).

The increased level of roof and floor failure with increasing depth from 340 to 400 m is shown in **Figure 97**. The implication for the shallower Area 5 workings is that the magnitude of any stress guttering in the development roadways would be less. It is also highlighted that the K ratio of 2 in this figure may be a conservative assumption.

Examine 2D is unable to model layers with different strengths, however the 60 MPa floor strength assumption is valid where the immediate floor is removed in development.

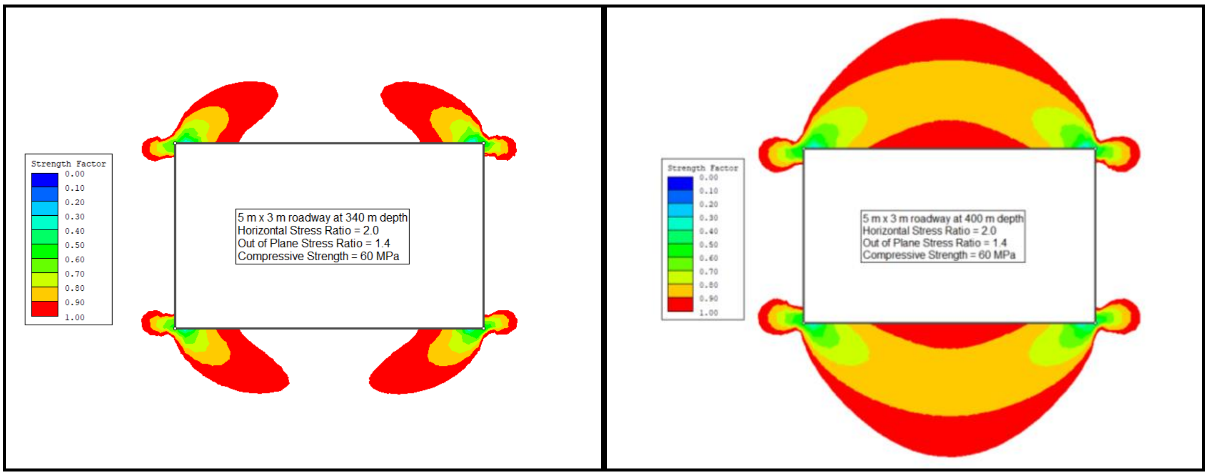

Figure 97. Comparison of Strength Factor at Different Depths in 60 MPa Strata.

6.3.1.2 About a Longwall

Tailgates

Reductions in the horizontal stress in the Tailgate of Longwalls 20B and 21 have been measured at Ulan by Shen et al (2006)[17]. As shown in **Figure 99**, the vertical stress has increased fourfold. This compliments the model proposed by Seedsman (2001)[18], where a combination of increasing vertical stress and decreasing horizontal stress, together with the compression of the chain pillar, results in an increase in the tensile stresses in the roof.

[17] Shen, B, Guo, H, King A, and Wood M (2006). An integrated real-time roof monitoring system for underground coal mines. COAL2006.

[18] Seedsman, R.W. (2001). The stress and failure paths followed by coal mine roofs during longwall extraction and implications to tailgate support. 20th International Conference on Ground Control in Mining. Morgantown, WV.

Hence tailgates are exposed to tensile failures which are especially significant in coal roof, where the roof is already destressed. This does not apply to the stone roof conditions in Area 5.

Maingates

In stone roof environments, the horizontal stress increases from 20% to >100% at the Maingate corner of a retreating longwall depending on the orientation (**Figure 98**). Typically, the vertical stress is doubled at the maingate corner (**Figure 99**).

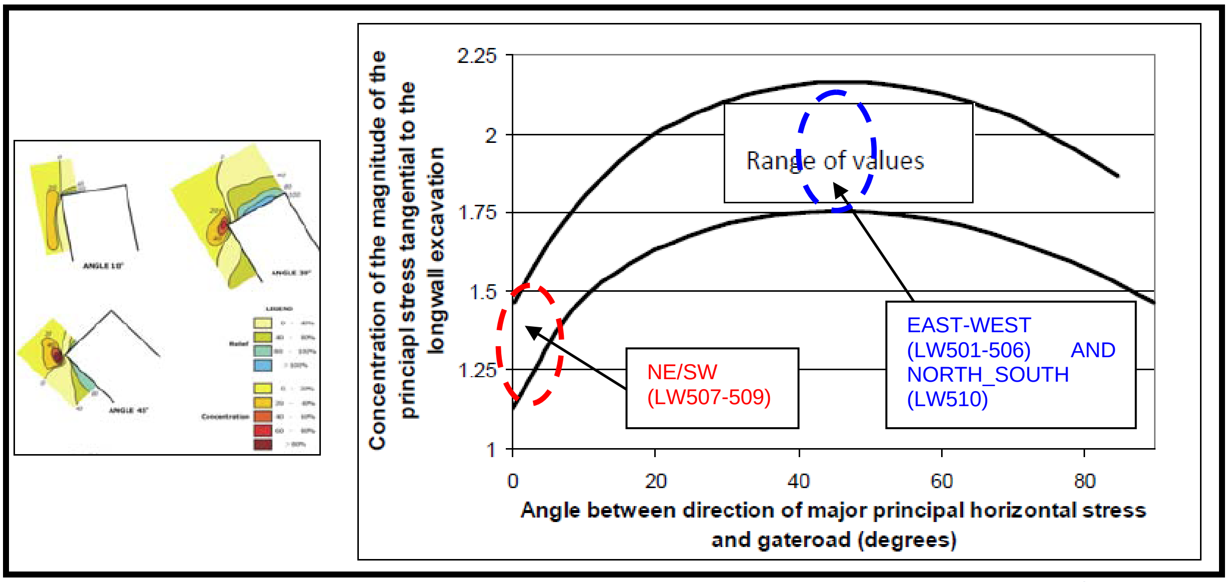

Figure 98. Horizontal Stress Concentration Factors (Gale, 2008[19]).

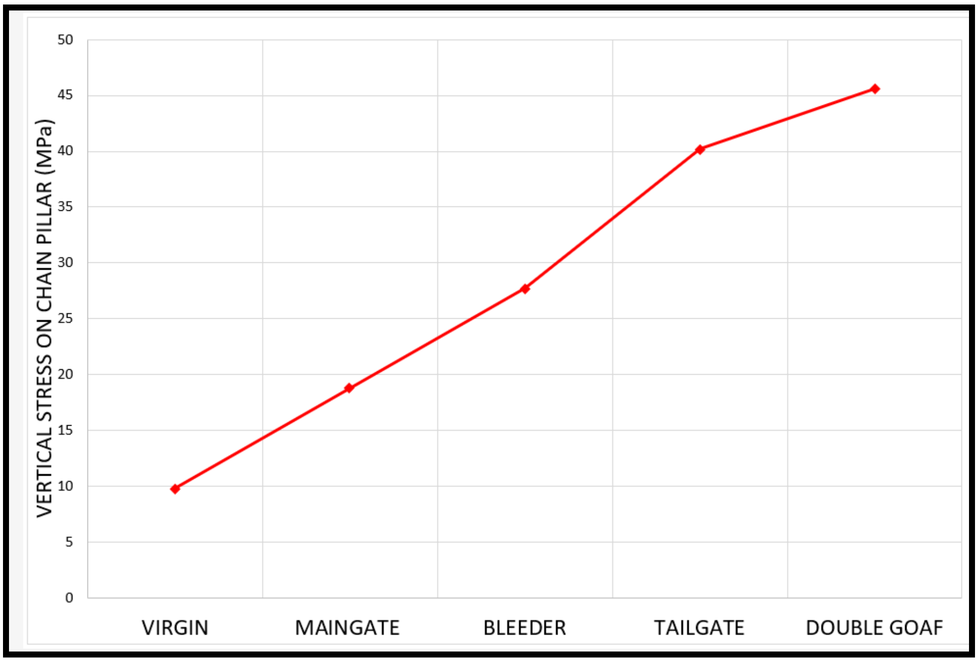

Figure 99. Vertical Stress Developed above 42 m Chain Pillars at 400 m Depth.

19 Gale, W. J. (2008). Stress issues in underground coal mines and design approach. Paper presented in "Stress Measurements, Monitoring and Modelling Techniques and their Design Applications", Wollongong: Eastern Australia Ground Control Group.

Analysis of the deviatoric stress and bedding parallel shear stress, as well as the horizontal stress, indicates that stone and coal rock masses can fail in several ways either due to compression, tension or bedding shear, if not adequately supported (Seedsman et al, 2009).

6.3.2 Height of Roof Failure

Seedsman (2011)[20] proposed a brittle failure criterion that utilises the unconfined compressive strength and a spalling limit of 3.4, together with a tensile strength cut-off that can be used to model the height of failure above coal mine roadways.

To predict the height of failure the three key variables are the RSI, the horizontal to vertical stress ratio (K) and the Young's Modulus/Shear Modulus (E/G) ratio. By factoring in the stress concentrations that occur during longwall extraction, the criterion can be used to predict heights of failure on initial roadway development and in the maingate. The stress ratios determined from the overcoring presented in **Table 5** are used in this analysis.

6.3.2.1 Development

Firstly, the K ratio (major horizontal: vertical stress) across the gateroads needs to be adjusted as follows (**Figure 100**):

$$K = K_i * D_v$$

Using an <u>average</u> major horizontal stress orientation of 40^oGN, the gateroad headings for the east-west longwalls (85^oGN) are oriented at 45^o to the major horizontal stress direction. For a σ_h/σ_H or K2/K1 ratio of 0.71 (**Table 5**), a 0.86 correction factor is required for the east west headings

Using an upper bound K_i ratio of 2.2 (average + one standard deviation), a correction factor of 0.86 reduces the K ratio to 1.89 (2.2*0.86) for the gateroad headings of the east-west Bulli Seam longwalls. The same value applies to the cut-throughs of the east-west gateroads and also the north-south gateroads of LW510.

For the NE/SW longwalls (507-509), the gateroad headings are oriented at 2^o to the major horizontal stress direction. Again, using an upper bound K_i ratio of 2.2, a correction factor of 0.71 reduces the K ratio to 1.56 for the gateroads in this area. For the gateroad cut-throughs, the K ratio is 2.2 (**Figure 100**).

For a typical RSI (or Competence Index) of 6-9 for the Bulli Seam immediate roof in Area 5 (**Figure 44**), the heights of failure in the development headings and cut-throughs are indicated using the methodology of Seedsman (2012[21]), within the primary roof support horizon in the majority of the area, even using the conservative K ratio of 2.2 (**Figure 101**).

[20] Seedsman, R.W. (2011). Application of the brittle failure criterion to the design of roof support in the soft rocks of coal mines. 2011 Underground Coal Operator's Conference. Pp. 60-72.
[21] Seedsman, R.W. (2012). The development and application of a logical framework for specifying roof and support/reinforcement in Australian underground coal mines. Seventh International Symposium - Rockbolting and Rock Mechanics in Mining.

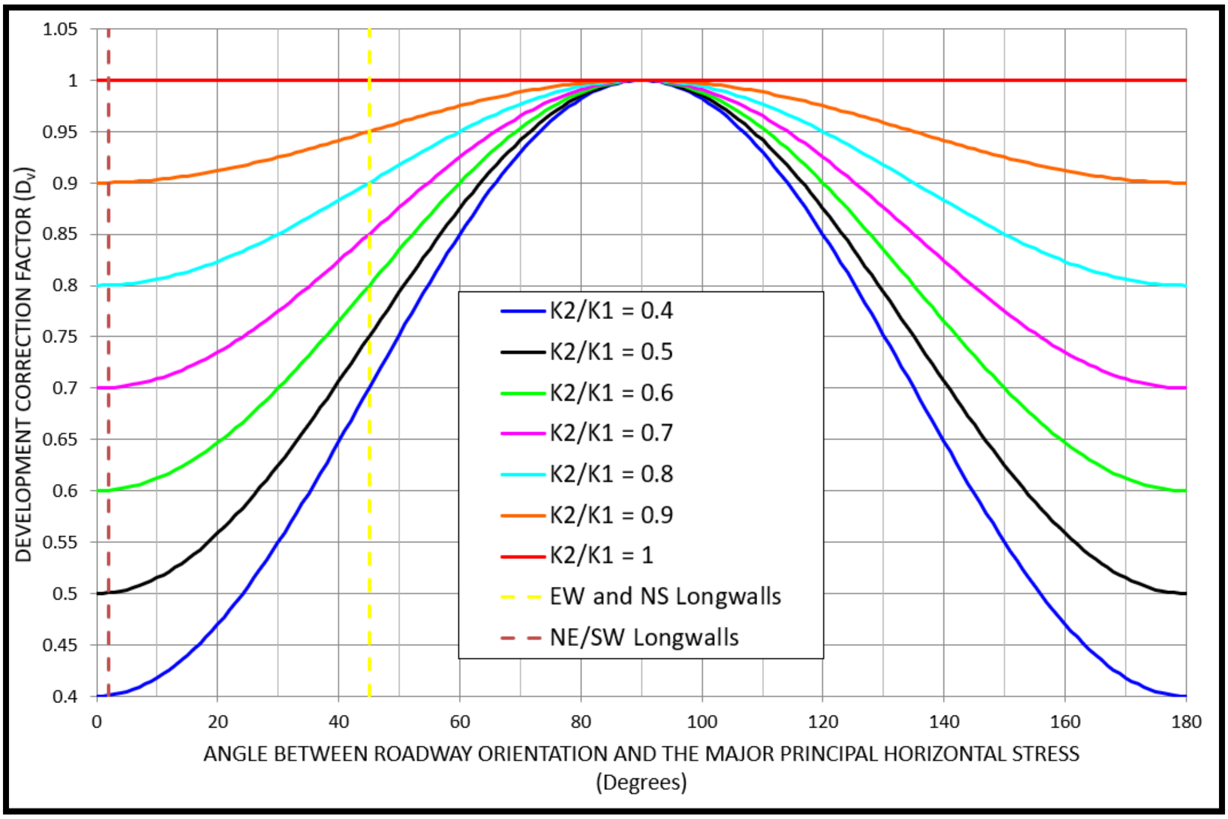

Figure 100. Development Correction Factor for Roadway Alignment D_v.

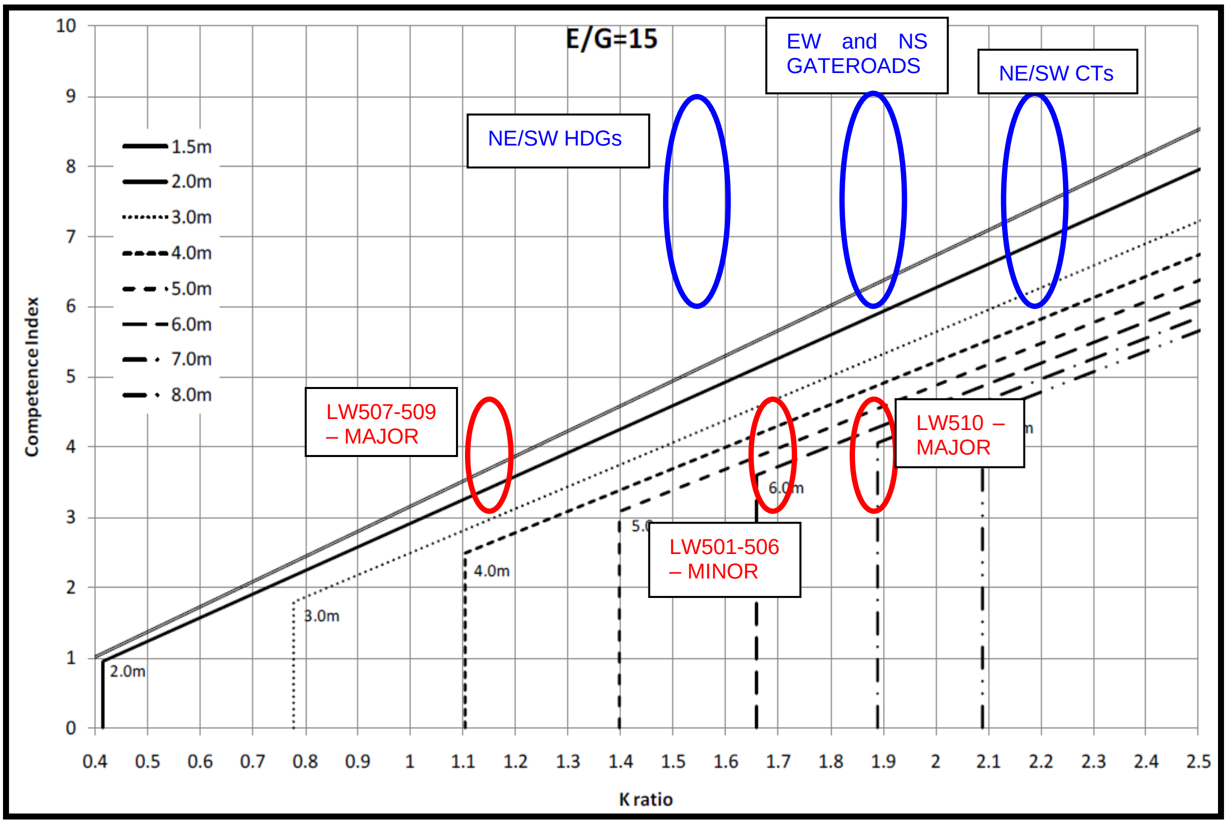

Figure 101. Height of Failure above a 5 m x 3 m Roadway (Seedsman, 2012).

6.3.2.2 Longwall Extraction

Similar to the primary support patterns the analytical calculations for the onset of compressive failure in the Maingate during longwall retreat are documented below (Seedsman, 2011). For longwall retreat, the K ratio (major horizontal: vertical stress) is adjusted as follows:

$$K = K_i * F_m / M_v$$

Where: F_m = Concentration of the horizontal stress at the maingate corner resolved across the roadway.
M_v = Concentration of the vertical stress at the maingate corner.
K_i = Stress ratio before mining.

The F_m value is determined from **Figure 102**, depending on whether the major or minor horizontal stress is concentrated at the Maingate.

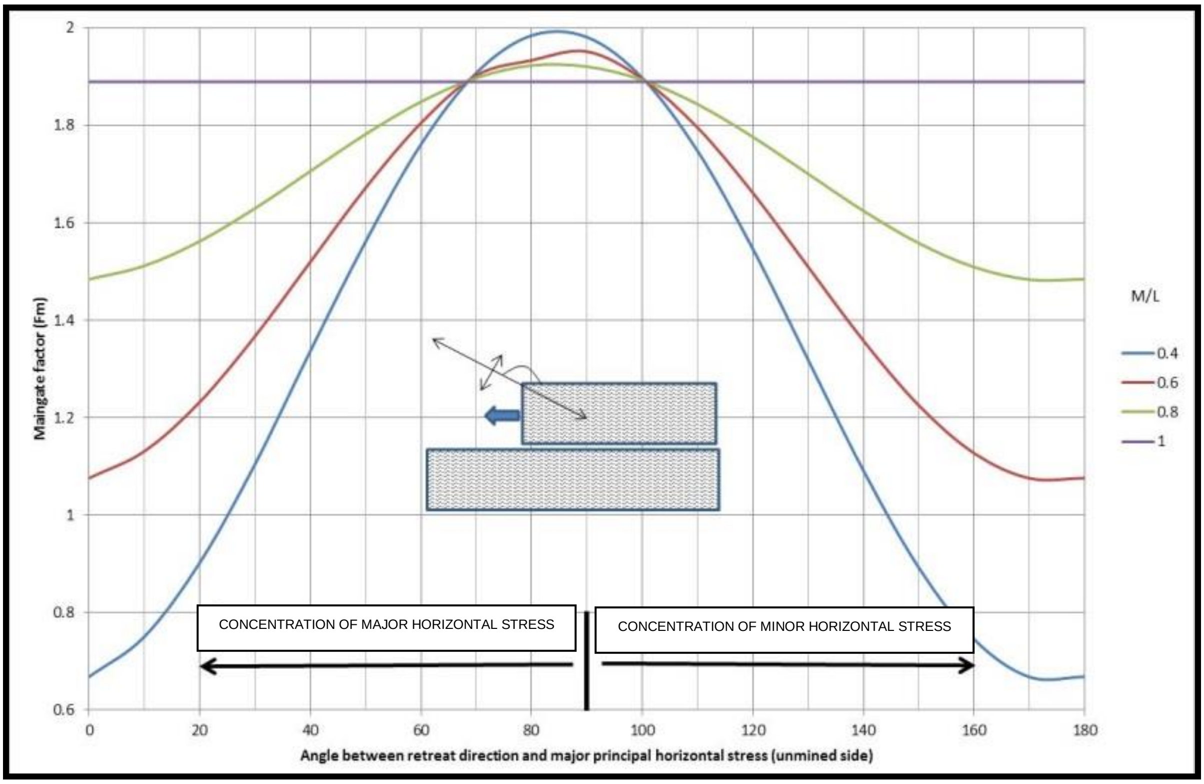

Figure 102. Stress Factor for Component Normal to Roadway Centreline – F_m (Seedsman, 2011).

The competence index typically halves at the Maingate corner as the vertical stress doubles:

$$CI = RSI/M_v$$

From **Figure 102**, the F_m value for Longwalls 501-506 for the minor horizontal stress concentrated at the Maingate and a σ_h/σ_H ratio of 0.71 is 1.55. For longwall extraction, the stress ratio at the Maingate of these panels is therefore 1.71

(2.2*1.55/2). This value increases to 1.87 for Longwall 510 for the major horizontal stress concentrated at the Maingate (**Figure 102**).

For the favourably aligned Longwalls 507-509, the stress ratio is significantly lower as anticipated at 1.14, even assuming a major stress concentration at the Maingate.

Based on **Figure 101**, routine secondary support is anticipated during longwall retreat for the Bulli Seam gateroads in these longwall panels, particularly the east/west and north/south panels. Even if the average K ratio of 1.76 is used in the analysis rather than the 2.2 value, routine secondary support is indicated in the majority of the area. Some optimisation and reduction in the density of the patterns may be possible in the favourably aligned Longwalls 507-509 (**Figure 101**).

As Seedsman (2011) indicates, some caution is necessary if this model is used. There are other failure modes as well as compressive failure, which must be considered. In particular, the potential delamination of thinly bedded roof must be addressed.

6.3.3 Bedding Plane Delamination

For the reinforcement of bedding partings, the key determinants of roof support density are the magnitude of the horizontal stress (directly related to the depth of cover) and the presence/absence of low friction bedding surfaces such as slickensides.

A compilation of Australian support densities shows an underlying trend of bolting densities increasing with depth (**Figure 103**). The coloured lines on **Figure 103** are derived from the analysis of bedding parallel shearing stresses for different friction angles.

