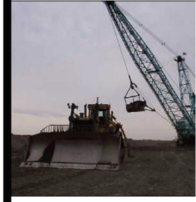
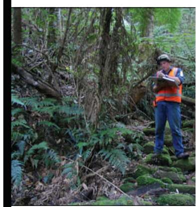
SUBSIDENCE IMPACT ASSESSMENT








APPENDIX 4

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CENTENNIAL AWABA PTY LTD

SUBSIDENCE ASSESSMENT

PART 3A SUBMISSION

Awaba-30 SEPTEMBER 2010

SEEDSMAN GEOTECHNICS PTY LTD
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Tuesday, 07 September 2010

Ref: Awaba-30

Mr G Watson
Manager – Awaba Colliery
PO Box 1000
Toronto NSW

Dear Grant,

Re: Subsidence assessment

We are pleased to submit this report that examines the subsidence implications of the layout being proposed for Study Areas 2 and 3 at Awaba Colliery.

Please contact the undersigned if you require further information.

Yours truly,

Ross Seedsman

EXECUTIVE SUMMARY

The mining layout for second workings at Awaba Colliery involves pillar stripping is conducted within panels that are less than 100m wide. This layout reduces the likelihood of rapid uncontrolled collapse of the Teralba Conglomerate while maintaining acceptable levels of coal recovery.

Previous mining immediately adjacent to the rail barrier has been reviewed. Subsidence at the rail lines has been less than 20mm and there has been no measured impact on the rail of the subsidence/floor heave events.

A model for subsidence/floor heave events has been developed and related to possible low strength horizons in the Awaba Tuff. Recent coring of the floor and a review of previous drilling at Awaba and Newstan Collieries indicates that such low strength layers have not been present in the area to the east of the rail line.

Subsidence levels of approximately 100mm are predicted above the pillars with an additional 100mm above the extraction panels. There may be some plug collapses activated during heavy rainfall events. No long-term additional subsidence events are predicted when the mine is flooded.

The predicted maximum subsidence is 200mm and the associated tilts and strains will not be measurable with standard survey tools. A plug collapse geometry, which has a negligible likelihood of developing is also provided as the basis for a risk assessment.

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1 INTRODUCTION

This introduction was provided by GSS and is reproduced in full, with the only change being the figure numbering to be compatible with this report.

1.1 Background

Awaba Colliery is a small underground coal mine operated by Centennial Newstan Pty Ltd (Newstan), a wholly owned subsidiary of Centennial Coal Company Ltd (Centennial). The mine entry and primary surface facilities are located approximately one kilometre south of the Awaba village and 5.5 kilometres (km) south west of Toronto on the western side of Lake Macquarie, near Newcastle NSW.

Awaba Colliery has been producing coal by bord and pillar method since 1947. The site is situated on crown land under lease to Centennial for the purpose of mining under Consolidated Coal Lease CCL746, and is adjacent to the Newstan-Eraring haul road owned by Eraring Energy. The locality of the mine is illustrated on Figure 1.

Awaba Colliery is a small operation with approximately 100 employees and contractors, historically producing around 800,000 tonnes of thermal coal annually. Since commencing mining operations in 1947, over 30 million tonnes of coal has been won from the Great Northern Seam using a combination of first workings development, pillar extraction, pillar quartering, and pillar stripping.

A form of pillar extraction of narrow panels is used to recover coal in pillars developed previously by bord and pillar methods. Development of bords (roadways) and pillars is ongoing but in some areas were developed many years ago. This mining method currently utilises continuous miners. Mine planning ensures panels are not extracted where depth of cover or surface constraints preclude total extraction. This mining method has been developed in consultation with the Department of Primary Industries – Mineral Resources (now known as Industry and Investment, NSW (I&I)) and has been used successfully to date, and is proposed to be continued for the Project.

Mining operations commenced at the Awaba Colliery in 1947, prior to the commencement of any planning controls, and have continued without abandonment since that time. Consequently, the Awaba Colliery presently operates pursuant to section 109(1) of the NSW *Environmental Planning and Assessment Act 1979* (EP&A Act) and clause 6B(1) of the *State Environmental Planning Policy (Major Development) 2005*. An application for a Part 3A Project Approval has been lodged by Centennial for the ***Awaba Colliery Mining Project (the "Project")***, which seeks approval from the Minister of Planning to allow an extension of underground mining and the ongoing use of associated surface operations. A detailed description of the Project and the **Project Application Area (*the "Application Area"*)** (including focus study areas) is detailed further in **Sections 1.2 and 1.3** below.

Minimal changes are proposed to existing surface operations, with one proposed additional surface disturbance relating to increased pollution control dam capacity located in a previously disturbed area. No significant changes to coal handling are proposed. Underground mining areas requiring approval to allow continued mine operations and production are outlined in **Sections 1.2** and **1.3** below.

At present, it is anticipated that the Project will recover approximately 2.0 million tonnes of coal which will be extracted from those areas depicted in Study Area 2 and Study Area 3 (refer **Section 1.2.1**) over a period of approximately five years or more, depending on actual mining conditions and relevant market drivers.

The application for the proposed Project is supported by an Environmental Assessment (“EA”).

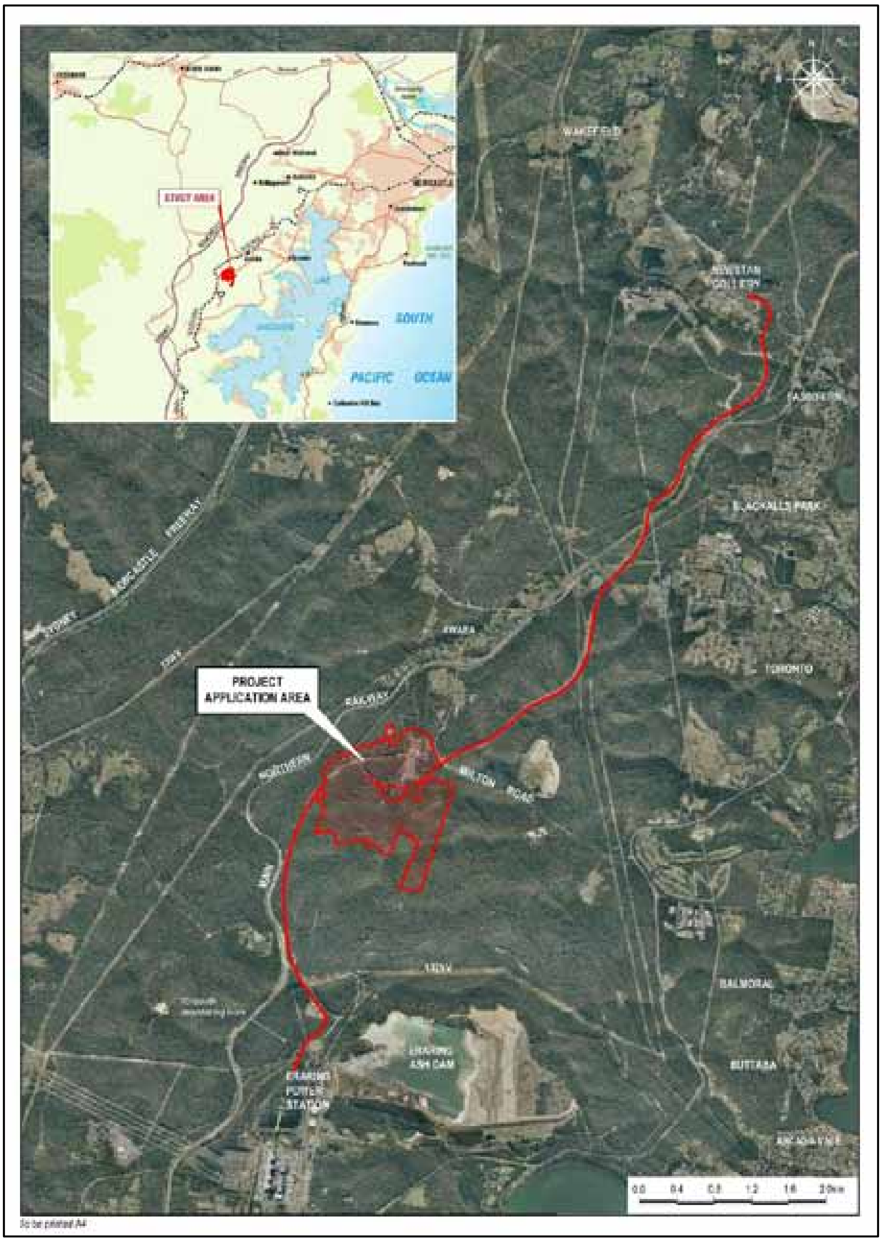

Figure 1 Locality plan (supplied by GSS Environmental)

1.2 Project Application Area

The **Project Application Area** (the “Application Area”) is illustrated on Figure 2. The Application Area has been identified as the footprint of the proposed Project including proposed mining areas and related surface operations that are considered relevant to the continuation of Awaba Collieries operations, as well as, the existing workings areas that will continue to be relied upon for ventilation and other mining related purposes, access to proposed mining areas or for any required emergency evacuation.

The Application Area has been broken into a number of Study Areas based on the types of activities to be undertaken for the Project. These Study Areas are outlined below in **Section 1.2.1**. The extent of the existing workings has not been included as a Study Area as it is considered inappropriate to obtain retrospective approval for historical operations. Additionally, there are no activities proposed in these areas for the Project and ongoing management of these areas is covered by the existing Awaba Colliery Mining Lease conditions.

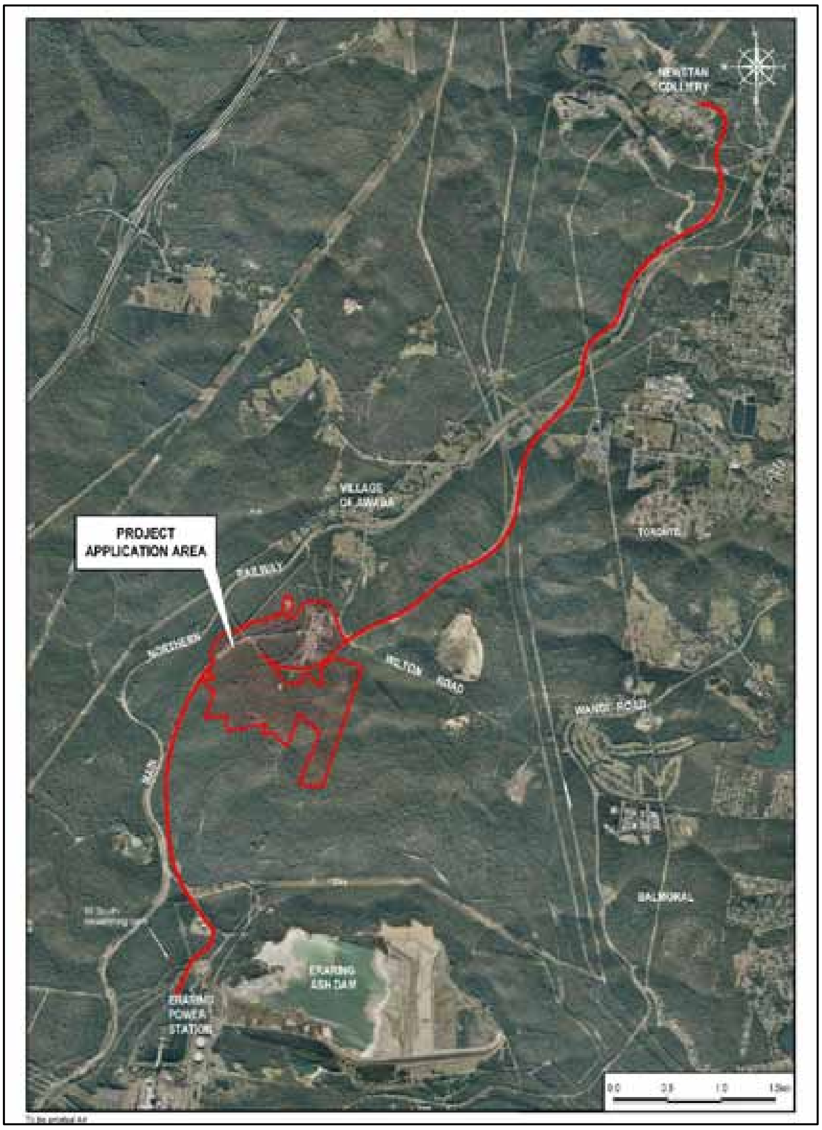

Figure 2 Project Application Area (supplied by GSS Environmental)

1.2.1 Study Areas

The Study Areas that have been assessed as part of this EA are shown on **Figures 3** and **4** and include the following:

- **Study Area 1 – Surface Facilities and Ancillary Infrastructure –** This area includes the colliery pit top facilities (including office and amenities buildings, existing coal crushing plant, workshop and storage areas) ventilation shafts, an existing quarry and mine dewatering bore (10 South Bore).

- **Study Area 2 – Continued Mining within Existing Main South Area staged SMP Approval Areas (including the Remaining Coal to be Mined within Stage 2 and the Revised Stage 3)** – The impacts associated with mining in these areas have previously been assessed in Subsidence Management Plan (SMP) Applications. The Stage 2 Area application was approved by Industry and Investment in September 2008, with the SMP Application for the Revised Stage 3 Area submitted to I&I in December 2009 awaiting approval. These areas are defined by a 26.5 degree angle of draw (as per DPI-MR SMP Guidelines, 2003). The outcomes from the SMP assessment will be summarised along with any impacts that are not considered to have been adequately addressed for this EA. It is important to note that, in relation to Stage 2 Area, only the coal remaining from the 1st of August will require approval for this Project (this boundary has been indicated on **Figure 4**); and

- **Study Area 3 – Proposed Project Mining Areas** - Consideration of the proposed Mining Area (East B Area) defined as the proposed workings plus 26.5 degree angle of draw (i.e. as per DPI-MR SMP Guidelines, 2003);

- **Study Area 4 – Existing Internal Private Haul Road –** This haul road will be utilised for transporting coal from the Awaba Colliery operations to Newstan Collieries existing Run of Mine Stockpile or Rail Loop and subsequently transported to the Port of Newcastle or Port Kembla for shipping to export markets (to be undertaken in accordance with the Newstan Colliery development consent) and also to the Eraring Power Station. It is noted that a modification to the Newstan Colliery development consent (DA 73-11-98) will be applied for under Section 96(1A) of the EP&A Act to allow for the preparation of coal sourced from the Awaba Colliery using the existing Newstan Colliery infrastructure.

In general, potential environmental impacts associated with mine access, ventilation and other services provided through the existing workings areas to the active and proposed mining areas will also be addressed in the EA.

