Report of the Independent Review Panel

Established to Review and Report on

Accuracy and Reliability of

Mine Subsidence Impacts on Sensitive Features

Across the Airly Mine Extension Project

Application Area

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Summary

Airly Mine is an underground coal mine located 5 km northeast of the village of Capertee and approximately 171 km northwest of Sydney on the northern fringe of the Western Coalfields. Centennial Coal Company Limited (CCCL), the owner of the mine, is proposing to extend the mine using a variety of mining systems designed to limit subsidence impacts to overlying cliff formations associated with Mount Airly and Genowlan Mountain in the Mugii Murrum-ban State Conservation Area. Given the public interest in the proposed development and the sensitivity of the surface to potential mining impacts, CCCL and the Department of Planning and Environment (DPE) commissioned an Independent Review Panel (IRP) to review and report on the accuracy and reliability of mine subsidence impacts presented in the Environmental Impact Statement (EIS) and associated documentation for the Airly Coal Mine Extension Project (AMEP) as per the Terms of Reference reproduced in full in Appendix 1. This report presents the results of the review of the IRP prepared jointly by Professor Ismet Canbulat (University of New South Wales), Mr Don Kay (Mine Subsidence Engineering Consultants), and Dr Ken Mills (Strata Control Technology).

The IRP understands the reference in the Terms of Reference to "sensitive surface features" means cliff lines, pagodas, and other similar sandstone formations. Other surface features such as those that may be sensitive to the impacts of subsidence on groundwater systems for instance have not been considered in this review.

The IRP is satisfied that the proposed methods of extraction have the potential to avoid significant impacts and minimise residual effects and impacts from subsidence on cliffs, steep slopes, and pagodas. However, high confidence subsidence monitoring over initial panel and pillar mining areas (i.e. mini wall or partial extraction mining areas) is required to confirm the levels of ground movement are as predicted and the protection zones proposed are appropriate to provide a high level of protection to cliff formations. Initial monitoring should be conducted in areas remote from sensitive features and prior to any mining in these sensitive areas. This initial monitoring is important to confirm that the panel and pillar mining system does indeed limit subsidence to less than 125 mm at overburden depths of 250-300 m and to provide confidence in one or more remote subsidence monitoring techniques that can be used on an ongoing basis to measure subsidence in the rugged terrain above Airly Mine.

The IRP is satisfied that CCCL can avoid the risk of the most significant impacts to cliff lines by using combinations of the various mining systems proposed all of which are relatively conservative by comparison with industry standards and all of which are expected to maintain surface movements at low levels.

The proposal to use protection zones either side of the cliff lines to define the cliff line zones is expected to be effective in protecting cliff formations from rock falls at close to background levels. It should be recognised that cliff formations do experience rock falls naturally at a relatively rapid rate which is why they exist in the landform so full protection is not possible. A precautionary approach is recommended because the database of experience of appropriate setbacks from mining to protect cliff formations is relatively limited and Trigger, Action, Response Plans are unlikely to be effective to prevent rock falls.

A 30 m wide protection zone is expected to be sufficient to protect many of the cliff formations provided the subsidence above panel and pillar mining areas is less than 125 mm, the angles of draw are consistent with expectation, and the protection zones are determined on the basis of including any significant cliff formations that are peripheral to the main vertical cliff face. It is recognised that in practice mining geometries will lead to the protection zone being generally greater than 30 m wide because of the irregular nature of the cliff lines. There will however inevitably be a number of "pinch points". The IRP recommend that at the Extraction Plan (EP) stage, an assessment of the likely stability of cliff formations at these pinch points is included in the protection zone sizing strategy on a case by case basis to recognise the particular sensitivities of individual cliff formations, particularly

cliff height and cliff geometry, to mining induced ground movements and to manage the range of other influences that can affect cliff line stability other than just vertical subsidence.

An assessment of the long term pillar stability conducted by the IRP confirms that the proposed pillar geometries in the cliff protection zones and pillar splitting areas have high probabilities of remaining long-term stable under tributary area loading so as to maintain low levels of surface subsidence. A program of further work is recommended at EP stage to confirm the loading distributions in the vicinity of steeply dipping terrain below high cliffs where pillar splitting-and-quartering is proposed does not lead to loading conditions significantly higher than the tributary area loading used in the various assessments. There is recognised to be flexibility within the mining systems proposed to accommodate any variation in design that may be necessary to ensure long term stability.

There are several areas where internal cliff lines are reliant for their protection on the low levels of subsidence predicted in the EIS for the panel and pillar mining geometries proposed. The potential for rock falls is acknowledged in the EIS and appears to be acceptable to DPE. Issues of public safety and how they will be managed in the vicinity of these internal cliffs into the future does not appear to have been specifically addressed and would need to be addressed at EP stage.

Mining in close vicinity of the New Hartley Shale Mine is expected to increase the potential for perceptible impacts including rock falls with implications for public safety and visual amenity. This potential is recognised in the EIS. The IRP recommends that if further surface impacts in the vicinity of the New Hartley Shale Mine are to be avoided, proposed panel and pillar mining should not approach to closer than half depth plus 50 m from the edge of the existing New Hartley Shale Mine workings. If surface impacts and rock falls are deemed to be tolerable in some areas but not others, the IRP recommend not mining proposed panel and pillar mining within half depth plus 50 m of those areas that are required to be protected.

Adaptive management strategies based on the results of monitoring have potential to control some of the impacts of the proposed mining but the limitations of adaptive management strategies should be recognised. Adaptive management is not effective if the changes occur too quickly for an effective response (i.e. rock falls), occur too slowly for an effective response (i.e. after mining is complete), or the critical characteristics are not able to be measured effectively (i.e. steep terrain prevents access).

The adaptive management process proposed to ensure appropriate protection for sensitive features at Airly Mine requires accurate monitoring and regular reviews of the monitoring results against the predicted effects in the early panels remote from sensitive features. The chosen mining methods being proposed for the AMEP are flexible and if monitoring in areas remote from sensitive features indicates adjustments are necessary to provide protection, the mine has the capacity to modify the mine layout and adaptively manage the impacts, within the limitations of adaptive management strategies.

The IRP recommend conventional survey monitoring with high confidence far field GPS survey control over the initial three or four panels mined using the panel and pillar mining system in areas remote from sensitive features and at the greatest overburden depth that is practical, ideally greater than 250 m.

A range of other subsidence monitoring techniques such as dInSAR, LiDAR, and unmanned aerial vehicle based photogrammetry are available and likely to be suitable at various levels of accuracy. The IRP recommend CCCL consider one or more of these techniques to duplicate the conventional subsidence monitoring observed over the initial panels. Recognising that the upper limit of subsidence is 125 mm, the maximum subsidence observed needs to be less than 125 mm by at least the effective tolerance of the survey system used so as to give confidence that subsidence is indeed less than 125 mm. The development of a high confidence, high accuracy, low tolerance survey technique suitable for remote monitoring in rugged terrain is considered likely to be a critical component of this project from a coal recovery perspective in order to ensure confidence in a geometry that can maintain subsidence to less than 125 mm.

Underground monitoring of pillar loads is not considered suitable as a monitoring technique to confirm low levels of subsidence and protection of cliff formations, but would be useful to develop an understanding of the loading conditions on pillars in the vicinity of high cliffs.

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1. Introduction

Airly Mine is an underground coal mine located 5 km northeast of the village of Capertee and approximately 171 km northwest of Sydney on the northern fringe of the Western Coalfields. Centennial Coal Company Limited (CCCL), the owner of the mine, is proposing to extend the mine using a variety of mining systems designed to limit subsidence impacts to overlying cliff formations associated with Mount Airly and Genowlan Mountain in the Mugii Murrum-ban State Conservation Area. Given the public interest in the proposed development and the sensitivity of the surface to potential mining impacts, CCCL and the Department of Planning and Environment (DPE) commissioned an Independent Review Panel (IRP) to review and report on the accuracy and reliability of mine subsidence impacts presented in the Environmental Impact Statement (EIS) and associated documentation for the Airly Coal Mine Extension Project (AMEP) as per the Terms of Reference reproduced in full in Appendix 1. This report presents the results of the review of the IRP prepared jointly by Professor Ismet Canbulat (University of New South Wales), Mr Don Kay (Mine Subsidence Engineering Consultants), and Dr Ken Mills (Strata Control Technology).

A combined site visit was undertaken on 6 April 2016 to inspect the surface areas over the mine. The IRP was provided with background information on the project during this visit. A subsequent underground visit was undertaken by Professor Canbulat on 21st April 2016 on behalf of the panel to inspect the condition of the pillars and roadways in existing sections of the mine.

Figure 1 reproduced from Figure 8.2 in the EIS presents an overview of the location of sensitive features and mining zones within the AEMP. Five zones are identified on the basis of the five different mining system proposed to be used to protect surface features. The details of each mining system and the magnitude of the subsidence are explained in the EIS and subsequent documents. These zones are:

1. Cliff line zone and zone of first workings (first workings).

2. Panel and pillar mining zone (mini wall).

3. Partial pillar extraction zone (pillar lifting – subsequently replaced with pillar splitting-and-quartering).

4. Shallow zone (first workings).

5. New Hartley Shale Mine potential interaction zone.

Although pillar lifting was proposed in EIS, the IRP understands that Airly Mine Management decided not to use this mining method and it has been replaced instead with a pillar splitting-and-quartering system that leaves larger, more stable pillars and does not require specialist mining equipment.

The Terms of Reference request advice and recommendations on:

- the accuracy and reliability of the predicted subsidence impacts on sensitive surface features across the AEMP area, particularly cliff lines

- the adequacy of the management regime in the proposed conditions of consent, including the subsidence impact performance measures, management plans and monitoring requirements, in the context of providing appropriate protection to sensitive surface feature.

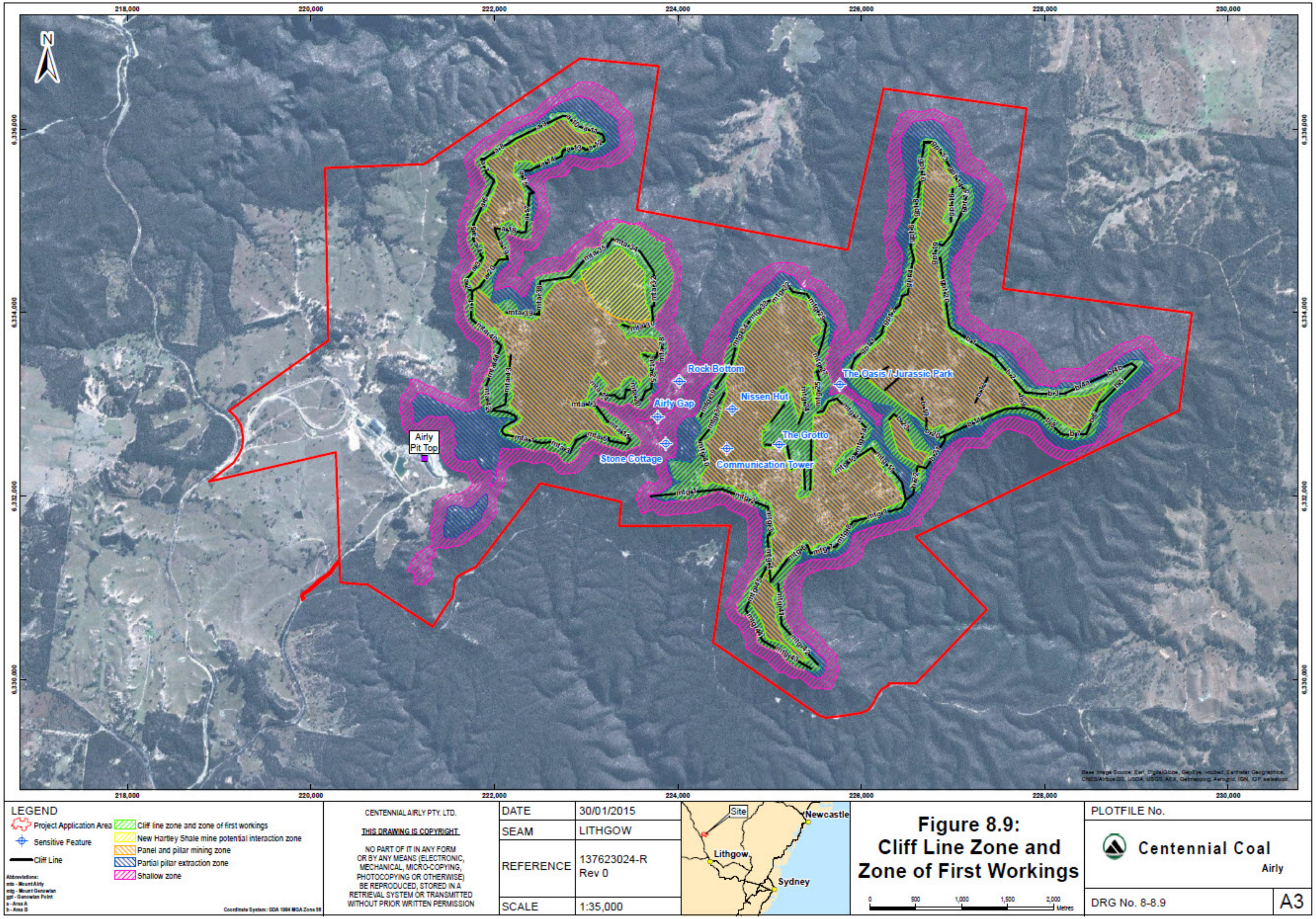


Figure 1: Site plan showing sensitive features and mining zones. (Reproduced from 8.9 in RTS)

The sensitive surface features within the AMEP area considered in this report include:

- Significant cliff formations that surround the Mount Airly and Genowlan Mountain mesas and are typically higher than 20 m (10-140 m) and visible from the surrounding valleys,
- Lesser cliff formations and pagodas that are typically less than 20 m high and are typically located within the central parts of the mesas and back from the edges of larger cliffs.

Surface features such as roads, towers, buildings, heritage sites are not considered sensitive to impacts at the subsidence levels expected and are not considered further in this review except in the context of potential impacts from rocks falls. Groundwater related systems that may be affected by mining subsidence have not been considered in this report. Other surface features such as a flora and fauna are not reviewed because they are not within the areas of expertise of the IRP.

The report is structured to broadly follow the structure of these Terms of Reference. Section 2 provides some context in relation to the processes that influence cliff stability as background to considerations of accuracy and reliability of protection measures. Sections 3 to 7 focus on the accuracy and reliability of the subsidence impacts in each of the different mining zones. Section 8 discusses the adequacy of the management regimes, including performance measures, underground monitoring, adaptive management strategies, and recommendations for ongoing monitoring. Section 9 presents a summary of conclusions and recommendations.

The full Terms of Reference provided to the IRP by CCCL are presented in Appendix 1 together with a discussion of concerns raised by Dr Gang Li following his review of the EIS. The results of a mine inspection undertaken by Professor Cambulat are presented in Appendix 2. Detail of the approach used by the IRP to assess long term pillar stability is presented in Appendix 3. Various approaches that can be used to estimate the subsidence, particularly subsidence above the panel and pillar panels, are presented in Appendix 4. Appendix 4 includes a review by Don Kay of the subsidence predictions made using the Incremental Profile Method. Background to the project and various stages in the development of the project are presented in Appendix 5 mainly sourced from material that was provided to the IRP. Appendix 6 presents a review of submissions and response to submissions. Appendix 7 provides a list of references and a bibliography of information that the IRP used as a basis for this review.

The IRP have assumed that the reader is familiar with the project and the full detail of the project is not reproduced in this report unless it is relevant to the context of the review. Detail of the project is presented in the EIS and associated documentation and the interested reader is referred to those documents on the DPE website. Some background is also included in Appendix 5.

2. Context to Assess Accuracy and Reliability of Predictions

The mine design proposed in the EIS has been developed with the aim of reducing subsidence to low levels of less than 125 mm of subsidence with similarly low levels of associated strain and tilt. Most subsidence experience around cliff formations is based on extractive mining where surface subsidence is typically in the range 1-1.8 m. Experience of impacts at low levels of subsidence is much more limited and Airly Mine is in the position where the mine needs to develop this database for the local conditions at the mine and confirm that the mining systems proposed do actually achieve the expected outcomes.

Experience at Clarence Colliery at low levels of ground movement (less than 100 mm and generally less than 57 mm) has been used in the EIS to support the expectation that rock falls and other perceptible impacts around cliffs are not significantly increased above natural background levels. The mine designs proposed in the EIS appear generally reasonable and based on the IRP's experience appear likely to give low levels of impact to cliff formations provided that the ground movements can be controlled to be as or less than predicted and demonstrated to be so within the tolerance of the subsidence monitoring systems available to use.

The potential for the subsidence to be greater than expected is discussed in more detail in the following sections for each of the various mining systems proposed. However, there are several aspects to the behaviour of cliff formations that are worth clarifying as context before considering how cliff formations might be protected from the impacts of mining subsidence.

2.1 Natural Rate of Regression

Cliff formations are naturally in a state of regression and rock falls occur naturally from time to time, typically after heavy rainfall events. The rate of regression is not necessarily uniform across regions but as an example, a study conducted at the University of Wollongong indicates that the Illawarra Escarpment near Wollongong is retreating at an average rate of about 0.017 m per year (Flentje, 2015). At this rate, a “significant” rock fall that is, for example, 1 m from front to back and 100 m wide would be expected somewhere along the approximately 40 km of high cliff faces in the AMEP about once every 7 years.

Aerial photos and related documents provided by CCCL indicate six separate rock falls (all unrelated to mining activity and not counting expansion of previous falls) have occurred in the Mount Airly / Genowlan Mountain area over thirty years. This experience is broadly consistent with the rate measured by Flentje (2015) for the Illawarra Escarpment. Although it is recognised that there are many ways to manipulate this data, depending on the rock fall size and the rates of retreat may not necessarily be the same across different regions, there is nevertheless a natural underlying rate of cliff falls that is unrelated to mining and cannot be eliminated by providing protection measures.

Natural rock falls are generally observed to occur after heavy rain. Open joints in the immediate vicinity of the free surface of cliffs, frequently assisted over time by tree root jacking, become pressurised by the build-up of pore pressures as surface run-off enters the joints. This rapid build-up of pore pressure during high rainfall events has a destabilising effect on the rock structure of the cliff and is usually the catalyst for natural rock falls.

Mining related rock falls are most likely to occur during and immediately after the period of active mining.

In summary, total protection from mining related subsidence effects does not imply that rock falls will be completely eliminated and natural rock falls are most likely to occur during periods of heavy rain.

2.2 Thermal Effects

Seasonal and diurnal thermal variations ranging up to about 50°C have been measured on the surface of rock formations such as cliffs (Walsh et al., 2014). At the surface, this variation is equivalent to about 0.5 mm/m of horizontal strain. These natural variations are observed to reduce with depth from the surface to be insignificant at a distance of about 10 m. These cyclic repetitions of up to about 0.5 mm/m occur on a daily and annual basis. They are accommodated by the cliff formations without apparently impacting their stability.

These observations provide a basis to estimate a background tolerance that cliff formations have to be subjected to low level ground movements. It should be recognised that a once off permanent change associated with mining is not necessarily the same as an ongoing cyclic repetition of thermal effects, but the scale of change that the cliff formations can tolerate on a daily basis does nevertheless give an indication of the quantum of ground movements that can be accommodated without apparent impact.

2.3 Mining Induced Effects

Notwithstanding the influence of natural retreat rates and thermal effects, mining induced ground movements associated with longwall mining and full pillar extraction are recognised to cause rock falls and there are many examples of mining induced impacts within the area of mining i.e. directly above the fully extracted panels and the intermediate pillars between such panels. There have been a few examples of mining induced rock falls occurring in the area outside the immediate mining footprint but these are usually a continuation of a rock fall that was initiated directly over the mining area. Perceptible cracking is commonly observed over mining areas and has been observed from time to time to extend out to a distance of up to about 0.4 times overburden depth from the edge of full extraction panels such as longwalls, particularly at the start of panels. Sloping terrain directly over the panel in the direction of mining can exaggerate surface cracking.

Studies of the mechanics of mining impacts on cliff formations undertaken by the IRP panel members over more than 25 years indicate that horizontal movements generated parallel to the cliff face are typically the main cause of rock falls. Vertical movements and compressive horizontal movements outward toward the free surface of the cliff do not, of themselves, significantly change loading on the rock strata that comprises the cliff formations. Horizontal compressive movements parallel to cliff faces tend to be limited only to areas directly above extracted panels and so rock falls also tend to be mainly observed directly above extracted panels.

Cliff formations, where there are re-entrant gullies, have a geometry that tends to concentrate horizontal stresses parallel to the cliff face so these types of formations are more vulnerable than plane cliffs to rock falls. Overhanging rock formations and very high cliff formations create a set of stress conditions that tend to reduce the effective compression strength of the rock strata that forms the cliffs. Overhanging cliff formations and very high cliff formations therefore tend to be more sensitive to compressive horizontal ground movements parallel to the cliff face than smaller cliff formations that are not overhanging.

Stretching movements along the cliff or perpendicular to the cliff face are observed to cause tensile fracturing and perceptible fracturing has been observed to a distance outside the mining area of up to about 0.4 times overburden depth from the edge of extractive mining. Tensile fractures of themselves are not typically associated with causing rock falls. It is plausible that the existence of tensile fracturing may increase the natural retreat rate of cliff formations, but the IRP is not aware of any published information supporting, or otherwise, this relationship. Contrary to early hypotheses, tilting associated with mining subsidence has not been observed to have any significant effect on cliff stability. Although ground tilting does occur in areas where rock falls occur, close inspection of the fracture patterns generated in the rock strata are not consistent with tilting, but rather with horizontal compression movements parallel to the cliff face as discussed above.

The upshot of these characteristics is that not all cliff formations respond similarly to mining induced ground movements and so it is not really possible to have a one size fits all approach to the design of protection measures. Some consideration of the complex interactions that are observed to cause rock falls needs to be part of the design process if protection zone sizes are not to be overly conservative in some areas or ineffective in other areas.

2.4 Previously Mined Areas

The cliff formations above the New Hartley Shale Mine have been subject to full extraction mining. The history of cliff falls and perceptible cracking of rock formations in the vicinity, as presented in the EIS, are consistent with the experience at other sites of full extraction mining. As indicated in the EIS, special consideration needs to be given to the New Hartley Shale Mine area because of the potentially adverse effects of previous mining.

While recognising the sensitivity of this area to future mining, it is noted that the previous rock falls and other impacts associated with the New Hartley Shale Mine form part of the natural vista from

Capertee Valley and do not appear to have significantly detracted from this vista (at least no mention has been made of such in the many submissions that were reviewed in the preparation of this report). The IRP are not aware of any experience that indicates whether cliff formations that have been previously impacted by mining are more stable because they have been impacted and have now reached equilibrium or a less stable because their strength has been compromised. A conservative approach is to assume the latter and this approach has been adopted in this assessment on the basis that rock falls present a significant public safety hazard and this hazard therefore warrants a conservative approach.

3. Cliff Line Zones

Cliff line zones are located directly under many of the high cliffs identified in the EIS. The key issue for the adequacy of providing protection to cliff line zones is the confidence that can be placed in the pillar system to be long term stable. An assessment of the long term pillar stability conducted by the IRP confirms that all proposed pillar geometries within the cliff line zones are long-term stable.

A second issue is the size of the cliff line zone required to provide protection to the cliffs when other systems of mining are proposed in close proximity. The IRP is not aware of any database of experience suitable to determine with high confidence the width of a cliff line zone. A precautionary approach is recommended at Airly Mine to develop confidence that the width of the cliff line zone proposed in the EIS is adequate to provide a high level of protection, particularly recognising that more sensitive cliff features may require a larger cliff line zone. Nevertheless, given the nature of the mining systems proposed and provided the subsidence associated with the panel and pillar mining system is confirmed to be less than 125 mm as predicted, the IRP consider it likely that a protection zone as narrow as 30 m to sandstone cliff formations (including secondary features associated with the cliff formations and not just the sheer cliff face) is likely to be suitable to provide a high level of protection to most of the cliffs. These issues are discussed in this section.

3.1 Long Term Pillar Stability

The IRP independently assessed the long-term stability of the proposed pillar geometries within the cliff line zone i.e. the 35 m square, main heading pillars. The 17.5 m square, split-and-quarter pillars discussed in a Section 5 were also assessed using this same method. The survival probabilities of the proposed pillars at Airly Mine have been calculated and these indicate the geometries proposed at Airly Mine are long term stable.

The pillar in the cliff line zone have a nominal width to height ratio of greater than 11 and as such are sufficiently large to continue to build strength as they become loaded. This characteristic means that they are effectively indestructible and implicitly long term stable provided the roof and floor strata are strong enough to develop the confinement necessary to generate this load. For such large pillars, the additional confinement provided by fallen roof material is sufficient to offset any increase in height that may be associated with a roof fall. The pillars are therefore considered to be long term stable.

A more thorough analysis is presented below. By definition, the pillar strength formulae established in South Africa, Australia and USA (and elsewhere) deals with pillars that don’t spall, their height stays constant and floor is stable within the working life of panels. The probability of stability calculated using these formulae therefore refers to probability of failure of an intact pillar. When the initial dimensions of pillars start changing due to spalling or increased in mining height, the assessment of their stability becomes complex. Therefore, any particular safety factor value proposed for long-term stability of pillars using the previously established formulae can only provide guidance and should be used with caution in design of long-term stable panels.

For example, in Australia, commonly a safety factor of 2.11 is used to ensure the long-term stability of pillars. The apparent reason for this recommendation is that the safety factor of 2.11 corresponds to a probability of failure of 1 in 1,000,000, which provide some level of confidence. However, this approach does not explain explicitly how and why long-term stability of pillars is ensured. In order to achieve a reliable long-term stability of pillars, a method that considers both mechanistic behaviour of pillars and the fundamental principles of the coal pillar strength formulae has been used.

The methodology used in this analysis considered two long-term conventional pillar failures modes, namely:

(i) pillar failure due to pillar spalling (i.e., reduced pillar width).
(ii) pillar failure due to roof failures (i.e., increased mining height).

The floor of workings at Airly Mine is considered to be competent and no attempt was made to evaluate the potential for long-term floor failure.

In order to determine the failure potential in the case of pillar spalling, the methodology developed by Salamon et al. (1998) using the South African coal pillar strength formulae and Canbulat (2010) using the Australian pillar strength formulae was used. This methodology assumes that the coal pillar is the weakest element in the system. For a range of reasons (e.g., weathering, time dependent behaviour, ventilation humidity changes) pillar spalling occurs and progressively reduces the strength and thus the safety factor of pillars over a period of time and eventually pillars fail when they reach the critical safety factor (i.e., Sc=1).

A new methodology recently developed by the University of New South Wales (UNSW) is also used to determine the second pillar failure potential due to roof falls. Unlike the pillar spalling mode, this mode of failure assumes that the weakest element in the system is the roof. Due to roof falls the mining height increases and the strength of pillars progressively reduces over a period of time and the pillars eventually fail when they reach the critical safety factor.

It is considered in this study that a survival probability (i.e., probability of an infinitely stable geometry) of 75% and above will be reasonable to assume that the pillars will be infinitely stable. An important assumption in these calculations is that the spalled pillar or roof material will not increase the strength of pillars due to possible confinement effects. It is therefore reasonable to assume that the calculations presented in this report are somewhat conservative.

Details of these methodologies are presented in Appendix 3.

3.1.1 Assumptions and Input Parameters

The aim of this study was to calculate the probability of infinite stability of the standing pillars proposed at Airly Mine.
There are no pre-defined mine plan but the following design parameters are consistent with the plans proposed by Airly Mine:

- Maximum roadway width is 5.5 m.
- Roadway height is 2.8 m (but no more than 3.0 m maximum for design purposes).
- Primary pillar dimensions (under the cliff lines) are 35 m centres (29.5 m x 29.5 m skin to skin)
- There will be a minimum of 40 m barrier between the mini wall panels and the 35 m centre pillars (unrelated to and not to be confused with the 30 m cliff line protection zone which will be maintained at 30 m irrespective of the location of the main headings).
- The maximum depth of cliff line pillars under the cliffs (i.e., primary pillars with 35 m centres) is 290 m.

The following general input parameters are also used in calculations:

- Coal bulking factor 1.35.
- Roof bulking factor 1.5.
- Angle of repose 35^o.

All simulations were executed using 10,000 Monte Carlo simulations.

3.1.2 Stability Assessment for Cliff Line Zone Pillars

Under the cliff lines, dimensions of the proposed pillars are 35 m x 35 m. These pillars will be subjected to development loads at depths of 30 m to 290 m and potentially some level of abutment loads in cases of mini wall extraction in the vicinity.

Table 1 shows the safety factor and the probabilities of infinite stability of 35 m square pillars under development loads for a range of depths from 30 m to 290 m.

Table 1. Survival probability of 35m square pillars under development loads at cover depths of 30 to 290m

Cover depth (m)	Safety factor	Probability of infinite stability
30	28.6	>99.99%
55	15.6	>99.99%
80	8.2	>99.99%
130	6.6	>99.99%
155	5.5	>99.99%
180	4.8	>99.99%
205	4.2	99.80%
230	3.7	98.49%
255	3.4	93.4%
290	3.0	75.5%

It is evident from this table that the proposed main heading pillars will be infinitely stable at cover depths of 30 m to 290 m. It is also evident that the probability of infinitely stable geometry reduces with increasing depth. However, it is noted that the area where the pillars will be subjected to development loads at maximum cover depth of 290 m is relatively small.

The 35 m square pillars will also be subjected low level abutment loads when the mini wall panels are extracted. Table 2 shows the initial and final safety factor of pillars and their probability of infinite stability under abutment loads

Table 2. Survival probability of 35m square pillars under abutment loads at 290m

Abutment loading	Initial pillar safety factor	Final pillar safety factor	Probability of infinite stability
When mini wall panels are extracted (at 290 m cover depth)	3.0	2.95	74.74%

Notes: abutment loads are calculated using the pillar abutment loading model of Mark (1990) and an abutment angle of 21^o from vertical.
*A minimum of 40 m barrier is assumed between the mini walls and the main heading pillars.
**30 m x 100 m chain pillars and a 40 m wide barrier are assumed. Using Mark (1990) it is estimated that majority of the abutment loads (>95%) will be arrested by the chain pillars and the proposed 40 m barrier between the panels and the mains.

3.1.3 Other Considerations

The assessment presented in the previous sections indicates that the proposed pillars in the cliff line zone are long term stable under abutment loads from the mini wall panels at depths up to 290 m.

The IRP recognise that flooding may accelerate deterioration of pillars but flooding causing further deterioration is of no real consequence because pillar spalling stops when the aprons of failed material reach the roof as per the pillar spalling failure mode used in the assessment. Therefore, it is reasonable to assume that water or flooding will not cause any more spalling of pillars than has been assumed above.

There are a significant number of other cliff lines (discussed on Page 230 of the EIS and in the Department of Planning and Environment's (DPE) Preliminary Environmental Assessment Report (PEAT)) that are greater than 20 m high but are not to be protected by cliff line zones. The IRP was not shown how visible or otherwise these formations are from Capertee Valley and whether any perceptible impacts that may occur from the proposed mining would detract significantly from the natural vista and tourism value of the area. These cliffs are reliant for protection on the low levels of subsidence predicted above the panel and pillar mining zones. The adequacy of this protection is discussed in Section 4 of this report.

3.2 Size of Cliff Line Zones

A 30 m wide protection zone is expected to be sufficient to protect many of the cliff formations provided the subsidence above panel and pillar mining areas is less than 125 mm, the angles of draw are consistent with expectation, and the protection zones are determined on the basis of including any significant cliff formations that are peripheral to the main vertical cliff face.

Cliff formations typically comprise a series of sheer faces. For large cliff formations, there is usually a main cliff face, but there are often smaller cliffs, re-entrants (gullies), overhangs, and other irregularities. The determination of the point on the ground that represents the edge of the cliff is not necessarily a simple task.

It is also recognised that in practice mining geometries will lead to protection zones being generally greater than 30 m wide because of the irregular nature of the cliff lines. There will however inevitably be a number of "pinch points".

The IRP recommend that at the Extraction Plan (EP) stage, an assessment of the nature and likely stability of cliff formations at these pinch points is included in the protection zone sizing strategy on a case by case basis to recognise the particular sensitivities of individual cliff formations, particularly cliff height and cliff geometry, to mining induced ground movements and to manage the range of other influences that can affect cliff line stability other than just vertical subsidence.

The width of the cliff line zones required to provide full protection to the cliffs is something that CCCL needs to determine from the results of initial monitoring undertaken during extraction initial early panels, i.e. particularly over the panel and pillar (mini wall) panels. The proposed 30 m wide protection zones appear adequate from a pillar stability perspective as discussed although the effectiveness in terms of limiting subsidence effects needs to be confirmed through monitoring.