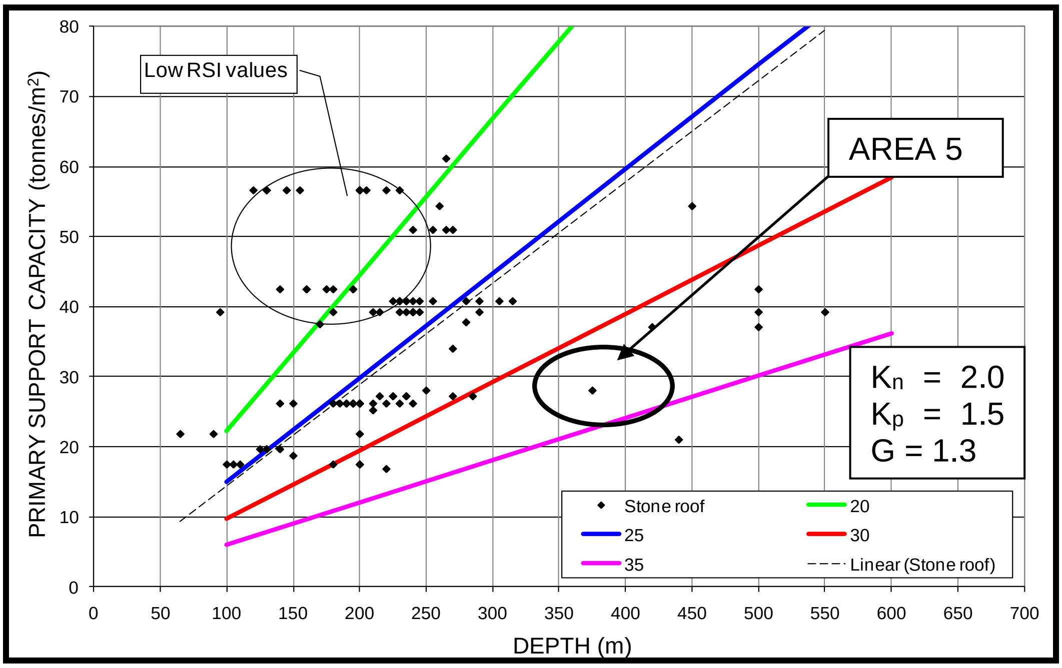

Figure 103. Comparison between ideal BPXS support capacity at 0.4 m into the roof and the Australian database (Seedsman et al, 2009).

In the Area 5 workings at depths of cover of 345-395 m and assuming a friction angle of 30°, primary support capacities of 34.5-39.5 t/m^2 are indicated (**Figure 103**). For a 5.2 m wide roadway, this equates to 5.3-6.0 bolts/m indicating that a primary support pattern of 6 bolts/m could be installed in the majority of Area 5 where the depth is <395 m. This is consistent with experience at shallower Bulli Seam operations.

From both an occupational health and safety (OH&S) context and also the requirement to restrain skin failure, full mesh panels are recommended.

6.3.4 Rib Behaviour

Based on an analysis of brittle coal and observations at numerous mines in both coking and thermal coal, Seedsman (2006)[22] proposed that compressive failure in coal ribs will initiate when the vertical stress/coal UCS ratio exceeds 0.27.

Average coal strength values of 23-26 MPa are indicated for the Bulli Seam, suggesting that mining induced fractures (MIF) will develop at depths greater than about 270 m (assuming an average strength of 25 MPa). This is consistent with the observations at other Bulli Seam mines. These assumptions are for uniform overburden loads.

The magnitude and the depth of failure are controlled by the selection of a value for the spalling limit and are independent of the magnitude of the vertical stress (**Figure 104**). The practical implication of this is that once rib failure develops it should not worsen progressively with increasing depth.

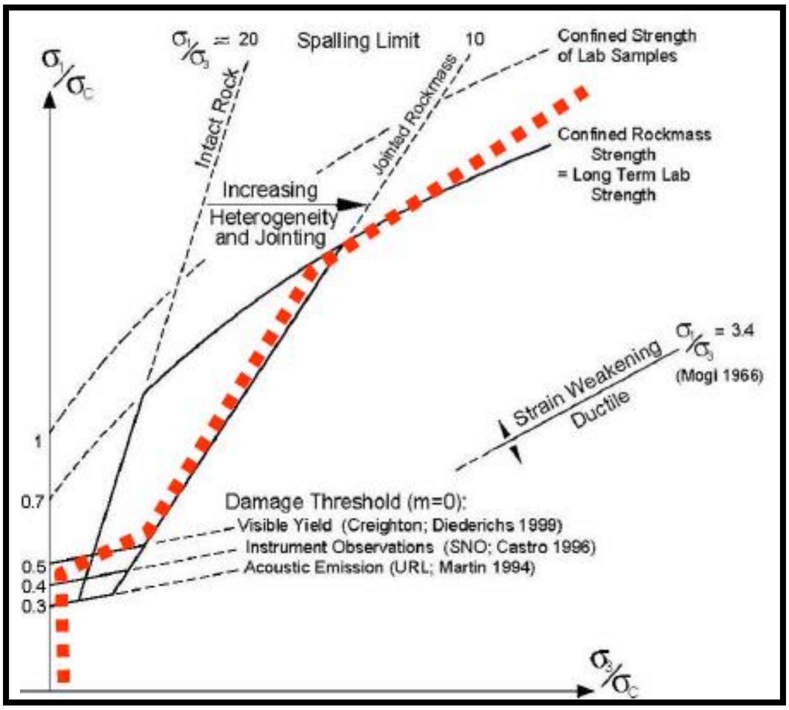

Figure 104. Modes of Rock Damage and Failure and the Composite In-situ Strength Envelope for Hard Rocks (Seedsman, 2008).

[22] Seedsman, R.W. (2006). Joint Structure and Coal Strength as Controls on Rib Stability. Proceedings of the 2006 Coal Operators' Conference, Wollongong, Pp. 44-51.

A brittle analysis using a spalling limit of 10 and isotropic elastic assumptions derived from back analysis, indicates the coal competence index is the major control on the depth of failure (**Figure 105**). Index values generally <3 indicate failure of the Bulli Seam ribs to depths greater than 0.8 m are likely in Area 5.

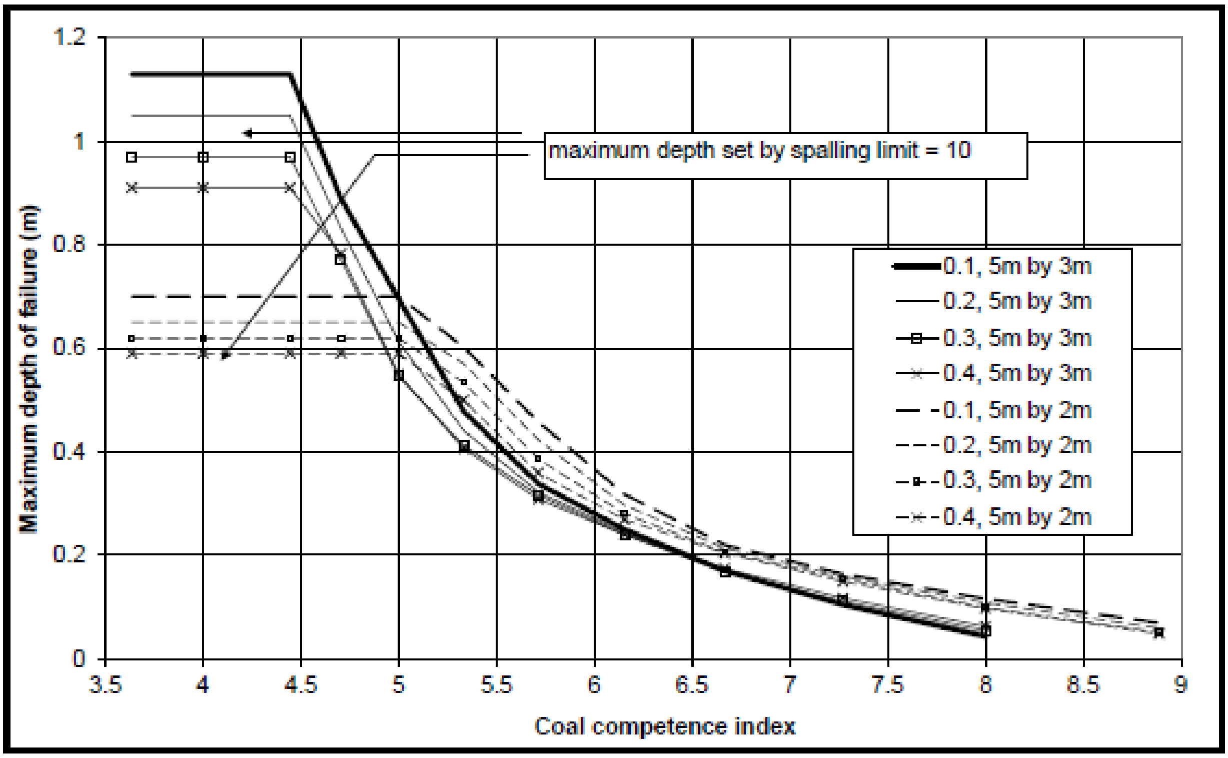

Figure 105. Depth of Brittle Failure in Coal Ribs for Different Roadway Heights and K Ratios (Seedsman, 2012).

The preceding discussion focuses on the compressive failure of coal ribs. Ribs can also be exposed to planar and wedge slides along the joints and toppling failures across steep seam grades.

6.4 Roof Support Patterns

For roadway development, roof bolting is required to either reinforce bedding partings in the immediate roof or to support rock undergoing compressive failure or rock that is exposed to the onset of tensile roof stresses.

During longwall operations, the stress changes that occur can sometimes lead to the need to install additional support in the maingate against the onset of compressive failure. For longwall tailgates, there is a need to consider additional support against the hazard of stress reductions and the onset of tensile stresses.

The specification of the roof support in Area 5 has used the logical framework proposed by Seedsman et al (2009), as shown in **Figure 106**. This framework can be applied at the different stages of the mining cycle (i.e. roadway formation on development, maingate corner and tailgate corner).

Based on the preceding discussion, the roof support design in the Bulli Seam in Area 5, in stone roof conditions, will be based on the possibility of delamination along bedding partings in higher RSI areas. Compressive failure should be considered in lower RSI areas during longwall retreat.

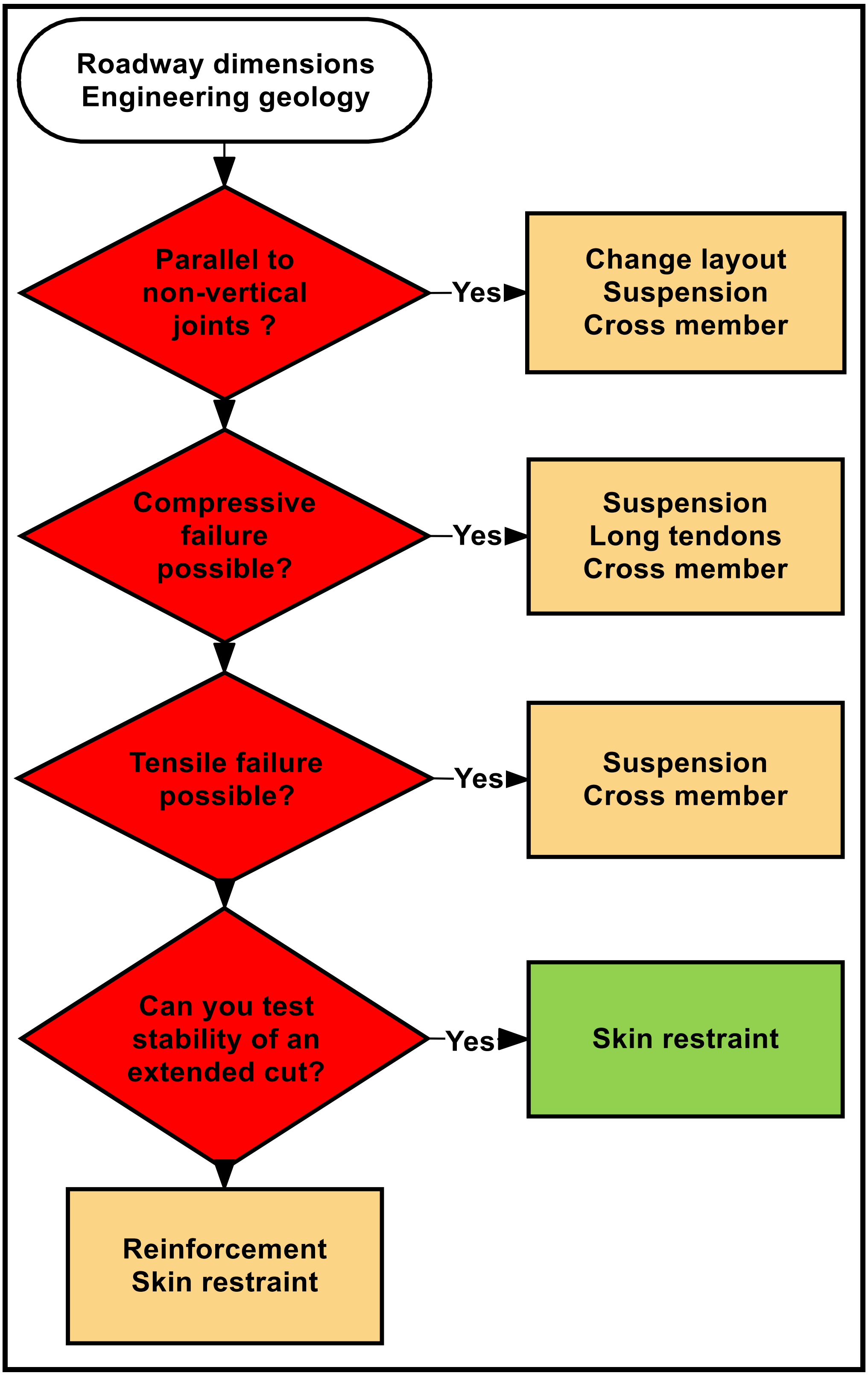

Figure 106. Flow Chart for the Design of Roof Support (Seedsman, 2012).

6.4.1 Primary Support

6.4.1.1 Other Bulli Seam Mines

The primary roof support patterns used in the current Bulli Seam workings at the Appin Mine, range from Level Green to Level Red as follows:

- Green - 6 x 2.1 m x grade bolts/m with full mesh.
- Yellow - 8 x 2.1 m x grade bolts/m with full mesh.
- Red - 8 x 2.1 m x grade bolts/m with full mesh + 2 x 8m tendons/2 m.

There is also a Double Red pattern, which infills the Red pattern to 2 cables every 1 metre.

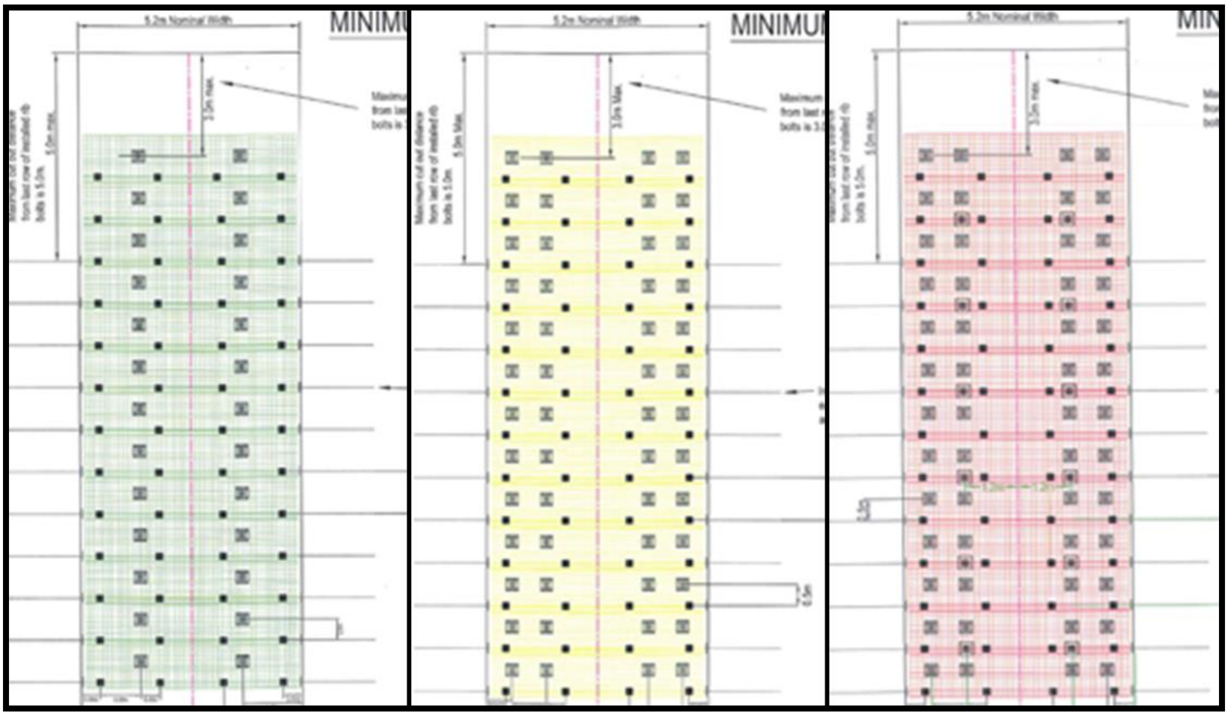

Figure 107. Primary Roof Support Plans at the Appin Mine.

6.4.1.2 Proposed Patterns in Area 5

As detailed above, in non-structured areas the two failure mechanisms to be addressed in Area 5 are compressive failure and bedding plane delamination.

Based on the previous discussion, indicative primary bolting patterns considering depth of cover, roof strength and geological features are shown in **Figure 108**.

Due to the relatively shallow depth in Area 5, a 6 bolts/m primary support pattern has been specified for the gateroads (Code Green). This has been upgraded for the longer-term Mains and bleeder drivage to an 8 bolts/m Code Yellow pattern (**Figure 108**).

Adjacent to the sills, faults and dykes and also in the drift drivage, the primary support pattern has been upgraded to a minimum Code Orange 8 bolt pattern with cables (**Figure 108**). The minimum Code Orange cable support in the drifts is also justified by the orientation of the horizontal stress at 90º to the drifts, in conjunction with the anticipated slow cutting rates and life of mine function of these drifts. This standard cable support pattern used at the Dendrobium and Appin mines provides sufficiently high factors of safety to support potential deadweight fall masses.

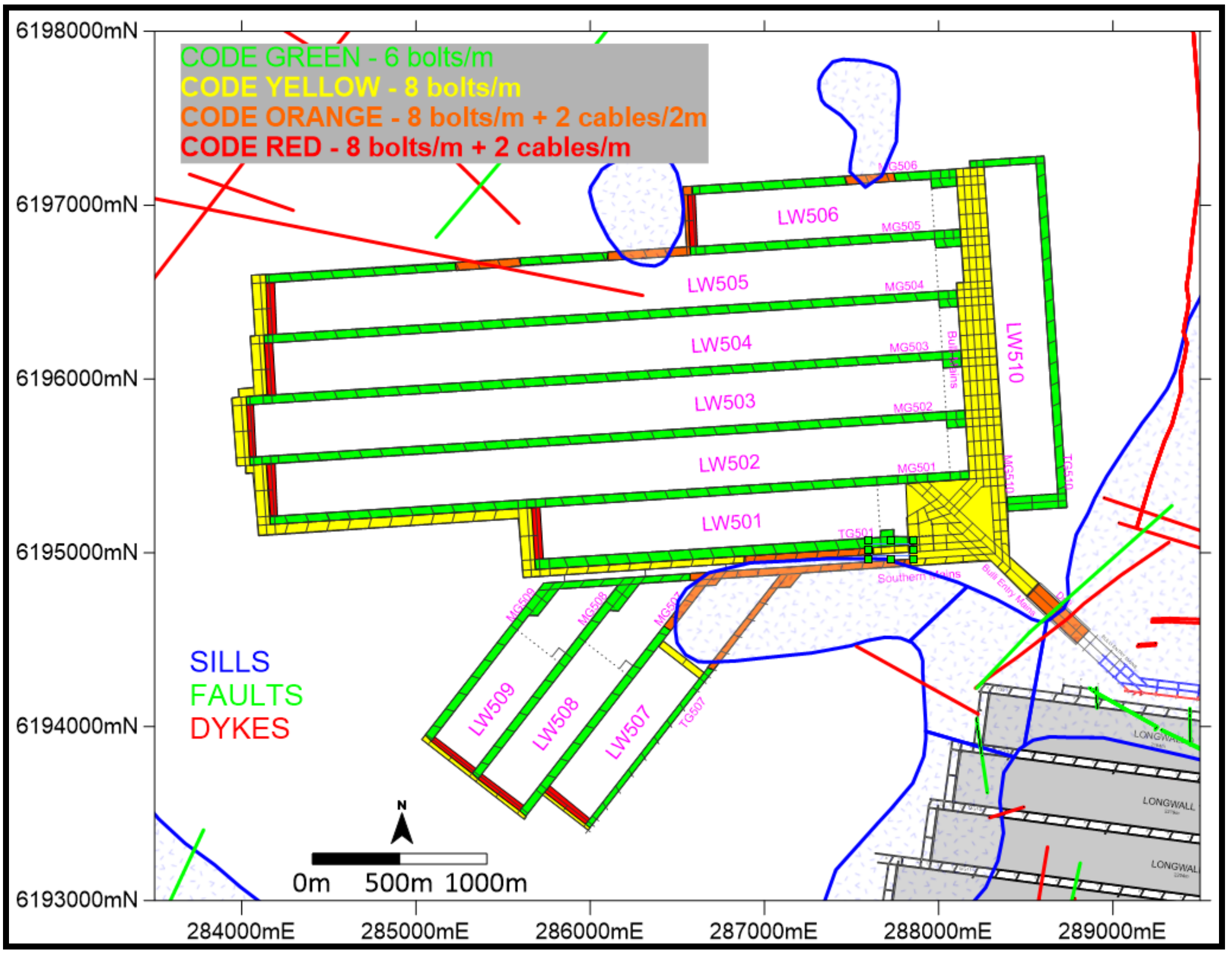

Figure 108. Proposed Primary Roof Support.

Indicative Code Red support has been specified for the first pass of the face roads and may be required in geologically structured areas when triggered by the development TARP (**Figure 108**). It is highlighted that specific designs for each face road should be carried out on an individual case by case basis and documented in design reports.

At the Appin Mine, the following support patterns were specified by Pitt and Sherry (2015) for the proposed coal clearance drifts (**Figure 109**):

- Code Yellow – 8 x 2.1 m per metre.
- Code Red - 8 x 2.1 m per metre and 2x 8 m cables/2 m.

The Code Red pattern was specified for the majority of these drifts. This pattern is equivalent to the proposed minimum Code Orange support pattern for the Area 5 access drifts in **Figure 108**. It should be highlighted that the drifts were never developed at the Appin Mine.

The design methodology used by Pit and Sherry (2015) addressed the variability in the geological and geotechnical conditions such as lithology, strength and stress by incorporating sensitivity studies into the engineering analysis. A number of geotechnical models were used and these were calibrated to known conditions at the Appin Mine.

A similar methodology documented in the standard Dendrobium Mine support design report is recommended in the preparation of the drift support patterns. This methodology and documentation should be extended to all support patterns once mining commences in the Bulli Seam.