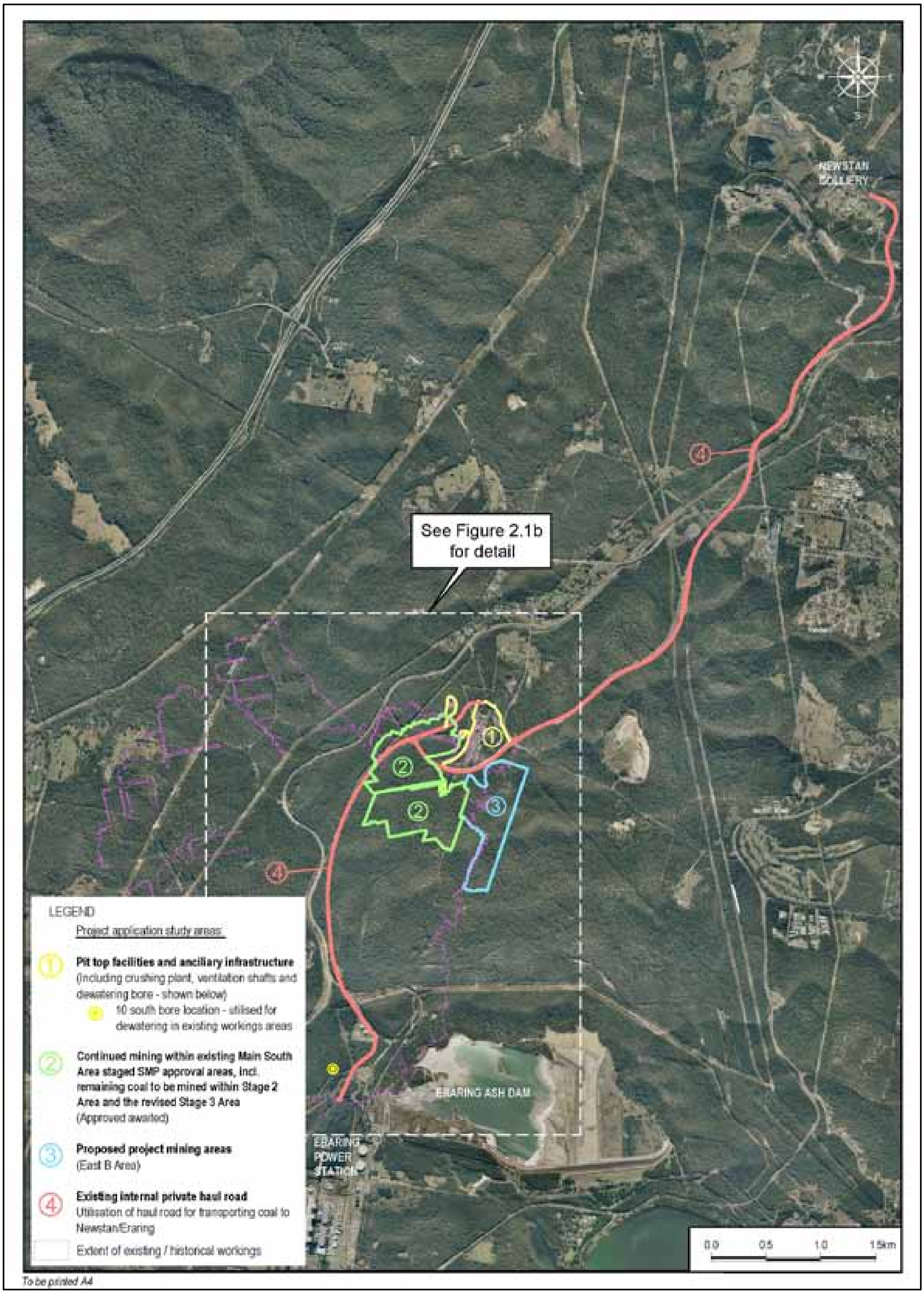

Figure 3 Study areas (supplied by GSS Environmental)

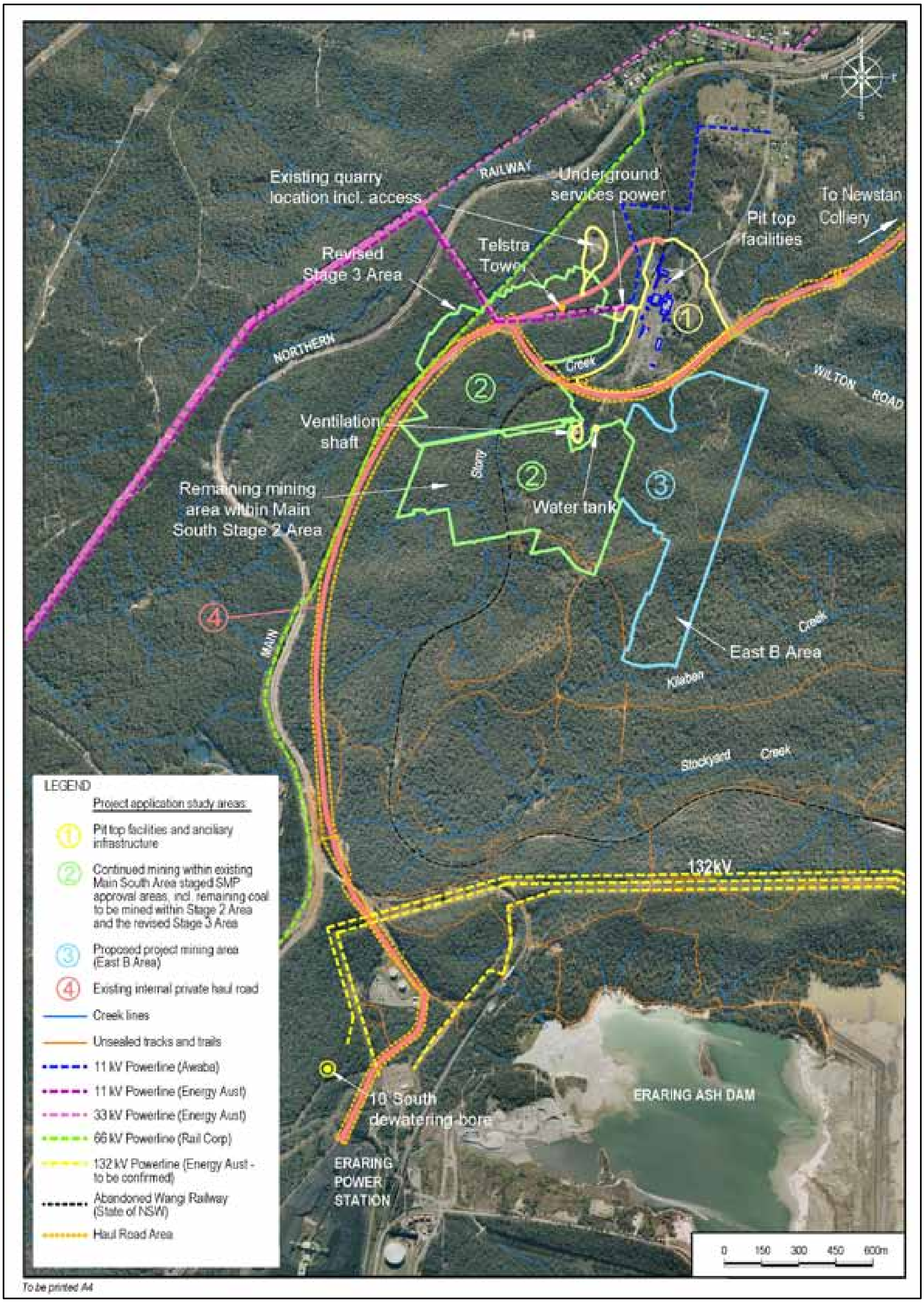

Figure 4 Detail of study areas (supplied by GSS Environmental)

1.3 Project Description

Awaba Colliery is seeking an approval from the Minister of Planning under the provisions of Part 3A of the EP&A Act to:

- Continue bord and pillar development and pillar extraction by continuous miners within the "Main South Area" (being the remaining sections of Stage 2 and Revised Stage 3, refer **Study Area 2**);

- Extend bord and pillar development and pillar extraction by continuous miners into the "East B" Area (refer **Study Area 3**);

- Produce, handle and distribute up to 880,000 tonnes of Run of Mine coal per annum (financial year) utilising existing surface facilities;

- Continue the use of existing ancillary surface facilities (all **Study Areas**);

- Expand the existing final Pollution Control Dam (refer **Study Area 1**);

- Continue the delivery of coal to the Newstan Colliery and/or the Eraring Power Station using existing private haul road/transport facilities (refer **Study Area 4**).

The proposed East B Area contains a proportion of coal that extends beyond the existing footprint of mining at Awaba Colliery and includes areas of both existing workings and areas requiring new workings to be developed. Subsequently, areas of new workings are lateral extensions to the mine footprint which will require new development approval (being sought under the current Part 3A application). The East B area is located to the east of the Main South Stage 2 Area. The overlying surface in the East B Area is predominantly bush land on crown land leased to Centennial Newstan and contains no significant surface infrastructure. This area forms ***Study Area 3*** for the Project, as illustrated on Figures 3 and 4.

Mining will also be continued at Awaba Colliery in two (2) separate areas, these have been outlined below and illustrated as ***Study Area 2*** on Figures 3 and 4:

- **Remaining sections of Stage 2 of the Main South Area** (currently being mined) – this area was approved by I&I in September 2008 following an SMP application (as modified) under the NSW *Mining Act, 1992*.
- **Revised Stage 3 Area** (of Main South Area) – this area has recently undergone a number of specialist surveys relating to a SMP application submitted in December 2009 (approval currently awaited from I&I prior to December 2010).

At present, it is anticipated that the Project will recover approximately 2.0 million tonnes of coal which will be extracted from those areas depicted in Study Area 2 and Study Area 3 (see Figure 4) over a period of approximately five years or more, depending on actual mining conditions and relevant market drivers.
All existing ancillary surface facilities, supporting infrastructure, workings and their associated uses will continue to be relied upon by the Awaba Colliery (no significant change)

as outlined further below. These aspects of the Project will continue to be used until such time as the Awaba Colliery is placed on care and maintenance, and thereafter throughout that phase also. When the Awaba Colliery is placed on care and maintenance, this will be done in accordance with the *Life of Mine Plan* approved by NSW in 2009, until such time that a final Detailed Life of Mine Strategy has been developed.

Annual production, handling and distribution of approximately 880,000 tonnes per financial year is required.

Awaba Colliery requires approval to deliver coal via the private haul road to the Newstan Colliery ROM coal stockpile (in addition to the Rail Loop stockpile). This is assessed within **Study Area 4**. Newstan Colliery has submitted an application to modify its development consent in order to process coal received from the Awaba Colliery
Existing mining areas, will continue to be utilised for ongoing mining operations including (but not limited to) mine access, emergency management and underground services and infrastructure.

Continuing Mine Operations:

For the purposes of environmental assessment, further to the information above regarding continued mining areas, it is noted that the following aspects of mine operations are proposed to continue and remain unchanged. Existing mining operations are presented in detail in Section 3 of the *Environmental Assessment (EA)* and, where relevant, components are discussed further in this specialist report.

- **Coal Handling, preparation and stockpiles –** No changes are proposed to the current coal handling, preparation or stockpile procedures to the existing operations;

- **Mine support facilities and site access –** No changes are proposed to the current infrastructure and facilities, with the only exclusion being the expansion of the Pollution Control Dam (PCD) mentioned earlier above, with related water management considerations. Mine access from Wilton Road will continue to be utilised and no significant change is anticipated from current use;

- **Plant and equipment –** No changes are proposed to the typical plant and equipment used at the Awaba Colliery;

- **Transportation procedures –** No changes are proposed to the current transport procedures. The Project will continue to use the Newstan-Eraring private haul road to transport coal from the operations to Newstan and Eraring;

- **Mining methodology –** There will be no significant changes to current mining methods for the Project. This includes predicted subsidence levels and operational structure. Production rates may be slightly increased from approximately 800,000 to 880,000 tonnes per annum (financial year), depending on mining efficiency and market demands;

- **Operational water management –** the domestic wastewater generation rate from the Pit Top facilities will be similar to that which currently exists as there is no plan for an increase or significant change in staff numbers. Disposal of the domestic wastewater will remain as currently exists at site;

- **Mine dewatering procedures –** the10 South Bore will continue to be used for groundwater management and dewatering during both continued operation and care and maintenance conditions.

2 DEVELOPMENT OF THE RECENT MINING STRAGEGY

2.1 Background

As a result of difficulties in obtaining approval for an extraction strategy based on stripping one side of the current standing pillars, as well as a review of the layout subsequent to a floor heave and subsidence event in late 2006, a new mine plan was formulated. This layout involves the taking of more coal from selected standing pillars but with panels that are no more than 100m wide, and has been applied since mid 2007. The dark shaded areas in Figure 5 show where this extraction has been conducted up to February 2010.

Awaba Colliery has large expanses of first working pillars that have typical minimum pillar centres of 21m to 23m with roadways of nominal 5.5m width (Figure 5). Typically, 5 to 7 rows of pillars define panels that are identified by name. Study Area 2 is such an area of standing first working pillars. New first workings are proposed for much of Study Area 3.

The proposed second workings at Awaba are based on exploiting the spanning capabilities of the Teralba Conglomerate that lies above the Great Northern Seam. The layout is referred to as the “bridging layout” to contrast it to the stripping layout previously considered. In general, pillars within panels that are no more than 100m wide are stripped by a maximum of 15m thus leaving small stooks that should manage any wind blast hazard. A row of standing pillars will then be left before another panel is formed. The rows of pillars have factors of safety relating to the coal strength greater than unity and on this basis their stability should be consistent with contemporary pillar extraction and longwall mining practice. The pillar design does not necessarily produce long-tem stable pillars.

The stability of the pillar/floor system will vary depending on the nature of the Awaba Tuff in the floor. It is recognized that the floor may fail if very low strength material is present, and this hazard can be managed to some degree by testing the floor prior to extraction. A key aspect of the planning for the layout is that floor failure does not result in rapid and uncontrolled collapse of the strata above the extraction panels.

The implementation of the bridging layout recognizes the agreement with Rail Corp that the requirements of the Department of Primary Industry be adopted. Thus no second workings are to be conducted within a protection zone defined as the sum of 20m from the nearest rail, a step out distance defined by a 35^{o} angle of draw, and an additional distance of 100m. Furthermore, there have been requirements not to extract pillars under certain creek lines.

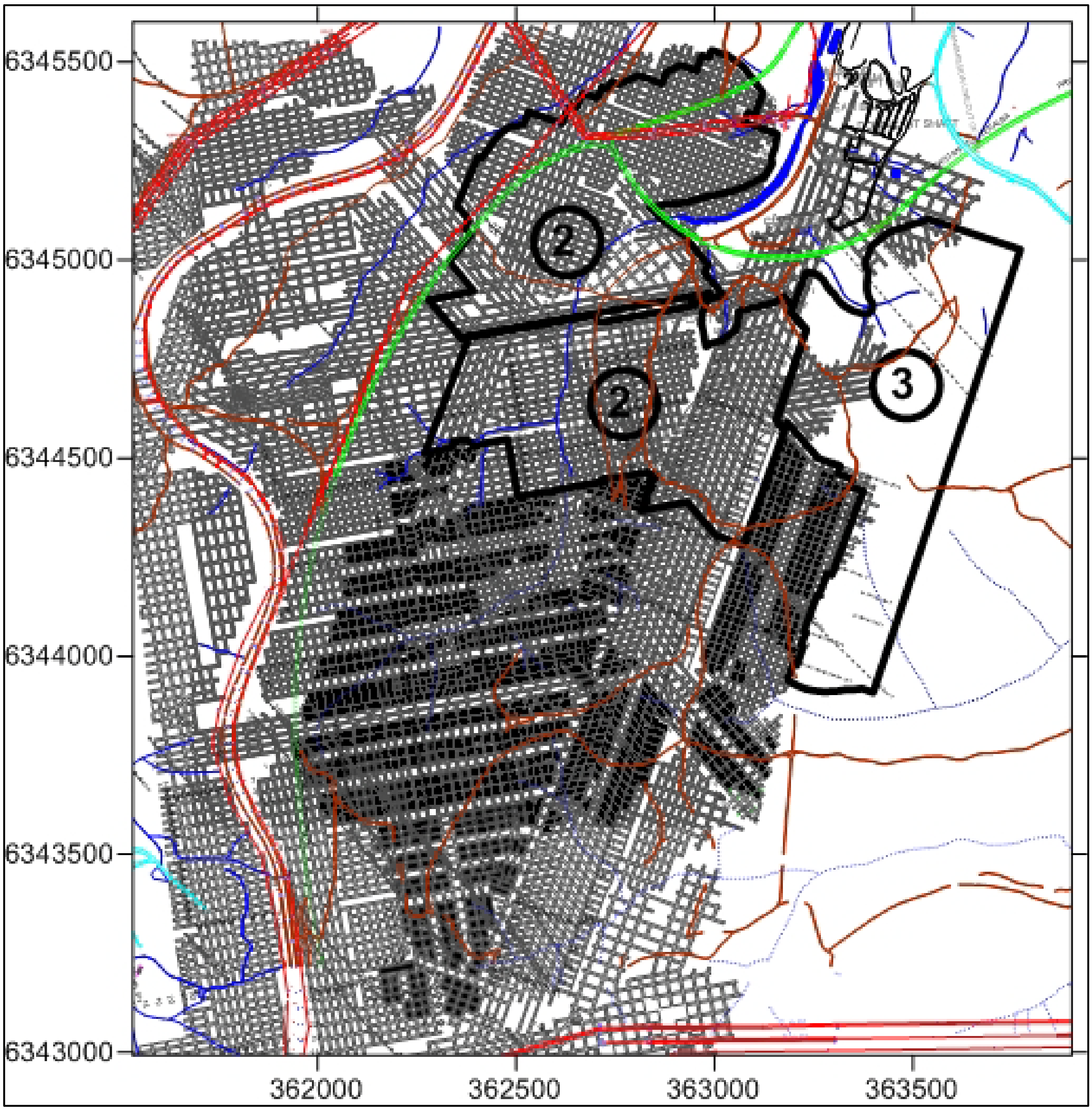

Figure 5 Indication of the extent of first working pillars and the area over which new mining system has been applied up to February 2010.

2.2 Previous mining

Awaba Colliery has experienced a number of events in which there was rapid subsidence of the surface and the onset of floor heave in working panels. The pillars involved had been formed on 20m centres and at depths from 25m to 80m such that the pillars themselves have had very high factors of safety. There have also been reports of wind rush events in association with the failures. It is important to note that such events did not always develop with pillars of these dimensions – there are many areas of Awaba still standing with pillars formed on 20m centres.

The term "creep" has been used for these events. Creep is informally defined as a progressive pillar collapse and hence may not be the ideal terminology for these events as they happen very quickly and do not involve the failure of the coal pillar themselves. It would be better to refer to them as floor heave/subsidence events. Neither the floor heave/subsidence events nor other mining have had an adverse impact on the railway barrier as there are no reports of any closing of the rail line.

2.2.1 Subsidence along the rail barrier

The rail line was monitored during the extraction of 4 South, 9 West, 2 East, and 15 West (Figure 6) in the early 1980s. The depth of cover in this area is about 50m. The results of the survey along the rail line are shown in Figure 7, and for the 9 West line in Figure 8.