The experience of longwall mining at Baal Bone and Angus Place Collieries has been that cliffs of any height that are directly undermined with high levels of longwall subsidence have a high probability of being significantly impacted; typically with up to about 20% of the undermined length experiencing rock falls. It was found that, despite the high levels of subsidence at Baal Bone Colliery (up to 1.8 metres) protection zones between the cliff and the goaf area were adequate when they were equal in width of half the depth of cover plus 50 m. Such protection zones have provided a high level of protection to the 50 m high cliffs of the Wolgan Escarpment and various similarly high internal cliffs with no perceptible impacts, i.e. no cracks and no rock falls, even though adjacent subsidence was of the order of 1.8 m.

The experience at Clarence Colliery appears to indicate that cliffs of up to 80 m high were undermined with no impact provided subsidence was limited to less than the subsidence observed at Clarence Colliery (i.e. less than 57 mm).

To the panel's knowledge, there is not a large body of experience between these two end points and this experience needs to be developed at Airly Mine. If subsidence is limited to less than 125 mm over the panel and pillar zones at Airly Mine and only first workings are extracted under the cliff line zones, then, the subsidence at the cliff line is expected to be much lower than the maximum predicted subsidence level of 125 mm.

Monitoring over partial extraction panels at Clarence Colliery (White, 2014 and Strata Engineering, 2011) indicates that the maximum subsidence over first working areas was monitored at between 5 mm and 10 mm, i.e. well below the historically applied measurable subsidence limit of 20 mm. Reports on the monitored subsidence, following partial extraction areas at Clarence Colliery since 1999, indicate subsidence levels typically between 20 mm to 40 mm with a reported average of 31 mm (White, 2014). This measured subsidence increased in the long term to an average of 57 mm, with associated average tilts and strains of 0.2 mm/m and 0.4 mm/m respectively; also considered to be negligible.

Typically, subsidence beyond the boundary of a partial extraction panel at Clarence Colliery was measured to be below the 20 mm measurable limit and often the angle of draw, a measure of the distance to where 20 mm of subsidence is monitored, is negative. The maximum recorded angle of draw associated with a partial extraction panel at Clarence Colliery was 5.9° (Strata Engineering, 2011). This offset appears to be the basis for providing a nominal 30 m protection zone to high cliffs as proposed in the EIS, but the levels of subsidence and the resulting angles of draw should be verified with monitoring over early panels at Airly Mine before any mining is undertaken near any significant cliff formations. The IRP recommend that CCCL use subsidence monitoring over the initial panel and pillar monitoring areas to demonstrate that low levels of subsidence can be achieved at 30 m outside these areas and adjust the widths of the cliff line zones accordingly if they cannot be.

It is also recommended that consideration be given on a case by case basis to assess whether the width of cliff line zone should be increased or possibly reduced in some cases to provide a high level of protection against the effects of horizontal subsidence movements. Locations where cliffs are particularly vulnerable to the effects of horizontal stress concentration (overhangs, re-entrants) may require locally wider cliff line protection zones. Locations where there is potential for horizontal stress concentrations parallel to the cliff line may also require wider protection zones.

4. Panel and Pillar Mining Zones

A system of panel and pillar mining also commonly known as mini wall mining is proposed for most of the internal areas of the mesas, including under some of the high cliffs that have not been specifically protected by cliff line zones. This system of mining has potential to limit surface subsidence to low levels. Whether or not the maximum subsidence will be able to be limited to less than 125 mm as indicated in the EIS and supporting documents is something that remains to be demonstrated in practice and a suitable program of high confidence subsidence monitoring is recommended to confirm this during mining of initial panels remote from sensitive features.

4.1 Subsidence Components

Subsidence above full extraction can be divided into two components sag subsidence and strata compression subsidence over the chain pillars. Sag subsidence occurs above each individual panel as a result of sagging or draping of the overburden strata into the void created by mining and is centred over each panel. Strata compression subsidence occurs due to compression of the coal pillar and the strata above and below the coal pillars that remain in the ground after the coal in the voids on either side have been extracted as a result of redistribution of the load that was previously carried by the now extracted coal. Strata compression subsidence occurs after several panels have been mined.

4.1.1 Sag Subsidence

As the overburden depth increases, the sag subsidence for a given panel and pillar geometry tends to decrease until the panel reaches a supercritical width and from then on the subsidence in the centre of the panel remains at the maximum possible level. The values indicated in Table 8.2 of the EIS for single panel subsidence appear to provide a reasonable indication of the sag subsidence based on previous experience. The values shown in Table 8.2 illustrate the sensitivity of subsidence to void width.

It should be noted that most of the sag subsidence monitoring data available above narrow panels tends to be for relatively short periods after mining (months and occasionally more than a year) rather than for multiple years or decades. This limitation is primarily a result of the monitoring requirements that tend to focus on survey measurements soon after mining has finished. It is considered possible that the subsidence over narrow panel at close to the limit of overburden bridging may be sensitive to the passage of time and may continue to increase as the overburden strata gradually yields. It is recommended that the monitoring program at Airly Mine over the mini wall panels include a number of resurveys of subsidence across the first mined panels to confirm the significance or otherwise of this effect over time.

4.1.2 Strata Compression Subsidence

In contrast to sag subsidence, strata compression subsidence tends to increase as the overburden depth increases for a given panel and pillar geometry. The weight of overlying strata that needs to be supported on the chain pillars increases with overburden depth and so the amount of compression of the strata above and below the chain pillars also increases.

Given the likely sensitivity of the proposed protection measures to the maximum subsidence generated above the mini wall panels, the IRP reviewed a range of alternative methods to predict the elastic compression of the pillars and the strata above and below these pillars. This review is presented in Appendix 4. These various methods indicated that while the predictions presented in the EIS are reasonable, there is some variability evident in the estimates and because of the generally low levels of subsidence involved, site specific curves should be developed for the specific lithology and geological setting present at Airly Mine.

The IRP therefore recommend undertaking local site monitoring over the first three to four mini wall panels at overburden depths above 250 m and in areas away from significant cliff formations to confirm that the predictions are appropriate for the local lithology and geological setting. The IRP note that the strata compression subsidence tends to be relatively insensitive to panel and pillar widths and tends to become significant at overburden depths above about 200 m. A significant reduction in coal recovery may be required in order to significantly reduce the surface subsidence if subsidence of greater than 125 mm is observed. Any exceedance of maximum subsidence is most likely to occur in areas of larger overburden depths, which is why initial monitoring should be conducted in an area where the overburden depth is as deep as possible. An area on Mount Airly where the overburden depth is approximately 250 m would be suitable.

4.1.3 Chain Pillar Failure

Subsidence may also occur as a result of chain pillar failure under a special set of circumstances. These circumstances are not expected at Airly Mine, but for completeness they are discussed here.

The methodologies available to assess long-term stability of pillars in bord-and-pillar panels are not suitable for the assessment of the long-term stability of chain pillars isolated in the goaf. Chain pillars are subjected to abutment loads and effectively increased mining heights on both sides when adjacent panels are mined. Experience of monitoring subsidence behaviour around typically sized chain pillars indicates that a special set of circumstances is required for pillar instability to occur and this circumstance is not expected at Airly Mine.

Under normal circumstances, fallen material from the failed roof strata above the extracted voids becomes available to support the chain pillar ribs so that confinement is generated within the pillar as a result of this support. The confinement provided by fallen material allows the coal strength to build up to resist loading without any potential for sudden failure or collapse. In effect there is nowhere for the coal in the pillar to go. High confinement is able to be generated. Pillar strength continues to build as the pillar deforms without there being any potential for failure of the overall pillar system.

The special circumstances where such pillar confinement is not generated occurs in narrow panels under strong roof conditions when the roof strata is able to bridge across each individual panel. Without any roof failure, there is no bulked up fallen material available to provide confinement to the coal pillar ribs, so there is potential for chain pillar instability if the pillars are too narrow to remain long term stable. Although this circumstance does occur from time to time, none of the conditions necessary are expected in the proposed mini wall panels at Airly Mine. The chain pillars between panels are expected to remain stable over the long term. Recommended subsidence monitoring over the initial panels is available to confirm this expectation.

4.2 Cliff Lines Not Specifically Protected by Cliff Line Zones

There are understood by the IRP to be six other cliff lines (discussed on Page 230 of the EIS and in the Department of Planning and Environment's (DPE) Preliminary Environmental Assessment Report (PEAT)) that are greater than 20 m high but are not specifically protected by cliff line zones. The IRP have assumed this lower level of protection is because the cliffs are deemed to be internal cliffs not requiring the same level of protection as the main cliff lines. The IRP was not shown how visible or otherwise these formations are from Capertee Valley and whether any perceptible impacts that may occur from the proposed mining would detract significantly from the natural vista and tourism value of the area.

These internal cliffs are reliant for protection on the low levels of subsidence predicted above the panel and pillar mining zones. In the EIS, there is indicated to be some potential for these cliffs to be impacted at the anticipated subsidence levels and the IRP support this view. While the panel and pillar system of mining proposed is intended to produce low levels of subsidence and therefore provide a high level of protection, the subsidence is nevertheless expected to be significantly greater than in the cliff line zones, where subsidence is effectively limited by the design to very low levels. The experience at Clarence Colliery indicates that mining induced rock falls were not evident when the subsidence was generally less than about 30-40 mm and up to 57 mm. The expectation that cliff lines have some tolerance to ground movement is consistent with this experience.

In areas where there is potential for rock falls to occur as a result of mining subsidence, issues of public safety will need to be considered at the point of developing an Extraction Plan.

5. Split-and-Quarter Pillar Zones

The system of partial pillar extraction proposed involves forming large square pillars at 35 m centres (as per the cliff line zones) and then splitting-and-quartering these pillars so that the remaining square pillars are 17.5 m wide (measured centre to centre).

The minimum factor of safety of these pillars is estimated to be 2.2 for loading expected at 110 m of overburden depth in flat terrain conditions. These pillars are therefore assessed as being long term stable under tributary area loading up to 110 m overburden depth.

In the more complex loading conditions expected close to high cliff lines, the loading conditions may vary from tributary area loading and as a result, the factor of safety may be reduced. A reduction in factor of safety under increased loading does not mean the pillars are necessarily unstable, but rather that long term stability cannot be guaranteed to industry accepted standards.

The width to height ratio of the remnant pillars after splitting-and quartering is indicated as being four and as such the potential for sudden collapse of large areas of standing pillars is considered remote. However, there is considered to be potential for a more gradual pillar convergence to occur if the pillars become overloaded at this width to height ratio and such a convergence would ultimately have a similar outcome to a collapse in terms of surface subsidence with up to an estimated 0.9 m of subsidence possible. Subsidence of this amount would be expected to be perceptible on the surface and would have potential to affect cliff line stability.

A mine design involving splitting the pillars on one axis only (i.e. not quartering them) in areas of high vertical loading (i.e. adjacent to the cliff line zones) would increase the factor of safety of the remnant pillars but without some indication of the complex loading conditions, long term stability would not be able to rigorously assessed.

A program of work to determine the loading conditions below cliff lines is recommended to determine how significant the variation is from the tributary loading conditions assumed for the stability analysis. This analysis might involve numerical modelling and field measurements of pillar loading along a profile in the existing workings where they pass below cliff lines. The field inspection conducted by Professor Canbulat provided the expected indications that the vertical stresses are increasing as the overburden depth increases, but it is not possible from these visual inspections alone to determine the loading profile below major cliff formations suitable for the type of analysis required. Such a program of work is also beyond the scope of the Terms of Reference for the IRP.

5.1 Stability Assessment for Split-and-Quarter Pillars Under Tributary Area Loading

In this section, the long term stability of the split-and-quartered pillars is assessed using the approach described in Sections 3.1 and Appendix 3. There are no pre-defined mine plan but the following design parameters are consistent with the plans proposed by Airly Mine:

- Maximum roadway width is 5.5 m.
- Roadway height is 2.8 m (but no more than 3.0 m maximum for design purposes).
- There will be no pillar splitting-and-quartering undertaken under the cliff lines.
- Pillar splitting-and-quartering will be conducted at cover depths of 30-110 m (and more than 30 m horizontally from the base of cliffs).
- Pillar dimensions after splitting-and-quartering are 17.5m (12m x 12m skin to skin).
- There will be no splitting-and-quartering within a minimum horizontal offset of 30 m from the base of any defined cliffs or a maximum of 110 m depth whichever comes first.
- No splitting-and-quartering will be conducted where a fault >0.5m in vertical throw or combination of faults adds to >0.5m are present.

The following general input parameters are also used in calculations:

- Coal bulking factor 1.35.
- Roof bulking factor 1.5.
- Angle of repose 35^{o}.

All simulations were executed using 10,000 Monte Carlo simulations.

Table 3 shows the safety factor and the probabilities of infinitely stability of 17.5m square pillars under development loads at depths of 30m to 110m. A factor of safety of 2.11 is considered to be long term stable. A probability of infinite stability of greater than 75% is considered long term stable.
It is evident from Table 3 that the proposed split-and-quarter pillars will be long term stable under tributary loading conditions up to 110 m of overburden depth. However, it is emphasised again that in the more complex loading conditions expected close to high cliff lines, the loading conditions may vary from tributary area loading. Therefore, a monitoring and numerical modelling study is recommended to confirm the loading conditions of these pillars.

Table 3: Survival probability of 17.5 m split pillars under development loads at cover depths of 30 m to 110m

Cover depth (m)	Safety factor	Probability of infinite stability
30	8.1	>99.99%
50	4.8	>99.99%
70	3.5	>99.99%
90	2.7	99.53%
110	2.2	90.89%

5.2 Other Considerations

Flooding of standing pillar panels may cause further deterioration of pillars as the ribs weather and spall. This weathering may cause further deterioration until the pillar spalling stops when the aprons of failed material reach the roof. The method described in Section 3.1 has been used to assess the stability of the pillars. Therefore, it is reasonable to assume that water or flooding will not cause any more spalling of pillars than assumed above.

6. Shallow Zones

The pillar geometry proposed in the shallow zone is based on small pillars with a width to height ratio of greater than four and nominal factors of safety of much greater than 2.11. As indicated in Section 4, these pillars are considered to be long-term stable.

The potential for sinkhole formation appears to be adequately addressed by the design. However, a further probabilistic study may be conducted to quantify the risks. The development or otherwise of sinkholes at shallow depth is unlikely to have any significant influence on cliff line stability.

7. New Hartley Shale Mine Potential Interaction Zone

Available mine plans of the New Hartley Shale Mine indicate that a high proportion of the area mined was fully extracted. However, it is not possible from the available information to develop a high level of confidence as to the extent or state of stability of any remnant pillars in the New Hartley Shale Mine. Evidence of surface impacts from rock falls and surface cracking indicate that surface subsidence occurred over large areas of the mine at the time of mining. The implication of these observations is that most of the pillars have collapsed and hence there are few left that can collapse in the future. On this basis, large scale pillar instability is considered by the IRP to be remote.

However, it is still possible that there are some remnant standing pillars within the mine that have not allowed full subsidence to develop and there are certainly areas around the periphery of the mine where full subsidence has not been able to develop because of the presence of the abutments. The proposed system of panel and pillar mining in the Lithgow Seam under the area of the New Hartley Shale Mine is expected to interact with the existing mine workings and cause areas of large downward movement in some parts of this old mining horizon. The redistribution of loads associated with this interaction is expected to cause areas of larger subsidence to develop at the surface.

If such areas of larger subsidence are able to be limited to within the confines of the mesa, surface impacts may be tolerable, albeit most likely greater than 125 mm in some places. If the larger subsidence extends under the cliff lines, there may be increased potential for rock falls. This possibility is recognised in the EIS.

It is not certain whether previous cliff instability above the area of the New Hartley Shale Mine means that the cliffs in this area are now more stable than they were prior to the rock falls or whether the cliffs are more unstable having already been impacted.

The concept of increasing the width of the cliff line zone in the vicinity of the New Hartley Shale Mine under all the significant cliffs (including internal cliffs) to greater than half depth plus 50 m from the top of the cliffs on all sides would be expected to provide protection to the cliffs. Developing pillars in geometries consistent with the cliff line zones and split-and-quartering zones would not be expected to significantly influence loading at the overlying New Hartley Shale mining horizon. On this basis no limitation on first workings in the vicinity of the New Hartley Shale Mine is proposed.

The possibility of some load redistribution in the panel and pillar mining area leading to a pillar run in the New Hartley Shale Mine would not be eliminated by having a half depth plus 50 m protection zone in place, but the potential for such an event to impact on the cliffs is considered by the IRP to be low.

8. Management Regime

The second section of the Terms of Reference requests a review of the adequacy of the management regime in the proposed conditions of consent, including the subsidence impact performance measures, management plans and monitoring requirements, in the context of providing appropriate protection to sensitive surface features. The Terms of Reference specifically requests consideration of:

a) the adequacy of the proposed subsidence impact performance measures in preventing impacts beyond negligible levels on the surface features above the workings in previously un-mined areas with a focus on sensitive surface features such as cliffs and pagoda features;

b) the adequacy of subsidence monitoring, pillar system performance monitoring programs and actions that would be taken as part of the proposed adaptive management response, having regard to environmental and safety aspects associated with subsidence monitoring;

c) review opportunities for conventional monitoring, cliff movement monitoring, remote monitoring and underground monitoring in order to ensure sufficient data would be obtained to allow calibration of subsidence predictions and inform management decisions such as adaptive management responses, while having regard to the rugged terrain, limitations of access and environmental sensitivities of the overlying Mugii Murum-ban State Conservation Area; and

d) an appropriate initial mining area in which to gain data on mining system performance and verify that the mine design parameters are performing as planned.

The management regime as outlined in the EIS is based on the concept of maintaining subsidence at low levels so that surface impacts are low enough to be either imperceptible or at least tolerably low. A key element of this strategy is the expectation that subsidence will indeed be maintained at these low levels, certainly during the period of mining, and implicitly into the distant future well after the mine has ceased operation.

An adaptive management approach is possible during the period of mining if there are any indications that the systems in place are not giving the outcomes intended. Changing the design to manage the outcomes is possible using this approach but only for those areas that have yet to be mined.

This management regime is not likely to be effective when significant impacts cannot be detected until it is too late to make any effective change. For instance when:

- The impacts occur too quickly. Events such as cliff falls occur quickly and are not usually predictable in advance. A rock fall can therefore occur before it is possible to do anything effective to prevent it.

- The impacts are delayed and don't become apparent until much later, possibly even after mining has finished. Once mining has finished, there is no real potential to make significant changes that can effect a different outcome, at least for most of the key subsidence related issues.

- The monitoring does not or is not able to provide the critical information because of practical considerations such as the nature of the surface terrain causing access limitations or the various challenges of measuring / monitoring impacts including cost.

8.1 Adequacy of the Proposed Subsidence Performance Measures

The performance measures outlined in the EIS (Table 11.3 Page 477) with regard to subsidence appear to be generally appropriate and consistent with the general thrust of the IRP recommendations.

A key subsidence performance measure at Airly Mine is that the maximum subsidence above the panel and pillar mining areas will be maintained at less than 125 mm and ideally at less than observed at Clarence Colliery. This key performance measure appears to be generally reasonable to achieve the outcomes of minimal impact. There is some increase in this parameter relative to the experience base at Clarence Colliery.

Experience of monitoring surface impacts at Clarence Colliery is reported that at subsidence levels of less than 100 mm and generally much less than 100 mm, there have been no perceptible impacts to overlying cliff and pagoda formations. Given the challenges of the difficult terrain, getting accurate confirmation of the actual subsidence is difficult. Nevertheless, the experience at Clarence Colliery is considered credible and is consistent with the expectation that cliff formations have some small tolerance to ground movements.

Reports on the monitored subsidence, following partial extraction areas at Clarence since 1999, indicates subsidence levels of typically between 20 mm to 40 mm with a reported average of 31 mm (White, 2014). This measured subsidence increased in the long term to an average of 57 mm, with associated average tilts and strains of 0.2 mm/m and 0.4 mm/m respectively; also considered to be negligible.

The experience at Clarence Colliery is being used in the EIS to support the use of a variety of mining systems that are intended to limit subsidence to less than 125 mm. This upper limit has been developed on the basis that the accuracy of subsidence monitoring at Clarence Colliery is about ±25 mm and the reported maximum subsidence at Clarence Colliery has been maintained at less than 100 mm. It would appear therefore that the upper limit of 125 mm proposed as the key performance measure does not include any survey tolerance at Airly Mine or that the survey tolerance is expected to be very tight.

In order to have confidence that the subsidence limit of 125 mm is achieved, the accuracy of the proposed subsidence monitoring needs to be taken into account. When setting thresholds for monitoring to confirm the subsidence levels can indeed be demonstrated to be less than 125 mm, the tolerance of the measurement system needs to be considered. For instance, a survey system with accuracy of ±25 mm would need to demonstrate subsidence of less than 100 mm in order for there to be confidence that maximum subsidence has been less than 125 mm whereas a system with accuracy of ±50 mm would need to demonstrate subsidence of less than 75 mm to have the same level of confidence.

8.2 Adequacy of the Proposed Subsidence Monitoring

There are usually practical limitations for conventional surveying in steep terrain, including the physical safety of the survey team. Although the accuracy of three dimensional surveying can be maintained in such terrain at less than ±20 mm with good survey control, accuracy is more commonly of the order of ±40 mm and can be much higher depending on the systems used. It is recommended that early panels of each mining system are located in areas where high confidence measurements of the surface movements can be measured across multiple panels so that the ground movements can be confirmed as being less than 125 mm within the survey tolerance of the systems used.

Survey pegs should ideally be set at $1/20^{th}$ of depth. Survey control should include periodic confirmation of position from remote locations on all sides of the proposed mining area. There are a variety of GPS controlled survey strategies that have proved effective over larger areas.

Pillar monitoring underground is not regarded as a management tool except in the context of providing better understanding of ground behaviour generally. For instance, the program recommended by the IRP to measure the complex loading conditions in close proximity to cliffs is useful in terms of understanding of pillar loading. A pillar monitoring program designed to indicate when pillars are approaching failure is likely to be less effective.

The accuracy of the measurements and the time involved in processing the results from pillar monitoring generally do not provide a method that is suited for adaptive management in real time or reflective of subsidence impacts on the surface. The value of pillar monitoring should be seen more in the context of confirming that pillar behaviour is generally as expected or for more specialist investigations targeting particular issues. Pillar monitoring at Airly Mine would be helpful to confirm general understanding of pillar behaviour, but it should not be seen as a management tool for protecting the cliff lines or other surface features from the long term effects of pillar instability.

8.3 Review of Monitoring Options

Conventional surveying is regarded as providing the most convincing confirmation of general subsidence behaviour. In steep terrain, there are significant limitations to what is practically possible and these limitations are further increased in a State Conservation Area where the opportunities to clear vegetation to install subsidence lines are more limited.

Satellite based differential interferometry (dInSAR) offers an opportunity for large area subsidence monitoring to accuracies of a few millimetres in a vertical direction. The capability of this method to measure horizontal movements is still in its infancy, but satellite interferometry is regarded as a credible basis to measure vertical subsidence.

Airborne LiDAR surveying is not expected to be accurate enough to detect the low levels of ground movement expected at Airly Mine, although LiDAR systems are continually improving and this may be an option.

Unmanned aerial vehicles mounted with a camera have developed as an option suitable for routine subsidence monitoring. The IRP is not aware of the potential accuracy of these types of system, but the system appears likely to be suitable for use in the rugged terrain above Airly Mine.

Point to point survey methods have been found to be useful for increasing the accuracy of measurement parallel to cliff lines. Survey accuracy of less than ±2 mm is possible with suitable equipment.

Stress change monitoring within the cliff forming sandstone has been found to have accuracies capable of detecting stress changes of about 0.1 MPa and 0.01MPa over short duration events such as micro-seismic events. These accuracies are about 10-100 times better than survey accuracy, but access to drill suitable holes and long term stability of the instruments need to be considered. Deployment of these systems is helpful to investigate the nature of mining induced impacts, but they are not generally suitable to be used as the sole management tool to determine for instance when mining a particular panel should stop.

8.4 Review of Monitoring Options

The IRP is not aware of the details of the sequence of mining proposed at Airly Mine, but there appears to be a large area below Mount Airly that would be suitable to monitor to get the information that is required without impacting on sensitive cliff formations. It is recommended that CCCL identify areas where monitoring can be reliably used to confirm the adequacy of the designs proposed and these panels are mined first.

For the critical issue of confirming the 125 mm subsidence limit, the IRP recommend the mining sequence is arranged so that initial panels are located within areas where high confidence monitoring is possible without there being any potential to adversely impact sensitive surface features or to give misleading results.

The IRP recommend monitoring strategies such as satellite interferometry are conducted across the monitoring area and adjacent areas and more than one initial survey is conducted to develop confidence in the results prior to mining. Broad coverage is one of the significant strengths of using these types of system.

9. Conclusions and Recommendations

The IRP is satisfied that the proposed methods of extraction have the potential to avoid significant impacts and minimise residual effects and impacts from subsidence on cliffs, steep slopes, and pagodas.

The IRP is satisfied that CCCL can avoid the risk of the most significant impacts to cliff lines by using combinations of the various mining systems proposed all of which are relatively conservative by comparison with industry standards and all of which are expected to maintain surface movements at low levels.
However, high confidence subsidence monitoring over the initial panel and pillar mining areas (i.e. mini wall or partial extraction mining areas) is recommended to confirm the levels of ground movement are as predicted and the proposed protection zones sizes are appropriate to provide the high level of protection to cliff formations implied by the requirement for minimal impact.

Initial monitoring should be conducted in areas remote from sensitive features and prior to any mining in these sensitive areas. This initial monitoring is important to confirm that the panel and pillar mining system does indeed limit subsidence to less than 125 mm at overburden depths of 250-300 m and to provide confidence in one or more remote subsidence monitoring techniques that can be used on an ongoing basis to measure subsidence in the rugged terrain above Airly Mine.

The proposal to use a protection zone either side of the cliff lines to define the cliff zones is expected to be effective in protecting cliff formations from rock falls at close to background levels. It should be recognised that cliff formations do experience rock falls naturally at a relatively rapid rate which is why they exist in the landform; therefore, full protection is not possible. A precautionary approach is recommended because the database of experience of appropriate setbacks from mining to protect cliff formations is relatively limited and Trigger Action Response Plans are unlikely to be effective to prevent rock falls.

A 30 m wide protection zone is expected to be sufficient to protect many of the cliff formations provided the subsidence above panel and pillar mining areas is less than 125 mm, the angles of draw are consistent with expectation, and the protection zones are determined on the basis of including any significant cliff formations that are peripheral to the main vertical cliff face. It is recognised that in practice mining geometries will lead to protection zones being generally greater than 30 m wide because of the irregular nature of the cliff lines and the difficulty of identifying which part of the cliff formations constitutes the edge of the cliff formation. There will inevitably be a number of “pinch points”.

The IRP recommend that at the Extraction Plan (EP) stage, an assessment of the likely stability of cliff formations at these pinch points is included in the protection zone sizing strategy on a case by case basis to recognise the particular sensitivities of individual cliff formations, particularly cliff height and cliff geometry, to mining induced ground movements and to manage the range of other influences that can affect cliff line stability other than just vertical subsidence.

An assessment of the long term pillar stability conducted by the IRP confirms that the proposed pillar geometries in the cliff protection zones and pillar splitting areas have high probabilities of remaining long-term stable under tributary area loading so as to maintain low levels of surface subsidence. A program of further work is recommended at EP stage to confirm that the loading distributions in the vicinity of steeply dipping terrain below high cliffs, where pillar splitting-and-quartering is proposed, does not lead to loading conditions significantly higher than the tributary area loading used in the various assessments. There is recognised to be flexibility within the mining systems proposed to accommodate any variation in design that may be necessary to ensure long term stability.

There are several areas where internal cliff lines are reliant for their protection on the low levels of subsidence predicted in the EIS for the panel and pillar mining geometries proposed. The potential for rock falls is acknowledged in the EIS and appears to be acceptable to DPE. Issues of public safety and how they will be managed in the vicinity of these internal cliffs into the future does not appear to have been specifically addressed and would need to be addressed at EP stage.

Mining in close vicinity of the New Hartley Shale Mine is expected to increase the potential for perceptible impacts including rock falls with implications for public safety and visual amenity. This potential is recognised in the EIS. The IRP recommend that if further surface impacts in the vicinity of the New Hartley Shale Mine are to be avoided, the proposed panel and pillar mining should not approach to closer than half depth plus 50 m from the edge of the existing workings. If surface impacts and rock falls above the New Hartley Shale Mine are considered tolerable in some areas but not others, the IRP recommend maintaining a protection zone of half depth plus 50 m from proposed panel and pillar mining to those areas that are required to be protected.

Adaptive management strategies based on the results of monitoring have potential to control some of the impacts of the proposed mining but the limitations of adaptive management strategies should be recognised. Adaptive management is not effective if the changes occur too quickly for an effective response (i.e. rock falls), occur too slowly for an effective response (i.e. after mining is complete), or the critical characteristics are not able to be measured effectively (i.e. steep terrain prevents access).

The adaptive management process proposed to ensure appropriate protection for sensitive features at Airly requires accurate monitoring and regular reviews of the monitoring results against the predicted effects in the early panels remote from sensitive features. The chosen mining methods being proposed for the AMEP are flexible and if monitoring in areas remote from sensitive features indicates adjustments are necessary to provide protection, the mine has the capacity to modify the mine layout and adaptively manage the impacts, within the limitations of adaptive management strategies.

The IRP recommend conventional survey monitoring with high confidence far field GPS survey control over the initial three or four panels mined using the panel and pillar mining system in areas remote from sensitive features and at the greatest overburden depth that is practical, ideally greater than 250 m.

A range of other subsidence monitoring techniques such as dInSAR, LiDAR, and unmanned aerial vehicle based photogrammetry are available and likely to be suitable at various levels of accuracy. The IRP recommend CCCL to consider one or more of these techniques to duplicate the conventional subsidence monitoring observed over the initial panels. Recognising that the upper limit of subsidence is 125 mm, the maximum subsidence observed needs to be less than 125 mm by at least the effective tolerance of the survey system used so as to give confidence that subsidence is indeed less than

125 mm. The development of a high confidence, high accuracy, low tolerance survey technique suitable for remote monitoring in rugged terrain is considered likely to be a critical component of this project from a coal recovery perspective in order to ensure confidence in a geometry that can maintain subsidence to less than 125 mm.

Underground monitoring of pillar loads is not considered suitable as a monitoring technique to confirm low levels of subsidence and protection of cliff formations, but would be useful to develop an understanding of the loading conditions on pillars in the vicinity of high cliffs.

10. References

Flentje P. 2015 Personal communications with Dr Ken Mills.

Strata Engineering, 2011 "Review of Subsidence Information from Recent Partial Extraction Areas" Report No. 04-001-CLA-109 to Clarence Colliery.

White E. 2014 "Clarence Colliery - Partial Extraction to Protect Surface Features", Proceedings of the 9th Triennial Conference on Mine Subsidence, 2014.

Appendix 1 Terms of Reference

Based on the suggestion by DRE and the conclusions from the PEAR and the PAC report, an Independent Review Panel was established with the Terms of Reference presented below. Some relevant items of correspondence referred to in the Terms of Reference were not received until late in the review process. These issues are discussed in this section because of their significance in the context of setting up the IRP.

A1.1 Terms of Reference for the Independent Pre-Determination Review Panel (IRP) for the Airly Coal Mine Extension Project (MEP) (SSD 5581)

Introduction

Centennial Coal Company Limited (Centennial) has accepted that there are some geotechnical uncertainties around the mining systems proposed in the Airly Coal MEP. Those uncertainties were initially proposed to be managed by an independent expert panel during the Extraction Plan process after determination of the Airly Coal MEP. However, the Planning Assessment Commission (Commission), on the advice of the Division of Resources and Energy (DRE) has recommended that the panel be constituted and carry out its review function prior to the determination of the Airly Coal MEP.

These terms of reference for the IRP are based on an initial proposal by Centennial, which was revised by the Department of Planning and Environment (the Department) to closely reflect the Commission's review of the Airly Coal MEP (particularly recommendations 2 and 3), comments received from DRE and the Department's own consideration.

Members of the IRP

Consistent with the advice of DRE and the Commission, the following three members are recommended to comprise the IRP:

- Emeritus Professor Jim Galvin (Galvin and Associates Pty Ltd);
- [Dr] Ken Mills (SCT Operations Pty Ltd); and
- Mr Don Kay (MSEC Pty Ltd).

In the inability of any one of the above to undertake the role of a member, an alternative can be considered, with the first alternative to be:

- Prof Ismet Canbulat (UNSW Mining Engineering).

Terms of Reference

In accordance with the Commission's recommendation, the IRP should provide advice and recommendations to Centennial and DPE on the following two key aspects of the proposal:

1. The accuracy and reliability of predicted subsidence impacts on sensitive surface features across the Airly Coal MEP application area, but particularly in relation to cliff lines in the vicinity of the areas to be mined and beneath the former New Hartley Shale Mine. This should include consideration of:

    a) the subsidence predictions made for each proposed mining zone and the angles of draw associated with the proposed mining, including the special case of multi-seam workings proposed beneath the New Hartley Shale Mine interaction zone;

    b) the long-term stability of pillar systems after extraction, including an assessment of the adequacy of system factor of safety (FoS) and the FoS of individual elements (or panels), the final pillar width to height ratios and the geological conditions including soft roof conditions, topographic relief, potential for post-mining flooding and pillar spalling across the proposed depth of workings; and

c) the adequacy of the proposed size of the "cliff line zone and zone of first workings" as a result of the analysis undertaken in 1(a) – (b) and 2(a) inclusive.

