Narrabri Coal Pty Ltd

ABN: 76 107 813 963

Narrabri Coal Project

Subsidence Assessment

Prepared by:

Mining Geotechnical Services Pty Ltd

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Subsidence Assessment

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EXECUTIVE SUMMARY

This report considers:

- subsidence above the proposed Stage 1 and Stage 2 workings for the proposed underground mine at Narrabri Coal's exploration licence near Baan Baa in northern NSW; and
- the likely extent of sub-surface fracturing above secondary extraction workings.

It is established that the maximum surface subsidence above the Stage 1 workings would be 12mm, ie. well below the target 20mm requirement.

Empirical prediction methods have been used to estimate a range of likely subsidence parameters, including expected maximum subsidence, above the Stage 2 longwalls. The expected maximum subsidence over the Stage 2 longwalls is 2.79m.

Empirical prediction methods have also been applied to estimate the expected height above the workings to which that fracturing would propagate. For the Stage 2 longwalls, these values vary with the overburden depth.

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1. INTRODUCTION

This report considers expected worst case surface effects above the proposed Narrabri Coal Project near Baan Baa in northern NSW and the extent of likely sub-surface fracturing due to coal extraction.

The Narrabri Coal Project has been separated into two stages as detailed below and illustrated in **Figure 1**.

Stage 1 – Mining in this stage would be by continuous miner and incorporate:

i) mains development (areas marked green in **Figure 1**);
ii) partial extraction (areas marked blue in **Figure 1**); and
iii) development of initial gateroads within the potential longwall blocks (the orange areas in **Figure 1**).

Stage 2 – It is intended that mining in this stage would incorporate some form of high productivity mining, preferably longwall mining. If longwall mining is considered to be feasible, it is possible that the width of the panels would be governed by the expected behaviour of two massive strata units in the overburden, namely a 15m to 20m thick conglomerate in close proximity to the seam and a 0m to 20m volcanic sill typically 40m to 60m above the seam.

It is intended that subsidence during Stage 1 would be less than 20mm.

The extent of subsidence and sub-surface fracturing during Stage 2 would firstly be dependent upon the type of mining chosen. For this report, 250m wide longwall panels are assumed as these are considered to be close to the practical maximum width at the intended mining height and would give the worst case subsidence effects.

2. STAGE 1 SUBSIDENCE

2.1 Introduction

Subsidence associated with some form of pillar mining takes one of three forms. These are discussed below in relation to the mains development, partial extraction and gateroad development panels.

It is envisaged that the partial extraction panel design would not result in the creation of a goaf. It is intended that the pillars left behind would be capable of maintaining the overburden in an intact state over panels of restricted width.

