



REPORT



SUBSIDENCE PREDICTIONS AND IMPACT ASSESSMENT FOR AIRLY MINE

AIRLY MINE, CENTENNIAL COAL PTY LTD

Submitted to:

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Executive Summary

Airly Mine (Airly) is located on the western margin of the Sydney Basin and covers the Mount Airly / Genowlan Mountain plateau. Preliminary mine design for the Airly project began in 2010. The overriding aims of the design were to minimise impact in an environmentally sensitive area while improving the feasibility of the mine. In order to limit the surface and sub-surface impacts due to mining, Airly has adopted subsidence criteria that would result in “minimal subsidence impact”. Due to the similarities in topography, corporate and community expectations, the Clarence Colliery (Clarence) vertical subsidence limits were adopted as practical and proven criteria.

Due to differences in the geotechnical environments between Clarence and Airly, it was however not possible to adopt the same mining methods. Using a combination of empirical, numerical and analytical techniques, a number of mining methods were evaluated to understand the level of subsidence associated with each and included assessments of pillar stability. Surface features were also identified along with any required subsidence impact control measures. The impact of post-mining flooding on subsidence was also evaluated. The results from these assessments, combined with the results of a mining feasibility study, highlighted the preferred mining method to be a panel and pillar system with an optimal void width of 61m at a depth of cover $\geq 160\text{m}$. Two main factors influenced this choice; the Depth of Cover (H) and the Void Width (W). It was thus also concluded that the preferred panel and pillar mining method would not be appropriate to meet the subsidence design criteria over the total project area because of the highly variable Depth of Cover. It was therefore proposed that multiple first workings and partial extraction methods be applied in different areas of the mine to achieve the subsidence design criteria and the necessary constraints upon surface damage.

Based on the design of the mining system and the subsidence and pillar stability estimations, the project area has therefore been divided into five unique and distinct mining zones, each representing a specific geotechnical environment. The mining system for each of these mining zones was designed to address specific issues with regard to mining and the associated subsidence effects. Modifications were made to the mining zones to accommodate features such as watercourses, cliff lines and Aboriginal and European heritage sites as well as other surface infrastructure identified as being potentially effected by mining. The analyses have predicted that the mining systems thus devised for their specific areas of the mine will result in minimal surface impacts over the majority of the mining lease. A possible exception is the plateau area above old oil shale workings where surface damage has already occurred. If panel and pillar mining is undertaken in this area, additional surface damage is considered possible.

A programme for monitoring subsidence and pillar stability has also been suggested. Performance measures and adaptive management processes have been defined with a proposed Trigger Action Response Plan. In this way management will be able to respond in a timely manner to situations that could potentially lead to adverse surface impacts.



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APPENDIX A

GLOSSARY OF GENERAL SUBSIDENCE AND MINING TERMS



1.0 INTRODUCTION

Airly Mine (Airly) is situated approximately 40 km NNW of Lithgow, about 4 km NE of Capertee and is within the Lithgow City Council Local Government Area. The mine is accessed via Glen Davis Road approximately 3 km from Capertee.

The initial exploration at Airly commenced in 1984 consisting of 23 boreholes from which the economic significance of the project was established. In 1987 a bulk sampling program was established to verify the initial exploration work, including a limited extent first workings only trial mine. Subsequently in 1991 an Environmental Impact Statement was prepared and submitted to the Department of Planning.

Following a Commission of Inquiry the development consent for the Airly Mine was granted by the Minister for Planning on the 14th of April 1993. Centennial Coal purchased the Airly Mine in late 1997 and in 1998 a bulk sample was taken of the Lithgow and Lisdale seams by extending the original trial mine box cut. Construction of the current surface facilities commenced in March 2009. Full scale coal mining was started in December 2009.

The only method of coal extraction method used thus far at Airly Mine has been first workings bord and pillar mining. No pillar stripping or extraction has been undertaken to date, although full extraction was originally approved over parts of the lease in the 1993 consent.

That said, this report provides estimates of subsidence above the proposed future mining areas at Airly Mine and assesses the likely impacts on surface and sub-surface features within the assessed zone of influence of the mine workings. Critical surface features have also been identified along with any required subsidence impact control measures.

This report has been prepared by Golder Associates pursuant to an application for approval to mine under the **Environmental Planning and Assessment Act 1979 (NSW)**. A Subsidence Management Plan (SMP) will also be required under the mining lease and will be produced in accordance with the relevant guidelines from the NSW Department of Trade and Investment (Resources and Energy).



2.0 PROJECT OVERVIEW

Airly Mine will have a production capacity of up to 1.8 million tonnes per annum and will produce export and domestic thermal coal. Planned surface facilities at the mine include a coal stockpile and a rail loop with a modern rail loading facility. Coal will be transported by rail to both domestic customers and to export via Port Kembla. An aerial photograph of the mine lease is shown in **Figure 1**.

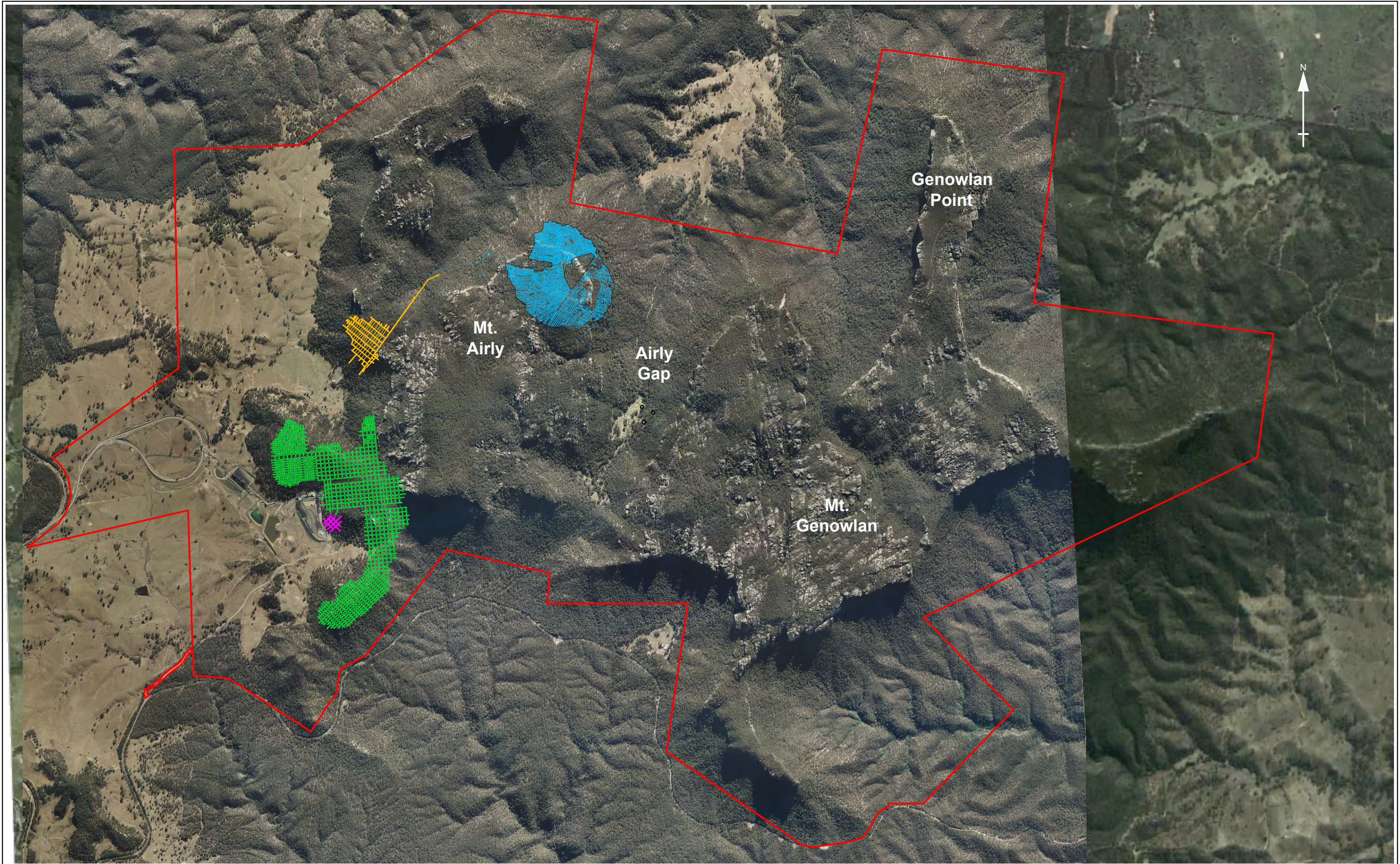
The Airly Mine Extension Project will:

- continue to extract up to 1.8 million tonnes per annum (Mtpa) of run of mine (ROM) coal from the Lithgow seam underlying the Project Application Area;
- extend life of mine by 25 years;
- extract coal using partial extraction methods within the mining lease (ML1331) and extend the mining area to the east of the existing workings into Authorisation 232 (A232) area;
- develop underground access headings and roadways from the current mining area to the east to allow access to the proposed mining areas;
- use various partial extraction mining methods, that will nominally limit vertical subsidence to 100mm but shall not exceed 125mm in previously unmined areas and minimise further potential subsidence impacts in areas where the historical New Hartley Shale Mine has already impacted the environment;
- continue to operate and maintain the existing ancillary surface infrastructure for mine access, underground ventilation, electricity, water, materials supply, and communications at the pit top, and upgrade the infrastructure as required for mining operations;
- continue to manage the handling of run-of-mine (ROM) coal through a crusher and screening plant at the pit top for transfer to the existing and proposed stockpile areas as required to meet market demands;
- construct a coal handling and preparation plant (CHPP) to process ROM coal;
- transfer processed coal from the CHPP, using the existing and new overland conveyor systems, to the product stockpile area for temporary storage prior to despatch to offsite locations;
- construct a life of mine reject emplacement area (REA) for the emplacement of reject materials from the CHPP and the underground mine;
- continue to use the existing water storage dams at the pit top for the separation of clean and dirty water;
- construct appropriately sized new management storage dams for the proposed life of mine REA;
- continue to manage non-production waste in accordance with the site's Mining Operations Plan;
- despatch ROM and product coal off site using the existing rail load out facilities for the export and domestic markets;



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- continue to undertake existing and initiate new environmental monitoring and geological exploration programs as appropriate;
- review and update existing environmental management plans as required;
- operate 24 hours per day and seven days per week for 52 weeks per year;
- provide employment to a full time workforce of up to 135 persons and 20 contractors;
- progressively rehabilitate disturbed areas at the pit top no longer required for mining operations and exploration boreholes;
- undertake life-of-mine rehabilitation at the pit top infrastructure disturbance areas to create final landforms commensurate with the surrounding areas and the relevant zoning in accordance with the Draft Lithgow City Local Environmental Plan 2013.



Key: Project application area Existing Lithgow Seam workings Existing Lithgow Seam trial mine (1987) Previous Torbane Colliery Lithgow Seam workings Previous New Hartley Shale Mine workings		Engineer:	M. MacKinnon	Client:	Airly Mine		
		Drawn:	B. Richardson	Title:	Aerial Photograph of Airly Mine Showing Existing Mine Workings		
		Date:	30.06.14				
		GOLDER ASSOCIATES PTY. LTD. www.golder.com		Ref:	127621105-003	Support Plan No:	N/A
				Scale:	NTS	Figure No:	1



3.0 GEOLOGY

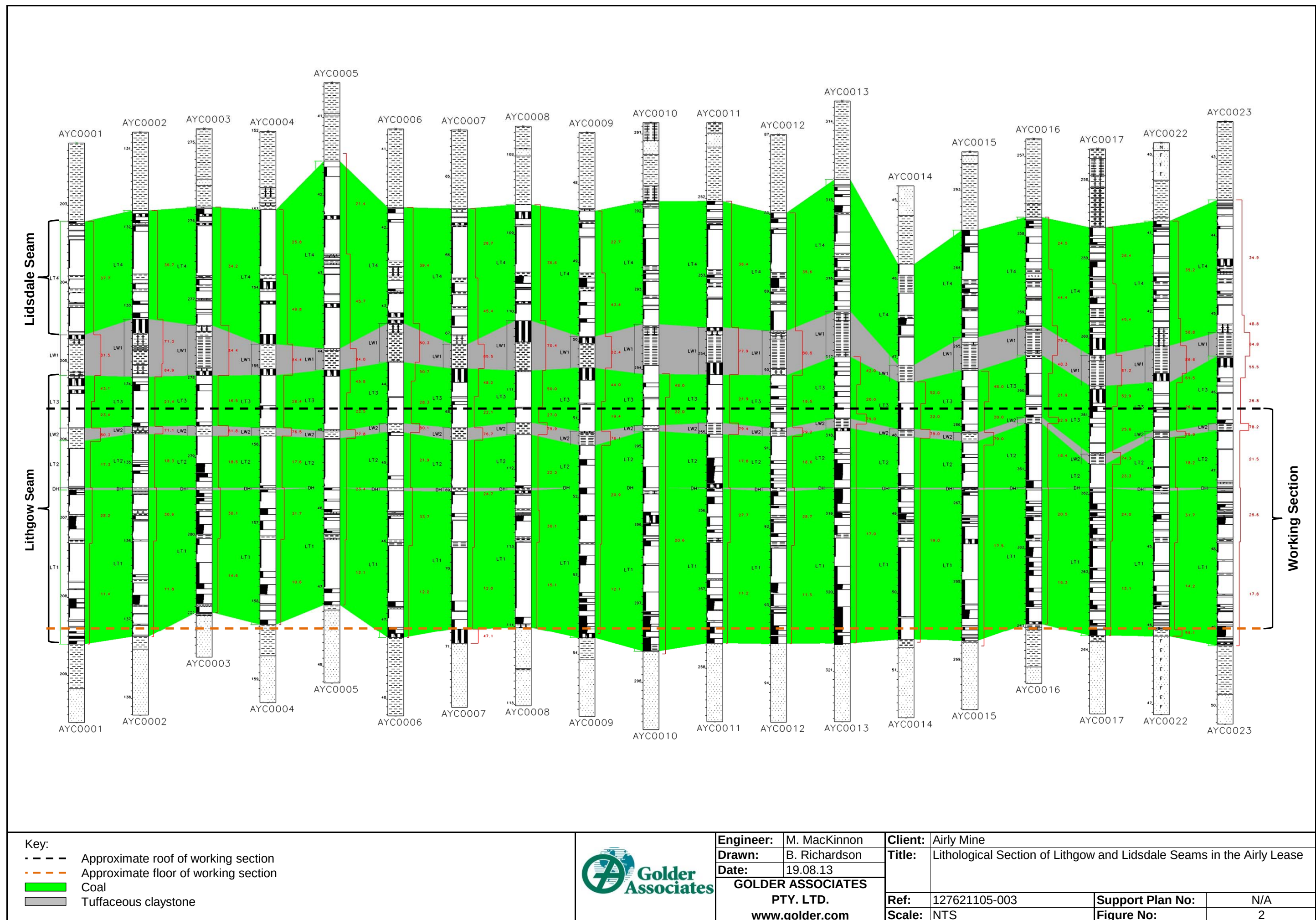
Airly Mine is located on the western margin of the Sydney Basin and covers the Mount Airly / Genowlan Mountain plateau (see **Figure 1**). Triassic Narrabeen Group strata cover most of the upper half of the plateau and form rugged escarpments (see **Table 1** for a summary of the relevant stratigraphic units). Small isolated outliers of Tertiary basalt cap the highest points of the plateau.

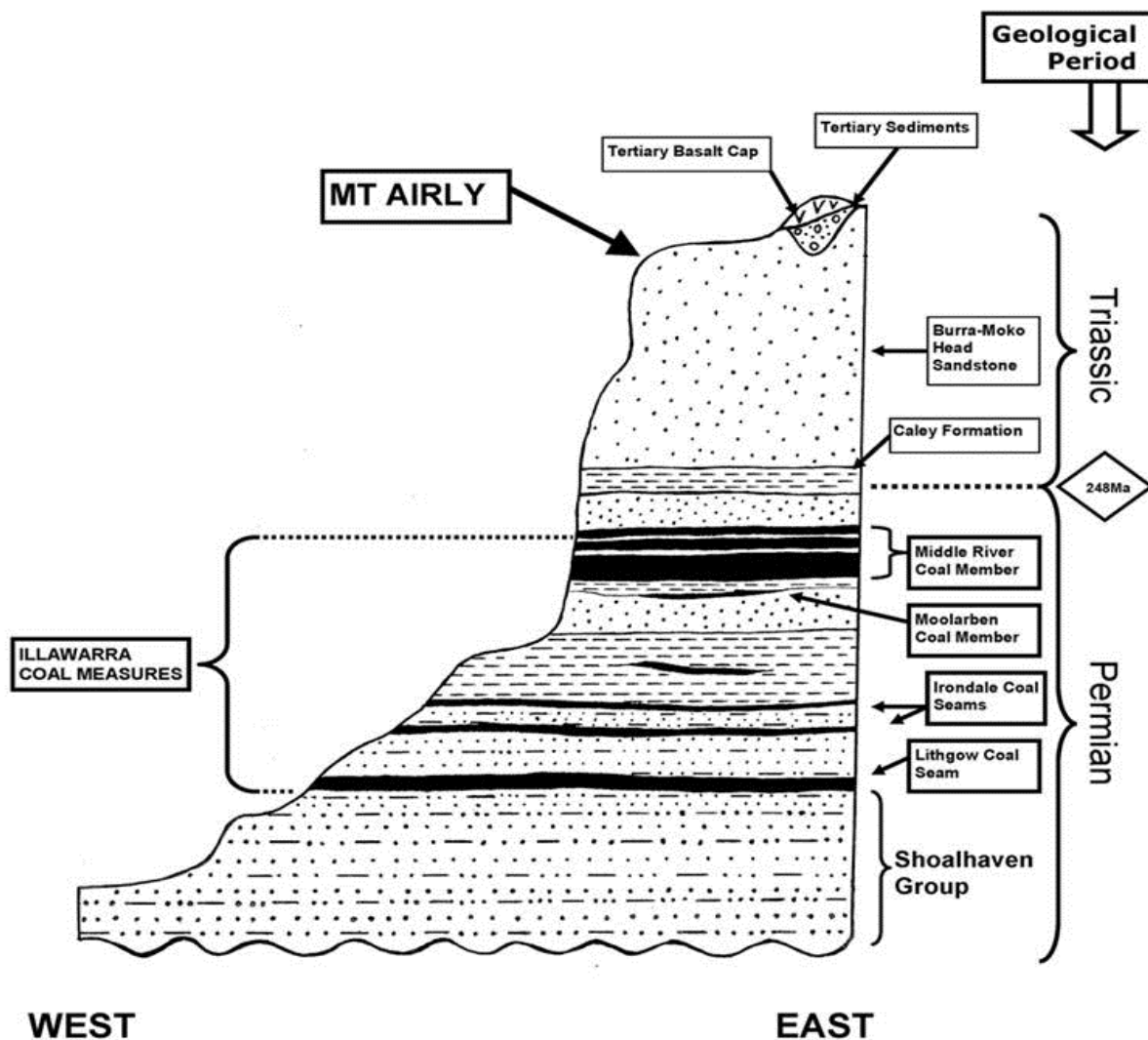
Much of the plateau surface and the massive vertical cliffs are formed in Narrabeen Group, Grose Sandstone. This sandstone unit is underlain by lower strength and more readily weathered interbedded siltstones, sandstones and shales of the basal Narrabeen Group. The weathering of these lower strength beds causes undermining of the Grose Sandstone and the formation of the cliffs.