2. The adequacy of the management regime in the proposed conditions of consent, including the subsidence impact performance measures, management plans and monitoring requirements, in terms of providing appropriate protection to sensitive surface features. This should include consideration of:

   a) the adequacy of the proposed subsidence impact performance measures in preventing impacts beyond negligible levels on the surface features above the workings in previously un-mined areas with a focus on sensitive surface features such as cliffs and pagoda features;

   b) the adequacy of subsidence monitoring, pillar system performance monitoring programs and actions that would be taken as part of the proposed adaptive management response, having regard to environmental and safety aspects associated with subsidence monitoring;

   c) review opportunities for conventional monitoring, cliff movement monitoring, remote monitoring and underground monitoring in order to ensure sufficient data would be obtained to allow calibration of subsidence predictions and inform management decisions such as adaptive management responses, while having regard to the rugged terrain, limitations of access and environmental sensitivities of the overlying Mugii Murum-ban State Conservation Area; and

   d) an appropriate initial mining area in which to gain data on mining system performance and verify that the mine design parameters are performing as planned. (*Centennial advises that, due to the expected high rate of extraction, the entire first proposed mining area of the Airly Coal MEP (approximately 17 panels) may be mined in a matter of 2-3 years. Determination of any initial mining area would need to take into account the context of a larger Stage 1 Extraction Plan area to allow for continuity of extraction while final mine design parameters are established and implemented*.)

In accordance with the Commission's recommendation, the IRP should review all material regarding subsidence submitted for the Commission's consideration, including information supplied directly to the Commission by the Applicant and its consultant, and comments from DRE and its Principal Subsidence Engineer (including the Minutes dated 12 December 2014 and 2 October 2015).

A1.2 Additional Correspondence

The IRP were provided on 22 June 2016 with items of correspondence which the IRP was advised covers all the issues referred to in the Terms of Reference as "Minutes dated 12 December 2014 and 2 October 2015". These items included:

- A letter from Adrian Delaney, Assistant Director Industry Coordination, to Thomas Watt, Planning Officer Mining Projects, Department of Planning and Environment, dated 18/12/14 (Ref OUT14/40912).

- An email from Thomas Watt to David King, Senior Mining Engineer, CCCL dated 18/12/14.

- A letter from Kylie Hargreaves, Deputy Secretary Resources and Energy, to Robyn Kruk AM, Member, Planning Assessment Commission, dated 8/10/15 (Ref BN15/7224) with attachment of Minute from Dr Gang Li , Principal Subsidence Engineer, dated 2/10/15.

- A letter from Kylie Hargreaves, Deputy Secretary Resources and Energy, to Clay Preshaw, Team Leader, NSW Planning Assessment Commission, dated 2/11/15 (Ref BN15/7880).

The IRP considers that despite only receiving this correspondence relatively late in the review process, the issues raised by Dr Gang Li were also recognised by the IRP during its review. After Dr Li's review was undertaken CCCL addressed many of the issues raised through reconsideration of one of the mine layout options to be used in close proximity to the cliff lines that had potential to cause long term instability.

CCCL redesigned the mining systems to be used by replacing the pillar lifting operations with a split-and-quarter mining system. The split-and-quarter pillar system leaves the remnant pillars with a sufficiently high factor of safety to exceed industry accepted standards for long term stability and therefore avoid many of the concerns shared by Dr Li and the IRP.
The issues that Dr Li raised specifically were:

- The cliff formations are significant features that require appropriate mining design for protection because the mine design is the primary and critical risk control measure.

- The cliff protection zone design is based on 30 m and not half depth as is industry standard practice.

- Some of the pillars as described in the EIS were not designed as long term stable by industry standards.

- Abutment loading and panel interactions were not considered in the EIS design.

- Potential for delayed subsidence.

In a context where there is potential for long term pillar instability, as there was in the design presented in the EIS, the concerns Dr Li raised in regard to potential impacts to the cliff lines and interaction effects are shared by the IRP.

In the interim between Dr Li's review and the IRP review, the mine design was changed. The IRP reviewed the revised design with pillar-and-quartering instead of the pillar lifting option. This revised design is long term stable by industry standards and dimensional control of the excavation geometry is much easier for this mining system than it is for a mining system that involves pillar lifting. As a consequence of this redesign by CCCL many of the IRP's concerns after reviewing the EIS have been addressed. Under the revised design, the critical mining systems in close proximity to the cliff lines are now assessed as being long term stable by industry standards.

The IRP investigated the influence of pillar rib spall and roof instability on long term stability including with the effects of abutment loading and this investigation indicated that provided the split-and-quarter mining system is maintained at overburden depths less than 110 m to give a margin of conservatism, the pillars can be considered as long term stable for all practical purposes. The pillars directly under the cliff line are long term stable with a high margin of conservatism. The IRP have recommended a program of stress measurements to confirm the pillar loading in the vicinity of cliff lines is less than or equal to tributary area loading and therefore consistent with the assumptions that have been made in the assessment.

With greater certainty over long term pillar stability there is no potential for delayed subsidence.

On the assumption that subsidence over the mini wall panels is confirmed as being less than 125 mm, the IRP consider it reasonable that the minimum size of the protection zone required to provide full protection to the cliff lines can be reduced from an industry standard half depth for full extraction to not less than 30 m with a number of provisos. These are provisos are:

- Subsidence over the first three or four mini walls is confirmed as being less than 125 mm at overburden depths of greater than 250 m taking account of the survey tolerance of whatever systems are used to measure this subsidence (i.e. if the tolerance of the surveying technique is ±50 mm, maximum indicated subsidence needs to be less than 75 mm in order to have confidence that maximum subsidence is less than 125 mm).

- No mini wall mining takes place below significant cliff line features until maximum subsidence has been confirmed as being less than 125 mm.

- A suitable system for measuring low level subsidence is confirmed over the first three or four mini walls as being viable in the rugged terrain above Airly Mine and consistent with the results of conventional subsidence monitoring over these panels.

- The 30 m cliff line zone is defined to include any significant secondary cliff formations in addition to the main cliff face.

- The characteristics of individual cliff formations located at or near "pinch points" where the cliff line zone is at a minimum width of 30 m are assessed at EP stage to take account of their particular vulnerabilities to mining subsidence that may include for instance height, overhang, and susceptibility to other effects not related solely to vertical subsidence such as horizontal compression movements.

With these provisos in place and ongoing review of the design at EP stage, the IRP consider that the concerns raised by Dr Li can be suitably addressed.

Appendix 2 Underground Inspection Report

An underground site visit was undertaken by Professor Ismet Canbulat in the company of David King, Senior Mining Engineer, Centennial Coal to inspect the condition of the existing pillars for a variety of pillar geometries at a range of overburden depths.

Four panels, namely 101A, 101B, 205 and 205A, were visited and photographs of pillars were taken. The path taken during the site visit is shown in Figure A2-1.

Cover depth varied from 50 m to 140m in 101A and 101B panels and from 60m to 240m in 200 Panel.

The following observations are of note:

- In general, the conditions can be described as “good”.
- Dimensional control was excellent. Minimal off-line cutting was observed, which is a critical consideration in splitting-and-quartering mining method.
- No pillar spalling was observed at shallow depth. The pillar ribs were straight up with cutter marks clearly visible on them.
- The roof conditions were very good, as expected in a typical shallow, low stress bord-and-pillar environment.
- An average pillar spalling of 0.2m was observed at depths of ~110m. A maximum pillar spalling of up to 0.5m was observed (mostly in corners of pillars) under the edges of sudden changes in depth. It is understood that this spalling occurs within a week of excavation and stops.
- In 205 Panel, where the cover depth is 240m, 0.5m pillar spalling was also evident in the roadways.
- Floor conditions were generally very good with no observable floor heave.
- Roof and floor were dry. In only one area some level of water accumulation was observed.
- Two falls of ground was observed in areas of unsupported cuts in split pillars. The thickness of the fall was approximately 0.3m, up to the soft clay band. The falls stopped at the mount the splits; therefore, they are considered to be localised, minor falls with no impact on the overall stability of the panel.
- A series of faults was also observed, mostly in 101B Panel. But the impact of those faults on the overall stability in the panel is considered to be minimal, if any.
- Photographs presented in Figures A2-2 to Fig. A2-10 illustrate the underground conditions that were observed.

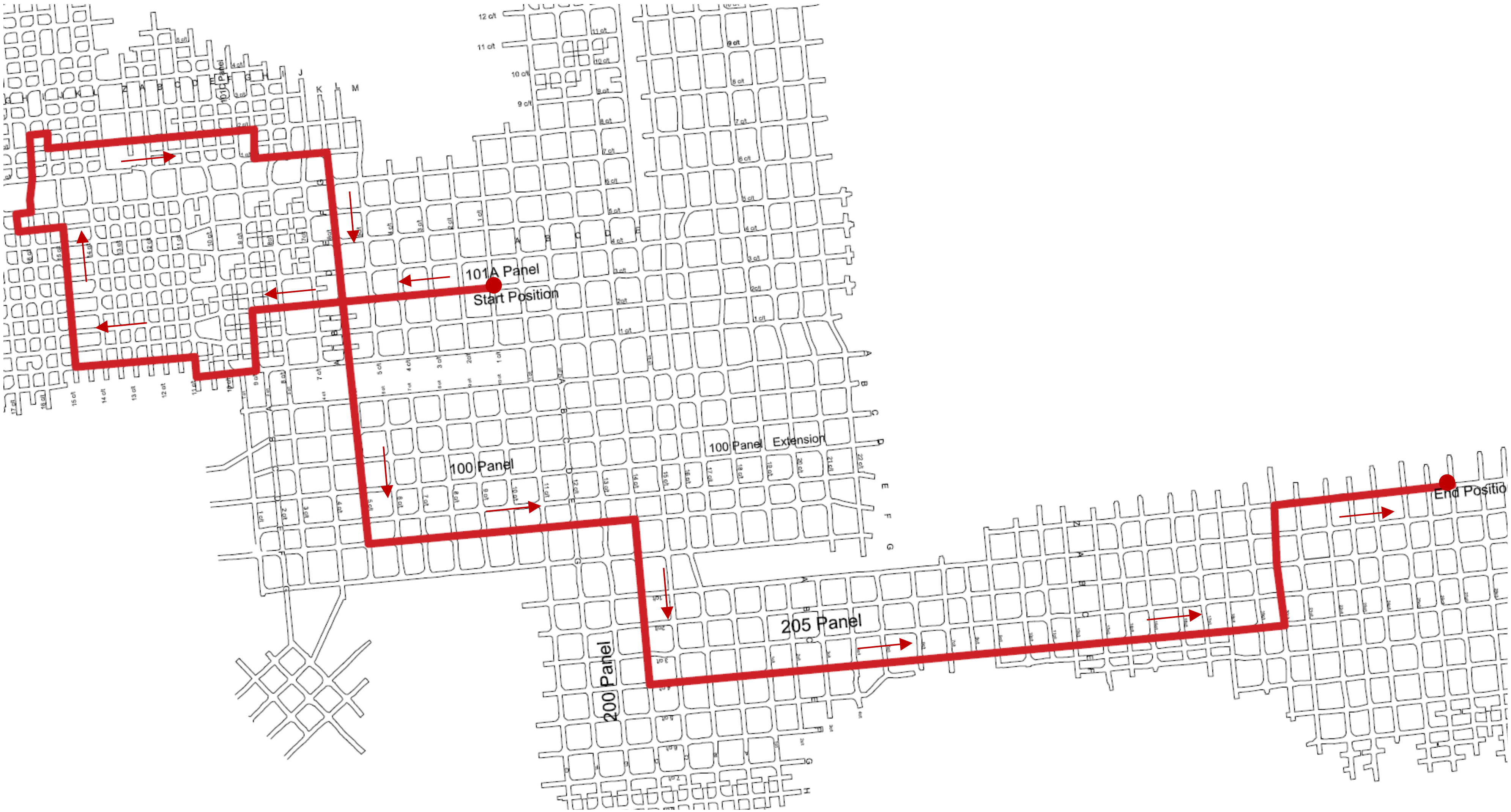


Figure A2-1 Airly Mine Plan Showing the Path of Underground Inspection

Figure A2-2: 101A Panel, 10 Cut-Through, B Heading looking towards C Heading

Figure A2-3: 101A Panel, 12 Cut-Through, B Heading looking into an unsupported split

Figure A2-4 101A Panel, 15 Cut-Through, J Heading, looking towards I Heading

Figure A2-5: 101A Panel, 15 Cut-Through, J Heading looking towards I Heading

Figure A2-6: 101A Panel, 16 Cut-Through, J Heading looking towards 15 Cut-Through

Figure A2-7: 205A Panel, 20 Cut-Through, C-D Heading looking towards B Heading

Figure A2-8: 205A Panel, 20 Cut-Through, B Heading looking into pillar corner

Figure A2-9: 205A Panel, 26 Cut-Through, Z Heading looking towards 25 Cut-Through

Figure A2-10: 205A Panel, 30 Cut-Through

Appendix 3 Assessment of Time to Failure of Coal Pillars

Following the Coalbrook disaster in South Africa, efforts went into statistical analyses of collapsed and uncollapsed cases using the Maximum Likelihood (ML) method. This led to establishment of the well-known empirical coal pillar strength formula of Salamon and Munro (1967). Over 2.5 million coal pillars have been developed in South African coal mines since the establishment of this formula (Salamon, Canbulat and Ryder, 2006), which has certainly been successful and prevented further violent multiple pillar failures.

In 1996, a back analysis of the collapsed and uncollapsed cases led to the development of the Australian empirical coal pillar strength formulae in the form of power and linear functions (Salamon et al., 1996). During the intervening years, this formula has also been proven to be successful in most instances.

An obvious disadvantage of the original study of Salamon and Munro (1967) was that the databases used in the analysis had a limited number of collapsed and uncollapsed cases. A further study by Salamon, Canbulat and Ryder (2006) overcame this problem and introduced a series of formulae for different coalfields and seams in South Africa using the same principal of statistical back analysis of collapsed and uncollapsed cases. The limitations associated with computing power were also overcome in the study and different distributions and formulae in the form of power, linear and non-linear functions were established.

Today, the resultant pillar strength formulae from these previous studies as well as the behaviour of the coal pillars are well understood. However, an important assumption made in these previous studies, for practical reasons, was that the behaviour of the pillars is not time dependent; therefore, the formulae established do not provide an associated probability of survival for the life of coal pillars. In other words, there is no unique relationship between the initial mining geometry and pillar life. This is evident in Figure A3-1, which shows the safety factor and life of collapsed South African pillar cases in the database presented by Salamon, Canbulat and Ryder (2006).

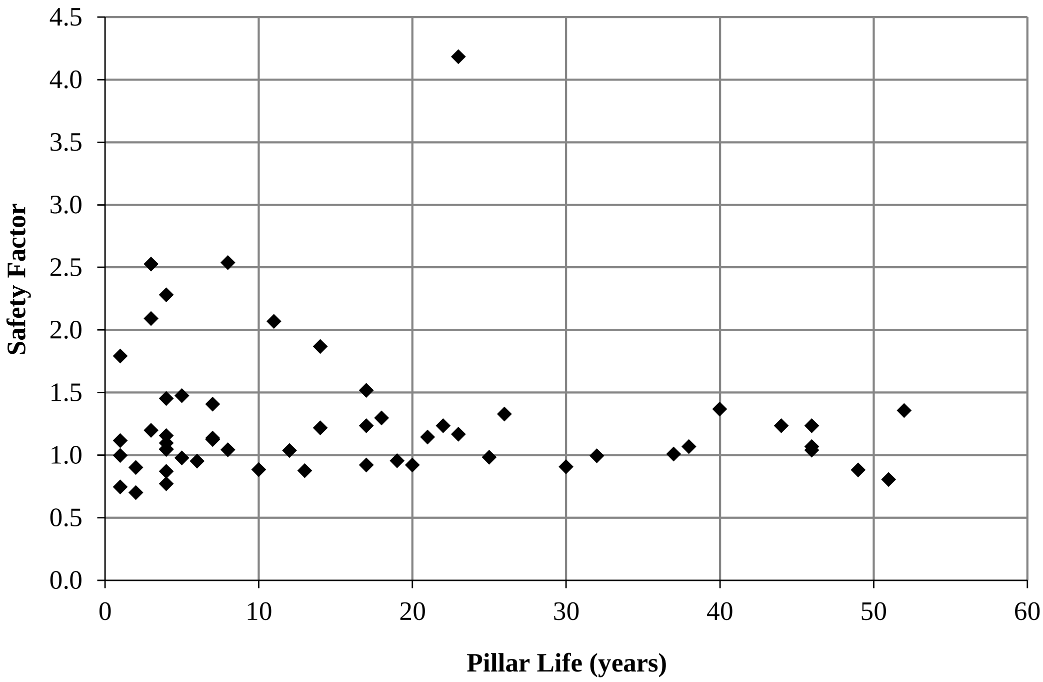


Figure A3-1: Design safety factor versus time interval. Data from South African collapsed cases using the original Salamon and Munro (1967) pillar strength formula (after Salamon, Canbulat and Ryder, 2006)

Numerous authors in Australia, USA, South Africa and elsewhere attempted to establish a relationship between the time to failure and the pillar safety factor and/or other variables (e.g., mining height, pillar width to height ratio, etc). Unfortunately all these attempts were regrettably failed to come up with a sound and acceptable methodology. The simple reason for this is that the fundamental principles of coal pillar strength formulae have not been taken into account in calculating the time dependent behaviour of coal pillars.

A3.1 General Remarks

The methodology used in the studies of Salamon and Munro (1967) in South Africa and Salamon et al. (1996) in Australia are identical. In both studies it was postulated that (i) the strength of a pillar can be expressed as a function of the linear dimensions of the pillar, (ii) the mean stress acting on a pillar is the tributary area load and (iii) failure occurs when the true load exceeds the actual strength, which can be expressed in terms of the conventional safety factor (*SF*):

$$SF = \frac{Strength}{Load} \qquad [1]$$

The general 'power' formula for strength (σ_p) was defined by Salamon et al. (1996) as:

$$\sigma_p = K \frac{(w\Theta)^{\alpha}}{h^{\beta}} \qquad [2]$$

where K, α and β were determined by a statistical analysis of collapsed and uncollapsed pillar geometries, *w* and *h* are pillar width and mining height, in metres. Θ is a dimensionless 'aspect ratio' factor to account for pillar length. Salamon et al. (1996) determined the values for K, α and β to be 8.6 MPa, 0.51 and –0.84 respectively.

The dimensionless aspect ratio is a modification of hydraulic radius concept (effective pillar width) of Wagner (1980) and as follows:

When pillar width to height (w/h) ratio <3:

$$\Theta = 1 \qquad [3]$$

When 3≤w/h≤6:

$$\Theta = \left[\frac{2l}{w+l}\right]^{\frac{(w/h)-3}{3}} \qquad [4]$$

where *l* is pillar length.

When w/h >6:

$$\Theta = \left[\frac{2l}{w+l}\right] \qquad [5]$$

Salamon (1982) proposed an extension to his original pillar strength formula to account for the increased strength "squat" pillars with large width to height ratios. Laboratory tests, field trials and *in situ* measurements were conducted to observe the performance of squat coal pillars. This was achieved by examining the extent of fracturing on the pillar sides as well as monitoring pillar dilation and the stress profile of pillars designed according to the squat pillar formula, with the assumptions that the critical width to height ratio (R_0), where deviation from Salamon and Munro's (1967) original formula occurs, is 5.0 and that the rate of strength increase (ε) is 2.5. The assumption that the critical width to height ratio be equal to 5.0 was also partly based on the fact that no pillar had collapsed with a width to height ratio greater than 3.75 until 1988 (Madden and Canbulat, 1997).

Salamon et al. (1996) proposed the following squat pillar formula in Australia:

$$\sigma_s = \frac{27.63\Theta^{0.51}}{w^{0.22}h^{0.11}}\left\{0.29\left[\left(\frac{w}{5h}\right)^{2.5} - 1\right] + 1\right\} \quad [6]$$

where σ_s is the strength of a squat pillar.

As mentioned above, in the analyses, the load acting on pillars was calculated using the Tributary Area Theory (TAT), which assumes that each pillar carries a proportionate share of the full overburden load. Assuming H is depth to the seam floor, b is roadway width, w is pillar width, C is centre distance, then for a square pillar layout the pillar load (q_m) can be estimated in MPa units as:

$$q_m = \frac{\gamma H C^2}{w^2} \quad [7]$$

where $C=w+b$ and γ is the average specific weight of the overburden rocks.

A3.1.1 Maximum Likelihood Method

In all three of the above mentioned studies, the ML method was utilised to estimate the unknown variables in the strength formulae.

The ML method is a well-known and frequently used statistical procedure for parameter estimation, K α and β in pillar strength formulae. The estimation begins with the mathematical expression known as the likelihood function of the sample data (Salamon, Canbulat and Ryder, 2006).

In pillar strength studies, the starting point in the ML method is to write down the critical safety factor S_c of a given pillar (the safety factor at which a collapse actually occurs), as in Equation [1].

The strength is given by some assumed expression which is a function of pillar geometry and a set of unknown strength parameters; while the load q_m is known from TAT and is given by Equation [7].

A probability density distribution, *f(S)*, with corresponding cumulative distribution, *F(S)*, also has to be assumed in order to describe the spread of critical safety factors about the median of 1.0. The standard deviation of these distributions is another unknown parameter which has to be estimated by ML analysis.

Next, a 'likelihood function' is set up, which is simply the product of the probabilities of observing the given instances of collapsed and uncollapsed pillars. An optimum set of unknown parameters is then chosen such that this 'likelihood function' is maximised. To simplify the calculations, it is usual to maximize the natural logarithm of the likelihood function, so that the ML formulation finally takes the form:

$$Maximise\, L_L = \sum \ln(f(S_c)) + \sum \ln(F(S_u)) \quad [8]$$

where $f(S_c)$ = probability of collapsed cases
$F(S_u)$ = probability of uncollapsed cases

Note the summations are taken out over the collapsed set c and over the uncollapsed set u. Maximisation of L_L is accomplished by means of a comprehensive search through the space of unknown parameters, starting with a set of arbitrary initial values. Thus, to develop the maximum likelihood approach, it is necessary to postulate that the pillar strength and statistical probabilistic distributions assume a specific form.

A3.3.2 Density Functions of the Critical Safety Factor

Any probability density function, *f(s)*, describing the spread of critical safety factor values, should have the property of median centred at S_c=1 (i.e. satisfying F(1)=50%) and should be zero for negative values of the critical safety factors. Such distributions are inherently skewed. Three distributions, namely lognormal, Weibull and Gamma, were evaluated in the study of Salamon, Canbulat and Ryder (2006) in South Africa. This study indicated that the lognormal distribution provides results at least as robust and consistent as those produced by the Gamma and Weibull distributions. Therefore lognormal distribution is considered to be appropriate to describe the critical safety factors.

This distribution is symmetric in the logarithmic scale, and the standard deviation (σ) is simply a measure of the scatter about the central value of zero. An increase in the logarithmic standard deviation indicates a wider (more scattered) distribution of the data.

The frequency distribution of S_c itself is given by:

$$f(S_c) = \frac{1}{\sqrt{2\pi}\,\sigma\,S_c} \exp\left[-\frac{1}{2}\left(\frac{\ln S}{\sigma}\right)^2\right] \qquad [9]$$

The corresponding cumulative distribution function, $F(S_c)$, is the integral of $f(S_c)$ between the limits zero and S_c, and:

$$F(S_c) = \Phi\left(\frac{\ln S_c}{\sigma}\right) \qquad [10]$$

where Φ is the cumulative normal distribution function.

A3.2 Conventional Modes of Pillar Failure

The exact mode of failure of coal pillars is not known with any certainty, particularly in old, sealed panels. All cases in the failed databases collated around the world were gathered using the observed surface subsidence and where possible, mining experiences in neighbouring panels of the failed panels. Nevertheless, many authors discussed the possible pillar failure modes and found that there are four conventional *long-term* failure modes of a pillar system (excluding (i) sudden, violent failure due instantaneous release of strain energy and (ii) flooded workings that may completely disintegrate the coal pillar). These modes are:

a. Pillar spalling (i.e., pillar is the weakest element in the system).

b. Roof failures (i.e., the roof is the weakest element in the system).

c. Pillar foundation (floor) failure, which in turn pulls the pillars apart and fails it (i.e., floor is the weakest element in the system)

d. Any combination of the above.

By definition, the pillar strength formulae established in South Africa, Australia and USA (and elsewhere) deals with pillars that don't spall, their height stays constant and floor is stable within the working life of panels (i.e., Salamon and Munro, 1967; Salamon and Oravecz, 1976; Salamon et al., 1996, Salamon, Canbulat and Ryder, 2006, Bieniawski, 1992; Mark and Chase, 1994, van der Merwe and Mathey, 2013). When the initial dimensions of pillars start changing due to spalling or increased in mining height, the assessment of their stability becomes complex. Therefore, any particular safety factor values proposed for long-term stability of pillars using the previously established formulae can only provide guidance and should be used with caution in design of long-term stable panels. For example, in Australia, commonly a safety factor of 2.11 is used to ensure the long-term stability of pillars. The apparent reason for this recommendation is that the safety factor of 2.11 corresponds to a probability of failure of $1E^{-6}$, which provide some level of confidence. However, it does not explain explicitly how and why it ensures the long-term stability of pillars. In order to achieve a *reliable* long-term stability of pillars, a method that considers both mechanistic behaviour of pillars and the fundamental principles of the coal pillar strength formulae should be utilised.

A3.3 Pillar Failure Caused by Spalling

It is well-known that the strength of pillars may reduce over time by a spalling process that starts at the pillar edges and works its way into the pillar core (van der Merwe, 1993; Salamon, Canbulat and Ryder, 2006; Canbulat, 2010). The spalling can be caused due to various factors, including, weathering, ventilations changes in the panel and/or flooding of workings. In this failure mode it is assumed that the weakest element of pillar system is the pillar and the roof and floor are stable. As the pillar sides get weaker, spalling occurs and the effective size of the pillar is decreased. Eventually it reaches the stage where the loss of strength is sufficient to result in failure of the pillar (van der Merwe, 1993). This failure mechanism is entirely controlled by the volume of space available underground to allow sufficient spalling for failure, which also implies a maximum depth of spalling. This limitation is referred to as "Geometrical Limits". This concept of spalling was first suggested by Salamon, Ozbay and Madden (1998). A further study conducted by Canbulat and Ryder (2002) somewhat simplified the model. These methods are utilised in this current report.

Using the observations of van der Merwe (1993) and Salamon, Ozbay and Madden (1998) examined the mechanism of pillar failure when the pillars are spalling. In their study, the pillar strength was based on the original model of Salamon and Munro (1967) and the time dependency was introduced through a simple model of time dependent spalling. This combination of effects yields a situation where the pillar width decreases with increasing time. This approach has facilitated the estimation of pillar life expectancy, probability of survival for a specified number of years or indefinitely and to a methodology of designing pillars with a specified probability of survival and of life. It appears on the basis of this work that the time dependent spalling of pillar sides could be an explanation of the failures observed at relatively high nominal safety factor values. Canbulat (2010) adapted this methodology using the pillar strength formulae developed in Australia (Salamon et al., 1996).

It is postulated in the "Geometrical Limits" model that:

- the failure of a pillar is controlled by the volume of space available underground to allow sufficient spalling for failure,
- the underlying strength of pillars remains unaltered and the changes come about merely as a result of time-dependent reduction in pillar width,
- the pillar will fail when the safety factor reaches the critical safety factor, and
- the nominal safety factors at failure are distributed according to the same lognormal distribution obtained in the derivation of the empirical pillar strength formulae.

A3.3.1 Geometrical Limits

In their study Canbulat and Ryder (2002) assumed that a spalling pillar (Figure A3.2), of original width (w) and height (h), continues to scale until a width (w_1) is reached at which the 'apron' of scaled material forms a fully confining rim of height (h) and width (c) given by:

$$c = h \cot \varphi \qquad [11]$$

where φ = angle of repose.

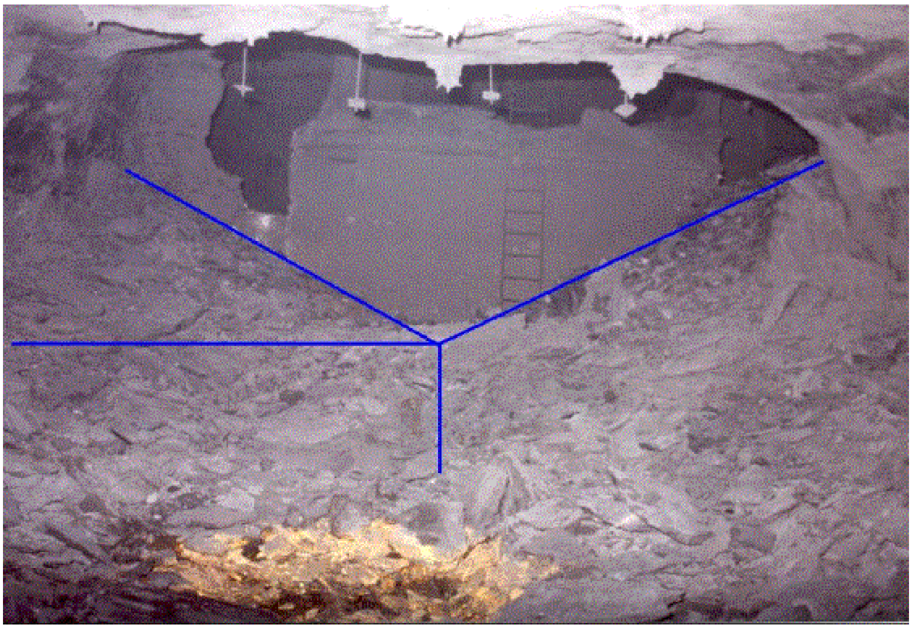
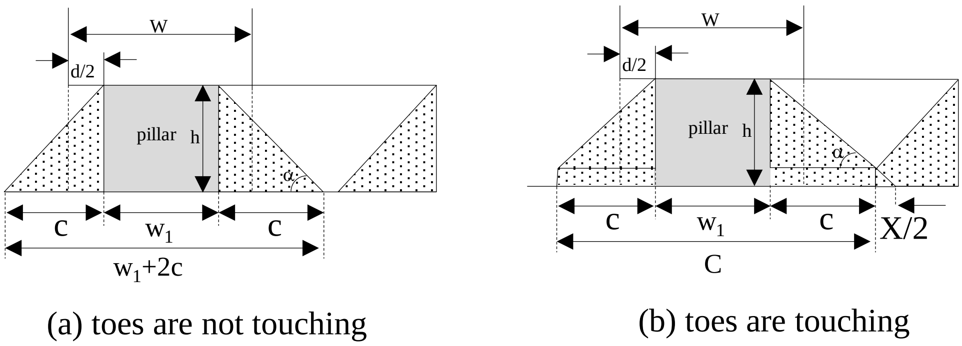


Figure A3.1. A scaled pillar indicating the angle of repose and the height of the rubble (after Canbulat and Ryder, 2002)

Figure A3.3a illustrates the geometry involved. (It may be that the total width of the spalled apron w_1+2c exceeds the centres spacing *"C"* of the pillars, and overlap occurs with the aprons around the neighbouring pillars. This case is examined later.)



w = Original pillar width (m)
b = bord width (m)
c = peeled off material distance (m)
α = angle of repose (35°)
h = mining height (m)
w_i = pillar width after scaling (m)
d = amount of scaling on one side
C = centre distance (m)
X = amount of overlap

Figure A3.2: Section view of a spalled pillar

The volume of apron must equal the volume of scaled coal, allowing for a bulking factor *B*. The volume of a truncated pyramid is given by $V = (h/3)[A_1 + A_2 + \sqrt{A_1 A_2}\,]$, where A_1 is the area of the base, A_2 is the area of the top, and *h* is the height. Thus, for square pillars, the volume of scaled material is given by:

$$V = \frac{h}{3}[(w_1 + 2c)^2 + w_1^2 + (w_1 + 2c)w_1] - hw_1^2 \qquad [12]$$

This must equal the volume of bulked material from the pillar:

$$V = Bh(w^2 - w_1^2) \tag{13}$$

Equating, and solving this quadratic equation for w_1, the result is

$$w_1 = -\frac{c}{B} + \sqrt{w^2 - \frac{c^2}{B^2}\left(\frac{4B}{3} - 1\right)} \tag{14}$$

The total depth of spalling d is then given by:

$$d = w - w_1 \tag{15}$$

For validity of Equation [14], it is obviously necessary that $w_1>0$. For this to be true, it can be shown that:

$$\frac{w}{h} > \sqrt{\frac{4}{3B\tan^2\alpha}} \tag{16}$$

That is, provided the original w/h ratio of the pillar exceeds about 1.5, the pillar can still spall to the limit set by Equation [14] and will be left with an uncollapsed core of width $w_1>0$.