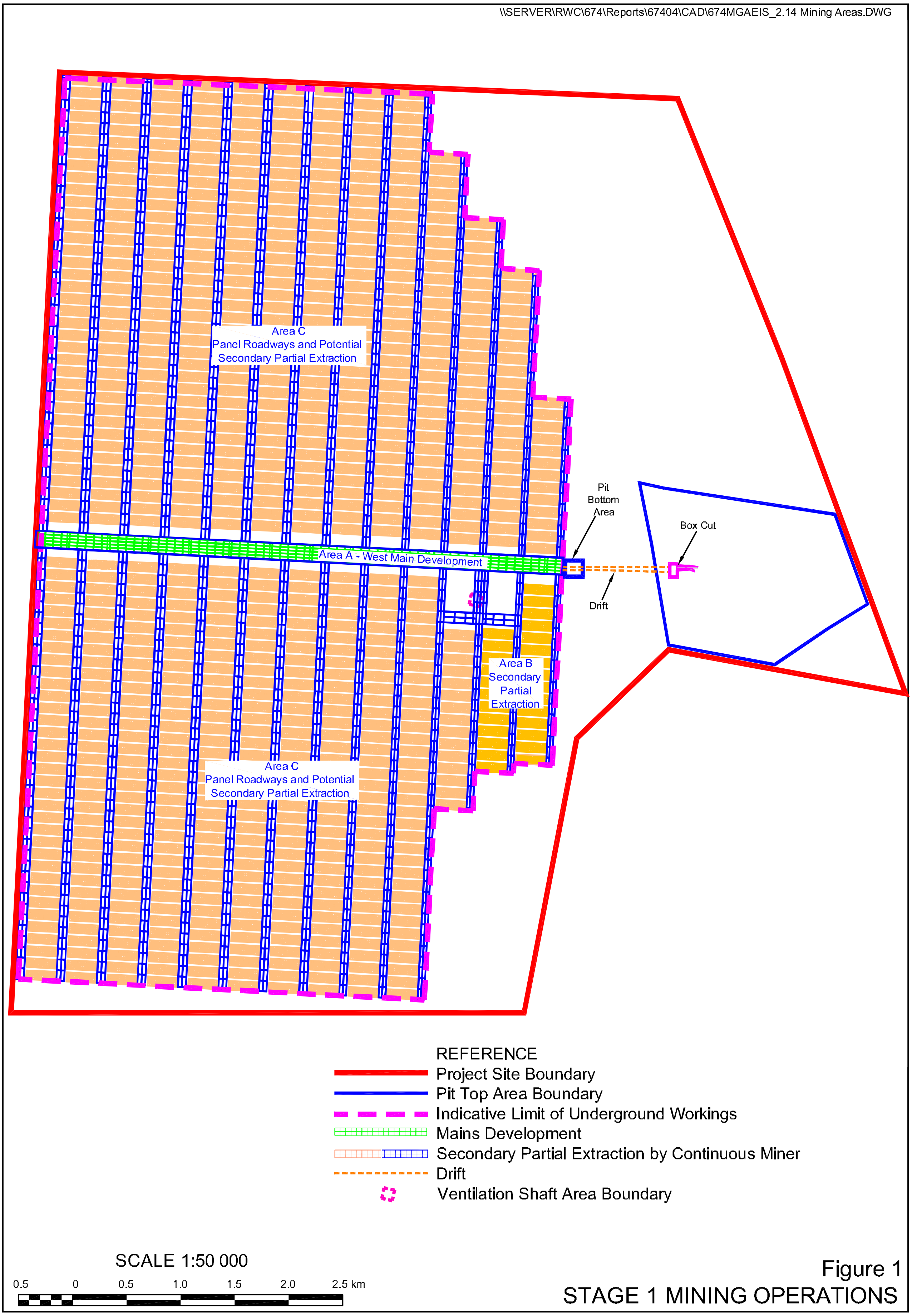

Figure 1

STAGE 1 MINING OPERATIONS

2.2 Chimney Subsidence

Chimney subsidence (**Figure 2**) occurs when the roofs of underground roadways collapse, typically at the intersection of two roadways. The broken overburden material would fill the void beneath and in the immediate vicinity of the collapse, causing further overburden material to collapse. This can progress to surface, resulting in the development of a crater-like subsidence depression on surface. However, as broken rock bulks, i.e. it occupies a larger volume than the same mass of intact material, a point can be reached where the broken rock completely fills the available void space and no further collapse is possible.

Whether or not the collapse of a mine roof would propagate to surface would depend on factors such as mining height, mining widths and the depth of the workings (overburden thickness). According to Crowell (2001), chimney subsidence is limited to mines where the total overburden thickness (solid and unconsolidated) is less than 165 feet (~50m). Piggot and Eynon (in Dyne, 1998) consider the maximum depth at which chimney subsidence would occur as being 10 times the extracted seam height, i.e. ~40m in this instance.

As the minimum depth of workings at the Narrabri Coal Project is to be of the order of 160m, it is clear that there is no practical likelihood of chimney subsidence occurring. This is reinforced by the presence of the massive strata units which are comfortably capable of spanning such small dimensions as the roadway width of 5.5m.

2.3 Trough Subsidence

Trough subsidence **(Figure 3)** can occur if pillars collapse or if the pillars ‘punch’ into the floor. For trough subsidence to be prevented during pillar mining, it is necessary that the pillars remain stable and that the pillar stress does not exceed the bearing capacity of the floor rocks.

The pillars in Stage 1 of the Narrabri Coal Project would be designed to be stable based on the methodology developed by the UNSW (Galvin et al, 1999).

