SUBSIDENCE REPORT FOR THE ENSHAM LIFE OF MINE EXTENSION PROJECT

Prepared for AECOM Australia Pty Ltd
On behalf of Ensham Resources Pty Ltd

JANUARY 2020

EXECUTIVE SUMMARY

Ensham Resources Pty Ltd (Ensham) operates the Ensham Mine, an open cut and underground coal mine located approximately 35 kilometres (km) east of Emerald in Central Queensland. The operation currently produces approximately 5.2 million tonnes per annum (Mtpa) of run of mine (ROM) coal from open cut and underground operations. Ensham proposes to develop the Ensham Life of Mine Extension Project (the Project). The Project comprises three areas: an area on MDL 217 (Zone 1), and two areas across current Mining Leases (MLs); Zone 2 comprises ML 70326, 70365 and ML 7459 and, Zone 3 comprises ML 7459 and ML 70366.

The Project will operate using the same bord and pillar mining method currently being used on site. This mining system forms a regular array of stable coal pillars and roadways in each panel and does not cause large scale overburden fracturing and subsidence.

The assessment of the stability of the Project coal pillars resulting from the proposed underground mine has been undertaken using the industry accepted University of New South Wales Pillar Design Procedure. The subsidence predictions from the assessment have been verified to a high level of confidence using information from the existing bord and pillar operations at Ensham Mine site. The subsidence assessment is based on the Project design Factor of Safety (FoS) and width: height ratios of the pillars, as well as the estimated critical level of overburden displacement. This assessment, using a minimum pillar FoS of 1.6, has confirmed the long-term stability of the proposed mine layout.

Due to the nature of the bord and pillar mining method, subsidence is predicted to be typically less than 40 mm in the Project Area; this is as a result of elastic compression of the strata (i.e. compression due to the additional load on the pillars after the coal is extracted). To provide context, the Australian Government Department of the Environment and Energy (DoEE) states that seasonal variation in surface levels can be up to 50 mm or more as a result of changes in moisture content.

Due to the low levels of subsidence and associated strains and tilts, no surface cracking is anticipated within the Project Area. The expected low levels of subsidence are also unlikely to result in the formation of significant depressions in the surface topography, where ponding of the surface drainage may occur. This is consistent with experience at the existing Ensham Mine operations, where no surface cracking or ponding has been observed above the operating bord and pillar mine areas.

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List of Abbreviations

AHD - Australian Height Datum
D - Disturbance Factor
E_i - Laboratory Modulus
E_{rm} - Rock Mass Modulus
FoS - Factor of Safety
GGPL - Gordon Geotechniques Pty Ltd
GSI - Geological Strength Index
UCS - Uniaxial Compressive Strength

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Glossary

Bell out	An area on the perimeter of the panels where coal is mined and ground support is not installed.
Bord	A roadway developed in an underground mine.
Empirical	Based or acting on observation and experiment, not on theory.
Floor	Strata immediately below the mined seam.
Inbye	Direction towards the coal face.
Modulus	The ratio between applied stress and resultant strain.
Outbye	Direction away from the coal face.
Overburden	Sequence of strata above the mined seam.
Pillar	Coal that is not mined within the underground workings.
Roof	Strata immediately above the mined seam.
Secondary Coal Recovery	Mining of floor coal and bell outs.
Stratigraphy	A branch of geology that studies rock layers and layering. It is primarily used in the study of sedimentary and layered volcanic rocks.
Subsidence	Sinking or settlement of the land surface, due to any of several processes. As commonly used, the term relates to the vertical downward movement of natural surfaces although small-scale horizontal components may be present. The term does not include landslides, which have large-scale horizontal displacements, or settlements of artificial fills.
Strain	Relative change in the volume, area or length of a body as a result of stress. The change is expressed in terms of the amount of displacement measured in the body divided by its original volume, area, or length, and referred to as either a volume strain, areal strain, or one-dimensional strain, respectively. The unit measure of strain is dimensionless, as its value represents the fractional change from the former size.
Tilt	The rate of change in vertical subsidence between two points divided by the horizontal distance between those two points.

1 INTRODUCTION

Gordon Geotechniques Pty Ltd (GGPL) was commissioned by AECOM Australia Pty Ltd (AECOM) on behalf of Ensham Resources Pty Ltd (Ensham) to complete a subsidence assessment, as part of the environmental approvals process to facilitate bord and pillar mining in the Project Area. The Project comprises three areas: an area on MDL 217 (Zone 1), and two areas across current Mining Leases (MLs); Zone 2 comprises ML 70326, 70365 and ML 7459 and, Zone 3 comprises ML 7459 and ML 70366. (**Figure 1**).

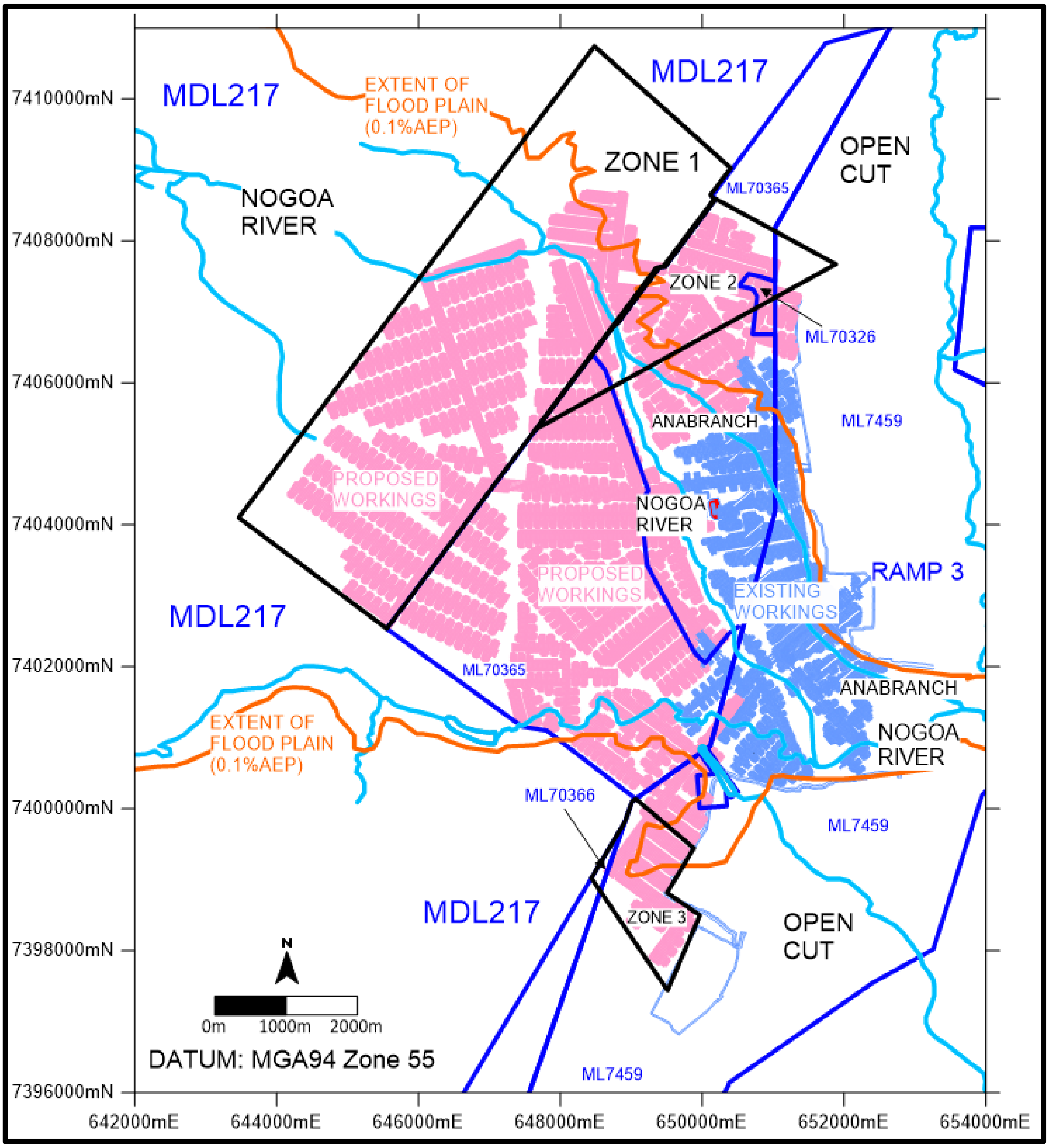

Figure 1. Location Plan – Ensham Mine Site

This assessment and the associated approvals process are focussed on the proposed mining activities within the Project Area only.

1.1 Project Description

Ensham is currently operating a bord and pillar mine downdip of the open cut (**Figure 1**). Underground coal production commenced at Ensham in 2011, once the Aries-Castor Seam had been accessed by two stone drifts from Ramp 3 (**Figure 1** and **Figure 2**). These drifts provide both men and materials and belt access from the open cut to the underground workings.

Figure 2. Access to the Underground Workings from Ramp 3

The bord and pillar mining methodology currently used at Ensham is also planned for the Project Area, with access through the existing underground workings (**Figure 1**). The majority of the proposed mining layout in Zone 1 is located below the flood plain of the Nogoa River (**Figure 1**). Zone 2 and Zone 3 are located both below the flood plain and outside the flood plain (**Figure 1**).

1.2 Project Setting

Due to the overlying Nogoa River and flood plain, the surface topography in the Project Area is relatively flat (**Figure 3**). In Zone 2, there is a localised high in the topography (**Figure 3**).

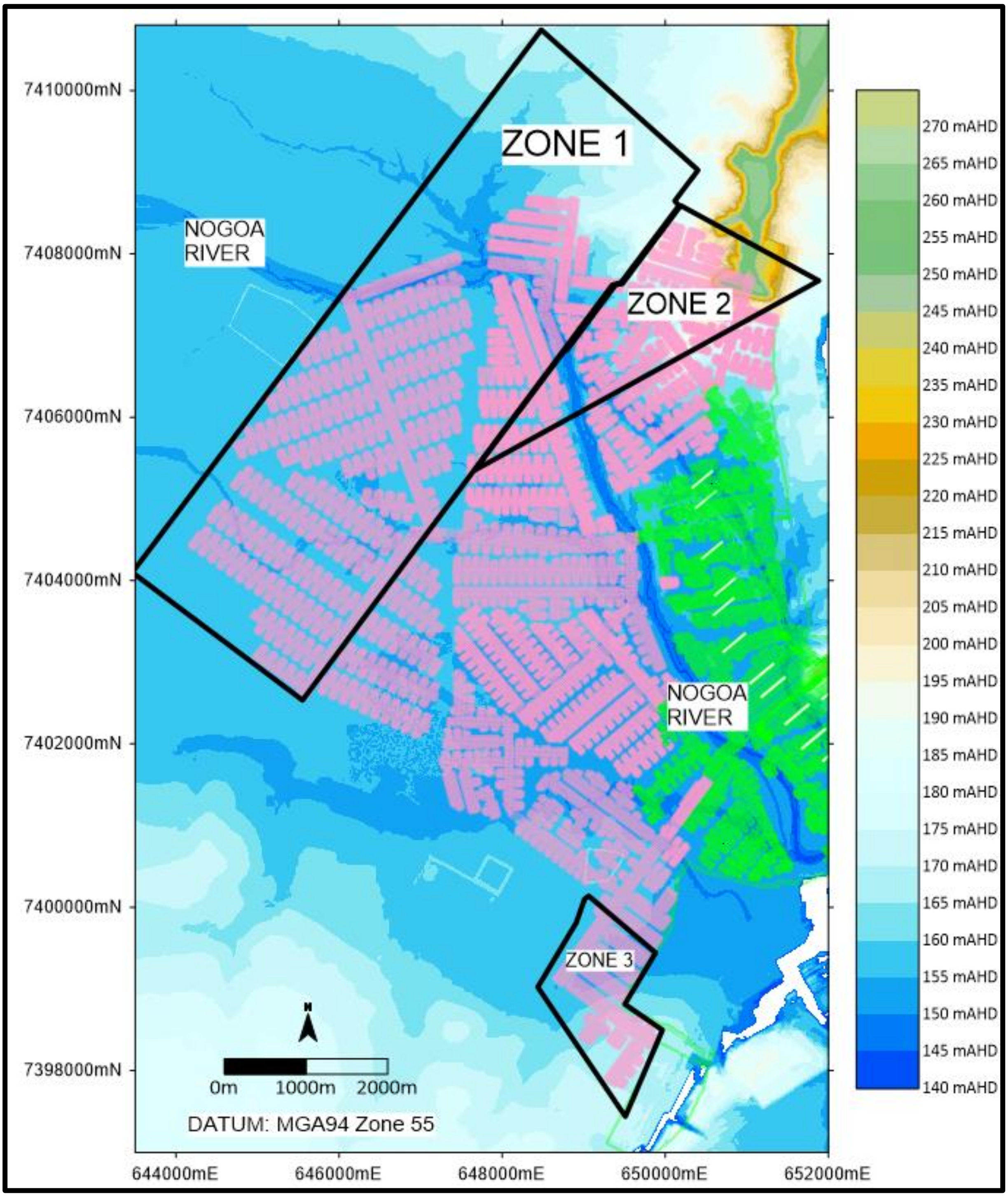

Figure 3. Surface Topography

1.3 Project Mining Method

To assist in the discussion on the subsidence aspects of the proposed bord and pillar layout in the Project Area, a description of the mining method is presented below.

The fundamental concept of the bord and pillar method is that the coal seam is divided into a regular block like array, by mining the coal to form bords or roadways (**Figure 4**). The headings are intersected at regular intervals by connecting cut-throughs (**Figure 4**).

The ***bords*** are the headings and the cut-throughs and the ***pillars*** are the blocks of coal bounded by the bords (**Figure 4**). The pillars of coal support the overlying strata as the bords are driven.

Each regular array of bords is called a ***panel***. Where smaller panels are developed from the main panel, they are called ***sub panels*** (**Figure 4**).

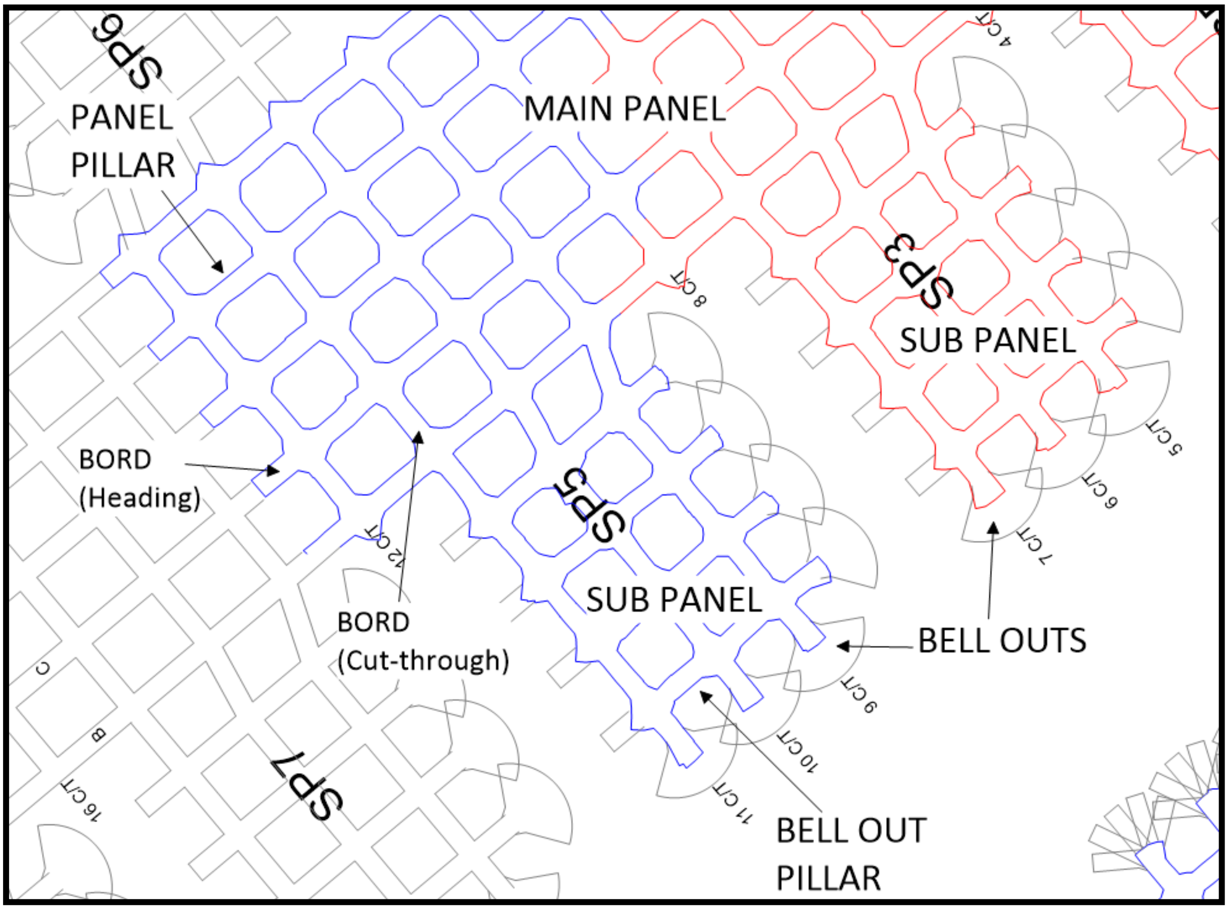

Figure 4. Bord and Pillar Layout Terminology

In the bord and pillar method, the bords are excavated, where ground conditions allow, to a maximum horizontal distance of 14 m, without the installation of roof and rib support. The maximum cut out distance is determined by the distance from the second last roof support to the operator of the shuttle car.

Excavation is carried out using the continuous miner cutting machine, which loads the coal into a shuttle car machine. The shuttle car then transports and loads the coal onto the conveyor belt system. Once the bord is excavated to the maximum distance, the continuous miner is moved to the next mining sequence and ground support is installed using a bolting machine termed a multibolter.

The development roadways (bords) in the current underground workings are typically 6.5 m wide and 3.1-3.5 m high (**Figure 5**). In poorer ground conditions, the roadway width may be reduced to 5.5-6.0 m to improve roof stability. This reduction in width also increases the factor of safety (FoS) of the pillars. In the Project Area, the roadways are also planned to be 6.5 m wide. In the thinner seam areas of the Project Area, a lower roadway and pillar height is anticipated.

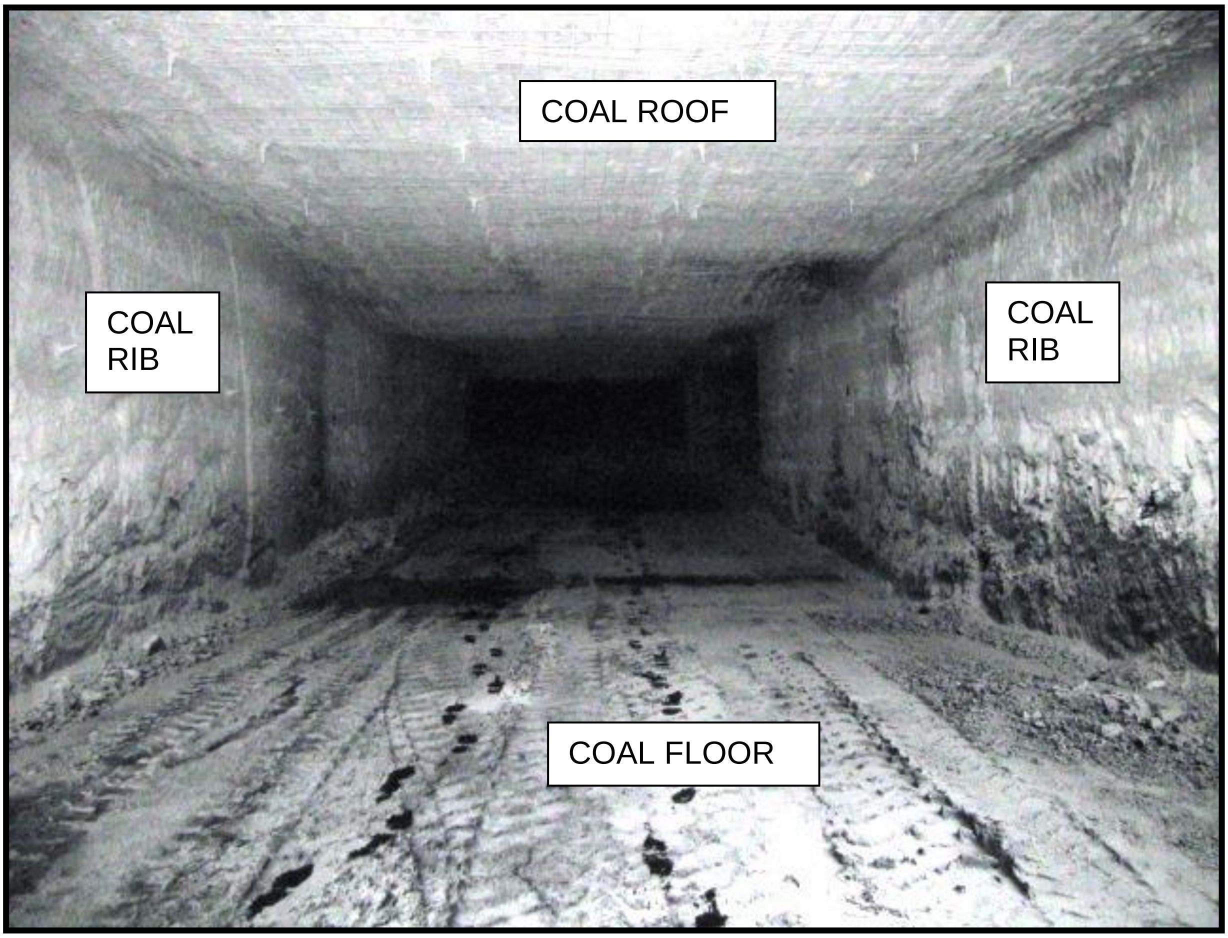

Figure 5. 6.5 m Wide x 3.3 m High Development Roadway (Bord) at Ensham

After the completion of panel development, secondary coal recovery on retreat is carried out as follows:

- Floor coal is mined in the panels and sub panels (**Figure 6**).
- Bell outs are mined at the perimeter of the panels (**Figure 4**).