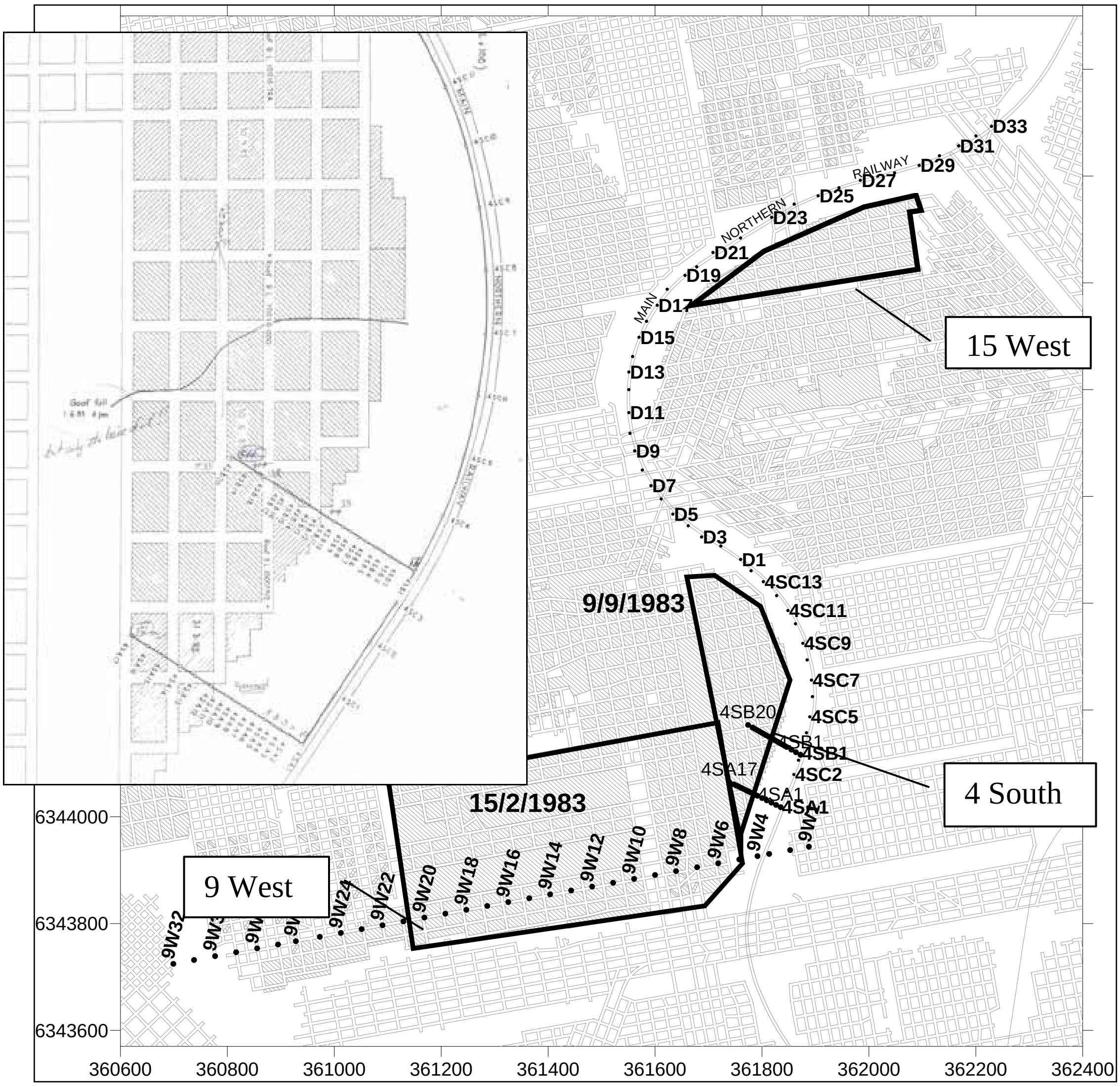

Figure 6 Survey points along rail and along 9 West, also showing dates of pillar extraction

Maximum subsidence at the rail was 32mm and this occurred when there was pillar extraction on both sides of the railway zone (Figure 6). With first workings on one side and extraction on the other side, the measured movements were less than 20mm.

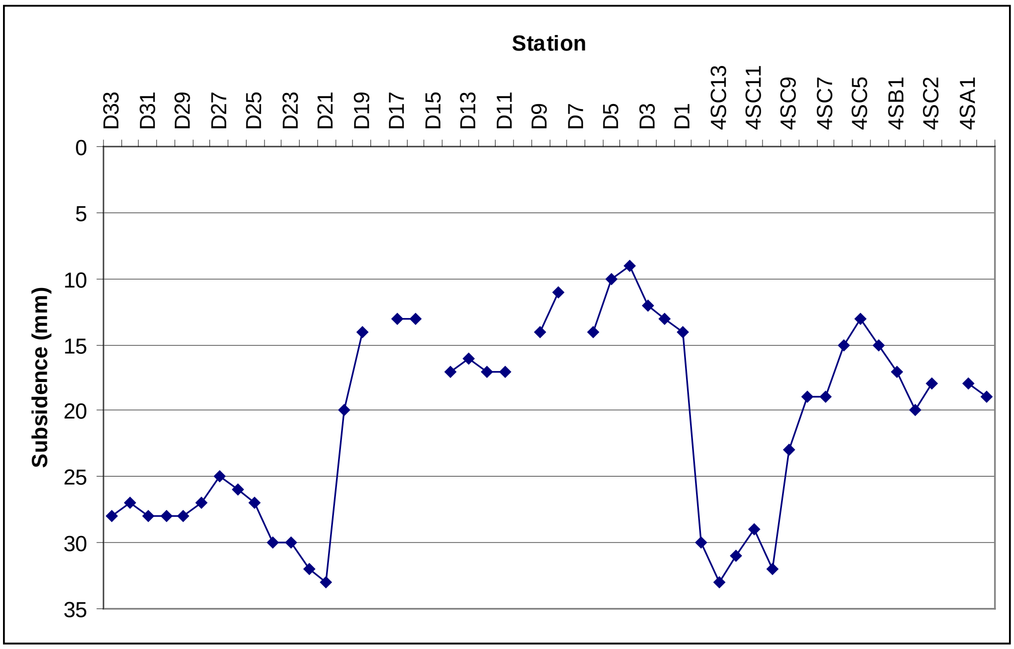

Figure 7 Compilation of vertical subsidence along D and 4SC lines (Drawings HA-536 and HA-437, end 1985)

During the extraction of 9 West, the goaf edge subsided by approximately 40mm, and the 20mm subsidence level was measured at station 9W4, approximately 55m from the goaf edge.

Figure 8 Vertical subsidence above 9 West (Drawing HA-338/1 - December 1985)

The extraction of 4 South was monitored with 2 cross lines (Figure 9). Crossline 4SA suggests that the conglomerate roof did not fully cave, and that there was approximately

26mm of subsidence at the goaf edge. Crossline 4B suggests that there was incomplete subsidence of the conglomerate and that the 20mm subsidence level was about 15m from the goaf edge.

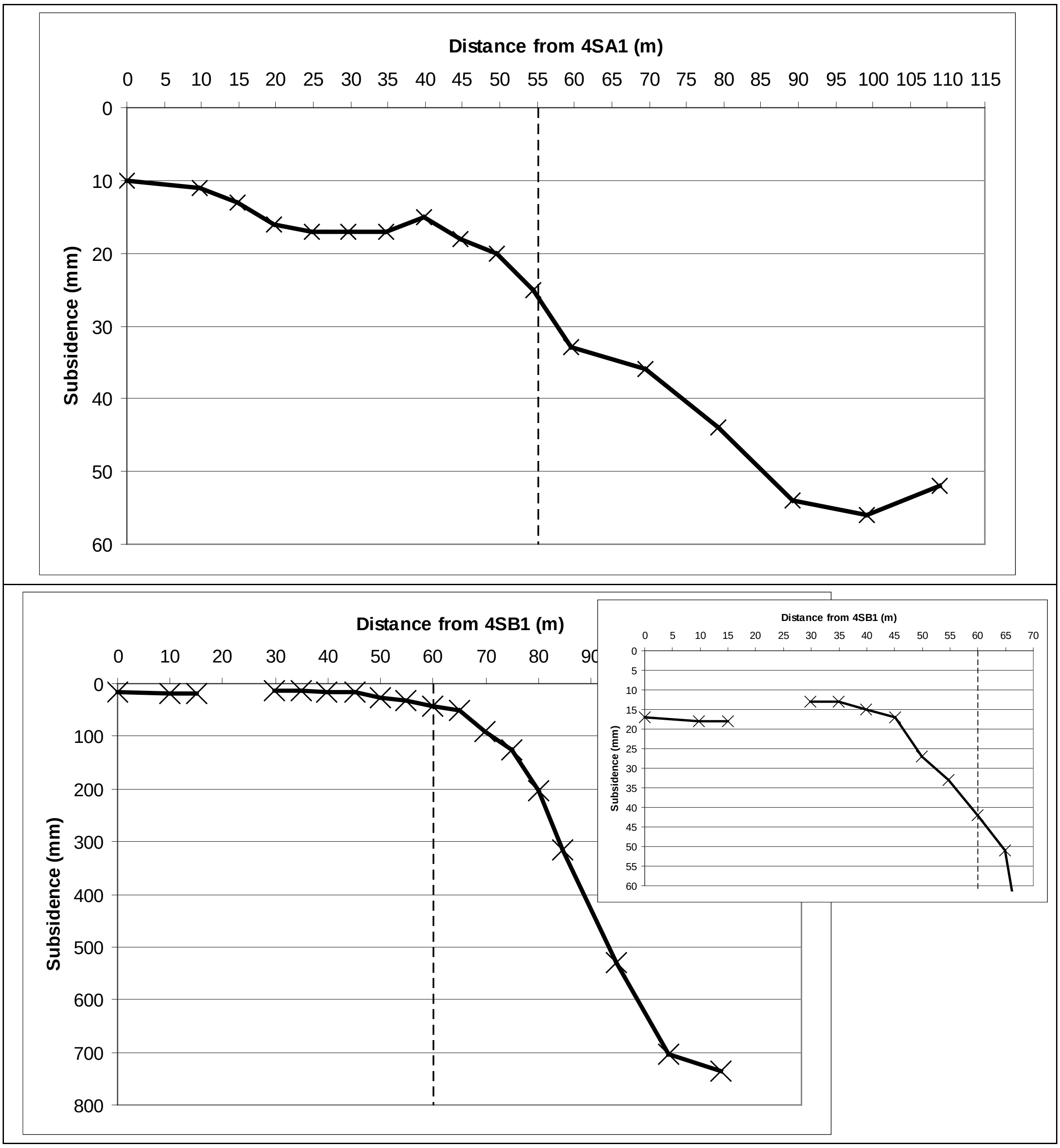

Figure 9 Vertical subsidence above 4 South (Drawing HA-338/2 – December 1985)

2.2.2 Location of floor heave/subsidence events

The location of known floor heave/subsidence events is shown in Figure 10. All events have occurred on the west and north side of the railway, and at depths between 25m and 80m.

there have been no heave events to the east of the railway line. The information in Figure 10 is drawn from colliery plan AW1253 which was created in November 2003 based on personal recollections from the 1980s. The plan identifies the panels that experienced floor heave/subsidence events, but not exactly which parts of the panels did. The plan does not show the status of the adjacent layout when the panels collapsed.

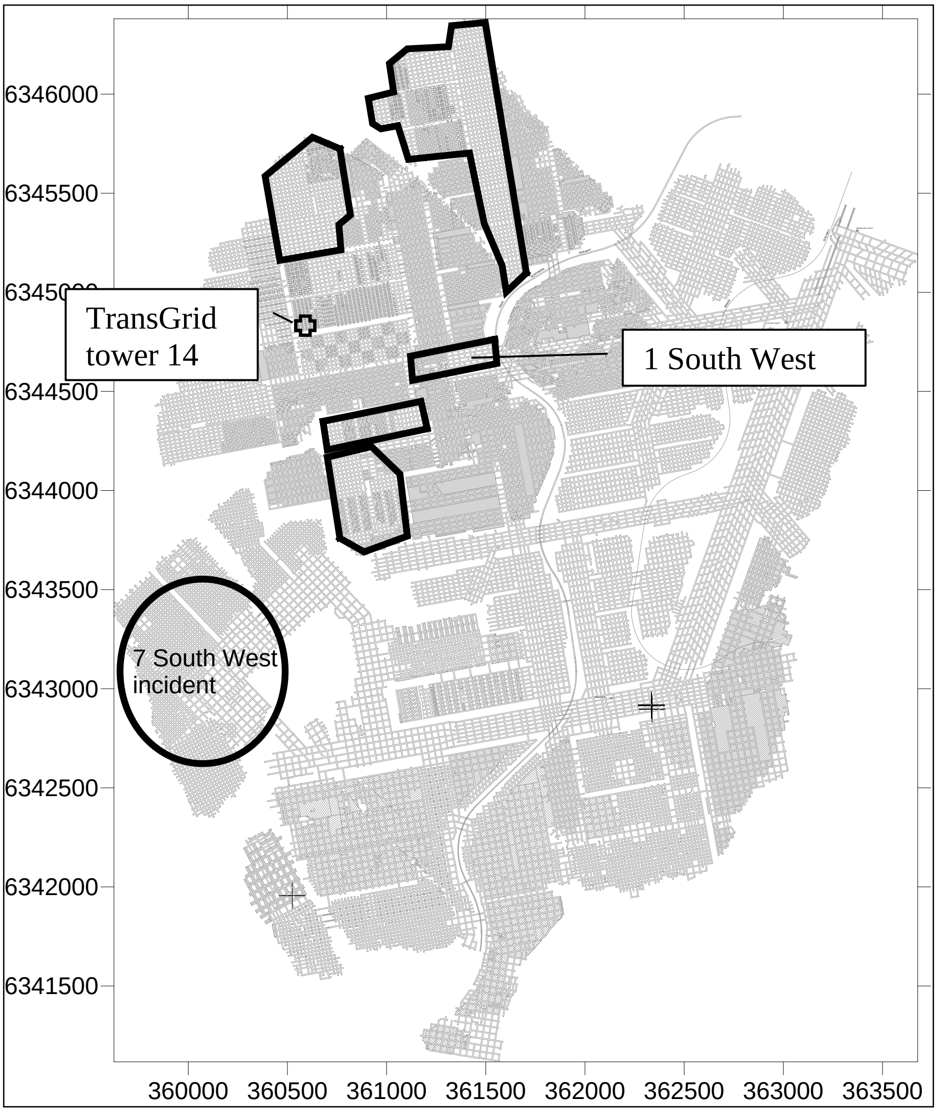

Figure 10 Location of floor heave/subsidence events and previous subsidence lines

It is understood that the 2 events that were immediately adjacent to the railway did not result in adverse impacts to the function of the rail.

The 7 South West event occurred on the morning of 13 September 2006. The pillars were originally formed on 33m centres at a depth of 60m, increasing to 36m centres for a depth of 80m. The pillars were then quartered on retreat leaving pillars on 16m centres (nominally 10.5 wide with 5.5m roads).

The event was characterised by rapid floor heave, a dust cloud, and surface subsidence. There was no significant additional rib spall. Operators reported that the event was complete within 15-40 seconds.

Floor heave was present in old roadways in the panel but there was no active heave in the newly formed roadways prior to the event. Typically 0.5m to 1.0m of floor coal had been left in the new roadways and this was taken during the quartering.

Analysis by others indicated factors of safety for the coal in the pillars was greater than 1.5 with the worse case assumption of 7.5m wide roadways. No testing of the Awaba Tuff was conducted prior to the panel design or subsequently in the area of interest. Testing immediately outbye suggested floor strengths of 1.5 MPa to 6.5 MPa. It was concluded that a failure of the floor was more likely than a coal pillar failure.

It is important to note that none of the rapid collapses extended throughout the mine, indicating that either the geotechnical conditions were not similar, or that larger pillars or unmined coal stopped the progression. In fact, this argument can be taken further to suggest that if there are standing pillars in panels more than 150m wide, this is evidence that the floor is adequately strong to prevent failure.

2.2.3 Models for floor heave

The floor heave/subsidence events have not been formally or exhaustively studied. There appears to be 2 models proposed.

One model proposes that abutment stresses around an extraction panel generate failure in relatively large pillars and that this propagates through the first workings. This model requires elevated vertical stresses that are well in excess of tributary area loading and that these persist over large areas.

The adopted model is that the pillar floor foundations are unstable and that these will collapse once the panel is wide enough so that full loading is applied (Figure 11). Because of the presence of low strength floor horizons, the bearing strength of the pillar foundation is significantly less than the strength of the coal component. The bearing strength is a function of the width of the pillar compared to the thickness of the low strength layer, so wider pillars have higher bearing strength. The massive conglomerate roof means that it can bridge across narrow panels and transfer more of the vertical stress to the abutments. As the panel increases in width, a condition develops where the conglomerate cannot span – the conglomerate then collapses and loads the pillars directly and the foundations fail; at the same time loads are reduced on the abutments. An implication of this model is that until the conglomerate beam fails there may be no indication of floor heave or other evidence of low strength floors.