According to COMRO (1988) laboratory tests have shown that pillar foundation (i.e. floor) failure occurs when the average pillar stress exceeds the uniaxial strength of the floor rocks by a factor of 3.5 and suggests, due to the levels of uncertainty associated with rock mass properties, that a factor of 2.5 be used for design purposes.

The eight UCS tests conducted on seam floor samples produced results ranging from 30 MPa to 40 MPa with an average of 35.6 MPa. Taking the worst case suggests that the average pillar stress should not exceed 75 MPa.

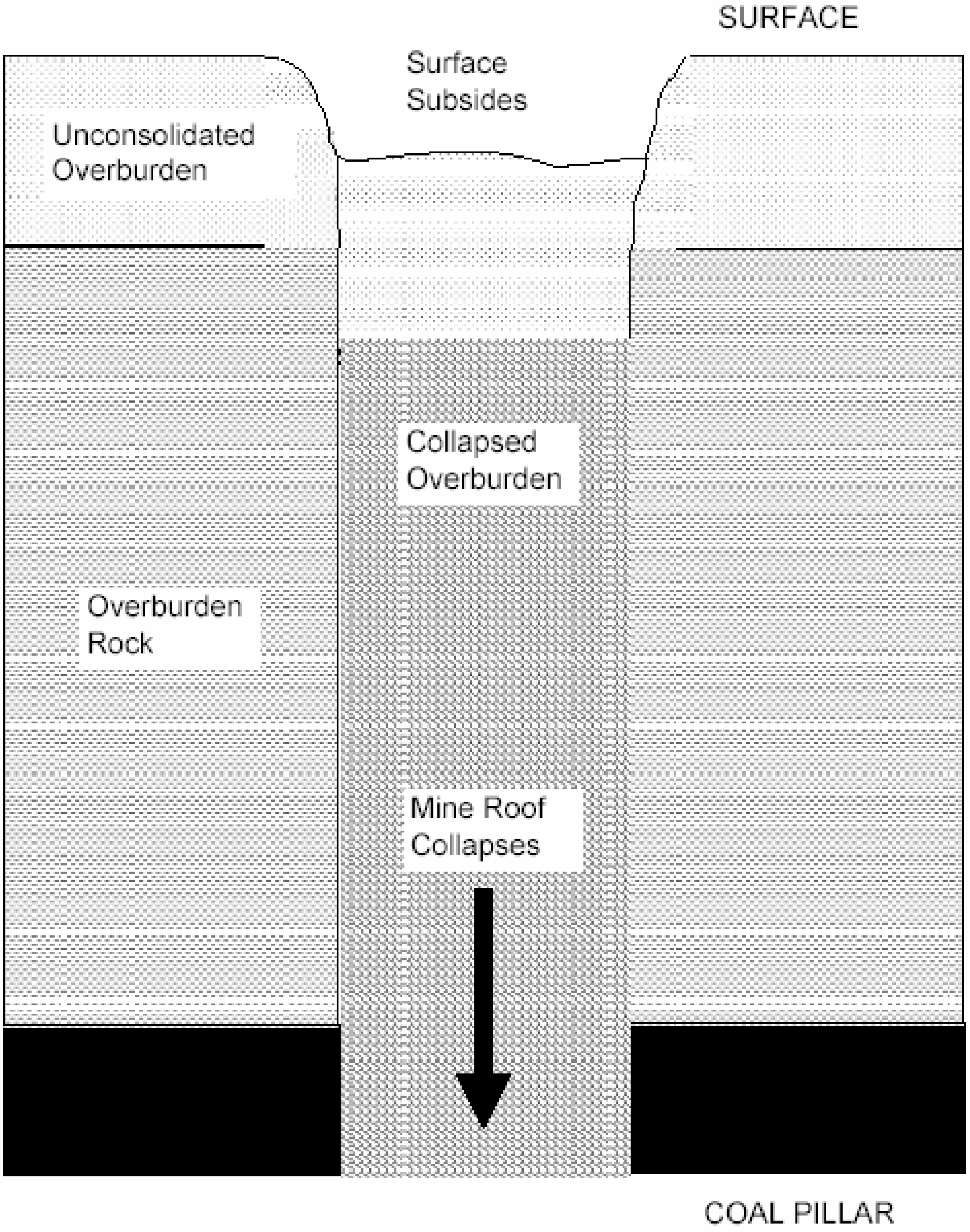