The underlying Permian Illawarra Coal Measures outcrop around the perimeter of the topographically elevated plateau, and in the north-south trending “gap” which separates Mount Airly in the west from Genowlan Mountain in the east (see **Figures 2 and 3**). The Illawarra Coal Measures contain the coal seams located in the Airly lease. The only coal seam deemed to be of any significant economic importance is the Lithgow Seam, which is located in the lower part of the Illawarra Coal Measures. All of the existing and proposed workings in Airly Mine are located in the Lithgow Seam. Lastly, the Illawarra Coal Measures and underlying Shoalhaven Group lie unconformably on Lower Devonian shales, tuffs and limestones.

Table 1: Generalised Stratigraphic Column for the Western Coalfield

Period		Group	Sub-group	Formation
Tertiary				Flood basalt
Triassic		Narrabeen	Grose	Burralow Formation Banks Wall Sandstone Mt York Claystone Burra-Moko Head Sandstone Caley Formation
Permian	Late	Illawarra Coal Measures	Wallerawang	Katoomba Seam
				Woodford Seam
				Middle River Seam
			Charbon	Moolarben Seam
				Baal Bone Formation
				Upper Irondale Seam
				Irondale Seam
				Long Swamp Formation
	Cullen Bullen	Lidsdale Seam		
		Lithgow Seam		
		Marangaroo Conglomerate		
	Nile	Gundangaroo Formation		
Coorongooaba Creek Sandstone				
Mount Marsden Claystone				
Early	Shoalhaven		Berry Siltstone	
			Snapper Point Formation	
Lower Devonian				Shales, tuffs and limestones





Legend:

	Basalt
	Gravel and Sand
	Coal
	Sandstone
	Siltstone
	Interbedded Sandstone and Siltstone

NB: Not to Scale



Engineer: R. Trueman
Drawn: B. Richardson
Date: 19.08.13
GOLDER ASSOCIATES
PTY. LTD.
www.golder.com

Client: Airly Mine
Title: Schematic Representation of the Stratigraphic Section in the Western Coalfield (NSW Department of Trade and Investment, Regional Infrastructure and Services (Minerals and Energy Division))

Ref: 127621105-003	Support Plan No: N/A
Scale: N/A	Figure No: 3



4.0 GEOTECHNICAL ENVIRONMENT

The geotechnical properties of the lower and upper overburden strata have been ascertained from a review of the following:

- The original exploration borehole data (23 holes) from the early 1980's.
- Geotechnical data gathered from four drill holes during the 2012 exploration program, including a generic geophysical strength correlation.
- Underground mapping (including borescope surveys) and monitoring information.
- Relevant previous studies conducted for Airly and other mines working the Lithgow Seam, including:
 - Design of Partial Extraction Layouts for Airly Mine (**Strata Engineering, 2010**),
 - Preliminary Subsidence Estimates for Four Mining Concepts for Airly Mine (**Strata Engineering, 2012a**)
 - Geotechnical Assessment for the Airly Deposit (**Strata Engineering, 2012b**)
 - Cliff Line Assessment of the Mount Airly and Mount Genowlan Messa Complex (**Golder Associates, 2013**)

4.1 Roof, Floor and Coal Seam Lithologies

Notable features of the roof, floor and coal seam strata are as follows (see **Figure 2**):

- i) The combined Lithgow / Lidsdale seam is 4.8 to 5.9m thick, averaging 5.4m and thinning to the south-east. The Lithgow Seam (plies LT1 to LT3) constitutes the base of the combined seam and averages 3.4m in thickness. This is of higher quality and is the target for mining. The overlying Lidsdale Seam (ply LT4) is of lower quality, being characterised by several persistent claystone, mudstone and siltstone bands. Ply LT4 averages 1.6m in thickness and is separated from the Lithgow Seam by the LW1 tuffaceous claystone band, which averages 0.4m in thickness.
- ii) The planned development and extraction height is 2.7m to 2.8m, approximately mid-way between the LW1 claystone band and the lower LW2 claystone band, the latter being typically 0.1m thick. This results in a roof bolt horizon typically comprised of 0.3 to 0.4m of top coal, overlain by 0.4m of LW1 claystone and the Lidsdale Seam with its dirt bands.
- iii) The seam has an Unconfined Compressive Strength (UCS) of 5 to 10MPa. The claystone and mudstone bands in the upper portion of the seam are stronger, with UCS values ranging from typically 30 to 50MPa, but are prone to delamination and moisture related breakdown. Furthermore, the inhomogeneous composition of the bolted horizon makes it weak.
- iv) The overlying 6m of roof is comprised typically of mudstone / siltstone grading upwards into siltstone / sandstone. This material is more consistently strong, with UCS values of around 40MPa and is less prone to delamination and is therefore deemed more competent.
- v) The remainder of the Permian overburden, which varies in thickness from 70m to 140m and averages 105m, is composed of interbedded mudstone, siltstone and sandstone units with thin coal seams. Material strengths are typically of the order of 30 to 40MPa.



- vi) The Triassic capping is up to 200m 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 40MPa, with occasional bands of up to approximately 60MPa. Generally, the fine grained units are better cemented and therefore stronger than the coarse grained sandstone / conglomerate units.
- vii) The immediate 1 to 2m of floor is generally comprised of silty sandstone with a UCS of around 40MPa, underlain by medium grained sandstone with a UCS of 20 to 30MPa. The sandstone has very little sensitivity to moisture. Appreciable floor heave has been experienced in deeper Lithgow Seam mines (Angus Place and Springvale), but no significant issues are expected with regard to trafficability or the floor bearing capacity at the Depths of Cover anticipated at Airly.

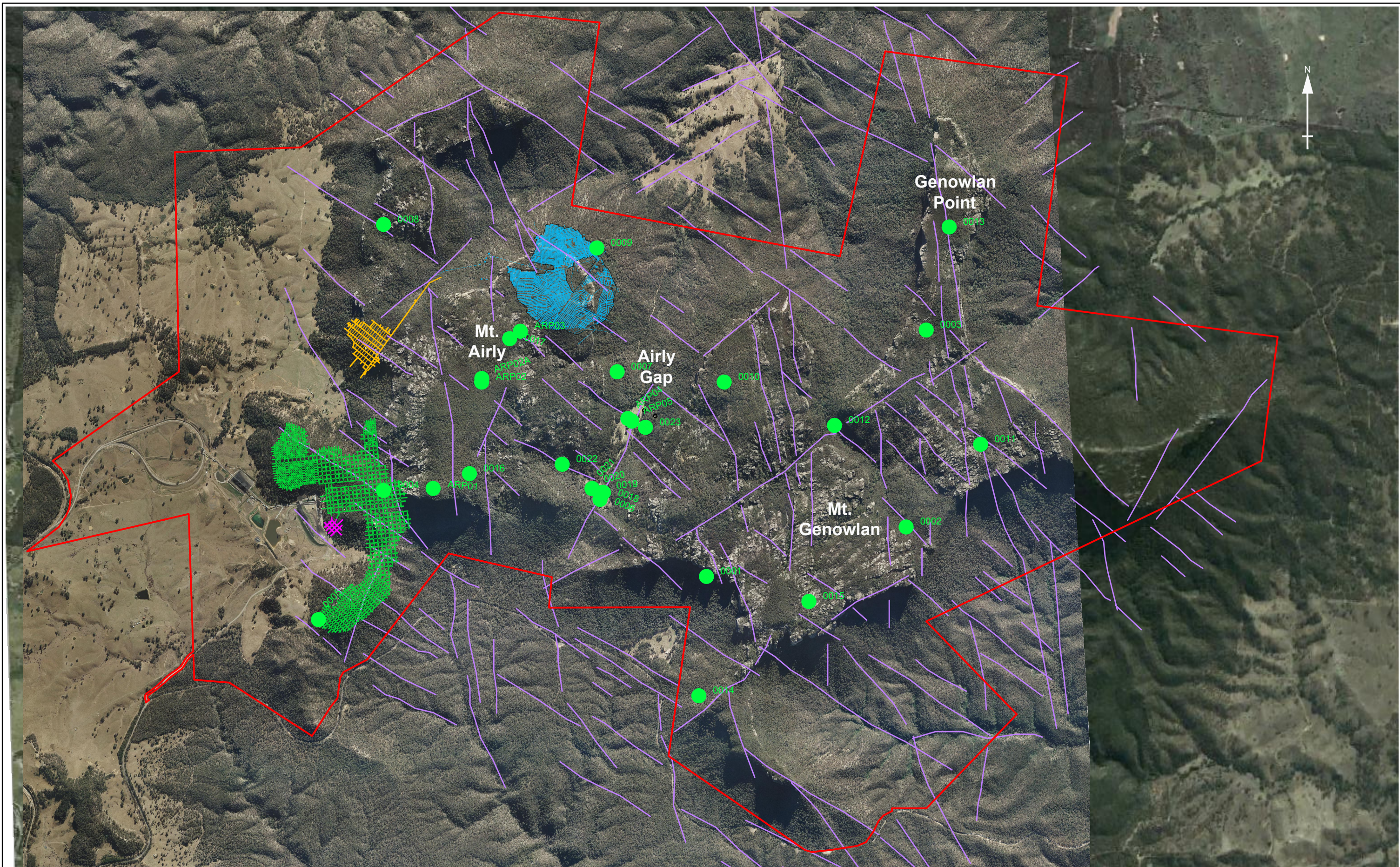
4.2 Rock Mass Structure

Sources of structural data assessed as part of this study include:

- An aeromagnetic survey (**SRK, 2012**).
- A LiDAR survey.
- Bore core logging.
- Aerial / satellite photographs of the area.
- Underground mapping.
- Aerial cliff line assessment.
- Fieldwork and surface mapping over selected areas to ground truth other surveys.

From the above, the following conclusions can be drawn with regard to this study:

- i) Seam dip is very gradual, around 1° , to the ENE.
- ii) The primary joint strike direction is between N-S and NW-SE, as is evident from aerial photography (see **Figure 4**).
- iii) The secondary joint strike direction is between NE-SW and ENE-WSW (also clearly evident in **Figure 4**).
- iv) There are also signs from the aerial photography of E-W and NW-SE trending lineaments.
- v) The main cleat directions are approximately NW-SE and NE-SW, although N-S and E-W orientations are also evident and are typically sub-vertical (i.e. dipping at 70 to 90°).
- vi) Underground mapping indicates a series of mid-angle (i.e. $<70^{\circ}$) normal faults striking typically N : S to NNE : SSW across the area mined to-date. These faults dip almost entirely to the ESE. Occasionally, faults striking approximately NNW : SSE have also been encountered. The mapped faults have limited throws (i.e. typically $<1\text{m}$, with a maximum of 1.5m encountered on a fault in 101 Panel), with little evidence of strike-slip movement thus far.
- vii) Away from the already mined area, work undertaken by **SRK (2012)** suggests approximately NW : SE, NE : SW and N : S orientated seam and surface faults (see **Figure 4**).



Key: Project application area SRK mapped surface fault 0014 Exploration borehole Existing Lithgow Seam workings Existing Lithgow Seam trial mine (1987) Previous Torbane Colliery Lithgow Seam workings Previous New Hartley Shale Mine workings Note: cliff lines surveyed by Golder Associates (2013), refer to Figure 25		Engineer:	M. MacKinnon	Client:	Airly Mine			
		Drawn:	B. Richardson		Title:	Aerial Photograph Showing Surface Faults Mapped by SRK (2012) and Exploration Boreholes		
		Date:	30.06.14					
		GOLDER ASSOCIATES PTY. LTD. www.golder.com		Ref:	127621105-003	Support Plan No:	N/A	
		Scale:	NTS	Figure No:	4			



- viii) No reverse faults or large (i.e. >2m throw) normal faults have been encountered to-date or have been interpreted from previous studies. However, given the persistence of some of the main lineaments across the lease area (for example, at Airly Gap), the size of the resource and experiences gained from elsewhere in the Western Coalfield, it would be considered unusual for no major faults to be encountered.

4.3 *In Situ* Stress

The Depth of Cover ranges from 20m at the sub-crop to a maximum of 280m under Mount Airly and 310m under Genowlan Mountain. Although no horizontal stress measurements have been conducted at the mine, insight can be gained regarding the stress environment from the Australian database summarised in **Figure 5**. At depths of <300m, typical of Airly, a major horizontal stress magnitude of <15MPa would be expected (see **Figure 5**). In regard to Australia, this is a moderate stress level. The ratio of the major horizontal to the vertical stress (i.e. $\sigma_1 : \sigma_v$) would be expected to be in the range of 0.5-1.5 at depths of up to 150m, increasing to 1.5-2.5 at depths of 150m to 300m. In the specific case of Airly, given the topography and the associated potential for horizontal stress relief by virtue of the neighbouring cliff lines and surface valleys, it is considered likely that the maximum ratio of σ_1 to σ_v would be around 1.5-2, such that the maximum value of the major horizontal stress would be around 12 to 13MPa.

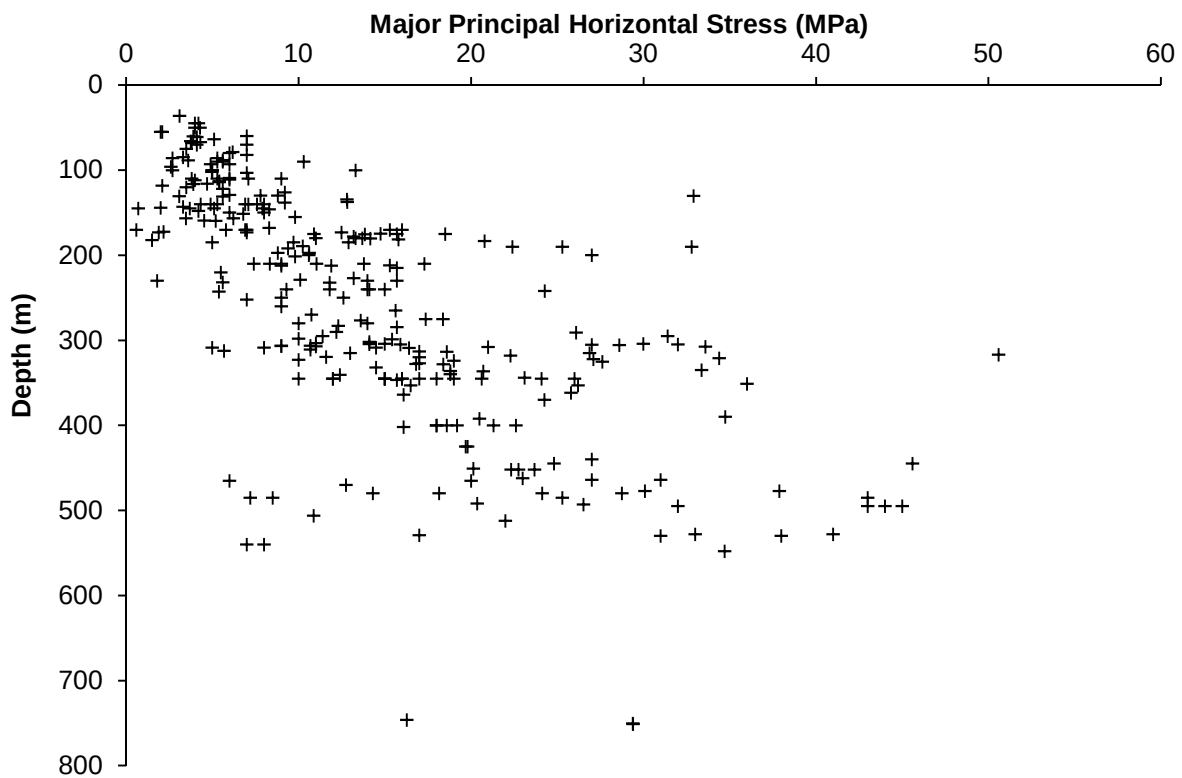
In terms of directions, Western Coalfield measurements indicate a regional major horizontal stress direction of WNW : ESE to ENE : WSW. Without any information to the contrary, it is considered likely that Airly will be consistent with this and is probably reflected in the fact that the majority of the cavities that have formed to-date on development at the mine tend to be more common in roadways driven in an approximate N-S direction (and as such, against the major horizontal stress).

A specific issue for Airly is however that a proportion of the resource is located at a depth of <50m. The areas involved require particular consideration in terms of both roof strength and the stress environment. Related ground control issues encountered at other mines include:

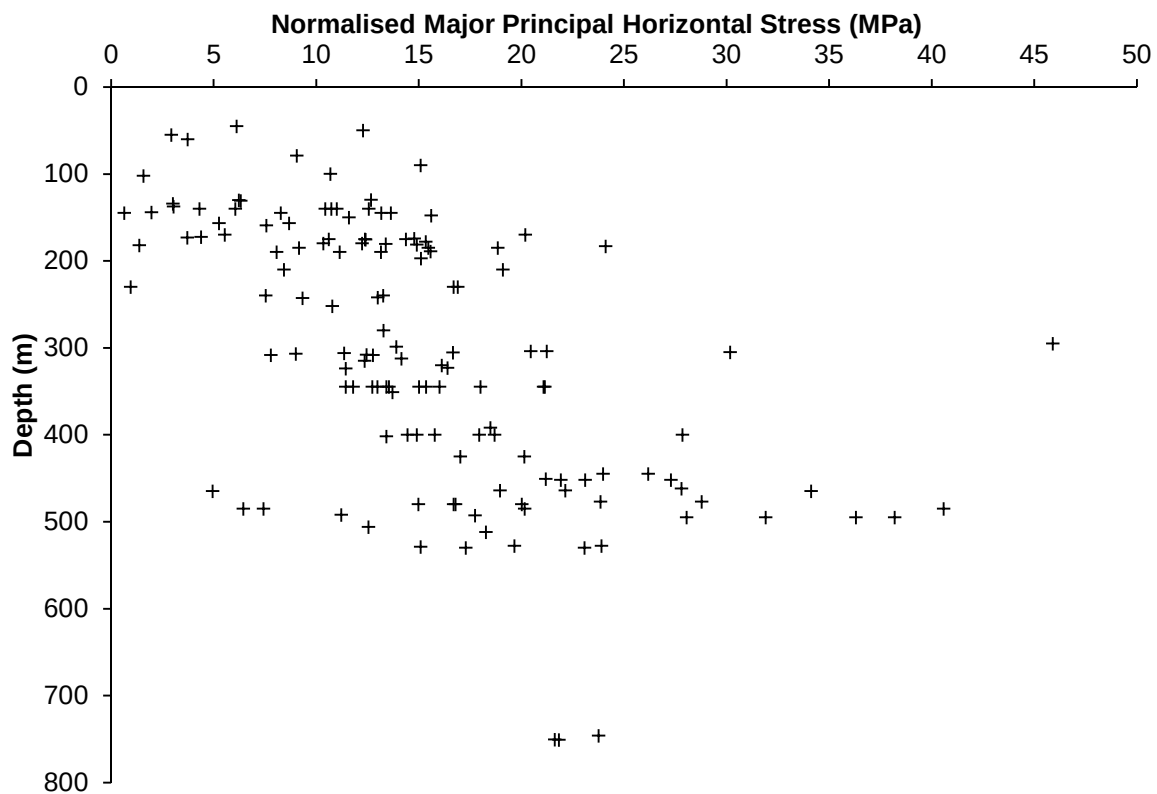
- The potential for roof failure due to low stress and an associated lack of confinement.
- The potential for roof failure due to weak overburden strata.
- Concentrations of horizontal stress in shallow areas beneath steeply sided valleys / canyons.
- Zones of major geological structure (i.e. lineaments) in shallow areas located beneath steeply sided valleys / canyons.