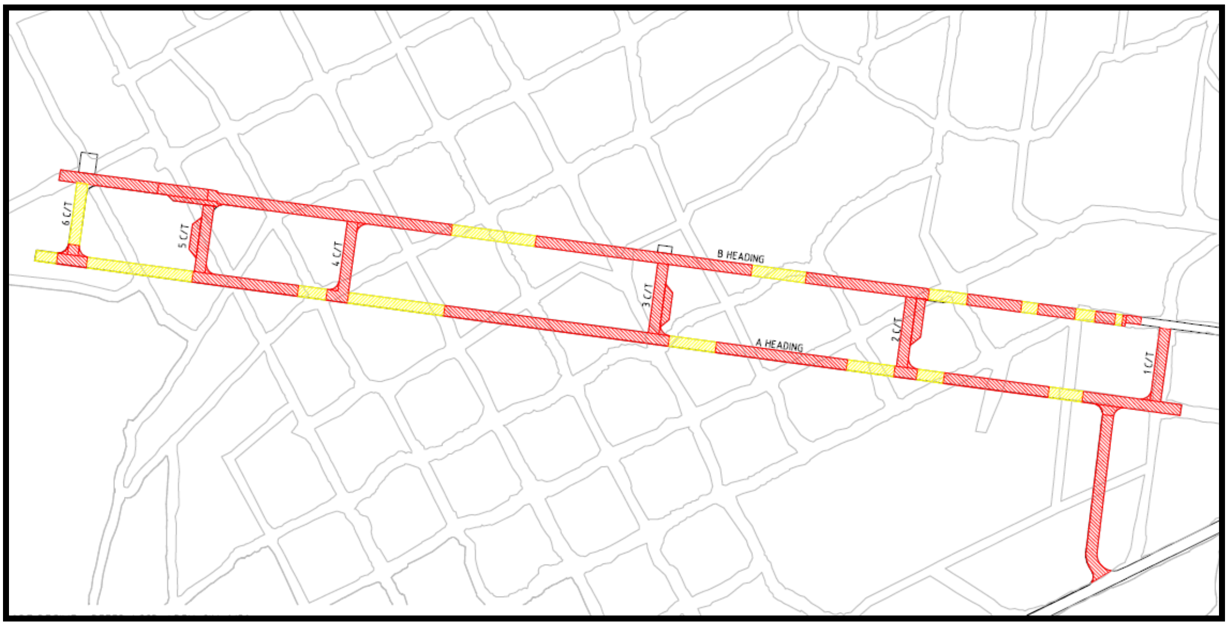

Figure 109. Roof Support – Appin Mine Coal Clearance Drifts (Pitt and Sherry, 2015).

6.4.1.3 Bolt Length

At other deeper Bulli Seam mines, the standard bolt length is 2.1 m. Due to the minimum 2.7 m gateroad development height in Area 5, double pass drilling would be required to install this length of bolt. The potential to install 1.8 m in the anticipated roof conditions in Area 5 has therefore been addressed.

The minimum bolt length can be assessed by analysis of the two potential roof failure mechanisms, namely compressive failure and bedding plane delamination.

Compressive Failure

For compressive failure, the range of RSI values in Area 5 for the immediate stone roof are typically 6-9 (**Figure 44**). Assuming transverse isotropy (E/G=15) and a σ_H:σ_V ratio (K ratio) of 1.76, the height of compressive failure for an RSI of 9 is 0.23

m and localised to the roof/rib corner in areas with roof RSI values of >8 (**Figure 110**).

This height increases to 0.8 m and 0.36 m for RSI values of 7 and 8 respectively (**Figure 110**). It is only in the lowest RSI values approaching 6 in the north-western part of the area where the height of compressive failure increases to 1.59 (**Figure 110**).

It should be highlighted that this analysis is dependent on the K ratio used. For example where the RSI is 8, the height of failure increases from 0.36 m to 0.83 by increasing the K ratio from 1.76 to 2.

The analysis shown in **Figure 110**, has been carried out on a 3 m high x 5.2 m wide roadway. Varying the roadway height between 2.7 m and 3.2 m has minimal impact on the height of compressive failure.

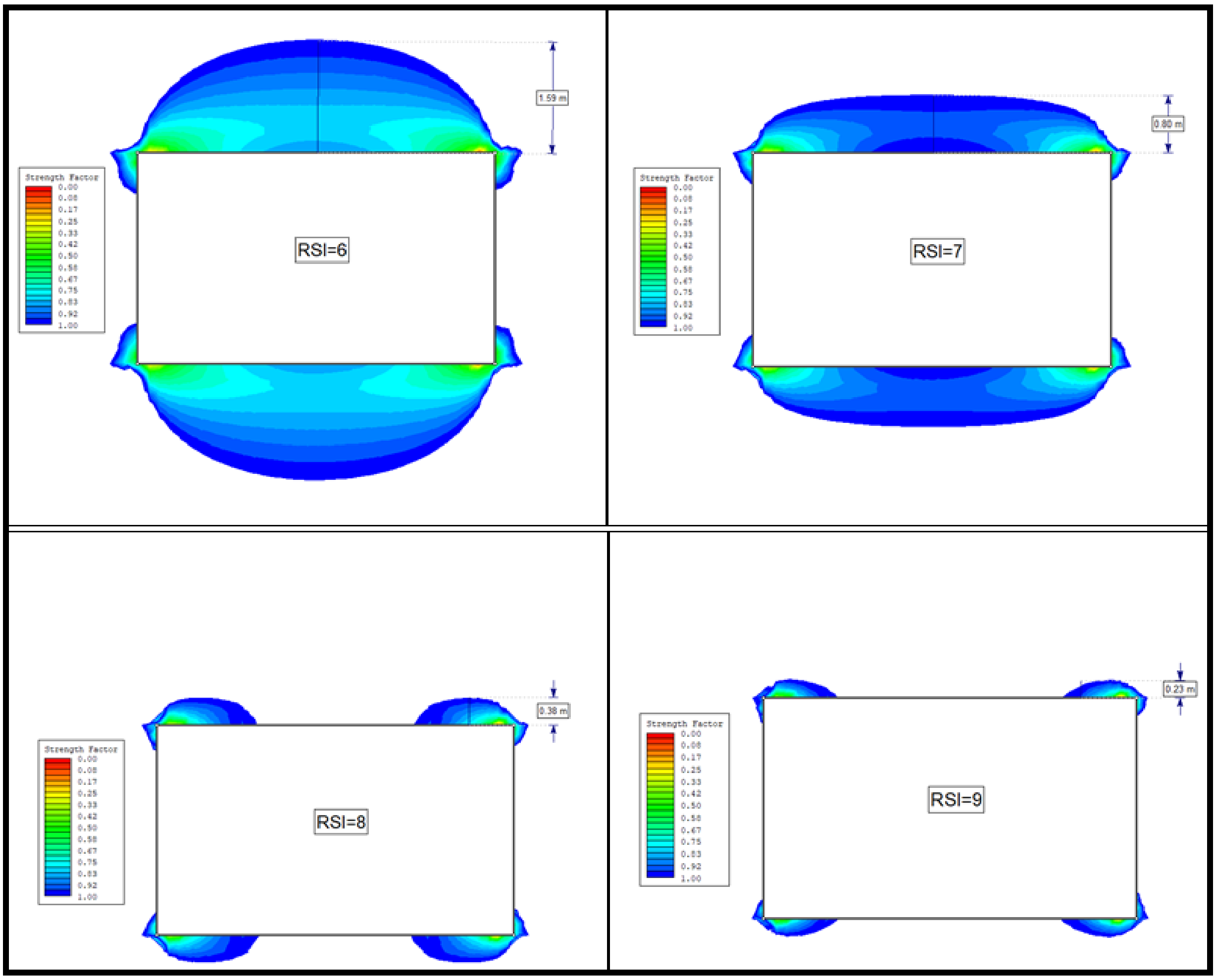

Figure 110. Height of Compressive Failure for Roadways Developed Normal to the Major Principal Horizontal Stress.

The appropriate ground control response to this possible compressive failure would be to suspend the failure mass with bolts longer than the height of failure. Using the RSI of 7 example, which applies to the majority of the area, the mass of a 0.8 m high rectangular block is 10.4 tonnes (5.2 m * 0.8 m * 2.5 t/m^2). This is well below the installed capacity of just one 34 tonne bolt.

The anchorage above the failure mass also needs to be considered and for typical 70 MPa Bulli Seam stone roof, 0.45 m of anchorage is required (**Figure 111**).

The minimum bolt length in areas of RSI >7 is therefore 1.35 m (0.8 m + 0.45 m for anchorage and 0.1 m for the tail).

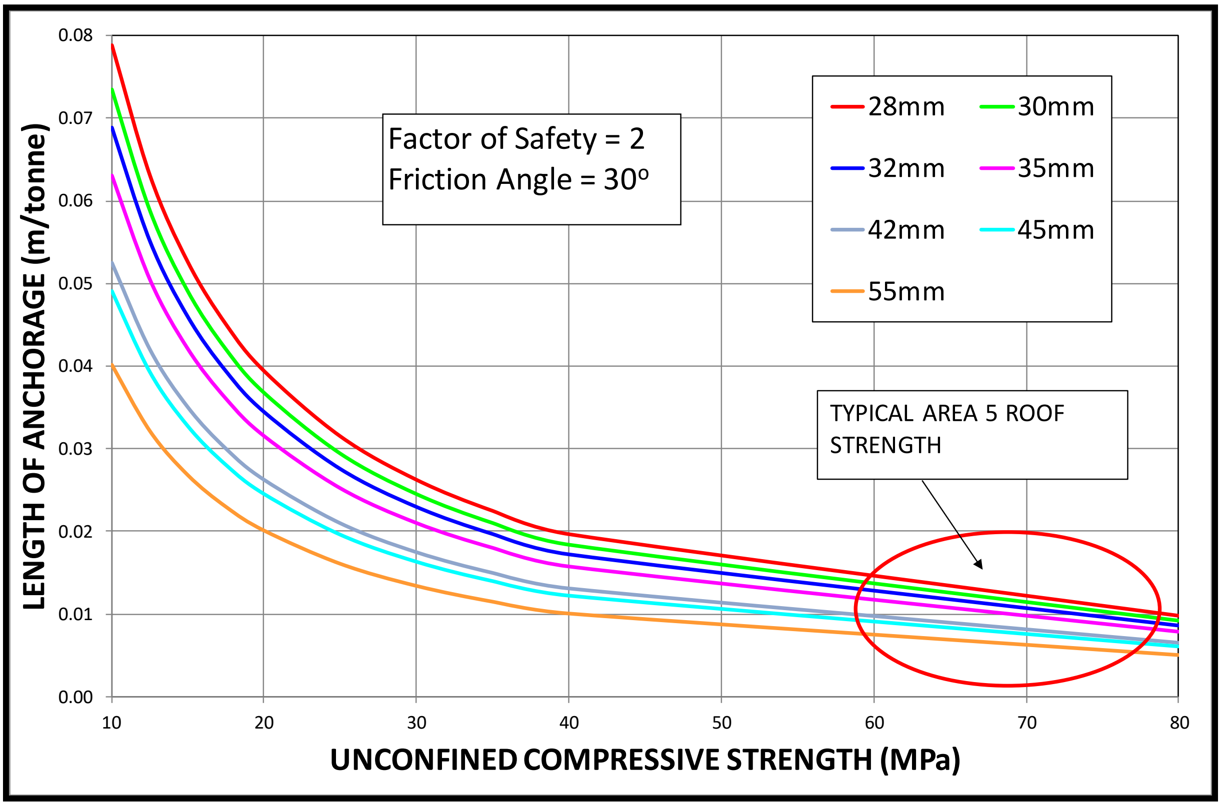

Figure 111. Nomogram to Estimate Necessary Anchorage Length for Bolts and Cables in Different Diameter Holes.

Bedding Plane Delamination

For the reinforcement of bedding planes the methodology of Seedsman et al (2009) has been used. The method determines the required beam thickness to span a 5.2 m roadway and then calculates the bedding reinforcement required to create the beam.

A voussoir beam analysis is used to determine the required thickness of the roof beam created by bolt reinforcement. For 60 MPa roof and a conservative height of softening of 5 m (surcharge on the beam), a roof beam thickness of 0.4 m would provide a sufficient level of conservatism (**Figure 112**).

To calculate the reinforcement of the bedding, requires the determination of the bedding parallel shear forces and the resistance offered by the roof bolts.

The calculation of the bedding parallel shear forces is based on the application of elastic theory in three dimensions. The bedding plane excess shear force per metre of roadway advance (BPXS) is the elastic shear stress parallel to bedding aligned normal to the roadway centreline, in excess of the frictional resistance on that plane associated with the normal stress.

BPXS is a function of the vertical stress, K ratios acting normal and parallel to the roadway, the total friction angle (x) along the bedding and the location of bolt installation with respect to the development face (F_b). XS is a function of height and R is a correction factor for different K_n and K_p values.

$$BPXS = XS * \text{Vertical Stress (MPa)} * (1 + (R*((35-x)/25)))*F_b$$

The timing of the bolt installation with respect to the development face is corrected using the F_b factor .

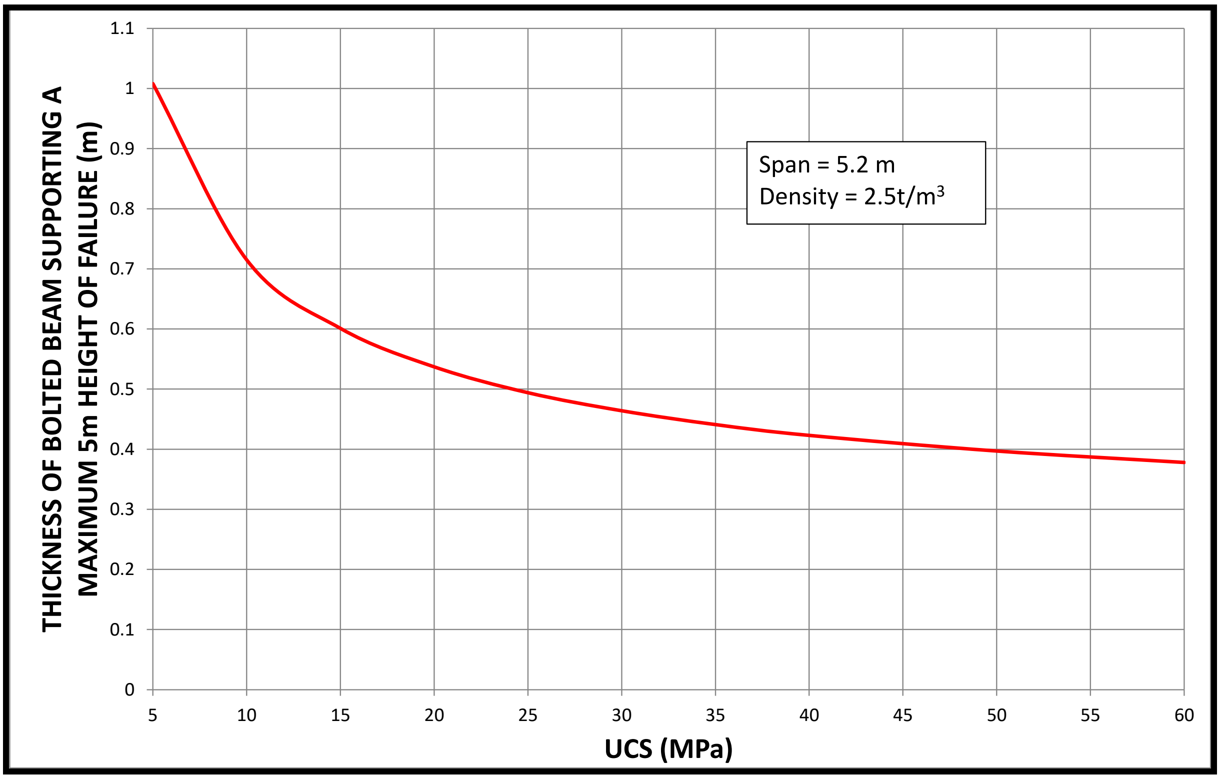

Figure 112. Required Beam Thickness.

For bedding reinforcement, the minimum bolt length should be 1.35 m to allow for 0.4 m of localised compressive damage at the roof/rib corner (**Figure 110**), 0.4 m for the beam to be built (**Figure 112**), 0.45 m for anchorage (**Figure 111**) and 0.1 m for the tail.

Synopsis

Based on these analyses, 1.8 m bolts could be installed in the majority of Area 5. Minimum 2.1 m bolts are recommended in the access drifts from the Wongawilli to Bulli Seam.

The initial Bulli Seam drivage with 1.8 m bolts should be appropriately instrumented and monitored to confirm the analysis presented above. Test hole drilling during bolt installation should also be used to determine potential roof partings.

6.4.2 Secondary Support

6.4.2.1 Other Bulli Seam Mines

Secondary support in the Maingate belt roads at Bulli Seam mines is based on the conditions encountered, typically ranging from 1 cable/2 m up to 3 cables/m in the poorest conditions or to maintain Z ventilation through the goaf. Lower density patterns are installed where U ventilation is in place. Experience at the Appin Mine indicates cable patterns as dense as 5 cables/m are installed in major stress notch areas with laminite roof.

The cable support in the travel road is normally TARP driven. Due to significant deterioration in the travel roads resulting from abutment stresses in the current longwall area at the Appin Mine, cables are routinely installed prior to longwall retreat. Depending on the retreat direction, additional support may also be required in stress notch areas.

At other Bulli Seam operations, cribless Tailgates using 3 cables/m are used. From a ground control aspect, 2 cables/m are typically sufficient but additional support is installed due to ventilation requirements to maintain the return airway. A tailgate shield is used at one Bulli Seam operation.

As such, secondary support designs may be denser to cater for both ventilation and ground support aspects. At the Appin Mine, standing support using either pumpable cribs or Link ‘n’ Locks (both 4 and 9 point) are installed in conjunction with cables. As expected, the support density is increased through intersections.

6.4.2.2 Gateroads in Area 5

The height of failure anticipated during longwall retreat as shown in **Figure 101** indicates secondary support would be required in the majority of gateroads in Area 5, with some optimisation of the cable bolt length and density once mining commences particularly in the favourably aligned Longwalls 507-509.

Where standing support can be installed, patterns of tin cans or timber cribs at 3 m spacing in the intersections and 4 m in the mid-pillar sections are anticipated in the Tailgate, based on experience at other Bulli Seam mines to supplement the long tendon support. The design of the support in the Tailgate should be based on the presumption of low horizontal roof stress and the onset of tensile roof stresses to restrain dead weight of blocks of roof.

The proposed secondary support patterns are detailed in **Figure 113**, assuming a U ventilation with the majority of the area supported with Code Yellow in the Tailgate and Code Orange in Maingate. Code Red is specified for the stress notch area where LW502 retreats past LW501 and potential areas of geological structure including faults, dykes and sills (**Figure 113**).

The Tailgate support for the first Longwall 501 and the inbye end of LW502 in virgin ground has been upgraded to Code Orange due to these roadways potentially experiencing increased levels of horizontal stress concentration (**Figure 113**).

Increased levels of support are also anticipated in the longwall take-off areas.

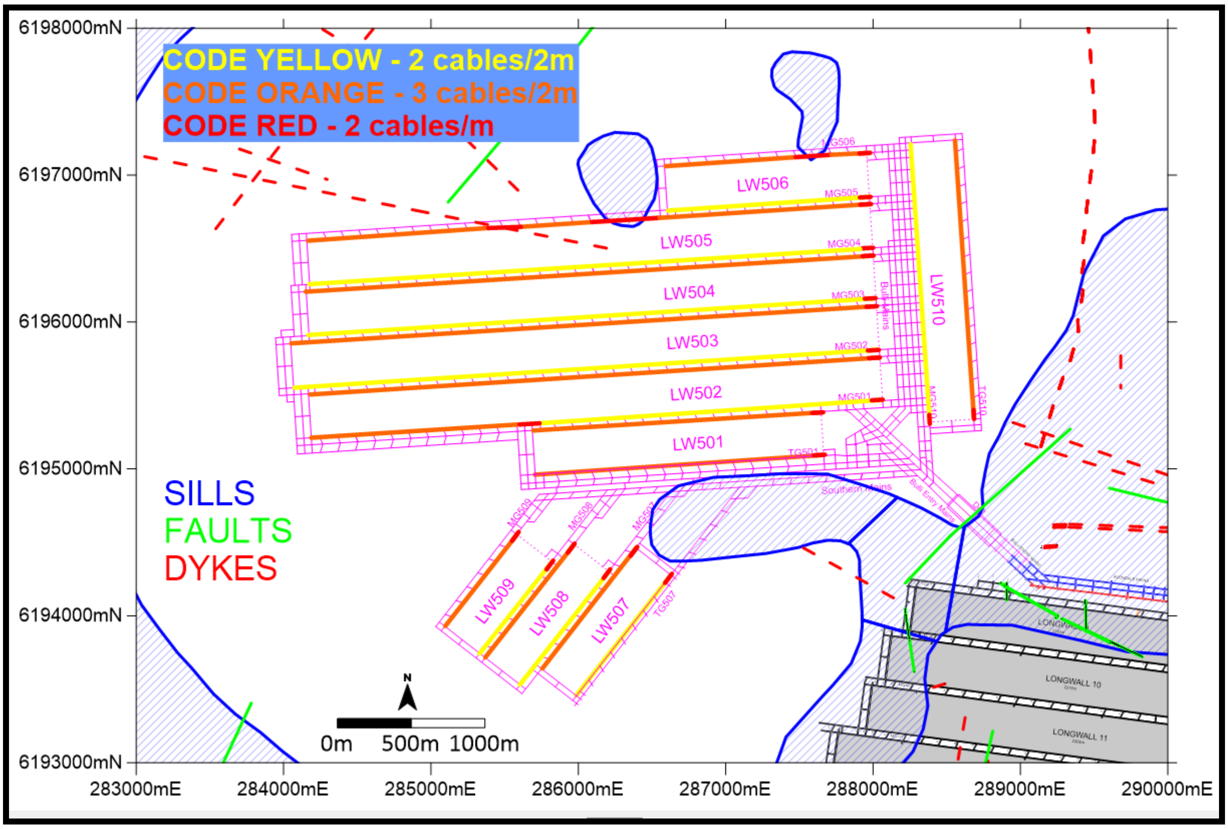

Figure 113. Proposed Secondary Roof Support.

6.4.2.3 High and Wide Driveages in Area 5

For both high and wide drivages the dimensions should be minimised where ever possible to assist in ground control in the Bulli Seam. Secondary support design for the wide drivages should be based on deadweight suspension. The length of the cables will be controlled by the roof lithology and the necessary anchorage (**Figure 111**). The exact design of the individual drivages will be site specific and should be carried out at a later date. A roof coring program may assist in this regard.

For cable design, it is also important that there is a match between the stiffness of the support elements and the loading and the associated allowable deformation of the roof. For example, grouted cables are very stiff in tension and may fail within 10-15 mm of displacement, whereas point anchored systems will stretch about 5% of the free length before they fail.

6.4.2.4 Geological Conditions in Area 5

There will be geological conditions such as close spaced joints and faults, as well as areas affected by igneous intrusions, where the standard patterns outlined in this section of the report cannot be directly applied and that specific strategies will need to be developed based on what is encountered.

6.5 Rib Support

6.5.1 Issues

The Appin Mine and West Cliff Rib Support TARPs provide a good indication of where additional rib support is likely to be required in Area 5. These include increased severity of the spall and the number of joint sets encountered.

The majority of the gateroads in Area 5 are aligned at <30º to the trend of either the primary and secondary cleat in the coal (**Figure 77**). This orientation increases the hazards associated with planar slide and wedge failures, as well as toppling failures. The logical framework of Seedsman (2012) can be used to specify the rib support required (**Figure 114**).