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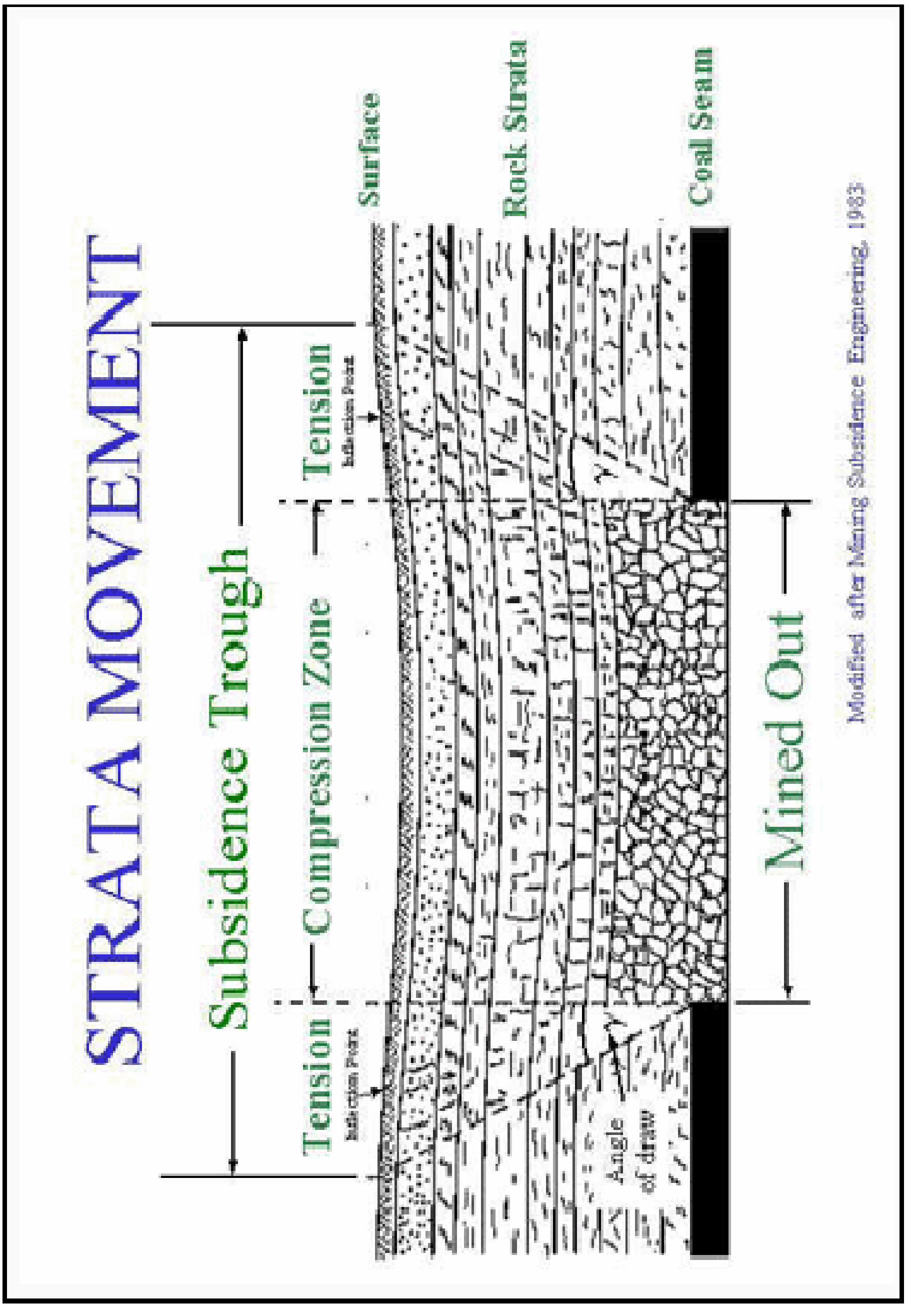
FIGURE 2	Schematic Illustration of Chimney Subsidence		



Modified after Mining Subsidence Engineering, 1983

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FIGURE 3	Schematic Illustration of Trough Subsidence		

The stress on a pillar where there is no secondary extraction nearby is typically calculated on the basis of the Tributary Area Theory which assumes that the load resting on a pillar is due to the overburden immediately above the pillar plus half of the overburden above the adjacent roadways **(Figure 4)**.