During floor coal recovery, canchs (or benches) of coal, nominally 0.3-0.5 m thick, are left along the side of the roadway to protect the mining personnel from the coal rib (**Figure 6**). The maximum roadway (bord) height is determined by the FoS of the pillar (**Section 4.1**).

The same secondary coal recovery methodology is proposed for the Project Area. This methodology is a non-caving mining method such that large-scale overburden fracturing and subsidence, due to overburden sag, does not occur.

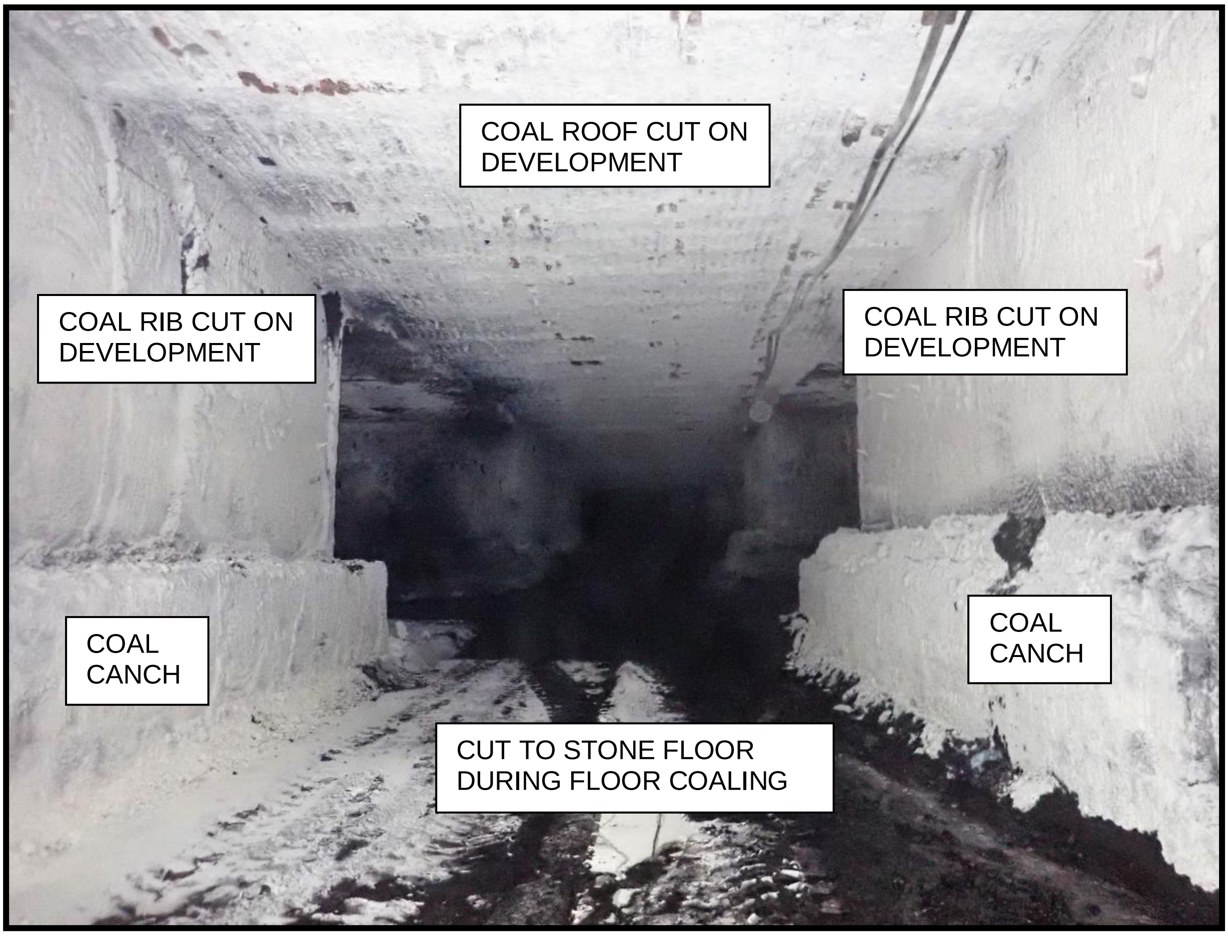

Figure 6. 5.5-6.5 m Wide x 4.8 m High Roadway after Floor Coaling at Ensham

The panel pillars in the Project Area are designed with centre dimensions of 24 m x 28 m, which for 6.5 m wide roadways leaves solid 17.5 m x 21.5 m pillars (**Figure 7**). In the sub-panels, the pillars will have centre dimensions of 24 m x 24 m. The coal recovery ratios for the panel and sub-panel pillars are 44% and 46.8% respectively.

The naming convention for each panel is shown in **Figure 7**, for ease of reference in the subsidence assessment part of this report in **Section 4**.

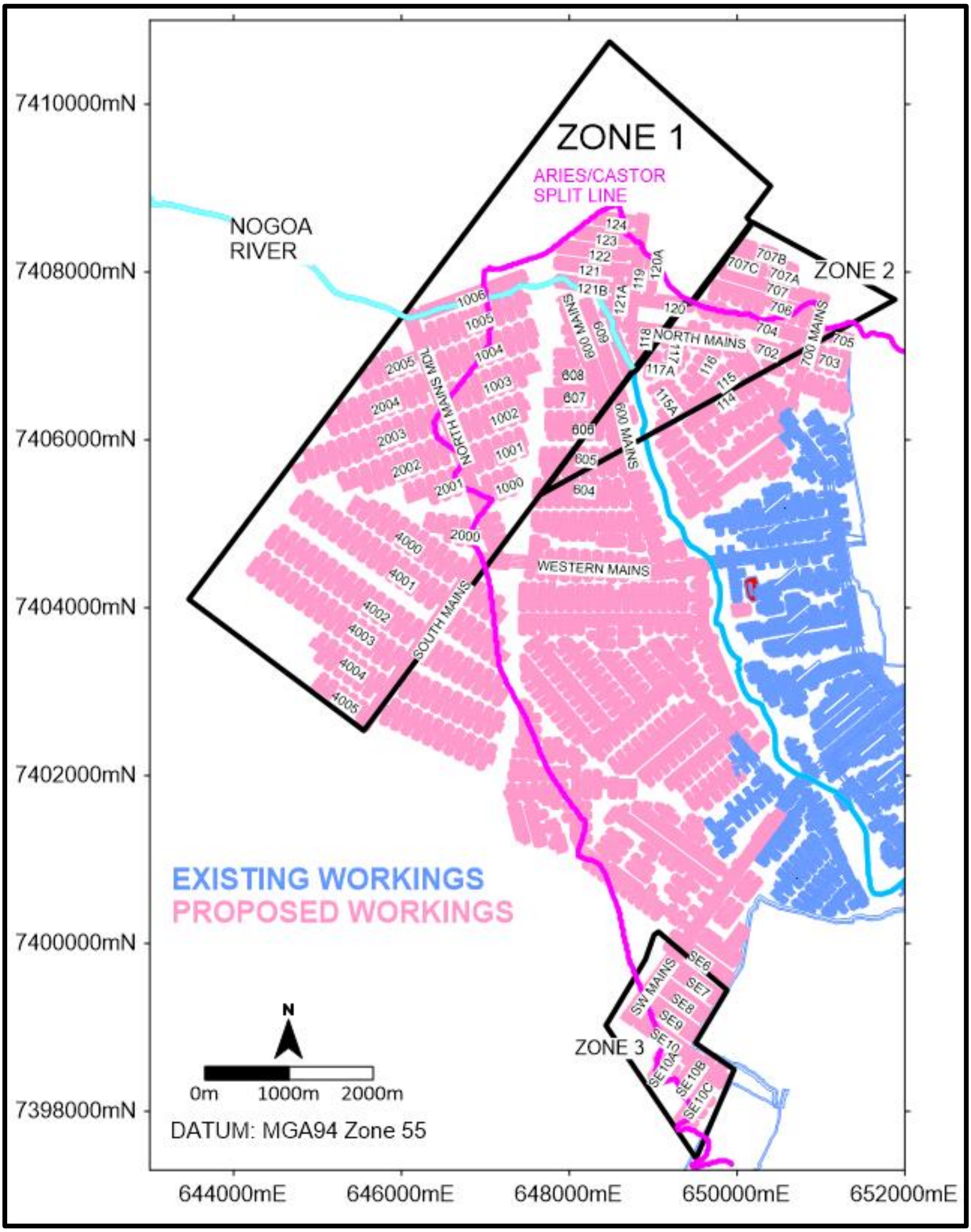

Figure 7. Proposed Bord and Pillar Layout and Panel Nomenclature

It should be stated that this assessment is being carried out on a generic mine layout that may still be modified based on the results of the 3D seismic survey, which is planned to be acquired over Zone 1 in two stages in November 2019 and June 2020. This survey may identify geological faults that require the panel design to be changed to optimise coal recovery.

These changes would not make the results of this subsidence assessment invalid. Rather, this assessment confirms that the various layout rules used by Ensham in developing the mine layout in the Project Area are fit for purpose, as they return long-term stable remnant mine workings.

In the thicker seam areas, coal roof and coal floor will be left during the development part of the mining process, prior to secondary coal recovery (**Figure 5**). In the thinner seam areas, it is anticipated that the roadways will be mined to stone roof and stone floor, with no subsequent secondary floor coal recovery.

Between each panel, large 35-40 m (solid) barriers (blocks of coal) have been left and within each panel, the sub-panels are separated by a 25 m coal barrier (**Figure 7**). These barrier pillars are significantly larger than the panel pillars and minimise the interaction of overburden loads between the panels.

1.4 Objectives

The objective of this assessment is to predict the subsidence associated with the proposed mining activities within the Project Area. The predictions are to be undertaken following a transparent and robust methodology.

1.5 Report Structure

Section 1 of this report introduces the Project Area, including the proposed bord and pillar mining layout and methodology and setting.

Section 2 details the stratigraphy, depth of cover and coal seam thickness of the Project Area.

Section 3 details previous subsidence monitoring data for the current Ensham underground workings and comparable bord and pillar mining operations.

Section 4 describes the subsidence prediction methodology, subsidence predictions and potential subsidence effects from the Project Area.

Section 5 presents the key conclusions of the subsidence assessment.

2 ENGINEERING GEOLOGY

2.1 Geological Data

The Project Area and its surrounds are covered by closely spaced exploration drilling at an average spacing of 420 m in Zone 1 and more closely spaced in the Zone 2 and Zone 3 mining areas, as shown in **Figure 8.** This spacing of boreholes is considered to be sufficiently detailed to identify any significant changes in the roof and floor strata that would affect the subsidence predictions prepared in this report.

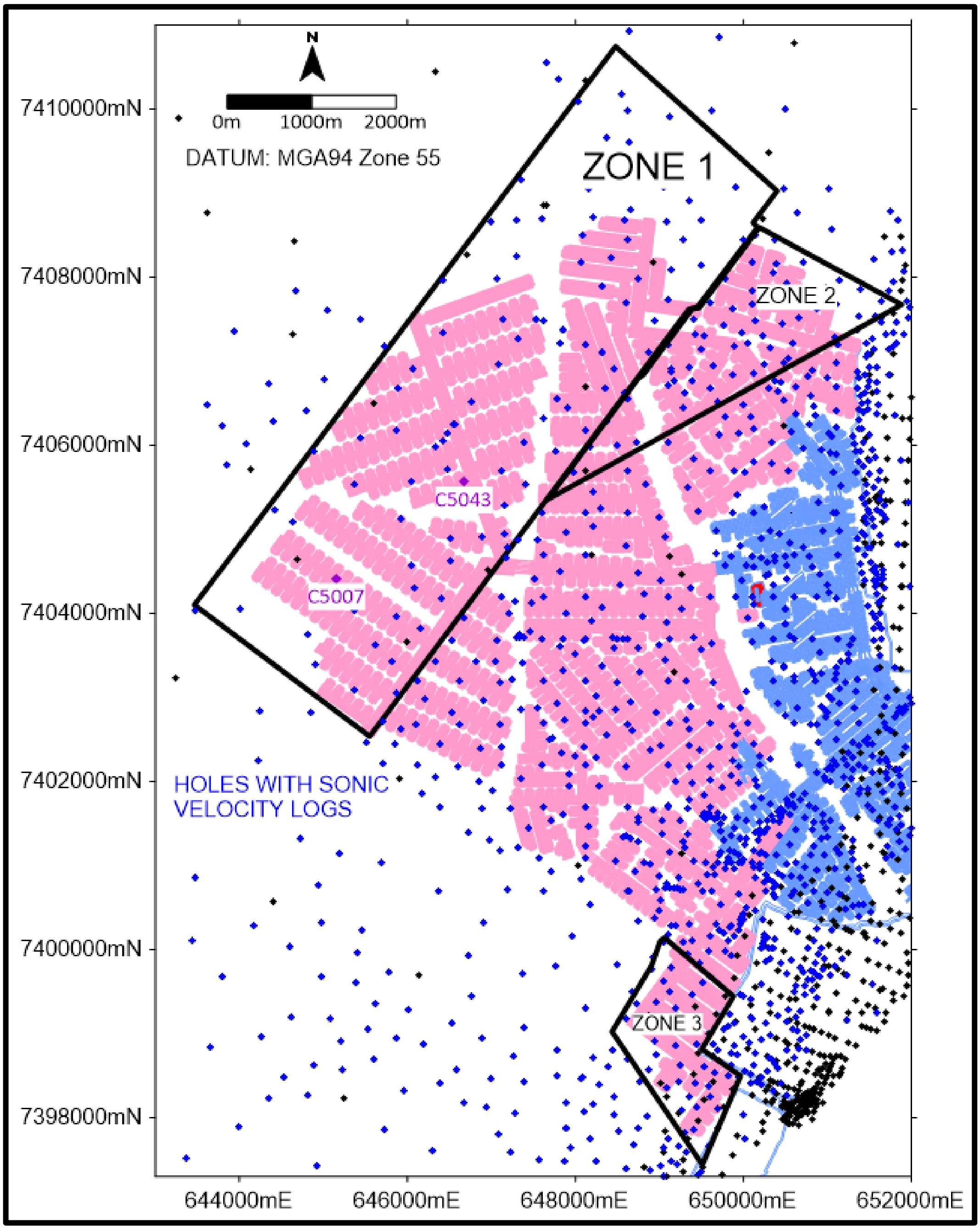

Figure 8. Location of Exploration Boreholes

These drill holes record the geological sequence of the overburden and coal seams, as well as the sediments immediately below the coalesced Aries-Castor and Castor Seams targeted for mining.

In the majority of the drill holes, geophysical logs are also available, which provide additional data on the rock and coal seam properties. This density of data provides a high level of confidence in the geological variables in the Project Area. The geological data presented in this report is based on the April 2018 geological model.

2.2 Stratigraphy

The Project Area is located in the central part of the Bowen Basin, a sedimentary basin comprising Permian to Triassic age geology. Within the Project Area, the Aries and Castor Seams are part of the Permian Rangal Coal Measures.

A generalised sequence of the coal seams in the Ensham area from north to south in the ML areas and also in the Project Area is shown in **Figure 9**. This figure illustrates the roof and floor seam splitting, which is characteristic of the Ensham area. The individual plies labelled A, C, P, Q and V refer to the Aries, Castor, Pollux, Orion and Virgo Seams respectively (**Figure 9**).

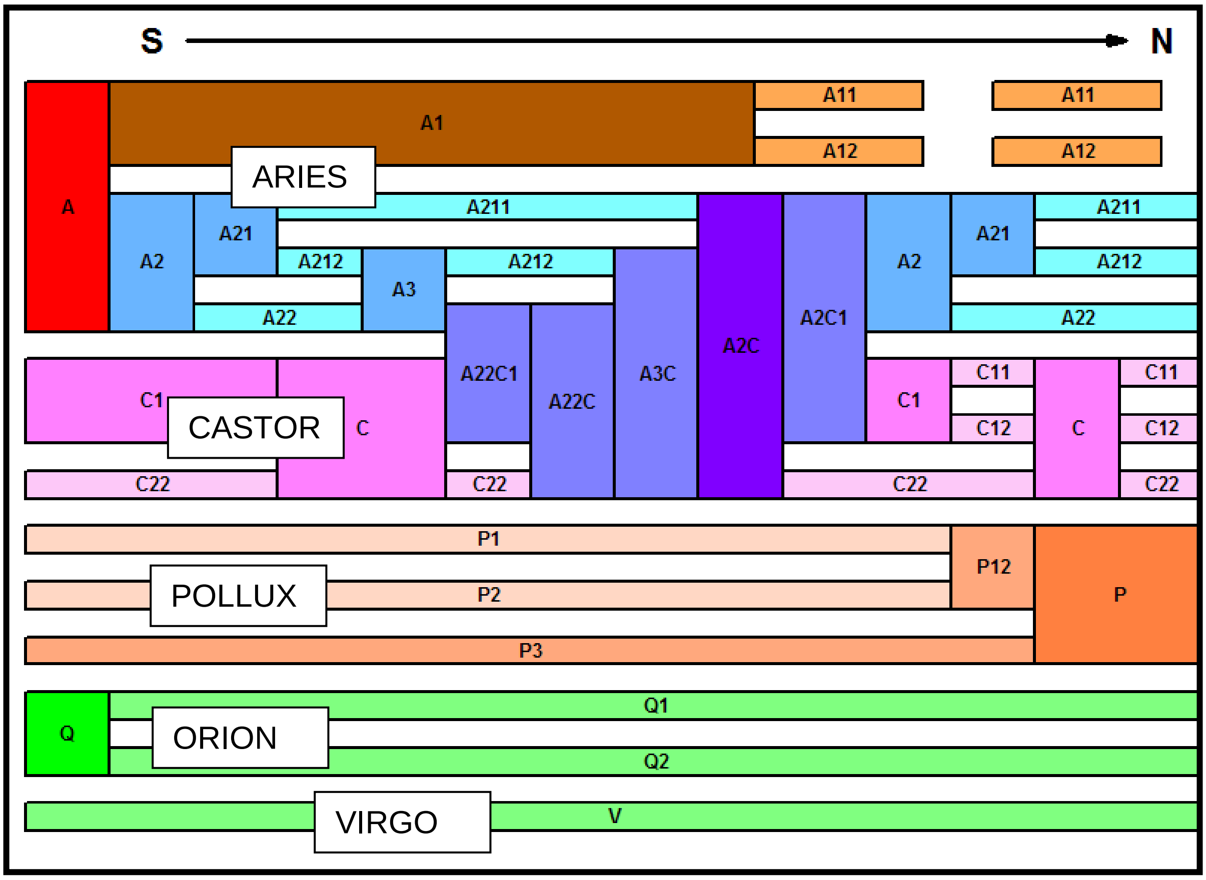

Figure 9. Permian Coal Seams across the Ensham Area

The current underground mining area is located in the thicker central part of the ML area where the Aries and Castor Seams are coalesced (**Figure 9**).

2.3 Seam Thickness

In the central part of Zone 1, the Aries and Castor Seams are coalesced as typically either the A2C or A3C and the working section is 4.0-5.5 m thick (**Figure 9** and **Figure 10**). In the remainder of Zone 1, the Aries and Castor Seams are split and the Castor Seam is the targeted working section with a typical thickness range of 2-3 m (**Figure 10**).