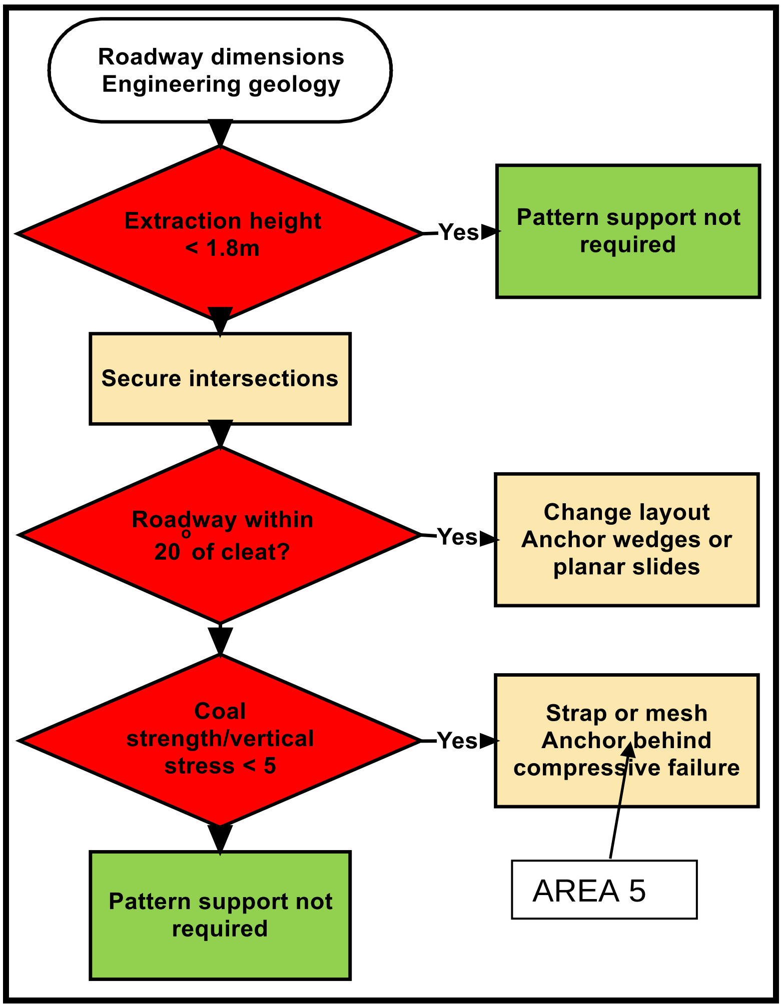

Figure 114. Logical Framework for Rib Support (Seedsman, 2012).

6.5.2 Proposed Rib Support Patterns in Area 5

Mining induced fracturing of the ribs in the Bulli Seam workings can be expected at depths >270 m, based on an average 25 MPa coal strength. In conjunction with the alignment of the gateroads to the cleat, routine pattern rib support can be expected in Area 5.

With reference to **Figure 105**, the depth of failure in 25 MPa Bulli Seam coal on development at depths >350 m, is expected to be more than 0.8 m into the rib side. This is consistent with the Appin Mine where the depth of failure has been measured at around 1 m.

Similar rib support patterns to other Bulli Seam operations of 2-3 x 1.5 m bolts/m are recommended in Area 5. Steel bolts with mesh should be installed in the pillar ribs and cuttable bolts in the blockside. Longer bolts may be required in the higher drift drivages to ensure anchorage behind geological features that may be encountered. 1.8 m long rib bolts were specified for the proposed Appin Mine coal clearance drifts (Pitt and Sherry, 2015).

6.6 Wongawilli to Bulli Seam Drifts

Access to the Bulli Seam is planned utilising three drifts from the Wongawilli Seam. These drifts are planned to be 404 m long and inclined at 1 in 8. In this area, the interburden is approximately 20 m from the floor of the Bulli Seam to the top of the Wongawilli Seam.

Extensive drilling of the area using one vertical hole and four angled holes has been carried out since the pre-feasibility study was completed to provide an indication of the conditions likely to be encountered during the excavation of the drifts.

For ease of reference the core photography of these holes from the Bulli to Wongawilli Seams is presented in **Figure 115, Figure 116 and Figure 117** to illustrate the features likely to be encountered.

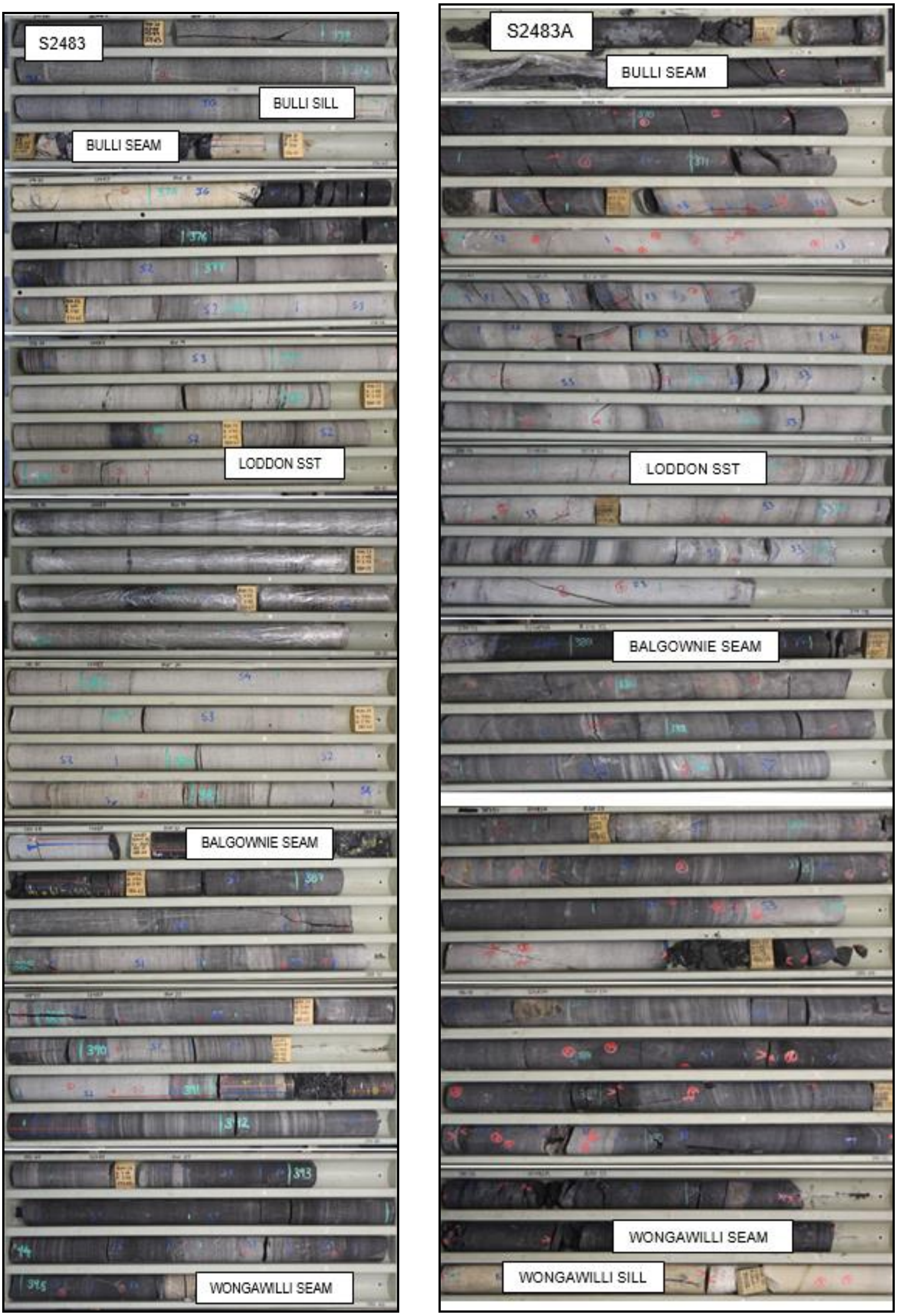

Figure 115. Core Photography – S2483 and S2483A.

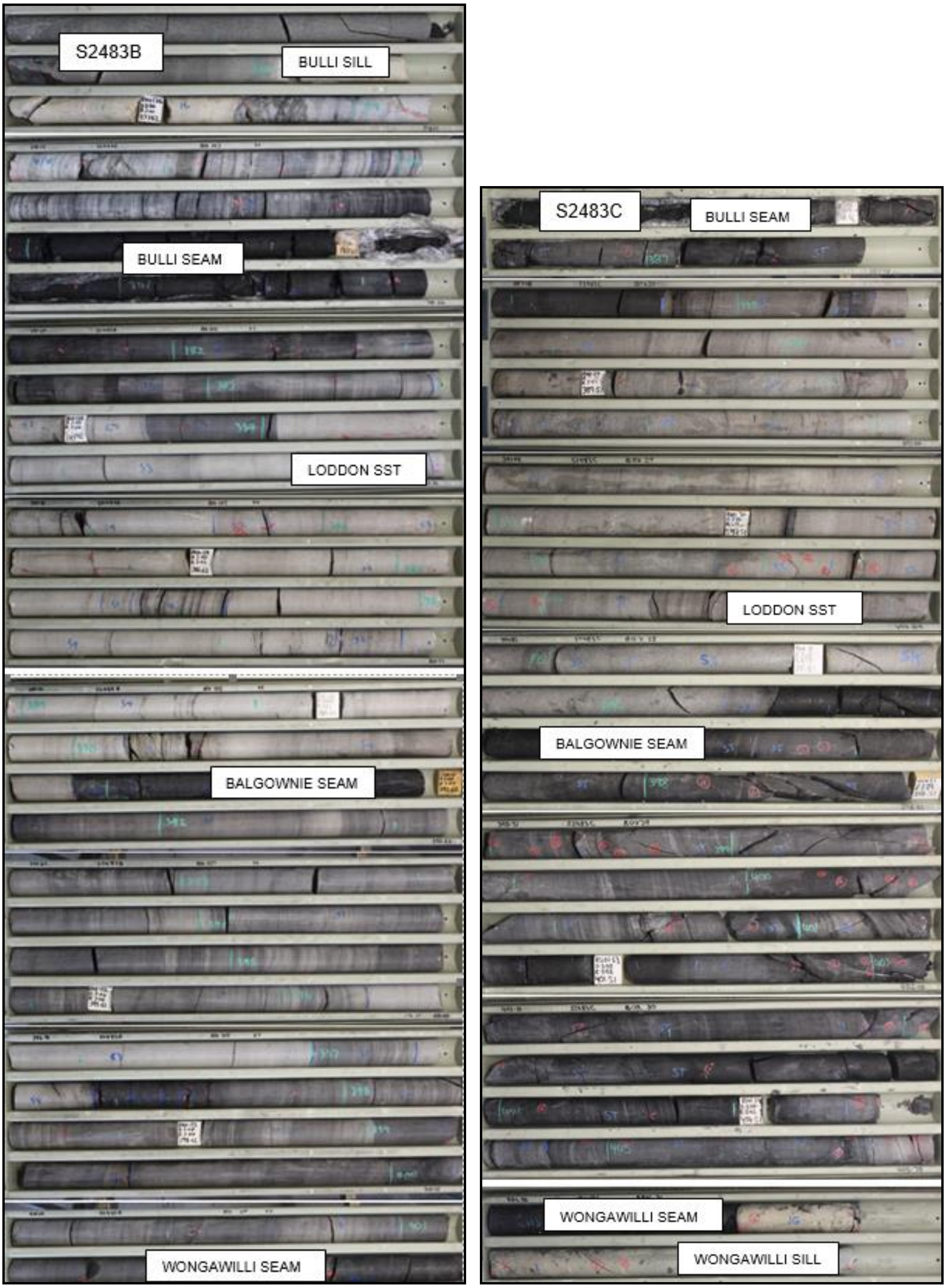

Figure 116. Core Photography – S2483B and S2483C.

Figure 117. Core Photography – S2483D and S2410.

Based on the observations by South32 geological personnel, that the silling appears more separated on the north-eastern side compared to the south-west, the drifts were moved 50 m to the north-east (D. McCarthy pers. comm.). As detailed earlier, in-seam drilling is planned prior to commencing the drifts (**Figure 70**).

The detailed exploration drilling has identified a possible fault/dyke/roll zone in the central part of the drifts. Structural interpretation from the scanner logs has also identified some variability in the jointing either side of this zone. On the western side, the joints are dominantly north-south and on the outbye eastern side they are aligned more to the east-west. Both these orientations are favourable to the NW/SE alignment of the drifts.

The drilling has allowed a refinement in the prediction of the extent of the Bulli and Wongawilli Seam sills. Along drift alignment 0, the Wongawilli Seam sill is thick in S2483A but has silled out in S2483B. Conversely, the Bulli Seam sill is evident in S2483B but absent in S2483A. It is planned to position the drifts away from these two sills (**Figure 118**).

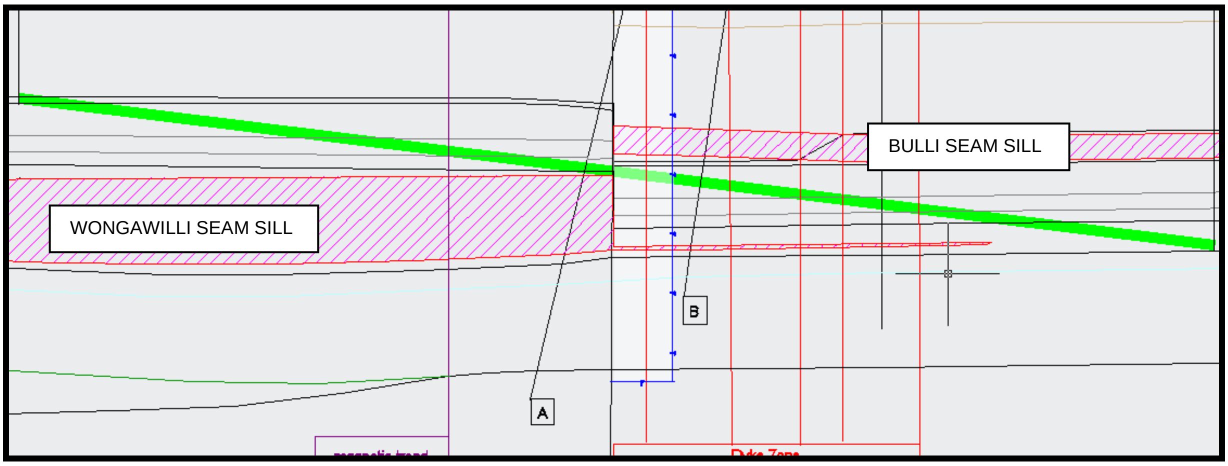

Figure 118. Cross Section – Drift Alignment 0.

A similar strategy is planned for drift alignment 1, albeit with some excavation of the Bulli Seam sill for approximately 35 metres (**Figure 119**).

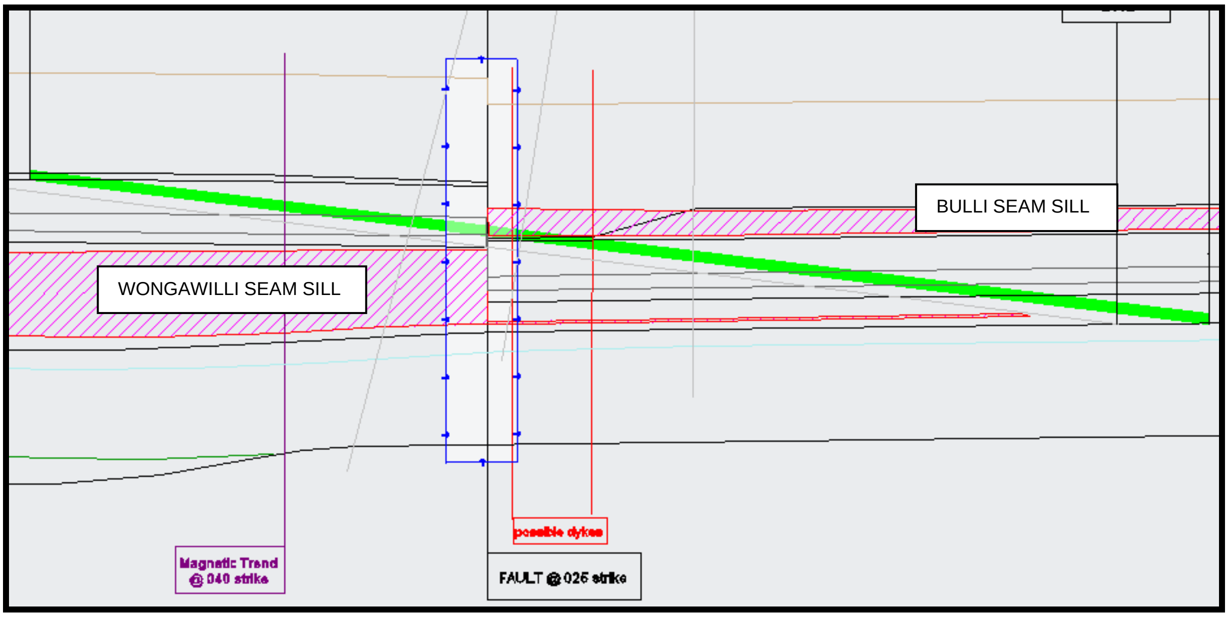

Figure 119. Cross Section – Drift Alignment 1.

In the southern drift alignment 2, a greater amount of excavation of the Bulli Seam sill is anticipated (**Figure 120**).

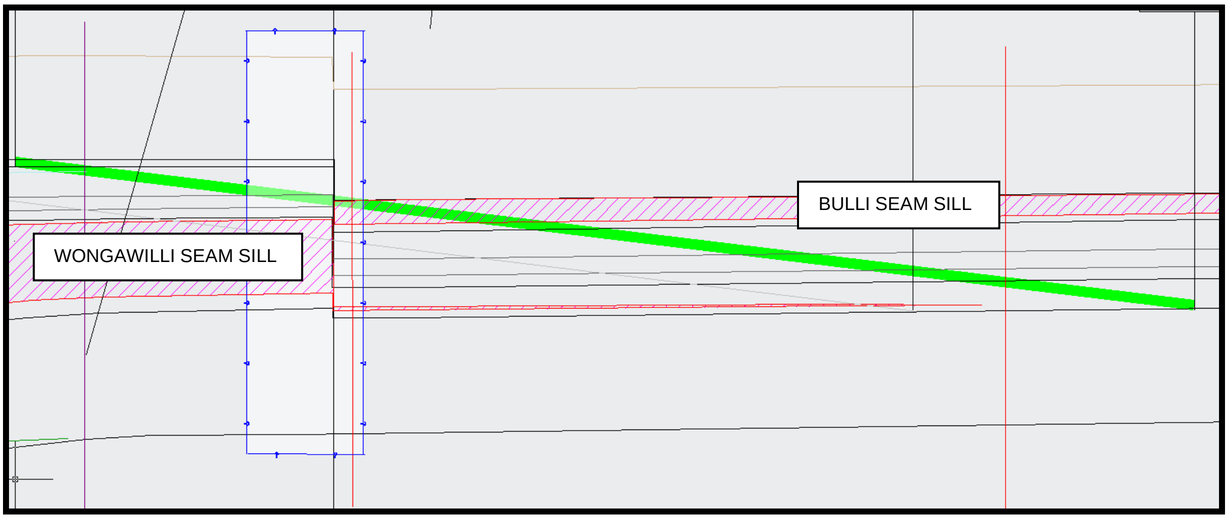

Figure 120. Cross Section – Drift Alignment 2.

Experience from drift drivages at other mines, is that localised slabbing can be expected as the drifts are excavated across sedimentary layers. Poorer ground conditions may also be experienced where a weaker coal seam with laminated roof and floor are encountered in the bolting horizon.

Areas of fracturing are also anticipated associated with the predicted structural zone as illustrated by the Balgownie to Wongawilli Seam interval in borehole S2483C (**Figure 116**).

It is planned to excavate the initial drift drivage of 56 m with a continuous miner then complete up to the Bulli Seam with a road-header. Indications from the sonic velocity logs is that the lower portion of the Bulli Seam sill is weaker. This may be of particular benefit to the central drift, which is predicted to excavate the lower part of this sill (**Figure 119**). The Wongawilli Sill is harder and should be avoided where possible. Some shotfiring may still be required in the southern drift alignment 2, which mines through the stronger upper part of the Bulli Seam sill (**Figure 120**).

7 LONGWALL LAYOUT

7.1 Geotechnical Issues

From a geotechnical perspective, GGPL consider there are a number of geotechnical issues that should be addressed when assessing the suitability of Area 5 for longwall mining.

1. Floor conditions.
2. Mining horizon and dilution.
3. Caving characteristics of the overburden.
4. Geological features.
5. Alignment of the joints and cleats with respect to the longwall face.
6. Seam grade.
7. Horizontal stress direction.

A number of models are presented in this section for the likely geotechnical conditions, with recommendations based on the interpretation of the mechanisms acting on these conditions. The observations of development and longwall conditions at other Bulli Seam mines are also invaluable for the prediction of conditions in Area 5.

The additional geological and geotechnical data that has been collected since 2017, has improved the assessment of these issues.

7.2 Floor Conditions

The issues associated with the floor in a longwall extraction area include the punching of the longwall supports and floor heave.

As a simple rule of thumb, longwall face supports punch into the floor when the UCS is less than about 5 MPa. This value is supported both by observations at longwall mines with areas of soft floor conditions such as Cooranbong, Southern and Oaky North and by analysis of bearing capacity.

Expressed as a uniformly distributed load, the stresses applied to the floor under a longwall support are typically in the order of 2 MPa. In reality, higher loads of about 6 MPa can occur at the front of the base causing the supports to punch into the floor.

As a general indicator of the hazard, the acceptable toe load is given as:

Acceptable toe load (MPa) = 4.4*UCS (MPa)/FOS

A FOS (factor of safety) value of 1.5 - 2 is recommended if floor strengths have been measured and a higher value, possibly 3 or more if relying solely on geophysical data. For a typical 6 MPa toe load, this corresponds to a floor uniaxial compressive strength of at least 4 MPa.

With reference to the average strength of the immediate 0.5 m of stone floor below the Bulli Seam of >30 MPa, floor punching by the longwall supports is not likely in Area 5 (**Figure 45**).

Floor heave can be an issue for a longwall panel in drive head areas, around seals and in the Maingate belt road ahead of a retreating longwall. GGPL also use the Floor Strength Index (FSI), defined as the sonic derived floor strength/(depth*average density) to assess the likelihood of floor heave. Where the FSI is used at mines extracting to a stone floor, values less than about 2 are strong indicators of the onset of floor heave around the longwall face.

For the stone below the Bulli Seam, the FSI values for the immediate 0-0.5 m of floor are typically 4-5 (**Figure 47**). Due to the thickness of the Bulli Seam within Area 5, varying thicknesses of the weaker immediate stone floor may also be excavated during development, exposing stronger stone further below the seam with FSI values typically >5 and strengths >50 MPa. Significant heave of this stronger floor material is not anticipated during longwall retreat.

7.3 Mining Horizon and Dilution

The minimum gateroad development height required in Area 5 is 2.7 m. The Bulli Seam is typically <2.7 m thick in >70% of the area and the floor would be mined in preference to the stronger roof material. The immediate 0.5 m of stone floor averages 40-50 MPa (**Figure 45**), compared to 50-80 MPa for the immediate 0.5 m of stone roof (**Figure 40**).