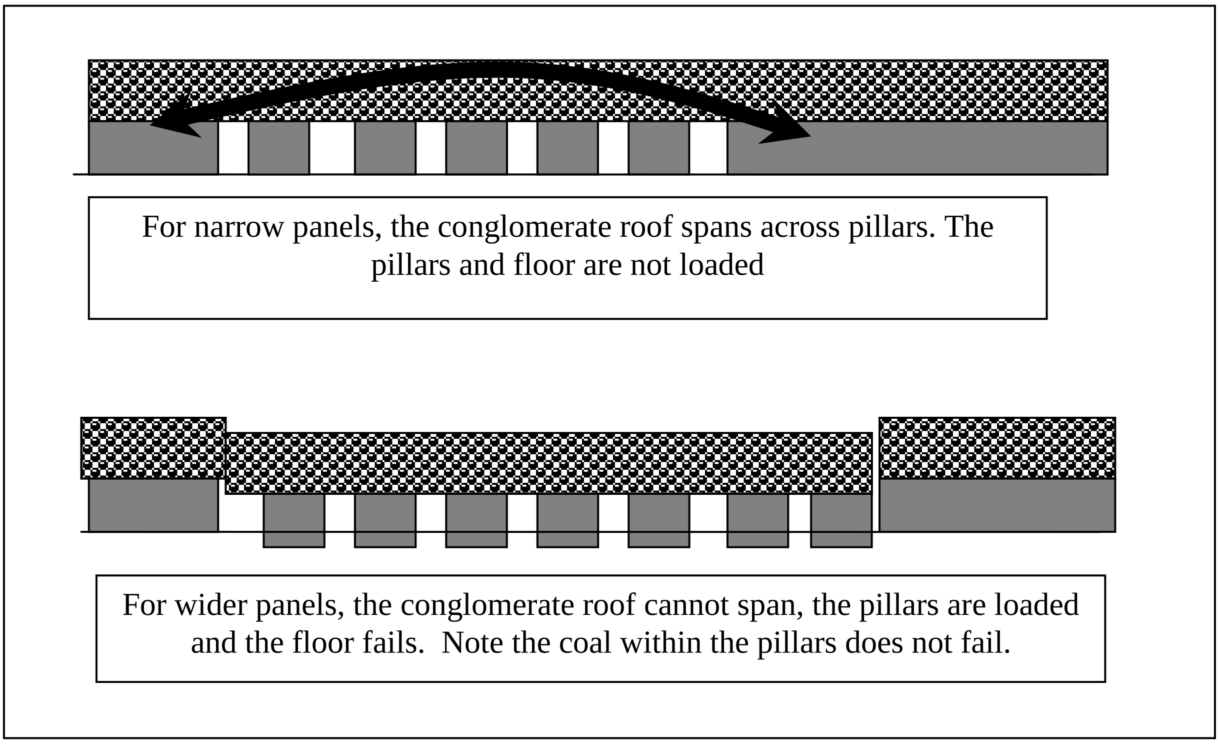

Figure 11 Model for the development of previous floor heave and wind rush events

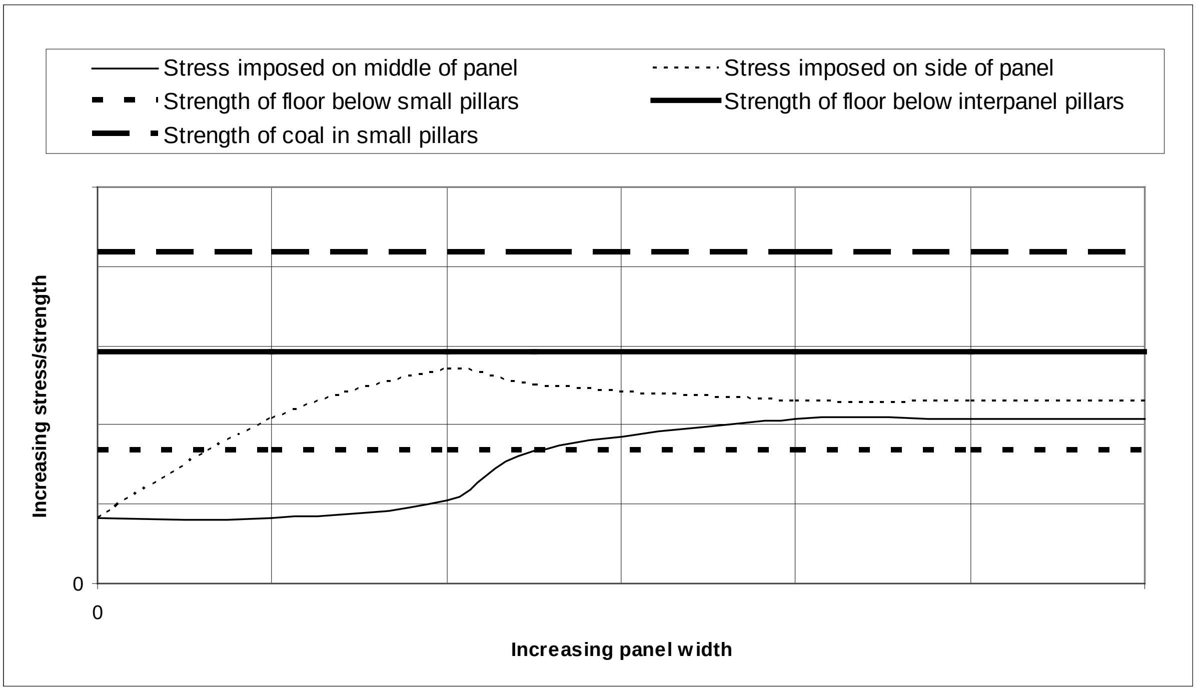

Figure 12 Conceptual model of stresses and strength involved in pillar extraction at Awaba

Key mechanisms are collapse of the conglomerate roof and the collapse of the floor. These can be analysed using standard engineering methods – voussoir beams and foundation engineering. Both of these are application of standard physical laws and elastic theory.

Voussoir beam theory was originally developed in the UK coal mining industry and developed further in several mining text books and mining journals. It has been adopted by civil engineers working in stratified rock masses (e.g. Sydney tunnels) and also for coal mine design (Mandalong). Foundation engineering concepts have been applied to mine pillars extensively in the past and are included in standard text books.

2.3 Geotechnical Conditions

Having identified the failure mechanism the mine design exercise is to prevent this from happening. The direction given by Centennial is that this collapse must not occur during the mining of the panel as the safety implications are not acceptable.

The engineering analyses require an understanding of pillar stress and the strength of the floor and the conglomerate in the overburden.

2.3.1 Vertical stresses

Awaba Colliery mines the Great Northern Seam and in the area of interest the depth ranges between 20m and 60m (Figure 13). It is appropriate to assume an average overburden density of 2.5 t/m3, and since the mine design is based on the overburden units spanning across the extraction a derivative of the tributary area loading model can be used.

2.3.2 Pillar height

The full thickness of the Great Northern Seam is in the range of 2.5m to 3.8m depending on the location.

2.3.3 Floor conditions

The floor of the Great Northern Seam is the Awaba Tuff, which in this area is 2.7m to 4.5m in thickness, and this overlies the Fassifern Seam.

ADC27, drilled in 1961 and located near the railway and one of the floor heave events (1 South West, Figure 10) includes the following description:

> SILTSTONE (?TUFF) very friable and easily powdered between fingers. 3’1” (0.94m). With modern logging definitions, this would have a UCS of 150-700 kPa.

Logging of other holes in the 1980 makes reference to moderately soft and soft strengths with no definitions of the terms provided.

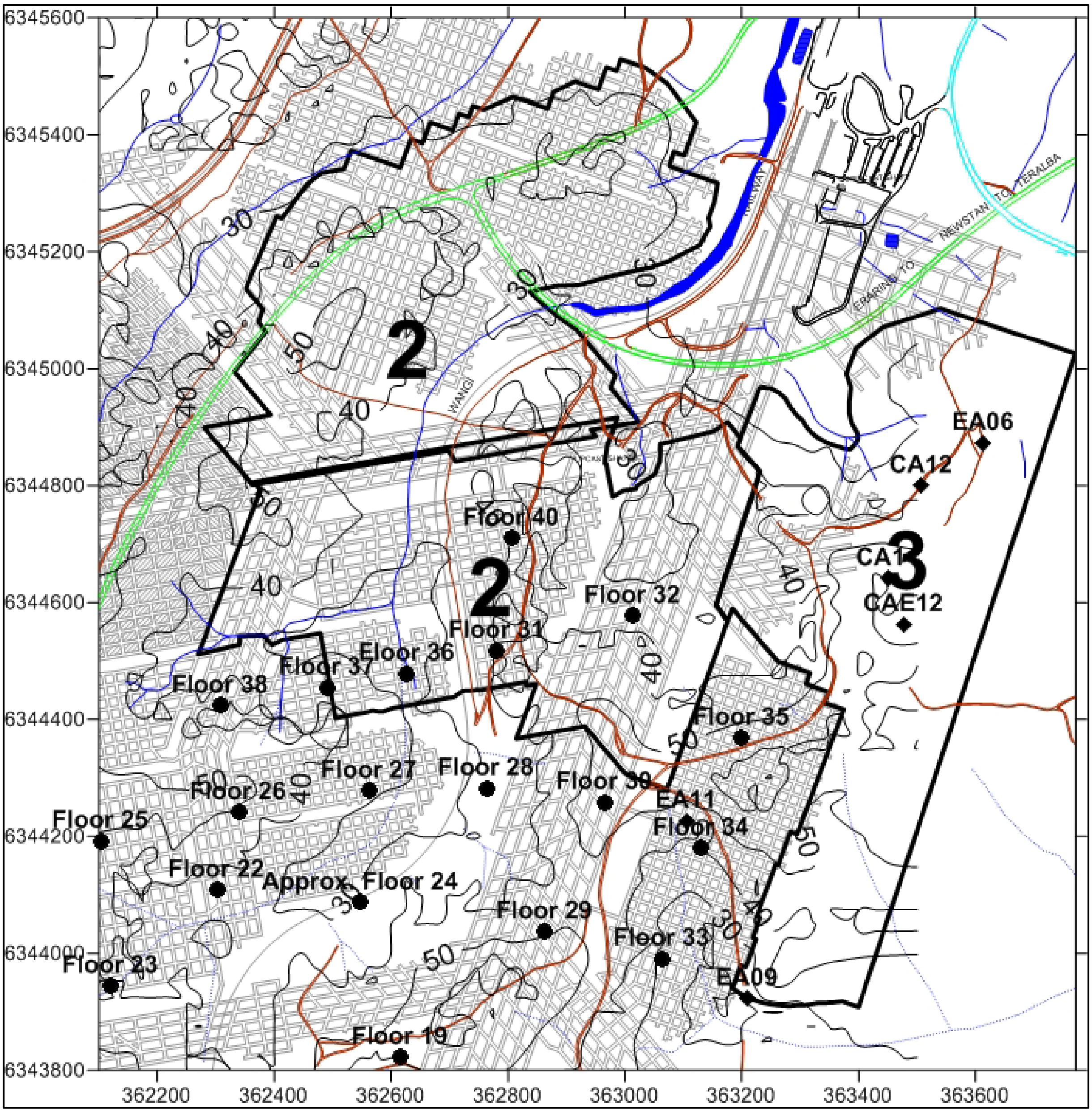

Figure 13 Depth of cover to Great Northern Seam and location of floor and overburden holes

Cores of the Awaba Tuff drilled recently (Figure 13) have included visual and tactile strength assessments (Table 1). It will be suggested below that the materials with 500 kPa strengths are probably associated with the collapse of the pillars.

The fact that much of the Awaba Tuff has strengths of less than say 10 MPa to 20 MPa is significant in itself, as materials of these strengths can swell when exposed to water. Free swell values of up to 30%-40% have been measured on similar Awaba Tuff from Cooranbong Colliery. It is assessed that the floor heave that is seen in old roadways at Awaba is caused by the swelling of the Awaba Tuff in the floor of the roadways. This is the reason why hole Floor 7 reported lower strengths – it was drilled vertically into the roadway floor and not at an angle under the pillars. Note that such swelling and associated strength loss does not develop in the Awaba Tuff below the pillars that, by definition, is under higher stress following mining than in the recent geological past.

Table 1 Visual and tactile tests

Symbol	Term	Visual and tactile	Approx strength
S4	Hard soil	Cannot be moulded, readily crumbled	150-700 kPa
S5	Transitional soil/rock	Readily trimmed, thumbnail easily scratches core	0.7-1.5 MPa
R1	Very low strength rock	Peeled with moderate effort, G pick leaves deep impression	1.5 – 3.0MPa
R2	Low strength rock	Peeled with difficulty, G pick leaves minor impression	3.0 – 10 MPa
R3	Medium strength rock	Barely shows mark when attempted to be peeled. Blow by G pick leaves minimal impression	10 – 25 MPa

Table 2 Summary of low strength (S4-R2) layers in floor

Easting	Northing	Hole	Thickness	Strength
362616	6343823	Floor 19	None	
362626	6343422	Floor 20	None	
362735	6343728	Floor 21	None	
362302.2	6344108	Floor 22	0.14	S5
362120.6	6343945	Floor 23	0.07	S5
362548	6344087	. Floor 24	0.26	R2
362103.5	6344192	Floor 25	0.35	R2
362339.2	6344242	Floor 26	0.4	S5
362563.2	6344278	Floor 27	0.1	S4
362763.2	6344282	Floor 28	None	
362863.5	6344038	Floor 29	None	
362965.5	6344259	Floor 30	None	
362781.4	6344517	Floor 31	0.2	5
363013.7	6344577	Floor 32	0.02	R1
363063.8	6343991	Floor 33	None	
363131.4	6344180	Floor 34	None	
363200	6344369	Floor 35	None	
362627.6	6344479	Floor 36	0.1	S4
362491.7	6344455	Floor 37	0.33	R2
362308.5	6344424	Floor 38	0.44	S5
363065.9	6343760	Floor 39	0.39	R2
362806.5	6344710	Floor 40	0.02	S5

Investigation at Newstan Colliery in 2004 included some core drilling of the Awaba Tuff near TransGrid Tower #14 (Figure 10). Based on the core and the sonic logging conducted in the hole, it was concluded that there may be 1m of 0.5 MPa material present in the floor under the barrier pillar. The coincidence with the logging of ADC27 is noteworthy.

2.3.4 Teralba Conglomerate

The stratigraphic unit above the Great Northern Seam is the Teralba Conglomerate and this extends all the way to the surface.

There are 6 boreholes in the area that have been used to define the geological model for Stage 3. There are useful geotechnical data from 4 holes (Table 3), including 3 ELCOM Awaba (EA) holes and a more recent Centennial hole (CAE12). Table 1 presents data on the thickest continuous unit within the Teralba Conglomerate stratigraphic unit that comprises the overburden. In the geophysical log of CAE12, the unit was defined according to the gamma log signature.

Compared to EA11 above early panel and pillar layouts, the other holes reveal a thinning of the conglomerate unit that is relied on in the panel design.

Table 3 Conglomerate unit above the Great Northern Seam

Hole	Great Northern depth (m)	Conglomerate thickness (m)	Depth to top of unit(m)	Maximum indicate panel width (m) – Figure 4
EA6	44.69	12.73	31.96	82
EA11	44.24	18.393	25.84	119
CAE12	78.8	15.46	63.34	76
EA9	17.61	8.607	7.5	89

Based on previous studies of the Teralba Conglomerate at Newstan Colliery, it is considered that the Teralba Conglomerate has an unconfined compressive strength of 65 MPa and a Youngs Modulus of 20 GPa.

2.3.5 Faults

The geological plan attached to the 2005 SMP application shows a series of normal faults occurring in swarms of 3 or 4, and about 500m apart. Throws are indicated to be 0.5m-1.5m. Such normal faults have not been shown to be implemented in unexpected subsidence events with the Teralba Conglomerate.

2.4 Analysis of Floor Heave/Subsidence Events

The geotechnical data presented in the previous section allows the analysis of various behaviours to assist in assessing the likely contributors to the floor heave/subsidence events.

2.4.1 Collapse of Teralba Conglomerate

The relationship between the span and thickness at which the Teralba Conglomerate could collapse is shown in Figure 14. For 20m thick layers of conglomerate the critical span is shown to be in the order of 150m to 200m. It is noted that this is in agreement with the observations at 4 South and other extraction panels at Awaba. Reducing the panel width to 100m or less, the required thickness of conglomerate is in the order of 10m, which is significantly less than the layering that is seen in most holes.

The deflections at failure shown in Figure 15 are of interest – the analyses suggest that there can be 2m to 3m of surface subsidence without collapse of the beam. For panels of less than 100m, the deflections are predicted to be less than 200mm.