A further limit to the validity of Equation [14] is that the edges of the spalled aprons do not touch or intersect; that is, that

$$w_1 + 2c < C \tag{17}$$

where C is the centre distance. For high mining heights (i.e., $h>2.5$m), this relationship may not be satisfied, and the following more complicated situation has to be analysed (Figure 3b).

The actual total width of the apron is now C, and the amount X of overlap is given by:

$$X = w_1 + 2c - C \tag{18}$$

The height of overlap h_0 is given by:

$$h_0 = \frac{1}{2}X\tan\varphi = \frac{Xh}{2c} \tag{19}$$

The volume, V_0, of the overlapped portion of the apron has now to be subtracted from Equation [12], where:

$$V_0 = \frac{1}{3}h_0\left[(C+X)^2 + C^2 + (C+X)C\right] - C^2h_0 \tag{20}$$

$$V_0 = \left(\frac{X^2h}{2c}\right)\left(C + \frac{X}{3}\right) \tag{21}$$

After substituting Equation [18], this leads finally to a *cubic* equation for w_1. The exact form of Equation [14] for this case now reads:

$$w_1 = -\frac{c}{B} + \sqrt{w^2 - \frac{c^2}{B^2}\left(\frac{4B}{3} - 1\right) + \frac{X^2(C + X/3)}{2cB}} \qquad [22]$$

Given an initial estimate of w_1 from Equation [14]; Equations [18] and [22] are evaluated and give an improved estimate for w_1. This process is repeated until the change in w_1 becomes negligible; generally, only a few iterations will be required. Alternatively, the following formula, based on Newton iteration, allows a single step to the final solution:

$$w_1^{final} \approx w_1 + \frac{X^2(C + X/3)}{4c(c + Bw_1) - X(2C + X)} \qquad [23]$$

where w_1 is from Equation [14] and X is from Equation [18].

As before, the total depth of spalling d is then given by:

$$d = w - w_1^{final} \qquad [24]$$

Canbulat and Ryder (2002) identified the following limitations in this model:

- This model assumes a vertical rib profile. In reality, in the early stage s of spalling the lower portions of a pillar are probably protected by the spoil pile of scaled material, and only the upper portions of the pillar are susceptible to further scaling. This possible indicates a stepwise rib profile. Although the difference may be insignificant in terms of change in volumes, this is an issue that needs to be resolved.

- The strength of the spalled pillar would possibly be greater than that normally associated with a freshly-cut pillar of width, w_1, due to the strengthening effect of the spalled material.

- In certain circumstances, the roadway width can enlarge significantly due to assumed spalling. These large roof spans may be prone to instability in their own right, especially after years of potential deterioration.

A3.3.2 Spalling of Pillar at Failure

In order to determine the required spalling distance to reduce the safety factor to the critical safety factor (i.e., S_c=1), the approach developed by van der Merwe (1993) can be used. In this approach, it is assumed that the original pillar width spalls by an amount, d_c, then the effective pillar width at critical safety factor is w-d_c. The critical spalling depth at failure can be solved in Equations [1], [2] and [7] by assuming that the centre distance is constant; that is:

$$d_c(S_c) = \frac{1}{2}\left[w - \left(\frac{\gamma H S_c h^{\beta} C^2}{K}\right)\right]^{\frac{1}{2+\alpha}} \qquad [25]$$

Once the critical spalling depth is known, the time elapsed to failure can then be calculated using the following simple formula:

$$t_c(S_c) = \frac{d_c(S_c)}{r} \qquad [26]$$

where r is the rate of spalling in m/year.

Note that the frequency of the critical safety factor at failure is represented by a lognormal distribution. The standard deviation of this distribution was determined in the Australian study by Salamon et al. (1996) as to be 0.157.

A3.3.3 Pillar Life Expectancy and Probability of Survival in Case of Pillar Spalling

Salamon, Ozbay and Madden (1998) stated that it is not possible, due to the probabilistic definition of pillar strength, to determine unequivocally whether a pillar will or will not fail and that no unique relationship exists between the initial mining geometry and pillar life.

Salamon, Ozbay and Madden (1998) also stated that although no relationship can be established between pillar life and the initial mining geometry, the probability that failure will or will not occur can be determined. However, if pillar spalling occurs, the situation becomes complex. The effect of spalling reduces the pillar width and, therefore, may cause the failure of a pillar at some later time. The Monte Carlo technique can be employed to evaluate this phenomenon and the expected life of pillars.

A3.4 Pillar failure caused by Roof Failure

It is stated by many authors in the past that pillars may also fail through progressive roof failure, which in turn increases the effective mining height, reduces the pillar strength and the stiffness of the pillar. In this mode of failure it is assumed that the weakest element in the pillar system is the roof (Canbulat and Zhang, 2016).

It is postulated in this failure mode that:

- the failure of a pillar is controlled by the roadway volume of space available to allow sufficient roof failure to occur,
- the underlying strength of pillars remains unaltered and the changes come about merely as a result of time-dependent increase in pillar height due to roof failures,
- pillars will fail when the safety factor reaches the critical safety factor, and
- the nominal safety factors at failure are distributed according to the same lognormal distribution obtained in the derivation of the empirical pillar strength formulae.

It is also of note that since the roadways surround the pillars, the pillar stability is controlled by the roadway height more than the intersection height. However, intersections are inherently wider than the roadways; therefore, it is likely that the intersections will fail before the roadways fail. The failed material from the intersections will spill into the roadways and somewhat decrease the failure height in roadways. Therefore, the calculations presented in this section are somewhat conservative.

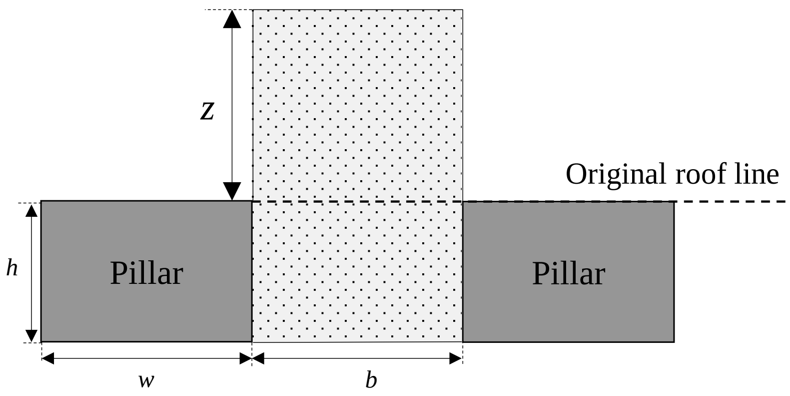
A3.4.1 Progressive failure of roof

In this case the failure is driven by increased roof height (Figure A3.4). As the roof fails, due to bulking factor, the failed material chocks up at some distance into the roof and reaches the maximum height of possible, provided that the pillars are not at shallow depth and the failure does not reach surface.

The maximum possible roof fall height (*z*) can be calculated using the following formula:

$$z = \frac{h}{B-1} \qquad [27]$$

Where *h* is the original mining height, *B* is the bulking factor. It is postulated that the failure of roof is a plug type, rectangular shape failure that increases the pillar height. It is also of note that the height of failure in intersections is expected to be larger than the roadways due to inherently wide dimensions of intersections. However, the pillar stability is mostly controlled by the failure of roadways as they surround the pillars.



w = original pillar width (m)
b = roadway width (m)
h = original mining height (m)
z = roof fall height (m)

Figure A3.3. Section view of progressive roof failure

A3.4.2 Pillar of Life Expectancy and Probability of Survival in Case of Roof Failures

Similar to the above pillar spalling calculations, the critical mining height (z_c) at failure can be solved in Equations [1], [2] and [7]:

$$z_c(S_c) = \left[\frac{8.6(w\Theta)^{2.51}}{\gamma H C^2 S_c} \right]^{1/0.84} \qquad [28]$$

where $z_c(S_c) = z+h$.

Once the critical roof fall height is calculated, the time elapsed to failure can be calculated using the following simple formula:

$$t_c(S_c) = \frac{z_c(S_c)}{r_r} \qquad [29]$$

where r_r is the rate of roof failure in m/year.

It is of note the value of rate of pillar spalling or roof failure has no influence on the results in this current study as the aim is to determine the survival probabilities of infinitely stability pillar geometries. However, if annualised probability of survival of pillars is required, the rate of pillar and roof spalling can be calculated more accurately and taken into account.

In calculation of pillar survival probabilities due to roof failures, it is postulated that the increased mining height reduces the pillar strength, which in turn causes the failure of a pillar at some later time. The Monte Carlo technique can also be employed to evaluate this phenomenon and the expected life of pillars. The following steps are implemented in these calculations:

- The maximum possible roof fall height is calculated using Equation [27].
- In calculation of survival probabilities, the critical height of pillars and thus life of pillars is calculated using the above equations.
- The calculated maximum life expectancy is checked against the probabilistic life expectancy to calculate the survival probability.

An example of these calculations is presented in the following section.

A3.5 Combined Failure Mode

The above sections provided methods to evaluate the long-term stability of pillars in cases of pillar spalling and roof failures. These methods provide survival probabilities of pillars based on the original pillar strength study outputs (i.e., strength formulae and the standard deviation) and the geometrical limits of underground space. The critical question is which probability of survival should be used in the design and evaluation of coal pillars.

The following example reveals an answer for this question. The following input parameters are used in this example.

Depth of cover (m)	Pillar width and length centres (m)	Mining height (m)	Roadway width (m)
110	15	2.8	5.5

The following general input parameters are also used:

Bulking factor (coal)	Bulking factor (roof)	Angle of repose (^{o})	Scaling rates for roof and pillar (m/year)
1.35	1.4	35	0.2

Using the UNSW pillar strength formula, the safety factor of the pillars is 2.7.

The following results are evident using the above equations:

- The roof fall height that will reduce the factor of safety from 2.7 to 1.0 is approximately 7m. Therefore, the life expectancy of the pillars is 35 years. In this mode, the pillar failure will be controlled by the increased pillar height.

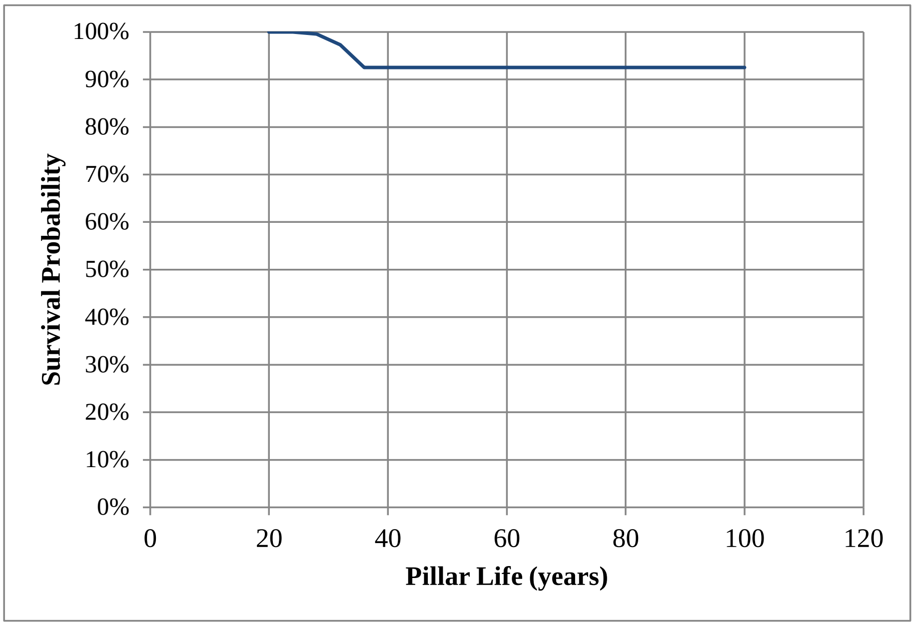
- The spalling depth that will reduce the pillar safety factor from 2.7 to 1.0 is 1.6m (on one side), i.e., approximately 1/5 of the total amount of roof failure required to fail the pillars. Therefore, in this failure mode the life expectancy is approximately 8 years. In this mode, the pillar failure will be controlled by the reduced pillar width.

- The survival probability of the pillars in the case of roof failures is 92.5% and survival probability due to pillar spalling is 99.1%, which indicates that it is highly likely that the pillar failure will be controlled by the roof failures (Figure A3.5).

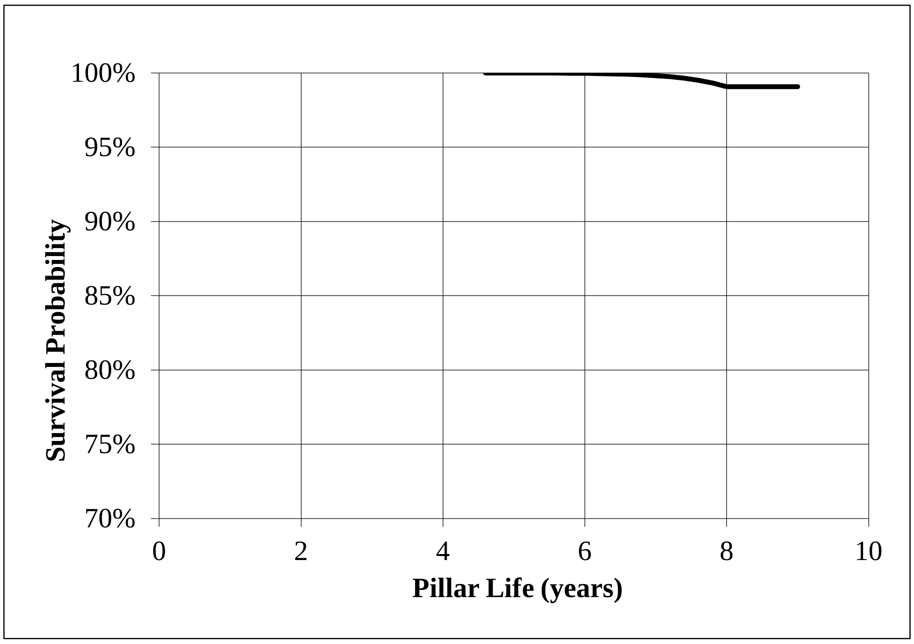
- Although survival probabilities can be calculated for both failure modes, it is not know exactly what the roof and pillar spalling rates will be. Therefore, it is reasonable to assume the minimum probability of survival of 92.5% in this case.

- It is considered that this minimum survival probability is reasonable to assume that these pillars will be long–term stable and it is highly likely that this panel will be infinitely stable.

- If the rates of pillar spalling and roof failure are similar, which is a possibility, the rib spalling will reach the maximum value before the roof failure is complete. In this case, it is highly likely that the pillar will be locked-in itself and the roof failures will not cause any further instability.



(a)



(b)

Figure A3.4. Survival probability of an example pillar (a) failure mode is controlled by roof falls, (b) failure is controlled by pillar spalling

A3.6 References

Bieniawski ZT, 1992. A method revisited: coal pillar strength formula based on field investigations. In: Proceedings of the Workshop on Coal Pillar Mechanics and Design. Pittsburgh, PA: U.S. Department of the Interior, Bureau of Mines, IC 9315, pp. 158-165.

Canbulat, I, and Zhang, C, 2016. Risks Associated with Shallow Bord and Pillar Workings in Coal Mines, International Journal of Rock Mechanics and Mining Sciences. (under review).

Canbulat, I and Ryder, JA, 2002. Prediction of Surface Subsidence and Sinkholes. Proceedings of the SANIRE Symposium: Re-Defining Boundaries, Vereeniging.

Madden, BJ. and Canbulat, I, 1996. Reassessment of Coal Pillar Design Procedures. Proceedings of the Safety in Mines Research Advisory Committee (SIMRAC) Symposium. Mintek, Johannesburg.

Madden, BJ. and Canbulat, I, 1997. Practical Design Considerations for Pillar Layouts in Coal Mines. Proceedings of the 1st Southern African Rock Engineering Symposium (SARES 97), Johannesburg, South Africa.

Mark C and Chase FE (1997). Analysis of retreat mining pillar stability (ARMPS). In: Proceedings - New Technology for Ground Control in Retreat Mining. Pittsburgh, PA: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 97-122, IC 9446, pp. 17-34.

Salamon, MDG, 1982. Unpublished report to Wankie Colliery. Zimbabwe.

Salamon, MDG., Canbulat, I and Ryder, JA, 2006. Seam-Specific Pillar Strength Formulae for South African Collieries. Proceedings of the 41st U.S. Rock Mechanics Symposium. Golden, CO.

Salamon, MDG, Galvin, JM, Hocking, G and Anderson, I, 1996. Coal Pillar Strength From Back-Calculation. Strata Control for Coal Mine Design, UNSW. Final Project Report, No: RP 1/96. Joint Coal Board.

Salamon, MDG. and Munro, AH, 1967. A Study of the Strength of Coal Pillars. Journal of Southern African Mining and Metallurgy, 68(2):55-67.

Salamon, MDG, Ozbay, MU and Madden, BJ, 1998. Life and Design of Bord and Pillar Workings Affected by Pillar Spalling. Journal of Southern African Mining and Metallurgy, 98:135-145.

Salamon, MDG., and Oravecz, KI, 1976. Rock Mechanics in Coal Mining (P.R.D. series no. 198). Johannesburg: Chamber of Mines of South Africa.

van der Merwe, JN, 2003. Predicting Coal Pillar Life in South Africa Journal of Southern African Mining and Metallurgy, V 103:293–301.

van der Merwe, JN, 2004. Verification of Pillar Life Prediction Method. Journal of Southern African Mining and Metallurgy, V 93:71–77.

van der Merwe, JN, 1993. Revised Strength Factor for Coal in the Vaal Basin. Journal of Southern African Mining and Metallurgy, V 104:667–676.

van der Merwe, JN, and Mathey, M, 2013. Update of Coal Pillar Strength Formulae for South African Coal Using Two Methods of Analysis. Journal of Southern African Mining and Metallurgy, V 113 (2):841-847.

Wagner, H, 1980. Pillar Design in Coal Mines Journal of Southern African Mining and Metallurgy, 80:37-45.

Appendix 4 Review of Airly Mine Subsidence Predictions

The IRP reviewed the subsidence predictions previously made for the project using the Incremental Profile Method, revisited the database to confirm it was relevant, reviewed a variety of analytical methods based on the concepts of elastic strata compression, and reviewed other experience in the Newcastle Coalfield. This section presents the outcomes of the subsidence reviews undertaken but, first, a section on the context of subsidence predictions is included to illustrate that adequacy rather than accuracy of predictions should be emphasised. For Airly Mine, there are a range of methods available to predicted subsidence. Given that there is opportunity to measure the actual subsidence above a series of panels prior to mining near or directly below sensitive features and the mining system can be adjusted to give less subsidence, albeit with the potential to leave significantly more coal, less reliance needs to be placed on accurately predicting subsidence by any method.

A4.1 Context

A review of the reliability of subsidence prediction methods in NSW was undertaken and presented in a paper by Holla (1991(b)). Of fourteen cases presented in the paper, predictions of maximum total subsidence did not differ from observed subsidence by more than 11%, with average differences of less than 7%. The perspective on accuracy of predictions was emphasised in the paper where Holla stated "*Those who argue that subsidence prediction should be done accurately to the nearest millimetre appear to believe that the subsidence prediction as an academic exercise is an end in itself. They lose sight of the fact that the prediction is only a means towards the end objective of assessing damage arising from the predicted subsidence*", and "*Available methods for predicting subsidence, their limitations and advantages are dealt with. The difficulties in achieving "accurate" predictions are highlighted. At the same time the need for and usefulness of such "accurate" predictions in all cases is questioned. The concept of adequacy of prediction rather than accuracy is emphasised*."

More recent reviews have indicated that the precision of predicting maximum vertical subsidence is in the range of ±15 % to ±25 % and probability of exceedance is 5% (or 95% confidence level). But all these reviews conclude that subsidence prediction is but one of the tools in the established decision making process for developing new mining areas and one of the tools used in developing strategies for managing the possible impacts resulting from mining.

An appreciation of the accuracy of the subsidence predictions is important in the decision making process.

The knowledge base of methods of subsidence prediction and the impacts resulting from subsidence effects continues to develop through ongoing research. Regardless of the level of detailed information and complexity of subsidence prediction models, no subsidence prediction should be regarded as being perfectly accurate and there will always be a limit to the accuracy of subsidence predictions that can be achieved given the inherent variability in the many factors that result in subsidence effects.

Similarly it is inevitable that exceedances of subsidence predictions will still occur, however, there are many monitoring and management strategies that can be used to minimise subsidence impacts once subsidence monitoring has detected the possibility of subsidence exceedances. A greater understanding of the accuracy and reliability of the subsidence predictions will hopefully lead to more informed decisions in developing management strategies for surface features affected by mining.

The ability to make accurate subsidence predictions is not the essential requirement of good decision making. Good decision making is possible without accurate predictions, if the decision maker can anticipate the worst eventually and design against it. Subsidence engineering involves deciding, in each situation, how much confidence should be placed in the results of calculations and what allowances should be made for the unpredictable. The definition of successful prediction, therefore, depends upon the consequences of incorrect predictions. When the possible cost of failure is small, then skating close to the edge may be justified.

Conservative upper bound surface ground movement predictions and the resulting conservative impact assessments may lead to conservative mine layout designs that may unnecessarily sterilise coal reserves. However, sterilisation may be justified when balanced against the consequences of bold but risky predictions.

While the consequence of the cost of damage to a structure may be considered acceptable, an irreversible cost of an escarpment cliff failure may be unacceptable. While the former cost to rectify a structure may be less than the value of coal sterilised, the latter may be considered "invaluable". When the possible cost of damage is small, taking risk in predictions may be justified. When the cost is large, safety and conservatism are paramount.

It is therefore highly recommended that subsidence monitoring above the early miniwall panels at Airly Mine is used to confirm that the total subsidence, sag subsidence plus strata compression subsidence, is within expectations and less than 125 mm as required by the consent conditions. In the IRP's experience, strata compression subsidence tends to be relatively insensitive to panel width and pillar widths. A significant reduction in coal recovery may be required in order to significantly reduce surface subsidence.

It is further recommended that mining under significant cliff lines that rely on subsidence being less than 125 mm for their protection is delayed until there is monitoring experience to demonstrate that subsidence levels can be maintained at the same or similar levels to those experienced at Clarence Colliery.

A4.2 Previously Estimated Subsidence Using Incremental Profile Method

In March 2015 MSEC undertook a review of the predicted subsidence levels over the proposed Airly Mine. These predictions were revisited as part of the IRP review and were found to consistent with the best available subsidence monitoring data.

The 2015 MSEC study advised:

"*If the IPM method is fully calibrated for the Airly Mine, then calibration factors would probably be applied because of the presence of the strong Burra-Moko Sandstone unit at Airly. However, because this peer review was limited to 8 working days, MSEC has not used a fully calibrated IPM method to predict subsidence at Airly Mine. Hence only a quick review has been undertaken, using an uncalibrated IPM model and assumed locations of panels and pillars within the Panel and Pillar Zones, in order to check the order of magnitude of the predicted levels of subsidence at Airly Mine."*

"The uncalibrated IPM model provided the following preliminary predicted subsidence contours plus the following six cross sections that show the predicted subsidence profiles along six prediction lines that are located as shown in the following sketches."

It can be noted from the above IPM predicted subsidence contours and the predicted subsidence cross sections at Airly Mine that the maximum predicted incremental over each of the proposed panels is approximately 60 to 70 mm and the total predicted subsidence after accumulating the influence at each point from the nearby incremental panels is less than 125 mm at a point over Mount Genowlan where the depth of cover and the compression or squashing of the chain pillar is the greatest, i.e. 310 m.

At these low predicted levels subsidence no surface cracking damage is expected over the plateau areas of the mesas (that were not previously impacted by old shale mine workings), unless there is some unexpected geological changes in the strata. Extracting panels under the old shale workings would result in additional subsidence, surface fracturing and cliff falls within the New Hartley Shale Mine potential interaction zone.

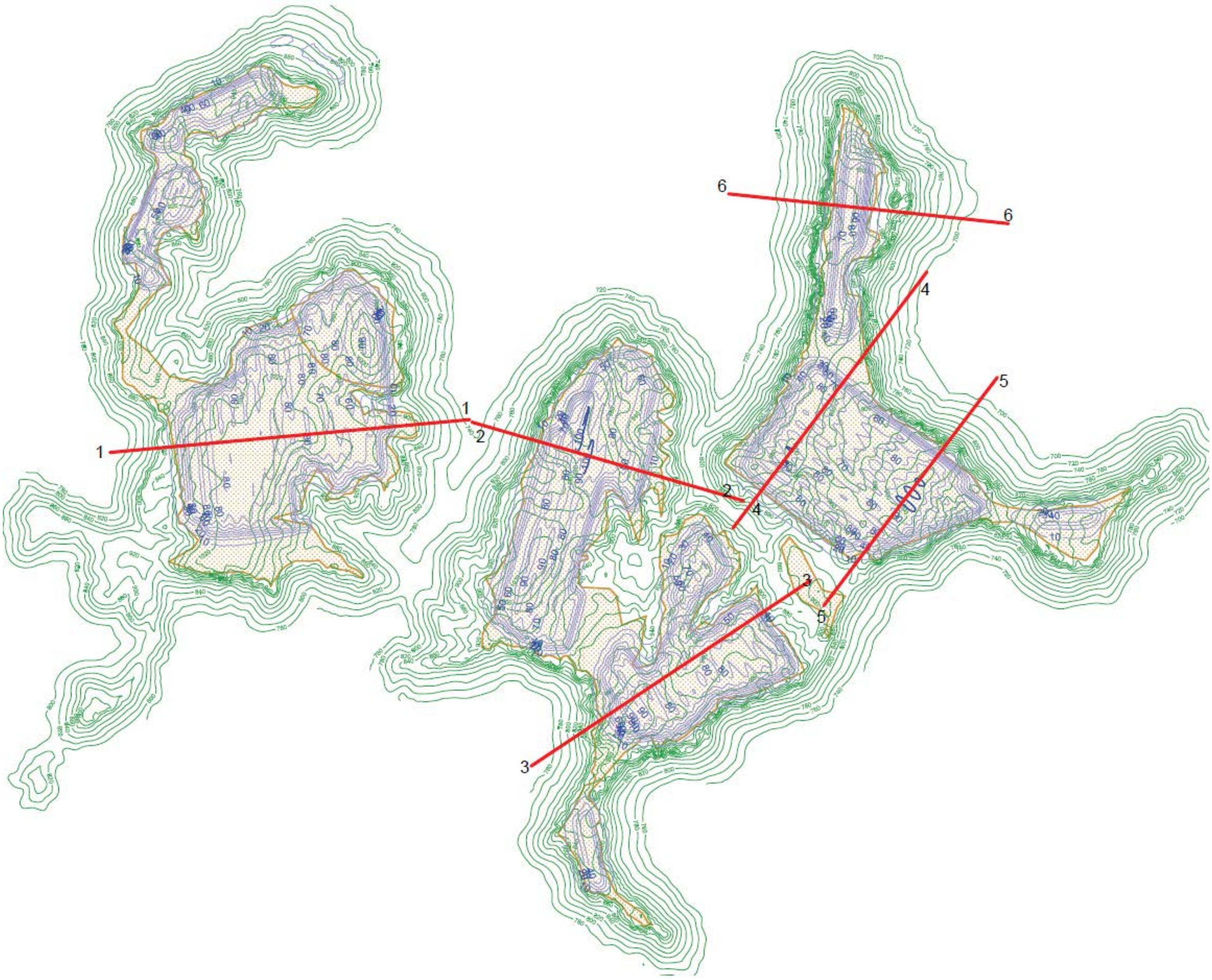


Figure A4.1: Predicted Subsidence Contours over the Airly Mine using an Uncalibrated IPM Model

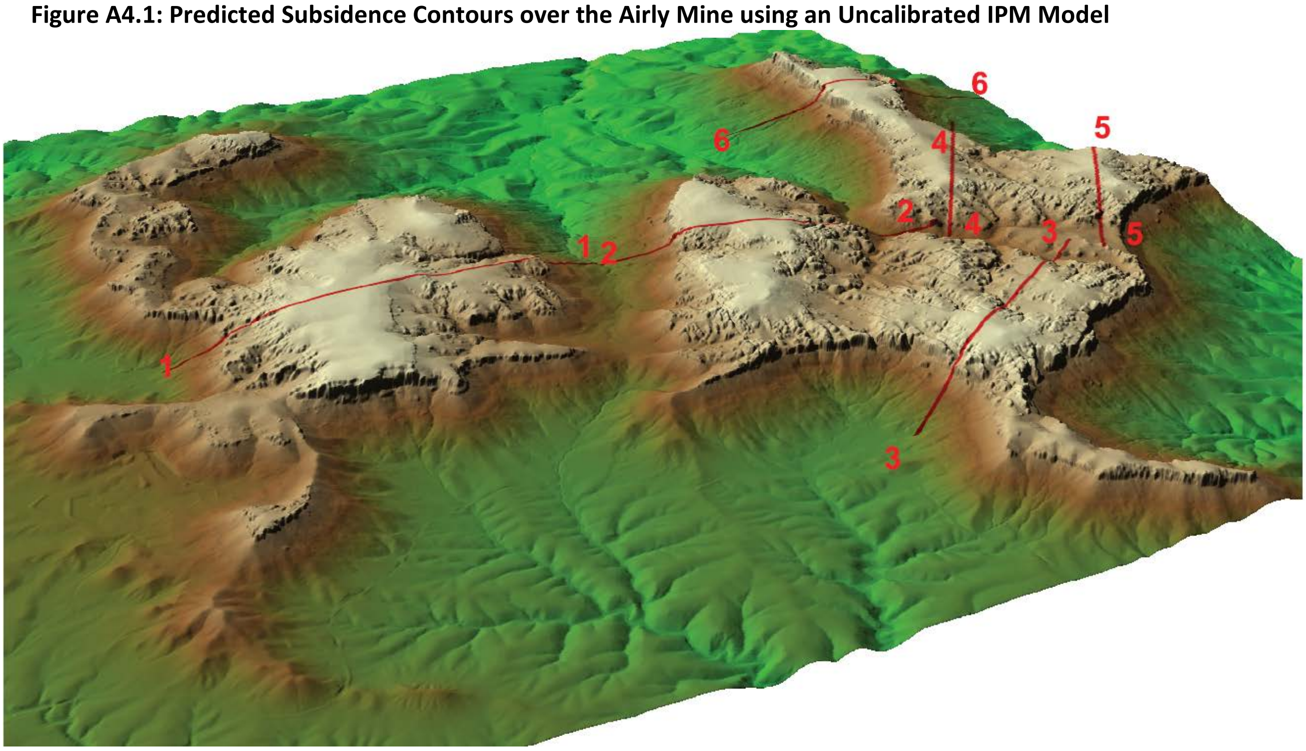


Figure A4.2: Cross-section locations

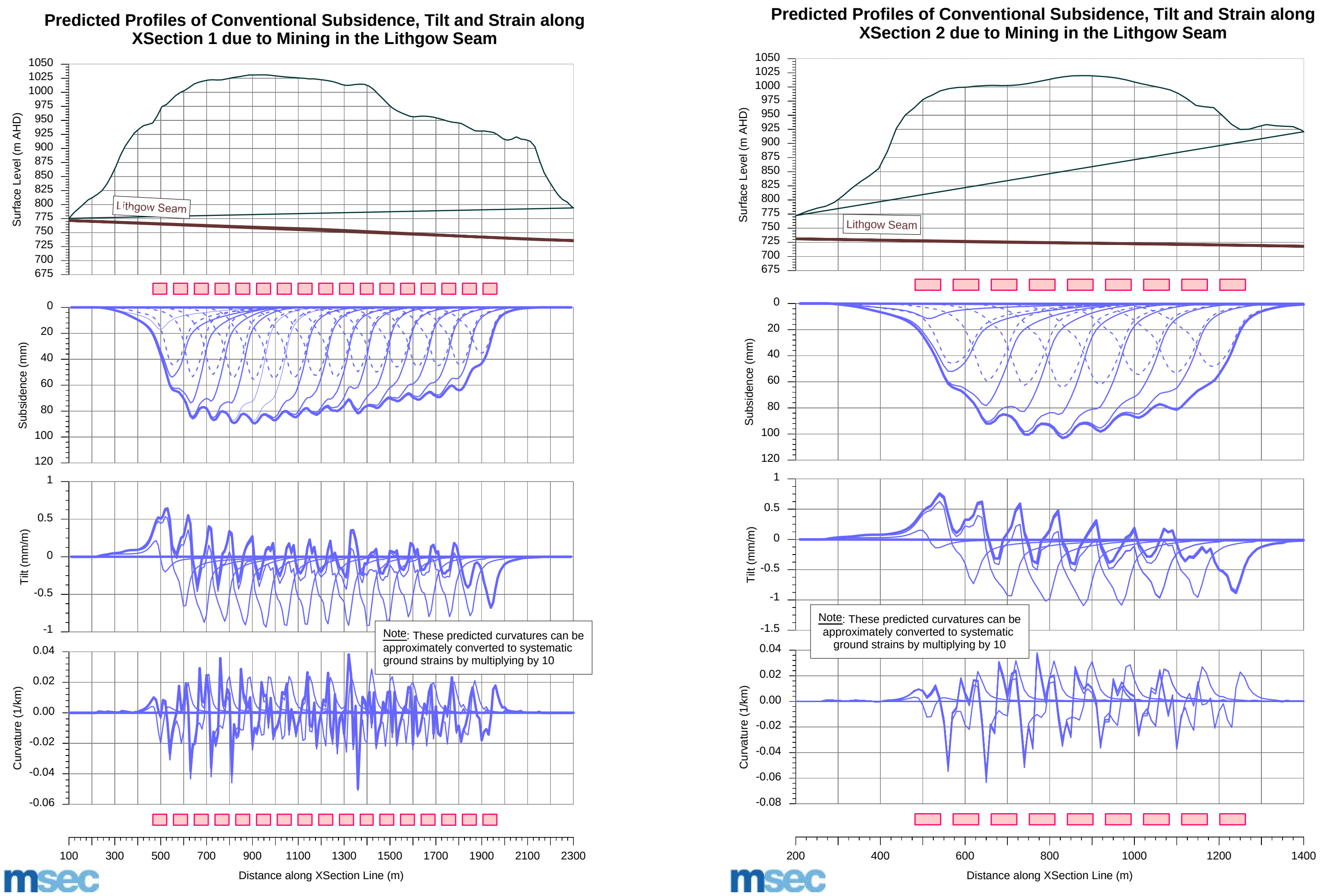
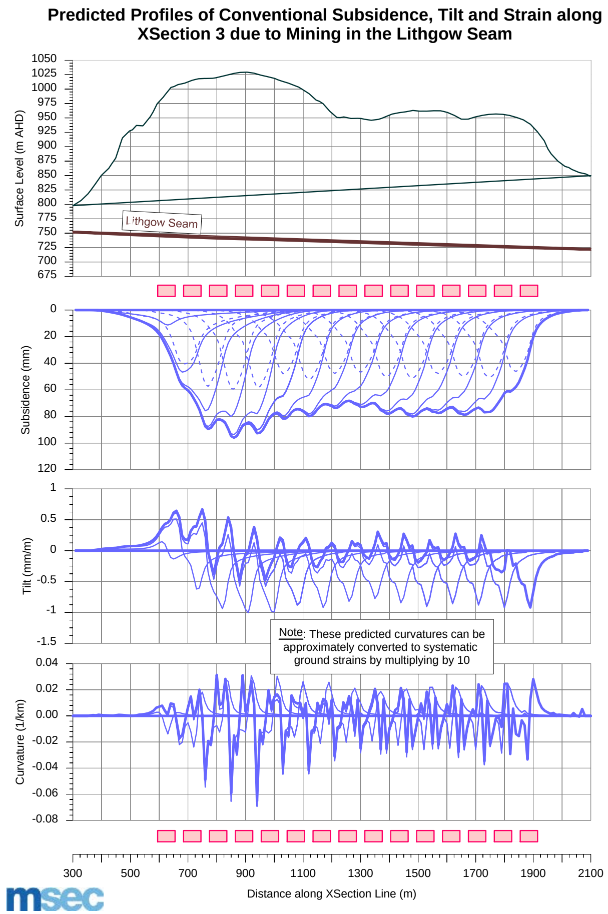