On the longwall face, it is understood that the minimum extraction height is planned to be 2.4 m and varying levels of dilution can be expected, depending on the seam thickness.

Based on the Bulli Seam thickness, as well as the operational requirements, three different mining horizon zones, with different levels of dilution are proposed for Area 5 longwall mining area as follows (**Figure 121**):

- ZONE 1 <2.4 m.
- ZONE 2 2.4-2.7 m
- ZONE 3 >2.7 m.

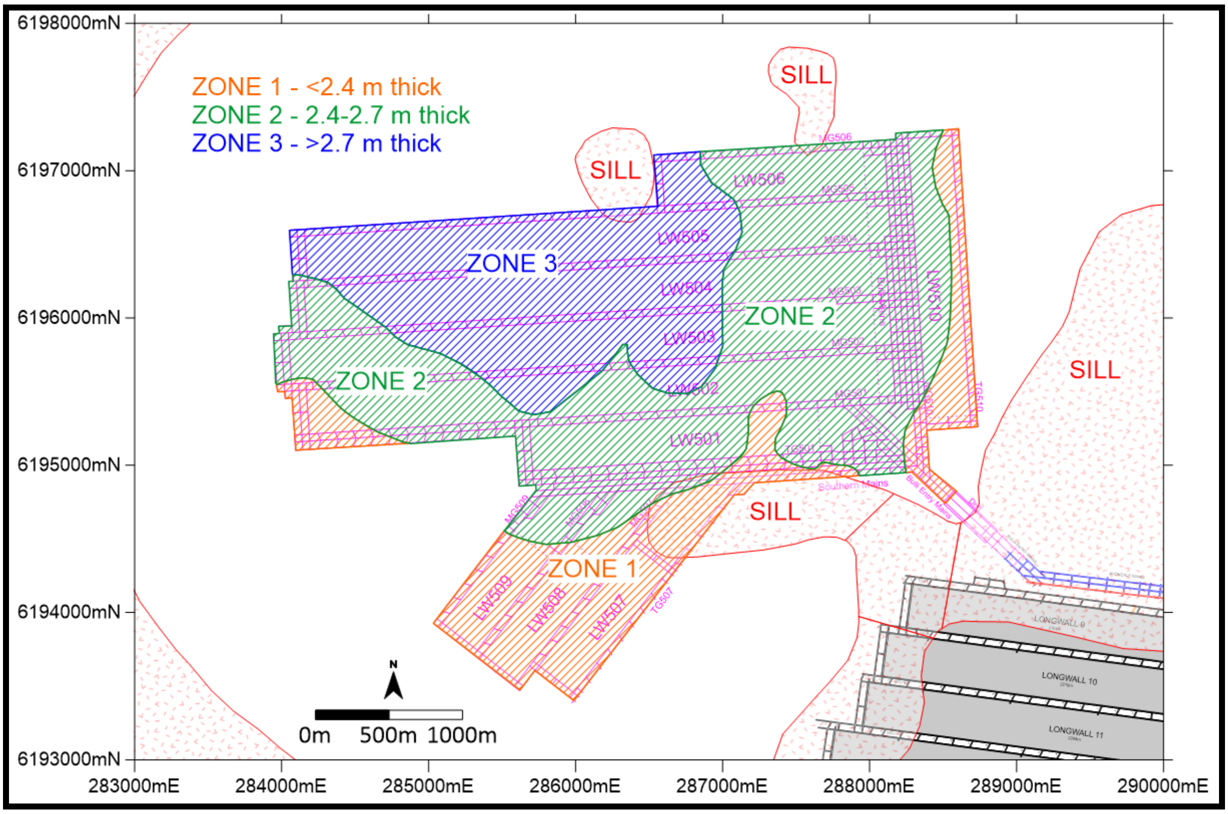

Figure 121. Proposed Mining Dilution Zones.

All zones contain some level of silling at the Bulli Seam level (**Figure 121**).

In Zone 1, there would be dilution with stone floor excavated in both development and on the longwall face.

In Zone 2, the majority of the longwall face can be mined in coal but up to 0.3 m of floor would need to be mined in the gateroads. Some grading at the gate ends would be required where the seam thickness is <2.7 m. This grading may account for approximately one quarter of the longwall face.

In Zone 3, both development and longwall can be mined in coal (**Figure 121**).

7.4 Caving Characteristics

Longwall hydraulic supports control the immediate face area by temporarily holding the roof in place until the next shear is taken. Experience at other mines suggests that heavy loadings due to massive units will only develop if these units are within 50 m of the seam. The massiveness of the overburden units is not only defined by the bedding but also the spacing of joints.

Empirical data collected as part of an ACARP Project C5015[23] suggests that overburden units with thicknesses of less than 10 m can be readily controlled by the current capacity hydraulic supports (**Figure 122**). It should also be pointed out that these layouts may <u>not</u> have been optimised with respect to the orientation of the joints, as longwall blocks in the Newcastle Coalfield are often aligned parallel to geological features to maximise reserve recovery.

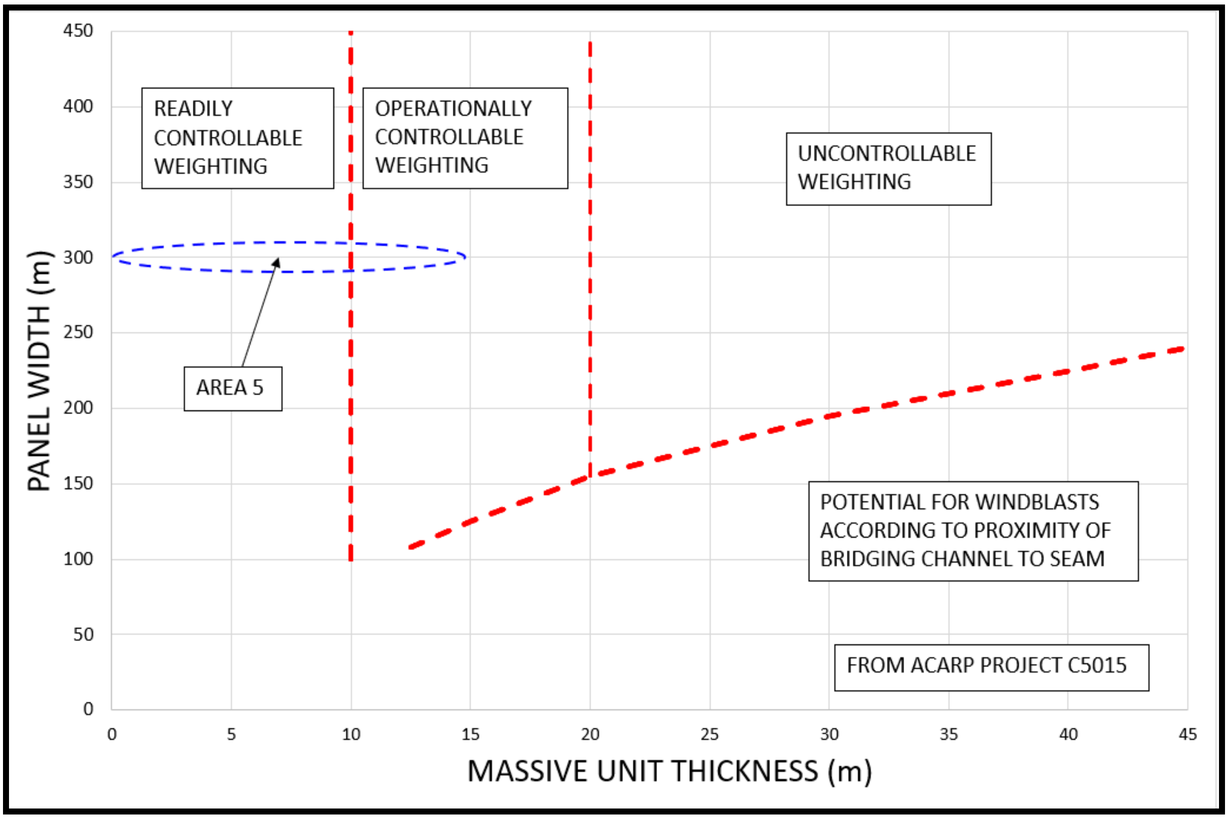

Figure 122. Loading of Longwall Faces (after ACARP Project C5015).

[23] ACARP Project C5015 (1997). Face Width Optimisation in both Longwall and Shortwall Caving Environments.

From **Figure 122**, it can be seen that as the thickness of the massive unit increases the control of the longwall face conditions becomes more difficult. For panels of supercritical width, where the thickness of the massive units is >20 m, longwalling is not possible due to uncontrollable weighting.

The north-south faces of the east-west oriented longwall panels are favourably aligned at around 40^{o} to the major NW joint set, which allows some partial cantilevering of the joint blocks over the face line, so that the loadings on the supports are reduced (**Figure 76**). The north-south LW510 is also favourably aligned at 50^{o} to the main jointing.

The NW/SE faces of Longwalls 507-509 are unfavourably aligned sub-parallel to the main joint set, however with reference to **Figure 23** the sandstone is <4 m thick in this part of Area 5 and unlikely to be associated with significant loading events. High standard face management practices would still be required on these longwalls operating in these conditions.

Examination of the core photographs and analysis of the geophysical logs indicates that the geotechnical thickness of the sandstone in the immediate 50 m of overburden is typically less than 10 m in Area 5 and weightings should be readily controllable (**Figure 23, Figure 76 and Figure 122**).

This sandstone does thicken to 10-14 m in the central part of the area, which would require operational controls, on the longwalls in this area (**Figure 23**). The location and thickness of the sandstone units should be identified on the longwall hazard plans.

This commentary is consistent with the assessment of the caving characteristics by SCT (2017)[24].

7.5 Geological Features

Faults with a range of characteristics including normal, reverse and strike-slip have been negotiated on the longwall face at other Bulli Seam operations. Experience elsewhere suggests that small scale normal faults are also not always an obstacle to longwalling.

The orientation of a fault with respect to the longwall face should also be considered. Medhurst et al, (2008)[25] concluded that major structures present a high level of risk if they are oriented at less than 30^{o} to longwall retreat, due to alignment with goaf cracks and mining induced fractures and the length of the longwall face exposed to poor ground conditions at any one time. The risk of face instability is also increased for faults that dip towards the longwall face.

[24] SCT (2017). Dendrobium Area 5 Pre-Feasibility Study: Numerical Modelling Geotechnical Assessment of Bulli Seam Longwall Caving. Report No. STH324671.
[25] Medhurst, T, Bartlett, M and Sliwa, R (2008). Effect of Grouting on Longwall Mining through Faults. COAL 2008. Pages 44-56.

For all faults, particularly those greater than half seam thickness additional risks to the business include dilution and additional wear and tear on equipment.

Area 5 may be traversed by several faults and intruded by a number of dykes (**Figure 57**). In particular, the dominant WNW/ESE fault and dyke trend is sub-parallel to the face of Longwalls 507-510 (**Figure 59**). These features may potentially be associated with an increase in the tip to face distance and poorer longwall face conditions. Fault management plans should be developed if these features are intersected in the gateroads of these panels. At this stage of the exploration, faults and dykes in this orientation have not been identified in these panels (**Figure 57**).

For the remainder of the east-west longwall panels, this fault/dyke orientation is favourable for the longwall face but there is the risk that one of these geological features may be carried for some distance on the face, such as the dyke interpreted on LW505 (**Figure 57**).

The dyke and sill features in the area should be dealt with using dyke management techniques. The potential for outbursts due to associated strike slip faults and increased pick wear should also be considered.

A number of SIS holes have been drilled to provide greater confidence in seam continuity. It is anticipated that this would be supplemented with in seam drilling once mining in Area 5 commences, to define the thickness and characteristics of any geological features. In particular, any silling and associated increase in thickness should be identified to allow remedial measures to be put in place. This may involve pre-mining of intrusive material.

Any geological features encountered should also be recorded and displayed on the longwall and development hazard plans.

7.6 Alignment to Joint and Cleat

Mining experience has shown that better roof and face conditions are encountered when the face is oriented at >20º-30º to the strike of the joints and cleats, similar to the preceding discussion on geological features and caving. For the Tailgate, the orientation is favourable in terms of a tensile tailgate model.

This variation in cleat/joint angle to the face is shown graphically in **Figure 123**, indicating optimal roof sensitivity index values for these panels. The N to NNE cleat is aligned unfavourably to the bleeder and install roads, as well as the face of the east-west longwall panels but is more favourable for the face orientation of Longwalls 507-510 (**Figure 123**).

Consideration should also be given to the occurrence of joints and cleats on the corners of intersecting roadways. Especially where the cleats/joints are not vertical and can define inverted pyramids of coal that may just simply slide into the gate/face corner.

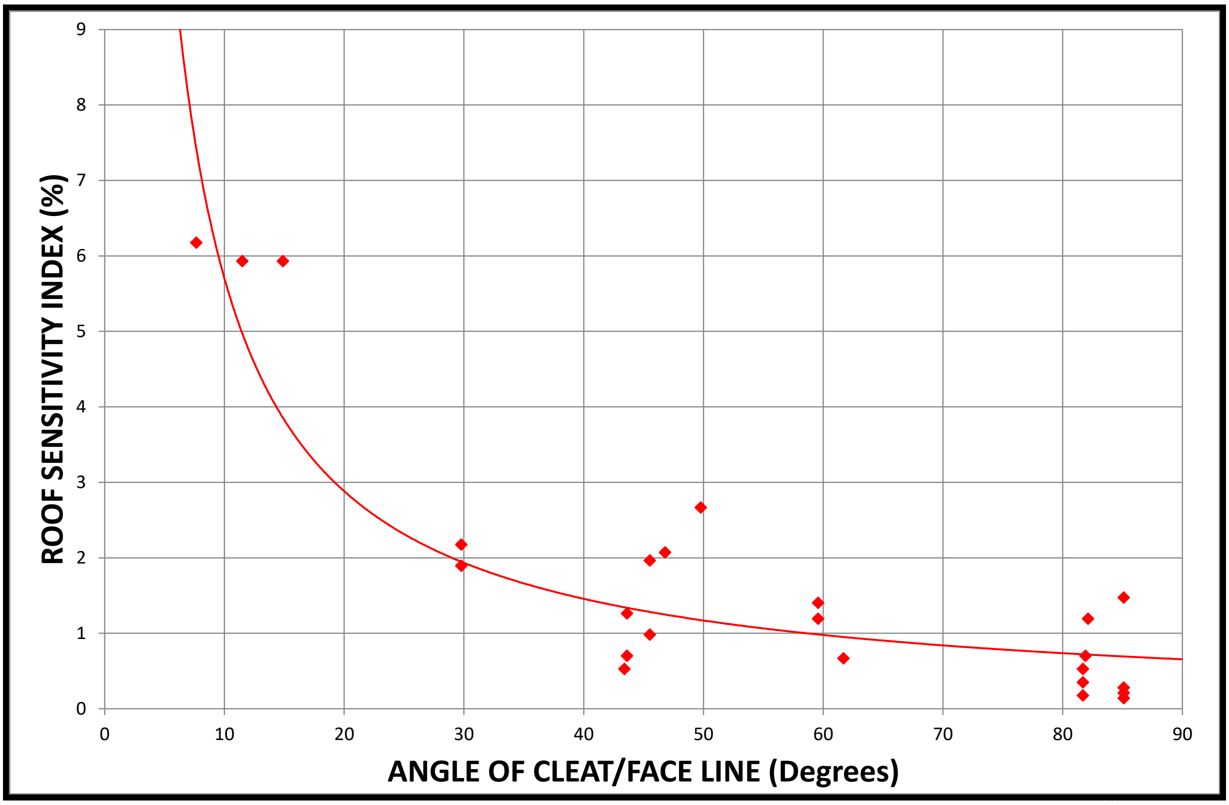

Figure 123. Preferred Alignment to Joints and Cleats (Farmer, 1984[26]).

7.7 Seam Grade

Analysis of the seam levels in Area 5 indicates that the majority of the area would encounter grades <2% (**Figure 10**). Grades up to 5% can be expected in the development drivage of Longwalls 507-509 and at the inbye end of Longwalls 502 and 503 (**Figure 10**).

Water control would still be of paramount importance, particularly in flat lying areas where water can pond.

7.8 Horizontal Stress Orientation

Traditionally the orientation of gateroads has been considered in terms of alignment to horizontal stress such that the stress acting across the roadway is minimised. The minimisation of stresses applies to both development and also longwall retreat. For longwall retreat, poor gateroad orientation can lead to a doubling of the horizontal stresses in the roof (**Figure 98**).

Orientation to horizontal stress will become significant in areas of stone roof where compressive failure is possible. Development headings in the gateroads are aligned typically at 0-45^{o} to the major horizontal stress in Area 5.

[26] Farmer, I.W. (1984). Coal Mine Structures. Chapman and Hall, pp. 310.

7.9 Panel Orientation

The orientation of longwall panels should not only consider the horizontal stress direction but also the orientation of geological features such as cleats, joints, faults and dykes. Utilising the acoustic scanner data from Area 5, the regional trends of the geological features have been plotted with respect to the proposed underground workings in **Figure 124**.

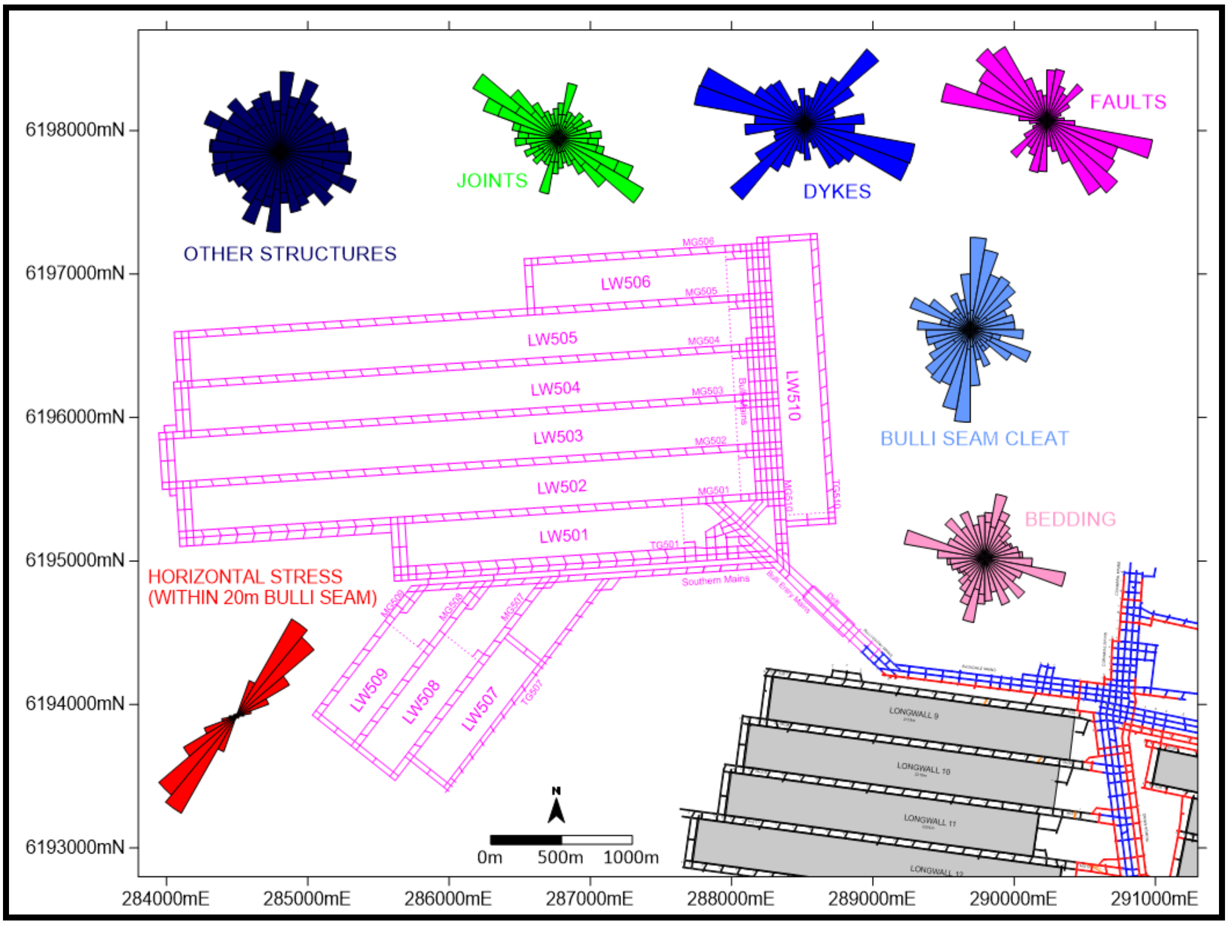

Figure 124. Orientation of Geological Features.

The acoustic scanner data indicates a dominant NE major horizontal stress direction (**Figure 81**). This is favourable from a horizontal stress point of view for Longwalls 507-509 but less favourable for Longwalls 501-506 and 510 (**Figure 125**).

TG501 and the inbye end of TG502 will experience a concentration of the major horizontal stress, with subsequent gateroads up to LW506 located in a stress shadow.

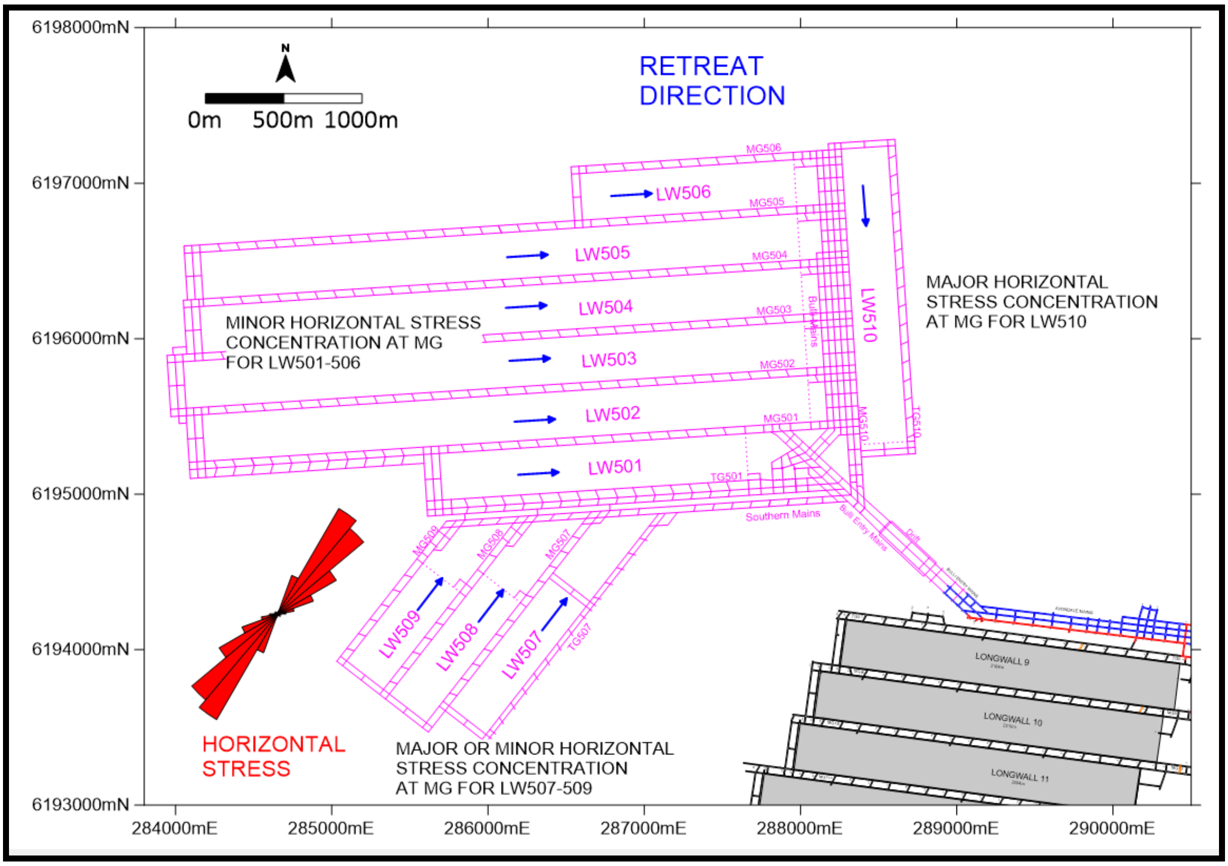

Figure 125. Retreat Direction and Stress Concentration.