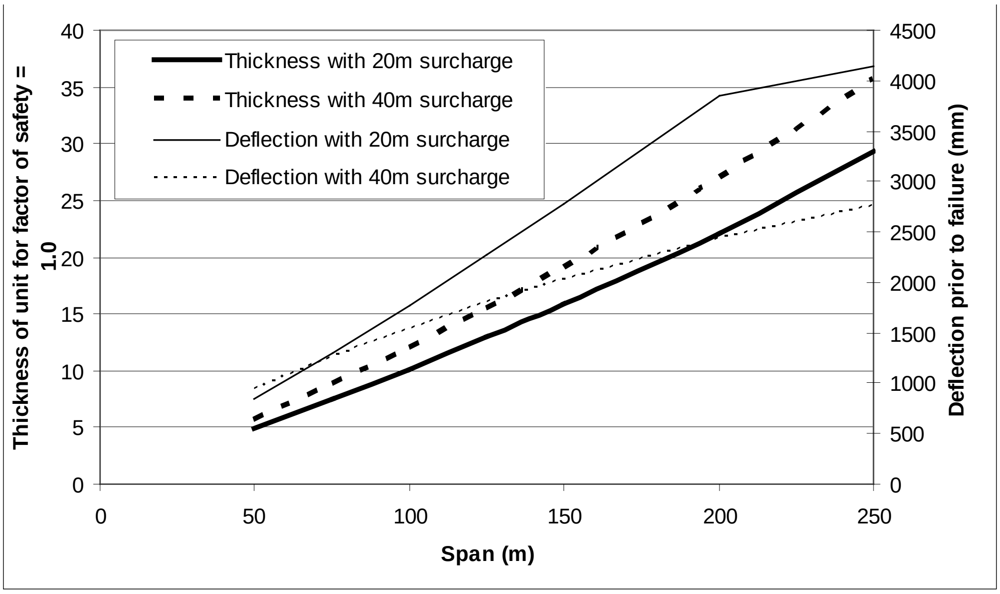

Figure 14 Collapse of Teralba Conglomerate (compressive failure, Factor of safety = 1.0)

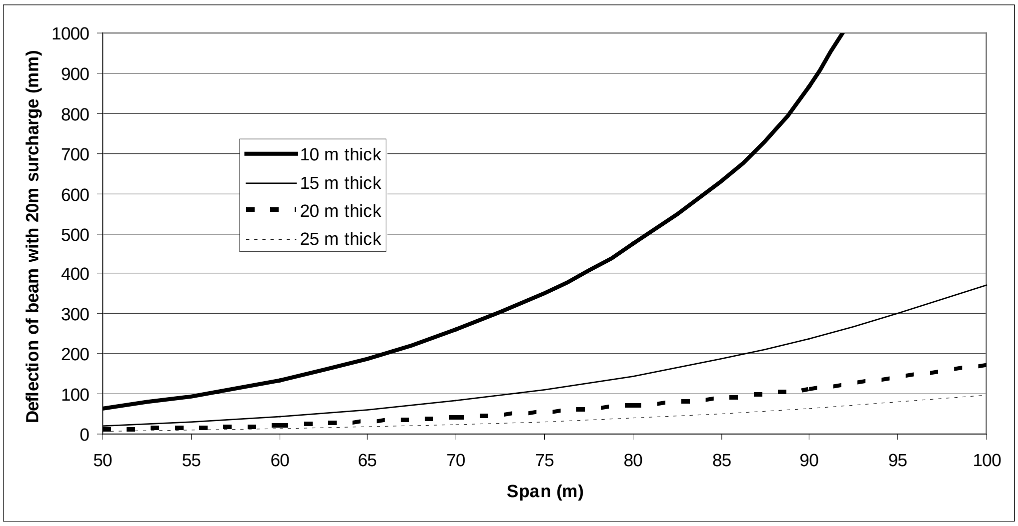

Figure 15 Deflection of Teralba Conglomerate

2.4.2 Back analyses of floor failure

In the past, one of the difficulties when analyzing the floor failure was that the floor strength was not known. However, hole ADC27 is adjacent to the 1 South West event and the logging can be used to estimate the floor strength. It is encouraging that the strength of the floor in this area is similar to an independent estimate of the floor in the vicinity of TransGrid Tower 14.

Figure 16 presents the allowable bearing stress on a 1m thick layer of 500 kPa strength assuming a factor of safety of 2.5 and compares it with pillar stresses based on tributary area loading. It can be seen that at 40m depth of cover, pillar stresses are in excess of the bearing capacity for pillar widths less than about 23m, and at 60m depth for pillars with widths less than 32m. The figure suggests that the progression of floor heave/subsidence events could have been stopped by pillars of the order of 25m in width – it is understood that this was the basis of successful management strategies at the mine in the later 1980s.

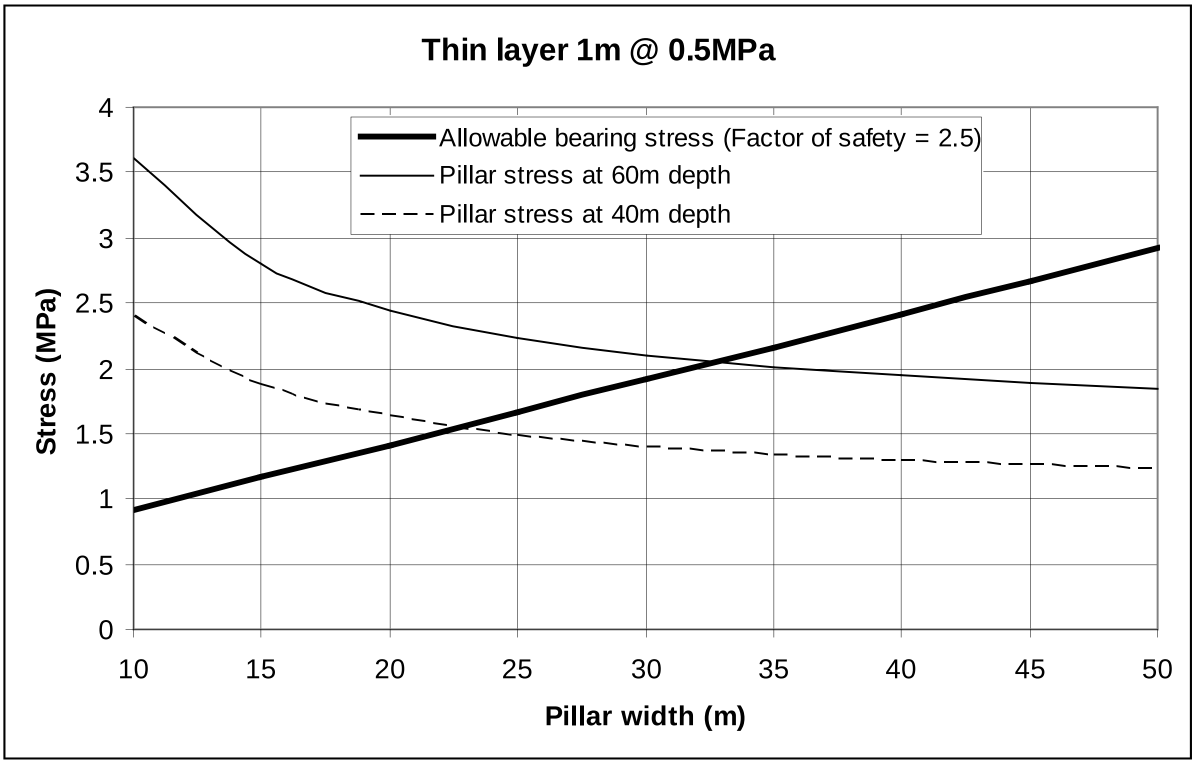

Figure 16 Analysis of bearing strength of thin layer of material

2.4.3 Lateral extent of vertical subsidence

Elastic analyses using a simple displacement discontinuity code (Examine TAB) with modified parameters to simulate the conglomerate and the pillar/floor system suggest that 20mm subsidence line would be located about 50m from the side of the panels and 25m from the end of the panels for the case of 100mm of vertical subsidence (Figure 17). The similarity to 4 South is noteworthy. This set of subsidence analyses are only made for cases where there is no failure of the floor. The mechanics of the massive beam may meant that the 20mm deformation line may extend further out for greater values of the vertical deformation of conglomerate beam. It is important to note that the traditional understanding of angles of draw may need to be modified for this type of subsidence behavour.

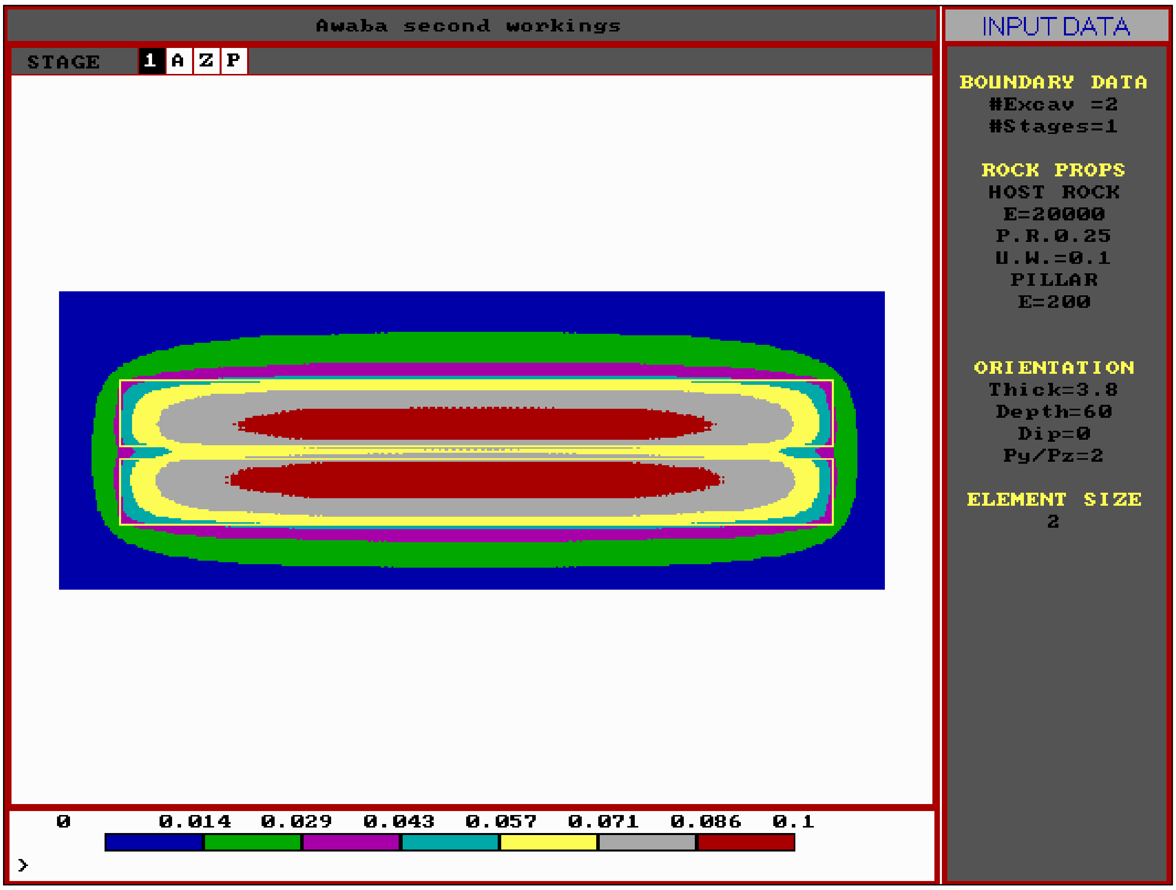

Figure 17 Displacement discontinuity analysis of the displacement (mm) above 2 bridging panels each of 100m width

3 MINING SINCE 2008

3.1 Survey results

Figure 18 presents a contour plan of the subsidence recorded up to December 2009 at Awaba with the extraction design applied to pillars that were formed some 50 years ago. The maximum vertical subsidence associated with the extraction is 125mm. The 20mm subsidence line is shown to be between 0m and 100m from the end of the panels.

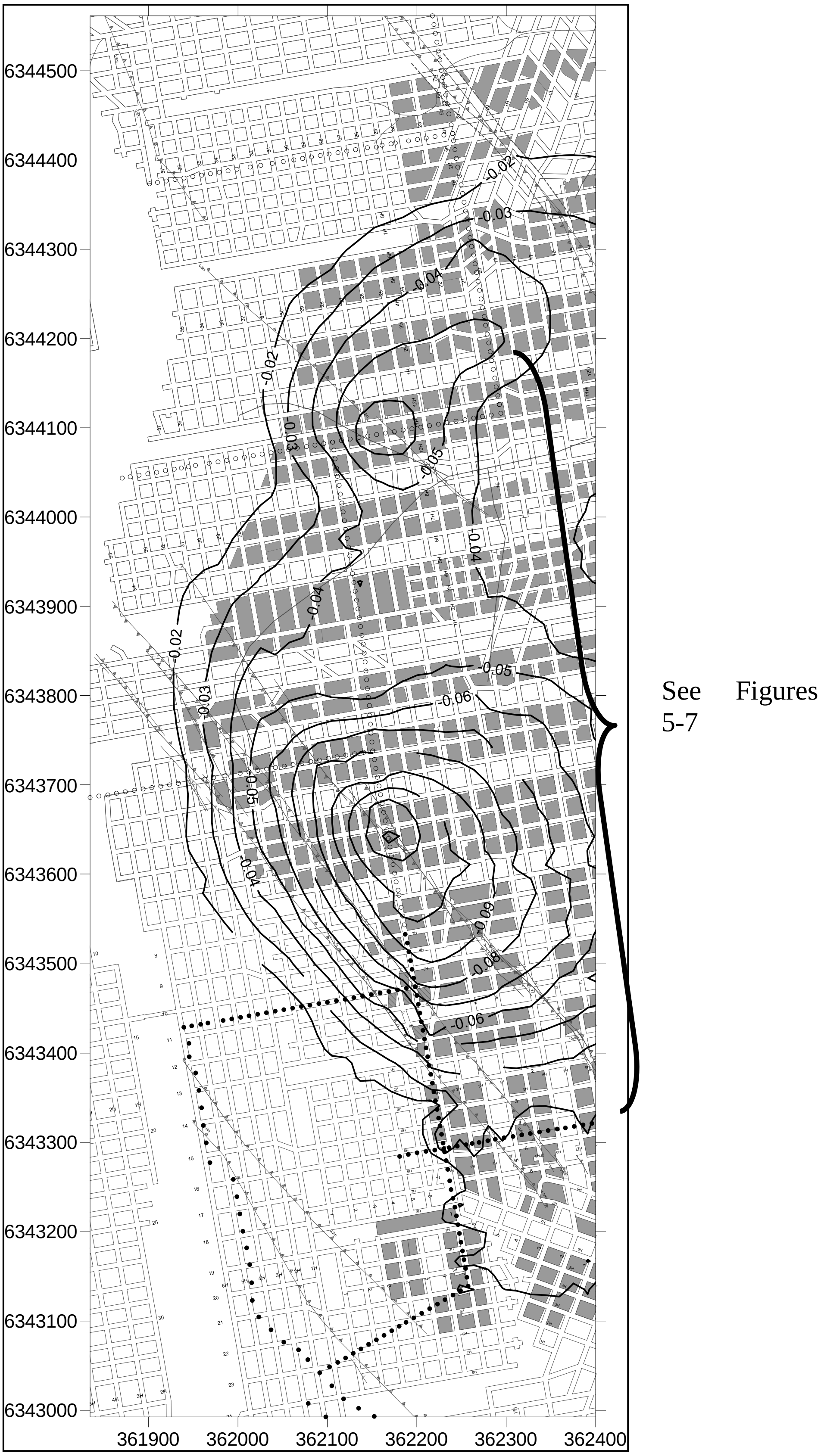

Figure 18 Interpreted vertical subsidence contours to date (grey areas are extracted pillars)

A typical survey line is shown in Figure 19. As the extraction progressed, the vertical subsidence has increased to about 125mm. The associated tilts for the last survey (Figure 20) show a large degree of noise (related to survey precision with such low absolute values) and the real values for tilt are assessed to be less than 1 mm/m.

Strains were measured during some of the initial extraction. When the maximum vertical subsidence was less than about 30mm, the strains were less than about 0.5mm/m (Figure 21).