The stress, σ_T, due to the Tributary Area load is given by the following equation:

$$\sigma_T = \frac{(L+r)(w+r)}{(wL)} \rho g H \qquad \ldots(1)$$

where: r = roadway width

ρ = density of overburden

g = gravitational constant

H = depth of cover

The Tributary Area Theory is only applicable where the width of the panel of coal pillars exceeds the depth (super-critical). Where the panel width is less than the depth (sub-critical), the Tributary Area Theory would overestimate the stress on the pillars. For panels that are considerably narrower than their depth, this overestimation would be significant.

This happens as a result of the relative stiffness between unmined, solid abutments and pillars. An unmined coal seam is confined and cannot deform significantly in response to an increase in stress. Consequently, solid abutments are appreciably stiffer than coal pillars, which are able to expand laterally in all directions in response to an increase in vertical stress, with an associated reduction in height.

One way of accounting for this difference in actual stress and Tributary Area Theory stress is to consider what happens when coal is extracted by a longwall. Under these circumstances, a certain amount of the vertical stress that formerly loaded the coal that has been mined, is redistributed to the adjacent, unmined coal. A concept known as the “abutment angle” is used to determine the overburden stress that is redistributed to chain pillars and the adjacent solid abutment due to the extraction of a longwall on one side. It is important to recognise that an abutment angle is not a physical reality (i.e. it is not the caving angle), but that it is a convenient and practical means of mathematically representing this additional stress based on empirical measurements from a number of underground coal mines.

The abutment angle concept may be used to estimate the stress redistributed to the solid abutments adjacent to a sub-critical panel of smaller pillars by assuming that the abutment angle represents the additional stress on the solid abutments. This is a reasonable assumption as, were the pillars to be extracted, the abutment angle would represent the stress expected to be redistributed to the abutments, the balance of the stress being the stress acting on the floor of the extracted area due to the goaf. This is illustrated in **Figure 5**.