7.10 Hazard Plan

Based on the geotechnical assessment detailed in this report, a preliminary hazard plan has been compiled (**Figure 126**).

This hazard plan includes the geological features, as well as seam thickness and the occurrence of thicker overburden sandstone units. The potential TG502 stress notch area is also highlighted (**Figure 126**).

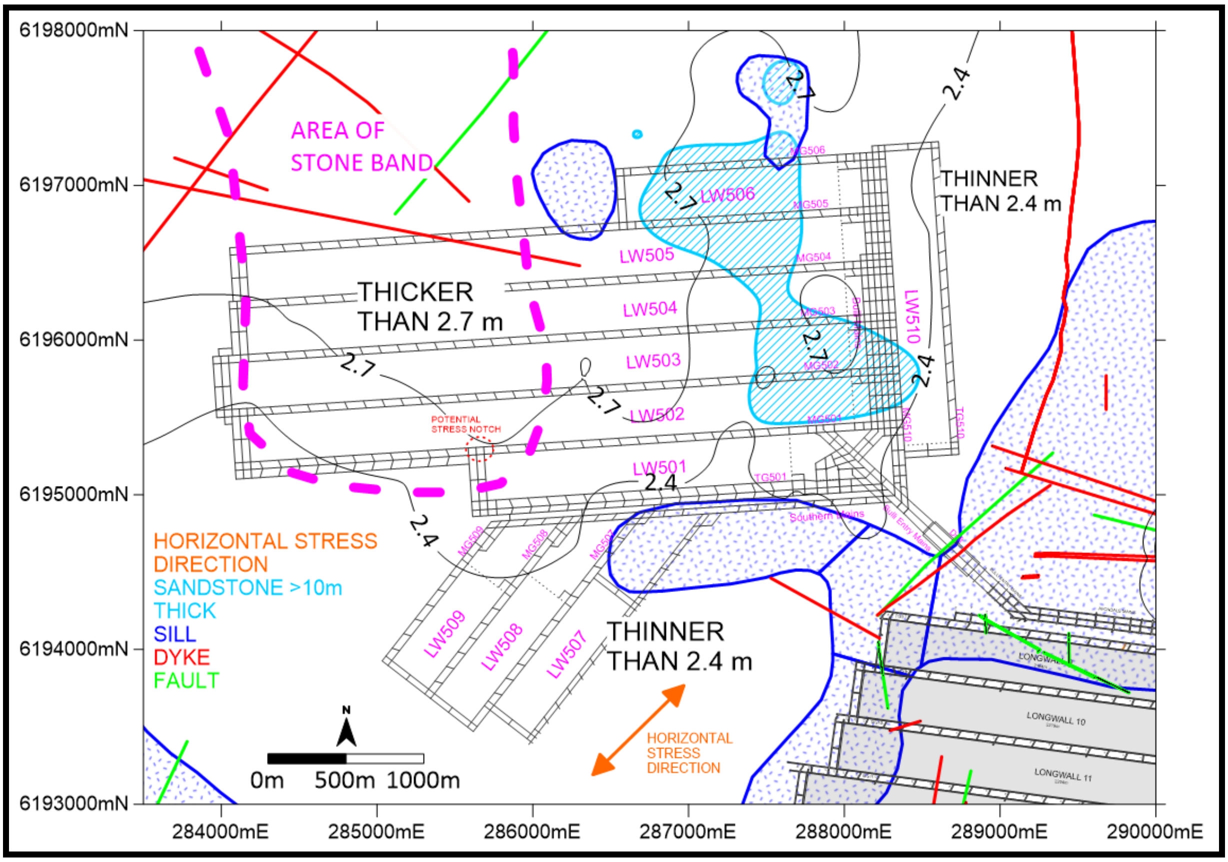

Figure 126. Area 5 Hazard Plan.

8 APPENDIX 1. THICKNESS OF STRATIGRAPHIC UNITS

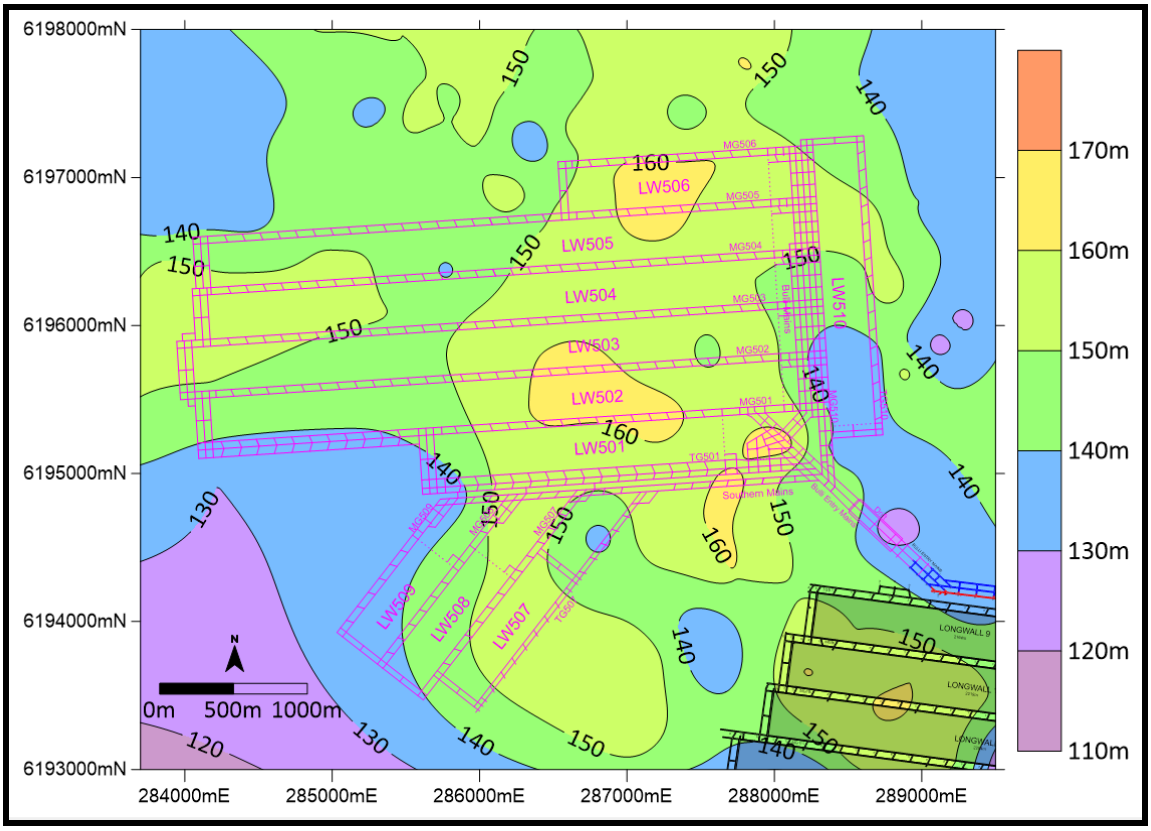

Figure 127. Hawkesbury Sandstone Thickness (m).

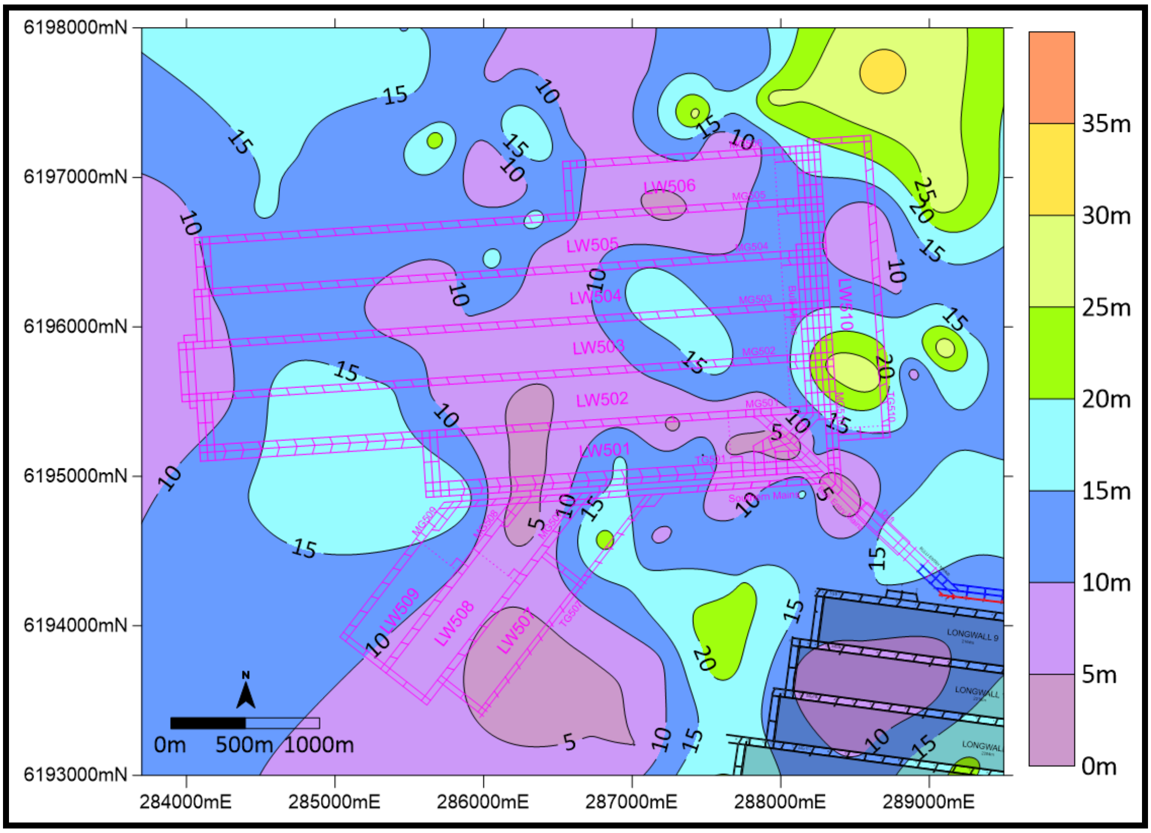

Figure 128. Newport Formation Thickness (m).

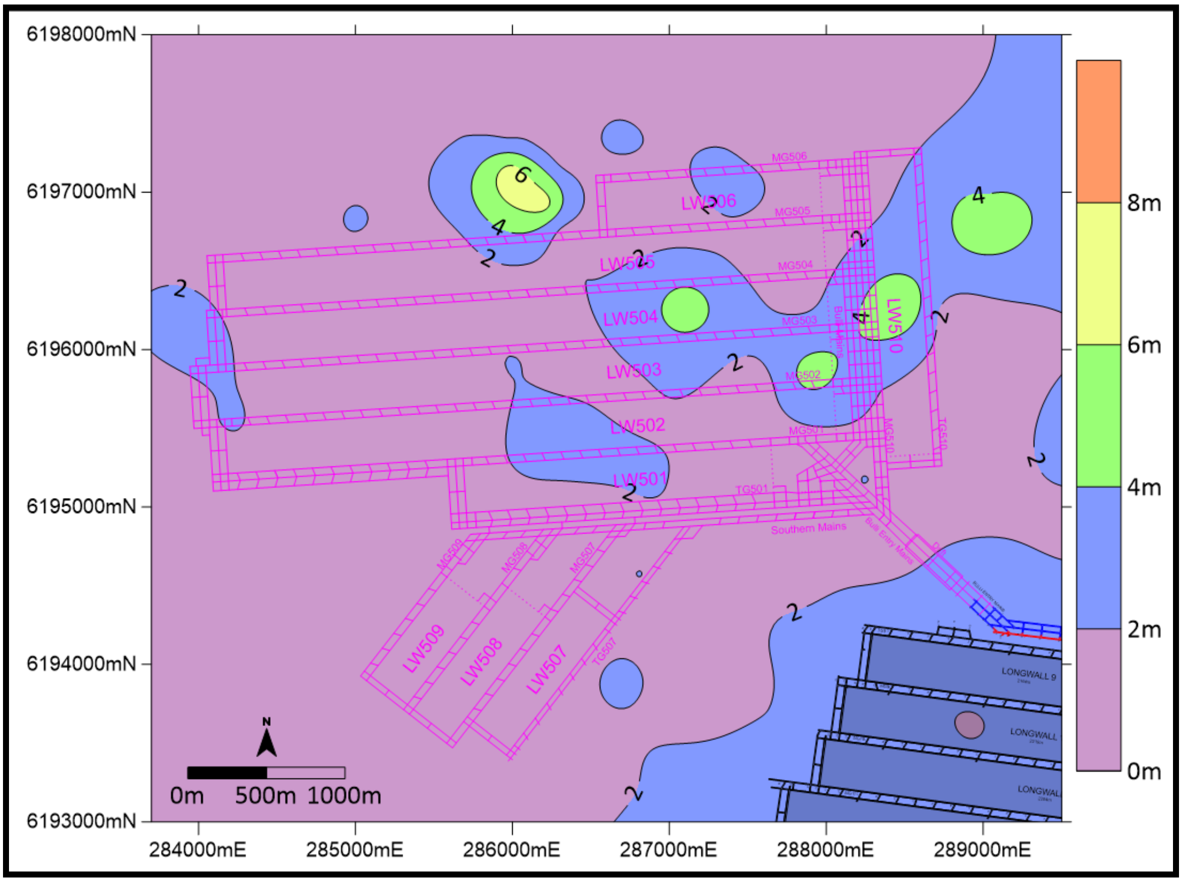

Figure 129. Garie Formation Thickness (m).

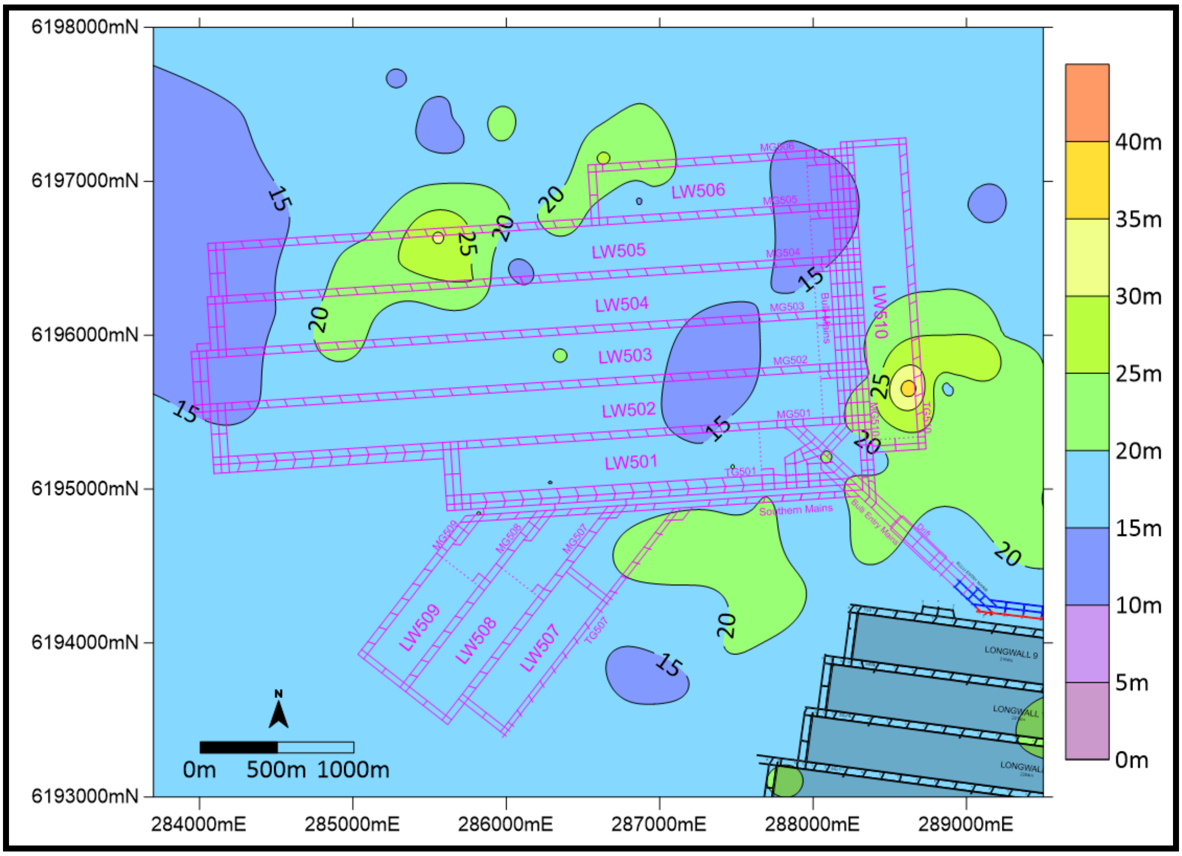

Figure 130. Bald Hill Claystone Thickness (m).

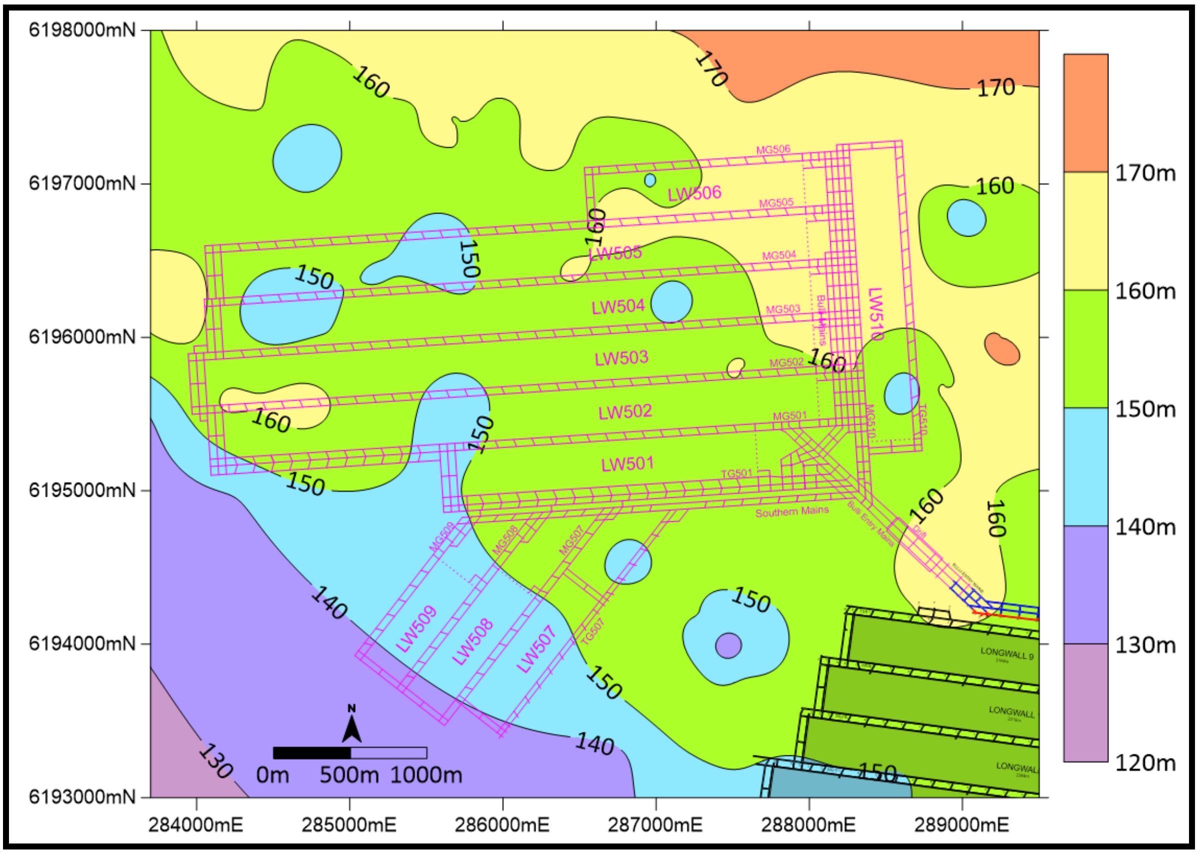

Figure 131. Colo Vale Sandstone Thickness (m).

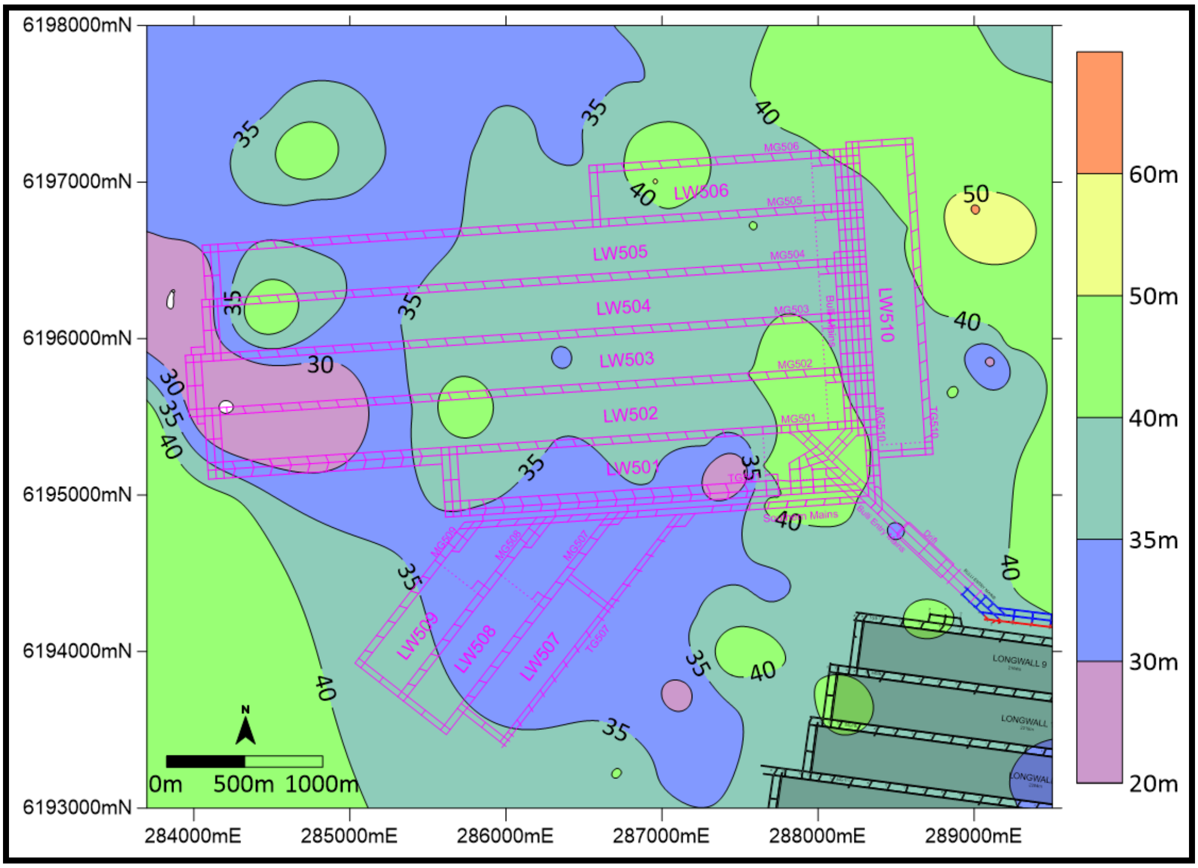

Figure 132. Wombarra Claystone Thickness (m).