Figure A4.3. Predicted profiles subsidence, tilt and strain along X-Sections 1 and 2 respectively



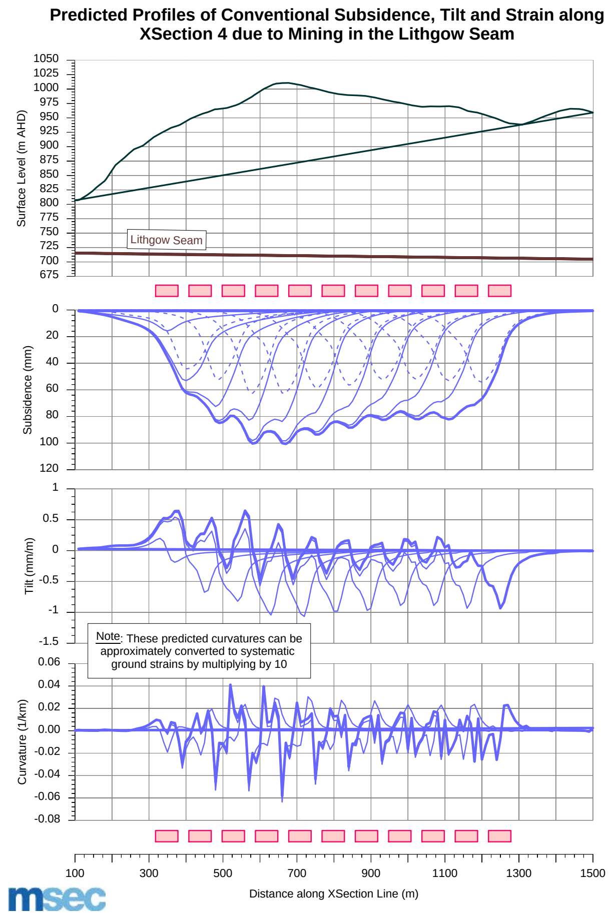
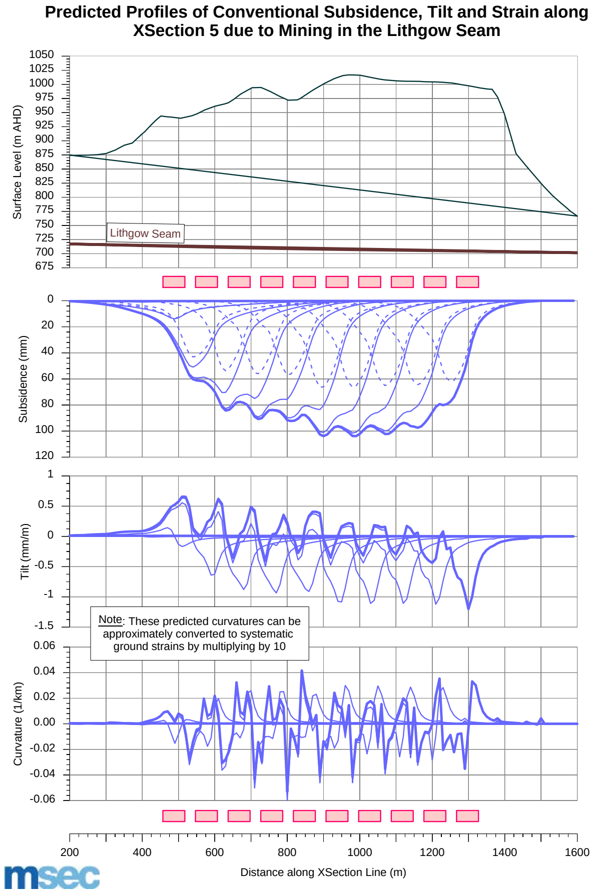


Figure A4.4: Predicted profiles subsidence, tilt and strain along X Sections 3 and 4 respectively



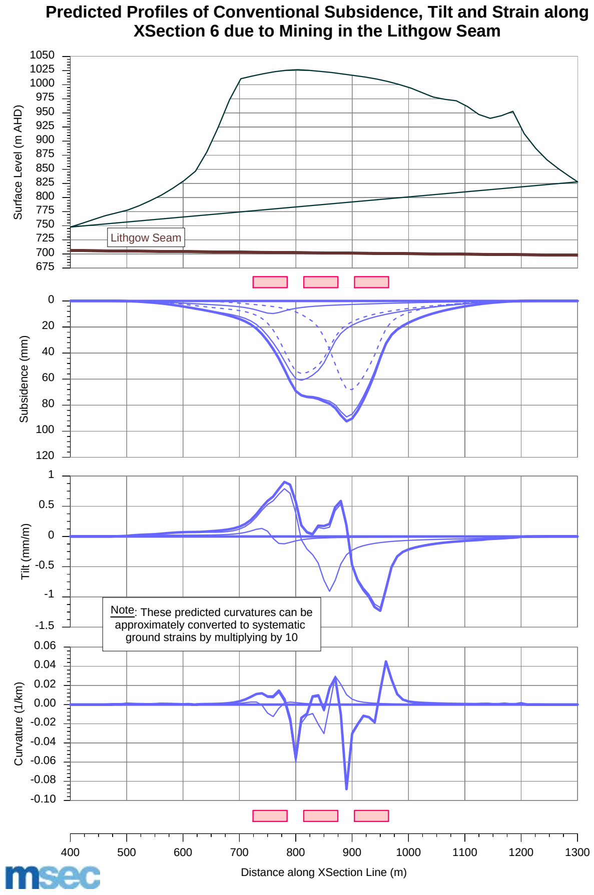


Figure A4.5: Predicted profiles subsidence, tilt and strain along X Sections 5 and 6 respectively

A4.3 Review of Incremental Profile Method Database

The database that forms the basis for the IPM method is reviewed in this section to confirm its relevance to Airly Mine.

Centennial Airly propose to use a panel and pillar method in the plateau or central areas of the mesas with the maximum panel void width of 61 m and the remaining rib to rib chain pillar widths will be 29.5 m by 94.5 m. The panels can be removed by various mining techniques including FCT systems with continuous miners or mini wall systems. These panels are sub-critical in width with W/H ratios ranging between 0.197 and 0.381 which are considered low compared to most current longwalls systems so sag subsidence is expected to be minimal. The resulting in minimum pillar widths on depth of cover ratios ranges between 0.095 and 0.184 and the pillar widths on pillar heights are nominally 10.5. For these geometries, surface subsidence is expected to result mainly from compression of the strata above, below, and within the chain pillars.

Although there are few monitoring cases, where:

- the depths of cover ranged from 80 metres to 310 m;
- the panel widths on cover ranged from 0.2 to 0.4;
- the pillar widths on cover ranged from 0.09 to 0.19;

there are many monitoring cases that show the trends in the observed subsidence data to account for these factors as is shown in the following Smax/T vs W/H monitored data plots that were produced for this review.

The plots discussed in this section show the observed maximum incremental subsidence per panel rather than the total subsidence over a panel as was shown in Figure A4.7 above. Figure A4.7 was prepared by Holla to show the measured maximum subsidence observed over single panels, but, Holla did not prepare curves to predict the maximum subsidence over a series of side by side panels in the Newcastle or Western Coalfields. The Incremental Profile Method (IPM) was initially developed in 1994 by Waddington Kay and Associates, (now known as MSEC), as part of a study for BHP, AGL and Sydney Water, to better assess the impacts of subsidence on particular surface infrastructure over a proposed series of longwall panels at Appin Colliery.

Reviews of the detailed ground monitoring data from the NSW Coalfields show that whilst the final subsidence profiles measured over a series of longwalls were irregular, the observed incremental subsidence profiles due to the extraction of individual longwalls were consistent in both magnitude and shape and varied according to local geology, depth of cover, panel width, seam thickness, the extent of adjacent previous mining, the pillar width and stability of the chain pillar and a time-related subsidence component.

For longwalls or panels in the Western Coalfield, the maximum predicted incremental subsidence is initially determined, using the IPM prediction curves for a single isolated panel, based on the void width (W) and the depth of cover (H). The maximum incremental subsidence can then be increased, using the IPM prediction curves to account for; multiple panels, the longwall number within a panel series, the void panel width-to-depth ratio (Wpan/H) and pillar width-to-depth ratio (Wpi/H). In this way, the influence of the void width (Wpan), depth of cover (H), as well as void width-to-depth ratio (Wpan/H) and pillar width-to-depth ratio (Wpi/H) are each taken into account, so as to avoid the shortcomings of a single subsidence prediction curve for all depths of cover based on one W/H prediction curve, (i.e. Holla, 1991).

The shapes of the incremental subsidence profiles are then determined using the empirical database of observed incremental subsidence profiles from the Western Coalfield. The profile shapes are derived from the normalised subsidence profiles for monitoring lines where the mining geometry and overburden geology are similar to that for the proposed longwalls and panels. The profile shapes can be further refined, based on local monitoring data, which is discussed further below. Finally, the total subsidence profiles resulting from the series of longwalls or panels are derived by adding the predicted incremental profiles from each of the longwalls or panels. Comparisons of the predicted total subsidence profiles, obtained using the Incremental Profile Method, with observed profiles indicates that the method provides reasonable, if slightly conservative predictions where the mining geometry and overburden geology are within the range of the empirical database. The method can also be further tailored to local conditions where observed monitoring data is available close to the mining area.

Whilst the shapes of the observed incremental subsidence profiles over first panels in a series are centred over the middle of the first panel, the skewed shapes of the observed incremental subsidence profiles over the second and third panels in a series indicate the relative contributions from the sagging over the current panel, the pillar squashing and additional sagging over the previously mined panels.

The following Smax/T vs W/H monitored data plots show that the amount of maximum subsidence measured over panels increases with depth of cover for the same W/H value.

Figure A4.6 shows the monitored data where the depth of cover is less than 310 m. Each site with a data label relates to sites where the depth of cover is between 250 m and 310 m. It can be seen that the results are generally below the Holla empirical prediction curve for the Western Coalfield, but the maximum subsidence tends to increases above the curve with increased depths of cover.

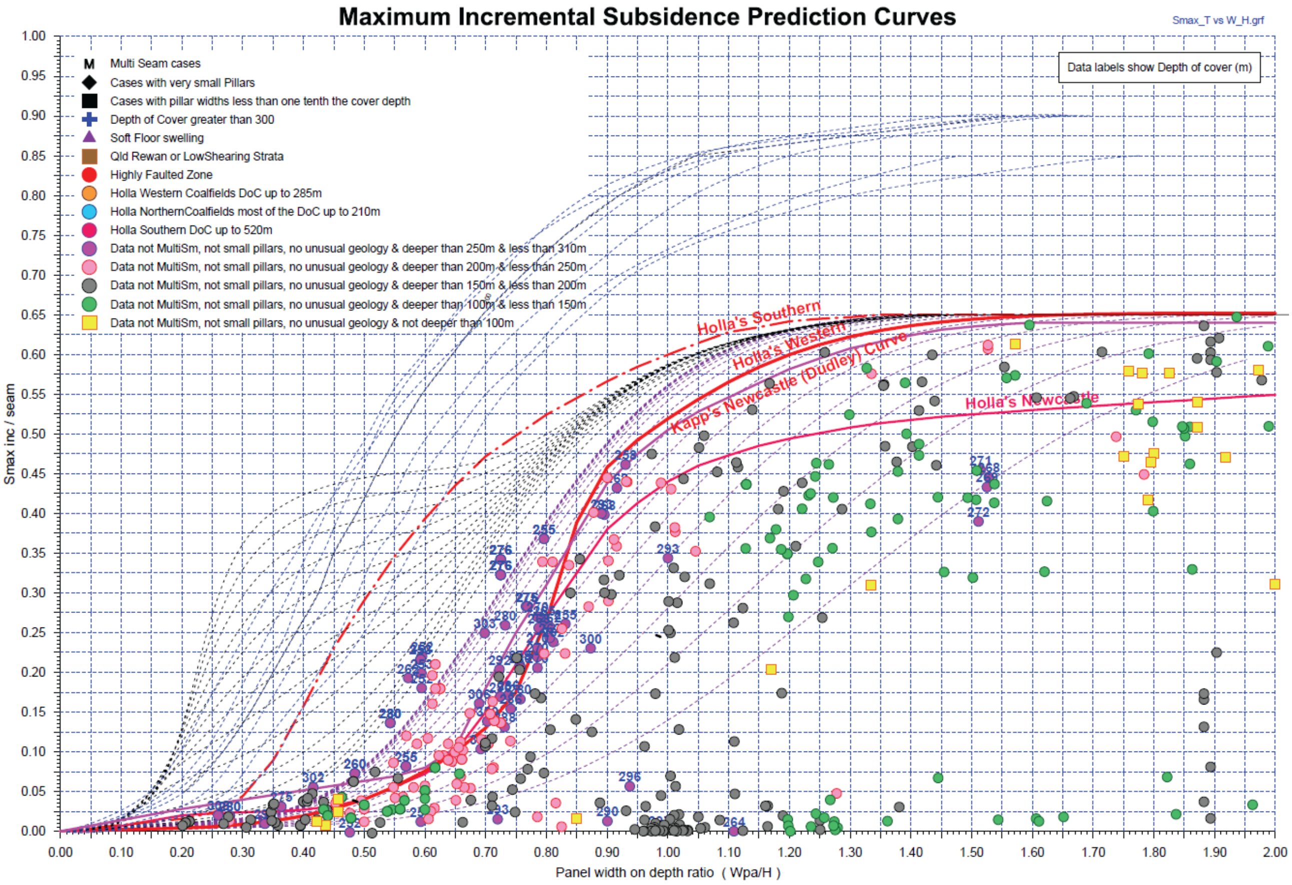


Figure A4.6 : Maximum Incremental Subsidence Curves for Cover Depth Less than 310 m

The conclusion drawn from the review of available subsidence data was that when the appropriate Smax/T vs W/H prediction curves are used (i.e. only using monitored case studies with appropriate depths of cover and chain pillar widths and local geology) then these upper bound empirical subsidence prediction curves should properly predict subsidence at Airly Mine. However, this review has highlighted that because Airly Mine will be working in an area where the predicted levels of subsidence are very low, then, there is additional reason for caution in undertaking local site monitoring in areas, away from the sensitive cliffs to confirm that the local lithology and geology is appropriate for these prediction curves.

The IRP recognise that the reliability and accuracy of empirical methods to predict subsidence are only reasonable, if:

- the mechanics of the subsidence processes are consistent enough to allow reproducible behaviour;
- the overall size of the available monitoring database used is representative,

- the appropriate variables/factors are chosen;

- the limitations of the predictions are understood, for instance whether the method provides a reasonable average or an upper bound style prediction; and

- conditions that are outside the range of available data within the database of experience are recognised.

A4.4 Elastic Strata Compression

The IRP initially reviewed alternative methods to predict the elastic compression of the pillars and the strata above and below the pillars. These formulas are all relatively simple and they are based on the following assumptions:

- the stresses within the pillars and strata layers remain low enough that the behaviour can be approximated as linear, elastic.

- load is distributed between the goaf and the pillar at some angle, θ, measured from the vertical, as shown in the figure below that has been reproduced from Galvin, (2016). In accordance with tributary area theory, this abutment angle concept results in the extra weight of a wedge of rock that projects off the abutment having to be supported by the pillar;

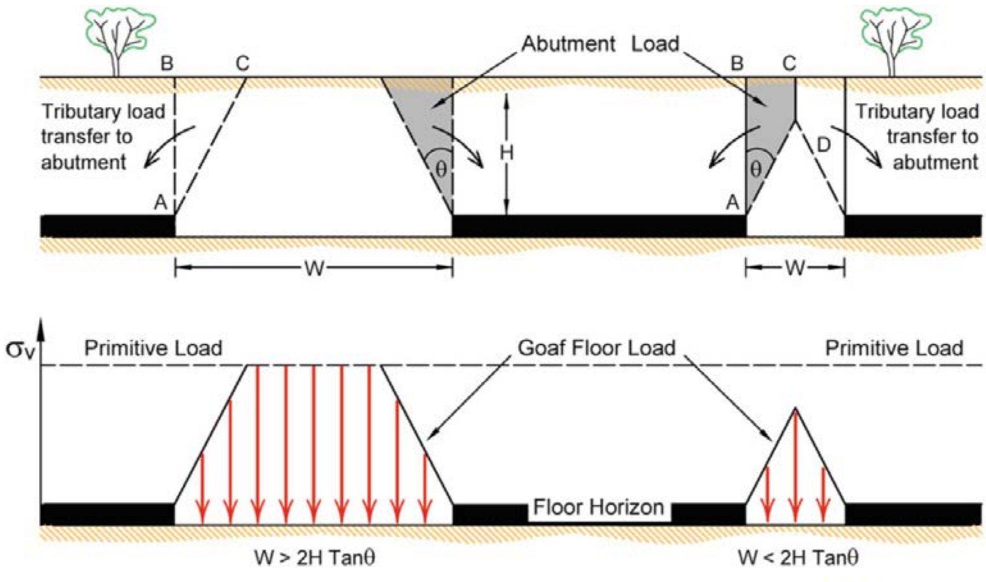


Fig. 3.11 Simplified model of load transfer around an isolated excavation (Adapted from Salamon 1991a, after King and Whittaker 1971)

Figure A4.7: Abutment loading concept (after Galvin, 2016)

- loading occurs uniformly across a pillar and variation of stresses across the pillar are not significant

- caving behaviour within the overburden strata is sufficiently uniform to not be affected by high strength bridging units (which tend to increase the loading on the pillars and increase strata compression).

- the Boussinesq pressure bulb or arch above and below the chain pillar can be equated to a column of strata above and below the chain pillar that are principally a function of only the chain pillar width and a nominal average value of elastic modulus.

Analytical formulae for estimating the compression of the strata above and below the chain pillar are generally based on multiplying the change in vertical stress, times the factor based on the width of the pillar divided by an average elastic modulus of the strata. There are a variety of methods that use different approaches to approximating the behaviour of the strata. These are typically based on experience across a range of sites and while not necessarily absolutely representing strata behaviour, nevertheless provide a basis for estimating strata compression subsidence (as distinct from sag subsidence that occurs as sagging over the extracted void).

The IRP recognise that these analytical methods are not sufficiently robust to be widely accepted within the subsidence engineering community but are nevertheless helpful as a general guide. There is no site specific experience available for conditions at Airly Mine to calibrate analytical formulae, but using generalised strata conditions observed at other sites the IRP noted that there is potential for strata compression subsidence to be greater than predicted in the EIS at overburden depths of greater than about 250 m.

On this basis, the IRP have recommended that high confidence monitoring is used over the first three or four panel and pillar panels to confirm that subsidence can be maintained at the low levels predicted prior to mining below sensitive features. Any changes that may be required to reduce the subsidence to predicted levels over subsequent can be accommodated by reducing the void width, increasing the chain pillar size or both.

A4.5 Newcastle Experience

Empirical prediction curves developed by Holla (1987) for the Newcastle Coalfield were based only on relatively shallow subsidence monitoring data. At Teralba where these Newcastle curves were used when the depths of cover were about 320 m, more subsidence was observed than was predicted over Longwalls 9 and 10 at Teralba Colliery near the Main Northern Railway Line.

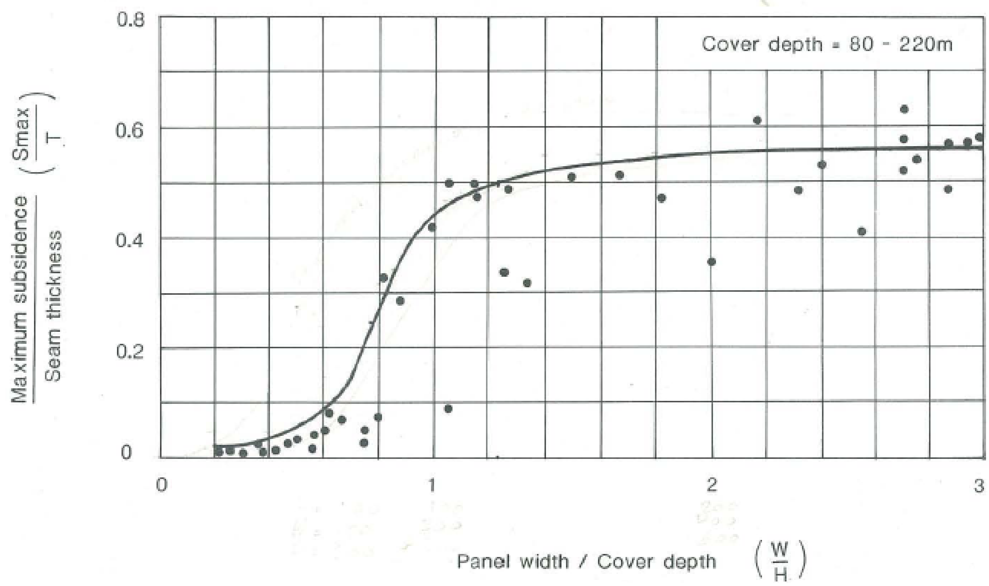


Figure A4.7: Maximum subsidence/seam thickness vs panel width to cover depth ratio (after Holla, 1987)

At the time the Teralba longwalls were approved, a maximum subsidence of 230 mm was predicted by the colliery and similar predictions were made by Holla. However, as the extraction of Longwall 9 commenced the early monitoring indicated that the maximum subsidence would be in the order of 400 mm and extra management steps had to be taken to ensure the safe operations of the trains along the railway.

The maximum subsidence, after Longwall 9 at Teralba Colliery was 460 mm and along the Main Northern Railway Line, the maximum observed subsidence after Longwall 9 was observed to be 390 mm. Eventually, after Longwall 10 was extracted, the maximum subsidence over these longwalls was observed to be 550 mm and the maximum observed subsidence along the Main Northern Railway Line was observed to be 460 mm.

These observed subsidence levels were much higher than the predicted subsidence for the extraction of Longwall 9 that were provided before mining by the colliery of 230 mm, using Kapp's early empirical subsidence model, and, the maximum subsidence of 140 mm that would have been predicted using Holla's Newcastle Coalfield empirical subsidence model.

Following the experience of extracting Longwalls 9 and 10 at Teralba Colliery, between 1990 and 1992, where the observed subsidence was two to four times greater than those predicted using Kapp's or Holla's Newcastle Subsidence Prediction curves, extensive reviews were undertaken of these early prediction curves and the subsidence monitoring data from the Newcastle Coalfield.

At that time the main causes for the increased subsidence were identified to be associated with the influence of multi-seam mining conditions, chain pillar deformation, variations in stratigraphy and geological structures (faults or dykes). However, now, the main cause is believed to be associated with increased depths of cover and changes in the local geology.

Over time, it has become apparent that the use of one Subsidence Prediction Curve (that was based on data where the depths were less than 200 m) for all of the Newcastle Coalfield even where the depths of cover exceeded 200 m, was likely to have been the main factor causing the observed subsidence to exceed the predictions at Teralba. It is now readily recognised that, for the same panels with the same width-to-depth (W/H) ratios, greater subsidence occurs with increased depths of cover as the magnitude of the depth of cover causes increased subsidence levels.

A4.6 Angles of Draw

Angles of draw indicate both the limit of measurable movements and the limit to where subsidence movements are likely to cause damage to structures. Differing angles of draw have been used to provide protection to surface features depending on the accuracy of the measuring system and depending on the sensitivity of a class of structure. It has now become accepted practice in N.S.W. to fix the subsidence limit at the point where the subsidence is 20mm, since practical surveying tolerances and background surface movements are observed to be of the order of 20 mm.

Studies have shown that the observed angles of draw to the point where 20 mm of subsidence is observed differ depending on the magnitude of the maximum subsidence, changes in geology, the depth of cover, surface topography and seam dip. However the most relevant factor for Airly is to note that the observed angles of draw reduce as the magnitude of the maximum subsidence reduces over the mined panel, i.e. where the maximum subsidence is about 1 m then the angle of draw extends out further than if the maximum subsidence over the panel was only 100 mm.

Golder advise that at Clarence Colliery, where similar very small narrow panels are extracted with long term stable pillars, the observed angles of draw to the 20 mm limit are either very low at about 8° or commonly negative values and they have indicated that similar angles of draw are appropriate for Airly Mine.

The IRP agrees that lower angles of draw are observed with lower depths of cover, as shown in Figure A2.8. Lower angles of draw are also observed wherever the maximum subsidence is reduced and wherever strong thick and massive strata units are present.

Usually, where it is essential that no cliff falls or rock falls should occur, then, higher angles of draw and additional setback distances would need to be adopted. For example, Baal Bone Colliery recently extracted the last longwall panel close to 50 m high cliffs alongside the Wolgan Valley. Based on local experience, the mine adopted a setback distance between the edge of the longwall panel and the cliff based on half depth (equivalent to an angle of draw of 26.5°) plus 50 m. This setback was successful in fully protecting the high cliffs from the effects of 1.5m of mining subsidence in the adjacent panel.

Where the maximum subsidence over the mined panel is reduced to less than 100 mm, the risk of cliff falls is reduced significantly and lower angles of draw, set back distances and subsidence at the cliff lines may be appropriate. To confirm this behaviour, the IRP recommended that CCCL use subsidence monitoring over the initial panel and pillar monitoring areas to demonstrate the low levels of subsidence that can be achieved at 30 m outside the mining area and increase the widths of the cliff line zones accordingly if greater angles of draw are observed.

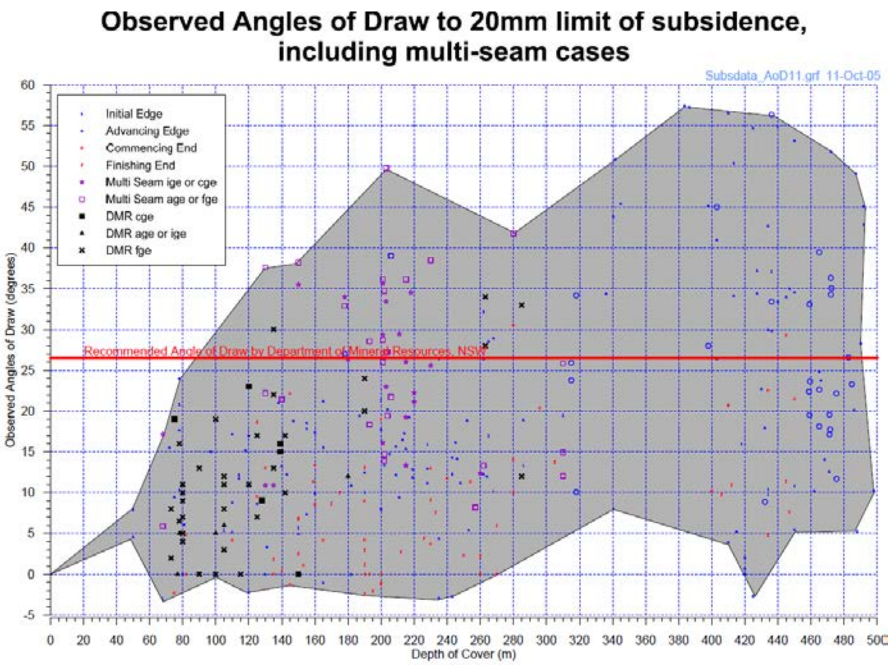


Figure A2.8 Influence of Cover Depth on Angle of Draw

Appendix 5 Background to Airly Mine Extension Project and Formation of the Independent Review Panel

This appendix presents some background information that has been drawn from information provided to the IRP and that is generally available from other sources. It has been included mainly for readers who may be unfamiliar with the project.

A5.1 Site Overview

The existing underground Airly Mine is located 5 km northeast of the village of Capertee in the Lithgow Local Government Area of NSW (Lithgow LGA). It is 40 km north- northwest of Lithgow and 171 km northwest of Sydney as shown in Figure A5.1. The Project is on the northern fringe of the Western Coalfields.

Centennial Airly Pty Limited (Centennial Airly) is the operator of Airly Mine and Centennial Airly is a wholly owned subsidiary of Centennial Coal Company Limited (CCCL).

The Project Application Area includes Mining Lease ML 1331 and Authorisation 232 (A232) as is shown in the photograph below. Most of the Project Application Area is within the Mugii Murrum-ban State Conservation Area (MM SCA), which was gazetted on 4 March 2011. The MM SCA is dominated by two irregular mesas (Mount Airly and Genowlan Mountain that are separated by a valley known as Airly Gap). These mesas are topped by thick Triassic sandstone beds which have formed prominent escarpments and cliff lines around most of the mesa perimeters and extensive areas of smaller cliffs, pagodas and sandstone gorges within the mesas, some of which can be seen in the photograph shown in Figure A5.1.