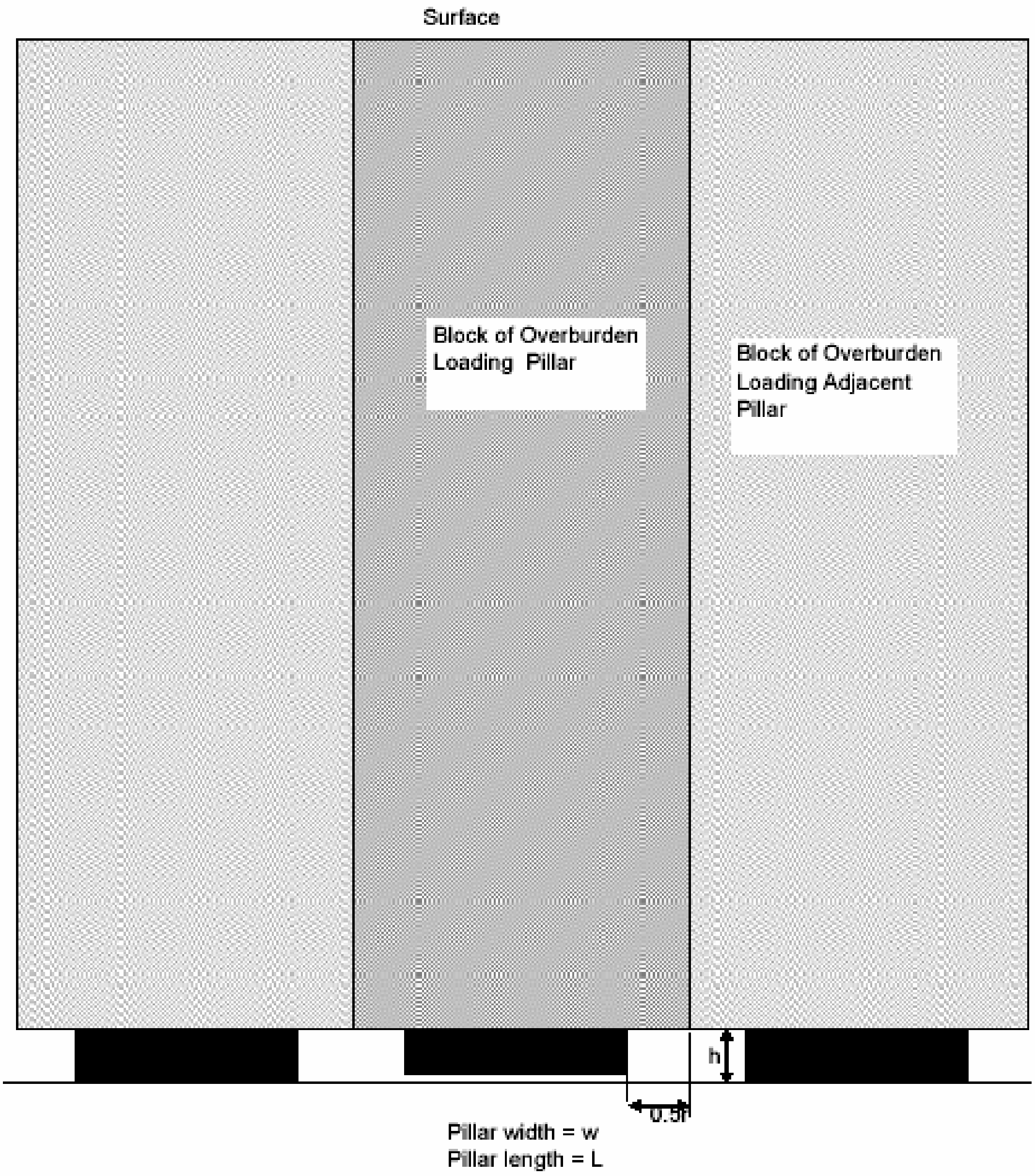

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FIGURE 4	Illustration of Tributary Area Theory for Pillar Loading		