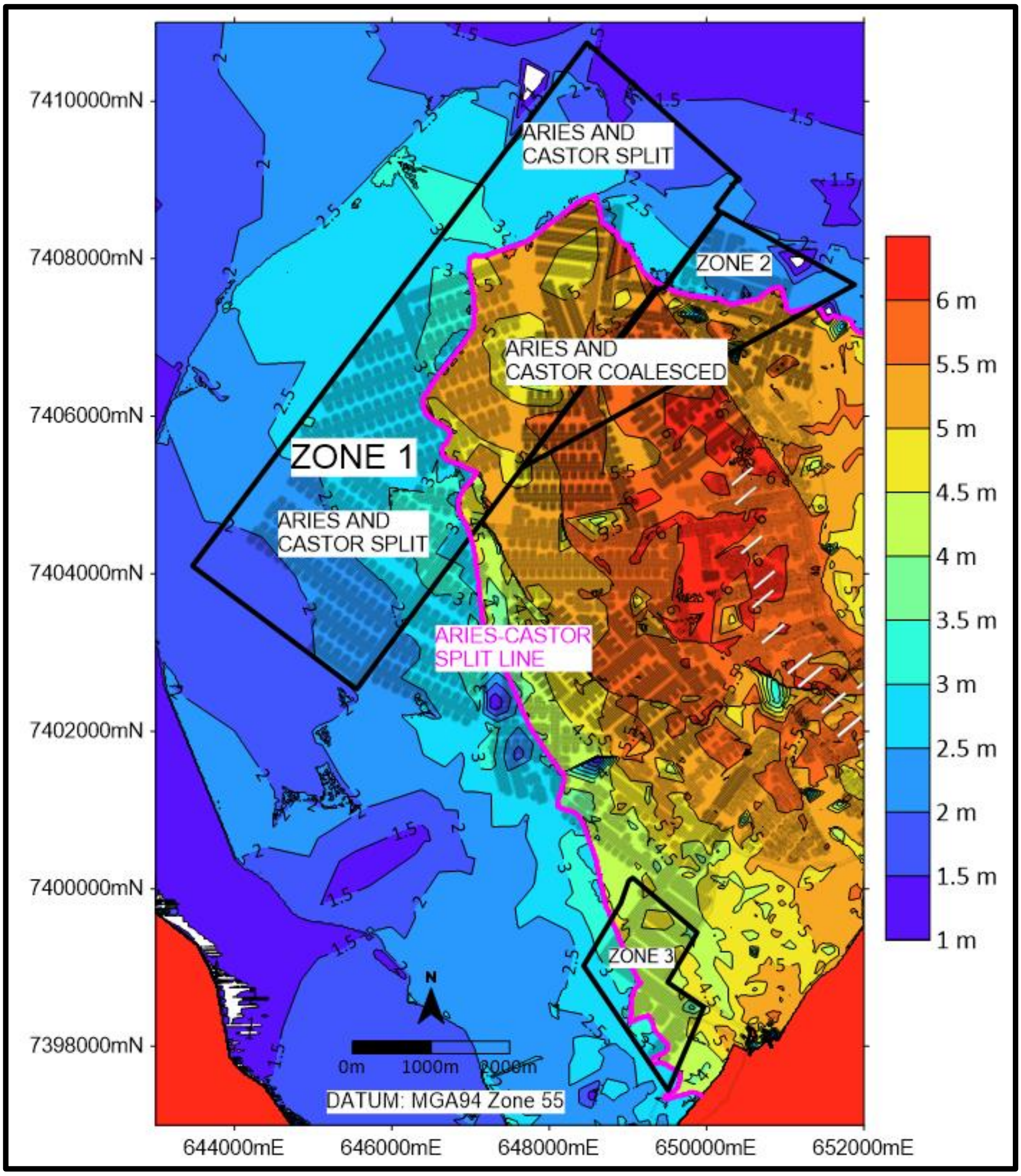

Figure 10. Working Section Thickness

The Aries and Castor Seams are coalesced in the majority of the Zone 2 and Zone 3 mining areas (**Figure 10**).

It should be highlighted that the thickness contours have been generated from grids that have been cropped either side of the Aries-Castor split line to ensure the accuracy of the thickness values used in the compression analysis presented later in this report (**Figure 10**).

2.4 Depth of Cover

Where the Aries and Castor Seams are coalesced in Zone 1, the depth of cover ranges from 130 m to 180 m (**Figure 11**). Where the Castor Seam only is mined in Zone 1, the depth is between 170 m and 210 m (**Figure 11**).

In the northern part of Zone 1, the depth to the working section is as shallow as 110 m, however no mining is planned in this area due to the inconsistent thickness of the plies in both the Aries and Castor Seams (**Figure 11**).

In Zone 2, the depth of cover is typically 130-140 m (**Figure 11**). A topographic surface feature, locally increases the depth of cover to 200 m in the eastern part of Zone 2 (**Figure 11**).

In Zone 3, the depth of cover ranges from 80 m in the east, up to 160 m in the western part of Zone 3 (**Figure 11**).

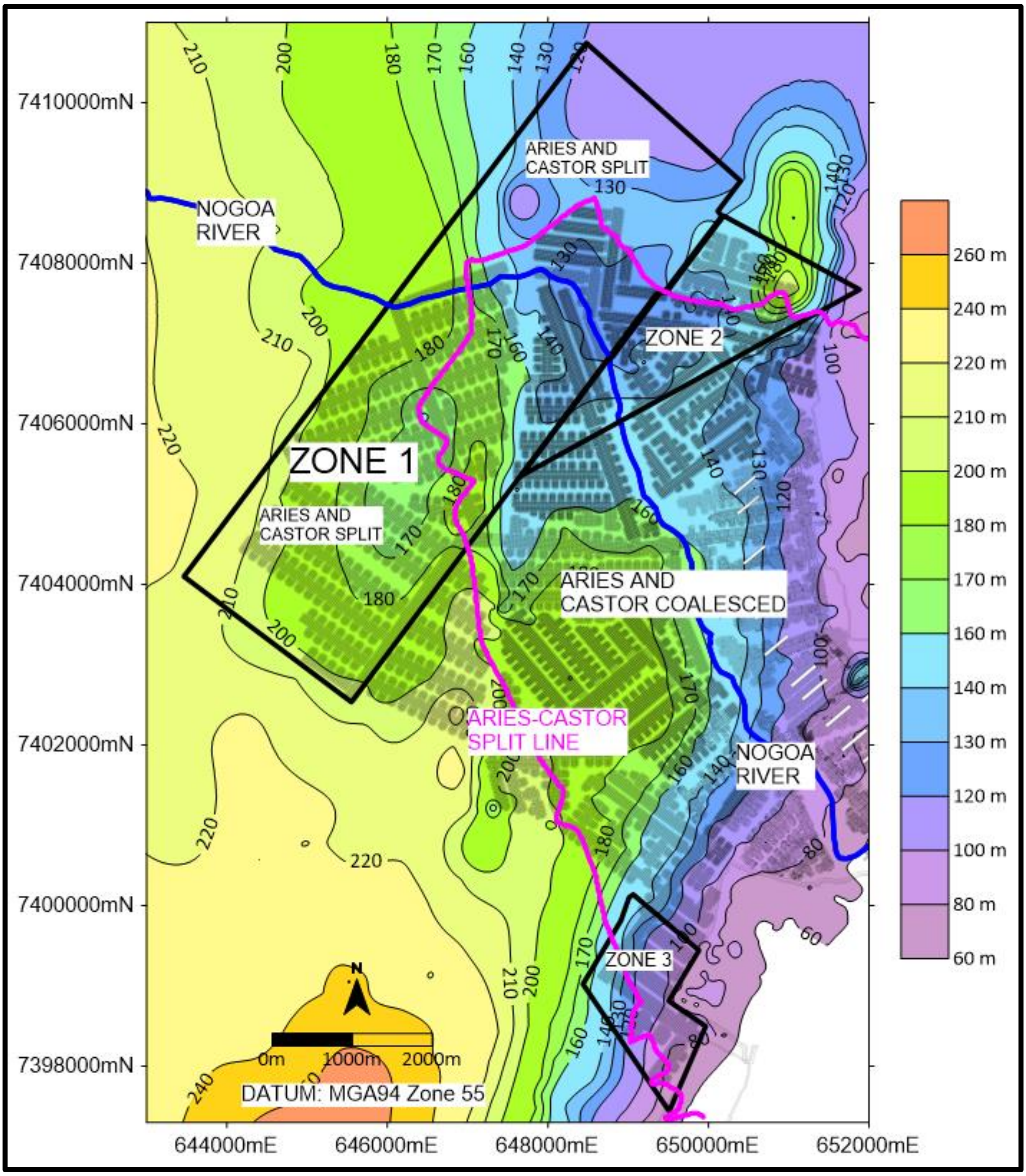

Figure 11. Working Section Depth

2.5 Depth of Weathering

The depth of weathering is typically 10-20 m thick across the majority of the Project Area (**Figure 12).** The depth locally increases to 50 m above the eastern part of the Zone 2 mining area, due to the surface topographic feature in this area (**Figure 12**).

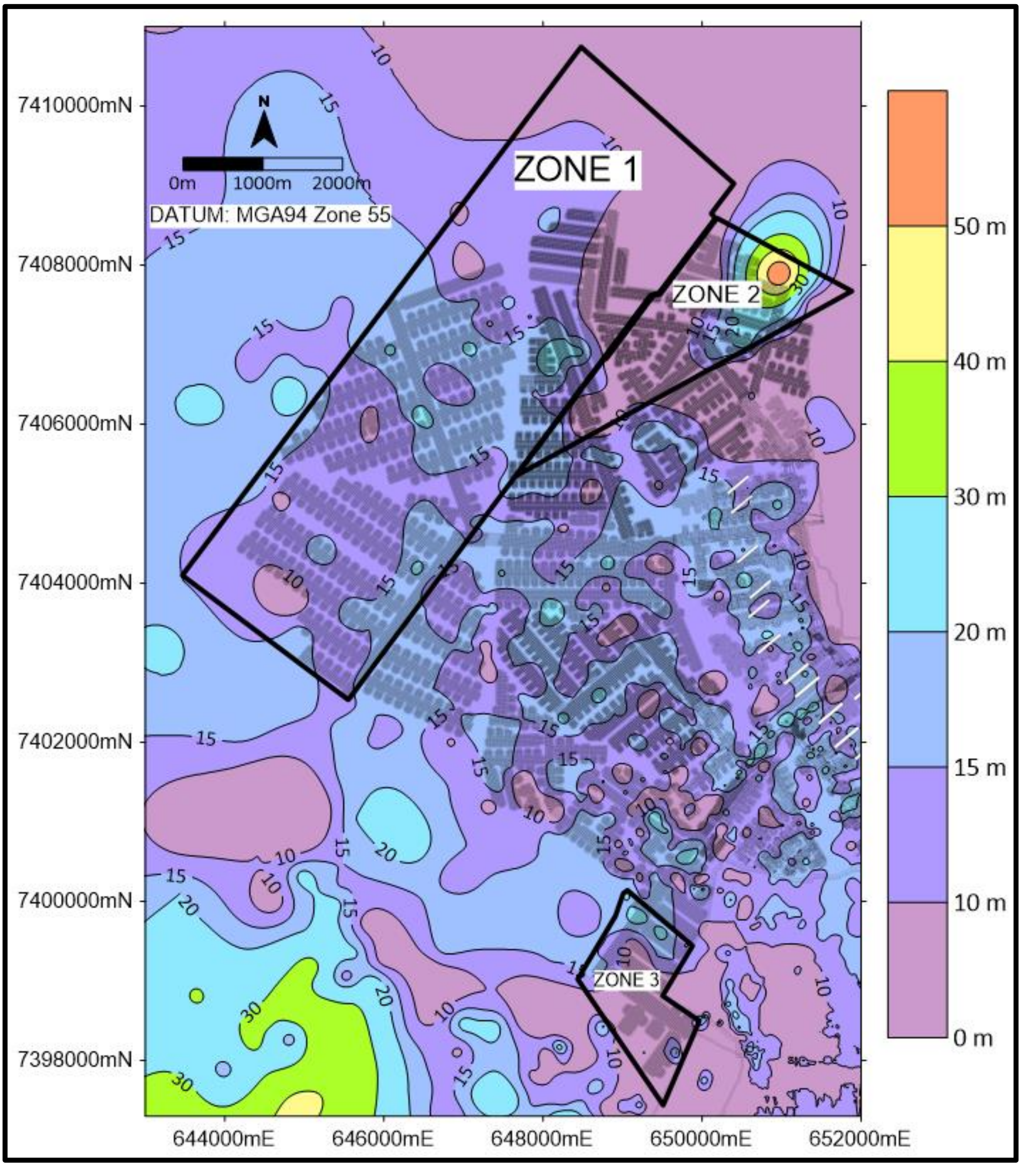

Figure 12. Depth of Weathering

3 PREVIOUS SUBSIDENCE MONITORING DATA

To assist in the prediction of subsidence in the Project Area, a review of the surface effects above the current underground workings has been carried out using the available LIDAR survey data.

In addition to the Ensham survey data, there is published subsidence data available from Clarence and Tasman Mines in NSW above partial extraction bord and pillar layouts. The relevant information from these three mining operations is discussed in the following sections.

3.1 Ensham Mine

LIDAR surveys flown in March 2016 and February 2017 have been used to assess potential surface effects above mined out areas at Ensham. The extent of the underground workings at the time of these surveys is shown in **Figure 13.**

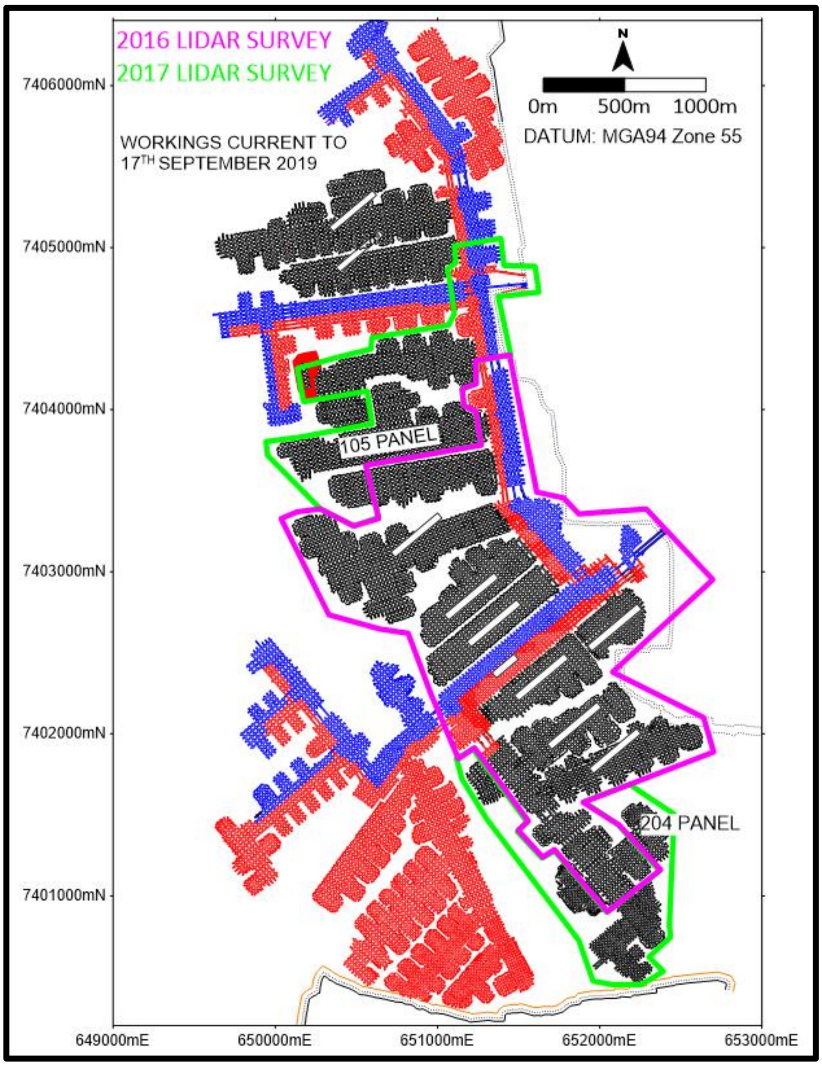

Figure 13. Extent of the Mine Workings at the time of each LIDAR Survey

These surface effects may also include natural ground movements, as well as potential subsidence effects. IESC (2015[1]) detailed in their report to the Department of the Environment, that in some environments, up to 50 mm or more of vertical movement may occur due to seasonal moisture changes.

Mining was completed in the shallower 204 Panel in the southern part of the mining area and the deeper 105 Panel located in the central part of the mine workings between the 2016 and 2017 surveys (**Figure 13**).

The section lines above both panels show that any ground movement is less than the ±50 mm accuracy of the surveys (**Figure 14** and **Figure 15**). These measurements validate the subsidence predictions of typically <40 mm in the Project Area presented in **Section 4.3** of this report.

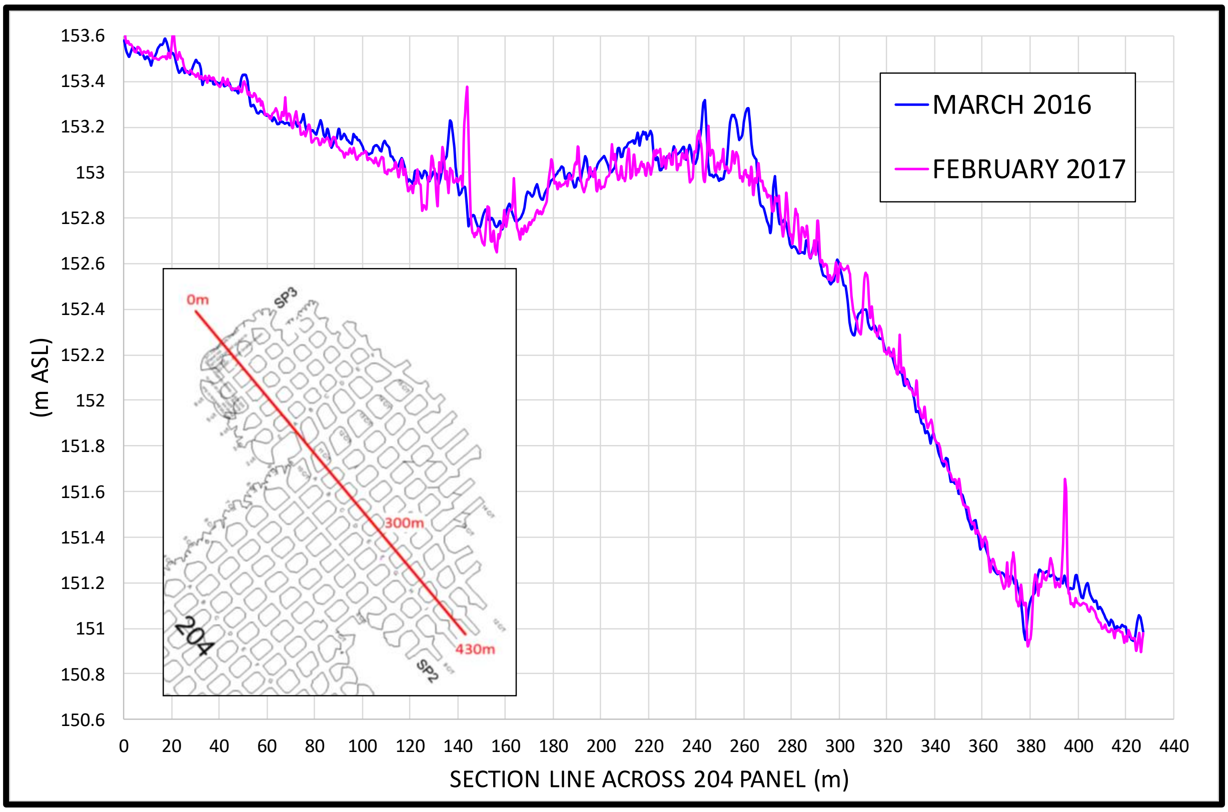

Figure 14. Section Line above 204 Panel

[1] Independent Expert Steering Committee (2015). Monitoring and Management of Subsidence Induced by Longwall Coal Mining Activity. Report to the Department of the Environment.

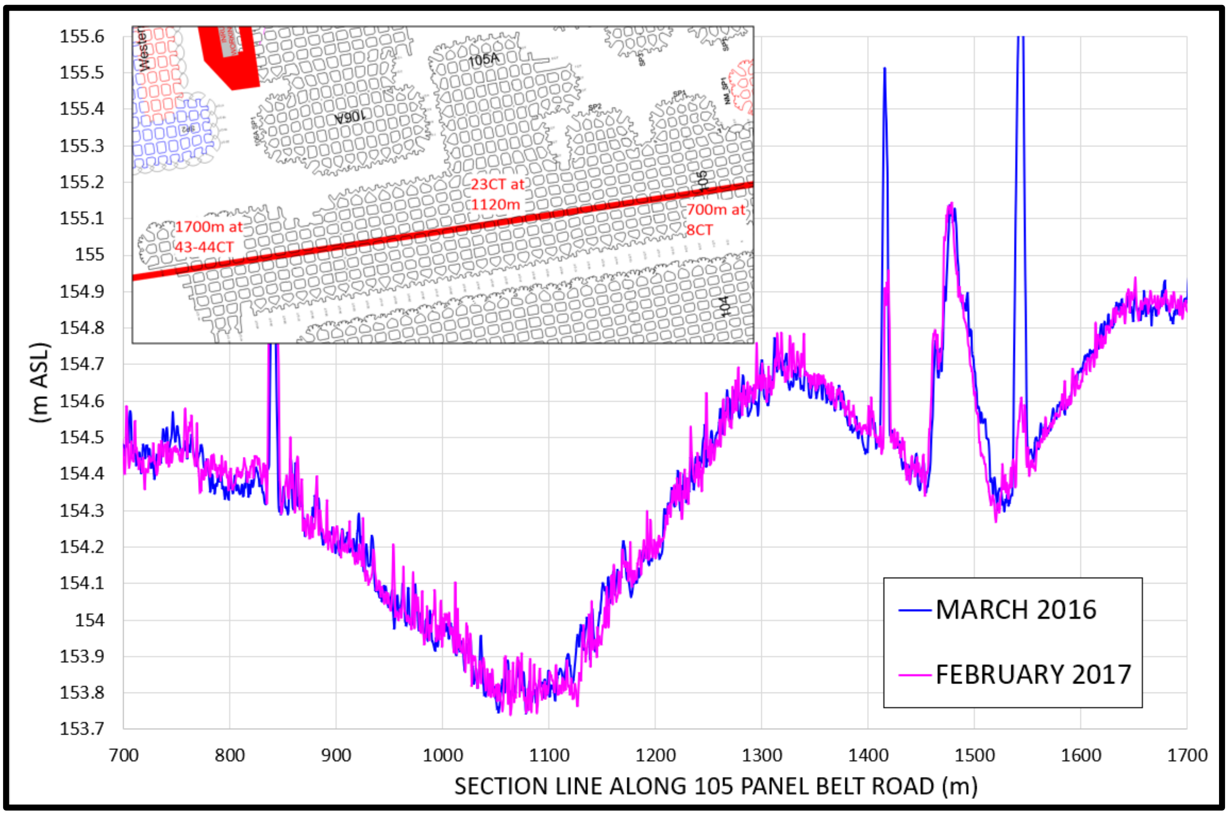

Figure 15. Section Line along the 105 Panel Belt Road

3.2 Clarence Mine

Clarence Mine operates adjacent to the Blue Mountains World Heritage area in the Western Coalfield of NSW. The 2.8-3.6 m thick Katoomba Seam is mined at depths between 60 m and 320 m (Hill and White, 2017[2]). The in-panel extraction ratios at Clarence are around 50-60%, slightly higher than those in the Project Area at Ensham where there is no partial extraction of coal pillars (**Figure 16**).