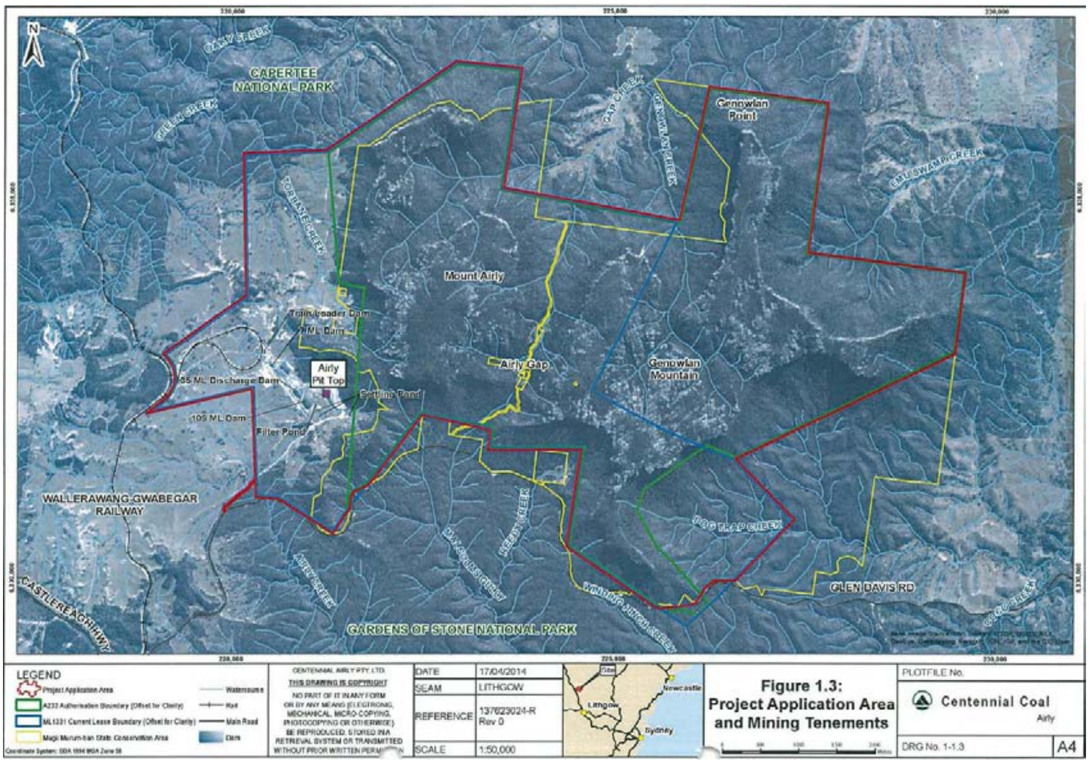


Figure A5.1 Aerial photograph showing the Airly Mine lease and surface features

The Gardens of Stone National Park, which is part the Greater Blue Mountains World Heritage Area, and Ben Bullen State Forest lie almost immediately to the south of the AMEP, whilst, Capertee National Park lies immediately to the north and the Wollemi National Park is located approximately 35 km to the east.

A5.2 Geological Setting

Figure A5.2 shows a cross section through the AMEP illustrating how the perimeter of the mesas are dominated by sheer cliffs with heights up to 160 m abutted by talus slopes with heights up to 300 m.

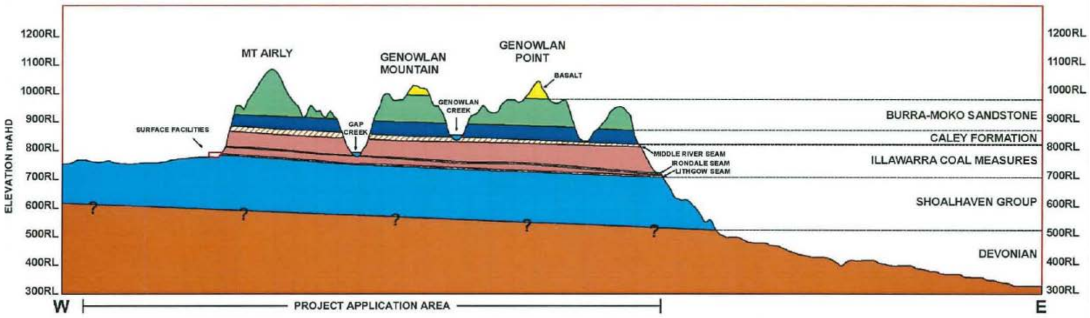


Figure A5.2 A cross section through the AMEP

Much of the plateau surface and the massive vertical cliffs are formed in the Burra-Moko Head Sandstone of the Narrabeen Group. This massive sandstone unit weathers slowly and is underlain by lower strength and more readily weathered interbedded claystones, siltstones and shales within the basal Narrabeen Group and the lower Illawarra Coal Measures, as is shown in Figure A5.3.

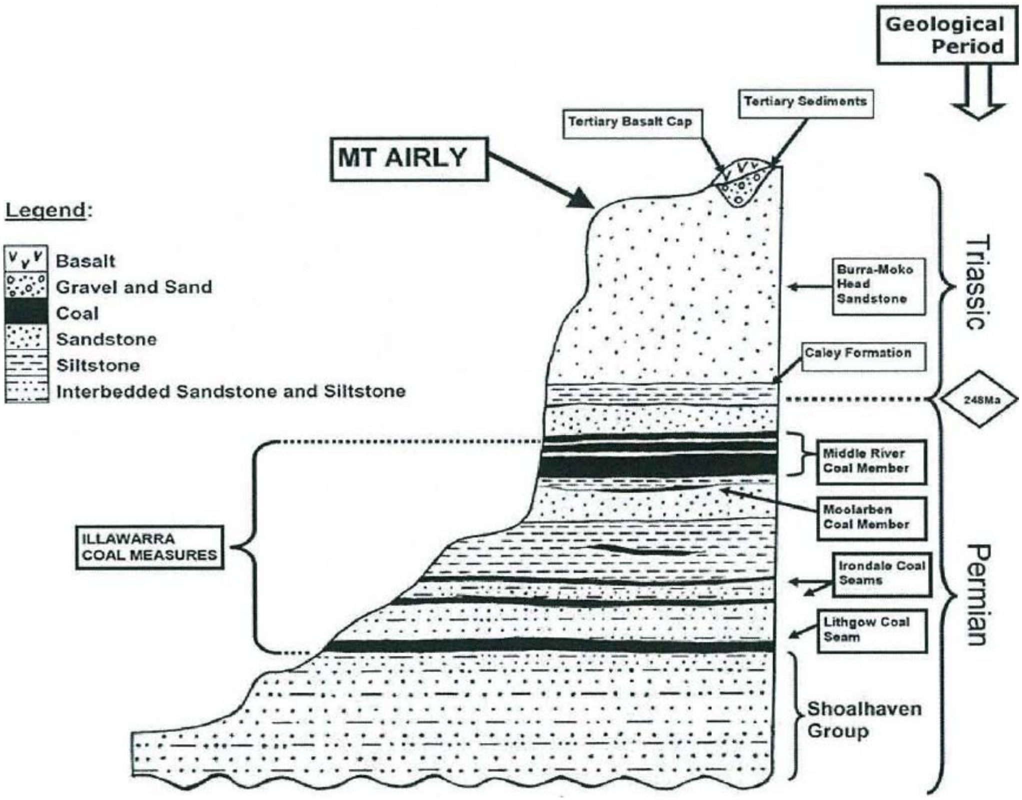


Figure A5.3 Coal measure strata, Airly Mine

Within the mesas, the action of wind and water erosion has formed deeply incised gorges that partly penetrate the sandstone units to form cliffs and valleys. Although these internal cliffs are smaller than those found on the exterior of the mountains, they nevertheless reach heights of over 50 m in places. Additionally there are many pagodas along the crests of the cliffs are comprised of low to moderate strength sandstone, with indurated ironstone bands that form small ledges and 'honeycomb' features.

The AMEP area sits more broadly within the landscape of the Capertee Valley. This valley is a large, broad-floored canyon measuring over 30 km from north to south and east to west. The valley is surrounded by sandstone cliffs and steep talus slopes that are similar to those found on Mount Airly and Genowlan Mountain.

A5.3 Surface Features

Mount Airly and Genowlan Mountain mountains sit as a one of several mesa complexes within the Capertee Valley. Both Mount Airly and Genowlan Mountain are clearly visible for tens of kilometres in all directions. The following photos of some of the high cliff lines that surround Mount Airly and Genowlan Mountain have been reproduced from varioius Golders' reports.

Figure A5.4 High cliff lines that surround Mount Airly and Genowlan Mountain (after Golder Associates, 2014)

The scenic beauty of the area encourages many visitors. Popular places visited include: The Grotto; Valley of the Kings; Hidden Valley; City in the Sky; Lyrebird Defile; and Grotto Defile. It has been noted that rock falls of these features occur regularly with the natural frequency of large scale cliff falls in the AMEP area being once every four years. Falls of isolated rocks occur more frequently, but, these are not noticeable at any great distance. As a result of the above factors, the cliffs within the AMEP area were assessed to be sensitive to the impacts of mining related subsidence.

A5.4 Development Consent

Airly Mine's current development consent (DA 162/91) was granted on 14 April 1993 for 21 years, pursuant to Section 101 of the EP&A Act. The Development Application was supported by the Airly Coal Project Environmental Impact Assessment (Novacoal, 1991) an addendum titled Supplementary Report to Environmental Impact Statement (Novacoal, 1992) and a mine subsidence impact assessment report that was prepared by Holt and Associates. The initial subsidence impact assessment report (Holt, 1991) predicted a maximum level of subsidence of 1.8 m, maximum predicted strain of 43 mm/m and maximum predicted tilt up to 85 mm/m respectively due to the extraction of the full extraction panels for the approved.

The cliff lines, which were identified as the outstanding features of the mesas, were to be protected by partial panel extraction in protection zones under the cliffs. The protection zones, which were based on a draw angle of 25 degrees, were to be partially extracted when cover depth between the Lithgow Seam and cliff top exceeds 100 m. Subsidence monitoring by way of surface cross lines over initial panels, coupled with laser ranging of cliffs was proposed to manage the subsidence around the cliff lines. The results of the monitoring were to be used to develop site specific subsidence guidelines.

Five subsequent modifications to DA 162/91 have been approved that allowed;

- an increased amount of trial mining coal throughput of up to 500,000 tonnes per annum for 2 years to be transported to Mount Piper Station by road (MOD 1),
- the construction and operation of a 66 kV power line to the pit top (MOD 2, August 2009),
- the extension of life of consent from 12 October 2014 to 31 October 2015 (MOD 3, October 2014).

- the extension of life of consent until 30 April 2016 (MOD 4, August 2015), and
- the extension of life of consent until 30 October 2016 (MOD 5, March 2015).

The development consent to mine under the existing consent, DA 162/91, stipulated;

- no mining within a 50m coal barrier measured horizontally from the outcrop,
- only first workings were permitted where the depth of cover was less than 50 m,
- partial extraction was permitted beneath Environmental Protection Zones, which were based on a draw angle of 25 degrees, and
- full extraction was permitted in areas outside these environmental zones (i.e. within the central mesa areas), with supercritical void widths and maximum predicted subsidence levels of 1.8m, tensile strains of 25.5mm/m, compressive strains of 42.5mm/m and tilts of 85mm/m.

Figure A5.5 shows the locations of the approved (DA162/91) Mining Zones and the location in yellow and orange of previous historical workings, i.e. New Hartley Shale Mine old workings and Torbane Colliery Lithgow Seam old workings.

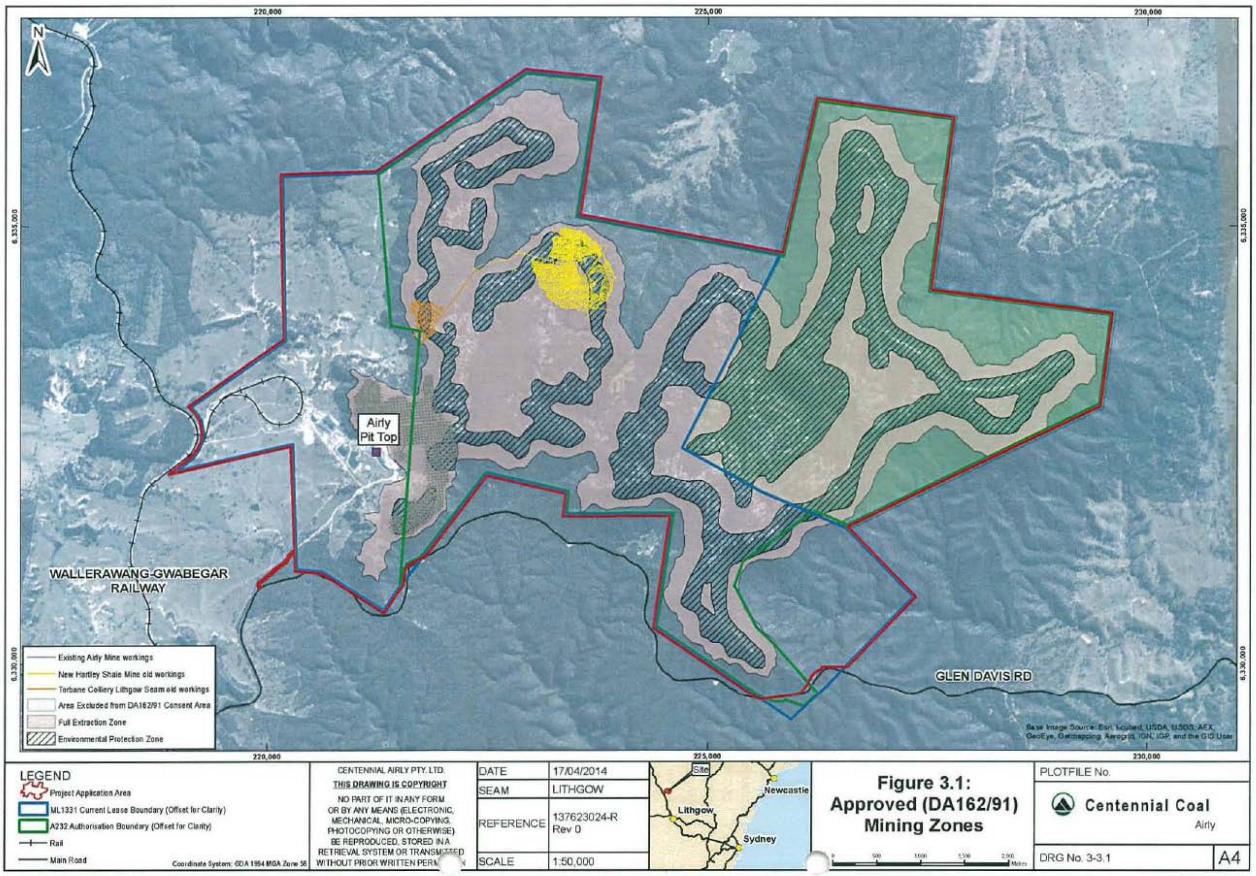


Figure A5.5 Locations of the approved (DA162/91) Mining Zones and previous historical workings

A5.5 Commission of Inquiry

While the initial development application (DA) for the Airly Coal Project was submitted in 1991, the then Minister of Planning, in 1992, established a Commission of Inquiry to examine and report on the subsidence risks associated with the project. The Inquiry Report canvassed many issues and advised

"*The protection of all these (cliff) features, as well as ensuring the availability of the general surface area of the mountains for pedestrian access, is the major issue for consideration as seen by the majority of the submitters and, hence, claims that the area should be included in Wollemi National Park (Gardens of Stone). However, such claim must be balanced against the advantages of (safely) recovering the underlying coal resource*."

This 1992 Airly Inquiry Report proposed an adaptive management monitoring system as is stated below;

- *"Approval should be given only to a limited number of panels in an area not containing sensitive surface features with conditions imposed on the applicant to undertake extensive surface subsidence monitoring and to build a local subsidence database. "*

- *"The data should be analysed and prediction curves modified, if required. In this way, the reliability of subsidence prediction will be continually upgraded in the light of additional information."*

- *"The design of mine layouts and size of protection zones should be on the basis of the continually upgraded information. For example, if monitoring leads to a different angle of draw, then protection zones will be redefined on the basis of the revised angle of draw. If partial extraction layouts develop less than predicted subsidence, then the layouts may be revised with wider panels or narrower pillars."*

"Given that the Department of Mineral Resources (DMR) adopts such a methodology for the Airly mine (such an assurance has been given to the Inquiry), it is my view that the 25 degree angle of draw is adequate for fixing the protection zone at Airly at this time. Such angle of draw combined with an appropriate coal recovery within the protection zone, determined on the basis of trial mining and monitoring, should ensure the stability of designated landform features."

"The DMR submits, in relation to the project generally, that any subsidence occurrence that creates significant environmental damage will be ameliorated. However, the expectation is that over the general area subsidence of up to 1.8m will occur with generally satisfactory outcomes to the environment. It anticipates only some 'fine tuning' to mining methodology may be required as mining proceeds. The DMR acknowledged during the course of the Inquiry that: ".....

- *"the major issue of significance that has been raised is potential subsidence damage to scenic features. The external cliffs will be fully protected together with areas of special conservation Significance such as the Valley of the Kings area and internal cliffs higher than 20 metres. Subsidence induced damage over remaining parts of the area is predicted to be of limited extent and will be carefully monitored. "*

"The boundaries of the proposed partial extraction zones are to be determined initially by the use of an angle of draw of 25 degrees. This is an angle off the vertical drawn from the top of the relevant cliff to intersect the coal seam at a point representing the closest goaf face of total extraction panels."

"Having regard to the totality of evidence before me including the above mentioned particularised expert views I am of the opinion that features such as cliffs, pagodas and beehives, and wet areas are likely to be affected to an 'unacceptable' degree resulting from total extraction mining under same causing surface cracking, tilting and/or rock falls. "

"Hence it is necessary that in the areas I have designated as Environmental Protection Zones only controlled partial extraction shall occur. In areas beyond such zones mining must be carried out in a selective manner to minimise damage to significant landform".

"The Applicant has proposed partial extraction zones under significant external high cliffs, i.e., higher than 20m, with the objective of limiting subsidence and tilting to such an amount that harmful structural and visual impact is not anticipated to occur. Those pagodas located above partial extraction zones will be 'protected' to some degree depending upon their distance from the edge of the total extraction zone. However, as said in its submission, it is DMR practice to examine and where possible provide protection for those pagodas or structures considered to be unique and where damage is likely to be sustained. "

"The proposed partial extraction protection zones will be subjected to second workings. In regard thereto I understand the Applicant desires to extract up to 60% to 65% of the area of the seam. All second workings are subject to prior and on-going detailed examination and approval by the DMR. Such approval will also stipulate requirements for comprehensive monitoring of impacts during second workings.

The Airly Coal Mine commenced trial mining in 1998 and, upon completion of trial mining in 2002, the mine was placed into care and maintenance. Construction to enable full operation mining commenced in 2009 with the first run of mine being coal produced that year.

In 2011, under the National Parks and Wildlife Act 1974, the area overlying the majority of the underground lease was declared as the Mugii Murum-ban State Conservation Area (MM SCA). The MM SCA reserve has significant natural and cultural heritage values and also contains significant mineral resources. As a state conservation area, the MM SCA is reserved to protect environmental and cultural heritage values while permitting mining and exploration

Mining operations went into care and maintenance again in October 2012 until further mining operations recommenced in May 2014. No partial extraction or full extraction has been undertaken at Airly Mine to date and the extended currently proposed mine layout was designed to minimise impacts to limit subsidence ground movements over all of the Project area.

A5.6 Revision of Airly Mine Design

On 12 June 2014 Centennial Airly Pty Limited (Centennial Airly) lodged an application to modify its current project approval under Section 75W of the EP&A Act. Centennial Airly advised the new mine design allows an economic return at Airly Mine, while minimising environmental and social impacts and preventing impacts to natural, built and socially sensitive features within Project Area.

A report titled "Subsidence Predictions and Impact Assessments for Airly Mine" (SPIA), which was prepared by Golder Associates Pty Ltd (Golders, 2014) (referenced as Report 127621105-003-R with 94 pages), was attached to the EIS as an appendix. The main differences between the revised proposal and the approved mine layout is detailed below, (DPE, 2015).

Table 1: Key components of the Airly proposal

Aspect	Existing Approval	Proposed Development
Mine Method and Design	Bord and pillar mining subject to: • No mining in the 50 metre (m) coal barrier (measured horizontally from the outcrop); • First workings only where the depth of cover is less than 50 m; • Partial pillar extraction only beneath Environmental Protection Zones; and • Full extraction outside of Environmental Protection Zones, with supercritical voice widths.	Bord and pillar mining subject to: • No mining in the 50 m coal barrier (measured horizontally from the outcrop); • Method of extraction varies to manage subsidence impacts on key environmental features, based on five mining zones, comprising: o panel and Pillar Mining Zone (PPMZ); o cliff Line Zone of first workings; o partial Pillar Extraction Zone (PPEZ); o shallow Zone; and o new Harley Mine Interaction Zone (Interaction Zone').
Subsidence Limits	• Maximum vertical subsidence limit of 1.8 m; • Maximum tensile strains of 25.5 millimetres/metre (mm/m); • Maximum compressive strains of 42.5 mm/m; and • Maximum tilt of 85 mm/m.	• Maximum subsidence levels in the Interaction Zone: o vertical subsidence of 500 mm; o maximum strains of 1.8-8.3 mm/m; and maximum tilts of 6.2-16.7 mm/m

The community raised significant concerns about possible subsidence impacts on natural features including cliff lines, pagodas, cultural heritage and water courses in addition to impact on the MM SCA. The proposed AMEP was designed to use mining methods that are designed to:

- limit maximum subsidence ground movements to less than 125 mm:
- to extend the mine life by 25 years,
- to extend the workings into areas where the historical New Hartley Shale Mine has already impacted the environment, and
- to extend the workings into areas to the east of the currently approved areas to mine under Mount Genowlan and Genowlan Point, i.e. within ML1331 and into the A232 boundary.

Figure A5.6 shows:

- the sensitive cliff line features;
- the locations of the proposed mining zones are (from Figure 8.2 from the EIS), i.e. the proposed cliff line zones, the pillar and panel zone, the New Hartley Shale Mine potential interaction zone and the shallow zones; and
- the location of Cross Section AA drawn in Figure A5.7.

CCCL and Golders advised that the revised mine layout had been designed to restrict the maximum vertical subsidence so that there should be no surface fracturing over the pillar and panel zones and no rock falls within cliff line zones. In this revised plan pillar lifting has subsequently been replaced by pillar splitting-and-quartering.

Over the panel and pillar zones, (i.e. in areas that are located up on the plateau areas of the mesas, behind the major cliff lines and where the depths of cover range from 160 m to 310 m and not near the major cliff lines and pagodas), Centennial Airly propose to use a panel and pillar method of coal extraction with the maximum panel void width of 61 m and with the remaining rib to rib chain pillar widths and lengths being 29.5 m by 94.5 m. The predicted maximum subsidence due to the extraction of the panels within the panel and pillar zones is predicted by Golders to be 125 mm, with maximum strains up to 2 mm/m, maximum tilts up to 3 mm/m.

The most restrictive form of proposed mining is that within the vicinity of the cliff line zones, where only bord and pillar first workings with no subsequent pillar extraction, splitting or quartering is proposed. These cliff line zones are based on a distance of 30 m (an angle of draw of 8° at 240 m) from the cliff top and cliff toe and further discussion is provided elsewhere in the report on the setback distances that are based on this angle of draw. The subsidence resulting from the extraction of the proposed first workings within the cliff line zones should result in small levels of subsidence that are less than 20 mm.

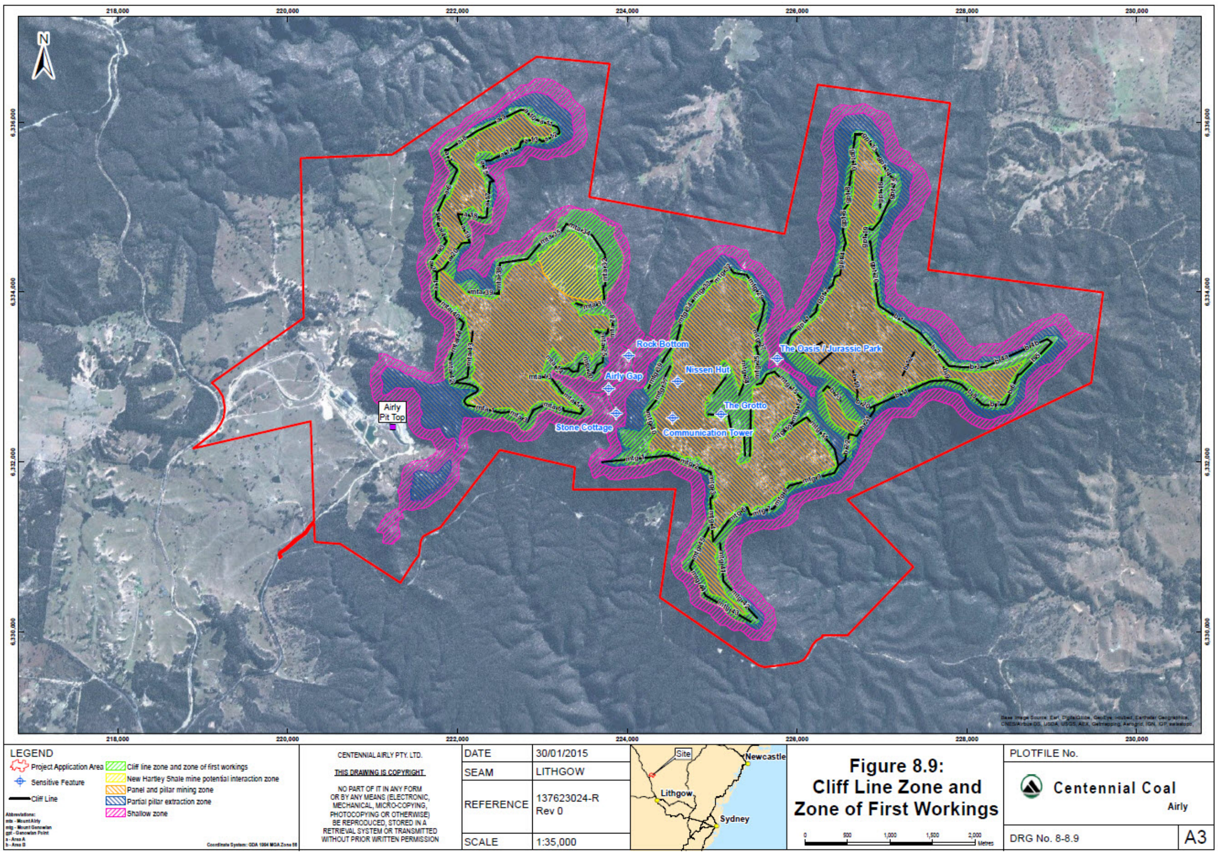


Figure A2.6. Mine lease showing the sensitive surface features and mining zones

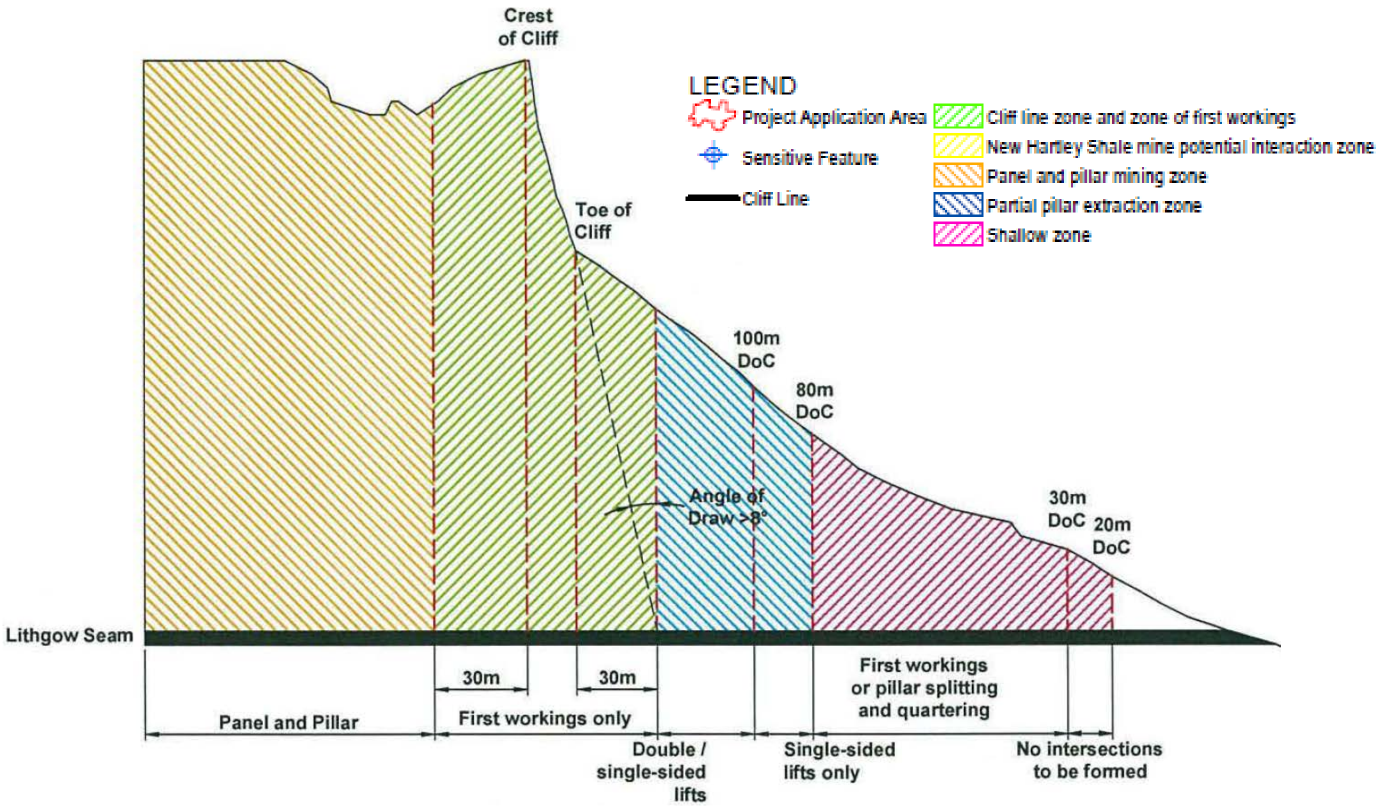


Figure A5.7 Cross section AA in Fig. A5.6

Similar methods were successfully developed by Centennial to protect cliff lines over the Clarence Colliery, where the cliff heights are up to 80 m. Subsidence ground movements at the cliff areas were restricted to be less than 100 mm by only extracting narrow panels and leaving long term stable pillars. The subsequent subsidence levels at the cliffs at Clarence were monitored to be less than the predicted 100 mm subsidence levels, even after the panels were flooded, (White, 2014). No rock falls were observed at Clarence Colliery even though Centennial extracted these narrow coal panels directly under the cliffs.

In those areas that are located away the panel and pillars zones and outside the cliff line zones, i.e. not under the mesas and not within the vicinity of the major cliff lines or pagodas, CCCL propose to, first, extract coal by bord and pillar first workings with headings being restricted to a 5.5 m maximum void width and the intervening pillars being be designed to be long-term stable. Then, or subsequently, CCCL propose to partially extract some of the coal within these pillars using pillar splitting-and–quartering.

The predicted levels of subsidence over the first workings and the pillar and panel areas were calculated in the Golders' reports using a range of methods, including:

- using estimates of the subsidence resulting from the compression of the coal pillar and the strata above and below the pillar, assuming elastic theory and conditions, estimates of the average stress change in the strata based on various assumptions that the Boussinesq pressure bulb or arch above and below the chain pillar can be equated to various heights columns of strata above and below the chain pillar based only the chain pillar width and Young's Modulus and assumptions on the averaged geomechanical properties of the strata;

- using a "LaModel" numerical mode; and

- using Holla's Western Coalfields' empirical Smax/T versus W/H prediction curves for single isolated panels and a calculation to increase the predicted levels of subsidence to account for multi-panels situations, based on data sourced from the Newcastle Coalfield.

These calculations have generally resulted in predicted subsidence levels below the required 125 mm subsidence target.

Similar methods of subsidence prediction were prepared by Golders for the Clarence Colliery for those areas where subsidence was required to be limited to less than 100 mm and the subsequent monitored subsidence levels have been found to be less than the predicted levels, even after the panels were flooded (White, 2014).

The panels within the panel and pillar zones can be removed by various mining techniques including FCT systems with continuous miners or mini wall systems. The panels are to be 61 m wide and the pillars are to be 29.5 m wide in areas where the depth of cover ranges from 160 m to 310 m. Hence the proposed panels will be sub-critical in width with W/H ratios ranging between to 0.197 (61/310) and 0.381 (61/160) which are low compared to most currently extracted longwalls systems. The minimum pillar widths on depth of cover ratios range between 0.095 (29.5/310) and 0.184 (29.5/160) and the pillar width on pillar heights will be 10.5 (29.5/2.8).

Additional subsidence has been predicted by Golders over the surface areas that are in vicinity of the previously extracted oil/shale workings (or torbanite) in the New Hartley Shale Mine. (See the yellow shaded areas in Figures A5.5 and A5.6).

These old workings are located approximately 25 m above the roof of the Lithgow Seam. This mine operated between 1893 and 1913 and fully extracted oil shale from the deposit using a type of hand worked advancing longwall method. Figure A5.8 shows that some large pillars were left unmined and additionally there many have been many roadway pillars and remnant stooks left to support the roadways.

The surface areas on the plateau areas over these old oil/shale workings has already been significantly impacted by the previous oil shale mining with many large subsidence cracks still visible as indicated in the sketch above. It has also been noted that these old workings were extracted beneath some of the major cliff lines around the northern parts of Mount Airly and it is understood that, as shown in the figure below, the extraction of the oil/shale workings probably led to several cliff falls (see photo below). CCCL is seeking approval to extract the proposed panels and pillars under these old workings and Golders have calculated that an additional vertical subsidence of up to 500 mm vertical subsidence, up to 8.3 mm/m strains, up to 16.7 mm/m tilts can be expected within this New Hartley Shale Mine potential interaction zone.