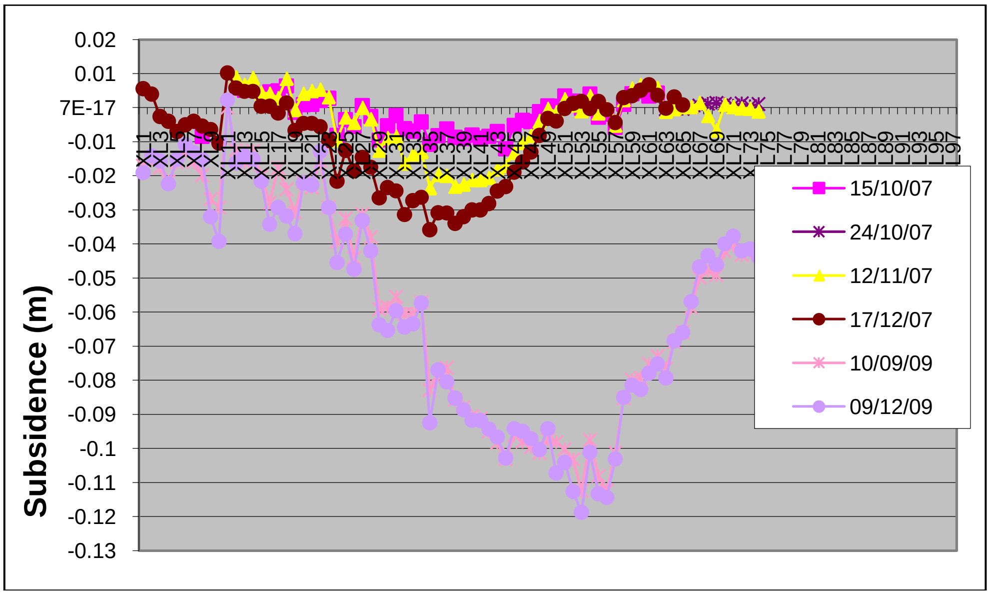

Figure 19 Progressive vertical subsidence movement as pillar extraction progressed

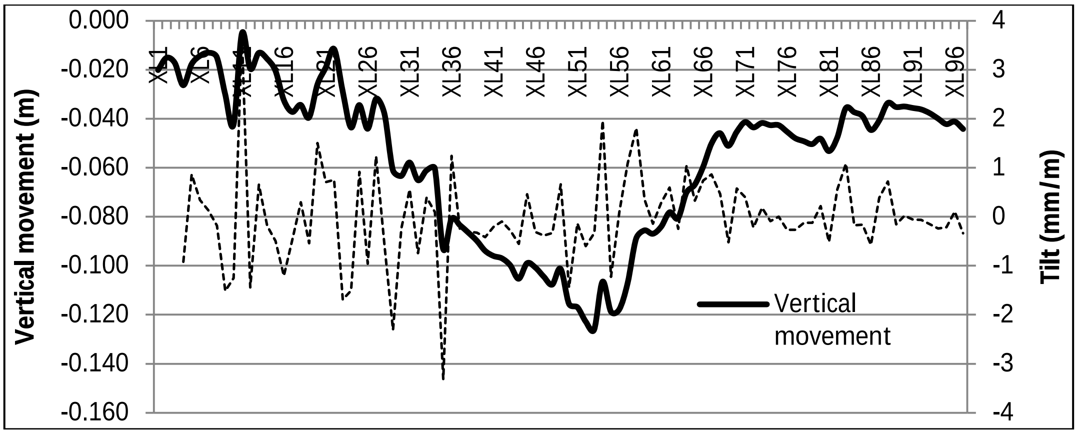

Figure 20 Vertical movement and associated tilts for the last survey

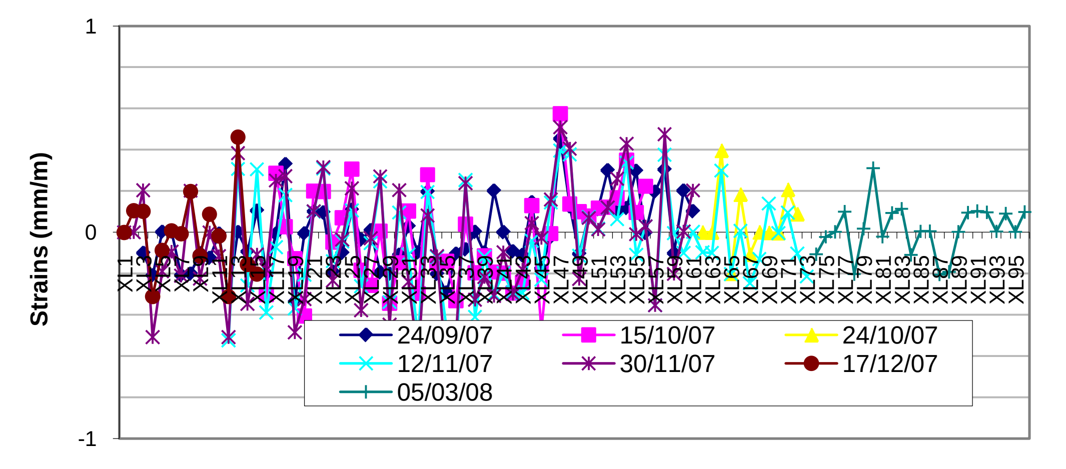

Figure 21 Strain measurement up to March 2008

3.2 Analysis

3.2.1 Pillar compression

There needs to be a wide expanse of extraction to achieve full subsidence, and this is assessed to be related to the arching of the Teralba Conglomerate. The maximum subsidence directly above a pillar is in the order of 80mm. A back analysis of this subsidence has been conducted assuming full tributary area loading, elastic compression of the pillars and a layer of low strength Awaba Tuff, and compression of the roof and floor strata assuming elastic deformations under a footing. Floor hole 17 (Figure 22) is relatively close to the peg 48 where the maximum subsidence has developed.

Table 4 presents the results of a back analysis conducted using presumed values for the deformation modulus of intact samples and the Geological Strength Index (so as to determine the sample-mass reduction). The values are consistent with our experiences at Mandalong. It is noted that the floor modulus value is relatively low to account for the presence of the Fassifern Seam as well as the high strength Awaba Tuff. This set of parameters implies that the majority of the surface subsidence is generated by compression of the floor units (55mm, Figure 23).

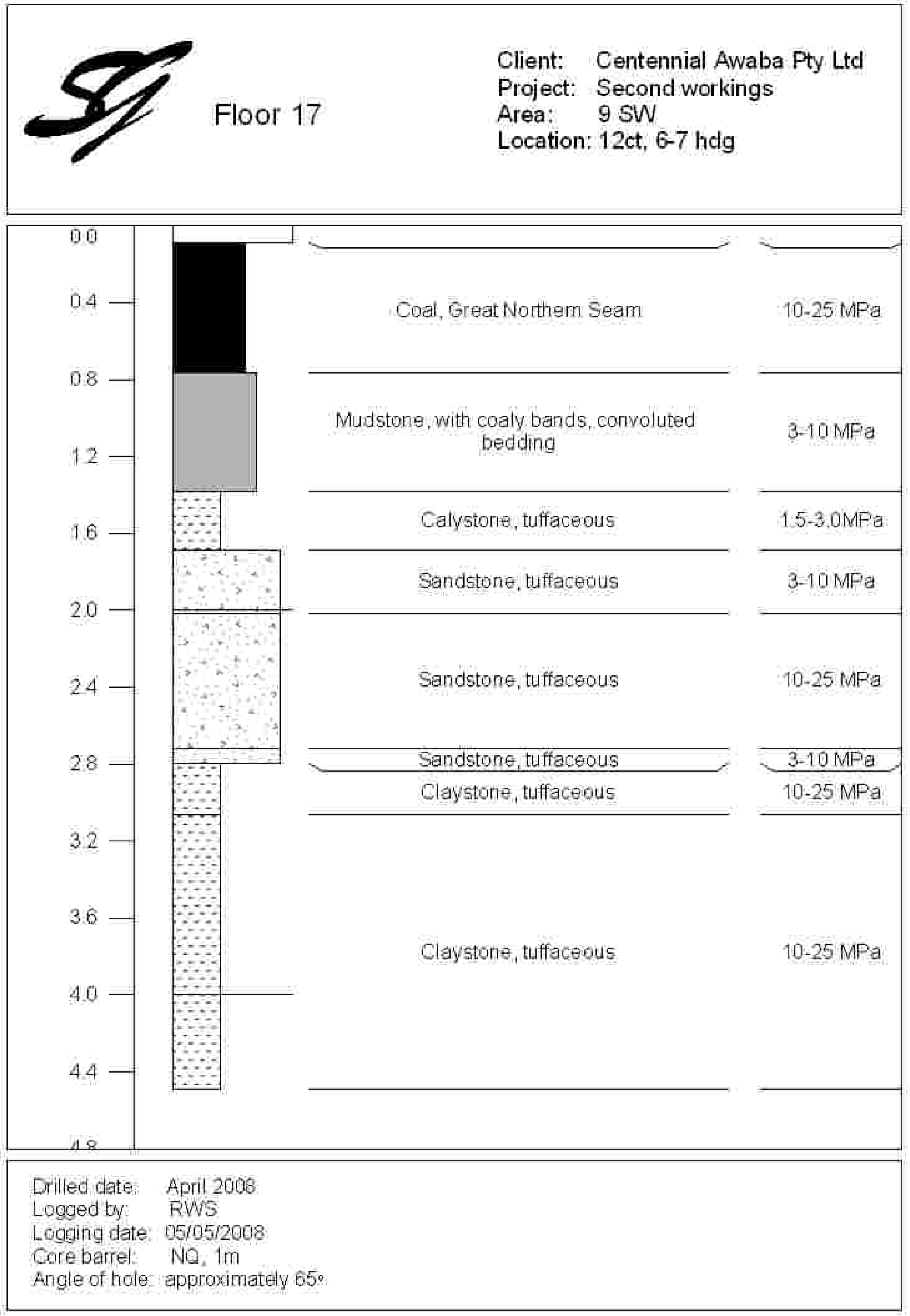

Figure 22 Logging from holes Floor 17

Table 4 Back analysed values for pillar subsidence

Parameter	Value
Thin layer UCS (MPa)	4
Thin layer thickness (m)	1
Thin layer sample modulus (MPa)	1000
Coal sample modulus (MPa)	2500
Coal Geological Strength Index	60
Roof sample modulus (MPa)	12500
Roof Geological Strength Index	95
Floor sample modulus (MPa)	5000
Floor Geological Strength Index	50
COAL MODULUS	1250
ROOF MODULUS	12000
FLOOR MODULUS	1435

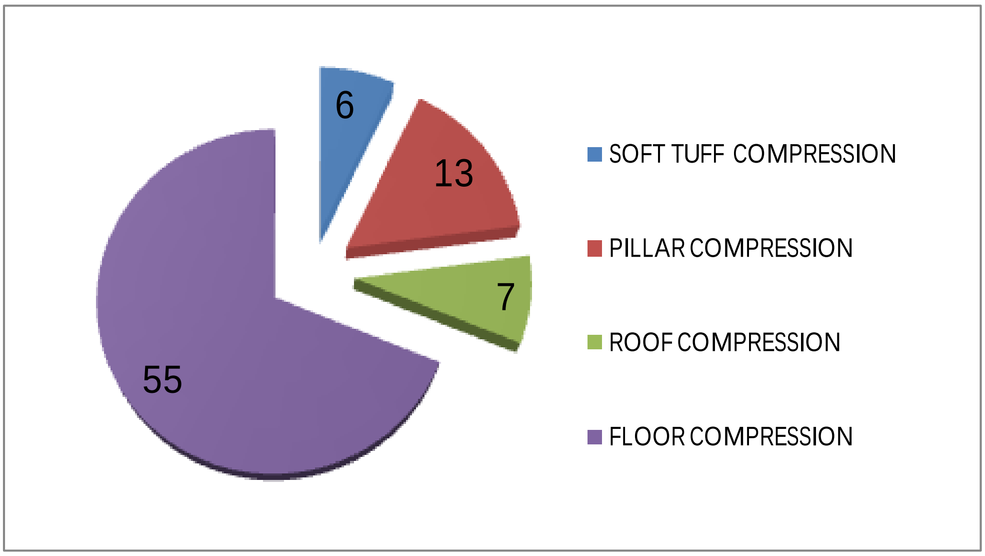

Figure 23 Components of subsidence (mm)

3.2.2 Panel sag

From Figure 19, it is possible to extract data on the sag between the pillars. These sag values are compared to the associated panel sag in Figure 24. The sag values are relatively small and it is difficult to resolve any trend from the survey noise.

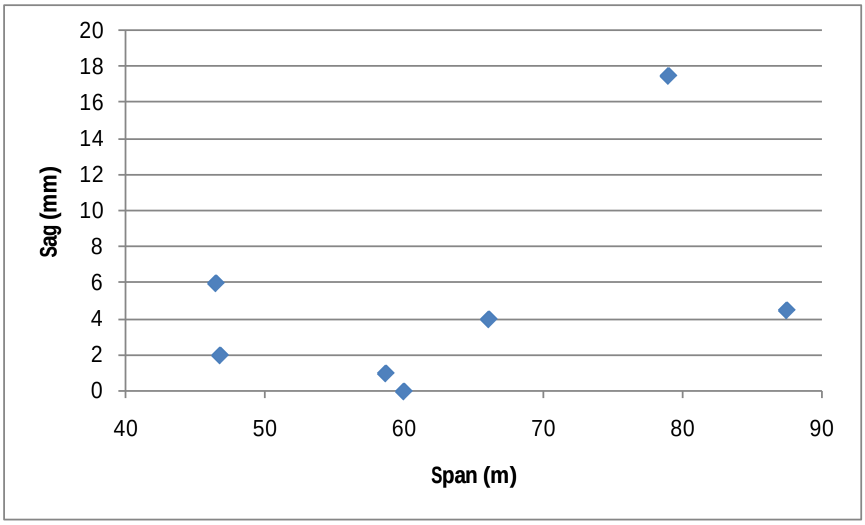

Figure 24 Sag above extraction panels

To some degree, the low sag values are indicative of the high levels of stability. Assuming rational values for the strength and deformation modulus of the Teralba Conglomerate, it is possible to use the sag values to determine the active thickness of the conglomerate (Figure 25). This analysis suggests very high values of the stability index for a beam thickness of 41m across a 90m panel. It is noted that there are not sufficient data on the performance of these rock beams to set a minimum value for the stability index.

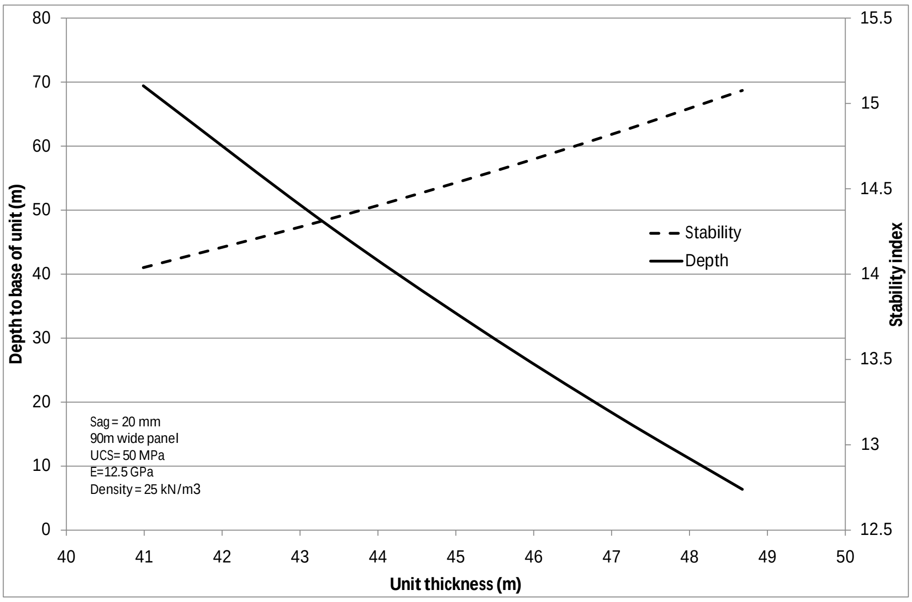

Figure 25 Geometries that give 20mm of beam sag

The analysis can be extended to assess the span required to generate failure of a 41m thick beam (Figure 26). It would appear that spans in excess of 250m would be required.

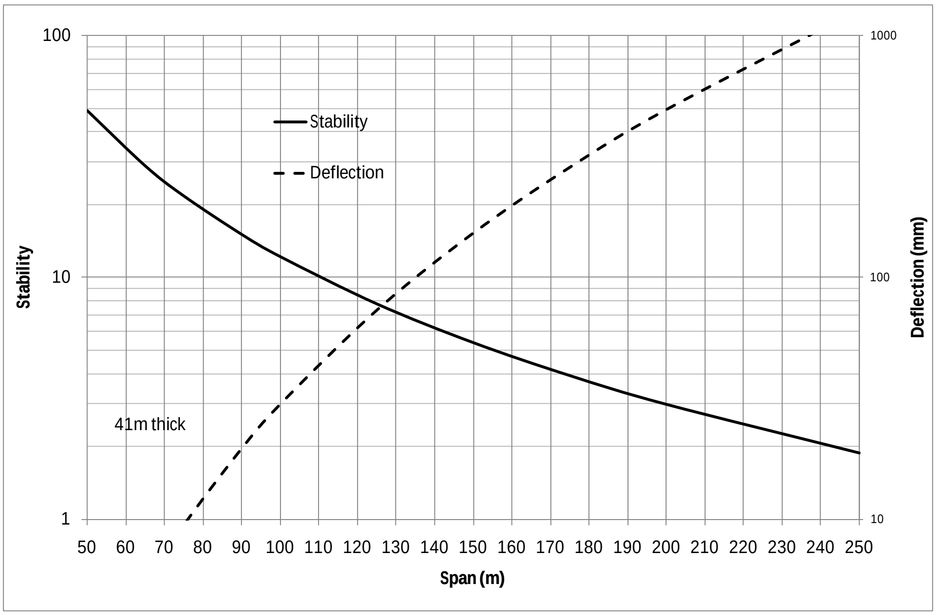

Figure 26 Stability and deflection of wide spans of a 41m thick conglomerate.