Specific ground control measures are therefore considered appropriate in shallow areas; at Airly this includes a programme of proving the actual thickness of solid (i.e. unweathered) cover, given that the shallower areas tend to be overlain by a significant thickness of talus sloping at typically 35 to 45° to the horizontal.

(i) Major Horizontal Stress Magnitude versus Depth



(ii) Major Horizontal Stress Magnitude (Normalised to Rock Stiffness) versus Depth



	Engineer:	D. Hill	Client: Airly Mine		
	Drawn:	D. Hill	Title: Australian Horizontal Stress Database Showing Relationship between Major Horizontal Stress Magnitude and Depth		
	Date:	19.08.13			
	GOLDER ASSOCIATES PTY. LTD.		Ref:	127621105-003	Support Plan No: N/A
	www.golder.com		Scale:	N/A	Figure No: 5



4.4 Caveability

Thickly bedded to massive units of sandstone and conglomerate can form significant cantilevers inbye of the extraction face or bridge across the panel and in doing so, can have a significant impact on caveability.

For the purpose of assessing caveability, thickly bedded / massive sandstone is defined by a bed spacing of $\geq 600\text{mm}$ and a UCS of $\geq 60\text{MPa}$. Weaker and / or more fractured units lack the ability to form significant cantilevers or bridge the goaf. Conglomerates are invariably thickly bedded to massive and have significant cantilevering and bridging ability, often at UCS values of $<60\text{MPa}$.

In this regard, overburden weighting and bridging experiences from Australia and elsewhere have been collated by Golder. This database indicates that thickly bedded to massive sandstone, conglomerate and igneous units in the overburden have often been associated with significant ("high level") periodic weighting in the past. For sandstone, weighting becomes apparent once the unit reaches a thickness of about 20m (**Strata Engineering, 2010**). Beds of conglomerate and igneous units generally have greater spanning capability and thinner units $\geq 14\text{m}$ in thickness have been associated with high level periodic weighting. With regard to the proximity of these units to the mining horizon, sandstone units up to 65m above (i.e. the interval to the base of the unit) have been associated with high level periodic weighting.

Considering the above information in conjunction with the limited partial extraction panel widths being considered for Airly, the database indicates that bridging is likely at conglomerate thicknesses of 8m to 12m, versus 10m to 15m for thickly bedded to massive sandstones.

As discussed, the Permian coal measures strata in the immediate Airly overburden comprises of beds of coal, claystone, shale, siltstone, sandstone and conglomerate. Above this (where not eroded), the Triassic capping comprises thickly bedded to massive sandstones varying from fine grained to conglomeratic, with occasional thin claystone and mudstone beds / lenses.

The 23 boreholes drilled in the 1980's and the four recent boreholes cover the entire deposit, albeit on a wide spacing. The logs and photographs from these boreholes were assessed for conglomerate units $\geq 8\text{m}$ thick and / or sandstone units $\geq 10\text{m}$ thick in the Permian strata. From this study no such units were observed and the immediate overburden is therefore considered readily caveable.

At locations with significant Triassic capping, thickly bedded to massive sandstone beds several tens of metres thick are however evident. Nonetheless, considering the thickness of these units in conjunction with their 70 to 140m height above the extraction horizon, it is assessed that they would bridge the panel widths proposed for Airly and therefore pose no threat of high level periodic weighting.



5.0 OVERVIEW OF THE DESIGN OF THE MINING SYSTEM

Preliminary pillar design and subsidence analysis for the Airly project began in 2010, **Strata Engineering (2010)**. The overriding aims of the design were to minimise impact in an environmentally sensitive area while improving the feasibility of the mine. In order to limit the surface and sub-surface impacts due to mining, Airly adopted subsidence criteria that would result in “minimal subsidence impact”. Due to the similarities in topography and corporate and community expectations, the Clarence Colliery vertical subsidence limits were therefore adopted as a practical and proven criteria. The current Clarence Colliery development consent subsidence criteria are:

- Vertical subsidence to be limited to 100mm,
- A maximum tilt of 3.0mm/m and
- A maximum strain of 2.0mm/m.

The subsidence design criteria that has been adopted for Clarence over the long term (**Shepherd, 1999; Strata Engineering 2005**) is for the magnitude of surface subsidence to be limited to a value well within that considered to be characteristic of ‘elastic’ overburden behaviour / displacement only (i.e. no-caving to surface). This has been defined as $100\text{mm} \pm 25\text{mm}$; i.e. vertical subsidence to be nominally limited to 100mm but shall not exceed 125mm.

These limits have proven to cause no adverse mining induced subsidence effects at Clarence Colliery and are considered appropriately conservative, given the lack of site specific data for Airly. However, it was recognised that Airly is proposing to mine a different seam with a different strata setting than Clarence and would require mining methods more suited to its geotechnical environment.

The subsidence assessment was therefore expanded to include a number of different mining concepts, **Strata Engineering (2011a)** and a full geotechnical assessment of these options was addressed in **Strata Engineering (2012a)**. These assessments included the following mining methods and varying void widths:

- A partial pillar extraction layout with void widths ranging between 50.5m and 70.5m.
- A form of Wongawilli extraction with narrow panels and void widths ranging between 45.5m and 65.5m.
- A panel and pillar layout with void widths ranging between 51m and 71m.
- A shortwall (extraction by continuous miner) with void widths ranging between 51m and 71m.

These mining methods were evaluated to understand the level of subsidence associated with each and included assessments of pillar stability. The empirical subsidence estimates for the partial pillar extraction layout is shown in **Table 2** as an example of the results obtained in this study. The influence of void width on subsidence can be clearly seen. For example, at a void width of 50.5m the upper bound subsidence is predicted to be 99mm and expected subsidence 45mm at a depth of 160m. At a void width of 70.5m, the upper bound subsidence is estimated to be 151mm and the expected 84mm at the same depth. That is a 52% increase in upper bound and an 87% increase in expected subsidence for a 40% increase in void width. Similar increases in subsidence for increases in void width were estimated for the other mining methods analysed.



SUBSIDENCE PREDICTIONS AND IMPACT ASSESSMENT FOR AIRLY MINE

Table 2: An Example of Empirical Subsidence Estimates for Partial Pillar Extraction Layout Considered for use at Airly Mine

Width of Void (m)	Depth (m)	W/H	Extraction Height (m)	Extraction (%)	Effective Height (m)	Single Smax/T		Single Smax (mm)		Multi-Panel Increment (mm)	Final Smax		Tilt (Holla K3 = 5.5)		+Emax (Holla K1 = 1.5)		-Emax (Holla K2 = 2.5)	
						Expected	Upper Bound	Expected	Upper Bound		Expected	Upper Bound	Expected	Upper Bound	Expected	Upper Bound	Expected	Upper Bound
50.5	120	0.42	2.8	76	2.1	0.022	0.04	46	112	36	82	148	3.8	6.8	1	1.8	1.7	3.1
50.5	130	0.39	2.8	76	2.1	0.02	0.037	43	105	10	53	115	2.2	4.9	0.6	1.3	1	2.2
50.5	140	0.36	2.8	76	2.1	0.019	0.035	40	99	10	50	109	1.9	4.3	0.5	1.2	0.9	1.9
50.5	150	0.34	2.8	76	2.1	0.017	0.033	37	93	10	47	103	1.7	3.8	0.5	1	0.8	1.7
50.5	160	0.32	2.8	76	2.1	0.016	0.032	35	89	10	45	99	1.5	3.4	0.4	0.9	0.7	1.5
50.5	170	0.3	2.8	76	2.1	0.015	0.03	33	84	10	43	94	1.4	3	0.4	0.8	0.6	1.4
50.5	180	0.28	2.8	76	2.1	0.014	0.029	31	80	10	41	90	1.2	2.8	0.3	0.8	0.6	1.3
50.5	190	0.27	2.8	76	2.1	0.014	0.027	29	77	10	39	87	1.1	2.5	0.3	0.7	0.5	1.1
55.5	120	0.46	2.8	76	2.1	0.024	0.043	51	120	36	87	156	4	7.1	1.1	1.9	1.8	3.2
55.5	130	0.43	2.8	76	2.1	0.022	0.04	47	113	36	83	149	3.5	6.3	1	1.7	1.6	2.9
55.5	140	0.4	2.8	76	2.1	0.02	0.038	43	107	36	79	143	3.1	5.6	0.9	1.5	1.4	2.5
55.5	150	0.37	2.8	76	2.1	0.019	0.036	41	101	10	51	111	1.9	4.1	0.5	1.1	0.8	1.8
55.5	160	0.35	2.8	76	2.1	0.018	0.034	38	96	10	48	106	1.7	3.6	0.5	1	0.8	1.7
55.5	180	0.31	2.8	76	2.1	0.016	0.031	34	87	10	44	97	1.3	3	0.4	0.8	0.6	1.3
55.5	200	0.28	2.8	76	2.1	0.014	0.028	30	79	10	40	89	1.1	2.5	0.3	0.7	0.5	1.1
55.5	240	0.23	2.8	76	2.1	0.012	0.024	25	68	10	35	78	0.8	1.8	0.2	0.5	0.4	0.8
55.5	280	0.2	2.8	76	2.1	0.01	0.021	22	59	10	32	69	0.6	1.4	0.2	0.4	0.3	0.6
60.5	120	0.5	2.8	76	2.1	0.026	0.045	55	127	36	91	163	4.2	7.5	1.1	2	1.9	3.4
60.5	130	0.47	2.8	76	2.1	0.024	0.043	51	120	36	87	156	3.7	6.6	1	1.8	1.7	3
60.5	140	0.43	2.8	76	2.1	0.022	0.041	47	114	36	83	150	3.3	5.9	0.9	1.6	1.5	2.7
60.5	150	0.4	2.8	76	2.1	0.021	0.039	44	108	36	80	144	2.9	5.3	0.8	1.4	1.3	2.4
60.5	160	0.38	2.8	76	2.1	0.019	0.037	41	103	10	51	113	1.8	3.9	0.5	1.1	0.8	1.8
60.5	170	0.36	2.8	76	2.1	0.018	0.035	39	98	10	49	108	1.6	3.5	0.4	1	0.7	1.6
60.5	180	0.34	2.8	76	2.1	0.017	0.033	37	93	10	47	103	1.4	3.2	0.4	0.9	0.7	1.4
60.5	190	0.32	2.8	76	2.1	0.016	0.032	35	89	10	45	99	1.3	2.9	0.4	0.8	0.6	1.3
60.5	200	0.3	2.8	76	2.1	0.016	0.031	33	86	10	43	96	1.2	2.6	0.3	0.7	0.5	1.2
60.5	210	0.29	2.8	76	2.1	0.015	0.029	32	82	10	42	92	1.1	2.4	0.3	0.7	0.5	1.1
60.5	220	0.28	2.8	76	2.1	0.014	0.028	30	79	10	40	89	1	2.2	0.3	0.6	0.5	1
60.5	240	0.25	2.8	76	2.1	0.013	0.026	28	73	10	38	83	0.9	1.9	0.2	0.5	0.4	0.9
60.5	260	0.23	2.8	76	2.1	0.012	0.024	26	68	10	36	78	0.8	1.7	0.2	0.5	0.3	0.8
60.5	270	0.22	2.8	76	2.1	0.012	0.024	25	66	10	35	76	0.7	1.5	0.2	0.4	0.3	0.7
60.5	280	0.22	2.8	76	2.1	0.011	0.023	24	64	10	34	74	0.7	1.5	0.2	0.4	0.3	0.7
65.5	120	0.55	2.8	76	2.1	0.028	0.048	60	135	36	96	171	4.4	7.8	1.2	2.1	2	3.6
65.5	130	0.5	2.8	76	2.1	0.026	0.045	55	127	36	91	163	3.9	6.9	1.1	1.9	1.8	3.1
65.5	140	0.47	2.8	76	2.1	0.024	0.043	51	121	36	87	157	3.4	6.2	0.9	1.7	1.6	2.8
65.5	150	0.44	2.8	76	2.1	0.022	0.041	48	115	36	84	151	3.1	5.5	0.8	1.5	1.4	2.5
65.5	160	0.41	2.8	76	2.1	0.021	0.039	45	109	36	81	145	2.8	5	0.8	1.4	1.3	2.3
65.5	170	0.39	2.8	76	2.1	0.02	0.037	42	104	10	52	114	1.7	3.7	0.5	1	0.8	1.7
65.5	180	0.36	2.8	76	2.1	0.019	0.036	40	100	10	50	110	1.5	3.3	0.4	0.9	0.7	1.5
65.5	190	0.34	2.8	76	2.1	0.018	0.034	38	95	10	48	105	1.4	3	0.4	0.8	0.6	1.4
65.5	200	0.33	2.8	76	2.1	0.017	0.033	36	91	10	46	101	1.3	2.8	0.3	0.8	0.6	1.3
65.5	210	0.31	2.8	76	2.1	0.016	0.031	34	88	10	44	98	1.2	2.6	0.3	0.7	0.5	1.2
65.5	220	0.3	2.8	76	2.1	0.015	0.03	33	84	10	43	94	1.1	2.4	0.3	0.6	0.5	1.1
65.5	240	0.27	2.8	76	2.1	0.014	0.028	30	78	10	40	88	0.9	2	0.2	0.6	0.4	0.9
65.5	260	0.25	2.8	76	2.1	0.013	0.026	28	73	10	38	83	0.8	1.8	0.2	0.5	0.4	0.8
65.5	270	0.24	2.8	76	2.1	0.012	0.025	27	71	10	37	81	0.7	1.6	0.2	0.4	0.3	0.7
65.5	280	0.23	2.8	76	2.1	0.012	0.024	26	69	10	36	79	0.7	1.5	0.2	0.4	0.3	0.7
70.5	120	0.59	2.8	76	2.1	0.03	0.05	64	141	36	100	177	4.6	8.1	1.3	2.2	2.1	3.7
70.5	130	0.54	2.8	76	2.1	0.028	0.048	59	134	36	95	170	4	7.2	1.1	2	1.8	3.3
70.5	140	0.5	2.8	76	2.1	0.026	0.045	55	127	36	91	163	3.6	6.4	1	1.7	1.6	2.9
70.5	150	0.47	2.8	76	2.1	0.024	0.043	52	121	36	88	157	3.2	5.8	0.9	1.6	1.5	2.6
70.5	160	0.44	2.8	76	2.1	0.023	0.041	48	115	36	84	151	2.9	5.2	0.8	1.4	1.3	2.4
70.5	170	0.41	2.8	76	2.1	0.021	0.039	45	110	36	81	146	2.6	4.7	0.7	1.3	1.2	2.2
70.5	180	0.39	2.8	76	2.1	0.02	0.038	43	106	36	79	142	2.4	4.3	0.7	1.2	1.1	2
70.5	190	0.37	2.8	76	2.1	0.019	0.036	41	101	10	51	111	1.5	3.2	0.4	0.9	0.7	1.5
70.5	200	0.35	2.8	76	2.1	0.018	0.035	39	97	10	49	107	1.3	2.9	0.4	0.8	0.6	1.3
70.5	210	0.34	2.8	76	2.1	0.017	0.033	37	93	10	47	103	1.2	2.7	0.3	0.7	0.6	1.2
70.5	220	0.32	2.8	76	2.1	0.017	0.032	35	90	10	45	100	1.1	2.5	0.3	0.7	0.5	1.1
70.5	240	0.29	2.8	76	2.1	0.015	0.03	32	83	10	42	93	1	2.1	0.3	0.6	0.4	1
70.5	260	0.27	2.8	76	2.1	0.014	0.028	30	78	10	40	88	0.8	1.9	0.2	0.5	0.4	0.8
70.5	270	0.26	2.8	76	2.1	0.013	0.027	29	75	10	39	85	0.8	1.7	0.2	0.5	0.4	0.8
70.5	280	0.25	2.8	76	2.1	0.013	0.026	28	73	10	38	83	0.7	1.6	0.2	0.4	0.3	0.7



The results from this 2012 assessment highlighted the preferred mining method to be a panel and pillar system with an optimal void width of 61m at a Depth of Cover >160m. Two main factors influenced this choice; the Depth of Cover (H) and the Void Width (W), noting that the W/H ratio is the critical determining factor for estimating subsidence. It was thus also concluded that the preferred panel and pillar mining method would not be appropriate to meet the subsidence design criteria over the total project area because of the highly variable Depth of Cover. It is therefore proposed to apply multiple partial extraction methods to achieve the subsidence design criteria and the necessary constraints upon surface damage.

Therefore following the 2012 assessment, the mining methods proposed were:

- **Panel and Pillar Mining**

The system involves a twin entry chain pillar and a fully extracted maximum void width of 61m. Voids can be extracted by various mining methods. The resulting chain pillars would be designed to be long-term stable.

- **Double-sided Lifting**

The lifts would be extracted on both sides of the roadway to a maximum depth of 10m, creating a span of 25.5m. The intervening spine pillars would compartmentalise the span and would be designed to be long-term stable.

- **Single-sided Lifting**

The lifts would be extracted on one side of the roadway to a maximum depth of 10m, creating a span of 15.5m. The intervening spine pillars would compartmentalise the span and would be designed to be long-term stable.

- **Pillar Splitting**

This system involves splitting pillars on retreat with the remnants designed to be long-term stable.

- **Bord and Pillar Mining**

This system involves first workings only with a continuous miner. The resulting spans would be restricted to the 5.5m maximum width of the roadways and the intervening pillars would be designed to be long-term stable.

Further to the above, a cliff line assessment was also carried out (**Golder Associates, 2013**) that identified and categorised the various cliff and pagoda features. This fed into the design of the mining system with the result being the Mining Zones Plan. This plan involves the different mining methods noted above and shows which mining method is appropriate in which area of the mine. This plan is discussed in detail in **Section 9** of this report.

A full evaluation of these mining methods was then carried out, as detailed in the following section of this report. It is noted that the sensitivity analysis described above was a preliminary analysis. Input parameters were further refined during the full analysis and there are some slight differences in the predicted values of subsidence between the two. The input parameters where refinements



were made included additional case histories to the in-house data base of highly sub-critical panels from the Newcastle and Western coalfields noted in **Section 6** and taking into consideration the effects of possible flooding post-mining.