At Clarence, the Development Approval limits surface subsidence to 100 mm. Monitoring since 2003 has shown that subsidence can be characterised in four stages (Hill and White, 2017):

1. Development drivage results in 5-10 mm of subsidence.
2. Partial extraction adds 15-20 mm (i.e. 20-30 mm of cumulative subsidence).
3. Drivage and partial extraction of the subsequent adjacent panel adds 5-10 mm (i.e. 25-40 mm of cumulative subsidence).
4. Long term water accumulation and panel flooding results in an additional 30 mm (i.e. 55-70 mm of cumulative subsidence).

[2] Hill, D. and White, E. (2017). Progress in Partial Extraction Layout Design for Productivity, Safety and Subsidence Management at Clarence Colliery. Proceedings of the 10th Triennial Conference on Mine Subsidence. Pp. 235-252.

There have been no exceedances of the 100 mm subsidence limit since partial extraction started in 2003 (Hill and White, 2017).

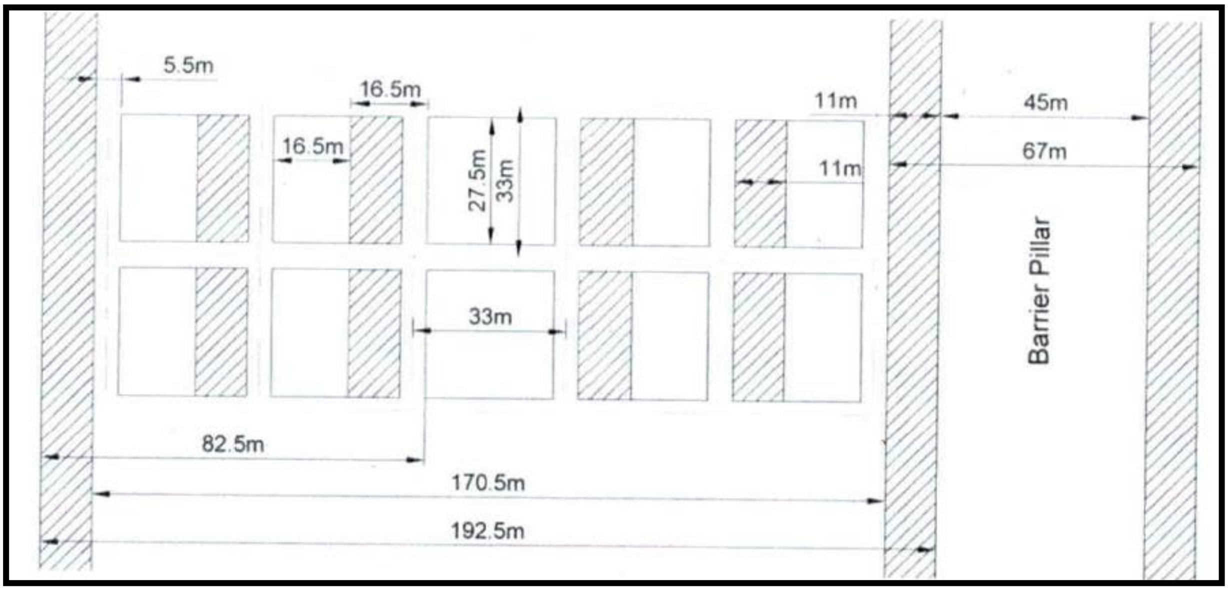

Figure 16. Bord and Pillar Layout – Clarence Mine

3.3 Tasman Mine

Tasman Mine in NSW commenced the Duncan Method of partial extraction in 2008 of the 2.2-2.5 m thick Fassifern Seam, at depths up to 250 m (McTyer and Sutherland, 2011[3]). The extraction ratios were between 67% and 82%, which are significantly higher than the 44-46.8% recovery proposed in the Project Area at Ensham.

The proximity and visibility of the cliff lines of the Sugarloaf Range State Conservation Area to Newcastle, resulted in strict mine approval conditions regarding subsidence outcomes. Under the Tasman Development Consent, there was to be no impact on the high-level cliff lines as a result of subsidence (Ditton and Sutherland, 2013[4]).

Man-made features on the site included three broadcasting towers, AAPT Optical Fibre Cable (OFC) and Telstra copper cabling, four TransGrid tension towers, Ausgrid 11 kV power line, public access road and several highly significant Aboriginal archaeological sites (Ditton and Sutherland, 2013).

[3] McTyer, K. and Sutherland, T. (2011). The Duncan Method of Partial Pillar Extraction at Tasman Mine, 11th Underground Coal Operators' Conference, University of Wollongong & the Australasian Institute of Mining and Metallurgy, 2011, 8-15.

[4] Ditton, S. and Sutherland, T. (2013). Management of Subsidence at the Tasman and Abel Mines - Issues and Outcomes, 13th Coal Operators' Conference, University of Wollongong, The Australasian Institute of Mining and Metallurgy & Mine Managers Association of Australia, 2013, 86-98.

Level 1 to 4 subsidence control zones were developed for mine planning purposes for the existing surface features (Ditton and Sutherland, 2013):

1. Level 1 - (Green) no mining constraints (total extraction allowed);
2. Level 2 - (Yellow) subsidence <150 mm along shallow cover below ephemeral creeks, steep slopes and minor cliffs; Aboriginal Heritage sites; Optical fibre cable.
3. Level 3 - (Red) subsidence <100 mm below Sugarloaf area, TransGrid Towers (tension).
4. Level 4 - (White) Subsidence <3 mm and horizontal displacements <20 mm at the Mount Sugarloaf Communication Towers (NBN, TransGrid and Broadcast Australia).

Level 1 areas were considered suitable for total pillar extraction, with the maximum subsidence up to 1.2-1.3 m.

Level 2 and 3 areas required partial pillar extraction techniques that could also support abutment loading from Level 1 areas. Level 2 and 3 had similar subsidence constraints however, the remnant pillar FoS ranged from 1.6 to >2.11 respectively and required squat pillar geometries (i.e. width/height ratio of >5) for strain hardening response in yield (Ditton and Sutherland, 2013).

McTyer and Sutherland (2011) reported the subsidence one year after mining was completed above partial extraction panel 3 North, to range from 51 mm to 101 mm, with a maximum tilt of 1.2 mm/m (**Figure 17**).

As documented by Ditton and Sutherland (2013), 2.5 years after mining had been completed, increased levels of subsidence up to 521 mm were measured (**Figure 17**). A surface crack of 30 mm width developed above the rib line and across a public access path after the subsidence exceeded 300 mm.

These increased levels of subsidence were inferred to be due to weak claystone layers (0.1-0.4 m thick) in the immediate 1.2 m of floor below the coal pillars, which softened to 0.15-1 MPa after mining. This softening of the floor resulted in punching of the pillar and lateral squeezing failures within the first 1.5 m of floor strata.

There is a history of similar subsidence events in the Newcastle coalfield due to the behaviour of very soft floor strata. In the 1980s, more than 1 m of subsidence was measured on the foreshore of Lake Macquarie above one of the mines in this area.

Based on these experiences in soft floor mining conditions, the subsidence assessment in the Project Area at Ensham has considered the floor strata below both the coalesced Aries-Castor and Castor Seams to identify any potential weak units to eliminate the possibility of similar subsidence events (**Section 4.2.1**).

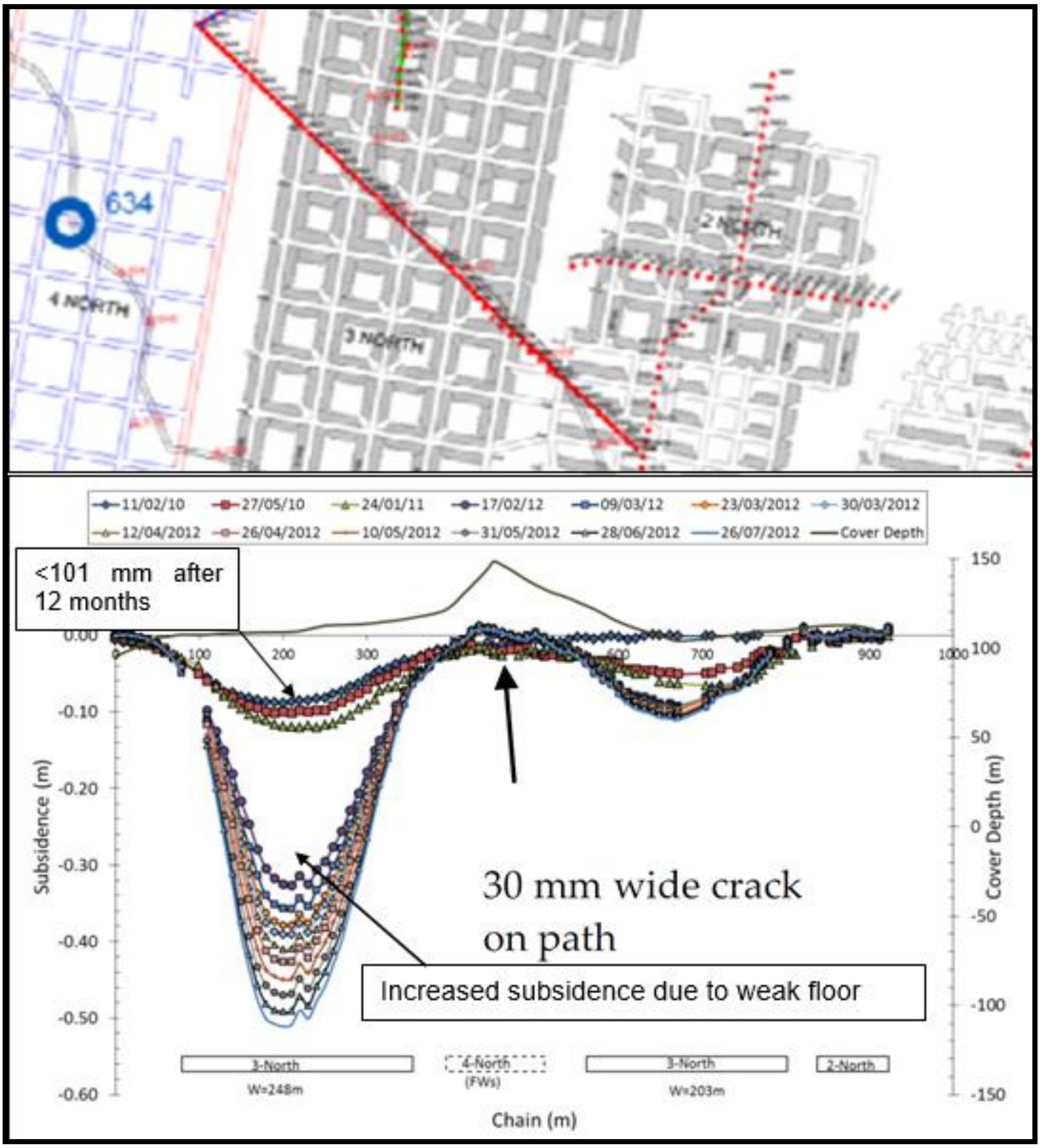

Figure 17. Subsidence over 3 North at Tasman

4 SUBSIDENCE PREDICTION METHODOLOGY AND RESULTS

The bord and pillar mining method proposed in the Project Area is described in **Section 1.3**. The proposed mine layout has been specifically designed to ensure that there will be no caving of the roof or pillar collapses.

The long-term stability of the proposed underground workings has been assessed in **Sections 4.1.1, 4.1.2** and **4.1.3** using the design FoS, pillar dimensions (width to height ratio) and stability of the overburden respectively.

Section 4.1.4 provides a comparison of the stability of the pillars in the Project Area, to published studies of pillar failure events and experience from the current Ensham underground workings.

The subsidence behaviour and effects have been assessed in **Sections 4.2** and **4.3**.

4.1 Stability of Underground Workings

4.1.1 Factor of Safety

The assessment of the stability of the coal pillars in the Project Area has been carried out using the industry accepted University of New South Wales Pillar Design Procedure to determine the design FoS as follows (Galvin et al, 1998[5]):

FoS = Strength of Pillar/Load on Pillar

The strength of the pillars in the Project Area was calculated using the UNSW Pillar Design Power Strength Formulae.

The load carried by the pillars was calculated using tributary area loading. The majority of the panels in the Project Area have panel width to depth of cover ratios >1, whereby the pillars experience the full tributary area load of the overlying strata.

A recent publication by Reed et al (2016)[6] has suggested that coal pillars may exceed their peak strength before the overburden moves enough to generate full tributary area loading conditions, as discussed further in **Section 4.1.3**.

[5] Galvin, J., Hebblewhite, B., Salamon, M. and Lin, B. (1998). Establishing the Strength of Rectangular and Irregular Pillars. Final Report, ACARP Project C5024.

[6] Reed, G., McTyer, K. and Frith, R. (2016). An Assessment of Coal Pillar System Stability Criteria Based on a Mechanistic Evaluation of the Interaction Between Coal Pillars and the Overburden. Proceedings 35th International Conference on Ground Control in Mining, Morgantown, West Virginia.

Galvin, (2016)[7] also proposed that the pillars on the perimeter of the panels do not carry the full tributary area load (**Figure 18**). However, for the purposes of this assessment, a conservative full tributary area load assumption is considered appropriate for the pillars in the main panels and sub-panels in the Project Area. The bell-out pillars on the perimeter of the panels are anticipated to carry 70% of the overburden load as shown in **Figure 18**.

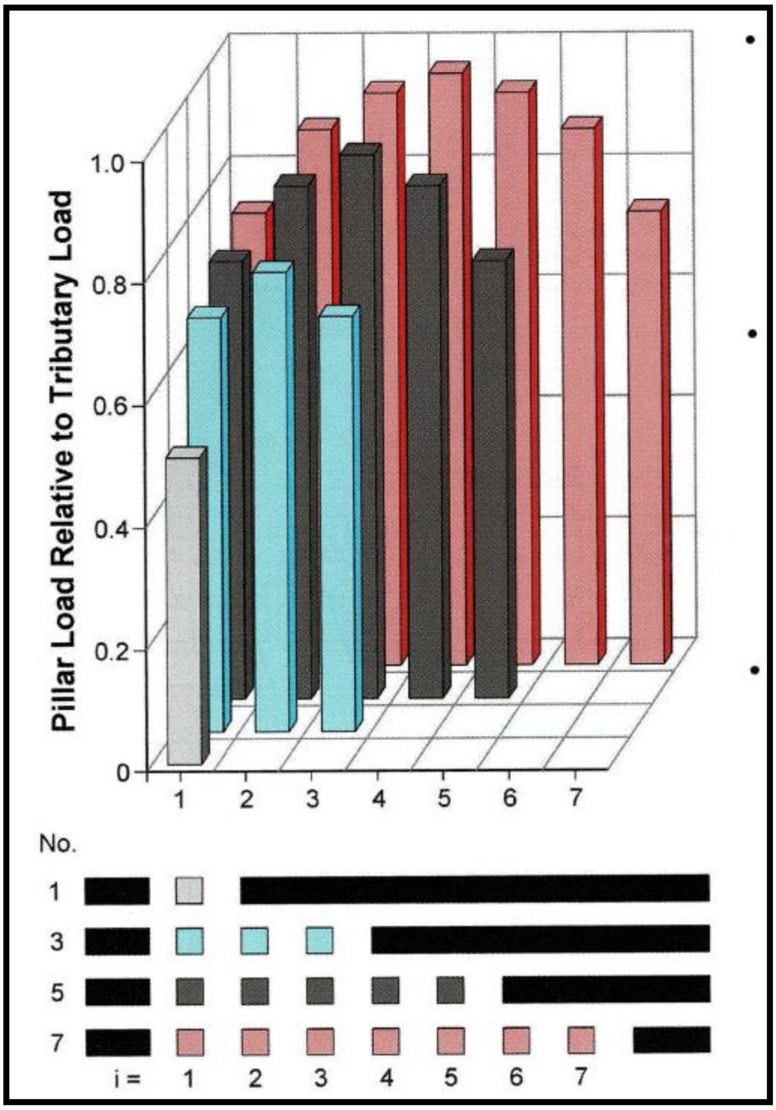

Figure 18. Influence of Panel Width on Pillar Load

4.1.1.1 Panel Pillars

The stability of the pillars in the Project Area has been assessed on a panel by panel basis, using a conservative maximum depth of cover (**Figure 11**). The mining height

[7] Galvin, J.M. (2016). Ground Engineering – Principles and Practices for Underground Coal Mining.

has also been adjusted for each panel to take into account the variability in the thickness of the coalesced Aries-Castor Seam and split Castor Seam across the Project Area (**Figure 10**). The depth and thickness values for each panel are tabulated in **Appendix 1** and **Appendix 2** of this report for Zone 1 and the Zone 2 and Zone 3 mining areas within the Project Area respectively.

Where the Aries-Castor Seam is coalesced within the Project Area, the depth of cover is between 80 m and 180 m and the seam thickness is typically 4.0-5.5 m (**Figure 10** and **Figure 11**). Based on mining experience in the current underground workings, typically 0.8 m of roof coal is left in the thicker seam areas. In thinner seam areas, the roof coal thickness is reduced to around 0.4-0.5 m.

In those areas within the Project Area where only the Castor Seam is to be mined, the seam thickness is <3 m and it is anticipated that the full seam section will be mined on development, with no secondary coal recovery (**Figure 11**).

The maximum allowable mining heights to satisfy a FoS of 1.6 for both the 24 m x 28 m (centres) pillars in the main part of the panels, as well as the 24 m x 24 m (centres) sub panel pillars, are summarised in **Figure 19** for a range of depths. This 1.6 FoS value also applies below the Nogoa River where it flows across the Project Area (**Figure 1**).

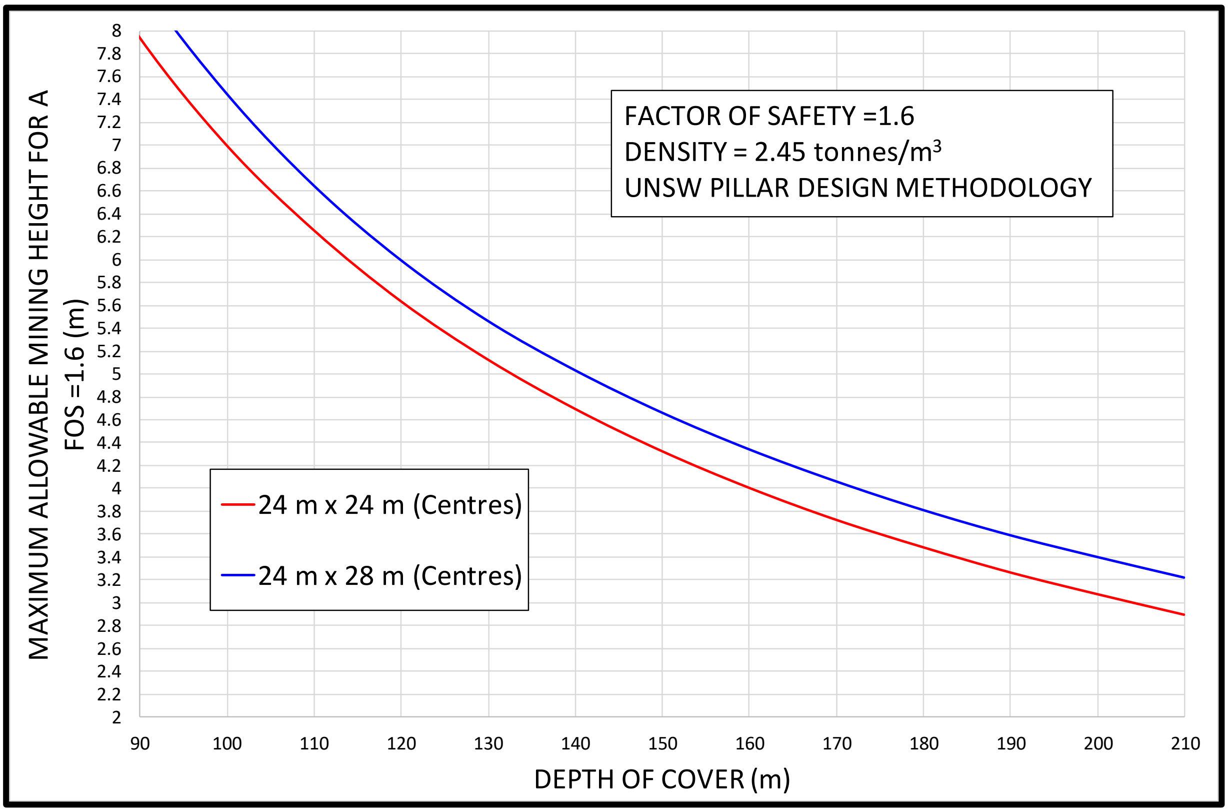

Figure 19. Standard Pillars - Maximum Mining Height for a FoS of 1.6

An overburden density of 2.45 tonnes/m^3 has been used based on the geophysical density logs from a large data set of exploration boreholes across the Ensham underground mining area (**Figure 8**).