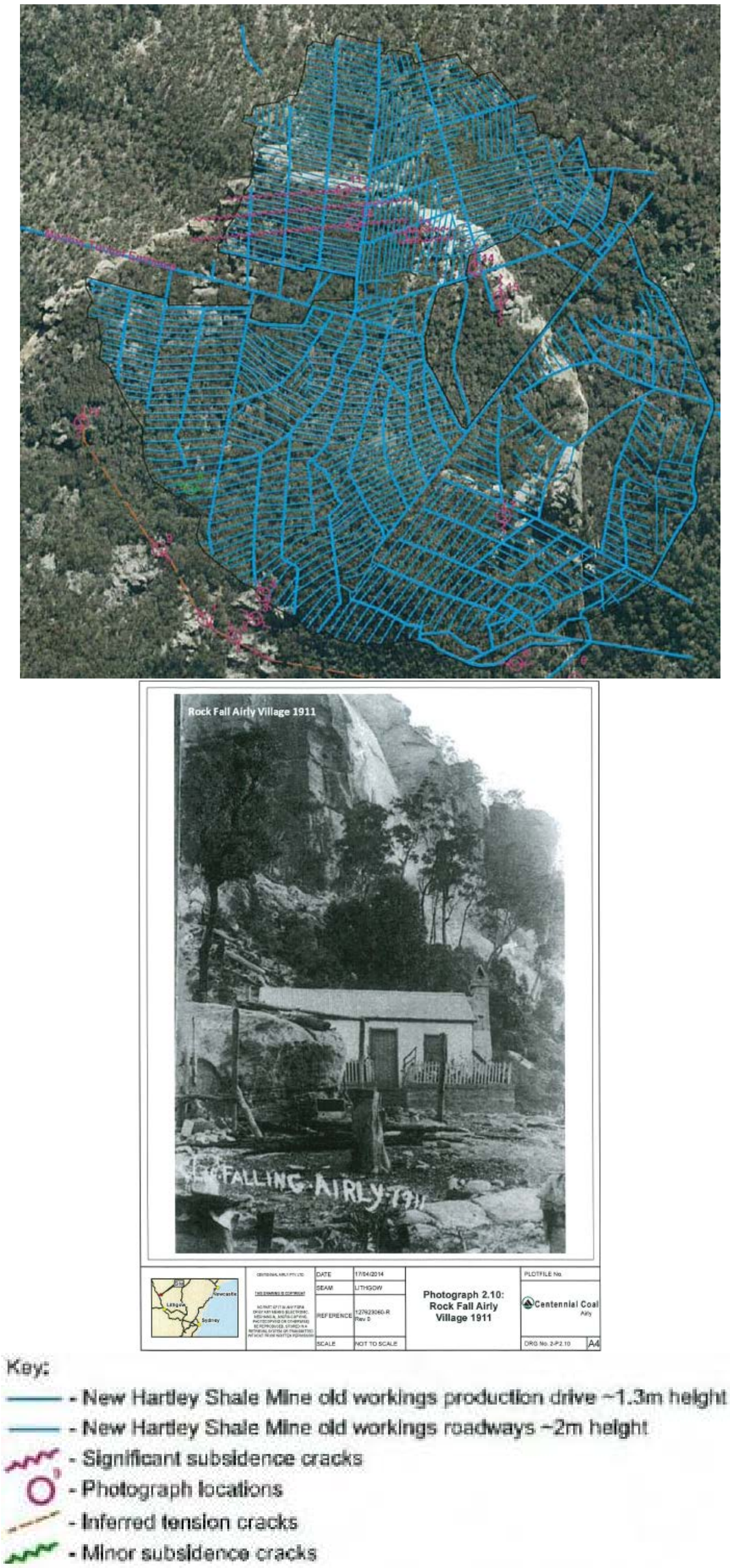


Figure A5.8 Surface photo showing the old workings and the surface features

The Golders's reports acknowledge that extracting the panels under these old workings would probably result in additional surface fracturing and cliff falls within the New Hartley Shale Mine potential interaction zone. CCCL highlight that surface fracturing and cliff falls has already occurred in this area.

A5.7 Geological / Geomechanical Setting

Golders (2014) present a summary of the geological and geomechanical setting reproduced here as context.

As indicated in Figure A5.2, the Permian Illawarra Coal Measures outcrop around the perimeter of the topographically elevated plateau or mesa, and in the north-south trending "gap" which separates Mount Airly in the west from Genowlan Mountain in the east.

Of the available coal seams, the only coal seam deemed to be of any significant economic importance is a lower section of the coalesced Lithgow/Lidsdale Seam. All of the existing and proposed workings at Airly Mine are located in this Lithgow Seam. In this area the combined Lithgow and Lidsdale seam is 4.8 m to 5.9 m thick, averaging 5 m and thinning to the south-east.

The Lithgow Seam (plies LT1 to LT3) constitutes the base of the combined seam and averages 3.4 m in thickness. This is of higher quality and is the target for mining. The planned development and extraction height is 2.7 m to 2.8 m, approximately mid-way between the LW1 claystone band and the lower LW2 claystone band, the latter being typically 0.1 m thick. This results in a roof bolt horizon typically comprised of 0.3 to 0.4 m of top coal, overlain by 0.4 m of LW1 claystone and the Lidsdale Seam with its dirt bands.

The Triassic capping is up to 200 m thick and is dominated by thickly bedded to massive sandstones varying from fine grained to conglomeratic, with occasional thin claystone and mudstone beds and lenses. The sandstone UCS is typically around 40 MPa, with occasional bands of up to approximately 60 MPa. Generally, the fine grained units are better cemented and therefore stronger than the coarse grained sandstone conglomerate units.

The overlying 6 m of the proposed workings' roof is comprised typically of mudstone / siltstone grading upwards into siltstone / sandstone. This material is more consistently strong, with UCS values of around 40 MPa and is less prone to delamination and is therefore deemed more competent. The remainder of the Permian overburden varies in thickness from 70 m to 140 m (and averages 105 m). This strata is composed of interbedded mudstone, siltstone and sandstone units with thin coal seams. Material strengths are typically of the order of 30 to 40 MPa.

The immediate 1 to 2 m of the proposed workings' floor is generally comprised of silty sandstone with a UCS of around 40 MPa, underlain by medium grained sandstone with a UCS of 20 to 30 MPa. The sandstone has very little sensitivity to moisture.

The depth of cover at the proposed Airly Mine ranges from 20 m at the sub-crop to a maximum of 280 m under Mount Airly and 310 m under Genowlan Mountain. At depths of less than 300 m a major horizontal stress magnitude of less than 15 MPa could be expected, but, given the topography and the associated potential for horizontal stress relief by virtue of the neighbouring cliff lines and surface valleys, it was considered likely that the maximum horizontal stress may be around 12 to 13 MPa.

Appendix 6 Review of EIS Submissions and Responses

The EIS was exhibited from 19 September to 31 October 2014. CCCL prepared an RTS report in accordance with Section 75H (6) of the EP&A Act that addressed the issues raised in the submissions received on the EIS. The report, dated February 2015, builds on information presented in the EIS and should to be read in conjunction with the EIS.

Reviews of the EIS by various government agencies led to the identification of a number of questions. The key issues relating to cliff line protection are presented in this section.

A6.1 Department of Resources and Energy

The NSW Department of Industry, Division of Resources and Energy (DRE) considered that these issues need to be addressed prior to the Extraction Plan stage. These questions are:

1. What should be the appropriate set-off distance from secondary extraction (in other words, what width should the "cliff protection zone" be to maintain the integrity of the significant cliff formations within the subject area on a long term basis?

2. Where should the "cliff protection zone" be applied to maintain the integrity of the significant cliff formations within the subject area on a long term basis?

In particular the DRE (Dr Gang Li) advised;

> *"Contrary to the common industry practices over the past decades, the proposed dimension of coal barrier for the protection of the significant cliff formations is substantially reduced from a nominal 26.5 degrees of angle of draw to only 8 degrees."*
>
> *"Long term stability of pillar workings is a significant and challenging issue in the area of subsidence. In the later 1990s, Galvin and others published their results of investigations into the coal pillar performance / strength, which have led to industry practices to use Factor of Safety (FOS) values greater than 2.1 to design long term stable (rectangular) pillars. It is noted that the FOS used by the Applicant is 1.6 only."*
>
> "*The cumulative effects of the significant reductions in both pillar factor of safety and coal barrier dimension, as compared with common industry practices, are likely to make the mine design, as the primary and critical risk control for the subject site, vulnerable to the inevitable variations in site conditions and time-dependent degradation or deformation within the proposed pillar workings. This situation is not consistent with the significant cliff formations above the proposed pillar workings."*
>
> *"It does not appear that the Applicant has considered:"*
>
> *"A. The potentially complex loading conditions within the workings under the cliff formations, regarding:"*
>
> - *"The magnitude and nature of abutment loads within the workings under the cliff formations where there are rapid changes in surface topography, and/or"*
>
> - *"The effects of potential interactions between the different mining zones within a highly irregular mine layout (in plan view) to impact on mining-induced stresses I deformations within the workings."*
>
> *B. "The potential impacts of the weak roof, as reported in the EIS, on long term stability of the pillar workings. In this case, roof falls are expected over time, which will cause reduction in pillar width-to-height ratio resulting in reduced FOS."*
>
> *C. "The long term stability of the slim/small pillars resulting from the proposed pillar quartering/splitting. In the case, the already low pillar width-to-height ratio may be further reduced W pillar spalling occurs over time resulting in reduced FOS. In my view, the proposed*

pillar Quartering/splitting has the highest level of uncertainty in relation to long term stability. It appears that this type of mining has been proposed to take place within the 26.5 degrees of angle of draw to some of the major cliff formations."

D. *"The practicality of undertaking pillar extraction 'within the different mining zones in a highly complicated mine layout (in plan view) while ensuring compliance with the proposed mine design. Note that the mine design in this case is the primary and critical risk control for subsidence."*

Given the significant cliff formations within the subject area, DRE recommended that an independent expert panel be established to undertake assessments of all relevant factors and identify the set off distance from secondary extraction and determine the appropriate cliff protection zone and DRE thought this assessment and determination should be made prior to the proponent submitting an extraction plan.

A6.2 Office of Environment and Heritage

The Office of Environment and Heritage (OEH) noted that Section 8 of the Subsidence Predictions and Impact Assessment emphasises the value of the installation of stress and deformation monitoring instrumentation in the underground pillars providing data in respect to the stability of these pillars. OEH stressed the importance of developing a monitoring system that minimised the impact on the environment. OEH recommended that the DPE considers applying a condition of consent to ensure that minimal impact monitoring systems are employed within MM SCA to minimise impact to the environment. OEH suggested the use of conventional subsidence monitoring lines and various remote monitoring systems over the first series of extraction panels beneath Mount Airly may demonstrate the accuracy of less intrusive remote monitoring, and may eliminate the reliance upon conventional subsidence survey lines in the other more environmentally sensitive areas.

A6.3 Special Interest Groups

Reviews of the EIS by various special interest groups were concerned that too much coal was proposed to be extracted and this extraction could cause significant damage to an area of national and international importance. The pagodas in the MM SCA were regarded as good examples of both smooth and platy pagodas and were an excellent showcase of pagoda geodiversity. They commented that the EIS stated that narrow deeply incised gorges are 'quite common' throughout the Blue Mountains. Apparently this is true of normal gorges, but, quite untrue of slot canyons such as the Grotto and Valley of the Kings. Slot canyons are apparently limited to the north-west edge of Wollemi NP and Gardens of Stone. The extent of slot canyons in this area was argued to be of international significance (Washington and Wray 2014). The Grotto is considered a slot canyon, a significant landform on the national and international stage.

Reviewers noted that:

- allow the angle of draw of 25 degrees to be retained so that the 'environmental protection zone' (for subsidence) in the existing consent is not reduced in width by about 50% as is currently proposed;

- The proposed width of cliff protection zone is far less than approved in the 1993 consent for Environmental Protection Zones, i.e. half the depth of cover. Reducing the angle of draw to 8° will cause avoidable cliff falls resulting in the predicted collapse of 5% of cliffs. The protection generated by the 25° angle of draw is necessary for not only internal and external cliffs but also for the Valley of the Kings and the Grotto, as protected by the initial consent. Surely the proposed flexible design plan can and should ensure no damage to cliff lines in a state conservation area;

- uncertainty of these predictions in a critical area at the base of the cliffs means would be wise to eliminate this zone and conduct only first workings from the shallow zone to the cliff zone (The shallow zone should comprise only first workings). The partial pillar extraction zone should be eliminated, or should not encroach within 60 m (not 30 m) of the cliff line toe lines. The first workings in the cliff protection zone must limit subsidence to less than 30 mm;

- Flooding of first workings under cliff lines may cause cliff instability due to up to 65 mm of subsidence and tilts in the range 0.6 – 1.0 mm/m, i.e. a cliff of 150 m would then be tilted up to 150 mm and some instability would be expected;

- the level of damage predicted in the shale mine zone should be unacceptable to government authorities and should be limited to first workings only;

- Ensure that the historical New Hartley Shale Oil Shale Mine are defined as sensitive heritage of special significance that must protected from any subsidence movement and impacts;

- ensure that high cliffs (including those at Point Hatteras and Genowlan Point), pagodas, the Grotto and the Valley of the Kings are defined as sensitive heritage of special significance and fully protected from any subsidence movement and impacts;

- the cliff falls along 10% of cliffs in the so-called panel and pillar zone and 5% in the cliff line zone are highly inappropriate;

- There are two problems with the proposed panel and pillar zone. The void width of 61 m producing recovery rates of 67% is too great, as the degree of cliff collapse generated indicates and must be reduced to prevent significant cliff damage in that zone. Secondly, this zone also needs to stand further back from the cliffs in the cliff zone to ease tilts and strains on cliff lines in the adjoining zones. This additional stand back consideration is particularly important for the very high cliffs at Point Hatteras and Genowlan Point where mining should be restricted to first workings;

- 500 mm of subsidence in the area adjoining the Airly Village is unacceptable - risk of rock falls endangering people visiting Airly Village and Tramway track. 5% cliff failure with isolated rack falls - unacceptable due to compromising the surface environment and safety of walkers;

- In areas of cliffs and pagodas first workings mining are planned, (but only 30 m either side of the cliff), and even that is assessed to result in 5% of mining related impacts to the majority of cliffs, and in some cases 10%. As such, there should be no mining under cliffs/pagodas or other significant surface features such as The Grotto, which are of national geodiversity significance;

Dr Pells questioned whether subsidence predictions would increase as a result of post-mining flooding within Airly Mine workings. CCCL has confirmed that the implications of post-mining flooding were a factor influencing the mine design and plan. The effects of flooding on subsidence have been accounted for in the upper-bound subsidence predictions. Therefore, the EIS's maximum predicted subsidence values represent a worst-case scenario, on which the remainder of the EIS is based.

A6.4 Centennial Coal Response to Submission

A Response to Submissions (RTS) report was prepared by CCCL and lodged with the DPE during and after the public exhibition of the EIS. CCCL prepared this RTS report dated February 2015 in accordance with Section 75H (6) of the EP&A Act to address the issues raised in the submissions received on the EIS.

Centennial Airly advised in the RTS report;

"As with other bord and pillar / partial extraction Centennial Coal operations (for example, Clarence Colliery, Myuna Colliery, Awaba Colliery), Airly Mine proposes to undertake geotechnical review of first workings development prior to the commencement of any extraction that may result in surface subsidence. This geotechnical assessment will assess the behaviour of the roof, rib and floor to ensure their respective competencies lie within the system factors of safety established for the mine. This type of assessment has been successfully applied at for example at Myuna Colliery (which mines under Lake Macquarie) for over 30 years. The Revised Statement of Commitments (refer Section 6.0) has been updated to include the geotechnical reviews noted above."

"It should also be noted the mining methods proposed for the Project are intended to be flexible to allow the mine to adaptively manage impacts to surface features and water systems. The design has been made conservative enough in terms of subsidence, that changes can be made to the underground operations should impacts be outside the predicted levels before any significantly adverse impact actually occurs. Actions, if required, could be used in isolation or in various combinations to adapt the mine workings to avoid adverse impacts outside the predictions discussed in the EIS and supporting technical assessments. These actions are: "

- *"increasing the size of cliff protection zones by commencing or stopping extraction further away from cliffs than planned*
- *"moving around sensitive features and not conducting extraction activities*
- *"leaving additional pillars unmined*
- *"changing the dimension of pillars or void widths*
- *"reducing the size and extent of roadways.*

"Each of these actions has the potential to have a significant impact on the feasibility of the operation, and would only be undertaken as a considered response to impacts outside predicted values."

"Airly Mine has recognised that impacts due to mining that were acceptable in the past are now no longer acceptable to society as a whole. The proposed mine design is specifically intended to avoid significant damage to cliffs and rock features as discussed in Chapter 8.0 of the EIS."

"The Clarence Colliery design subsidence criteria of (100±25) mm (hence up to 125 mm subsidence for the Airly Mine Extension Project) was used as the basis for the subsidence limits for the mine design as these have proven successful in similar topography for over 15 years. Subsidence levels recorded at Clarence Colliery using partial extraction have ranged up to 103 mm in some areas around significant cliffs, yet without impact. Clarence Colliery has proven, over the monitoring period, that controlling and minimising vertical subsidence to approximately (100±25) mm has resulted in no impact on surface features such as cliff lines and/or pagodas, as evidenced by their ongoing monitoring (EPBC 2012/6446 Referral) including surface subsidence, groundwater monitoring and underground pillar monitoring. So the decision to adopt the proposed mine design at Airly Mine has been informed by the objectively verifiable success of similar partial extraction methods and subsidence limits employed at Clarence Colliery with minimal impact on the environment."

"Subsidence modelling was based on the recognised industry database. There are few cases of partial extraction style voids in the database as the vast majority of underground workings in both Australia and internationally involve full extraction with much greater impacts than proposed for the Project. Airly is proposing workings that are at the extreme conservative end of the database experience where impacts are least."

"Cliffs and associated pagodas as well as the more significant canyons on the Mount Airly / Genowlan Mountain complex are located within the Cliff Line Zone and Zone of First Workings where extraction will be limited to first workings only with large long term stable pillars. Extraction ratio in this zone is approximately 31%. The Cliff Line Zone and Zone of First Workings extends at least 30 m on both the upslope and downslope sides of identified cliffs and large pagoda features to provide a buttress style foundation for these features."

"An angle of draw (AoD) of 26.5 degrees is not required in most areas of the Project Application Area as that value is used where full extraction (for example, a longwall mine) is taking place. Only partial extraction or first workings is being proposed for the Project. Golder Associates (2014) in the Subsidence Impact Assessment noted that the type of workings being proposed would not require any angle of draw due to the very low levels of subsidence, tilt and strain. But in the interests of precaution a zone of at least 30 m is being proposed. Increasing the size of the Cliff Line Zone and Zone of First Workings to a 26.5 degree angle of draw will result in a significant loss of mineable reserve from the more productive mining areas and impact the Project feasibility significantly, but note without actually reducing any potential impacts in the zone significantly."

"The Cliff Line Zone and Zone of First Workings in area adjacent to the New New Hartley Shale Mine Interaction Zone has been increased in horizontal size to an effective angle of draw of 26.5° against the panel and pillar workings. This is an industry accepted value where full extraction is taking place. The interaction between the proposed Airly Mine workings and the existing New New Hartley Shale Mine create the same impact as full extraction, hence the increase in the size of the cliff protection zone in this area. This will prevent further damage to the cliffs above the Airly Village site and thus provide protection of the site and manage risk to the public."

"The significant pagoda features are usually in association with cliffs and these are further protected by first workings only in the Cliff Line Zone and Zone of First Workings. Interaction of the proposed partial extraction panel and pillar workings within the New New Hartley Shale Mine Interaction Zone will effectively be similar to full extraction in terms of subsidence, but identified pagodas in this zone are already significantly fractured but have not collapsed."

"The EIS has recognised the presence of The Grotto and The Oasis within the Project Application Area and has proposed mining methods that provide for very low levels of subsidence, tilts and strains in order to prevent fracturing or damage to these features, and hence provide a very high level of protection to these features and landforms around it. As discussed in Section 8.3.7.1 of the EIS. The Grotto (along with The Oasis) is located in the proposed Cliff Line Zone and Zone of First Workings (refer revised EIS Figure 8.2 (included in Appendix G of this RTS)) within the mining area where only first workings with large pillars will be carried out. This proposed mining method in the area has been designed to protect The Grotto (and The Oasis). This zone is predicted to have low levels of subsidence and will prevent surface impacts to the landform. Section 10.1.3.3 of the EIS notes that no groundwater drawdown is predicted under The Grotto or The Oasis. No surface cracking is predicted due to the low levels of subsidence predicted. As such no impacts on The Grotto and The Oasis are predicted. Airly has committed to an independent review of the geotechnical and subsidence aspects of the EIS. (Refer Revised Statement of Commitments in Chapter 6). This is in addition to the ongoing geotechnical review of first workings development prior to the commencement of any extraction that may result in surface subsidence."

"Cliff falls are a naturally occurring phenomenon. The website http://world.time.com/timelapse2/ has a time-lapse set of satellite images of the entire earth from 1984 to 2012. When the locality of Capertee, NSW is inputted into the search box, a series of images will play on screen. The photographs provided in Appendix D show the years the falls of cliffs occurred that are visible from the satellite imagery. Falls of rock large enough to cause damage to the tree cover below occurred in 1984, 1989, 2004 (2 separate falls), 2006, 2008 and 2009. Since that time another fall occurred in November 2013 for which there is a separate photograph taken by local resident B. Upton. The locality of that fall is shown on the 2012 image for completeness. This is a total of eight individual falls of cliffs that were visible from satellite images in the past 31 years or an average of 1 fall in less than 4 years"

This RTS report also provided responses on the OEH and DRE comments and issues.

"Comment – OEH

"The EIS stresses the importance of developing a monitoring system that minimises the impact on the environment, an important consideration for OEH. Section 8 of the Subsidence Predictions and Impact Assessment emphasises the value of the installation of stress and deformation monitoring instrumentation in the underground pillars providing data in respect to the stability of these pillars. The use of conventional subsidence monitoring lines over the first series of extraction panels beneath Mount Airly is expected to demonstrate the accuracy of less intrusive remote monitoring, which "would eliminate the reliance upon conventional subsidence survey lines" in more environmentally sensitive areas. OEH recommends that the DPE considers applying a condition of consent to ensure that minimal impact monitoring systems are employed within Mugii Murum-Ban SCA to minimise impact to the environment."

"Response

"Centennial Airly can confirm that:

- *underground stress and deformation monitoring instrumentation will be installed in the pillars, where required, to provide data in respect to the stability of these pillars*

- *less intrusive remote monitoring systems in place of conventional subsidence survey lines are currently being investigated and will be implemented as much possible*

"to ensure that both the proposed techniques in combination will minimise impact to the environment while allowing valuable information required for subsidence monitoring to be obtained. These minimal impact monitoring systems will be discussed and agreed with OEH and DRE prior to their implementation."

Issue – DRE

"The review of the EIS has led to the identification of two fundamental questions, both of which are considered to be mine feasibility matters for the proposed project. DRE consider that these issues need to be addressed prior to the Extraction Plan stage. These questions are:"

1. *"What should be the appropriate set-off distance from secondary extraction (in other words, what should be the dimension of the "cliff protection zone"), to maintain the integrity of the significant cliff formations within the subject area on a long term basis?*

2. *"Where should the "cliff protection zone" be applied to maintain the integrity of the significant cliff formations within the subject area on a long term basis?*

"Given the significant cliff formations within the subject area DRE recommends that an independent expert panel be established to undertake assessments of all relevant factors and identify the set off distance from secondary extraction and determine the appropriate cliff protection zone. The assessment and determination should be made prior to the proponent submitting an extraction plan."

Response

"Subsequent to DRE's submission dated 18 December 2014, DPE advised on 19 December 2014 via a telephone call that assessments recommended above by DRE must be completed as part of the RTS process. "

"Centennial Airly can confirm an independent review for recommendations on the mine design criteria proposed in the EIS will be undertaken. "

"The responses to the two above noted questions will be provided in the review report. The review report will be provided to DRE and DPE as supplementary information to the RTS."

This RTS report also provided responses on the future monitoring and future management plan issues.

"Mining operations will be conducted in accordance with the design parameters and those parameters will be implemented in the areas defined in this EIS. Geotechnical reviews of first workings development prior to the commencement of any extraction that may result in surface subsidence will be undertaken on an ongoing basis."
"A new Extraction Plan will be developed as required by the new consent and in accordance with any requirements of Mining Act 1992. An independent review of the geotechnical and subsidence aspects of the EIS will be undertaken prior to the development of the Extraction Plan and as part of the Response to Submissions Process."

"The Extraction Plan will provide detail around the management of subsidence impacts on the natural and built environment. The Plan is supported by a Subsidence Monitoring and Reporting Program and Community Consultation Process."

"The new Plan will incorporate requirements for mine design criteria, implementation, monitoring, management of mining systems and response plans to manage impacts to landscape, surface water, groundwater, and ecology impacts identified in as identified in Chapter 8.0 and in Sections 10.1, 10.2 and 10.3 of this EIS. The Plan will be developed in consultation with DITRIS (DRE) and OEH (land owner)."

"The Plan will include subsidence management elements as follows.

- *"Visual inspection of all mining areas prior, during and after mining activities will be undertaken."*

- *"Subsidence monitoring of initial panel and pillar mining on Mount Airly to confirm mining system performance and establish correlation between surface subsidence and underground geotechnical monitoring."*

- *"Ongoing underground geotechnical monitoring to demonstrate mining system performance will be undertaken."*

- *"Implement where practical remote subsidence monitoring techniques."*

A6.5 Comments in DPE Preliminary Environmental Assessment Report

The Department prepared a Preliminary Environmental Assessment Report (PEAR) in August 2015. This PEAR report advised that the key issues of the proposed Airly Mine Extension Project relate to:

- subsidence impacts on the surface features and conservation values of the MM SCA including cliff lines, steep slopes, pagodas and gorges, and the critically endangered *Pultenaea* and Heathland EEC;

- impacts arising from the discharge of mine-water on the downstream environment of the Gardens of Stone NP, within the Greater Blue Mountains World Heritage Area (GBMWHA); and

- whether the project would generate a socio-economic benefit to the local Lithgow region and the State of NSW.

This Department's PEAR report advised that Centennial's proposed mining system, which involves the use of partial extraction methods with the retention of long-term stable pillars, would provide sufficient protection to surface features and water resources on the site. Mining subsidence would be limited to less than 125 mm. An exception would apply to mining beneath the old workings of the former New Hartley Shale oil shale mine (the 'Interaction Zone') where greater levels of subsidence of up to 500 mm are predicted, depending on the condition of the former workings and the extent and width of existing mining voids. Despite this, the Department considered that sufficient protection would be provided to nearby cliffs in the form of an extended setback to second workings. Minor reductions in catchment runoff would occur in first order drainage lines feeding Gap Creek and some further cracking to nearby pagodas is expected.

The Department's PEAR report advised that outside of the New Hartley Shale Mine interaction zone, subsidence impacts are not expected to result in unacceptable impacts to steep slopes, pagodas, gorges, Aboriginal and European heritage or biodiversity values. The Department accepts that potential impacts to the visually significant sandstone cliffs are likely to be avoided through Centennial's conservative mine plan and has recommended the imposition of a performance measure requiring Centennial to ensure that mining results in no more than 2% damage to the cliff face area (i.e. occasional rock falls, displacement or dislodgment of boulders, or fracturing). The Department advised that Centennial would be required to implement adaptive management techniques, based on a program of ongoing monitoring of past mined areas, to ensure that this performance measure is achieved.

The Department's PEAR report advised that The Airly Mine Extension Project would result in significant social and economic benefits for both the local area as well as the State. These benefits include:

- continued direct employment of 59 employees, increasing up to 135 under full operating conditions;

- employment of an additional 30 full-time equint contractors during construction;

- indirect employment of an estimated 550 people across NSW;

- community contribution of up to $200,000 to Lithgow City Council (to reflect three Centennial mines in the Lithgow region);

- a minimum of $80 M to the State in royalty revenue (net present value); and

- $14.8 M in Commonwealth, State and local tax revenue (net present value).

The Department's PEAR report commented that having considered the costs and benefits of the project, the Department is satisfied that it would deliver economic benefits to the local region and NSW, while avoiding and minimising environmental impacts. Consequently, the Department considers that the Airly proposal is in the public interest and should be approved, subject to strict conditions.

The Department's PEAR report noted that Centennial proposes to apply four mining methods across five zones developed with regard to the potential impact of subsidence on sensitive surface features (see Table 2 and Figure 5), comprising:

- panel and pillar mining beneath the plateau areas on Mount Airly and Genowlan Mountain (Panel and Pillar Mining Zone or PPMZ);

- panel and pillar mining beneath the New Hartley Shale Mine Interaction Zone;

- first workings only, beneath cliff lines and surface features such as the Grotto and internal cliffs (cliff line zone and zone of first workings, herein referred to as the 'Cliff Line Zone');

- partial extraction of pillars (involving single or double sided lifts of coal from pillars) beneath steep slopes (Partial Pillar Extraction Zone or PPEZ); and

- pillar splitting and quartering in shallow areas (herein referred to as the 'Shallow Zone').

The Department's PEAR report compiled the following table from the EIS and the Golders report for these different zones.

Table 3: Predicted subsidence levels across the proposed mining zones (see Figure 5)

	Vertical subsidence (mm)	**Tilt (mm/m)**	**Tensile strain (mm/m)**	**Compressive strain (mm/m)**	**Fractured zone – height above seam (m)**
Proposed Subsidence Criteria – General Limits	125	2.5	2.0	2.0	N/A
First Workings only (Cliff Line Zone)	10 – 65	0.6 – 1.1	0.2 – 0.3	0.2 – 0.5	<10
Pillar Splitting & Quartering (Shallow Zone)	3.5 – 25.5	0.6 – 1.1	0.1 – 0.4	0.2 – 0.6	<10
Partial Pillar Extraction (PPEZ)	25 – 65	0.5 – **2.6**	0.2 – 1.1	0.2 – 1.9	20 – 35
Panel and Pillar Mining (PPMZ)	40 – 106	1 – **3.3**	0 – 1	0 -2	60 – 70
Interaction Zone (first workings only)	10 – 65	0.6 – 1.1	0.2 – 0.3	0.2 – 0.5	<10
Interaction Zone (below super-critical voids)	**200**	2.5 – **6.7**	1.0 - 2	0.7 – **3.3**	To surface (pre-existing)
Interaction Zone (below sub-critical voids)	**500**	6.2 – **16.7**	**2.4** - **5**	1.8 – **8.3**	To surface (pre-existing)

Notes:

- Predicted exceedances of Centennial's proposed general subsidence limits are shown in bold.
- The effects of post-mining flooding and double –abutment loading are generally represented by the upper bound values.

The Department's PEAR report advised that the mining system and zones within the Airly Mine would be implemented through detailed mine plans developed as part of individual future Extraction Plans. As mining progresses from lower areas in the west to the higher cliffs and more extensive pagoda clusters in the east, Centennial would monitor and observe subsidence to calibrate future subsidence predictions and calibrate impact models. This would enable adaptive management techniques to be applied in subsequent mining areas, in the event that observations exceed predictions, which may include:

- increasing the size of the Cliff Line Zone by commencing or stopping extraction further away from cliffs than planned;
- moving around sensitive surface features and not conducting extraction activities;
- leaving additional pillars unmined in the seam;
- changing the dimension of pillars or void widths; and/or
- reducing the size and extent of roadways (i.e. first workings) in the seam.

The Department's PEAR report also provided the following comments on the subsidence effects and impacts for each of these zones:

- ***"Cliff Line Zone "***

"Centennial's proposed Cliff Line Zone would protect the majority of cliffs, pagodas and some parts of the steep slopes on the site by limiting extraction to first workings only. Centennial has defined this zone through applying a horizontal setback distance of 30 m measured from both the crest and toe of the cliff to areas of secondary extraction (see Figures 5 and 6). The SPIA predicts that this setback from secondary extraction would reduce potential damage to the face area of cliffs to a maximum of 10%. However, Centennial expects that, based on its experience of partial extraction methods elsewhere, this would more likely be < 5% and probably nil. Centennial believes that the level of damage would be similar to the natural rate of rock fall and/or cliff collapse."