6.0 SUBSIDENCE AND PILLAR STABILITY ESTIMATES FOR THE VARIOUS MINING METHODS CONSIDERED

6.1 Surface and Sub-surface Protection Strategy

Essentially, panel and pillar mining is planned for the plateau areas at depths of greater than 160m. A typical schematic layout is shown in **Figure 6** for the purpose of depicting the dimensions. It features the following:

- A 50m (solid) block width.
- Chain pillars 29.5m in width (again, solid).
- 5.5m wide roadways.
- A mining height of 2.8m.
- A void width of 61m.
- Panel lengths of typically 1 to 2km.
- In-panel extraction of 67%.

The stability of the pillars have been assessed using the FoS approach utilising the pillar strength formulae developed by the University of New South Wales (**Salamon, et al, 1996**). For subsidence control the pillars are required to be long term stable even under double abutment loading. An abutment angle of 21° has been assumed, which is conservative for these highly sub critical panel widths. The outcomes are summarised in **Table 3**.

Table 3: Summarised Stability Outcomes for Panel and Pillar Mining Pillars

Scenario	Pillar Strength (MPa)	Depth 160m		Depth 200m		Depth 250m		Depth 310m	
		Stress (MPa)	FoS	Stress (MPa)	FoS	Stress (MPa)	FoS	Stress (MPa)	FoS
First Workings	37.5	5.0	7.5	6.3	6.0	7.9	4.8	9.7	3.9
Double Abutment Loading	37.5	11.2	3.3	14.4	2.6	18.5	2.0	23.4	1.6

From a subsidence control perspective this layout has the following attributes:

- The chain pillars have a width to height (w/h) ratio of 10.5 and would commonly be regarded as indestructible. The pillars also have final FoS under double abutment loading (i.e., following the extraction of both neighbouring panels) that is consistent with a nominal Probability of Instability of 1 in 1000 at the maximum depth of 310m.
- The 61m void width is sub-critical across the applicable depth range of 160m to 310m. Width to depth (W/H) ratios are typically much less than 0.40, such that subsidence principles indicate natural arching of the overburden and a greatly restricted potential for surface deformation (i.e. subsidence).

As noted, with the very high width to ratio the pillars would commonly be regarded as indestructible, irrespective of the nominal Probability of Instability. Width to height ratio, applied in conjunction with other criteria (i.e. FoS), is a useful indicator of design reliability. This is seen in



Figure 7 (Hill, 2010), which presents the FoS versus pillar w/h ratio relationship for a combined database of failed South African and Australian bord and pillar panels, plus a database of highwall mining (CHM) failed pillar cases. The three databases are highly complementary in nature, reflecting the range of experiences of their respective industries. For example, the Australian data provides insight with regard to pillar behaviour at relatively high w/h ratios and furnishes the failed case at the w/h ratio of 8.2. In contrast, the South African coal industry has traditionally been characterised by geometries involving lower w/h ratios, which is partly reflected in the maximum w/h ratio of only 3.7 for a South African failed case. Similarly, CHM pillar cases cover the lower end of the range of w/h ratios, from 0.6 to 1.4.

There are no failed cases in this combined South African and Australian database with a w/h ratio of greater than 8.2, even at a very low Factor of Safety, and there is only one case at a w/h ratio of greater than 5. The highest Factor of Safety assigned to a bord and pillar collapse is 2.1 and this was associated with a w/h ratio of only 2.2. Although there are failed CHM pillars with Factors of Safety of >2, all of them have w/h ratios of <2.

A limit envelope can be defined for the database of failed cases, illustrated by the curve and given by the following equation:

$$\text{w/h ratio} = 22.419e^{-1.148 * (\text{Factor of Safety})} \quad [1]$$

Beyond this envelope, there is no precedent for failure within these databases. It is worth noting that the exclusion of the CHM pillar data would not materially change the shape of this limit envelope.

In the case of long life (>5 years) pillars, then it is generally considered prudent to design outside the envelope defined by this equation, even though there are many examples of stable pillars that fall within it.

Furthermore, in the case of critical, long-life pillars, it is considered prudent to allow an additional margin beyond this curve. Golder Associates generally suggests a 20% margin, which is defined by the second (i.e. outer) curve in **Figure 7** and the following equation:

$$\text{w/h ratio} = 26.903e^{-0.957 * (\text{Factor of Safety})} \quad [2]$$

The panel and pillar mining pillars all fall well outside of the 20% margin envelope even at the maximum depth of cover. There is therefore simply no precedent for such pillars to fail and they are regarded as long term stable.

More restrictive forms of mining are proposed in the vicinity of the cliff lines and areas shallower than 160m. First workings are proposed under significant cliff lines and partial pillar extraction is proposed in the areas below the cliff lines to a minimum depth of 50m. A provisional layout is shown in **Figure 8**. It features the following:

- 39.5m by 24.5m (solid) pillars.
- 5.5m wide roadways.
- A mining height of 2.8m.
- A lifting depth of 10m.
- First workings in-panel extraction of 28%.



- Single-sided lifting in-panel extraction of 46%. The final span of 15.5m would be sub-critical across the envisaged depth range of 80 to 160m, with W/H ratios of less than 0.2.
- Double-sided lifting in-panel extraction of 65%. The final span of 25.5m would be sub-critical across the envisaged depth range of 100 to 160m, with W/H ratios of less than 0.3.

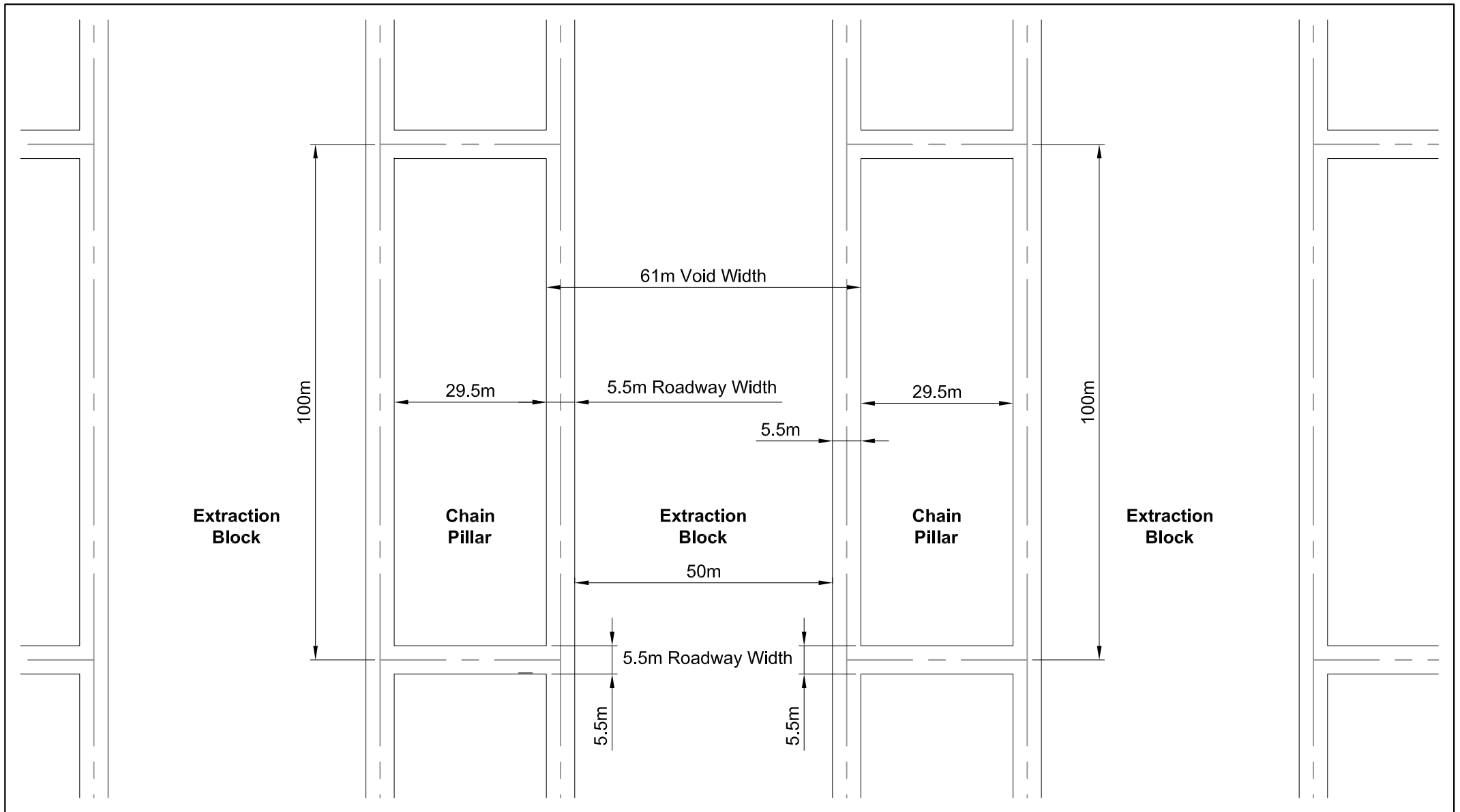
The stability of these pillars has been again assessed using the FoS approach utilising the pillar strength formulae developed by the University of New South Wales (**Salamon, *et al*, 1996**). The outcomes for the different pillar options are summarised in **Table 4**.

Table 4: Summarised Stability Outcomes for Coal Pillars on 30m by 45m Centres

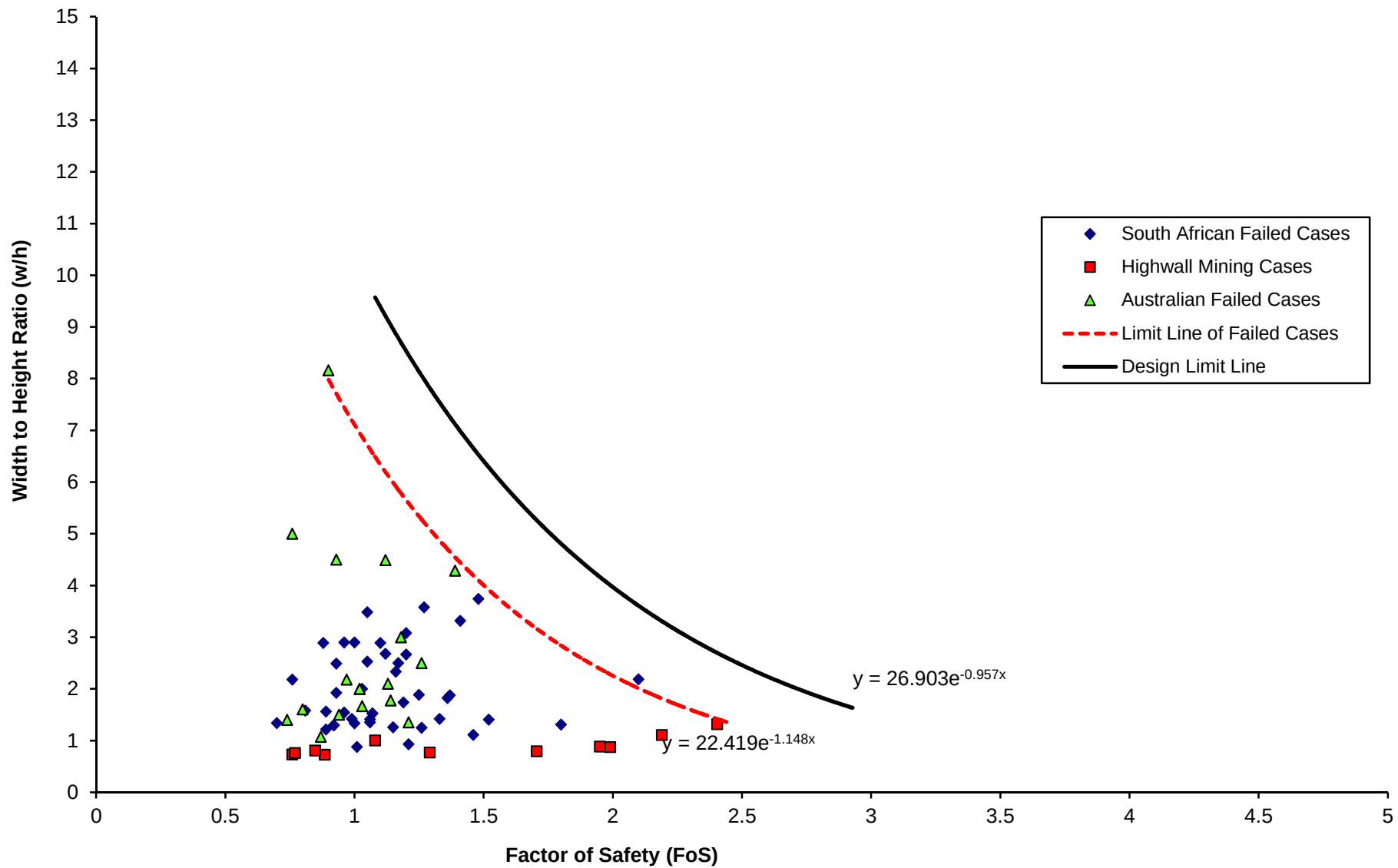
Scenario	Pillar Strength (MPa)	Depth 50m		Depth 100m		Depth 150m		Depth 200m	
		Stress (MPa)	FoS	Stress (MPa)	FoS	Stress (MPa)	FoS	Stress (MPa)	FoS
First Workings	25.6	1.7	14.7	3.5	7.3	5.2	4.9	7.0	3.7
Single-sided Lifting	24.1	2.3	10.3	4.7	5.1	7.0	3.4	9.3	2.6
Double-sided Lifting	18.6	3.5	5.3	7.1	2.6	10.6	1.8	14.1	1.3

The following comments are made regarding these outcomes:

- i) The first workings pillars have FoS ranging from 3.7 to 14.7 across the relevant depth range of 50 to 200m. It can also be shown that these pillars would have a FoS of 2.4 even at the absolute maximum depth of 310m for the resource. A FoS of 2.11 equates to a nominal Probability of Instability of one panel in a million, which is considered appropriate for ensuring the long-term stability of critical workings for the protection of key surface features. Also, the w/h ratio of the pillars is 8.8, which is considered to preclude the potential for collapse.
- ii) For single-sided lifting, the pillars have FoS ranging from 2.6 to 10.3 across a depth range of 50 to 200m. In practice, single-sided lifting will however be limited to a maximum depth of 160m (i.e. below the cliff lines) and the corresponding FoS would range from 3.2 upwards. These FoS would be regarded as acceptable for the maintenance of long-term stability in the presence of key surface features or infrastructure.
- iii) For double-sided lifting, the pillars have FoS ranging from 1.3 to 5.3 across the depth range of 50 to 200m. However, in practice double-sided lifting will be limited to a maximum depth of 160m (i.e. below the cliff lines) and the corresponding FoS would range from 1.6 upwards. A FoS of 1.63 equates to a nominal Probability of Instability of one in a thousand and coupled to the pillar w/h ratio of 7.0 is considered adequate for the maintenance of long-term stability, noting that the minimum FoS plots above the upper curve in **Figure 7**. There is therefore no known precedent of pillar failure for pillars with this FoS and w/h ratio.

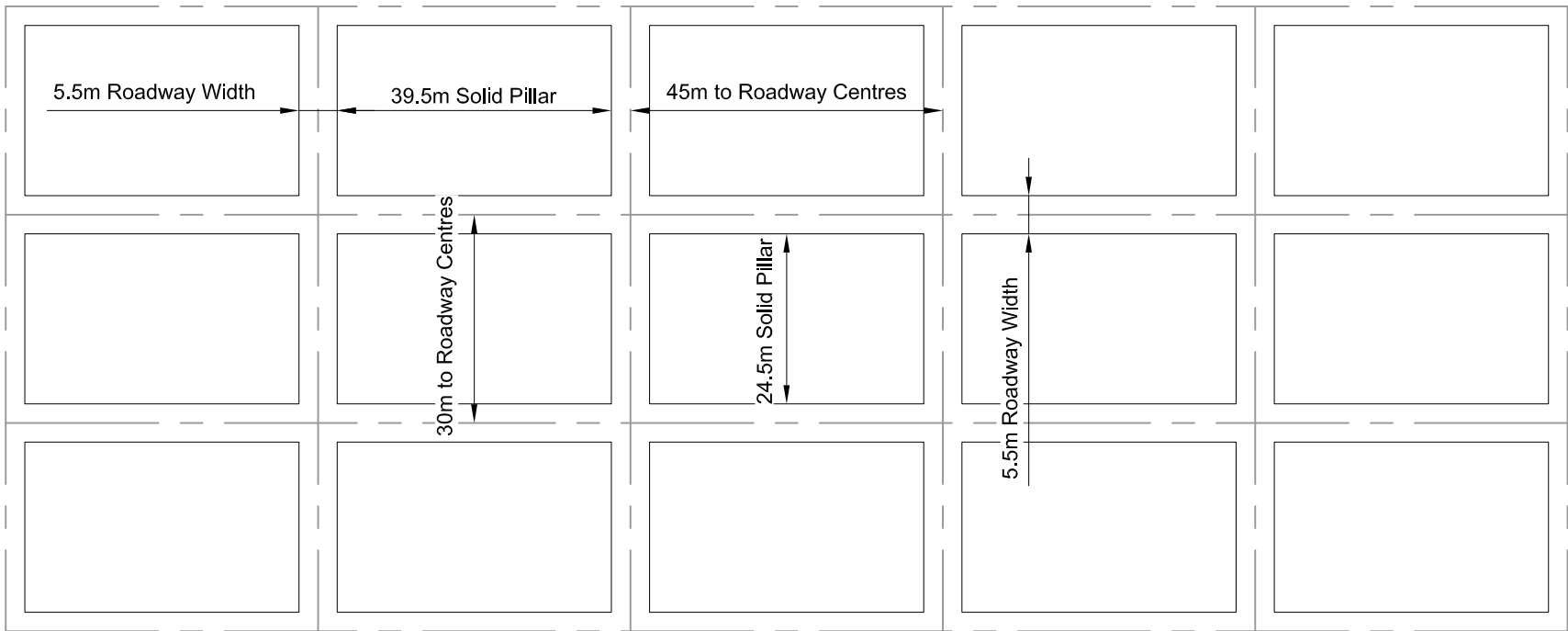


		Engineer: D, Hill	Client: Airly Mine		
		Drawn: I.Meek	Title: Panel and Pillar Concept Showing Representative Mining Geometries		
		Date: 19.08.13			
		GOLDER ASSOCIATES PTY. LTD.		Ref: 127621105-003	Support Plan No: N/A
		www.golder.com		Scale: NTS	Figure No: 6