4.1.1.2 Bell Out Pillars

The FoS of the bell out pillars also needs to be considered. As shown in **Figure 18**, a 70% load assumption is appropriate for these pillars located on the perimeter of the panels.

It is highlighted that the secondary coal recovery methodology forms a regular pillar between the bell outs, which allows the application of standard pillar design formulae (**Figure 4** and **Figure 20**). The analysis of these pillars has conservatively assumed a 10 m wide roadway equivalent to the mined bell out (**Figure 20**).

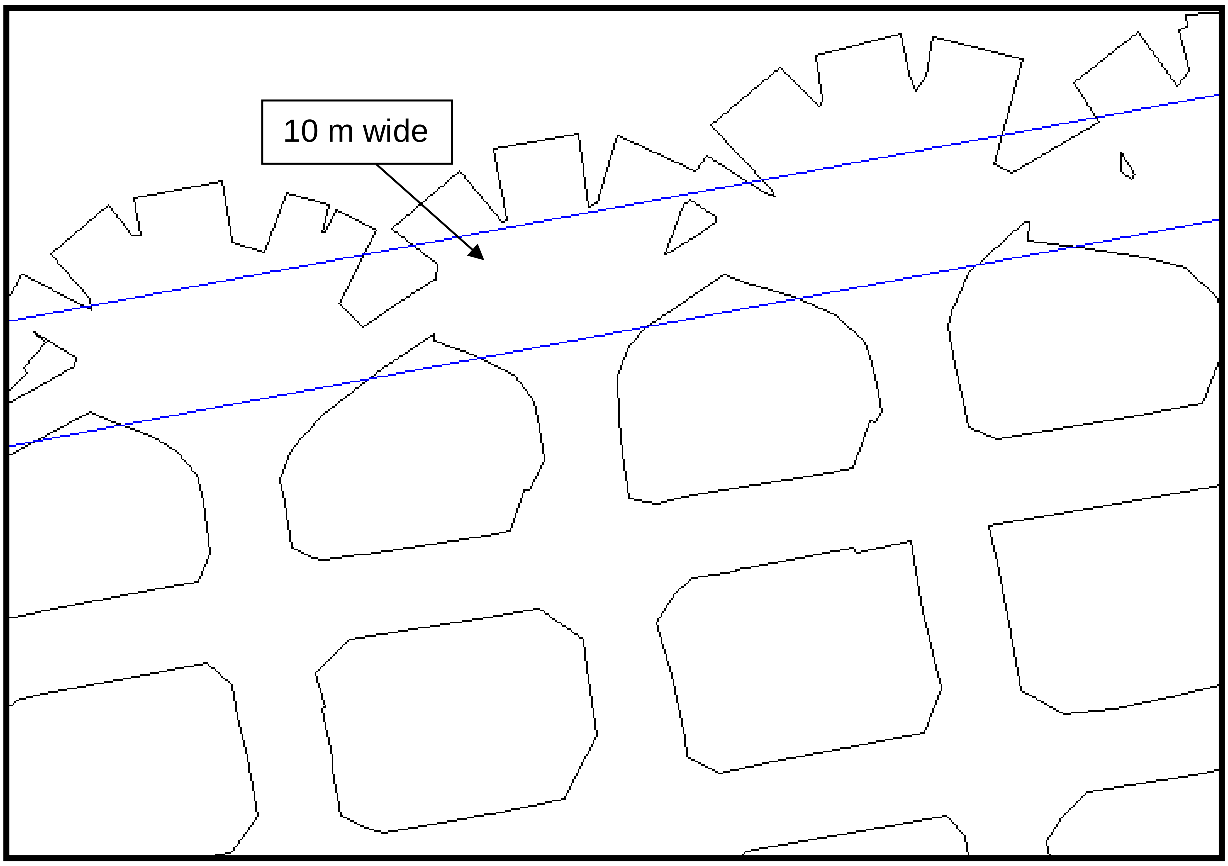

Figure 20. Comparison of Bell Out and Standard Pillars

Based on the standard bell out mining sequence, the effective width of the bell out pillar with a solid length dimension between bell out stubs of 17.5 m, is 15 m (**Figure**

21). This has been calculated using the hydraulic radius approach of Wagner (1980)[8], where the effective width (w_e) is given by:

$$w_e = 4A/P$$

where: A is the pillar solid area and
P is the pillar perimeter distance.

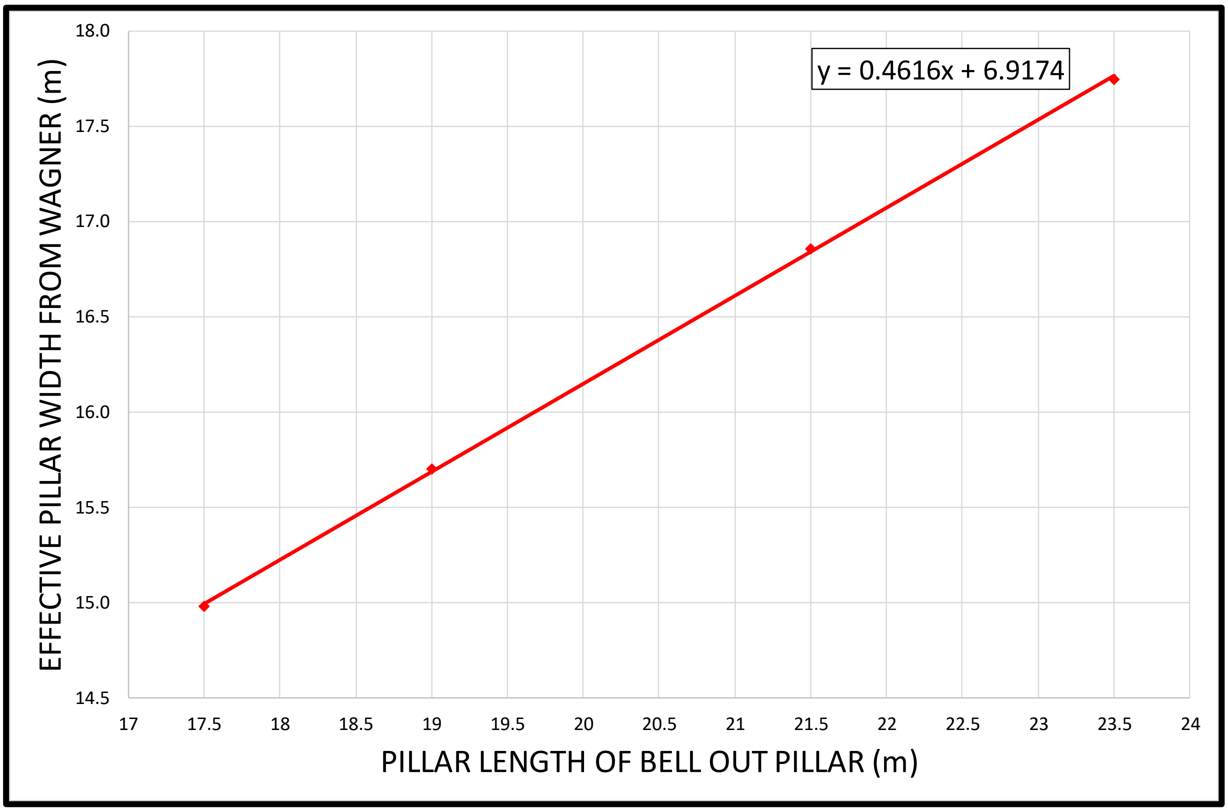

Figure 21. Calculation of the Effective Width of the Bell Out Pillars

For the bell out pillars with an effective width of 15 m (solid) and a 70% loading assumption, the maximum allowable mining heights to satisfy the 1.6 FoS requirement are shown in **Figure 22**.

[8] Wagner, H. (1980). Pillar Design in Coal Mines. Journal of the SAIMM, pp. 37-45.

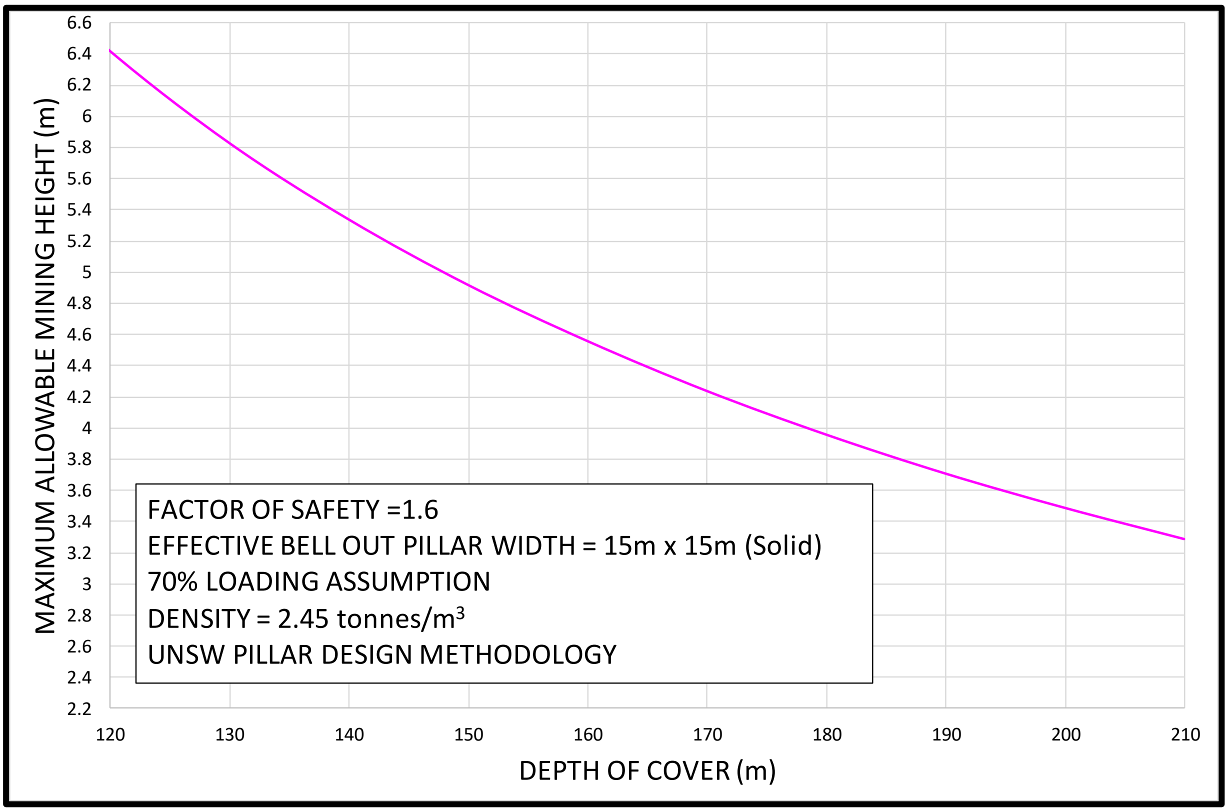

Figure 22. Bell Out Pillars - Maximum Mining Heights for a FoS of 1.6

It should be highlighted that the rib canchs have conservatively not been included in the FoS calculations (**Figure 23**).

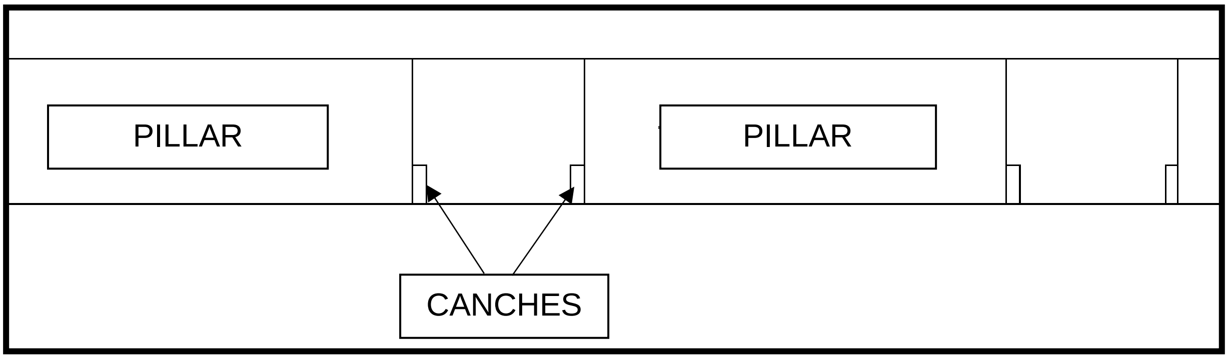

Figure 23. Scaled Diagram of the Rib Canches Left Around Pillars

4.1.1.3 Barrier Pillars

The barrier pillars between panels have high FoS. For a conservative 5 m mining height and minimum 50 m barrier length, the FoS of the 35 m wide barriers at 180 m depth is 2.75. This increases to 3.15 for the 40 m wide barrier pillars.

Similarly, the 25 m solid barriers between the sub-panels have minimum FoS values of 2.04 at 180 m depth of cover.

4.1.2 Width to Height Ratio

As well as the FoS, the width to height ratio of the pillars also has to be considered in the stability of the pillars. This ratio has a significant controlling influence on the post-failure behaviour of the pillar, ranging from a complete structural collapse (termed strain softening), to a more controlled squeeze with the pillar becoming stronger as it is compressed further (termed strain hardening).

Reed et al (2017[9]) suggest that the use of laboratory-based testing data may be flawed due to the very smooth top and bottom contacts in the test rig. This is particularly important as the transition to squat pillars is about the development of frictional based confinement within the core of the pillar. As such, published laboratory data shows substantial strain softening at width: height ratios as high as 9 (Das, 1986[10]).

Reed et al (2017) refer to the available in situ testing data for coal pillars that indicates that the post-failure modulus should transition from negative (strain-softening) to positive (work-hardening) at a width/height ratio of between 4 and 5 (**Figure 24**).

Galvin (2016) also indicated that if the width to height ratio is >4, any pillar failure will be controlled and may be arrested through the application of confinement to the pillar sides.

[9] Reed, G, McTyer, K and Frith, R. (2017). An Assessment of Coal Pillar System Stability Criteria Based on a Mechanistic Evaluation of the Interaction Between Coal Pillars and the Overburden. International Journal of Mining Science and Technology 27 (2017) 9–15.

[10] Das, M.N. (1986). Influence of Width/Height Ratio on Post Failure Behaviour of Coal. Int. J. Mining. Geological Engineering. No.4.

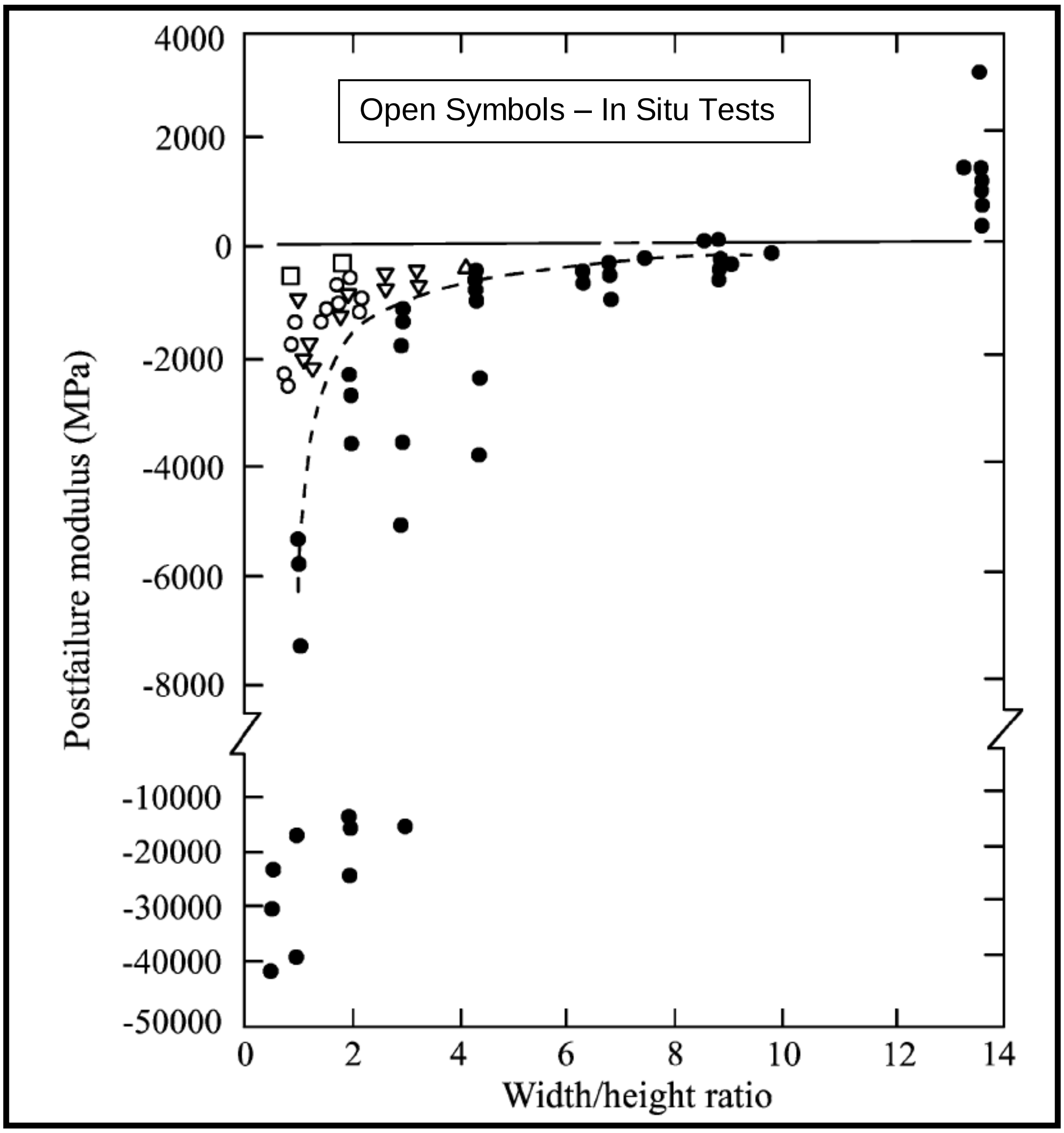

Figure 24. Post-failure Stiffness of Coal Pillars as a Function of Width to Height

Hill (2005[11]) presented an empirical database of Australian and South African failed pillars, in terms of both width to height ratio and FoS (**Figure 25**). This database is also consistent with the analysis of Reed et al (2017), with the majority of pillar failures occurring with width: height ratios <4 (**Figure 25**).

For the development pillars in the current underground workings at Ensham, the width to height ratios are typically 5 or greater. Using the limiting FoS of 1.6 for mining below the Nogoa River and flood plain, it is not until the width to height ratio is <3.5 that the design criteria in **Figure 25** become relevant.

[11] Hill, D (2005). Coal Pillar Design Criteria for Surface Protection. COAL2005 – Moving Technology – Maintaining Competence. 6th Australasian Coal Operators Conference. Brisbane, pp31-37.

It should be highlighted that there has been technical debate over the validity of the pillar in the database with a width to height ratio of 8.16 (**Figure 25**). The implications of including this data point are that the UNSW pillar strength formulae may underestimate the pillar strength and overestimate the probability of failure.

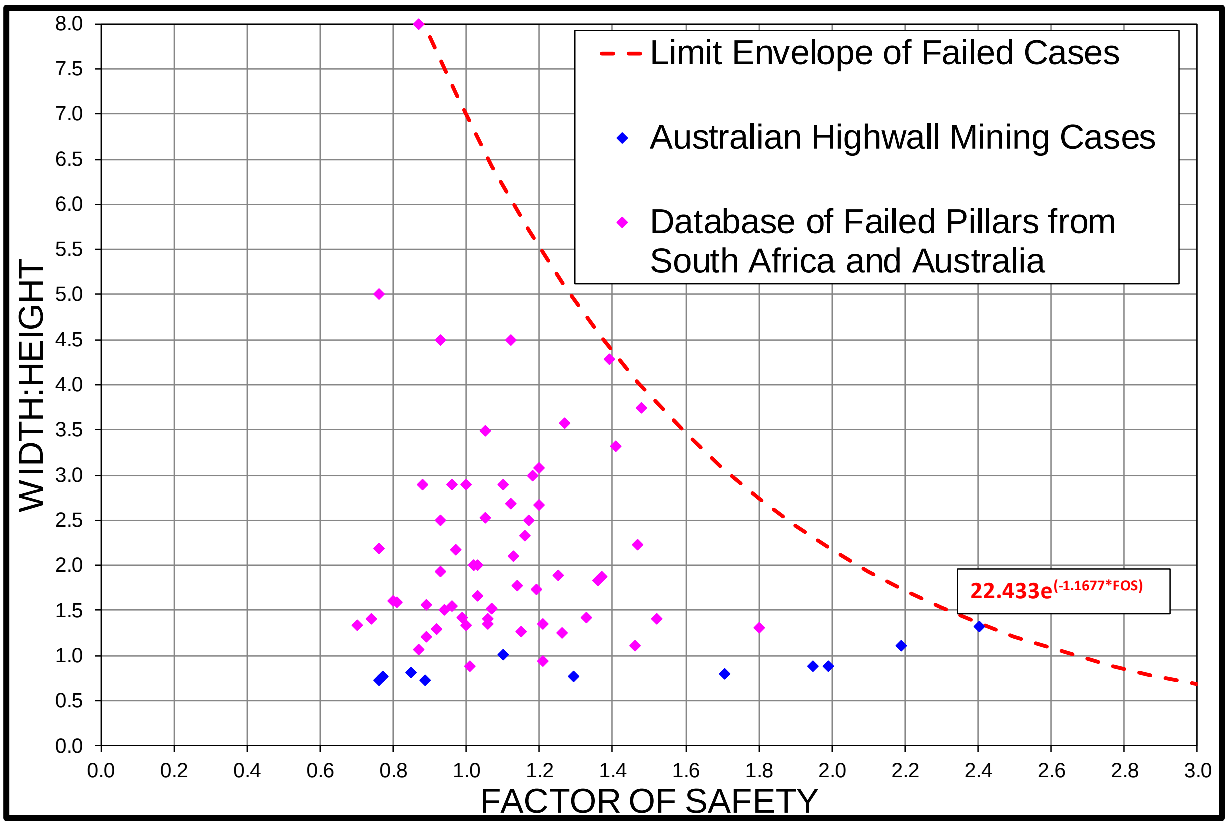

Figure 25. Design Criteria for Bord and Pillar Workings

There is value to step away from the empirical design criteria presented by Hill and consider what may be driving the upper bound for the width to height ratio. Considering the kinematic stability of a pillar that is cut diagonally from the roof on one side to the floor on the other is shown in **Figure 26**.