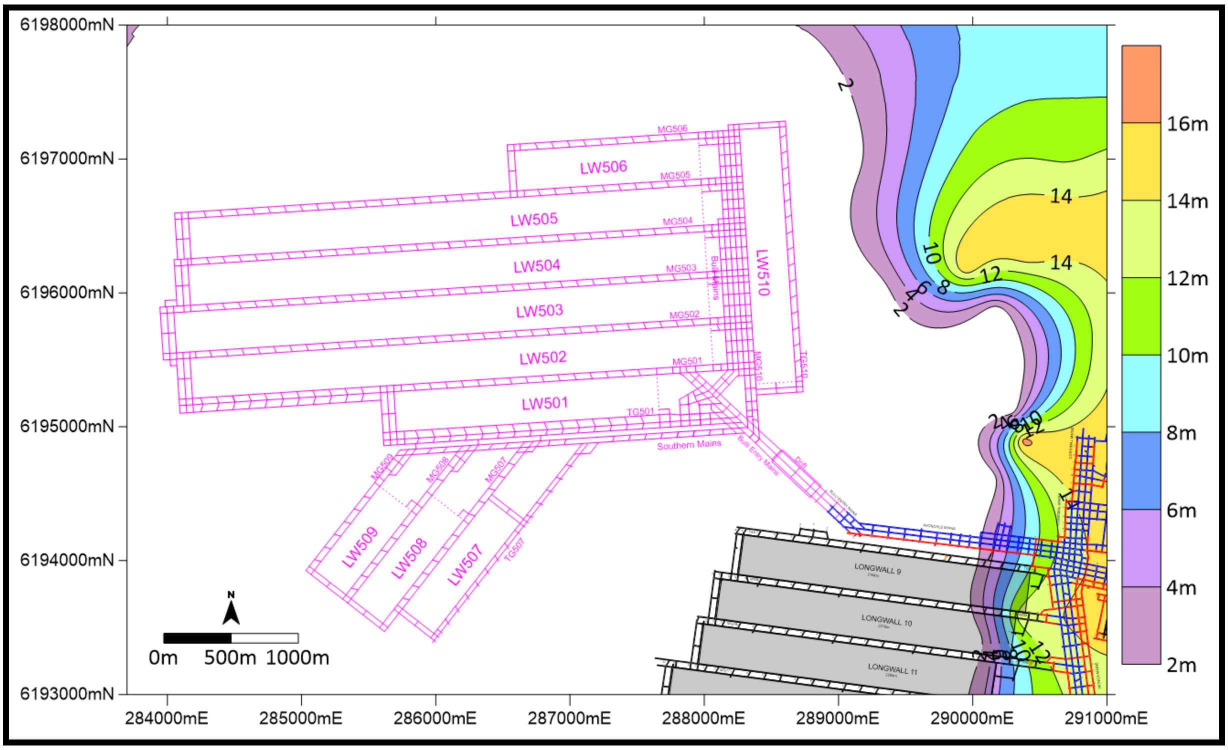

Figure 133. Coal Cliff Sandstone Thickness (m).

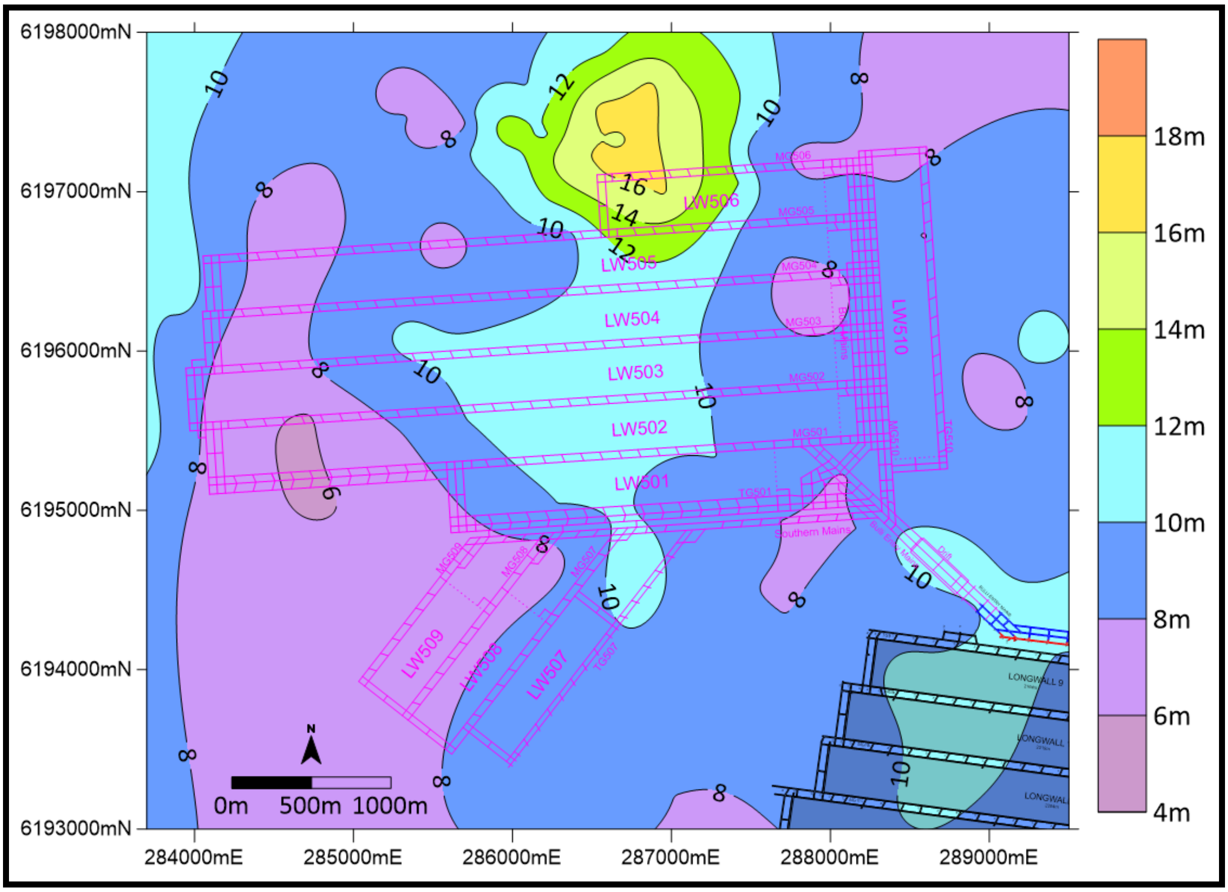

Figure 134. Loddon Sandstone Thickness (m).

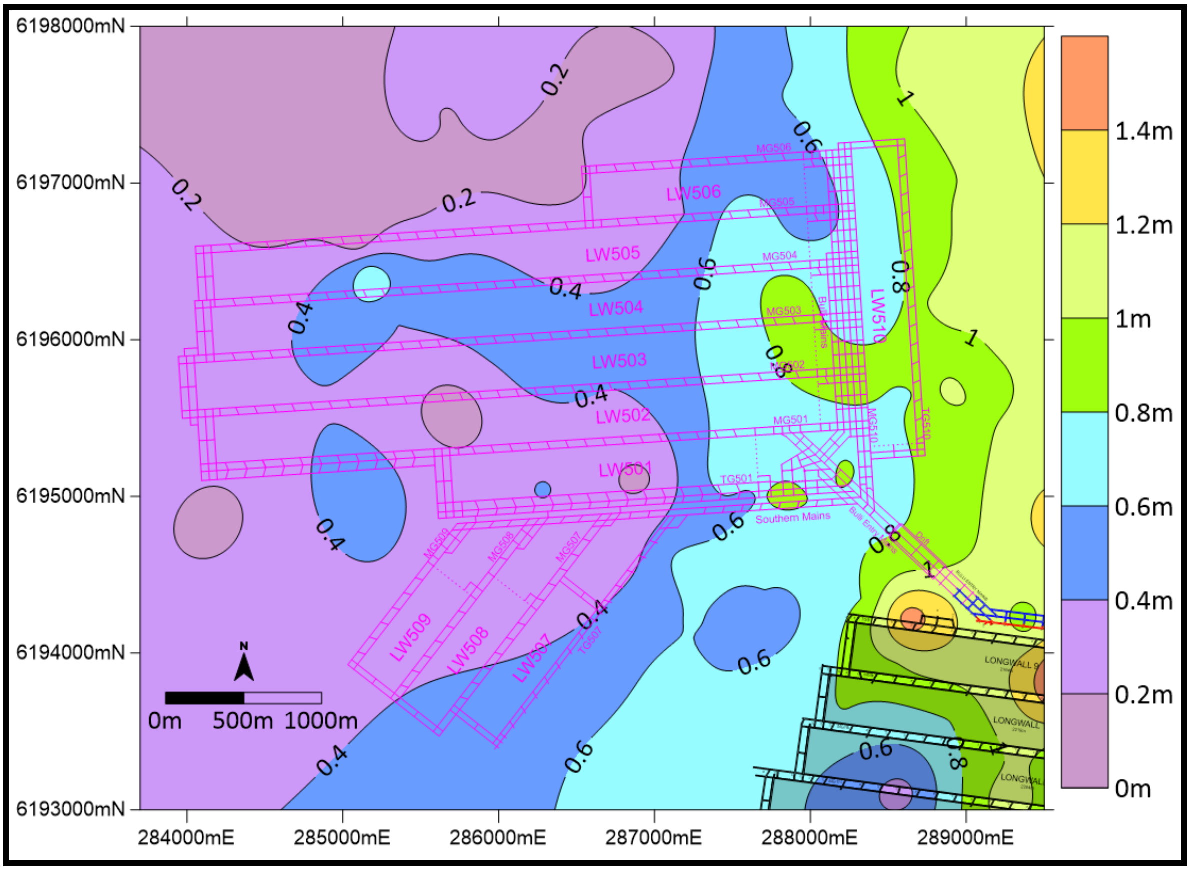

Figure 135. Balgownie Seam Thickness (m).

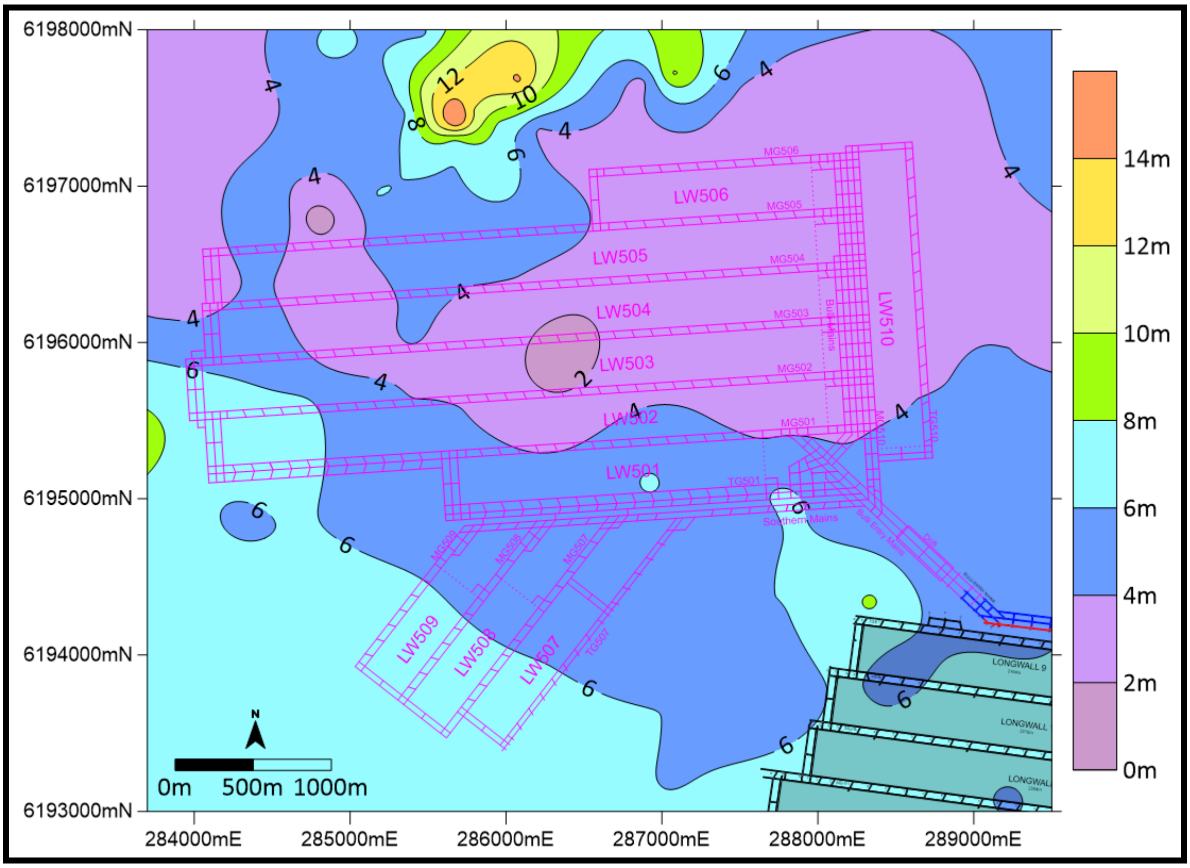

Figure 136. Balgownie to Cape Horn Seam Interburden Thickness (m).

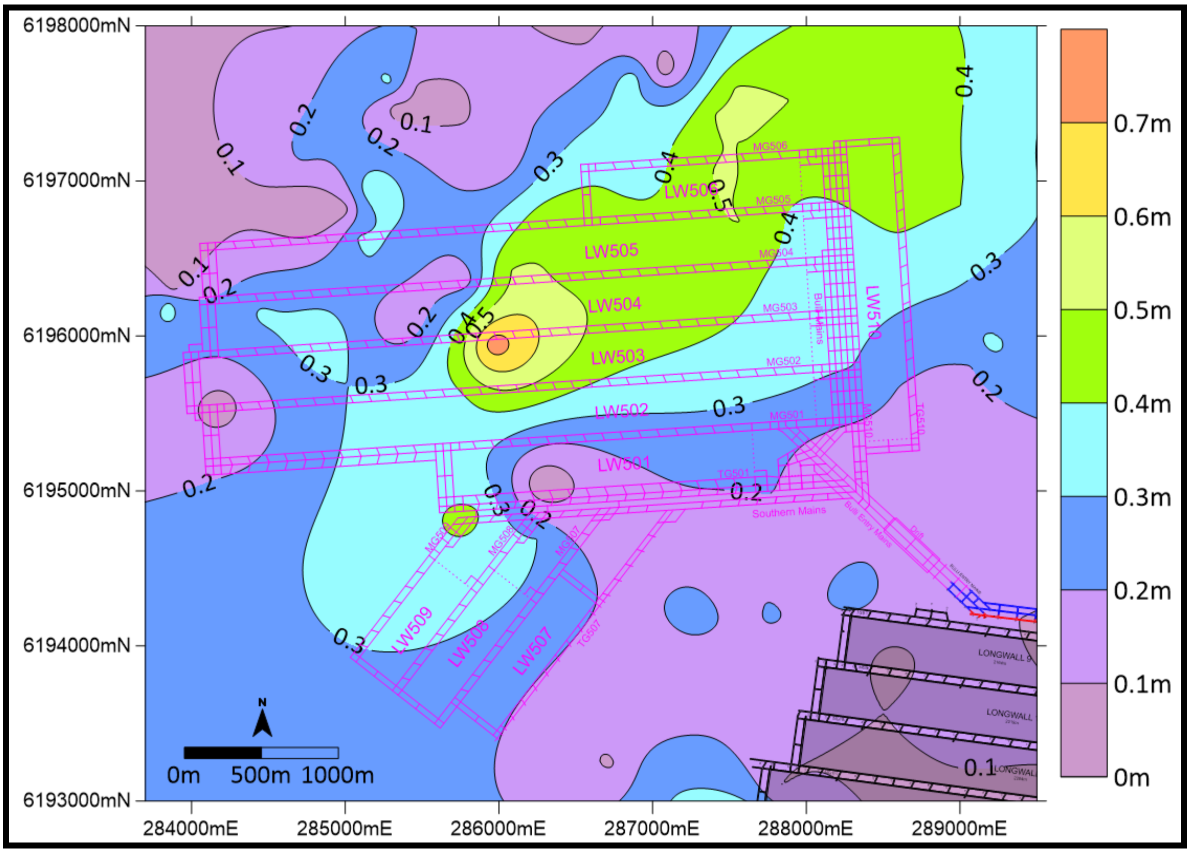

Figure 137. Cape Horn Seam Thickness (m).

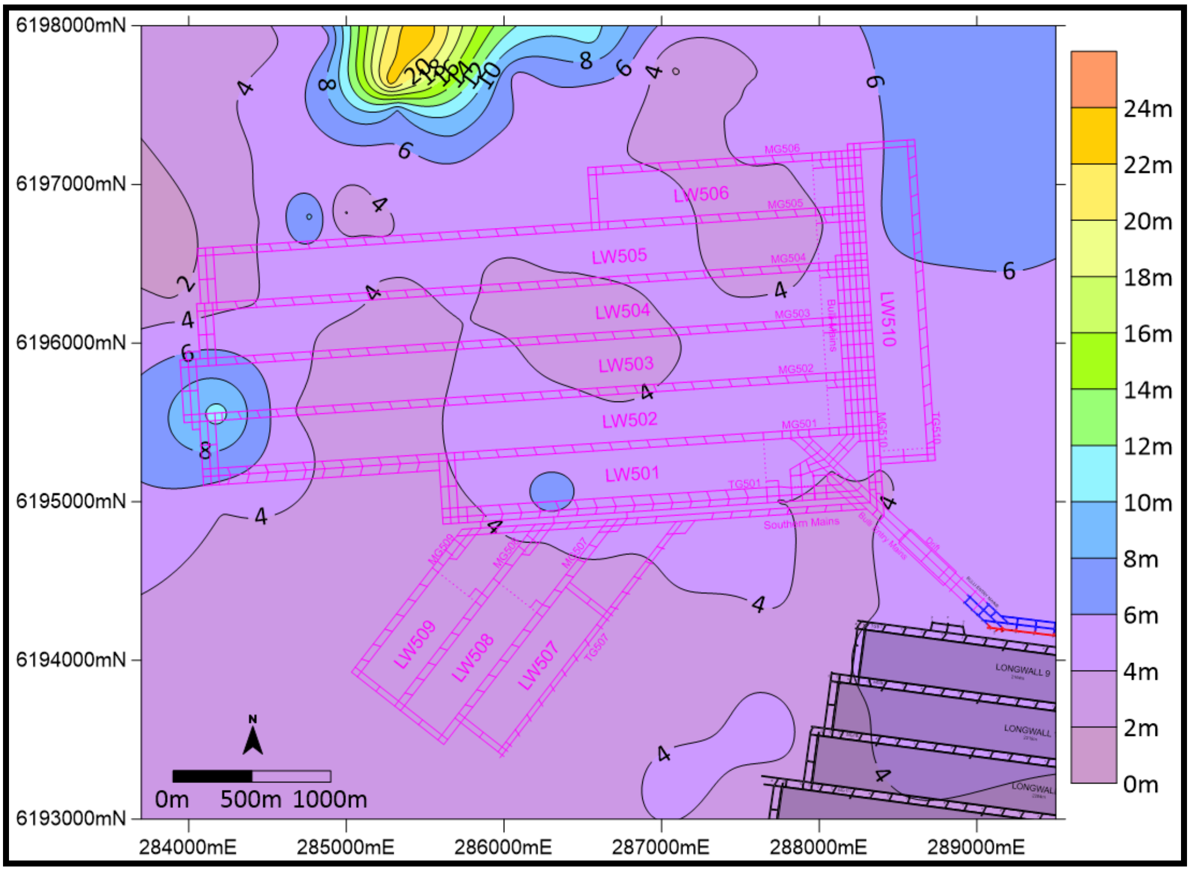

Figure 138. Cape Horn to Wongawilli Seam Interburden Thickness (m).

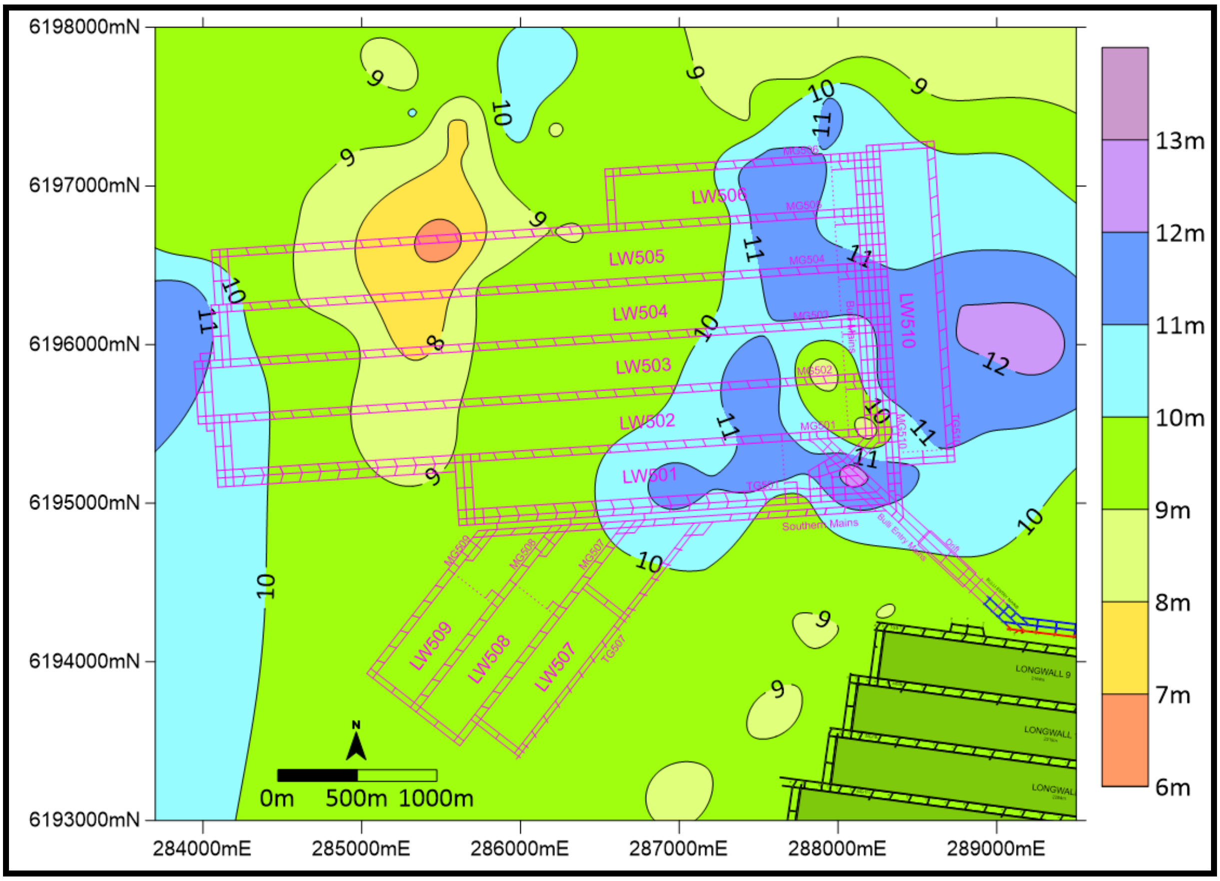

Figure 139. Wongawilli Seam Thickness (m).