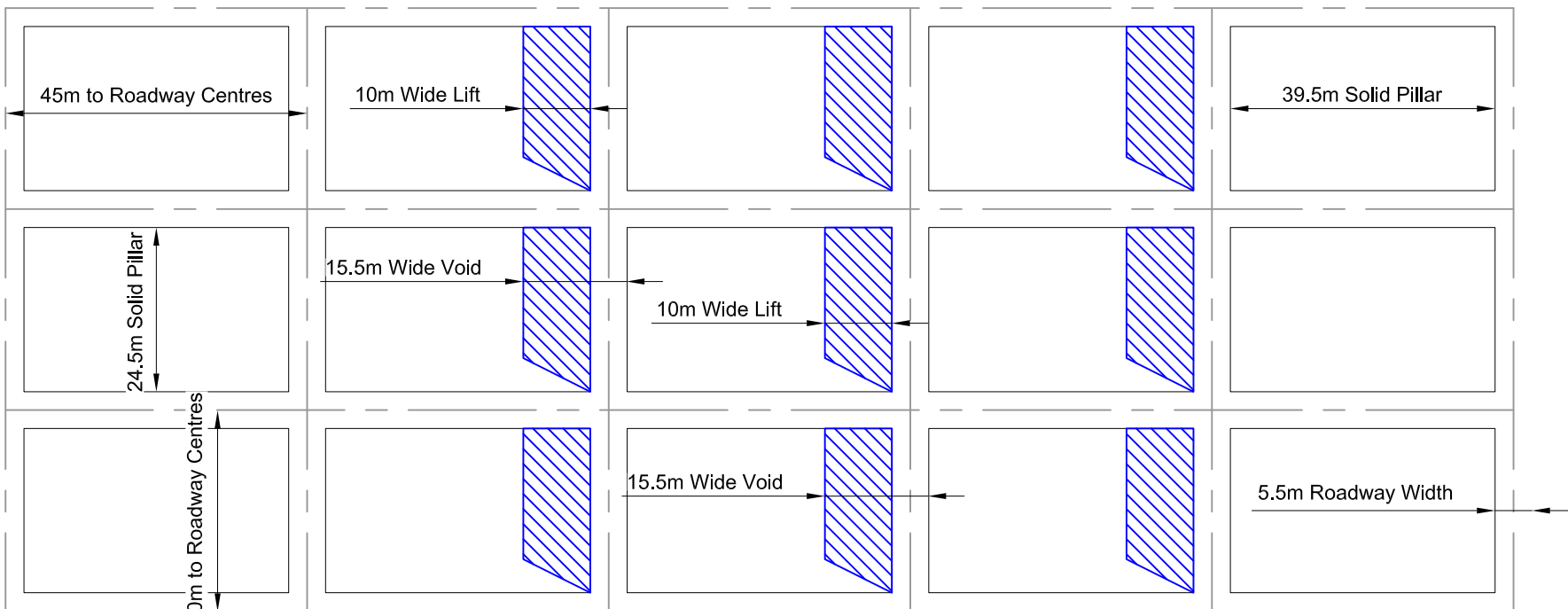


Engineer: R. Trueman Drawn: B. Richardson Date: 25.10.13	Client: Airly Mine		
	Title: Failed Pillar Database Showing Proposed Design Limit Line (Hill, 2010)		
	GOLDER ASSOCIATES PTY. LTD. www.golder.com		
Ref: 127621105-003-R	Support Plan No:	N/A	
Scale: N/A	Figure No:	7	

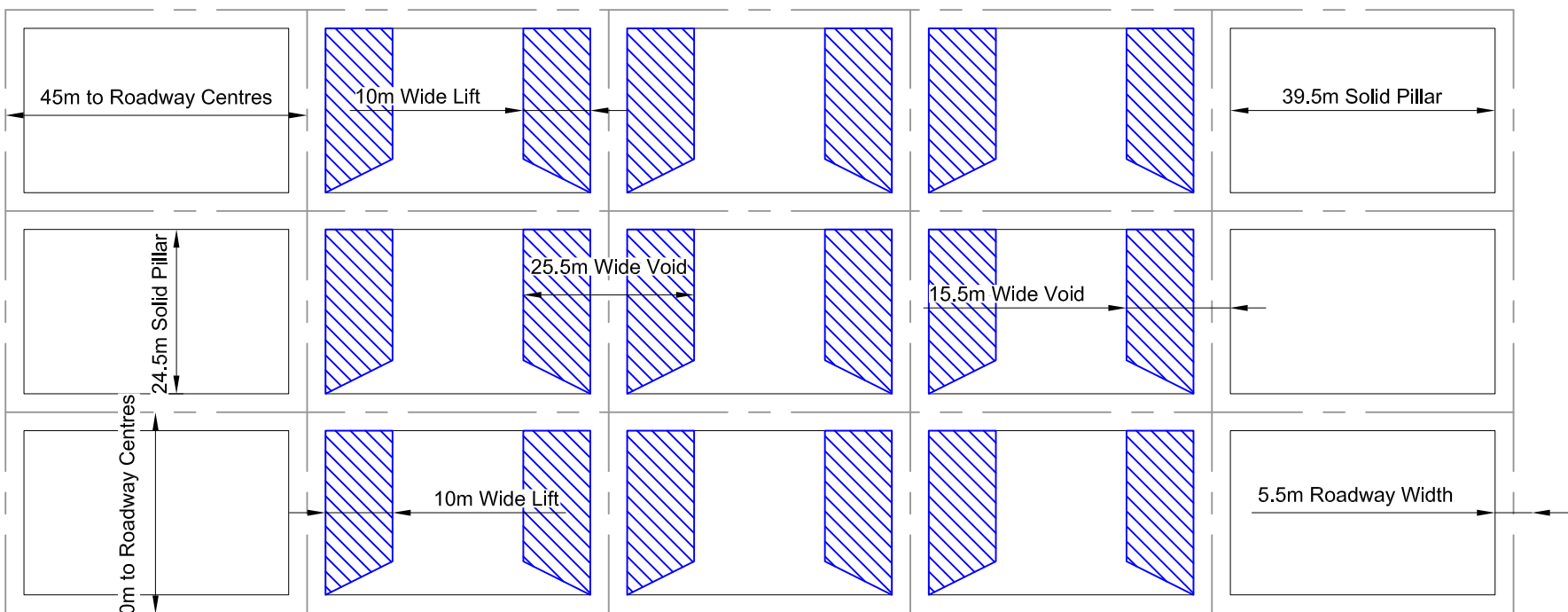
(i) First Working Pillars Only



(ii) Single-sided Lifts



(iii) Double-sided Lifts





For the depth range 20m to 80m (100m in areas that may flood post-mining), first workings are proposed, with pillar splitting and quartering to a minimum depth of 30m. Further to this, below a depth of 30m, no intersections will be formed. On this basis, a provisional layout is shown in **Figure 9**. It features the following:

- 35m (centres) first working pillars.
- 17.5m (centres) pillars after splitting and quartering.
- 5.5m wide roadways.
- A mining height of 2.8m.
- First workings in-panel extraction of 29%.
- Pillar splitting and quartering in-panel extraction of 53%.

In assessing the final split and quartered pillars, an allowance has been made for the impact of multiple breakaways on the nominal 12m wide (solid) pillars. Based upon previous splitting and quartering experience elsewhere, an effective final roadway width of 6.0m has therefore been assumed, such that the final pillar width is 11.5m. Using the same approach to pillar design as noted previously, the stability outcomes are summarised in **Table 5 (Strata Engineering 2011a and 2011b)**.

Table 5: Summarised Stability Outcomes for Coal Pillars on 35m Centres

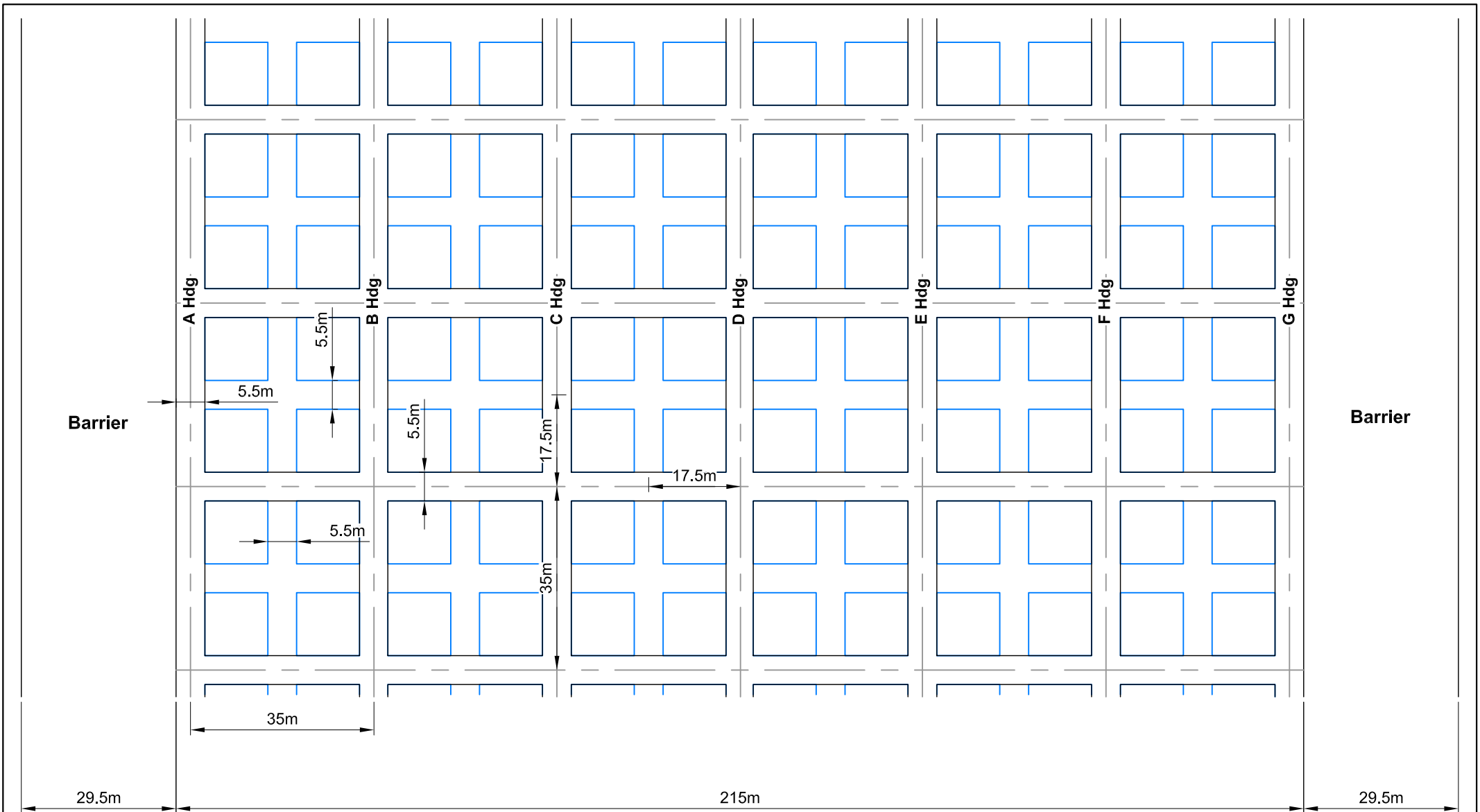
Scenario	Pillar Strength (MPa)	Depth 30m		Depth 50m		Depth 80m		Depth 100m	
		Stress (MPa)	FoS	Stress (MPa)	FoS	Stress (MPa)	FoS	Stress (MPa)	FoS
First Workings	30.2	1.1	27.5	1.8	16.8	2.8	10.8	3.7	8.6
Split and Quartered Pillars	12.6	1.7	7.4	2.9	4.3	4.6	2.7	5.8	2.2

The following comments are made regarding these outcomes:

- The first workings pillars have FoS ranging from 8.6 to 27.5 across the relevant depth range of 30 to 100m. These very high FoS will ensure the long-term stability of critical workings for the protection of key surface features. Also, the w/h ratio of the pillars is 10.5, which is considered to preclude the potential for collapse.
- The split and quartered pillars have FoS ranging from 2.2 to 7.4 across the depth range of 30 to 100m. These FoS would be regarded as acceptable for the maintenance of long-term stability in the presence of key surface features or infrastructure.

Overall, the proposed mining system aims to provide the following advantages:

- Caving heights will be restricted to the immediate Permian overburden, with minimal deformation of the Triassic sandstone units that form the cliff lines.
- Reduced disturbance to any overlying aquifers, particularly within the Triassic units.
- No appreciable adverse surface impacts. In particular, the intent is to avoid surface cracking and minimise mining-related rock falls.



		Engineer:	R. Trueman	Client:	Airly Mine			
		Drawn:	B. Richardson		Title:	Pillar Splitting and Quartering Layout Based on 35m Pillar Centres		
		Date:	19.08.13					
		GOLDER ASSOCIATES PTY. LTD. www.golder.com			Ref:	127621105-003	Support Plan No:	N/A
					Scale:	NTS	Figure No:	9



6.2 Subsidence Estimation

Surface subsidence associated with the proposed partial extraction workings has been estimated using a combination of empirical, numerical and analytical approaches.

6.2.1 Subsidence Estimates for Panel and Pillar Mining

Firstly, it is noted that the original empirical work done in the Western Coalfield by **Holla (1991)** indicates that subsidence due to panel and pillar mining at very low W/H ratios should be negligible. The empirical relationship between the subsidence factor (maximum subsidence, S_{max} , over mining height, T) and W/H ratio for single isolated panels is illustrated in **Figure 10**. It is evident that S_{max}/T approaches zero asymptotically at the anticipated W/H ratios of less than 0.4. For a maximum estimated subsidence factor of 0.02 and a mining height of 2.8m, 50 to 60mm of subsidence is estimated i.e. well within the 100mm limit criterion.

A limitation of the Holla database to the Airly situation is however the lack of information for W/H ratios of less than 0.4. Accordingly, expected subsidence has also been estimated by means of reference to an in-house database of highly sub-critical panels from the Newcastle and Western coalfields. The database is illustrated in **Figure 11**; it focusses on mining geometries that more closely approximate those envisaged for Airly (i.e. panel W/H ratios of ≤ 0.6 , over the applicable depth range).

This database has been used to derive two sets of subsidence estimates, namely expected values, based on the regression line and (given the large amount of scatter in the data) worst-case values based on the upper bound curve.

Also, because the database relates to “first panel” situations, an increment has been added to account for the impact of subsequent adjacent partial extraction panels. Therefore, accepting that these increments have been estimated from a limited database of panels with similar geometries and from data sourced from the Newcastle Coalfield, these estimates are summarised as follows:

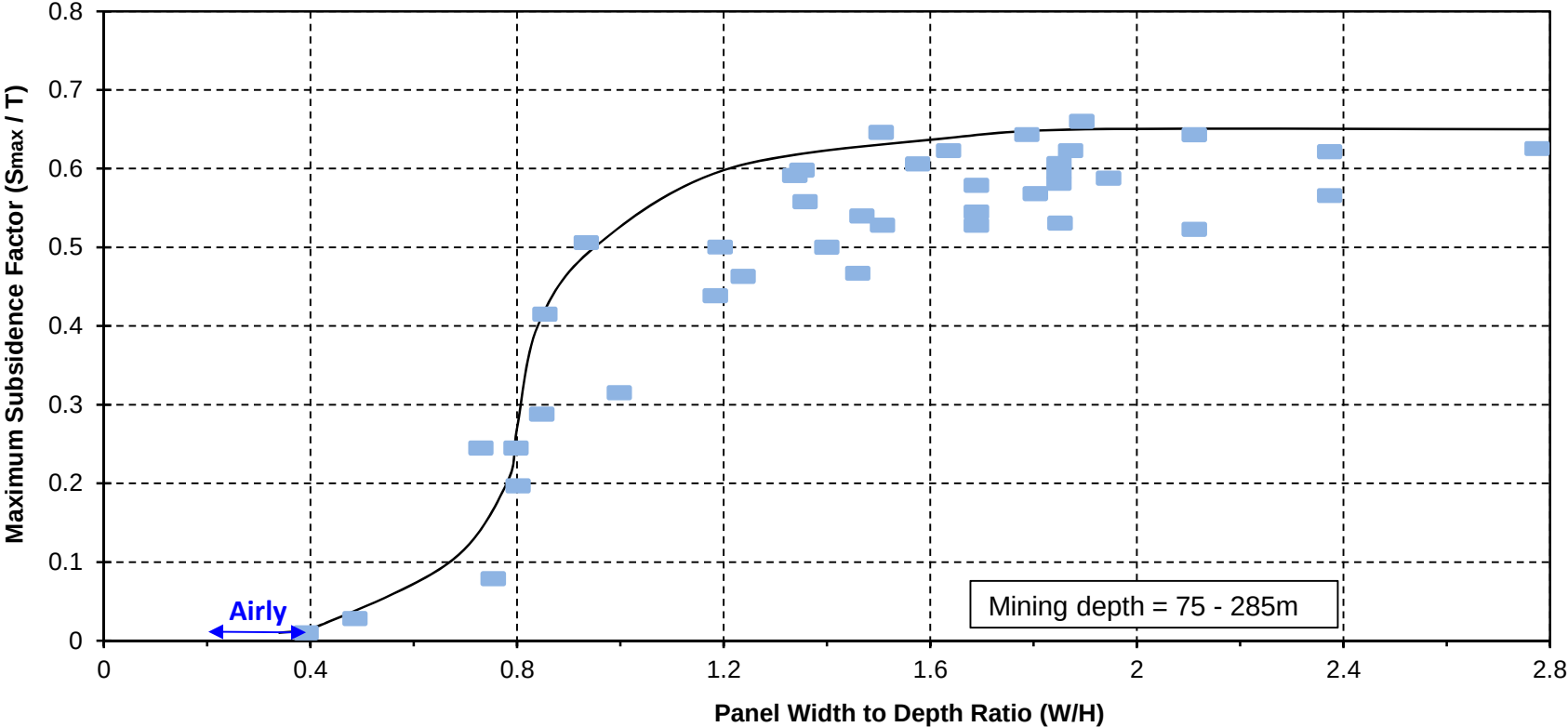
- Subsidence increases by an average of 10mm at W/H ratios of < 0.4 .
- Subsidence increases by an average of 36mm at W/H ratios of ≥ 0.4 .

The resulting empirical subsidence estimates for multi-panel situations are summarised in **Table 6**.