The top wedge may be pushed sideways depending on the shear strength developed along the roof line and on the diagonal surface. If frictional restraint only is assumed then using a conservative friction angle of 20º for unstructured coal indicates a width to height ratio of 2.75 is required to prevent shear of the coal pillar. This is consistent with the empirical database in **Figure 25**, where the majority of failed cases have width to height ratios of <2.75.

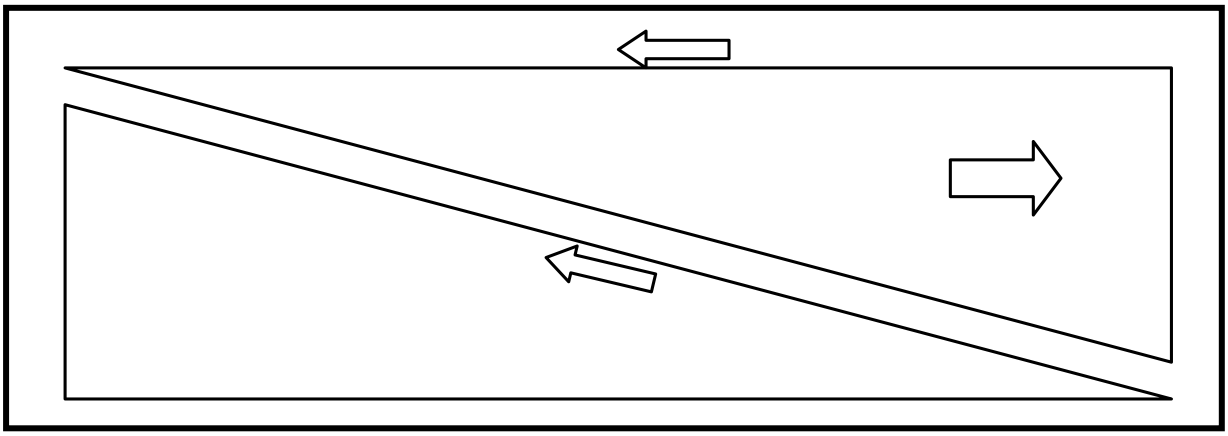

Figure 26. Kinematic Failure of Wedges

For structured coal, a lower friction angle of 15^o would be more representative, requiring a greater width to height ratio of 3.7 to prevent failure. This aspect is illustrated by Hill (2005) in **Figure 27**, where geological structure may weaken the pillar, hence reducing the FoS.

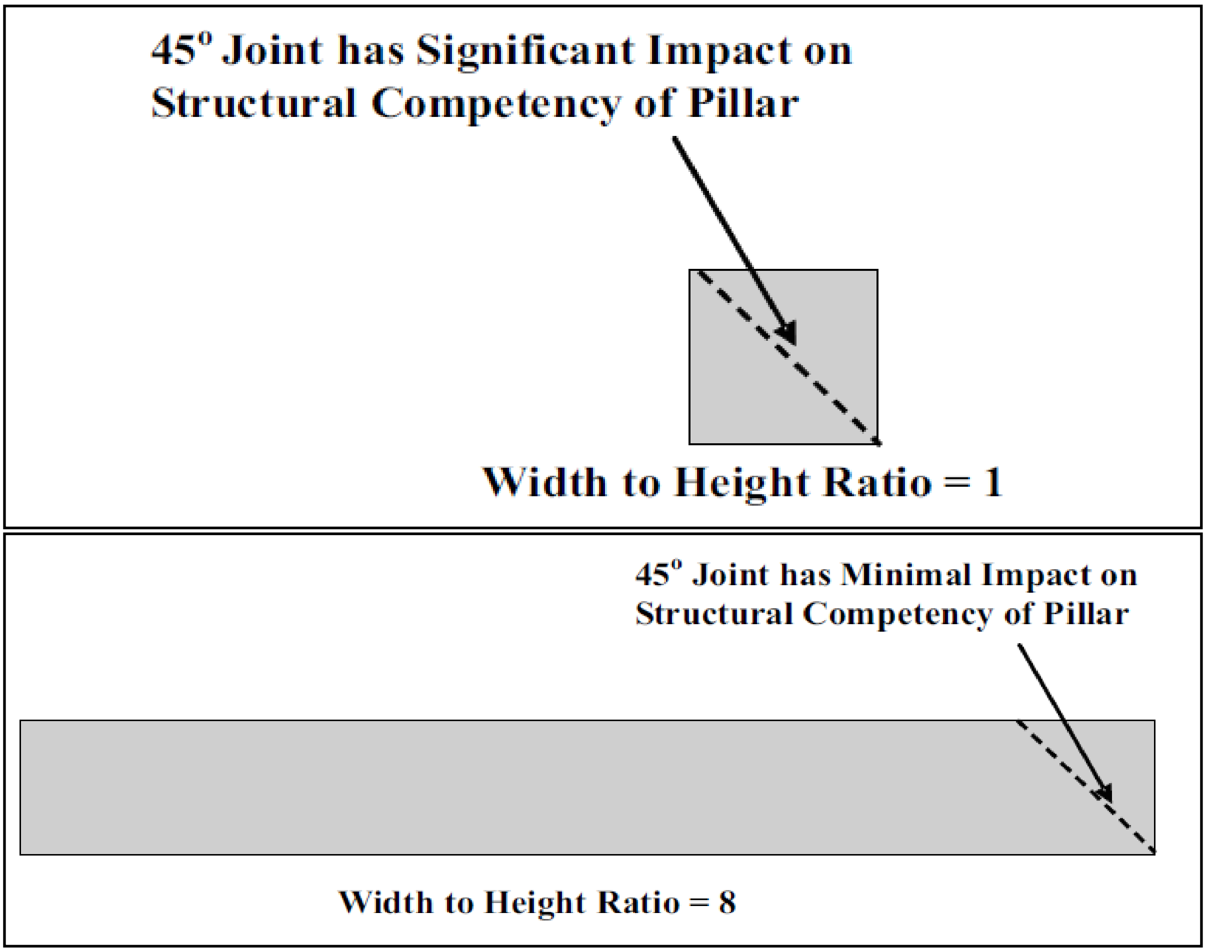

Figure 27. Impact of Geological Structure

4.1.3 Long Term Stability of the Overburden

Mine Advice (2018[12]) demonstrated for the Hume Project in NSW, that for the overburden to become critically unstable and so drive the coal pillars to a collapsed state or high levels of yield, a critical level of overburden settlement is first needed to be exceeded.

If the critical level of settlement is not exceeded, then the stability of the workings is strongly controlled by the stability of the overburden. If however the critical level is exceeded, then the stability of the workings is almost entirely reliant upon the coal pillars.

The idea of evaluating global mine stability via displacement criteria in addition to pillar loading criteria, was raised by Emeritus Professor Ted Brown during the experts review meeting of the Hume Project (Mine Advice, 2018).

With reference to the Hume Project, the predicted surface settlements were in the order of 20 mm. Published data indicates that surface settlements of at least 150 mm are required before the overburden starts to lose its stability.

Based on this discussion, Mine Advice (2018) defined the term system stability according to an overburden displacement FoS, to complement that of the pillar system. In the case of the Hume Project, the system stability FoS was found to be in the order of 7 (150/20).

This displacement based FoS for the overburden provides a measure to the level of conservatism involved in making the full tributary area assumption detailed in Section 4.1.1. This discussion adds further stability arguments to pillar FoS and width: height criteria for long term stability in the Project Area.

4.1.4 Comparison to Other Mines

As shown in **Figure 28**, the pillar dimensions in the underground workings at Ensham after secondary coal recovery, plot to the right of the red design curve of Hill (2005) and the width: height ratio is typically between 3 and 4 (**Figure 28**).

The lower width to height ratio pillars shown on **Figure 28**, were mined in the shallowest part of the Ensham underground workings with centre dimensions of 20 m x 20 m. These are smaller than the pillars planned in the Project Area.

With reference to **Figure 28**, the majority of the failed pillars have width to height ratios <3.

[12] Mine Advice (2018). Interpretation of the Numerical Modelling Study of the Proposed Hume Project EIS Mine Layout. Report No. HUME22/1.

In the Project Area, the FoS and width to height ratios of the pillars after secondary coal recovery, are also well above any of the failed cases from South Africa and Australia presented by Hill (**Figure 28**).

Furthermore, with reference to **Figure 28**, there are no cases of failed pillars with the design factors of safety and width to height ratios exhibited by the mine layout in the Project Area.

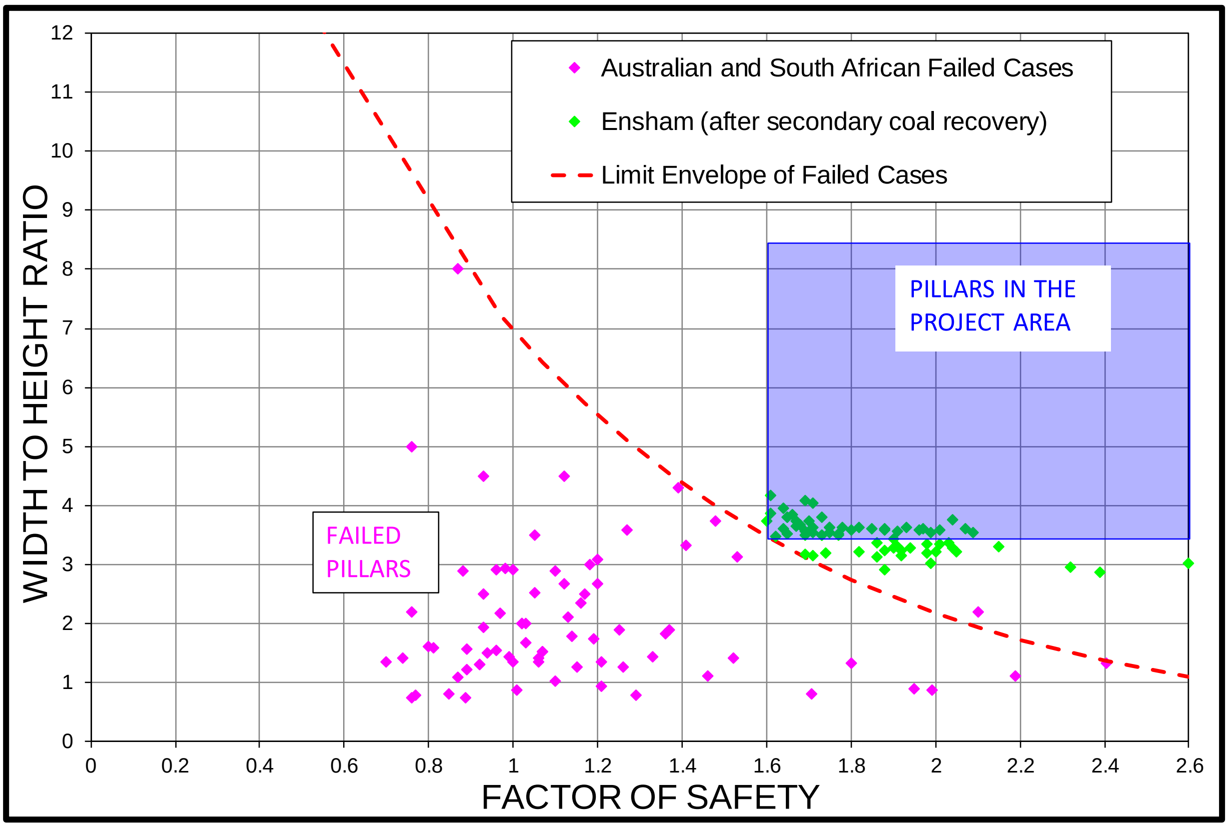

Figure 28. Summary of Pillar Design at Ensham

It is also highlighted that none of the failed cases with FoS >1.6 have occurred more than five years after mining based on the data of Hill (2005) shown in **Figure 29**. The time since the completion of secondary coal recovery in the older abandoned panels such as SE3 and 101 Panels at Ensham, is now approaching seven years.

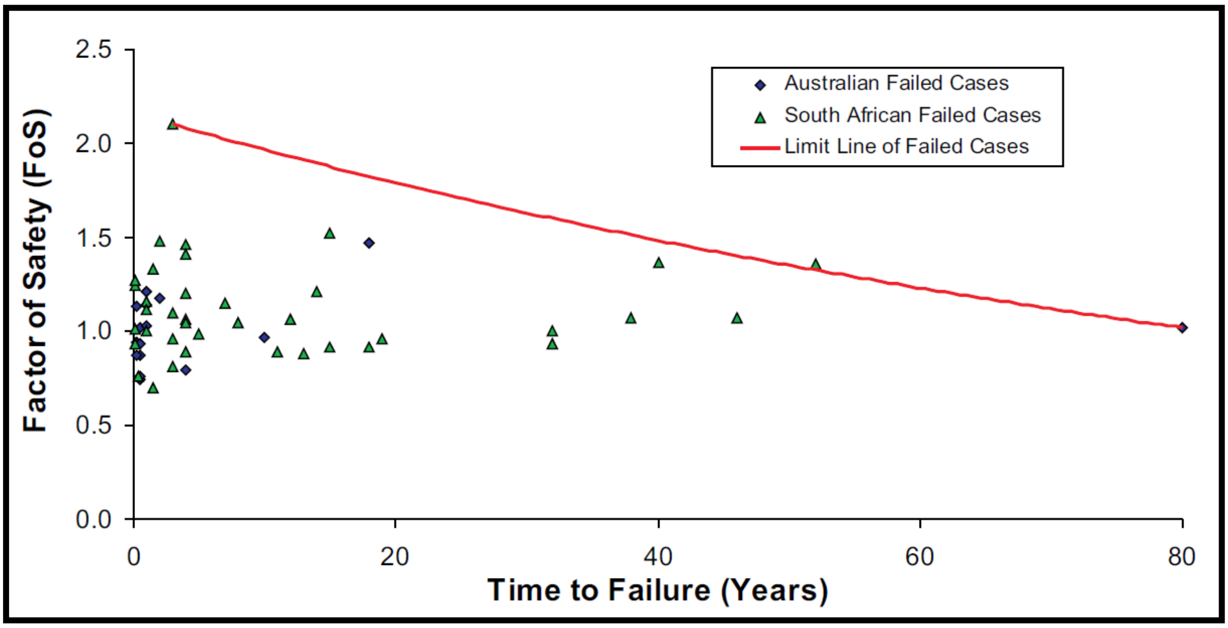

Figure 29. Factor of Safety versus Time to Failure

It is noted that Canbulat (2010[13]) has published data from South African collapsed cases using the original Salamon and Munro pillar strength formula. The data has a number of pillars with FoS >1.6 that have failed due to time dependent spalling or scaling of the pillars.

Frith and Reed (2019[14]) have provided an explanation for this apparent conundrum of these high FoS collapsed cases. Additional failed cases from South Africa with high FoS are also included in **Figure 30**. It is noted that the majority of failed cases occur at depths <100 m. The majority of the proposed workings in the Project Area are at depths >100 m.

These additional cases were published by Salamon et al (1998[15]) who put forward the idea of swelling clays driving pillar scaling as a possible explanation to explain the collapsed cases. The authors however did clarify that “no direct evidence appears to exist to substantiate the proposed model of pillar scaling”. The same model was used by Canbulat (2010) in his analysis of the time to failure of high FoS pillars.

[13] Canbulat I. (2010). Life of Coal Pillars and Design Considerations. In: Proceedings of the 2nd Australasian Ground Control in Mining Conference. Victoria (Australia): AusIMM; 2010. p. 57–66.

[14] Frith, R. and Reed, G. (2019). Limitations and Potential Design Risks When Applying Empirically Derived Coal Pillar Strength Equations to Real-Life Mine Stability Problems. International Journal of Mining Science and Technology 29 (2019) 17–25.

[15] Salamon, M.D.G, Ozba, M.U and Madden, B. J. (1998). Life and Design of Bord and Pillar Workings Affected by Pillar Spalling. J. S. Afr. Min. Metall. 1998;98(3):135–45.

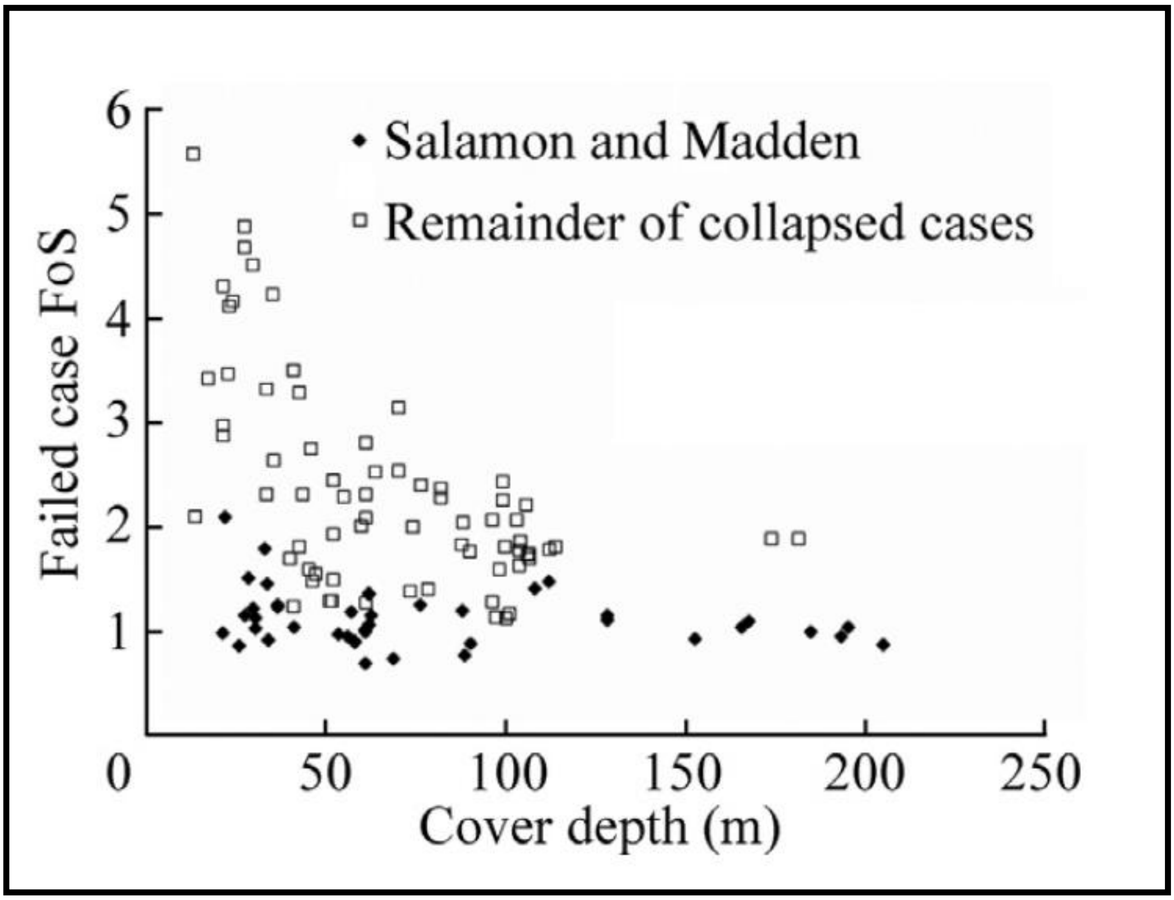

Figure 30. Factor of Safety vs Depth of Cover

Frith and Reed (2019) suggest that the high FoS values are erroneous due to the pillar strength equation used substantially overestimating the actual coal pillar strength. They concluded that the scaling is due to under designed pillars rather than the presence of swelling clays.

In comparison, the author of this subsidence assessment report for the Project Area recently inspected the abandoned workings of 106 Panel in July 2019, where secondary coal recovery had been completed. It was noted that the ground conditions had not deteriorated significantly since the panel was mined more than two years ago (GGPL, 2019[16]). Where rib spall occurs at Ensham, it is typified by thin 100-200 mm slabs and large-scale pillar spalling as documented by Canbulat (2010) is not present (**Figure 31**).