It is of value to compare the sag values in Figure 24 with the empirical Holla database for subsidence in the Newcastle coalfield. Normalised to the seam thickness the Smax/T values are 0.003 while the panel width/depth ratios have been within the range of 1.0-1.5. It can be seen that these outcomes are substantially less than in the database (Figure 27).

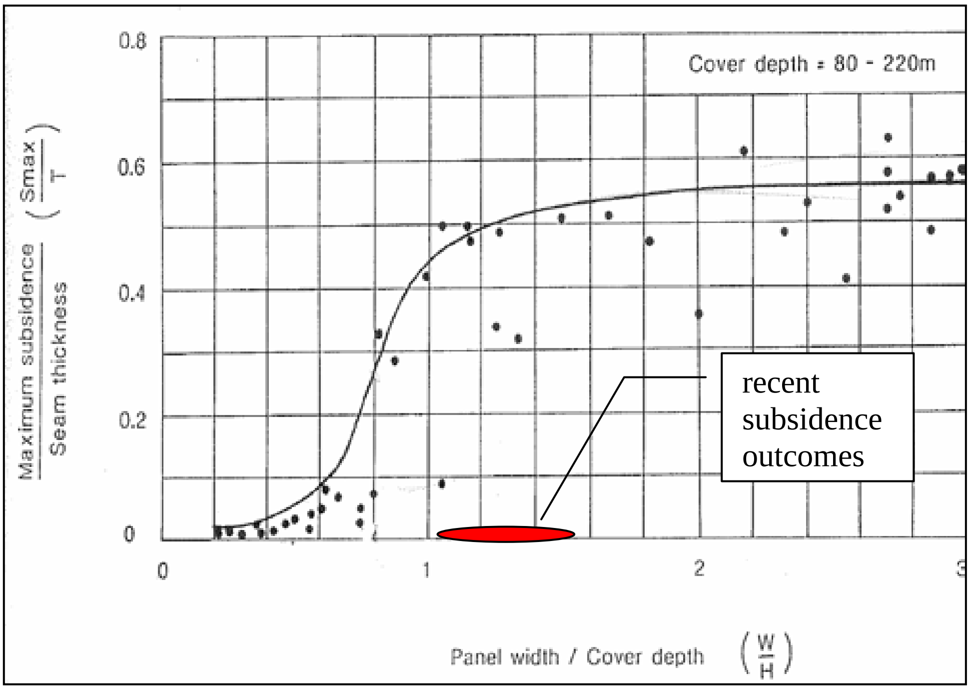

Figure 27 Recent subsidence outcomes compared to Holla Newcastle database

4 STUDY AREA 2

4.1 Layout

The layout for the extraction of Great Northern Coal in the Study Area 2 (Figure28) using the same panel and pillar concept as developed in recent years.

The standing pillars were originally formed on nominal minimum 20m centres with 5.5m wide roads. The proposal is to extract pillars in a somewhat staggered pattern so as to not extract under the haul roads and power lines on the surface. No extraction is proposed under the identified stream and water courses. The resulting voids will be in the order of 60m to 80m wide. The seam is 3.5m thick and the depth ranges between 30m and 50m.

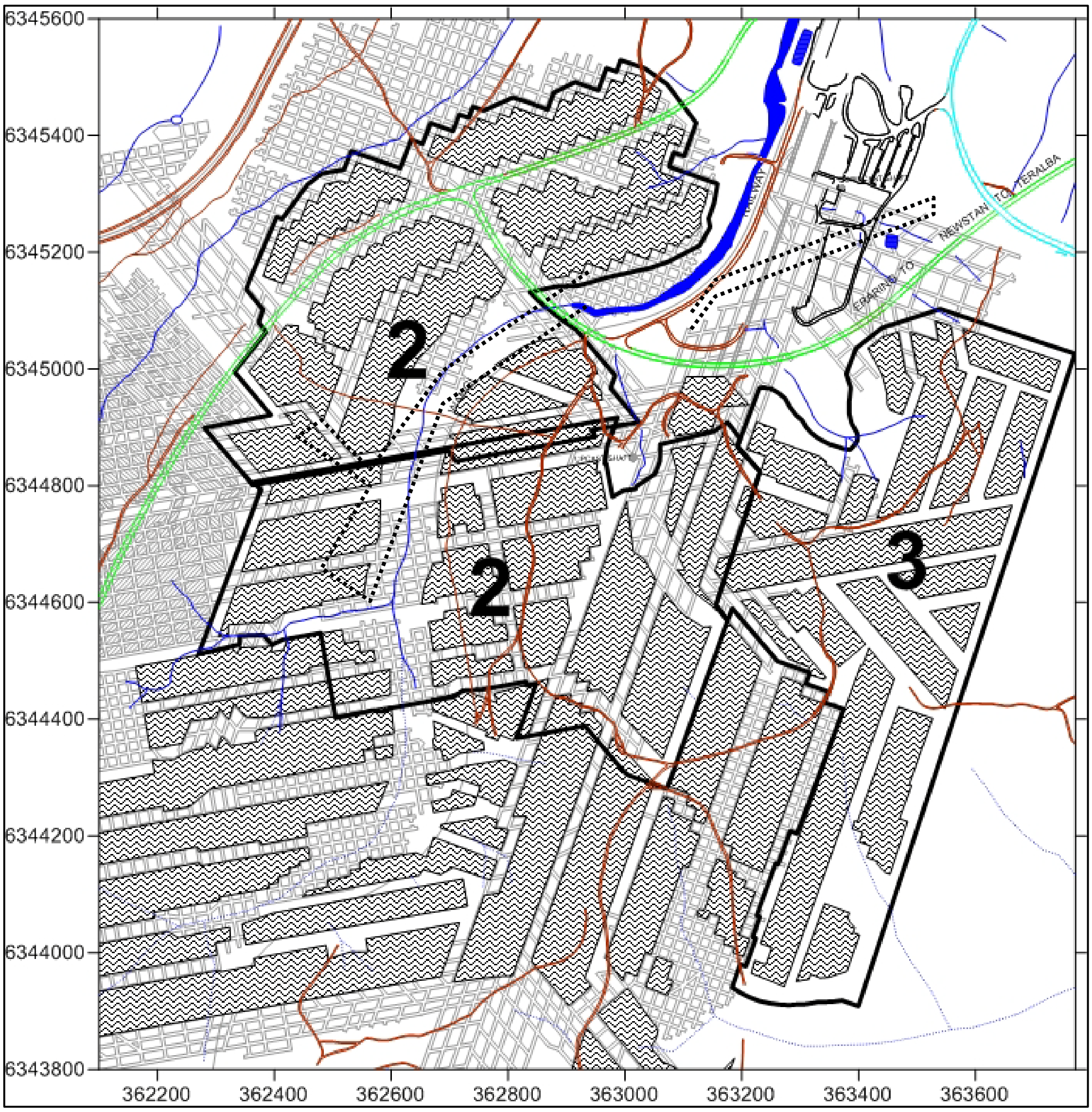

Figure 28 Proposed layout for Study Areas 2 and 3

The panel and pillar layout is based on total extraction within narrow panels such that the Teralba Conglomerate can span. It is understood that there will be a management plan that seeks to characterise the strength of the Awaba Tuff in the floor, as has been utilised in previous applications of this method. Geotechnically, the layout addresses the hazards presented by both weak floors and massive conglomerates.

The layout shown in Figure 28 includes 2 types of “pillars”:

- In-panel pillars – mostly a single row of pillars between the panels – these are required for underground safety considerations
- Barrier pillars – mostly 3 rows of pillars left under surface infrastructure so that the risk of adverse subsidence deformations is effectively zero.

The layout is not a “zero” subsidence plan. To prevent the uncontrollable collapse of the goaf the panel width is designed so that the conglomerate can span –it will still deflect. Relatively high loads are placed on the in-panel pillars and this means that the compression of the roof/pillar/floor system will exceed the 20mm subsidence threshold defined in the SMP guidelines (in fact up to 90mm has been recorded in similar layouts). In addition, the in-panel pillars have factors of safety of less than the long-term stable threshold. The barrier pillars are long term sable, and the subsidence above the central line pillars will be less than 60mm.

4.2 Subsidence Assessment

The proposed layout for Study Area 2 incorporates a hierarchy of risk management controls.

4.2.1 Elimination

Pillar extraction has been eliminated in the following areas:

1. Within a nominal 125m from the Rail boundary. This represents the barrier that was required by the Government Principal Subsidence Engineer (PSE) for the earlier application of this extraction method. It is noted that this barrier has performed adequately; in fact there has been no recorded instance of the “pillar run” or even anomalous subsidence for which the PSE has concerns at either Awaba or at the adjacent Newstan when similar pillars have been undermined by longwall extraction.
2. No extraction under the haul roads and the associated infrastructure or the identified water courses.
3. There is no extraction planned for less than 25m depth and only a very limited amount at less than 30m depth.

4.2.2 Substitution

The narrow panel and pillar layout represent “substitution” compared to the alternatives of very wide full extraction or the stripping of the pillars over a wide expanse. The layout has been adopted for a number of underground workplace safety considerations. An upshot of layout is that the subsidence is significantly lower than the alternatives.

4.2.3 Engineering controls

The layout continues with the same panel and pillars concept as used previously at the mine and the spans are no greater. At this time, it is reasonable to assume that the spans will be stable and that any sag will be less than 10mm.

In the Study Area 2 the maximum depth of cover is approximately 50m. Assuming a 14.5m wide in-pillar and two 80m wide extraction panels, the pillar stress can be calculated to be 7.9 MPa (full tributary area, plane strain). Recalling the full subsidence required extraction areas of about 550m width, full tributary area loading is considered appropriate given all the earlier extraction. For a 3.5m high pillar, the width to height ratio is 4.3, and the pillar strength can be estimated to be in the range of 11 MPa to 13 MPa based on a number of strength equations using minimum width. The factor of safety for pillar failure is between 1.4 and 1.7. This is assessed as adequate for the mining system being used in this seam.

The geographic proximity to the other extraction areas would suggest that the roof and floor materials should be similar. It is understood that you will have a management plan to confirm the floor strengths.

4.2.4 Administrative controls

The key administrative control will come from the workplace safety requirement to test the floor to identify the presence of low strength floor units. This will have advantages to the subsidence concerns as extraction will not be recommended in such areas.

Should the plug subsidence develop, the onset will be rapid and hence not amenable to control using the Observational Method.

A survey line along one of the haul roads would produce valuable information for the calibration of the prediction method – this line can be a simple pre-mining and post-mining survey of vertical movements.

4.2.5 Subsidence deformations

The following represents an appropriate estimate of the subsidence deformation on which the hazards and risks can be assessed.

4.2.5.1 During mining

The predicted maximum vertical subsidence is of the order of 200mm, and extending out to a 20mm level within a 45^{o} angle of draw.

The vertical subsidence will develop over a width of approximately 200m (2 panels and 1 pillar row), so the associated tilts and strains will be very low – for risk assessment purposes, values of 1 mm/m should be used for these vertical subsidence predictions.

A visualisation of the likely subsidence (Figure 29) has been conducted based on a set of arbitrary parameters and calibration to the maximum subsidence recorded to date above the previous area. The visualisation cannot incorporate the upsidence that has been measured. In addition, the visualised subsidence at the panel edges is greater than that measured. The maximum subsidence along the haul roads is likely to be in the order of 50mm-100mm with maximum strains and tilts less than 0.5mm/m.

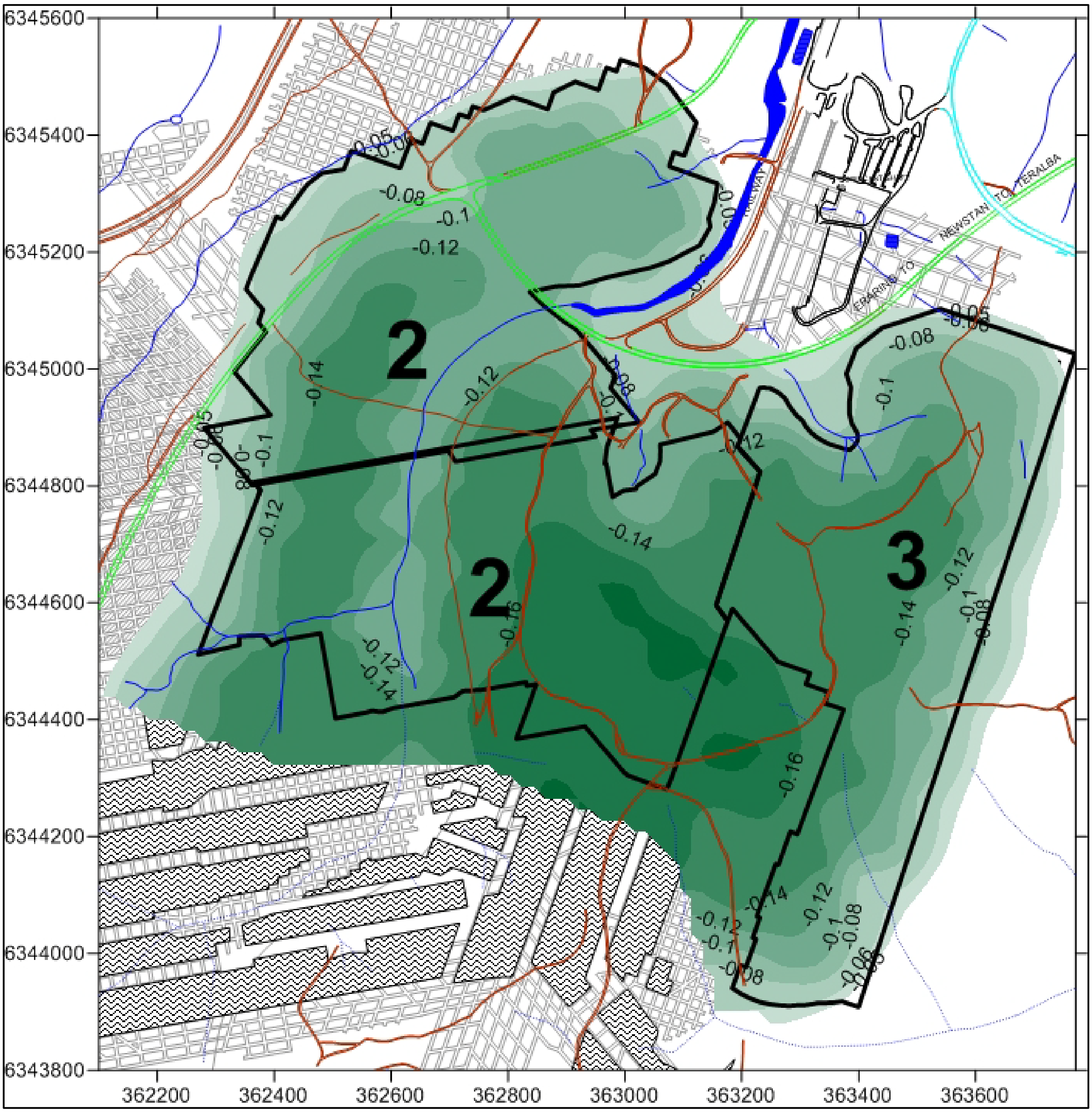

Figure 29 Visualisation of subsidence above Study Area 2 and its relationship to Study Area 3.

4.2.5.2 Subsidence over the longer term

The "unstable" behaviour of the floor is related to the immediate loading of the Awaba Tuff claystone and the associated rises in pore pressures (undrained state in soil mechanics). It follows that over time the stability of the pillars foundations will increase as the floor under the pillars consolidates. It is noted that the floor heave/subsidence events at Awaba happened during active mining and not sometime later. There would be further increases in stability if the mine floods as this reduces pillar loads by introducing buoyancy effects. A corollary of this would be a slight reduction in subsidence.

As is the case for other areas of Awaba, shallow mining introduces the risk of plug collapses above the voids. This behaviour should be restricted to periods of high rainfall and only in drainage channels.

4.2.5.3 Extreme subsidence outcome

There are a number of possibilities whereby the subsidence levels will be in excess of predictions.

- Lack of knowledge of the floor leading ultimately to the collapse of the pillars. This hazard could lead to increased subsidence and also loss of coal reserves and the onset of poor goaf edge conditions underground. We recommend progressive coring or other testing of the floor in extraction areas and adjacent to rail prior to second workings.
- Plug collapse. This can lead to formation of large cracks and steps at the surface and inflow of water into the mine. We recommend regular inspections of any water courses especially after heavy rainfall.
- In common with all geotechnical ventures, there is uncertainty about the selection of parameters for the design calculations. We recommend subsidence cross line(s) to check pillar compression and sag predictions.