Table 6: Empirical Subsidence Estimates

Depth (m)	Width to Depth Ratio	Maximum Subsidence (mm)	
		Expected	Upper Bound
120	0.51	109	164
160	0.38	65	106
200	0.31	54	87
240	0.25	47	74
280	0.22	41	61

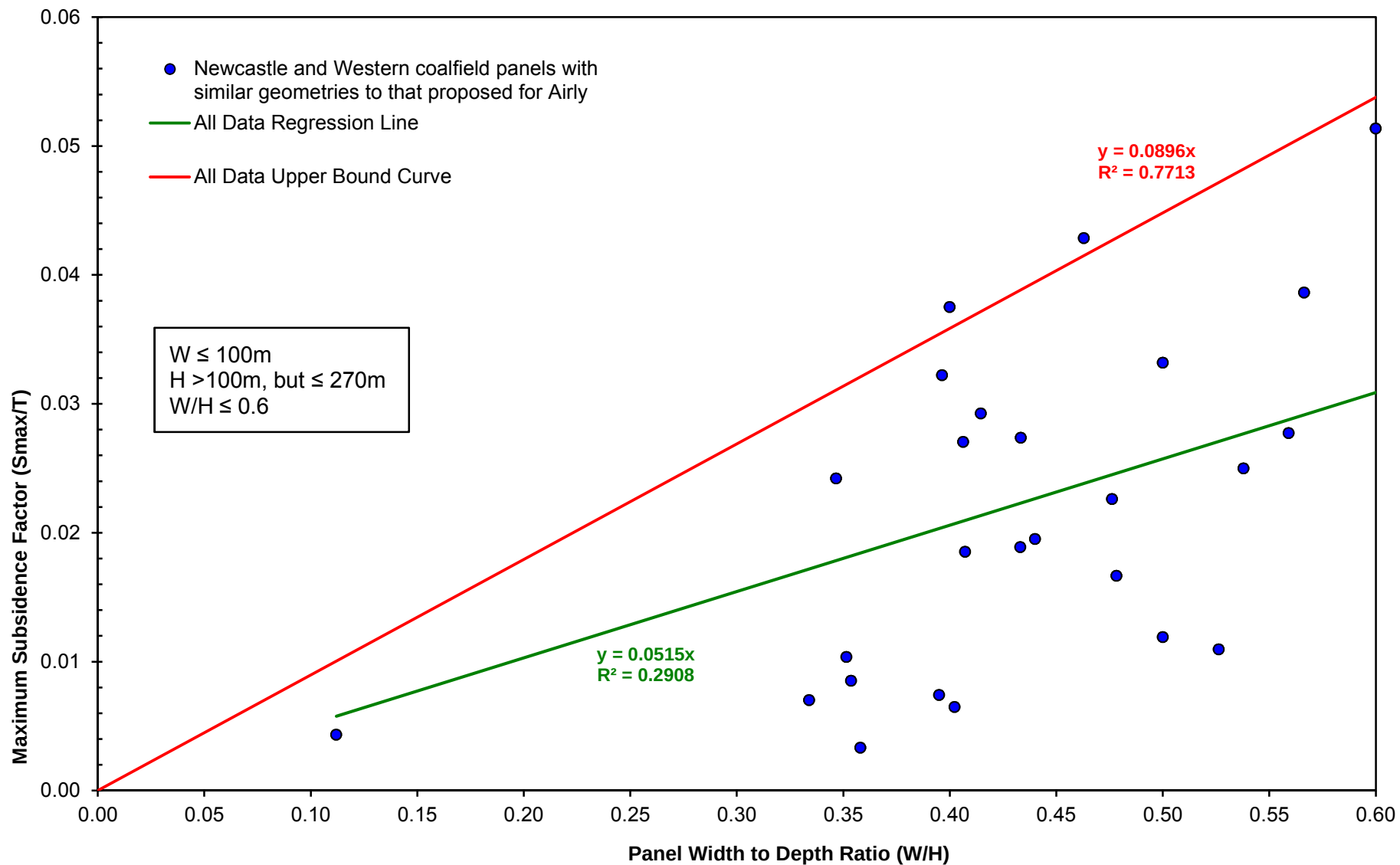
Note: panel and pillar mining for Airly is restricted to W/H ratios of <0.4, equivalent to a maximum estimated subsidence factor of 0.02, which suggests minimal subsidence. However, data for W/H ratios of <0.4 is limited in this database.



Note:
 S_{max} = maximum subsidence
 T = extraction thickness



Engineer:	D. Hill	Client:	Airly Mine		
Drawn:	B. Richardson	Title:	Relationship between Maximum Subsidence and Panel Width to Depth Ratio (adapted from Holla, 1991)		
Date:	19.08.13				
GOLDER ASSOCIATES PTY. LTD. www.golder.com		Ref:	127621105-003	Support Plan No:	N/A
		Scale:	N/A	Figure No:	10



Engineer: D. Hill
 Drawn: B. Richardson
 Date: 19.08.13
GOLDER ASSOCIATES
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 www.golder.com

Client: Airly Mine
 Title: Combined Newcastle and Western Coalfield Narrow Panel Database Showing Relationship between W/H Ratio and S_{max}/T for Panels Similar to that Proposed at Airly Mine
 Ref: 127621105-003
 Scale: N/A
 Support Plan No: N/A
 Figure No: 11



The following comments are made regarding the results in **Table 6**:

- i) At W/H ratios of <0.4 , expected subsidence ranges from 41 to 65mm, which is practically the same as that estimated from the Holla curve.
- ii) At a depth of 120m, the expected subsidence exceeds the 100mm criterion. Given that a depth of 120m corresponds closely to the base of the cliffs in the western portion of the project area, this suggests that panel and pillar mining should not be conducted beneath the cliffs.
- iii) At a depth of 160m, the upper bound subsidence estimate (106mm) marginally exceeds the 100mm criterion but is within the tolerance of ± 25 mm. Given that a depth range of 150m to 170m corresponds approximately to the cliff crest area in the western portion of the project area, this suggests that panel and pillar mining should be limited to the plateau areas above the cliff lines. This is the reason that panel mining at this void width has been limited to a minimum depth of 160m.

Subsidence estimates have also been made using the “LaModel” numerical model, which is a three dimensional displacement discontinuity code developed by the US National Institute for Safety and Health (NIOSH) specifically for modelling subsidence and pillar stress. The main input parameters for LaModel, in addition to the mining geometry, are the modulus of the coal (E_c), the modulus of the overburden (E_o) and the coal strength. The bulk modulus for coal is typically taken to be about 2GPa and this has been used for all simulations. A UCS of coal of 6.2MPa has also been used; this is again a typical value used in most numerical and empirical models. LaModel has been adequately calibrated for the partial pillar extraction layout at Clarence Colliery but has obviously not been calibrated for the panel mining layouts proposed at Airly. Nevertheless in the absence of appropriate monitoring data at Airly, the model is deemed to be useful in providing trends and comparisons to empirical data. Because elements are required to be of equal of size, in preference to the planned 61m, a void width of 62m was modelled.

In detail therefore, LaModel incorporates an analytical routine, whereby goaf material properties are determined from an input of the maximum stress in the goaf and the width thereof. The maximum goaf stress has been estimated using an abutment angle model, noting that the average stress on the goaf is that portion of the overburden load not transferred to the pillars. For modelling purposes, the height of the combined caved and fractured zone was estimated assuming a conservative Angle of Break of 17° . In the Western Coalfield, Angles of Break typically vary between 17° and 23° and it is not known what is appropriate for Airly, hence the use of the conservative estimate. The modulus of the material within the fractured zone (E_f) is estimated to an average of 1GPa, whilst the modulus of the intact overburden, above the fractured zone, is estimated to be 20GPa, given the generally competent upper sandstone. Currently, LaModel only allows one overburden modulus to be input into the model. To account for the lower caved / fractured and upper constrained zones, a weighted average of the modulus was calculated, taking into account the proportions of the two zones at varying depths. In this regard, it is also of note that LaModel has been used successfully for the estimation of subsidence over partial extraction workings at Clarence since 2008.

LaModel output graphs are provided in **Figures 12 to 14** and the corresponding subsidence estimates (inclusive of tilt and strain) are summarised in **Table 7**.



Table 7: LaModel Subsidence Estimates

Depth (m)	Width to Depth Ratio	Subsidence (mm)	Tilt (mm/m)	Strain (mm/m)
120	0.51	88	1.9	1.5
180	0.34	58	1.0	1.0
240	0.25	63	1.0	0.9
300	0.20	74	1.0	0.9

The following comments are made regarding these results:

- At W/H ratios of less than 0.4, the subsidence range of 58mm to 74mm is only slightly greater than that estimated from the Holla curve.
- This output also indicates that the shallower LaModel results are less conservative than the Newcastle and Western Coalfield empirical estimates.
- The marginal increase in subsidence between 180m and 300m is a function of increased pillar compression in the model (i.e. a multiple panel effect) and in this regard it is of note that the modelling suggests a maximum increase in subsidence of 7mm due to multiple panel effects at the maximum depth of 300m (i.e. slightly less than the 10mm estimated empirically).

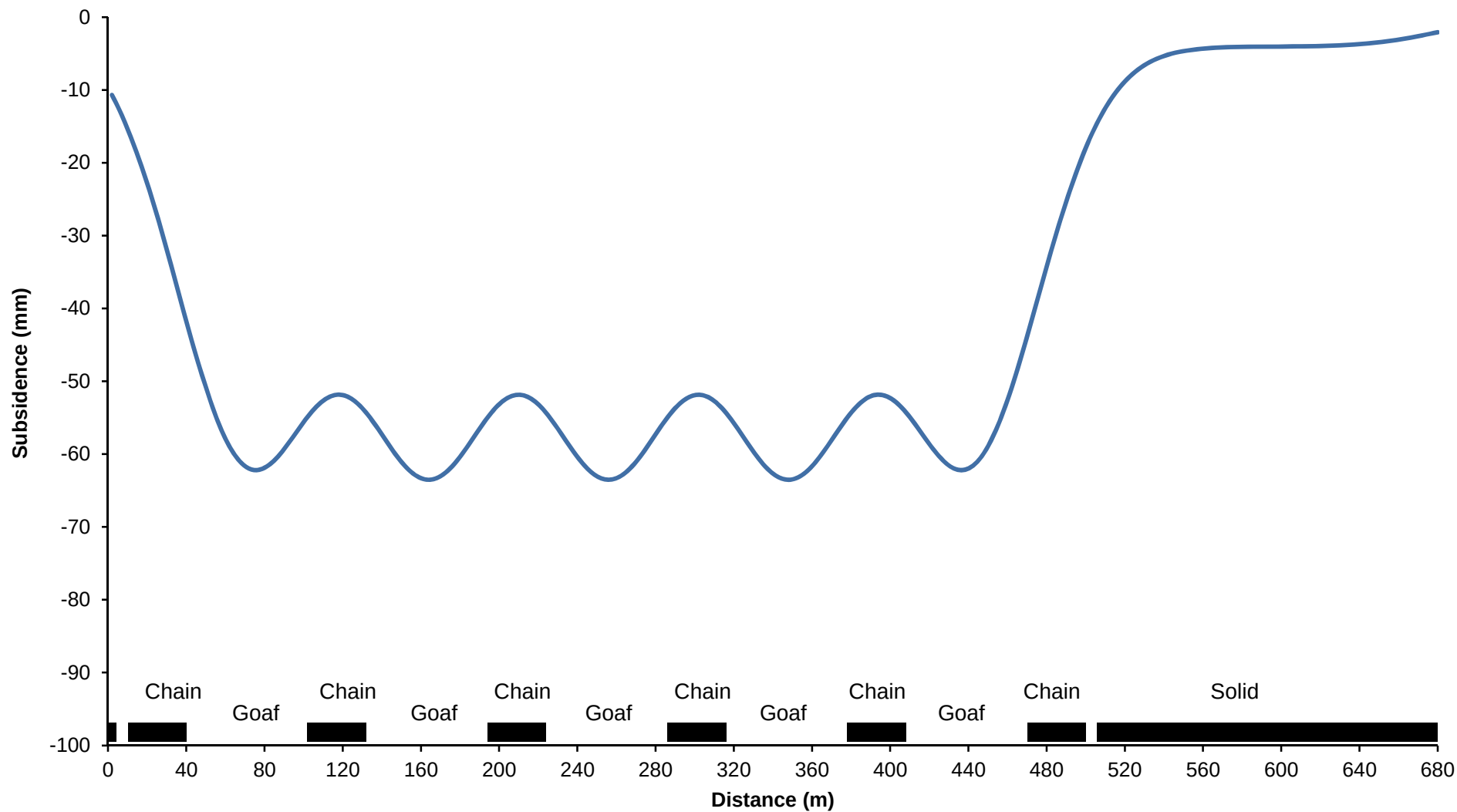
The empirical and numerical estimates are jointly illustrated in **Figure 15**. The subsidence trends are reasonably consistent and at the depths of greater than 160m suggested for panel and pillar mining, subsidence is expected to be typically in the range of 40mm to 80mm. Exceedance of the 100mm criterion is therefore considered very unlikely.

As shown in **Table 2**, the tilts and strains associated with these limited magnitudes of subsidence have also been estimated using empirical and numerical methods. The empirical methodology applies the formulae and 'K' factors derived by **Holla (1991)**, namely:

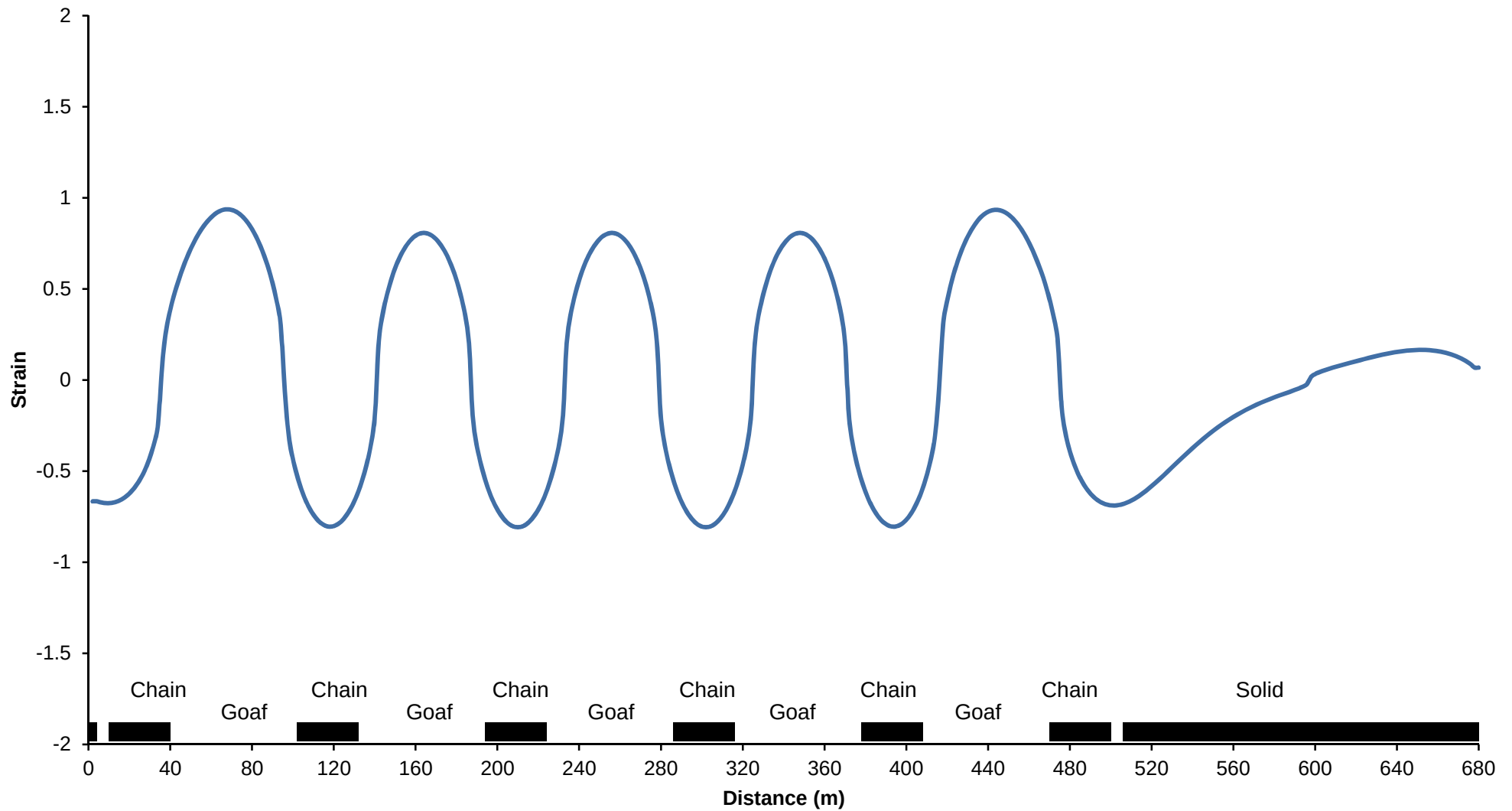
- Tensile strain, $+E_{\max} = 1,000 \times K1 \times S_{\max} / H$
- Compressive strain, $-E_{\max} = 1,000 \times K2 \times S_{\max} / H$
- Tilt, $G_{\max} = 1,000 \times K3 \times S_{\max} / H$

where:

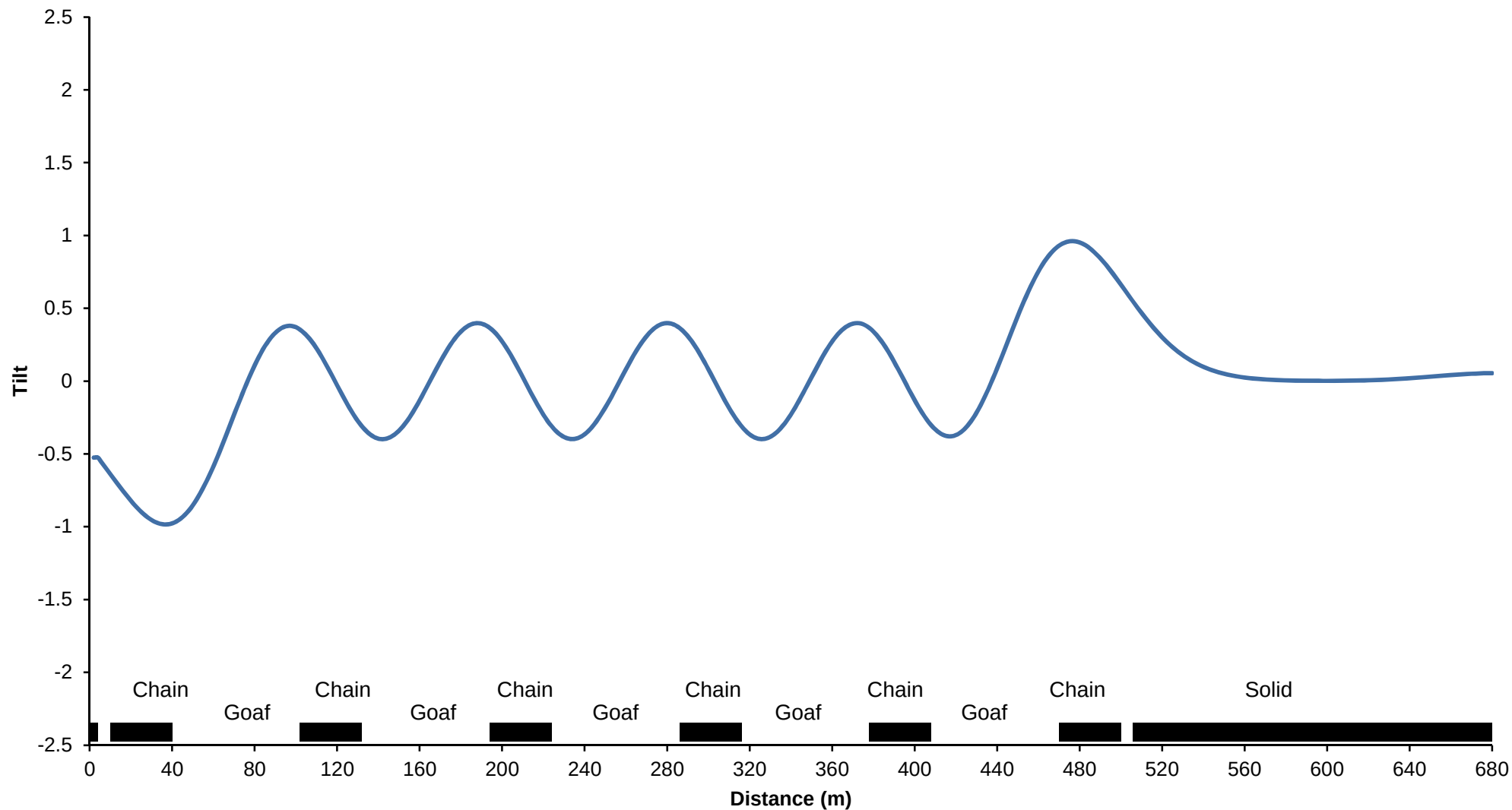
- K1 (tensile strain) = 1.2 to 1.5
- K2 (compressive strain) = 0.9 to 2.5
- K3 (tilt) = 3.1 to 5.0