It should also be highlighted that there are no swelling clay bands, such as those referenced by Canbulat (2010), present within the Aries and Castor Seams in the Ensham underground mining area neither existing, nor proposed.

[16] GGPL (2019). Inspection of the Underground Workings on 22-23rd July 2019. Report No. Ensham19-R8.

Figure 31. Typical Thin Rib Spall at Ensham after Secondary Coal Recovery – F23-24, 109A Panel

4.2 Subsidence Behaviour

Unlike longwall mining, where the subsidence comprises two main components namely sag subsidence and strata compression, in the Project Area, the subsidence will be due to strata compression alone. This results in low levels of surface lowering and minimal associated surface effects due to the associated low tilts, curvatures and strains.

Before a compression analysis of the roof, floor and coal in the Project Area can be carried out, the potential for bearing capacity failure of weak floor strata below the coal pillars needs to be assessed. A commentary is also included on the effect of flooding the workings after mining is completed.

4.2.1 Bearing Capacity Failure of the Floor Beneath the Pillars

Several years ago, in the Newcastle coalfield in NSW, the stone floor beneath the pillars failed in a panel designed with FoS >2.11. In this area, very soft layers (<1 MPa) were present in the immediate stone floor below the seam. The overburden consisted of thick conglomerate, which was able to span over more than 50 m.

The potential for bearing capacity failure of the floor beneath the pillars in the Project Area has therefore been analysed using the following formula:

Bearing Capacity of the Floor (MPa) = UCS/2*(4.14159+0.5*W/T)

Where:

W = Pillar Width (m)
T = Thickness of Weak Floor (m)
UCS = Floor Strength (MPa)

The FoS for floor failure is equal to the bearing capacity of the floor divided by the stress on the pillar.

For the proposed pillar sizes in the Project Area, a bearing capacity failure beneath these pillars after secondary coal recovery could only occur if there were layers of floor rock with a low strength of 1.8 MPa and a thickness of 2 m (**Figure 32**). For a 10 m floor layer, the strength required for failure marginally increases to 2.9 MPa.

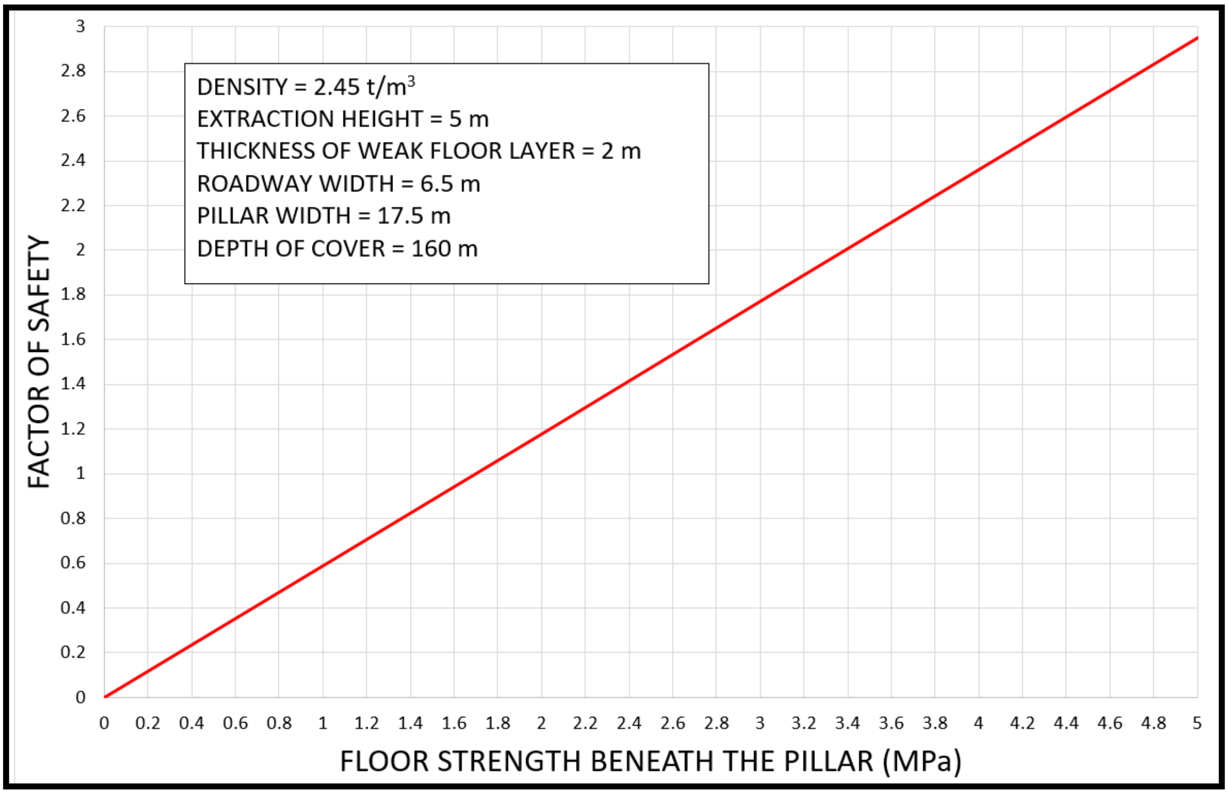

Figure 32. Bearing Capacity Analysis

Review of the geophysical sonic velocity logs in the Project Area identified that the weakest floor strata layers are less than 0.5 m thick and have a floor strength of 10 MPa. This demonstrates that a bearing capacity failure of the floor beneath the pillars is unlikely with a high FoS.

This analysis is consistent with the lack of any noticeable heave in the Ensham underground workings. Very minor floor cracking (<100 mm) has only been observed in localised areas after secondary coal recovery (**Figure 33**). This cracking is typically restricted to the higher quality, friable C22 ply that may have been left in the floor after secondary coal recovery has been completed. Heave and cracking of the stone floor has not been observed.

Figure 33. Minor Cracking of the Coal Floor, 101 Panel

4.2.2 Flooding Workings

In the longer term, the flooding of old panels in the Project Area needs to be considered. Galvin (2008[17]) discusses this aspect in more detail and suggested that flooding of mine workings could influence pillar load in two ways.

1. The water pressure acting on the roof of the workings would function as a hydraulic jack to unload the pillars or
2. The overburden may be fully saturated over the full water head, effectively reducing the density, resulting in lower loads on the pillars.

Both these mechanisms have a positive impact on the stability of old workings.

The other aspect that needs to be considered is the effect of water on the strength of the pillar system. Galvin (2008) details that water can reduce friction on fracture planes and roof/floor interfaces. The water can also accelerate the degradation of clay rich minerals in the roof, floor and coal seam.

It should be highlighted that the coal seam and immediate roof and floor strata in the Project Area do not contain puggy or water sensitive material that could degrade over time.

[17] Galvin, J. (2008). Geotechnical Engineering in Underground Coal Mining – Basic Principles of Pillar Behaviour and Design. ACARP Report.

There is a case of a pillar collapse in a flooded bord and pillar iron ore mine in France. Conversely, many of the mines in the Newcastle Coalfield of NSW have been flooded for years without adverse effect on stability.

Galvin cautions that careful consideration needs to be given to the possible adverse effects on stability by dewatering the workings, as there is a history of pillar collapses soon after being dewatered.

4.2.3 Strata Compression

The induced surface deformation due to strata compression has been estimated analytically by calculating the combined pillar, roof and floor compression using modulus values. This is discussed in the following sections.

4.2.3.1 Coal Strength Modulus

An in-situ modulus value of 2500 MPa has been used for the Aries-Castor and Castor Seams in the Project Area, based on geotechnical testing of coal core samples recovered during exploration drilling at Ensham.

4.2.3.2 Strength of the Stone Roof and Stone Floor

For a 17.5 m wide pillar, the influence into the roof and floor is one pillar width. As such, the average strength of both the stone roof and stone floor above and below the coal seam for this distance in the Project Area has been determined from the geological model.

The average strength of these intervals typically ranges from 20 to 40 MPa (**Figure 34** and **Figure 35**).

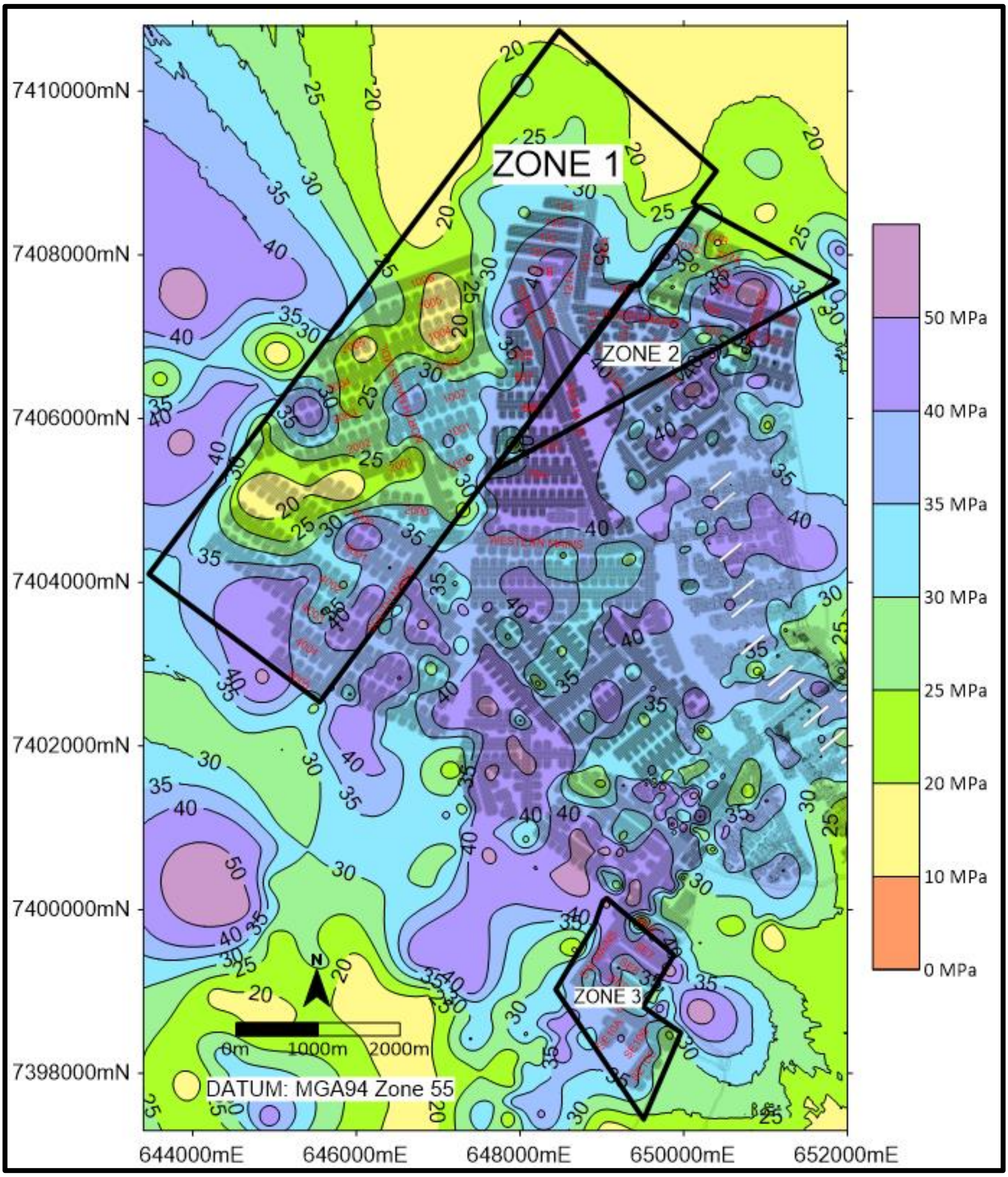

Figure 34. Average Strength for the Stone Roof 0 m to 17.5 m Interval

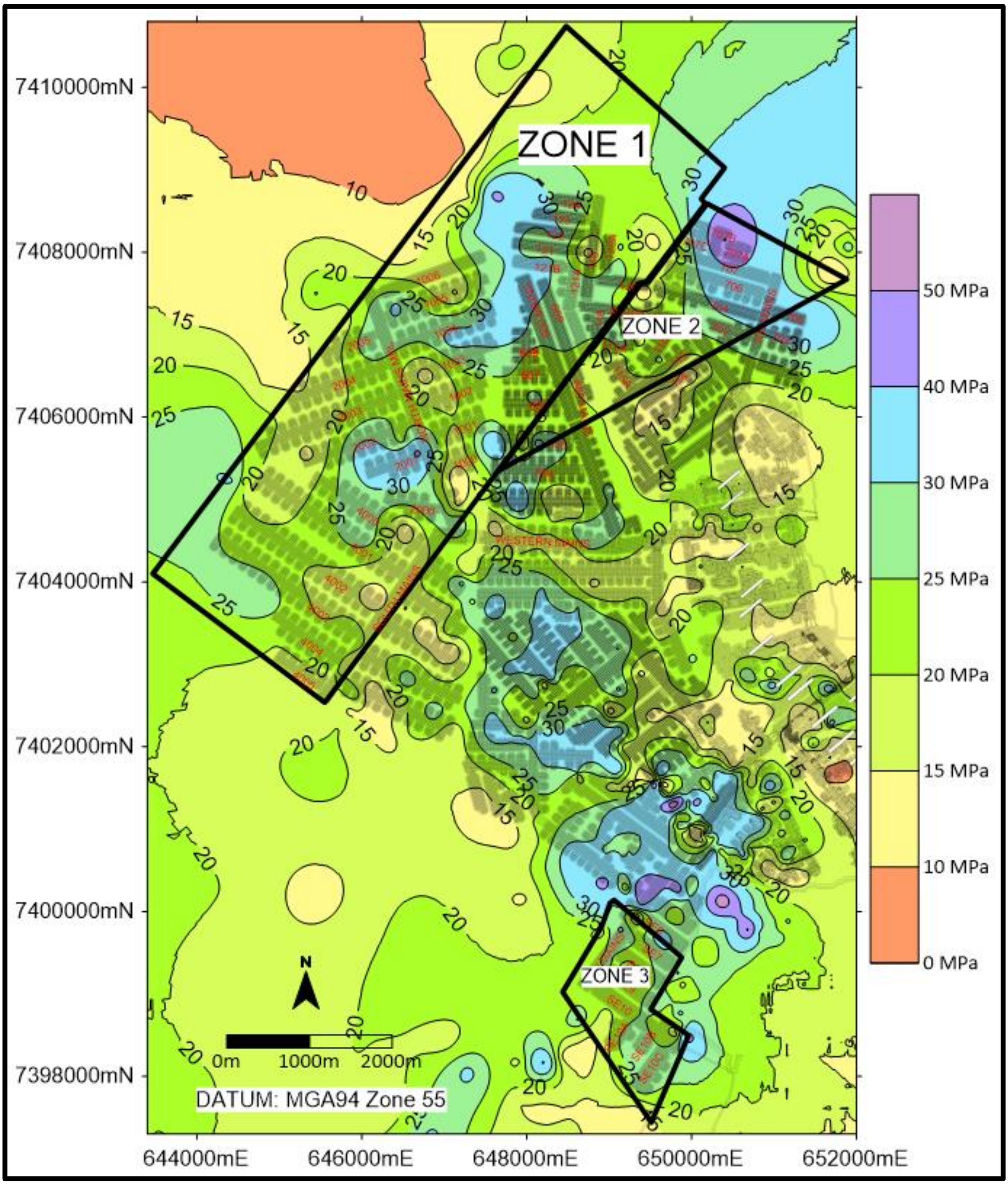

Figure 35. Average Strength for the Stone Floor 0 m to 17.5 m Interval

These values have been determined from the extensive database of sonic velocity logs recorded in the exploration boreholes in the Project Area, which have been converted to strength using the Ensham site correlation, as follows (**Figure 8**):

$$UCS = 0.583e^{(0.00117*t)}$$

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

4.2.3.3 Compression Analysis

As part of the strata compression analysis, the strength values have been converted to a laboratory modulus value using the formula from the geotechnical testing of core samples at Ensham (GGPL, 2018[18]):

$$\text{Laboratory Modulus (GPa)} = 0.325 * \text{Strength (MPa)}$$

The methodology of Hoek and Diederichs (2006[19]) is then used to reduce the roof and floor laboratory modulus values (E_i) to rock mass values (E_{rm}), to consider the discontinuities in the rock mass.

$$E_{rm} = E_i * \{0.02 + (1-D/2)/ (1 + \exp((60+15D–GSI)/11))\}$$

The laboratory modulus values are reduced using a Disturbance Factor (D) of 0 and representative Geological Strength Index (GSI) values for the roof and floor (**Figure 36**).

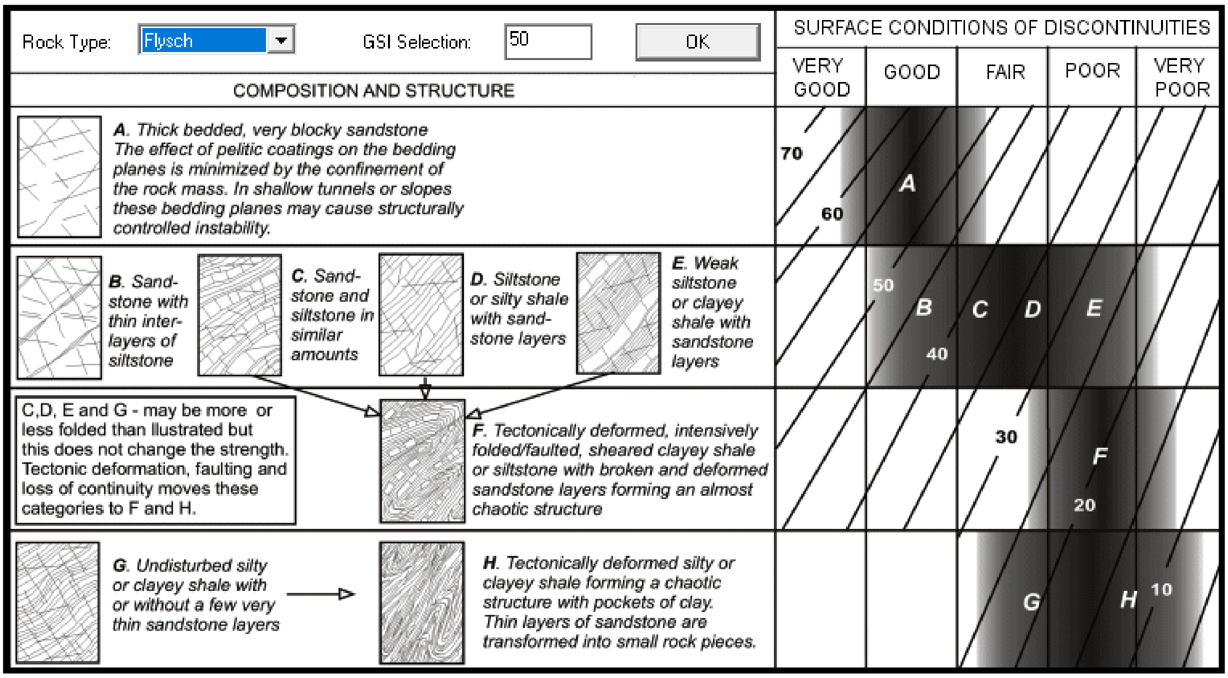

Figure 36. Determination of the Geological Strength Index (GSI)

[18] GGPL (2018). Geotechnical Reference Report for the Ensham Underground Mine. Report No. Ensham GRR - Rev A.

[19] Hoek, E. and Diederichs, M. (2006). Empirical Estimates of Rock Mass Modulus. International Journal of Rock Mechanics and Mining Sciences, 43, 203-215.

Based on the lithological and bedding characteristics shown in **Figure 37** for the Aries-Castor Seam and **Figure 38** for the Castor Seam, roof and floor GSI values of 55 and 50 respectively have been applied. The location of these two boreholes is shown on **Figure 8**.

Figure 37. Aries-Castor Seam Stone Roof and Floor – Borehole C5043, 2001 Panel

Figure 38. Castor Seam Stone Roof and Floor – Borehole C5007, 4002 Panel

The pillar compression is then calculated as follows using the methodology of Poulos and Davis (1974)[20] for analysing rigid footings:

$$Compression_{pillar} = (\sigma_c * h)/E$$

Where: σ_c = Vertical stress change (MPa)
h = Pillar height (m)
E = Young's modulus of coal pillars (MPa)

The compression of the roof and floor is calculated as follows:

$$Compression_{roof\ or\ floor} = I_P*(\sigma_c * w/2)/E$$

Where: σ_c = Vertical stress change (MPa)
I_P = Influence Factor (for a rigid footing) = 1.4
w = Pillar width (m)
E = Young's modulus of roof or floor (MPa)

The change in vertical stress on the pillars can be estimated as:

$$\sigma_c = \text{Tributary Area Stress} - \text{Virgin Stress}$$

4.3 Prediction of Project Subsidence Effects

4.3.1 Subsidence in the Project Mining Area

The compression analysis has been carried out for the maximum depth of cover above each panel pillar and bell out pillar in the Project Area, using the roof and floor strength values shown in **Figure 34** and **Figure 35**. The maximum seam thickness has also been applied. These assumptions provide the likely worst-case subsidence effects and therefore is a conservative scenario for the assessment of the impacts in the Project Area.

The strength values selected for each panel in the Project Area are tabulated in **Appendices 1** and **2**.