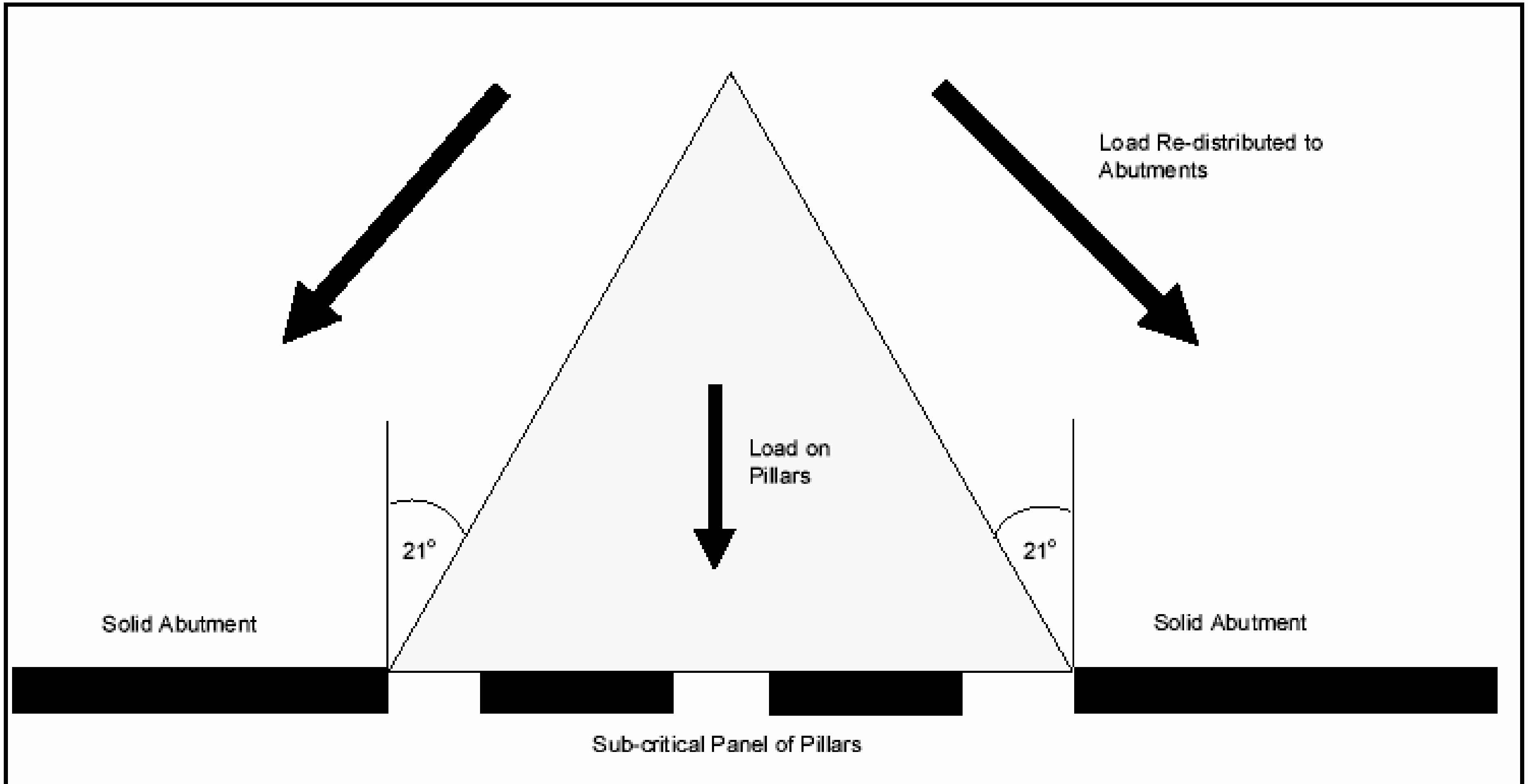

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FIGURE 5	Illustration of Abutment Angle Concept for the Loading of Pillars in Sub-critical Panels		

The stress on the pillars in a sub-critical panel may be determined from the "effective depth" of the pillars, which is the height of a rectangle of the same area and width as the load triangle shown in **Figure 5**, i.e. the effective depth, He, would be half the height of the load triangle. The value of He is then substituted for H in Equation (1).

The default abutment angle used by the two tailgate chain pillar design methods, Analysis of Longwall Tailgate Serviceability II (ALTS II) (Colwell Geotechnical Services, 2002) and Analysis of Longwall Pillar Stability (ALPS) (Mark, 1990), is 21º. This value would be used to determine the effective depth of sub-critical panels for the purposes of this report.

The pillar stresses for the various Stage 1 pillar mining scenarios are detailed in **Table 1**.

Table 1 Pillar Stresses for Stage 1 Pillar Mining

Panel	Pillar Width (m)	Panel Span (m)	Depth (m)	Effective Depth (m)	Ave. Pillar Stress (MPa)	Trib. Area Stress (MPa)
5 x Road Mains	25.5	107.5	300	70.0	2.7	11.6
8 x Road Mains	25.5	184.0	300	119.8	4.6	11.6
Gateroad Development	32	37.5	300	24.4	0.8	9.6
Partial Extraction	12	80.0	200	52.1	4.8	18.4

It is readily apparent from **Table 1** that, even assuming full Tributary Area Theory stresses, the average pillar stresses are considerably lower than the threshold value of 75 MPa, such that the lowest Factor of Safety is 4.1 using Tributary Area Theory and 15.6 using the more appropriate effective depth concept.

It is reasonable to state that the likelihood of the pillars punching into the floor is very low. With appropriate pillar design, there is little expectation of either pillar failure or pillar punching causing trough subsidence above pillar mining areas during Stage 1 mining at the Narrabri Coal Project.

2.4 Pillar Compression

The third type of subsidence is that due to the compression of the pillars once mined. The act of mining pillars would increase the stress levels above the pre-mining (virgin) stresses and reduce the stiffness of the coal seam within the pillars. There is little information with regard to pillar compression over pillar mining areas and the resultant surface effects because the surface subsidence is generally considered to be negligible.

However, using an *in situ* elastic modulus for coal of 4 GPa, as suggested by van der Merwe and Madden (2002), the expected compression of the pillars may be calculated **(Table 2)**.