Engineer: D. Hill Drawn: D. Hill Date: 24.07.13	Client: Airly Mine		
	Title: LaModel Output of Subsidence for the Airly Panel and Pillar Layout (Void Width 62m) at a Depth of 240m		
	GOLDER ASSOCIATES PTY. LTD. www.golder.com		
Ref: 127621105-003	Support Plan No: N/A		
Scale: N/A	Figure No: 12		



Engineer:	D. Hill	Client:	Airly Mine			
Drawn:	D. Hill		Title:	LaModel Output of Strain for the Airly Panel and Pillar Layout (Void Width 62m) at a Depth of 240m		
Date:	24.07.13					
GOLDER ASSOCIATES		Ref:	127621105-003	Support Plan No:	N/A	
PTY. LTD.			Scale:	N/A	Figure No:	13
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Engineer: D. Hill

Drawn: D. Hill

Date: 24.07.13

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Client: Airly Mine

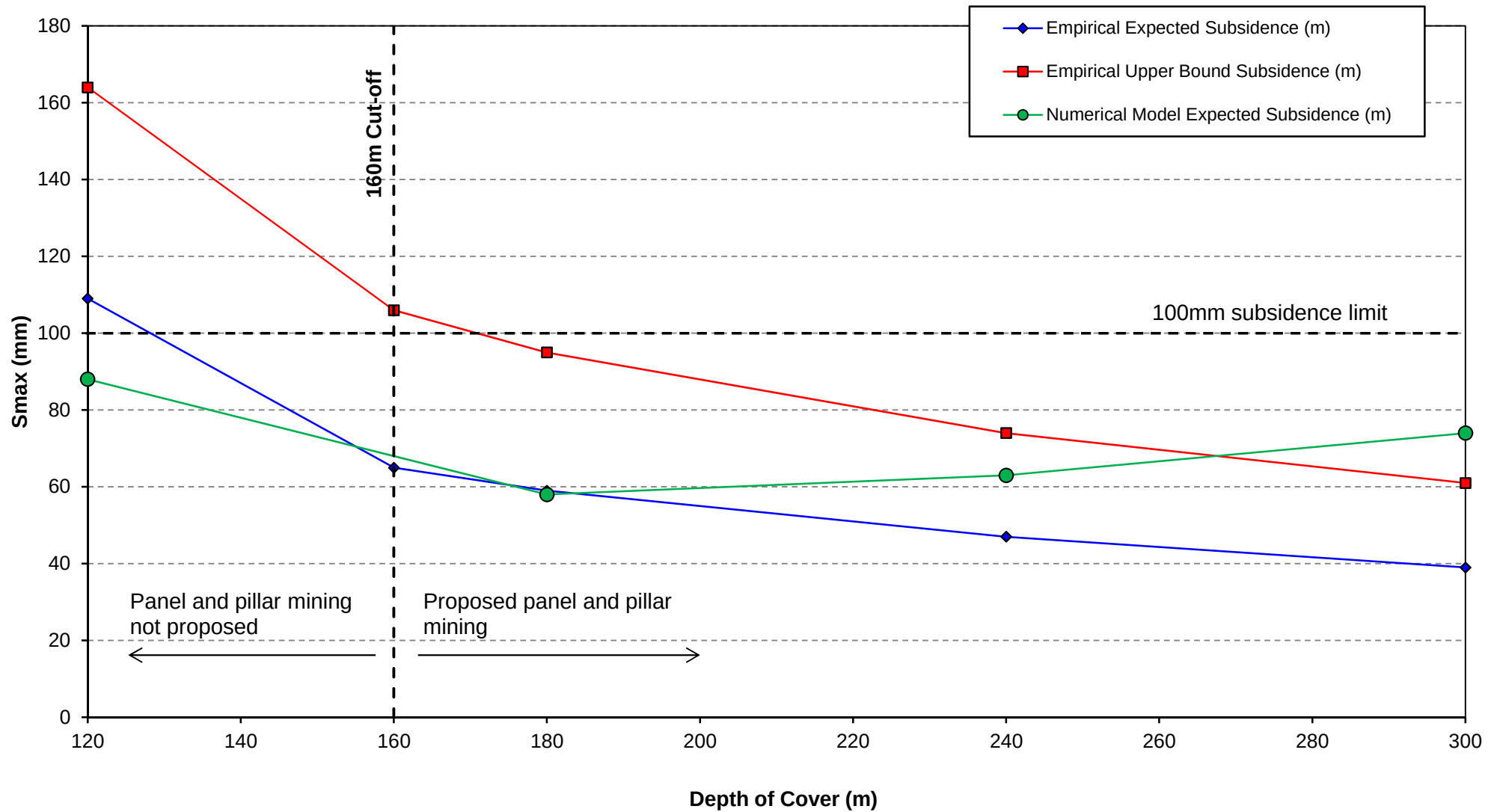
Title: LaModel Output of Tilt for the Airly Panel and Pillar Layout
(Void Width 62m) at a Depth of 240m

Ref: 127621105-003

Scale: N/A

Support Plan No: N/A

Figure No: 14



Note:

- 100mm subsidence criterion is not applicable to the New Hartley Shale Mine workings interaction zone
- Empirical estimate taken from combined Newcastle and Western Coalfield database
- Numerical model taken from LaModel



Engineer: D. Hill

Drawn: B. Richardson

Date: 19.08.13

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Client: Airly Mine

Title: Estimates of Maximum Subsidence versus Cover Depth for the Proposed Airly Panel and Pillar Layout

Ref: 127621105-003

Scale: N/A

Support Plan No: N/A

Figure No: 15



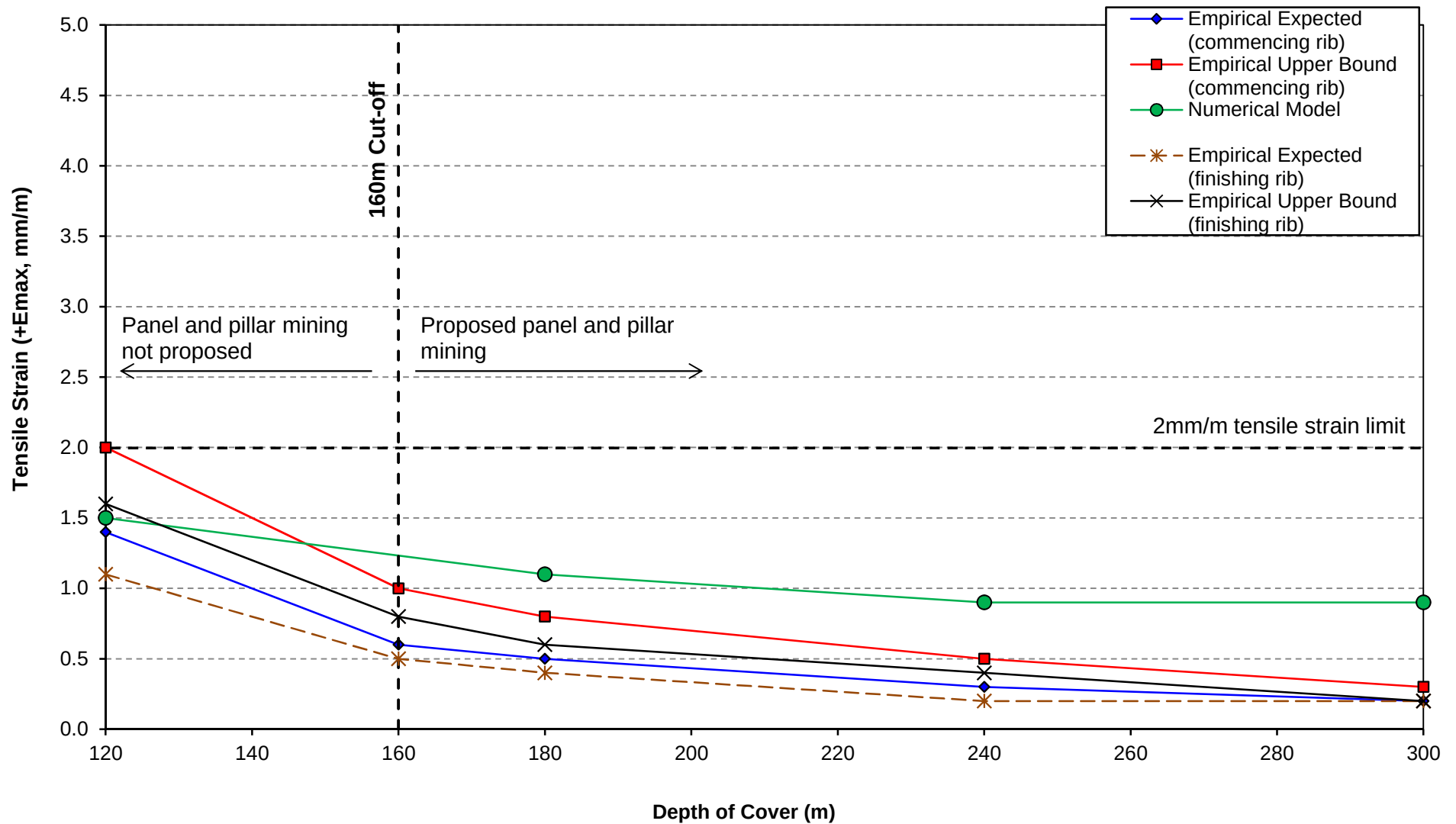
K factors are constraints of proportionality and relate to the finishing and commencing ribs (i.e. those ribs parallel to the face at the stop and start positions of the panel) respectively, and define the overall ranges. Although based upon single panels, the multi-panel effect has been effectively included by the addition of the empirical estimate of additional subsidence to account for chain pillar compression as previously discussed. Additionally, the bulk of the database used to determine the empirical relationships are from W/H ratios that are significantly greater than those anticipated at Airly. The relationships are therefore likely to be conservative for the limited W/H ratios proposed for Airly. The results are illustrated in **Figures 16 to 18** together with the results from the numerical modelling and in this regard, the following comments are of note:

- i) Tensile strain is typically in the range of 0 to 1mm/m, see **Figure 16**. Tensile strain only approaches 2mm/m at depths of around 120m, below the suggested cut-off depth. Given that tensile strains of greater than 2mm/m are commonly associated with the onset of surface cracking, no surface impact is therefore expected.
- ii) Compressive strain is typically in the range of 0 to 2mm/m, see **Figure 17**. Compressive strain only approaches 3mm/m at depths of around 120m, below the suggested cut-off depth. Given that compressive strains of greater than 3mm/m are commonly associated with the onset of surface cracking, no surface impact is expected.
- iii) Tilt is typically in the range of 0.5 to 2mm/m, see **Figure 18**, although the upper bound for the commencing rib approaches 3.3mm/m at a depth of 160m, which is slightly greater than the 2.5 mm/m recommended. However this upper bound is regarded as highly conservative given the fact that the W/H ratios at Airly are significantly less than the bulk of those included in the empirical database. As such, this magnitude of tilt is not regarded as practically credible.

Overall, the tilts and strains associated with the proposed panel and pillar mining at depths of greater than 160m would be commonly regarded as negligible and close to the limits of measurability. The reported tilts and strains are also comparable to that recorded at Clarence, which critically have not been associated with any appreciable surface impacts on landforms very similar to those in the Airly project application area.

As would be expected given the very limited values of subsidence, Angles of Draw to the 20mm subsidence limit are also low. The numerical modelling suggests Angles of Draw over the longitudinal rib lines (sides) of the panels of the order of 5° to 8° at depths of 120m to 300m and that the Angles of Draw reduce to between 1° and 4° over the commencing and finishing ends of the panels. These very low Angles of Draw are consistent with the partial extraction experiences gained from Clarence, where Angles of Draw are commonly very limited or negative.

It is noted that at Clarence Colliery there has been a reactivation of subsidence once panels are flooded. At Airly the main aquifer is in the Permian below the seam. From the hydrological studies (**GHD, Personal Communication October 2013**) it is predicted that post-mining about two thirds of the panel and pillar mining area will be totally flooded and the majority of the remainder partially flooded. However, subsidence estimates for panel and pillar mining have been made using an empirical data base. The upper bound estimate of subsidence will have undoubtedly captured panels that have flooded post-mining. The effect of flooding on subsidence has therefore been accounted for in these upper bound estimates.



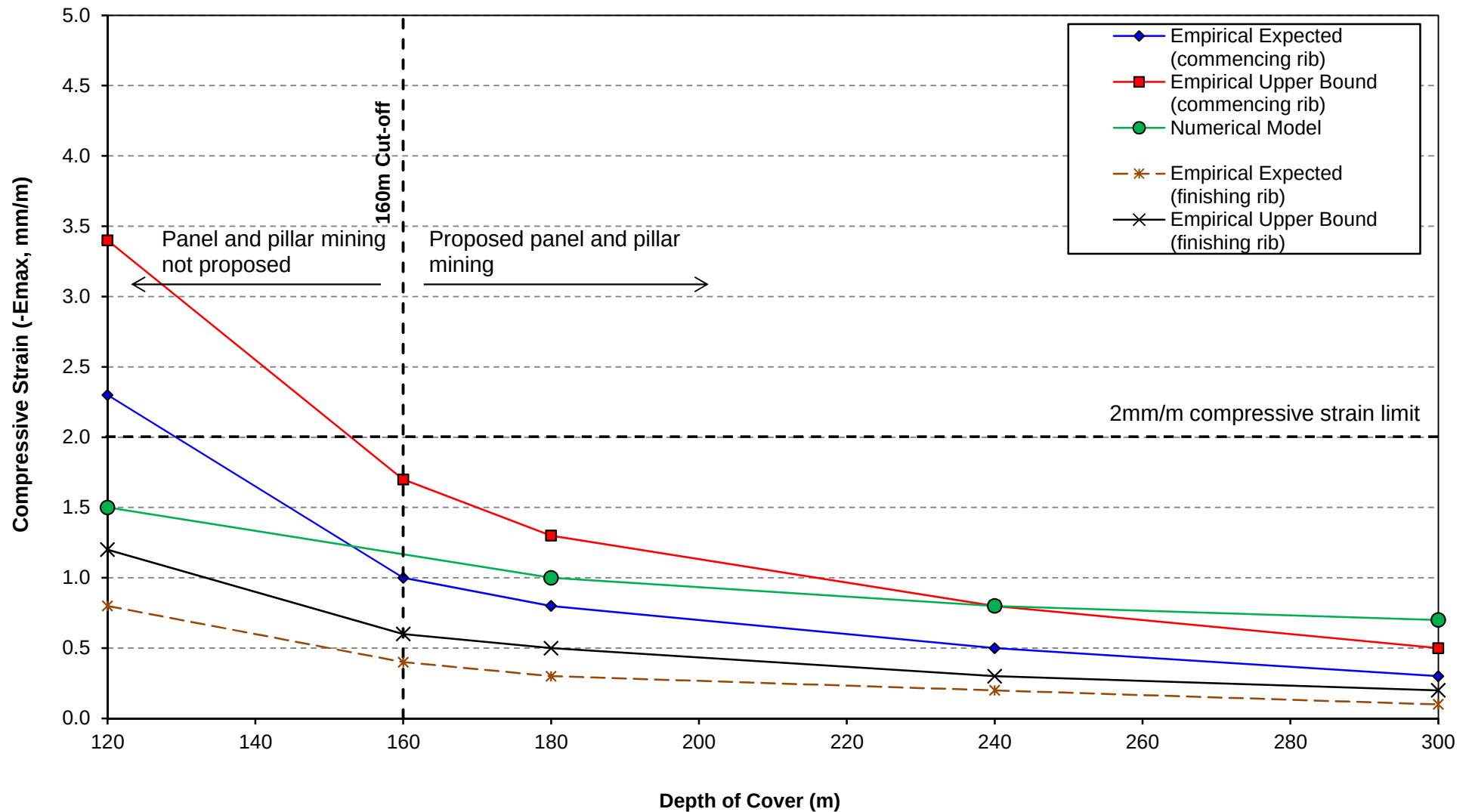
Note:

- 2mm/m strain criterion is not applicable to the New Hartley Shale Mine workings interaction zone
- Empirical estimate taken from combined Newcastle and Western Coalfield database
- Numerical model taken from LaModel



Engineer: D. Hill
Drawn: B. Richardson
Date: 19.08.13
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Client: Airly Mine
Title: Estimates of Maximum Tensile Strain versus Cover Depth for the Proposed Airly Panel and Pillar Layout
Ref: 127621105-003
Scale: N/A
Support Plan No: N/A
Figure No: 16