Where the maximum seam thickness is greater than the maximum allowable extraction thickness for a FoS of 1.6, the reduced thickness has been used in the compression analysis.

Based on this analysis, the predicted subsidence above the panel and sub panel pillars following secondary coal recovery in the Project Area is typically <40 mm (**Figure 39** and **Figure 40**). This reduces to typically <20 mm above the bell out pillars as they do not carry the full tributary area load on the perimeter of the panels (**Figure 41**).

[20] Poulos, H.G. and Davis, E.H. (1974). Elastic Solutions for Soil and Rock Mechanics.

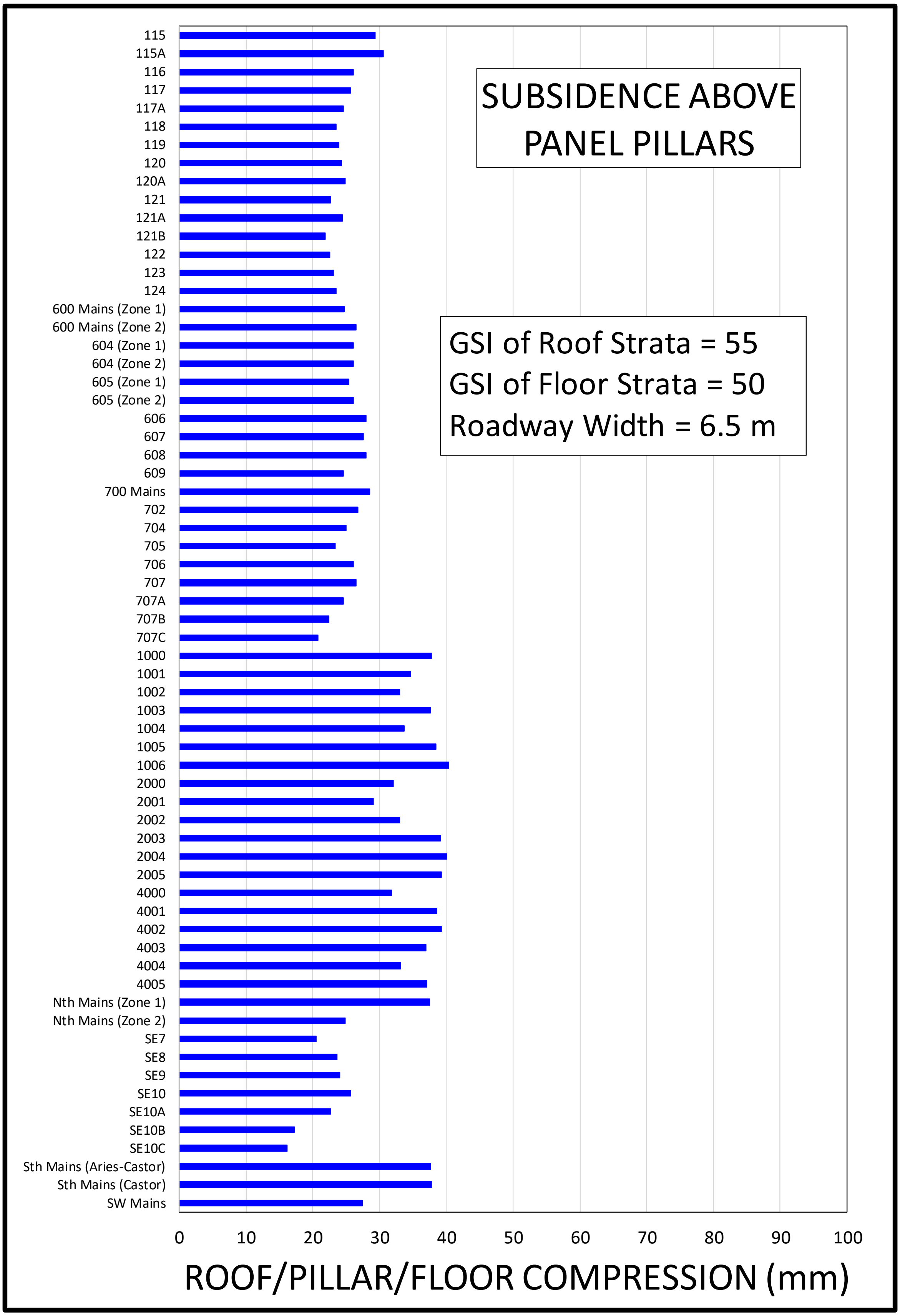

Figure 39. Subsidence above the Panel Pillars in the Project Area

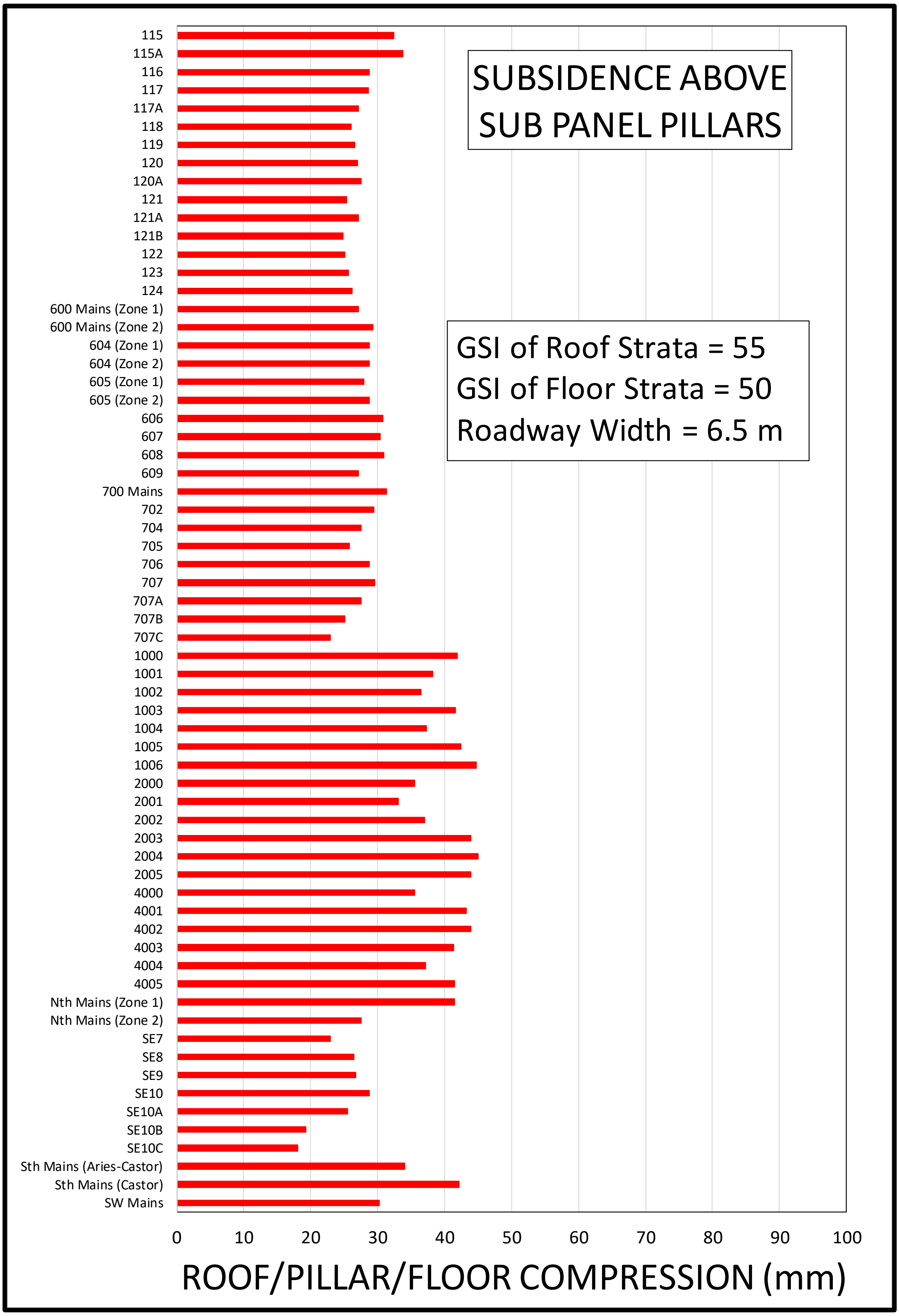

Figure 40. Subsidence above the Sub Panel Pillars in the Project Area

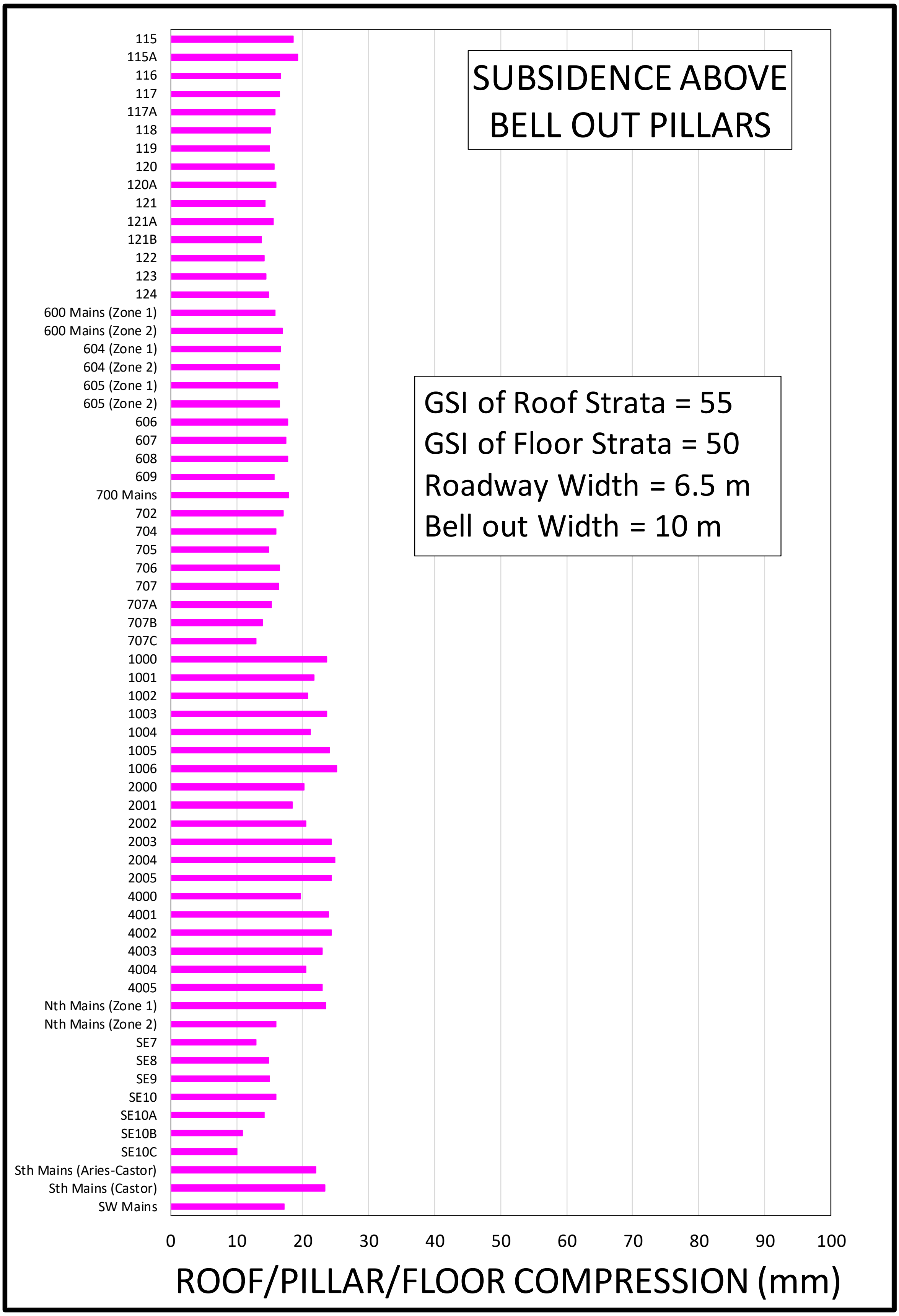

Figure 41. Subsidence above the Bell Out Pillars in the Project Area

In relation to bord and pillar mining, guidance published by the IESC states:

"Where the pillars have been designed to be stable, the vertical subsidence is typically less than 20 mm. Natural or seasonal variations in the surface levels, due to the wetting and drying of soils, are approximately 20 mm; hence, vertical subsidence of less than 20 mm can be considered to be no more than the variations that occur from natural processes and should have negligible impact on surface infrastructure."

This is consistent with Ensham's approach of developing stable pillars that result in negligible subsidence. Whilst the Commonwealth guidance discusses seasonal variation of 20 mm having a negligible effect on surface infrastructure, the guidance also states that seasonal variation can be as high as 50 mm or more due to changes in moisture content.

4.3.2 Surface Cracking

As detailed in **Section 3.3**, a surface crack of 30 mm width developed above the rib line of 3 North Panel and across a public access path at the Tasman bord and pillar mine in NSW, only after the subsidence exceeded 300 mm. No surface cracking developed in areas where the subsidence was <300 mm.

Based on this observation from NSW, and GGPL's experience at comparable Queensland bord and pillar mines, surface cracking is not predicted above the Project Area due to the predicted low levels of maximum surface subsidence typically <40 mm.

4.3.3 Sub-surface Cracking

The nature of the proposed mining method in the Project Area indicates that the surface subsidence will be due to elastic compression of the strata (**Section 4.2.3**). The mining activities do not create areas of caving, which could result in fracturing of the overburden.

This is confirmed by experience in NSW at Clarence Mine, which uses partial extraction bord and pillar methods at the north western edge of the Blue Mountains Heritage Area (**Section 3.2**). As detailed by Hill and White (2017), there have been no exceedances of the 100 mm subsidence limit and interaction with the overlying perched groundwater system since partial extraction started in 2003.

4.3.4 Limitations of the Subsidence Predictions

Based on the available data for the Project Area, there are no localised features or variations in the geology, geotechnical conditions or surface topography that are considered likely to result in any significant deviations from the subsidence predictions presented in this report.

There is a high degree of confidence in the subsidence predictions due to the amount of information from the existing bord and pillar mining at Ensham with similar mining heights, depth of cover and mining methodology. This information has allowed a robust calibration to be achieved and provided a sound basis to enable conservative subsidence predictions.

5 CONCLUSIONS

The key conclusions from this report include:

1. Due to the nature of the bord and pillar mining method, low levels of subsidence, typically less than 40 mm, are predicted in the Project Area as a result of elastic compression of the strata. This magnitude of subsidence is less than the natural ground movements of up to 50 mm or more that can occur (IESC, 2015).

2. Based on estimated critical levels of overburden displacement, high FoS are indicated for the long-term stability of the proposed mine layout. This provides further substantiation to the pillar FoS and width: height criteria for long term stability.

3. The nature of the mining method generating only elastic compression of the strata indicates that sub-surface cracking above the Project Area is not expected.

4. Due to the predicted low levels of subsidence and associated strains and tilts, no surface cracking is predicted above the Project Area. This is consistent with operational experience in the current Ensham underground where surface cracking has not been observed above the bord and pillar mining areas and is supported by experience at other comparable bord and pillar mines in Queensland and NSW.

5. The expected low levels of subsidence are unlikely to result in the formation of significant depressions in the surface topography where ponding of the surface drainage may occur. This is also consistent with operational experience in NSW and Queensland where ponding has not been observed above previous similar bord and pillar mining areas.

6 APPENDIX 1. PANEL DATA – ZONE 1

Panel	Min Depth (m)	Max Depth (m)	Max Thick (m)	Average 0-17.5 m Roof Strength (MPa)	Average 0-17.5 m Floor Strength (MPa)	Strata Compression above 17.5 m x 21.5 m Pillars (mm)	Strata Compression above 17.5 m x 17.5 m Pillars (mm)	Strata Compression above 15 m x 15 m Bell Out Pillars (mm)
118	130	130	5.8	38	26	23.5	26.1	15.1
119	130	130	5.2	38	25	23.9	26.6	15.0
120	130	130	5.8	36	25	24.3	27.0	15.7
121	130	130	5	36	28	22.7	25.4	14.3
122	130	130	5.2	38	28	22.5	25.1	14.2
123	130	130	5.2	35	28	23.1	25.7	14.5
124	130	130	5.2	33	28	23.5	26.2	14.8
604	150	150	5.2	40	26	26.0	28.7	16.6
605	150	150	5.6	44	26	25.4	28.0	16.2
606	140	150	5.2	40	23	27.9	30.8	17.7
607	140	150	5.4	38	24	27.5	30.4	17.5
608	140	150	5.2	36	24	27.9	30.9	17.8
609	130	140	5.6	38	27	24.5	27.1	15.7
1000	170	180	5.2	30	20	37.8	41.9	23.7
1001	170	180	5.2	34	22	34.6	38.2	21.7
1002	170	170	5.2	34	22	33.0	36.4	20.8
1003	170	170	5.2	26	20	37.6	41.6	23.6
1004	160	180	5	25	28	33.7	37.3	21.2
1005	160	190	5	22	26	38.4	42.5	24.0
1006	150	190	4.6	24	22	40.3	44.7	25.2
2000	180	180	5	32	26	32.1	35.5	20.2
2001	170	170	4.6	26	34	29.1	33.1	18.4
2002	170	180	2.8	26	26	33.1	37.0	20.5
2003	170	200	2.8	28	22	39.1	43.9	24.3
2004	170	200	2.8	26	22	40.1	45.0	24.9
2005	180	190	2.8	24	22	39.2	43.9	24.3
4000	170	180	3	30	26	31.7	35.5	19.7
4001	170	200	3	30	22	38.6	43.2	23.9

Panel	Min Depth (m)	Max Depth (m)	Max Thick (m)	Average 0-17.5 m Roof Strength (MPa)	Average 0-17.5 m Floor Strength (MPa)	Strata Compression above 17.5 m x 21.5 m Pillars (mm)	Strata Compression above 17.5 m x 17.5 m Pillars (mm)	Strata Compression above 15 m x 15 m Bell Out Pillars (mm)
4002	180	210	2.8	36	21	39.2	43.9	24.3
4003	180	210	2.4	38	22	36.9	41.4	22.9
4004	190	190	2.2	38	22	33.1	37.1	20.5
4005	200	200	2.2	38	20	37.1	41.5	22.9
120A	130	130	5.6	36	24	24.9	27.6	15.9
121A	130	130	5.6	39	24	24.4	27.1	15.6
121B	130	130	4.8	40	28	21.8	24.8	13.8
600 Mains	140	140	5.6	40	26	24.7	27.2	15.8
North Mains Zone 1	170	190	5	26	24	37.5	41.5	23.5
South Mains (Castor)	180	200	2.6	38	20	37.7	42.2	23.3
South Mains (Aries-Castor)	180	180	4.6	36	22	34	37.6	22.0

7 APPENDIX 2. PANEL DATA – ZONE 2 AND ZONE 3

Panel	Min Depth (m)	Max Depth (m)	Max Thick (m)	Average 0-17.5 m Roof Strength (MPa)	Average 0-17.5 m Floor Strength (MPa)	Strata Compression above 17.5 m x 21.5 m Pillars (mm)	Strata Compression above 17.5 m x 17.5 m Pillars (mm)	Strata Compression above 15 m x 15 m Bell Out Pillars (mm)
ZONE 2 MINING AREA								
600 Mains	140	140	5.6	44	22	26.5	29.3	16.9
115	140	150	5.8	36	22	29.3	32.4	18.5
115A	130	140	6	40	18	30.5	33.8	19.3
116	130	140	5.8	38	24	26.1	28.8	16.6
117	130	130	5.8	38	22	25.7	28.6	16.5
117A	130	130	6	38	24	24.5	27.2	15.8
North Mains	130	130	5.8	36	24	24.9	27.6	16.0
604	150	150	5.6	40	26	26.0	28.7	16.5
605	150	150	5.6	40	26	26.0	28.7	16.5
700 Mains	150	200	5.2	44	32	28.5	31.4	17.9
702	140	150	5.4	32	28	26.7	29.5	17.0
704	130	160	5.2	42	30	25.0	27.6	15.9
705	150	150	5.2	40	32	23.4	25.8	14.9
706	130	190	5.2	42	36	26.1	28.7	16.5
707	140	200	2.4	36	38	26.4	29.6	16.4
707A	150	170	2.2	28	38	24.6	27.6	15.2
707B	150	150	2.2	26	38	22.4	25.1	13.9
707C	140	150	2.4	32	38	20.7	23.0	12.9
ZONE 3 MINING AREA								
SE7	80	120	4.6	42	26	20.5	23.0	12.9
SE8	90	130	4.4	38	24	23.6	26.5	14.8
SE9	90	130	4.4	36	24	24.0	26.8	15.0
SE10	80	140	4.2	36	24	25.6	28.7	16.0
SE10A	100	120	4.2	38	22	22.7	25.5	14.2
SE10B	90	100	4.2	38	26	17.2	19.3	10.8

Panel	Min Depth (m)	Max Depth (m)	Max Thick (m)	Average 0-17.5 m Roof Strength (MPa)	Average 0-17.5 m Floor Strength (MPa)	Strata Compression above 17.5 m x 21.5 m Pillars (mm)	Strata Compression above 17.5 m x 17.5 m Pillars (mm)	Strata Compression above 15 m x 15 m Bell Out Pillars (mm)
SE10C	80	90	4.4	34	26	16.2	18.1	10.1
SW Mains	130	160	4.4	40	26	27.4	30.2	17.2