"The Department considers that damage to 10% of the cliff face area would represent an unacceptable impact to the visual significance of the prominent sandstone cliffs that define the SCA and the western edge of the Capertee Valley. It is clear in OEH's Statement of Management Intent for the SCA and in submissions from the public that the visual significance of these mesas and the sandstone cliffs are important in the regional viewshed. Moreover, the Department acknowledges that the GBMWHA Advisory Committee supports the addition of the SCA to the Gardens of Stone NP once mining activities at Airly have been completed. The Department therefore considers it important to preserve the visual and conservation values of the prominent sandstone cliff lines and proposes to achieve this through a targeted performance measure which would limit damage to no more than 2% of the cliff face area. In order to avoid this measure applying to natural cliff or rock falls, it would only apply to cliffs within 26.5° AoD of total proposed mine workings"

"The SCA is characterised by a range of both platy and smooth pagodas that vary in height and visual prominence. These are located at the top of cliff lines around the edges of Mount Airly and Genowlan Mountain, above the Grotto and across some plateau areas. The Cliff Line Zone has been extended to also provide protection to the internal cliffs and pagodas around these areas. Therefore, the vast majority of pagodas would be protected by the Cliff Line Zone, in which extraction is limited to first workings, and no surface cracking is predicted to occur. There are some small areas of pagodas, such as on the plateau of Mount Airly and Genowlan Mountain, under which panel and pillar mining would take place. In these areas, subsidence is predicted to range from as low as 40 mm up to a maximum of 106 mm with low tilts and strains. As no surface cracking is expected, the EIS predicts no impacts to these pagodas. "

Table 2: Centennial's proposed application of mining methods and zones across the site

Mining zones	Application	Mining methods	Overlying sensitive surface features
First Workings only (Cliff Line Zone)	Located beneath cliff lines around the edge of Mount Airly and Genowlan Mountain. Zone defined by a minimum 30 m measured horizontally from the crest and toe of cliff lines (or an 8° angle of draw) to adjacent second workings zones and subject to an approved Extraction Plan.* This setback distance is increased to a minimum of 26.5° angle of draw (or half the depth of cover at the crest of a cliff) to the adjacent PPMZ in relation to cliffs that have been previously affected by New Hartley Shale Mine subsidence.	First workings only with long-term stable pillars designed to a minimum: • factor of safety of > 2.11; and • width to height ratio of > 8.0.	Cliffs, pagodas, steep slopes, the Grotto, Aboriginal and non-Aboriginal heritage sites, ground water aquifers and listed threatened species and communities (including all *Pultenaea* and some Heathland EEC).
Partial Pillar Extraction (PPEZ)**			
Pillar Splitting & Quartering (Shallow Zone)	This zone extends around the edge of the PPEZ and Cliff Line Zone. Zone defined by a: • minimum depth of cover of 20 m; and a • maximum depth of cover of 100 m.	First workings to develop pillars which would be later reduced by driving additional roadways to split or quarter the original pillars subject to: • minimum factor of safety of ≥ 1.6; • minimum pillar width to height ratio of > 4; and • no formation of intersections at depths > 30 m.	Steep slopes, 3rd order and greater watercourses, groundwater aquifers, built features, Aboriginal and non-Aboriginal heritage sites and potential habitat for listed threatened species.
Panel and Pillar Mining (PPMZ)	On the plateau areas above the cliffs. Zone defined by: • the setback to cliff lines defined by the Cliff Line Zone (ie a minimum of 30 m); • a minimum depth of cover of 160 m; and • a maximum depth of cover of 310 m.	Panel and pillar mining would involve a maximum void width of 61 m separated by long-term stable chain pillars (29.5 m x 100 m) designed to a minimum: • factor of safety of ≥ 1.6; and • width to height ratio of > 9.	Cliffs, pagodas, groundwater aquifers, built features, Aboriginal heritage sites and listed threatened species (including remaining Heathland EEC).
Panel and Pillar Mining beneath the Interaction Zone	As above, panels would not commence within a setback defined by half the depth of cover (or a 26.5° angle of draw) to cliffs in proximity to the Interaction Zone. The setback is measured from the crest of the cliff.	As above	Cliffs, pagodas, groundwater aquifers and listed threatened species.

*Notes: *DRE has requested that an expert panel be convened to review the adequacy of the 30 m setback from cliff lines to second workings as part of the Extraction Plan process. Therefore, the 30 m represents a minimum setback which may be increased during the Extraction Plan process.*

*** Airly Mine has decided not to practice the single and double lifting mining method within the lease of the mine.*

The Department considers that, as many of the pagodas are situated on or in close proximity to the top of cliff lines, they should therefore be subject to the same performance standard as the cliff lines below (i.e. that mining should not impact more than 2% of the total area of pagodas).”

- *" The Grotto “*

“The Grotto is a slot canyon, or narrow gorge, with surrounding internal cliff lines topped by pagoda clusters. Recognising the conservation values of this feature, Centennial extended the Cliff Line Zone to provide additional protection to this feature. The EIS predicts that there would be negligible subsidence impacts on the Grotto. “

- *“Cliffs outside the Cliff Line Zone “*

“There are only six cliff lines located outside of Centennial’s proposed Cliff Line Zone under which panel and pillar mining is proposed to take place fully or in part in the PPMZ. The EIS predicts the following impacts to these cliffs:”

  - *" Mta 43 – upper bound damage to 18% of the cliff face area but expected to be less than 10%;*
  - *“B19 – upper bound damage to 13% of the cliff face area but expected to be less than 5%;*
  - *“B9 and B12 – upper bound of 2-3% damage but probably nil;*
  - *“B15 – upper bound of 5% damage but probably nil; and*
  - *“B17 – upper bound of 3% but probably nil.*

“These six cliffs are not the very high or visually prominent sandstone cliffs that define the boundaries of Mount Airly or Genowlan Mountain, but rather are small cliffs which run in towards the plateau areas, where panel and pillar mining is proposed to be undertaken.”

“The Department has weighed up the conservation values of providing additional protection to these cliffs however no further measures to avoid or mitigate impacts are considered necessary, these six cliff lines all would be subject to the recommended performance measure requiring damage to be limited to no more than 2% of the total affected cliff face area. The Department considers that this strict overall performance measure would satisfactorily protect the conservation values of the Mugii Murum-ban SCA.”

- *Steep slopes*

“Mining involving first workings in the Cliff Line Zone, secondary extraction in the PPEZ or pillar splitting and quartering in the Shallow Zone would take place under the steep slopes at the base of cliff lines. The SPIA states that the mine plan design with large long-term stable pillars and limited extraction spans used in the PPEZ would minimise subsidence to less than 70 mm (typically between 20 – 50 mm) with strains <1 mm/m and tilts ranging between 0.5 – 2.6 mm/m (see above Table 3). Based on these very small strains, surface cracking is not predicted and the maximum tilt is equint to a localised change in slope angle of 0.15°. This would constitute a negligible increase in the risk of landslide or slope impacts. As mining in both the Cliff Line Zone and Shallow Zone would generate lower subsidence levels (including tilts and strains) than those in the PPEZ, the Department considers that there would equally be a negligible risk to landslide and impact to slope in these zones. “

- *Interaction Zone*

“In the Interaction Zone, greater subsidence is expected to occur. There is existing surface cracking in areas of rock outcrops and pagodas on the plateau of Mount Airly, as well as large boulders and slabs of sandstone cliff located on the steep slopes below the cliff line in this area. Panel and pillar mining in this area is expected to recover 1 Mt of coal. Due to uncertainty around the condition of the old workings of the New Hartley Shale Mine, subsidence of between 200 mm and 500 mm may occur. The SPIA anticipates that this would result in new surface cracking and/or the reactivation of old surface cracks in this area. “

"There is evidence of past mining-induced subsidence effects on the cliff lines and pagodas in the vicinity of the Interaction Zone including surface cracking and evidence of rock falls. This has been attributed to the former workings in the New Hartley Shale Mine. In order to minimise further impacts to cliffs and associated pagodas near the Interaction Zone, the setback defined by the Cliff Line Zone from the crest of the cliff to second workings would be increased from 30 m up to half the depth of cover (or an angle of draw of 26.5°). This is equint to the level of protection afforded to sensitive surface features near full extraction mining methods such as longwall mining. Therefore, it is expected to provide protection to the cliff lines and associated pagodas from the less intensive form of panel and pillar mining proposed. Outside of this setback zone, there would remain some small areas of rock outcrop and pagodas that are around 5 m in height. These areas have already been damaged by surface cracking. This cracking may be reactivated, or new surface cracking may eventuate."

- *Public submissions*

"Many interest groups and public submissions commented on the potential impact of mining on cliffs, including that the: "

- *" original cliff protection zones in the 1993 consent, defined by an AoD of 25°, should be retained;*
- *" rate of coal extraction is too high, and contrary to Centennial's previous undertakings to leave 50% of coal in the ground; and*
- *"definition of the Cliff Line Zone could be reworded to improve clarity.*

"Centennial expects that the AoD from mining in the PPEZ (beneath the slopes below the cliffs, see Figure 6) to cliff faces in the Cliff Line Zone would be as low as < 8° and possibly negative, based on its observations at Clarence Colliery. Therefore, the application of a setback to second workings defined by an AoD of 25° would be overly conservative and unnecessarily sterilise part of the coal resource in the PPEZ. Despite the low AoD, Centennial has conservatively applied a 30 m setback measured from the crest and toe of the cliff line to second workings to protect cliff lines."

"The extraction rates were clarified in the RTS. Centennial calculated that it would recover around 52% of the total coal resource available beneath the SCA. Whilst the PPMZ zone would see up to 67% of coal recovered, this would reduce to 51% in the PPEZ and Shallow Zones. Only 31% of coal would be recovered in the Cliff Line Zone meaning that 69% would be left beneath cliffs in the form of long-term stable pillars. In all zones, long-term stable pillars would be retained to support the overlying strata, avoid caving and minimise subsidence and potential environmental consequences. The Department is of the view that the proposed mining system is suitably conservative, subject to recommended conditions."

- *"Performance measures "*

"The Department is satisfied that the proposed method of extraction should avoid significant impacts and minimise residual effects from subsidence on cliffs, steep slopes, pagodas and gorges. Consistent with other mining operations in NSW which have mined under cliffs and similar surface features, the Department has recommended that strict subsidence performance measures are included within the proposed development consent. A summary of the Department's recommended performance measures to protect cliffs, steep slopes, pagodas and gorges is provided in Table 4 below."

"DRE has proposed that an expert panel is formed to advise Centennial on preparation of Extraction Plans, such that there is confidence that final mining plans will achieve the performance measures which relate to cliffs and pagoda formations. The Department supports this proposal and has included it in recommended conditions."

Table 4: Subsidence impact performance measures for cliffs, pagodas, gorges and steep slopes

Land	
Mugii Murum-ban State Conservation Area (excluding land within the Interaction Zone)	Negligible subsidence impacts or environmental consequences
Mugii Murum-ban State Conservation Area (within the Interaction Zone)	No greater subsidence impacts or environmental consequences than predicted in the EIS
The Grotto	Negligible subsidence impacts or environmental consequences
Cliffs within a 26.5˚ AoD of underground mine workings	No greater subsidence impacts or environmental consequences than predicted in the EIS (ie occasional rock falls, displacement or dislodgement of boulders or slabs of less than $30m^3$ or fracturing, that do not impact Aboriginal heritage, EECs or public safety), that in total do not impact more than 2% of the total areas of such cliffs.
Pagodas within a 26.5˚ AoD of underground mine workings (other than pagodas affected by the interaction Zone)	No greater subsidence impacts or environmental consequences than predicted in the EIS ((ie occasional rock falls, displacement or dislodgement of boulders or slabs of less than $30m^3$ or fracturing, that do not impact Aboriginal heritage, EECs or public safety), that in total do not impact more than 2% of the total areas of such pagodas.
Pagodas within a 26.5˚ AoD of underground mine workings (within the Interaction Zone)	No greater subsidence impacts or environmental consequences than predicted in the EIS
Minor cliffs	No greater subsidence impacts or environmental consequences than predicted in the EIS
Steep slopes	No greater subsidence impacts or environmental consequences than predicted in the EIS

- *Monitoring and management*

"Due to the rugged topography, the use of conventional subsidence monitoring techniques such as surveyed monitoring lines may be impracticable in some parts of the site. OEH also considered that such monitoring could result in further environmental impacts on the conservation values of the SCA, since the line-of-sight survey lines are usually axe-cut. Centennial's EIS proposes an alternate subsidence monitoring regime which would include: "

- *"establishment of conventional surface subsidence monitoring to confirm system performance in the initial stages of mining, as it progresses from less sensitive plateau areas of Mount Airly to Genowlan Mountain which features the highest cliffs, more substantial areas of pagodas and the highly sensitive Pultenaea and Heathland EEC; "*
- *"underground pillar stress and deformation monitoring arrays to be installed in areas subject to surface subsidence monitoring to develop a correlation between underground observations and surface subsidence results. This would be cross-referenced to the stress and subsidence values predicted in the design and the models calibrated by this actual experience; "*
- *"surface subsidence monitoring involving conventional surveyed lines would then be discontinued, in favour of underground monitoring techniques combined with regular surface inspections; "*
- *"consideration would also be given to the use of remote station monitoring and remote sensing techniques such as InSAR and LiDAR. These would need to be evaluated for applicability given the small levels of subsidence involved and the densely wooded nature of the surface. Due to the inherent margins of error, techniques such as these may be more suited to the rocky outcrops in the site, rather than vegetated areas; and "*
- *"development of TARPs to provide consistent tools for performance management. TARPs would incorporate mining system design parameters, items to be monitored, appropriate trigger values to define normal and abnormal behaviour and actions to be taken to maintain normal behaviour or rectify abnormal behaviour. "*

"The Department and OEH support this approach and the Department's recommended conditions support and enhance these outcomes."

"Conclusion "

"The Department is satisfied that Centennial has avoided the risk of most significant impacts to surface features and threatened species and EECs within the Mugii Murum-ban SCA by proposing a conservative mining system based on methods of first workings and partial pillar extraction. The Department believes that this mining system would ensure the protection of cliff lines, steep slopes and pagodas by leaving more coal in the ground in the form of long-term stable pillars and through applying setbacks from second workings. The design criteria for these long-term stable pillars are highly conservative and would provide an equint level of protection as applied to key surface infrastructure elsewhere in NSW. In addition, increased protection is provided through an extended setback to second workings to cliffs near the Interaction Zone (which in turn would protect downslope heritage items from rockfall and cliff collapse)."

A6.6 PAC Report

On 17 August 2015, the Minister requested the Planning Assessment Commission (PAC) to conduct public hearings and review the merits of the project paying particular attention to the potential subsidence related impacts on the natural values of the Mugii Murum-ban State Conservation Area, water impacts, and socio-economic impacts due to the Airly Mine Extension Project.

The PAC was constituted by Ms Robyn Kruk AM (chair) with Mr Alan Coutts and Mr David Johnson. The PAC examined the documents referred to in the Terms of Reference, including the Preliminary Environmental Assessment Report (PEAR) provided by the Department of Planning and Environment (DPE). The PAC received 509 written submissions, held a public hearing, visited the site and surrounds and met with the Department, the Applicant and various government agencies, including Lithgow City Council.

The PAC noted that the PEAR was not entirely clear about the final position of some government agencies on certain key issues identified in the Terms of Reference and raised in public submissions, including the position of the Division of Resources & Energy (within the Department of Trade & Investment) (DRE) on subsidence issues and the Environmental Protection Authority (EPA) on water discharge issues. Consequently, PAC deemed it necessary to seek clarification from the Department in that regard, and to consult further with each of these agencies.

DRE provided further advice to PAC, in early November 2015, stating:

- Centennial Coal had applied the industry standard level of protection (a 26.5 degree angle of draw) to cliff lines located in the vicinity of the proposed panel and pillar mining beneath the former New New Hartley Shale Mine;

- In relation to factors of safety FoS, the proposed mining system would have FoS higher than 1.6 and, in the case of the Shallow mining zone specifically, it would have FoS of> 2, and would therefore be considered long-term stable;

- Centennial had committed to leaving first workings pillars in the Cliff Line Zone with a minimum FoS of 2.11;

- Centennial has proposed to implement a range of adaptive management measures to ensure it meets the environmental performance measures, including increasing the size of the Cliff Line Protection Zone by commencing or stopping extraction further away from the cliffs than planned, if required based on its Trigger Action Response Plan (TARP); and

- DRE recommended that an independent expert panel established should provide input into the Extraction Plan process and should review and provide advice on the mine plan as part of the initial stages of development of each extraction plan.

Later DPE advised the PAC; "*The Department also fully supports DRE's extra information and recommendation that any independent expert panel should provide input to the Extraction Plan process and should review and provide advice on the mine plan and relevant mine design principles as part of the initial stages of development of each such Extraction Plan*."

"The Commission notes the existing project approval provides for a maximum vertical subsidence limit of up to 1.8 metres however following further discussions between the Department and the proponent, the proponent confirmed the modification proposal seeks limited extraction of the resource which will result in maximum vertical subsidence of only 125 mm. The Department has recommended a robust suit of modified conditions to confirm this commitment from the proponent and to bring the conditions up to contemporary standards. The Commission is satisfied that appropriate measures including ongoing monitoring; adaptive management; and enhanced management plans have been recommended to address the risk of subsidence. The Commission also notes various Community Groups 'strongly support' the Department's recommended modified subsidence conditions. The Commission considers the recommended conditions, including an adaptive management strategy, provide a sound framework for ensuring adequate protection for natural features including cultural heritage and watercourses in the project area from project related subsidence impacts."

The PAC then released their report to the Minister later in November 2015, saying; The PAC report agreed with most of the findings and recommendations of the PEAR. The PAC advised; "*The Commission notes that the assessment of underground coal mining in areas of sensitive surface features is a relatively young science and the Commission recognises that there are a number of uncertainties associated with the current proposal. However, the Commission has been involved in the assessment of most of the key underground coal mines in NSW and understands that a robust set of conditions has been developed in recent years to deal with the inherent uncertainties surrounding underground mining. The Commission is satisfied that these uncertainties can be managed through a comprehensive framework involving performance criteria, the Extraction Plan process, and the role of the recommended Independent Expert Panel*."

"The Commission notes that bord and pillar mining allows a more responsive and adaptive approach than the more common longwall mining method, as there is flexibility to cease or change the mining operations based on any potential impacts or risks. However, the Commission also acknowledges that some parties have identified that the proposed mine plan proposes to use a reduced angle of draw and a reduced 'factor of safety' relating to long-term stability of pillars. The Commission agrees with the recommendations from both DRE and the Department that an Independent Expert Panel."

"The Commission notes that the Applicant has proposed that the Cliff Line Zone would protect the majority of the cliffs, pagodas and the steep slopes by limiting extraction to first workings. In addition, within the Cliff Line Zone the Department has recommended strict performance criteria to limit damage to no more than 2% of the total area of cliffs and 2% of the total area of pagodas."

"These performance criteria are consistent with other mining operations in NSW which have mined under cliffs and similar surface features. The Commission supports this approach. Consequently, the Commission is generally satisfied that the proposed method of extraction would appropriately minimise subsidence impacts on cliffs, steep slopes, pagodas and gorges."

"Nevertheless, the Commission considers that there is scope for improving the existing framework of conditions and believes the recommended Independent Expert Panel is a significant and appropriate step towards ensuring that subsidence-related impacts are properly addressed. In particular, the Commission has adopted a precautionary approach and considers that the Panel should be established prior to determination in order to confirm that the mine plan is appropriate and the predicted subsidence effects are accurate and reliable. Furthermore, the Commission does not consider that the role of the Panel should be merely advisory, rather the recommendations from the Panel should be enforceable through the Extraction Plan approval process, and publicly reported, to ensure that they are appropriately incorporated into the ongoing management of the mine."

"The Commission considers that the project is approvable subject to stringent conditions of consent. The Commission has made a total of nine recommendations. The most significant recommendations relate to the establishment of an Independent Expert Panel prior to determination to provide advice and

recommendations about the predicted subsidence impacts and the proposed subsidence management regime. The Panel would also have an ongoing role in any approval by providing enforceable recommendations through the Extraction Plan approval process."

Appendix 7 References and Bibliography

Bieniawski, ZT, 1992. A method revisited: coal pillar strength formula based on field investigations. In: Proceedings of the Workshop on Coal Pillar Mechanics and Design. Pittsburgh, PA: U.S. Department of the Interior, Bureau of Mines, IC 9315, pp. 158-165.

Canbulat, I and Ryder, JA, 2002. Prediction of Surface Subsidence and Sinkholes. Proceedings of the SANIRE Symposium: Re-Defining Boundaries, Vereeniging.

Canbulat, I, and Zhang, C, 2016. Risks Associated with Shallow Bord and Pillar Workings in Coal Mines, International Journal of Rock Mechanics and Mining Sciences. (under review).

Centennial Coal Airly Response to Submissions, Airly Mine Extension Project (SSD 5581 February 2015

Colomina, I, 2014, "Unmanned aerial systems for photogrammetry and remote sensing: A review", ISPS Journal of Photogrammetry

Creech, M and Tobin, C, (1991) 'Review of subsidence data and prediction methods for Teralba Colliery' in Unpublished OCAL Report – NC 91/105.

Creech, M, (1995) 'A review of subsidence data from the Newcastle coalfield and a new subsidence prediction method' in 'Proceedings of the Third Triennial Conference on Buildings and Structures subject to Ground Movement', Mine Subsidence Technological Society Newcastle, 5th to 7th February 1995 pp199-208

Creech, M, (1998), "The Effects of Conglomerate Channels on Longwall Mining Subsidence and Surface Subsidence", Proceedings of the 4th Triennial Conference on Mine Subsidence

Das, BM (1986). Influence of Width to Height Ratio on Post-failure Behaviour of Coal. International Journal of Mining and Geological Engineering, 4:79-87.

Ditton, et al (2003) 'Review of industry subsidence data in relation to the influence of overburden lithology on subsidence and an initial assessment of a sub-surface fracturing model for groundwater analysis' Ditton S, Frith R, Hill D, Australian Coal Association Research Program report C10023 September 2003

Frankham, B & Mould 1980 'Mining subsidence in N.S.W – recent developments' in the Aus. I.M.M Conference, New Zealand, May 1980 pp167-179

Gale, W and Sheppard, I, 2011 'Investigation into abnormal increased subsidence above longwall panels at Tahmoor Colliery NSW' in Proceedings of the 8th Triennial Conference on mine Subsidence, Mine Subsidence Technological Society Pokolbin, 15th to 17th May 2011 pp63-79

Gale, W, (2008), ACARP C13013, "Aquifer Inflow Prediction above Longwall Panels", SCT.

Galvin, J, 2016, Ground Engineering Principles and Practices for Underground Coal Mining, Springer

Galvin, J, et al, 1999, "Engineered Mine Design in Soft Strata Environments", ACARP C4026

Galvin, JM, Hebblewhite, BK, Salamon, MDG and Lin, BB (1998). Establishing the Strength of Rectangular and Irregular Pillars. Final Report for ACARP Project C5024.

Golder Associates, (2013). Subsidence Predictions and Impact Assessment for Airly Mine. GA Report No. 127621105-003-R-Rev2 to Airly Mine.

Golder Associates, (2014), “Environmental Impact Statement – Airly Mine Extension Project”, Report 137623024_061_R_Rev2

Golder Associates, (2014), “Subsidence Predictions and Impact Assessments for Airly Mine”, Report 127621105-003-R

Golder Associates, (2014). Pillar Stability and Subsidence Assessments for the 103 Panel, 200 Area Extension and 205 Panel. GA Report No. 127621105-093-R-RevO to Airly Mine.

Golder Associates, (2014). Pillar Stability and Subsidence Assessments for the 205 Panel Extension, 100 Cross Panel, 420 Panel, 121 Panel and 122 Panel. GA Report No. 127621105-109-R-Rev1 to Airly Mine.

Guo, Adhikary & Gaveva, (2007), ACARP C14033, “Hydrogeological Response to Longwall Mining”, CSIRO,

Hill, D.J. (2005). Coal Pillar Design Criteria for Surface Protection. Proceedings of Coa12005, AusIMM, Brisbane.

Hill, DJ (2010). Long-Term Stability of Bord and Pillar Workings. Paper presented at the Third International Workshop on Coal Pillar Mechanics and Design, Morgantown, W. Va.

Holla, L, & Barclay 2000 ‘Mine Subsidence in the Southern Coalfield, NSW, Australia’ New South Wales Department of Mineral Resources 2000

Holla, L, 1985(a) ‘Mining Subsidence in New South Wales, 1. Surface Subsidence Prediction in The Southern Coalfield’ Department of Mineral Resources December 1985

Holla, L, 1985(b) ‘Empirical prediction of subsidence movements in the Southern Coalfield of New South Wales, Australia’ in Proceedings of the 6th International Congress and Exhibition, International Society for Mine Surveying , Harrogate pp557-567

Holla, L, 1987 ‘Mining Subsidence in New South Wales, 2. Surface Subsidence Prediction in the Newcastle Coalfield’ Department of Mineral Resources January 1987

Holla, L, 1988 ‘Effects of Underground Mining on Domestic Structures – Prediction versus

Holla, L, 1991(a) ‘Mining Subsidence in New South Wales, 3. Surface Subsidence Prediction in the Western Coalfield’ Department of Minerals and Energy January 1991

Holla, L, 1991(b) ‘Reliability of Subsidence Prediction Methods for use in Mining Decisions in New South Wales’ in ‘Reliability Production and Control in Coal Mines’ Wollongong 2-6 September 1991 pp215-221

Holla, L, 1991, “Surface Subsidence Prediction in the Western Coalfield” Dept. Minerals and Energy.

Holt, G, 1984, “Monitoring the effects of subsidence under the Railway near Bell, NSW”, NERDDC/ACARP Project C0423

Holt, G, et al, 2000, “Monitoring the effects of Coal Extraction under the Great Western Railway near Bell, NSW”,

ISO 5725-1 ‘Accuracy (trueness and precision) of measurement methods and results - Part 1: General principles and definitions.’, pp.1 (1994)

Kapp, WA, 1973 ‘Subsidence at Kemira Colliery, New South Wales’ in Proceedings of the Symposium on Mines, Illawarra Branch – The Australian Institute of Mining and Metallurgy

Kapp, WA, 1982 'A review of subsidence experiences in the southern coalfield, New South Wales Australia, in Proceedings of the Society of Mining Engineers of AIME Conference England 1982 pp167-182

Kapp, WA, 1984 'Mine subsidence and strata control in the Newcastle district of the northern coalfield New South Wales' unpublished PhD Thesis, Dept. of Civil and Mining Engineering, University of Wollongong 1984

Kay, D, 1991, "Effects of Subsidence on Steep Topography and Cliff Lines", NERDDP, Dept. Min Res.

Madden, BJ, (1987). Coal Pillar Design - Can Increased Extraction be Achieved Safely? Mine Safety and Health Congress, Johannesburg.

Madden, BJ, and Hardman, DR (1992). Long-Term Stability of Bord and Pillar Workings. Proceedings of the Symposium on Construction over Mined Areas, Pretoria.

Madden, BJ. and Canbulat, I, 1996. Reassessment of Coal Pillar Design Procedures. Proceedings of the Safety in Mines Research Advisory Committee (SIMRAC) Symposium. Mintek, Johannesburg.

Madden, BJ. and Canbulat, I, 1997. Practical Design Considerations for Pillar Layouts in Coal Mines. Proceedings of the 1st Southern African Rock Engineering Symposium (SARES 97), Johannesburg, South Africa.

Mark, C,1990. Pillar Design Methods for Longwall Mining. Bureau of Mines Information Circular IC 9247.

Mark, C and Chase FE (1997). Analysis of retreat mining pillar stability (ARMPS). In: Proceedings - New Technology for Ground Control in Retreat Mining. Pittsburgh, PA: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 97-122, IC 9446, pp. 17-34.

Mills, K et al, 2009, "Monograph 12 - Australasian Coal Mining Practice, Ch 12 - Subsidence Engineering",

Mills, K, 1998, "Subsidence Mechanisms about Longwall Panels", Strata Control Technology

Mills, K, 2000, "Overburden Monitoring at Start of Longwall E1 South Bulga", Strata Control Technology

NSW Department of Planning and Environment, 2015, August, Preliminary Environmental Assessment: Airly Mine Extension Project (SSD 5581)

NSW Planning Assessment Commission, Airly Mine Extension Project, Review Report, November 2015

O'Donnell, S, 2001, "Longwall Mining beneath the Pacific Highway - Moonee Colliery – An Overview",
Performance' in Proceedings of the fifth Australia-New Zealand Conference on Geomechanics, Sydney 22-23 August 1988 pp351-355

Reynolds, RG 1977 'Coal mining under stored waters, a report on inquiry into coal mining under or in the vicinity of stored waters (NSW Government Printer, Sydney)

Salamon, MDG and Oravecz, KL (1976). Rock Mechanics in Coal Mining. Chamber of Mines of South Africa.

Salamon, MDG, 1982. Unpublished report to Wankie Colliery. Zimbabwe.

Salamon, MDG, Galvin, JM, Hocking, G and Anderson, I (1996). Coal Pillar Strength from Back Calculation.

Salamon, MDG, Galvin, JM, Hocking, G and Anderson, I, 1996. Coal Pillar Strength From Back-Calculation. Strata Control for Coal Mine Design, UNSW. Final Project Report, No: RP 1/96. Joint Coal Board.

Salamon, MDG, Ozbay, MU and Madden, BJ, 1998. Life and Design of Bord and Pillar Workings Affected by Pillar Spalling. Journal of Southern African Mining and Metallurgy, 98:135-145.

Salamon, MDG. and Munro, AH, 1967. A Study of the Strength of Coal Pillars. Journal of Southern African Mining and Metallurgy, 68(2):55-67.

Salamon, MDG., and Oravecz, KI, 1976. Rock Mechanics in Coal Mining (P.R.D. series no. 198). Johannesburg: Chamber of Mines of South Africa.

Salamon, MDG., Canbulat, I and Ryder, JA, 2006. Seam-Specific Pillar Strength Formulae for South African Collieries. Proceedings of the 41st U.S. Rock Mechanics Symposium. Golden, CO.

Seedsman, R, 1988, “Mining in Proximity to the Awaba Tuff”, CSIRO

Seedsman, R, et al, 1987, “Claystones of the Newcastle Coal Measures”, NERDDP, CSIRO

Strata Engineering, (2001). A Review of the Geotechnical Design Aspects Highwall Mining Based on a Back-Analysis of Australian Experiences. Report No. 00-001-RCH/1 to Roche Mining.

Strata Engineering, (2005). Partial Extraction Stability Assessment. Rep. No. 04-001-CLA-4 to Clarence Colliery.

Strata Engineering, (2005). Subsidence Impact Assessment on the Cliff Lines Above the Eastern SMP Application Area. Report No. 05-001-CLA to Clarence Colliery.

Strata Engineering, (2008). Review of Subsidence Information from Recent Partial Extraction Areas. Report No. 04-001-CLA-57 to Clarence Colliery.

Strata Engineering, (2008). Subsidence Impact Assessment on the Cliff Lines above the Outbye Areas SMP Application Area. Report No. 04-001-CLA-54 (Rev. B) to Clarence Colliery.

Strata Engineering, (2010). Design of Partial Extraction Layout for Airly Mine. SEA Report No. 09-001-AIR-4 to Airly Mine.

Strata Engineering, (2011). Review of Subsidence Information from Recent Partial Extraction Areas. Report No. 04-001-CLA-109 to Clarence Colliery

Strata Engineering, (2012). Geotechnical Assessment for Proposed Partial Extraction Layout Options. SEA Report No. 09-001-AIR-12 to Airly Mine.

Strata Engineering, (2012). Pillar Stability in 101 and 200 Areas. SEA Report No. 09-001-AIR-10 to Airly Mine.

Strata Engineering, 2011, “Subsidence Impact Assessment on the Cliff Lines Above the Proposed 700W and 800 Areas”, Strata Engineering

Tammetta, P, 2013 “Estimation of the Height of Complete Groundwater Drainage Above Mined Longwall Panels” Groundwater doi:10.1111/qwat.12003 p1-12

Tobin, C, (1997) 'A review of the Newcastle coalfield subsidence prediction curve' unpublished report September 1997

Tobin, C, 1997, "A review of the Newcastle Coalfield Subsidence Prediction Curve"

UNSW, Strata Control for Coal Mine Design, Final Project Report, No: RP *1/96.* Joint Coal Board.

van der Merwe, JN, 1993. Revised Strength Factor for Coal in the Vaal Basin. Journal of Southern African Mining and Metallurgy, V 104:667–676.

van der Merwe, JN, 2003. Predicting Coal Pillar Life in South Africa Journal of Southern African Mining and Metallurgy, V 103:293–301.

van der Merwe, JN, 2004. Verification of Pillar Life Prediction Method. Journal of Southern African Mining and Metallurgy, V 93:71–77.

van der Merwe, JN, and Mathey, M, 2013. Update of Coal Pillar Strength Formulae for South African Coal Using Two Methods of Analysis. Journal of Southern African Mining and Metallurgy, V 113 (2):841-47.

Waddington, A and Kay D, 1998 "Recent Developments in the Incremental Profile Method of predicting Subsidence, Tilt and Strain over a series of Longwall Panels" MSTS Workshop 1998

Waddington, A and Kay, D 1995 'The incremental profile method for prediction of subsidence, tilt, curvature and strain over a series of panels' in Proceedings of the 3rd Triennial Conference on Mine Subsidence, Mine Subsidence Technological Society, 1995 pp189-197

Wagner, H, 1980. Pillar Design in Coal Mines Journal of Southern African Mining and Metallurgy, 80:37-45.

White, E, 2014, "Clarence Colliery - Partial Extraction to Protect Surface Features", Proceedings of the 9th Triennial Conference on Mine Subsidence, 2014

Whittaker, B and Reddish, D, 1989, "Subsidence Occurrence, Prediction and Control",

Wilson, A, 1986, "Keynote Address - The Problems of Strong Roof Beds and Water Bearing Strata in the Control of Longwall Faces",