Table 2 Pillar Stresses for Stage 1 Pillar Mining

Panel	Mining Height (m)	Pillar Compression (mm)	
		Due to Effective Depth Stress	Due to Trib. Area Stress
5 x Road Mains	4.0	2.7	11.6
8 x Road Mains	4.0	4.6	11.6
Gateroad Development	3.2	0.6	7.7
Partial Extraction	4.0	4.8	18.4

Not all of the pillar compression would be apparent at the surface, however, due to the lack of studies in this area, the proportion of pillar compression expected at the surface is not known. Assuming a maximum value of 65%, as is the case for trough subsidence above super-critical longwall panels, gives a maximum surface subsidence of 12mm. This is very much a worst case as the massive strata units are expected to span the panels, reducing this value further.

3. STAGE 2 SUBSIDENCE

A detailed analysis of the expected subsidence over the Stage 2 mining areas is not necessary at this juncture as there are a number of factors which would impact significantly on the subsidence, including mining method and panel geometry. Furthermore, the actual subsidence over the potential caveability trial area would provide important information for the analysis.

At this stage, therefore, the analysis is confined to the worst case maximum subsidence and the extent of the subsidence trough.

The analysis is based on 250m wide longwall panels at a mining height of 4m. The chain pillars are taken to be 32m wide with a gateroad height of 3.2m.

For multiple panels, the maximum subsidence is influenced by chain pillar compression. According to Ditton and Frith (2003), “a reasonable, but generally conservative, estimate of the final subsidence expected for a panel with several subsequent extracted panels of similar geometry can be determined by adding 50% of the predicted chain pillar subsidence (S_p) to the single panel S_{max} estimate”.

Using this method of estimation and the Ditton and Frith (2003) empirical method for maximum chain pillar subsidence, the maximum expected subsidence at the eastern end of the potential longwall areas, where the depth of mining could be as low as 180m, would be 2.7m, with the value for S_p/T being 0.23. The maximum subsidence of 2.79m would occur between depths of 195m and 215m.

At the western end, the value for S_p/T reaches the maximum suggested by Ditton and Frith (2003) of 0.58. This value, however, is the same as for a single longwall panel with full extraction. The maximum value for S_p/T in the database used by Ditton and Frith (2003) is 0.31. It would appear reasonable to reduce the maximum value of S_p/T to 0.4 which is still likely to be conservative. This gives a maximum subsidence value in the east at a depth of 300m of 2.24m (2.53m at $S_p/T = 0.58$).

Using the values of 2.7m in the west and 2.24m in the east, the maximum extent of the subsidence trough is expected to be:

- 75m to the west of the potential longwall blocks;
- 10m to the east of the potential longwall blocks; and
- 125m to the north and to the south of the potential longwall blocks at the western extremity, reducing to 75m at the eastern extremity.

4. SUB-SURFACE FRACTURING

Ditton and Frith (2003) also provides an empirical and model based approach of determining the heights above the working horizon at which “Continuous” and “Discontinuous” fracturing occurs. The former results in complete drilling fluid loss when a cored hole is drilled into the overburden above an extracted longwall panel and the latter results in partial drilling fluid loss. These fractures occur above the edges of the panels where the strain is tensile.

Expected heights of fracturing above the working horizon for various depths of cover for the potential longwall panels are given in **Table 3**, i.e. the depth of the continuous fracture zone from surface for a depth of cover of 180m would be 106m and for the discontinuous fracture zone it would be 27m.

Table 3 Sub-Surface Fracturing Above the Potential Longwall Blocks

Depth (m)	180	200	220	240	260	280	300
Continuous Fracture Horizon (m)	74	83	91	97	102	107	112
Discontinuous Fracture Horizon (m)	153	171	187	202	217	232	246

5. CONCLUSION

Indicative expected maximum subsidence values have been developed for the potential longwall blocks and an estimate of the extent of the subsidence trough. Additionally, the expected horizons above the workings at which continuous and discontinuous fracturing would occur have been determined.

It must be remembered that these estimates are based on empirical design methods, as is the norm for subsidence engineering. As with all such geotechnical analyses, there is a degree of uncertainty and the possibility of local variations.

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