The worst-case subsidence outcome would be if the conglomerate fails – this will result in a type of plug subsidence, with the formation of vertical faces of say 2.5m height at the edge of the panels (Figure 30). Because of the serious threat such a collapse would pose to the underground workforce, the mine design process is focussed on seeking to eliminate this hazard through a series of engineering controls. There are no administrative controls that can be applied to this event

It is stressed that this is not offered as a prediction as the mine layout has been specifically designed to avoid such an outcome. In the context of a subsidence risk assessment, it is recommended that this plug subsidence should be used and, if the impacts are manageable, it will follow that the impacts at the predicted levels will also be acceptable. It is noted that if plug subsidence does develop, there will be no cracking within the barrier pillars and the subsidence along the haul roads will decrease as a consequence of the spanning loads being removed.

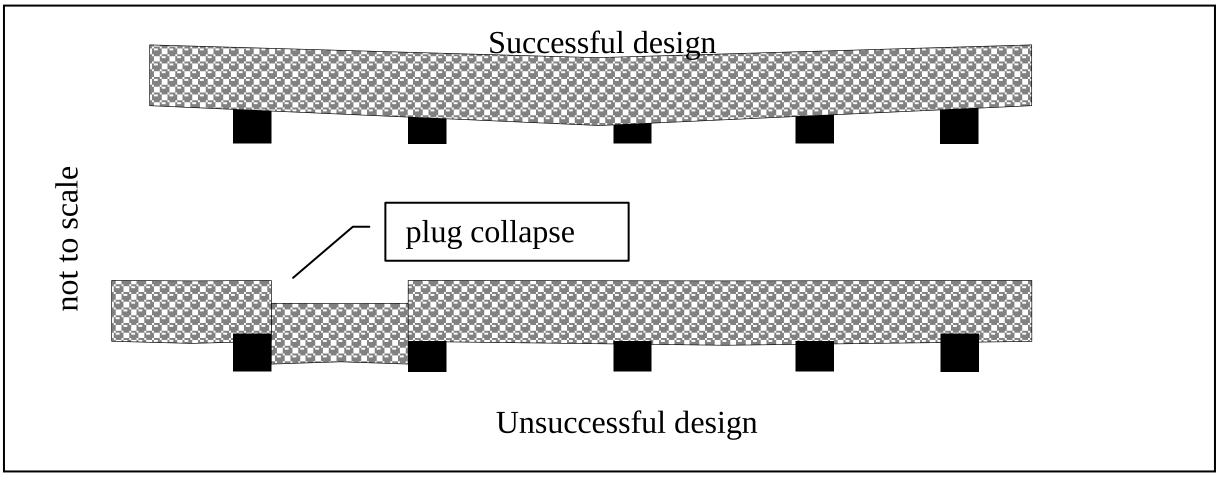

Figure 30 Cartoon defining a plug collapse in an unsuccessful design

5 STUDY AREA 3

5.1 Layout

Area 3 is an area of mainly undeveloped coal that lies to the east of the South Headings Mains (Figure 28). It differs from recent mining at Awaba as the area needs to be developed with first workings prior to extraction. It is bounded to the east by a thinning of the Great Northern Seam. The depth of cover ranges from less than 20m to approximately 80m. The seam thickness is in the range of 3.0m and 2.0m.

The mining proposal is to first develop the area with bord and pillar mining at depths greater than 20m, and then to extract selected pillars to form a panel and pillar layout similar to that adopted recently at the mine. Following earlier discussions with you, the width of the extraction panels will vary between 46m to 85m. There is to be no extraction of pillars at depths less than 25m.

The geotechnical design approach identifies the thickness of units within the Teralba Conglomerate forming the immediate roof of the Great Northern Seam. The thickness of the conglomerate, along with the relative shallow depth of cover, can allow the overburden to span across properly designed extraction panels. The approach also recognises the hazard of the possible presence of low strength Awaba Tuff in the floor of the Great Northern Seam. A management plan requires the floor conditions to be determined with coring and testing followed by a geotechnical assessment – if weak floor is present the initial response is to not conduct pillar extraction.

5.2 Subsidence Assessment

The key driver in the development of the layout is to maintain high levels of safety underground. This requires that the overburden does not collapse. The proposed layout for Study Area 3 incorporates a hierarchy of risk management controls.

5.2.1 Elimination

Pillar extraction has been eliminated for less than 25m depth and only a very limited amount at less than 30m depth.

5.2.2 Substitution

The narrow panel and pillar layout represent “substitution” compared to the alternatives of very wide full extraction or the stripping of the pillars over a wide expanse. The layout has been adopted for a number of underground workplace safety considerations. An upshot of layout is that the subsidence is significantly lower than the alternatives.

5.2.3 Engineering controls

Panel widths are specified with a nominal factor of safety greater than 2.0 against compressive failure of the spanning Teralba Conglomerate and the pillars have factors of safety against failure of greater than 1.6.

The proposed layout minimizes the risk of rapid collapse of the conglomerate by keeping spans to less than 85m. There is a high level of confidence in this part of the design because the Teralba Conglomerate is known to be a relatively consistent unit across the mining area.

The stability of the coal component of the pillar/floor system, as measured by the pillar factor of safety using the University of NSW method and assuming complete spanning of the conglomerate, is greater than 1.55 for the geometries examined. This would indicate that the pillars themselves will not fail.

The stability of the pillar foundations will depend on the presence or absence of low strength horizons – the distribution of which is not known at this time. Potentially problematic floor can be readily identified from drilling. The lack of floor heave in old workings would also be a very good sign as it suggests that no material with strength less than about 20 MPa.

5.2.4 Administative controls

There are a number of possibilities whereby the subsidence levels will be in excess of predictions.

- Lack of knowledge of the floor leading ultimately to the collapse of the pillars. This hazard could lead to increased subsidence and also loss of coal reserves and the onset of poor goaf edge conditions underground. We recommend progressive coring or other testing of the floor in extraction areas and adjacent to rail prior to second workings.
- Plug collapse. This can lead to formation of large cracks and steps at the surface and inflow of water into the mine. We recommend regular inspections of any water courses especially after heavy rainfall.

- In common with all geotechnical ventures, there is uncertainty about the selection of parameters for the design calculations. We recommend subsidence cross line(s) to check pillar compression and sag predictions.

5.2.5 Subsidence deformations

The following represents an appropriate estimate of the subsidence deformation on which the hazards and risks can be assessed.

5.2.5.1 During mining

The vertical subsidence is a function of the sag of the conglomerate (in the order of 10mm to 100mm for the panel widths utilised to date) and the compression of the pillar system (in the order of 50mm to 100mm for the panel widths utilised to date.). The 20mm subsidence limit is predicted to be within 50m of the end of the extraction panels.

A visualisation of the likely subsidence (Figure 31) has been conducted based on a set of arbitrary parameters and calibration to the maximum subsidence recorded to date above the previous area. The visualisation cannot incorporate the upsidence that has been measured. In addition, the visualised subsidence at the panel edges is greater than that measured.

5.2.5.2 Subsidence over the longer term

The “unstable” behaviour of the floor is related to the immediate loading of the Awaba Tuff claystone and the associated rises in pore pressures (undrained state in soil mechanics). It follows that over time the stability of the pillars foundations will increase as the floor under the pillars consolidates. It is noted that the floor heave/subsidence events at Awaba happened during active mining and not sometime later. There would be further increases in stability if the mine floods as this reduces pillar loads by introducing buoyancy effects. A corollary of this would be a slight reduction in subsidence.

As is the case for other areas of Awaba, shallow mining introduces the risk of plug collapses above the voids. This behaviour should be restricted to periods of high rainfall and only in drainage channels.

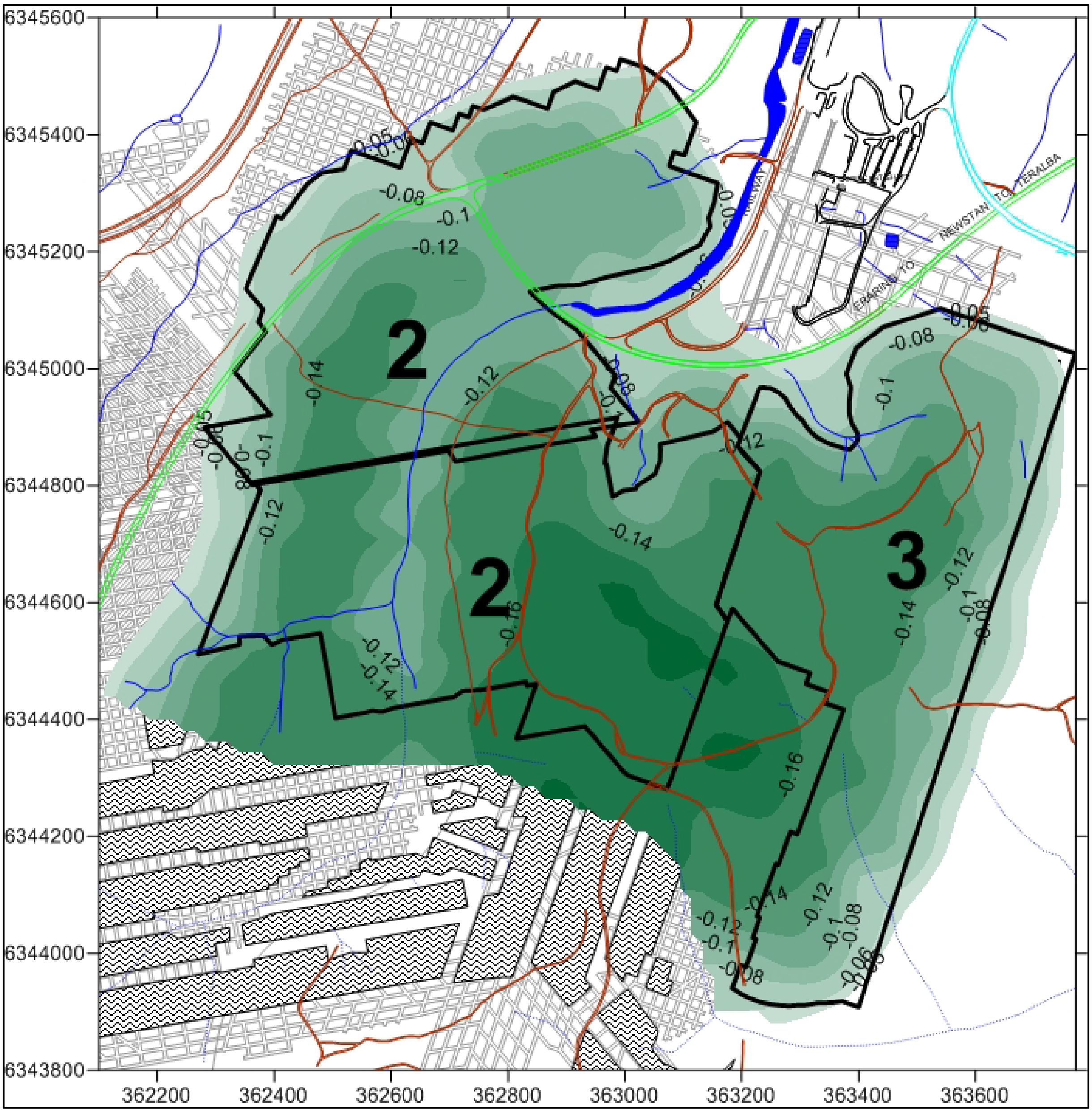

Figure 31 Visualisation of possible subsidence above Study Area 3 and its relationship to Study Area 2

5.2.5.3 Extreme subsidence outcome

There are a number of possibilities whereby the subsidence levels will be in excess of predictions.

- Lack of knowledge of the floor leading ultimately to the collapse of the pillars. This hazard could lead to increased subsidence and also loss of coal reserves and the onset of poor goaf edge conditions underground. We recommend progressive coring or other testing of the floor in extraction areas and adjacent to rail prior to second workings.

- Plug collapse. This can lead to formation of large cracks and steps at the surface and inflow of water into the mine. We recommend regular inspections of any water courses especially after heavy rainfall.
- In common with all geotechnical ventures, there is uncertainty about the selection of parameters for the design calculations. We recommend subsidence cross line(s) to check pillar compression and sag predictions.

The worst-case subsidence outcome would be if the conglomerate fails – this will result in a type of plug subsidence, with the formation of vertical faces of say 2.5m height at the edge of the panels (Figure 32). Because of the serious threat such a collapse would pose to the underground workforce, the mine design process is focussed on seeking to eliminate this hazard through a series of engineering controls. There are no administrative controls that can be applied to this event

It is stressed that this is not offered as a prediction as the mine layout has been specifically designed to avoid such an outcome. In the context of a subsidence risk assessment, it is recommended that this plug subsidence should be used and, if the impacts are manageable, it will follow that the impacts at the predicted levels will also be acceptable. It is noted that if plug subsidence does develop, there will be no cracking within the barrier pillars and the subsidence along the haul roads will decrease as a consequence of the spanning loads being removed.

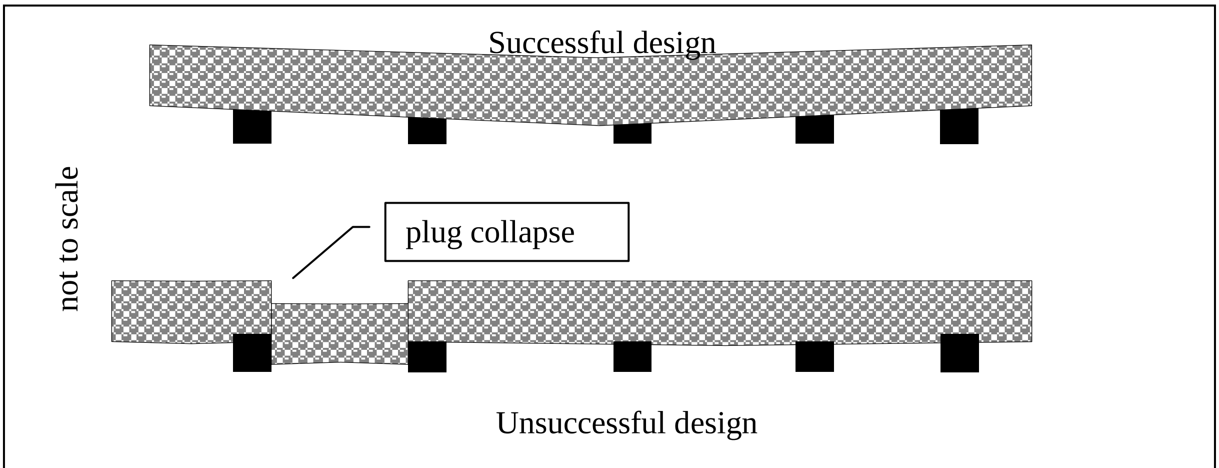

Figure 32 Cartoon defining a plug collapse in an unsuccessful design

6 CONCLUSION

The mine layout proposed for Awaba is based on the application of well-established rock mechanics principles that are applied conservatively. Pillar extraction is conducted only after a number of engineering and administrative controls are applied. This mans that the final location of extraction voids is an outcome of a comprehensive management plan that not only provides a safe ad productive workplace but also results in acceptable subsidence outcomes.

The engineering analyses are applied in parallel with back analysis of previous behaviours at the site and ongoing monitoring.

Risk management is an integral part of the mine planning and operational process. The same approach is applied to assessing a range of subsidence outcomes to provide a number of hazards for input to subsidence risk assessment.

7 GLOSSARY OF TERMS

Angle of Draw (AoD)	The angle to the vertical from the sides or ends of an extracted longwall block and the line drawn from the limits of extraction at seam level to the 20 mm subsidence contour at the surface. The 20 mm subsidence contour is an industry defined limit and represents the practical measurable limit of subsidence.
Bord	
Compressive Strain	A decrease in the distance between two points on the surface. Compressive strains may cause shear cracking or steps at the surface if > 3 mm/m and are usually associated with concave curvatures near the middle of the panels.
Cover Depth	The depth from the surface to the mine workings.
Factor of Safety (FoS)	The ratio between the strength of a structure divided by the load applied to the structure. Commonly used to design underground coal mine pillars.
First Workings	The tunnels or roadways driven by a continuous mining machine to provide access to the longwall panels in a mine (i.e. main headings and gate roads). The roof of the roadways is generally supported by high strength steel rock bolts encapsulated in chemical resin. Subsidence above first workings pillars and roadways is generally < 20 mm.
Mining Height	Refers to the height or thickness of coal extracted.
Outbye	An underground coal mining term used to describe the relative position of some feature or location in the mine that is closer to the mine entry point than the reference location.
Panel Width	The width of an extracted area between chain pillars.
Pillar	
Strain	The change in horizontal distance between two points at the surface after mining, divided by the pre-mining distance between the points. i.e. Strain = ((post-mining distance between A and B) - (pre-mining distance between A and B))/(pre-mining distance between A and B) and is usually expressed in mm/m.
Study Area	The area which may be influenced by mine subsidence
Subsidence	The difference between the pre-mining surface level and the post-mining surface level at a point, after it settles above an underground mining area.

Tilt	The rate of change of subsidence between two points (A and B), measured at set distances apart (usually 10 m). Tilt is plotted at the mid-point between the points and is a measure of the amount of differential subsidence. i.e. Tilt = (subsidence at point A - subsidence at point B)/(distance between the points) and is usually expressed in mm/m.
Tensile Strain	An increase in the distance between two points on the surface.