9 APPENDIX 2. STRENGTH OF STRATIGRAPHIC UNITS

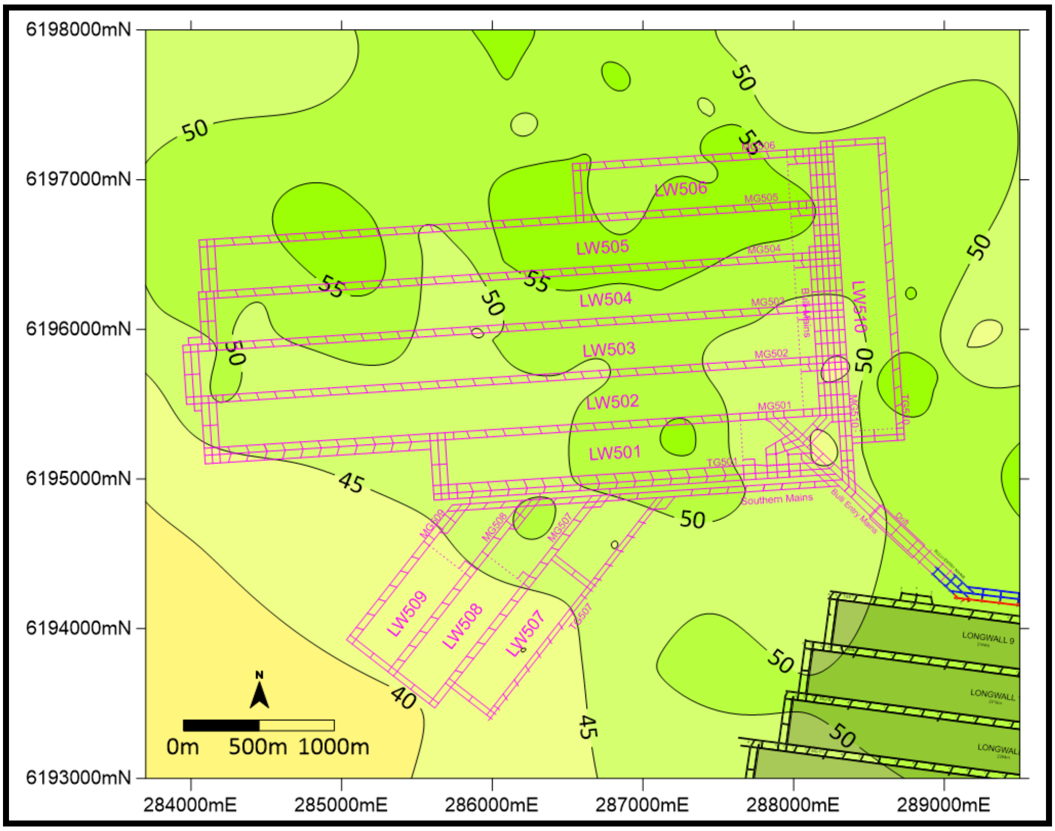

Figure 140. Hawkesbury Sandstone Average Strength (MPa).

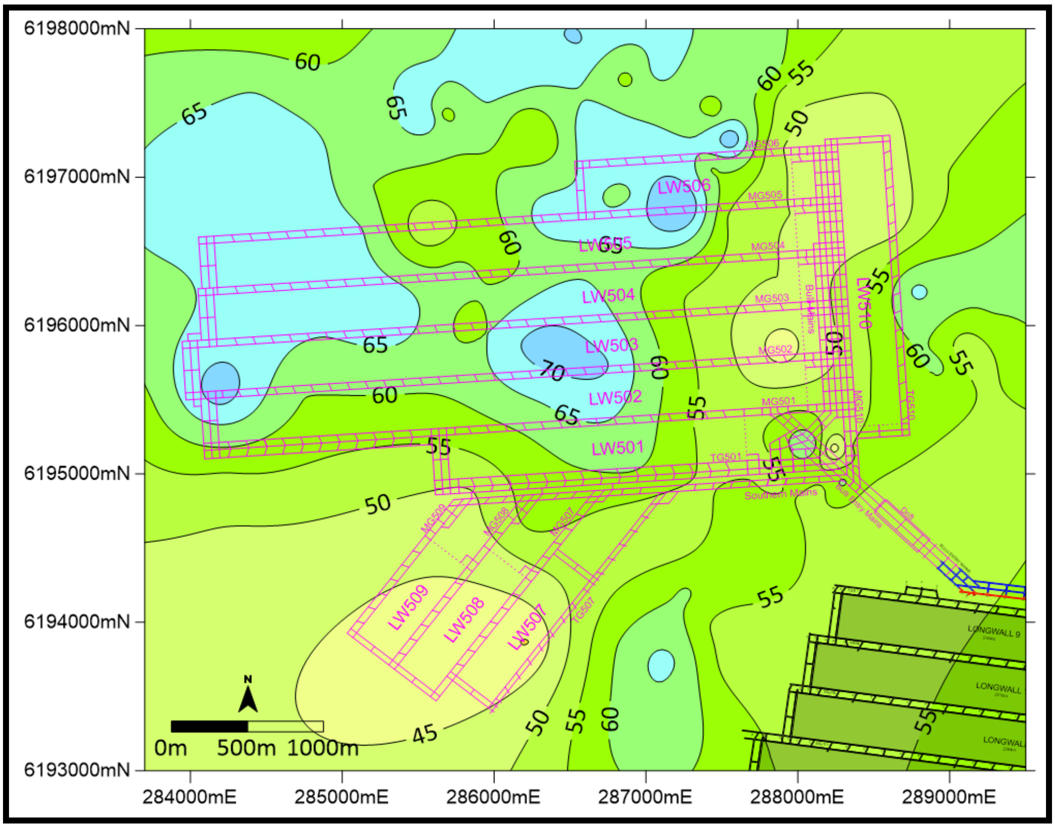

Figure 141. Newport Formation Average Strength (MPa).

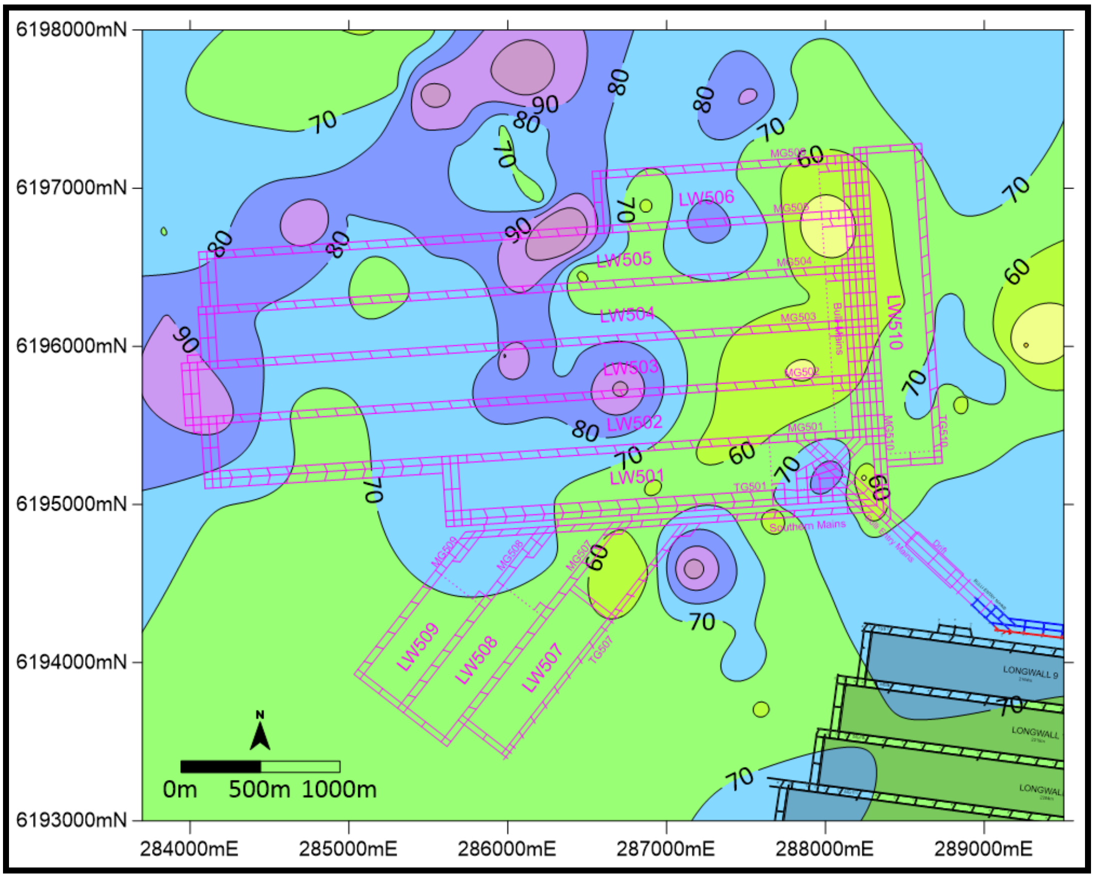

Figure 142. Garie Formation Average Strength (MPa).

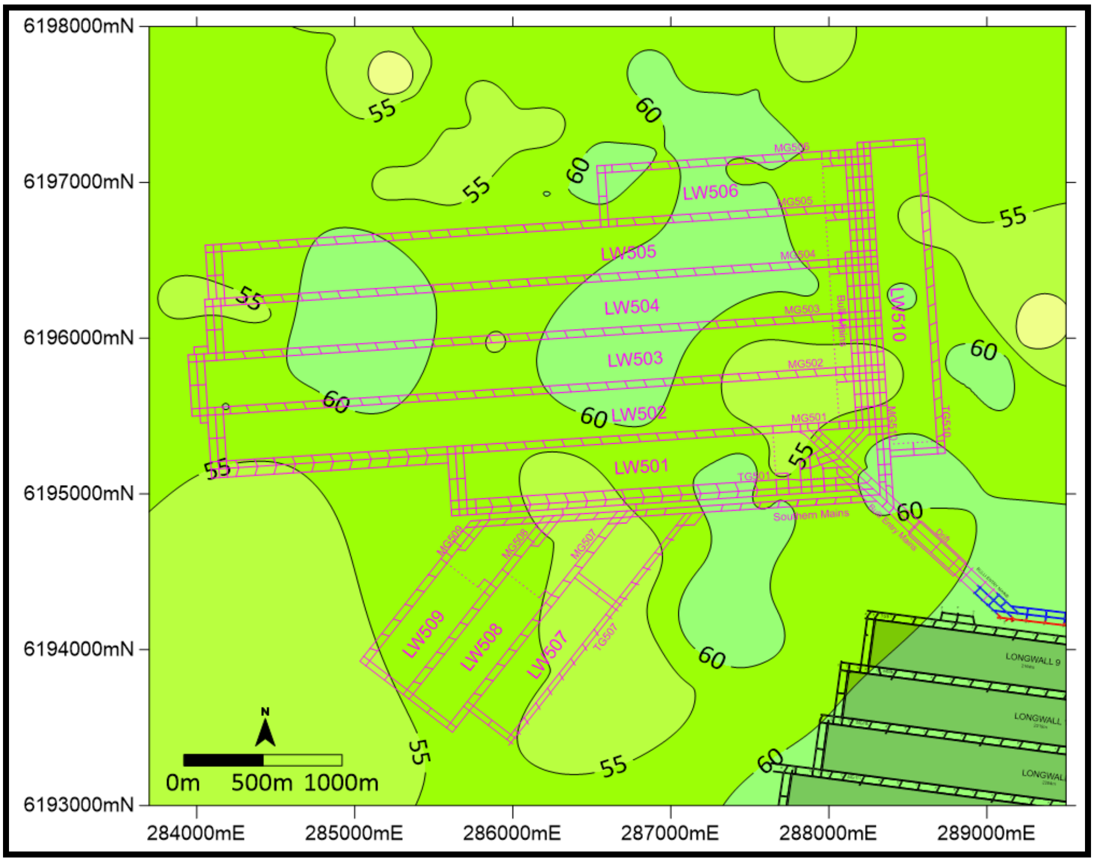

Figure 143. Bald Hill Claystone Average Strength (MPa).

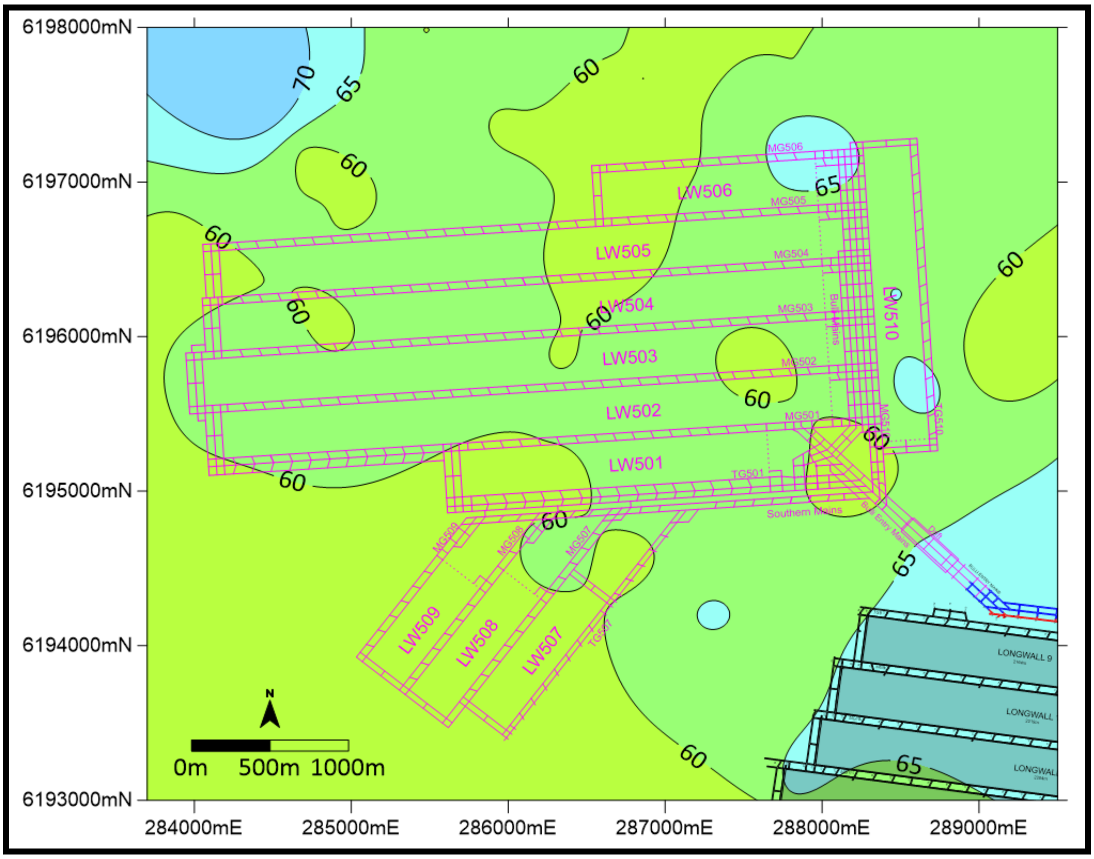

Figure 144. Colo Vale Sandstone Average Strength (MPa).

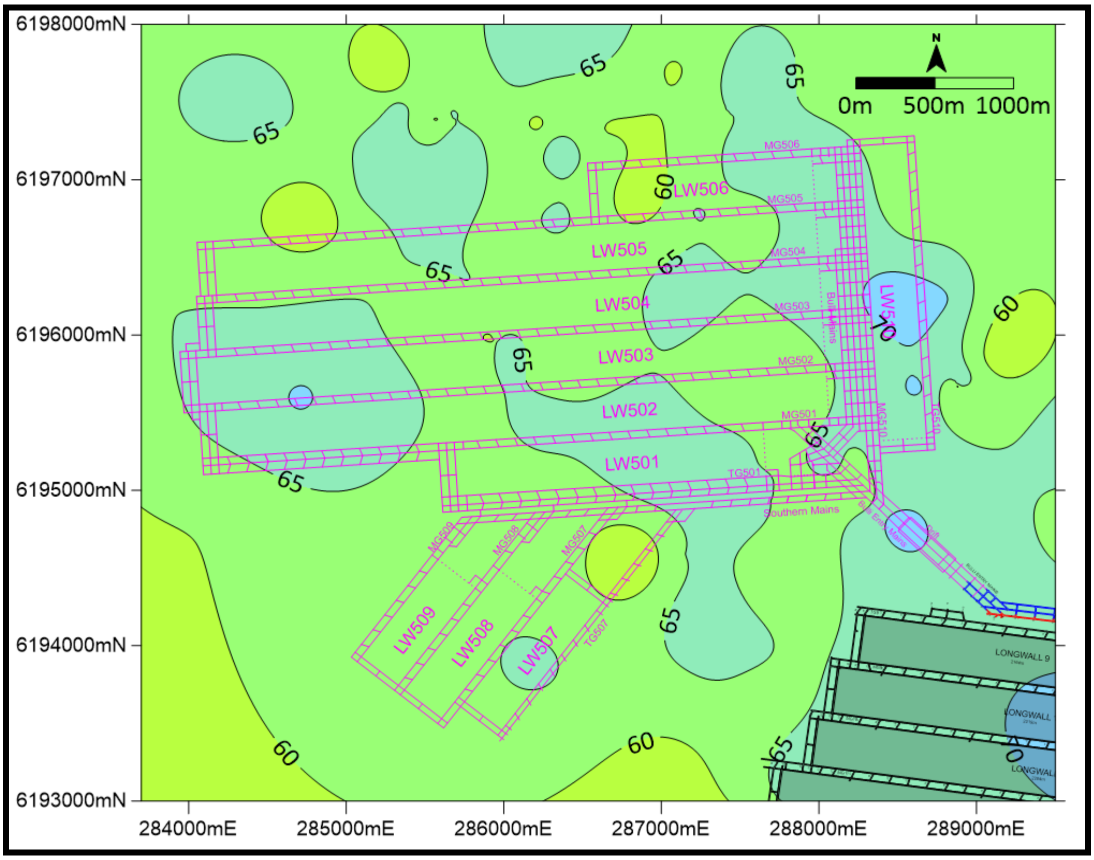

Figure 145. Wombarra Claystone Average Strength (MPa).

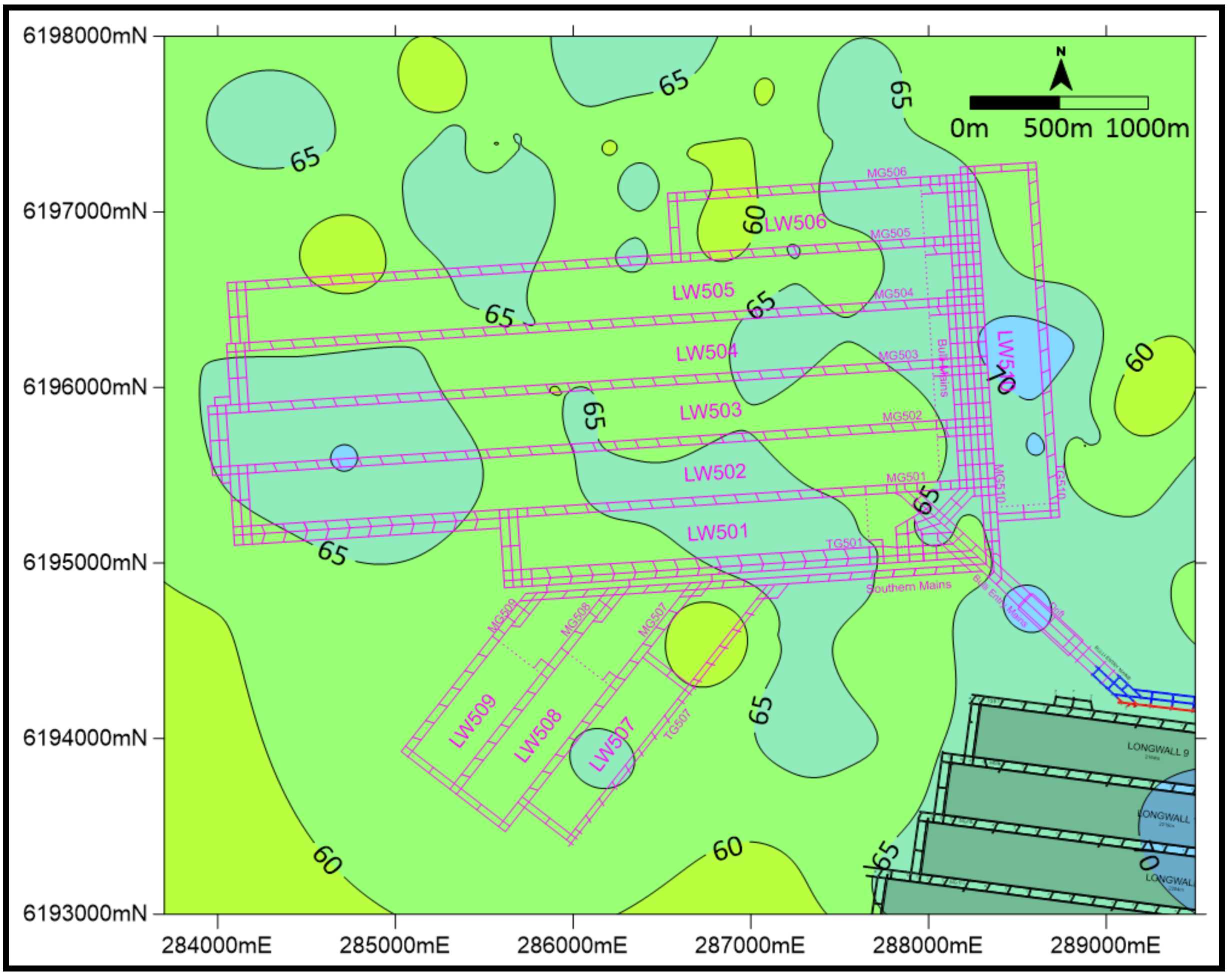

Figure 146. Loddon Sandstone Average Strength (MPa).