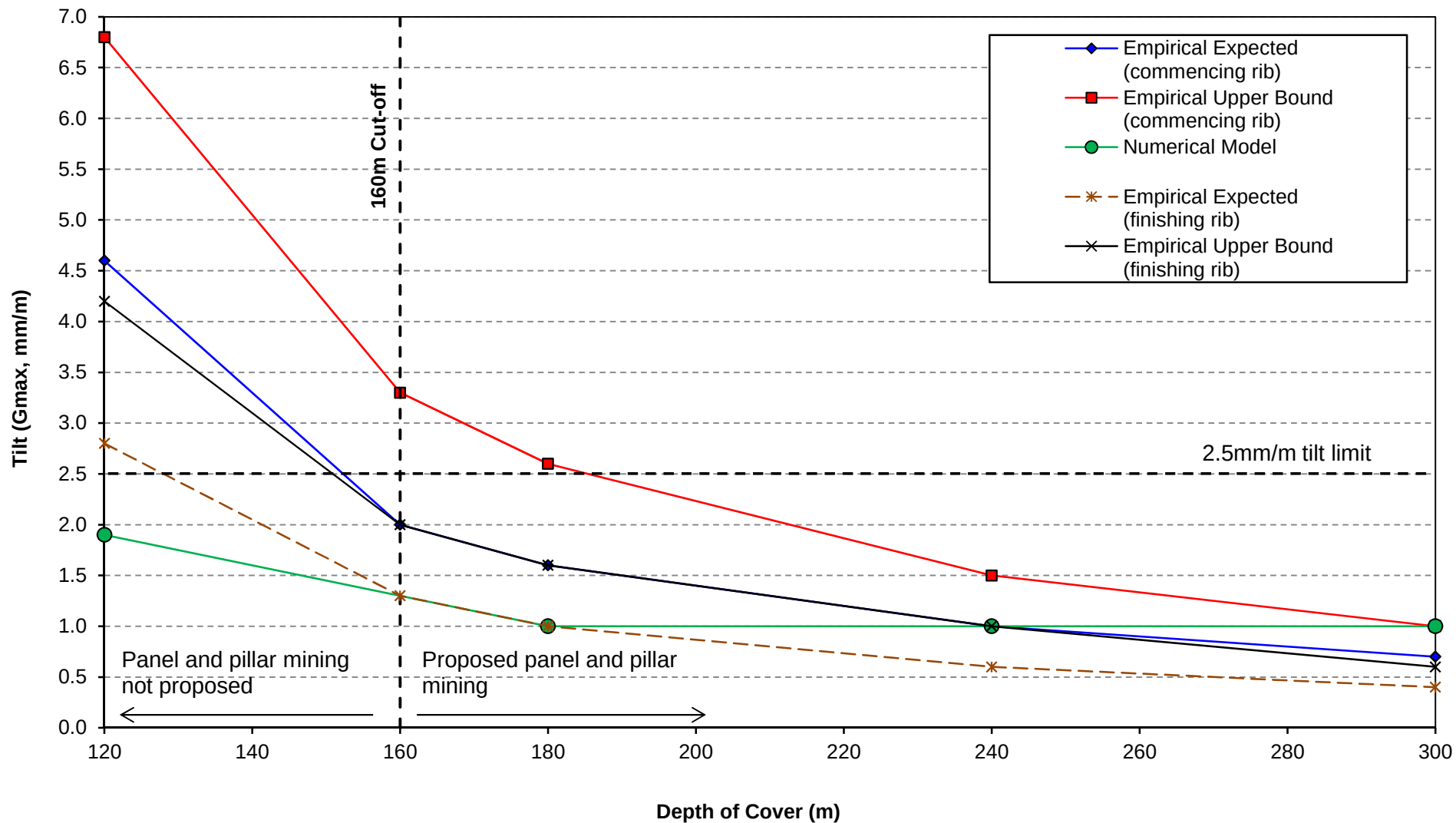
Note:

- 2mm/m strain criterion is not applicable to the New Hartley Shale Mine workings interaction zone
- Empirical estimate taken from combined Newcastle and Western Coalfield database
- Numerical model taken from LaModel



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Title:	Estimates of Maximum Compressive Strain versus Cover Depth for the Proposed Airly Panel and Pillar Layout		
Ref:	127621105-003	Support Plan No:	N/A
Scale:	N/A	Figure No:	17



Note:

- 2.5mm/m tilt criterion is not applicable to the New Hartley Shale Mine workings interaction zone
- Empirical estimate taken from combined Newcastle and Western Coalfield database
- Numerical model taken from LaModel



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Client:	Airly Mine		
Title:	Estimates of Maximum Tilt versus Cover Depth for the Proposed Airly Panel and Pillar Layout		
Ref:	127621105-003	Support Plan No:	N/A
Scale:	N/A	Figure No:	18



6.2.2 Subsidence Estimates for First Working Pillars at Depths of >80m

It was noted in **Section 8.2.1** that panel and pillar mining meets the 100mm of subsidence criterion at depths of greater than 160m associated with the plateau area located above the cliff lines. On this basis, a bord and pillar mining option has been put forward for the shallower areas, see **Figure 8**, noting that in practice a range of alternatives are available that would deliver similar (i.e. negligible) subsidence effects. In this regard, subsidence associated with bord and pillar mining has been estimated using an analytical technique.

Firstly, given that the pillars are designed to remain long-term stable, it is considered reasonable to estimate subsidence on the basis of elastic convergence for first workings. The methodology used to estimate the expected surface subsidence is based on the geomechanical properties of the strata and estimates of the average stress change using elastic theory. The predicted subsidence consists of three components, namely pillar, roof and floor compression. The equations used to determine these three components are shown below.

$$\begin{aligned}\Delta_{\text{pillar}} &= \sigma_{\text{net}} h / E_{\text{pillar}} \\ \Delta_{\text{roof}} &= \sigma_{\text{net}} w / E_{\text{roof}} \\ \Delta_{\text{floor}} &= \sigma_{\text{net}} w / E_{\text{floor}} \\ \Delta_{\text{total}} &= \Delta_{\text{pillar}} + \Delta_{\text{roof}} + \Delta_{\text{floor}}\end{aligned}$$

Where:

$$\begin{aligned}\Delta_{\text{pillar}} &= \text{pillar compression (mm)} \\ \Delta_{\text{roof}} &= \text{roof compression above pillar (mm)} \\ \Delta_{\text{floor}} &= \text{floor compression below pillar (mm)} \\ \sigma_{\text{net}} &= \text{net pillar stress increase (MPa)} \\ h &= \text{pillar height (2.8m)} \\ w &= \text{pillar width (m)} \\ E_{\text{pillar}} &= \text{Young's Modulus for coal (estimated at 2GPa)} \\ E_{\text{roof}} &= \text{Young's Modulus for immediate roof material (estimated at 7GPa)} \\ E_{\text{floor}} &= \text{Young's Modulus for immediate floor material (estimated at 5GPa)}\end{aligned}$$

Using the methodology described previously, subsidence values have been estimated for the pillars under first workings. These results are summarised in **Table 8**.

Table 8: Analytical Subsidence Estimates for First Workings (24.5m by 39.5m Solid Pillars)

Depth (m)	Vertical Virgin Stress (MPa)	Average Pillar Stress (MPa)	Stress Change (MPa)	Total Compression (mm)
50	1.2	1.7	0.5	5
100	2.5	3.5	1.0	11
150	3.7	5.2	1.5	16
250	6.2	8.7	2.5	27
300	7.5	10.5	3.0	33

The previously noted hydrogeological studies have predicted that part of the zone of first workings will be partially or fully flooded. At Clarence Colliery the impact of flooding on subsidence has been



accounted for using the above analytical technique by reducing the modulus of the roof and floor strata by half. This has been applied to the first workings at Airly and the results are summarised in Table 9.

Table 9: Analytical Subsidence Estimates for First Workings (24.5m by 39.5m Solid Pillars) with Flooding

Depth (m)	Vertical Virgin Stress (MPa)	Average Pillar Stress (MPa)	Stress Change (MPa)	Total Compression (mm)
50	1.2	1.7	0.5	10
100	2.5	3.5	1.0	21
150	3.7	5.2	1.5	31
250	6.2	8.7	2.5	52
300	7.5	10.5	3.0	63

From the above it is evident that first workings subsidence is insignificant, at less than 35mm for the areas that will not suffer flooding post-mining and typically will be less than 20mm, which historically has been regarded as the limit of measurability. In the deeper areas that may flood a post-mining subsidence level of up to about 65mm is possible. With the predicted levels of subsidence, strains will be in the range 0.2-0.5mm/m and tilts in the range 0.6-1.1mm/m. Tilts and strains have been estimated by conservatively assuming the relationships derived by **Holla (1991)**. The higher tilts and strains are associated with the areas that are predicted to flood post-mining.

6.2.3 Subsidence Estimates for the Partial Pillar Extraction Areas

In the partial pillar extraction areas using single-sided and double-sided lifting, the relatively weak roof strata at Airly means that spans will not be stable. Subsidence, tilt and strain estimates have therefore been made using the empirical technique used for the panel and pillar mining area. As with panel and pillar mining the multi-panel influence on subsidence has been accounted for by the addition of 10mm for W/H ratios of <0.4.

Empirical subsidence, tilt and strain estimates for single-sided lifting are summarised in **Table 10** and for double-sided lifting in **Table 11**.

Table 10: Empirical Subsidence, Tilt and Strain Estimates for Single-sided Lifting

Depth	Expected Subsidence mm	Upper Bound Subsidence mm	Expected Tensile Strain mm/m	Upper Bound Tensile Strain mm/m	Expected Compressive Strain mm/m	Upper Bound compressive Strain mm/m	Expected Tilt mm/m	Upper Bound Tilt mm/m
50	55	88	1.3-1.7	2.1-2.6	1.0-2.75	1.6-4.4	3.4-5.5	5.5-8.8
70	42	66	0.7-0.9	1.1-1.4	0.5-1.5	0.8-2.4	1.9-3.0	2.9-4.7
80	38	59	0.6-0.7	0.9-1.1	0.4-1.2	0.7-1.8	1.5-2.4	2.3-3.7
100	32	49	0.4-0.5	0.6-0.7	0.3-0.8	0.4-1.2	1.0-1.6	1.5-2.5
160	24	34	0.2-0.25	0.2-0.3	0.15-0.4	0.2-0.5	0.5-0.8	0.7-1.1



Table 11: Empirical Subsidence, Tilt and Strain Estimates for Double-sided Lifting

Depth	Expected Subsidence mm	Upper Bound Subsidence mm	Expected Tensile Strain mm/m	Upper Bound Tensile Strain mm/m	Expected Compressive Strain mm/m	Upper Bound compressive Strain mm/m	Expected Tilt mm/m	Upper Bound Tilt mm/m
80	56	90	0.8-1.1	1.4-1.7	0.6-1.8	1.0-2.8	2.2-3.5	3.5-5.6
100	47	74	0.6-0.7	0.9-1.1	0.4-1.2	0.7-1.9	1.5-2.4	2.3-3.7
120	41	63	0.4-0.5	0.6-0.8	0.3-0.9	0.5-1.3	1.1-1.7	1.6-2.6
160	33	50	0.25-0.3	0.4-0.5	0.2-0.5	0.3-0.8	0.6-1.0	1.0-1.6

Although subsidence levels are below the 100mm threshold over the full depth range analysed, tilt and strains exceed the threshold values at the shallower depths. **Tables 10 and 11** indicate that single sided lifting should be limited to a minimum depth of 80m in the areas not subject to post-mining flooding and 100m in areas subject to flooding. As with the panel and pillar mining zone, the upper bound estimates are assumed to capture the effect of flooding. The tables also indicate that double sided lifting should be limited to 100m in areas not subject to flooding and 120m in areas that are.

Assuming the depth range cut-offs noted above, the expected levels of subsidence associated with these are as follows:

- Single-sided lifting: 25 to 60mm.
- Double-sided lifting: 35 to 65mm

Again at the minimum depth cut-offs noted, tilts are expected to vary between 0.5 and 2.6mm/m and strains 0.2-2.5mm/m over the depth ranges envisaged. The 2.6mm/m is very slightly above the 2.5mm/m recommended but this is from an upper bound estimate, which is regarded as conservative even for areas subject to flooding.

6.2.4 Subsidence Estimates for Bord and Pillar Workings in the Shallow Zone

Using the same analytical and numerical methods noted in previous sections of the report, subsidence values have been estimated for the pillars under first workings, and pillar splitting and quartering. The expected depth range of this mining zone is 30m to 80m in areas that are not predicted to flood post-mining and up to 100m in areas that are predicted to flood. These results are summarised in **Tables 12 and 13**.

Table 12: Analytical Subsidence Estimates in Non Flooded Areas

Depth (m)	Subsidence (mm)	
	First Workings	Pillar Splitting and Quartering
30	3.5	4.5
50	6.0	7.5
80	9.0	11.5



Table 13: LaModel Subsidence Estimates in Non Flooded Areas

Depth (m)	Subsidence (mm)	
	First Workings	Pillar Splitting and Quartering
30	1.0	1.0
50	2.0	2.0
80	4.0	4.5

The subsidence estimates from the numerical modelling are again lower than those obtained by the analytical approach but both consistently show very low values of subsidence that would be well outside of the resolution of conventional subsidence measurements.

The hydrogeological studies predict that flooding or partial flooding within the shallow zone could occur in the Gap Creek area. The possible impact of this on subsidence has been estimated assuming that the modulus of the roof and floor are reduced to half their value. The predicted results of the subsidence post-flooding for the analytical technique are summarised in **Table 14**.

Table 14: Analytical Subsidence Estimates Post-flooding

Depth (m)	Subsidence (mm)	
	First Workings	Pillar Splitting and Quartering
30	6.5	7.5
50	11.0	12.5
80	17.0	20.5
100	21.0	25.5

Overall, the expected levels of subsidence associated with these shallow bord and pillar scenarios are as follows:

- First workings: <22mm.
- Pillar splitting and quartering: <26 mm.

The strains associated with these bord and pillar scenarios are predicted to vary between 0.1 and 0.6 mm/m and the tilts between 0.6 and 1.3 mm/m (conservatively assuming the relationships developed by **Holla,1991**). Again the higher values are associated with areas that are predicted to flood post-mining.

6.2.5 Multi-seam Subsidence Associated with the Old Oil Shale Workings

The oil shale (torbanite) workings located at the northern end of the Mount Airly plateau are shown in **Figure 18**. As can be seen, the oil shale workings extend under the cliff lines and the depth of the Lithgow Seam in the area affected varies widely between about 60m and 280m.

A report by **Lishmund (1974)** identified the oil shale deposit as a torbanite horizon located some 30m above the Marrangaroo Conglomerate, which is the floor of the Lithgow Seam. This implies



that the torbanite band is located around 25m above the roof of the Lithgow Seam. The mining method was a form of hand worked, advancing longwall. The equivalents of gate roads were driven, the thick blue lines shown in **Figure 19**, probably to a height of about 1.8m.

Production drives, the thin blue lines in **Figure 19**, were then driven to allow skips to be wheeled. The shale was then mined from either side of the production drive to the height of the oil shale bed. References suggest that the shale bed thickness varied from 0.3m to 1.4m in thickness, averaging 0.7m to 0.8m and that waste rock was packed alongside the drives. Given the above, an average extraction height of 0.8m has been assumed. Furthermore, although not shown on the mine plan, it is considered almost certain that some pillars will have been left through necessity for the protection of workers, so overall it is considered unlikely that the extraction ratio in the mine would have exceeded 75%.

The above said, the workings are considered sufficiently extensive to be super-critical in width in certain areas. If, as is likely, there are however remnant pillars within these super-critical areas, this will reduce subsidence. In such a situation the predicted subsidence can be determined by calculating an effective mining height by multiplying the actual mining height by the percentage extraction (**Holla, 1991**). Assuming a percentage extraction of 75% (this is merely an estimation given the lack of information) then this would equate to an effective average mining height of 0.6m. That being the case, the work by **Holla (1991)** suggests that maximum subsidence in the super-critical areas would be of the order of 390mm due to the old oil shale workings.

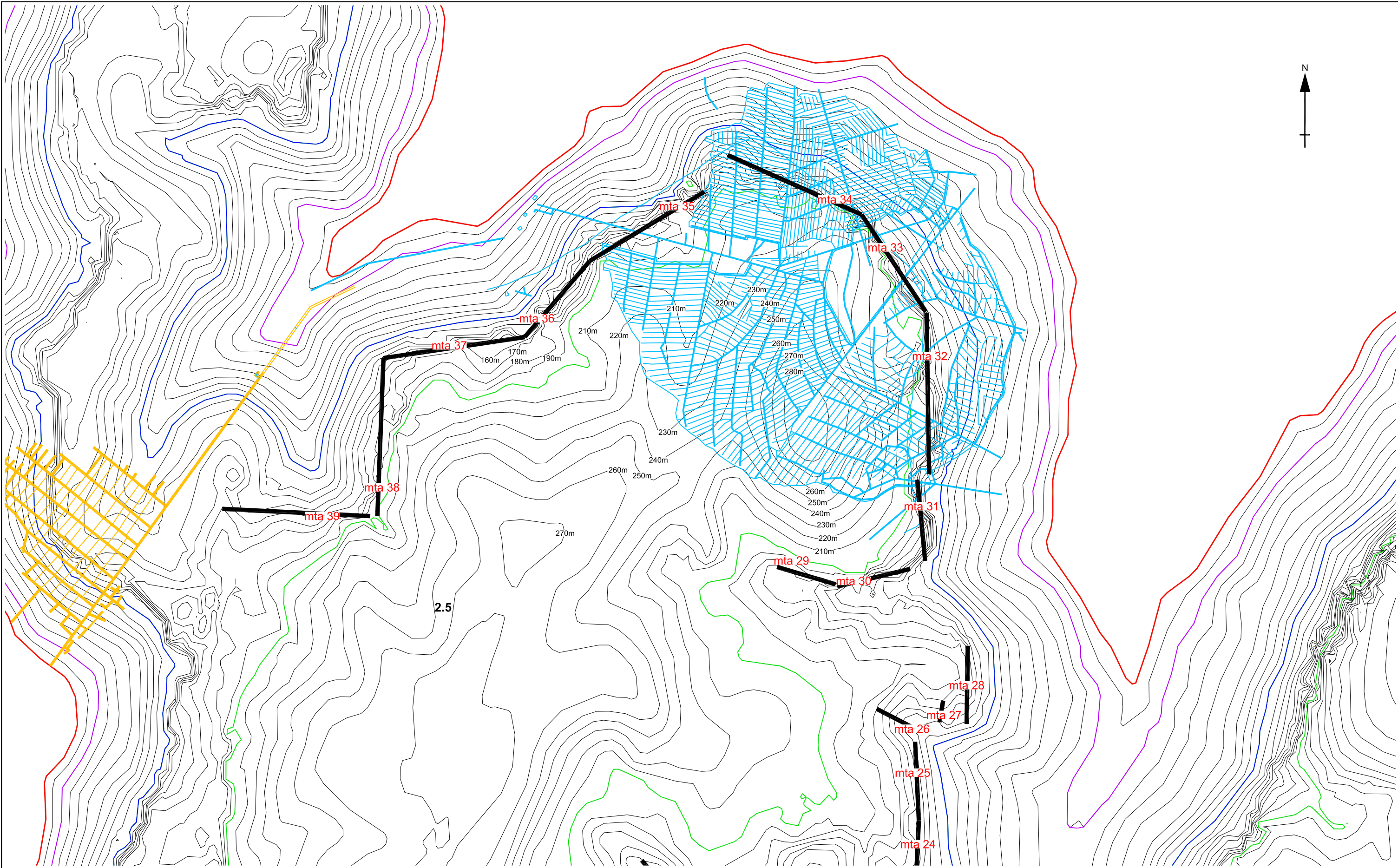
Applying the Holla 'K' factors over the depth range of 150m to 250m relevant to the oil shale workings and the plateau area above the cliff lines, suggests the following associated strains and tilts in the super-critical areas:

- Tensile strain: typically 3mm/m (ranging from 2 to 4mm/m).
- Compressive strain: typically 4 mm/m (ranging from 2 to 7mm/m).
- Tilts: typically 10 mm/m (ranging from 5 to 13mm/m).

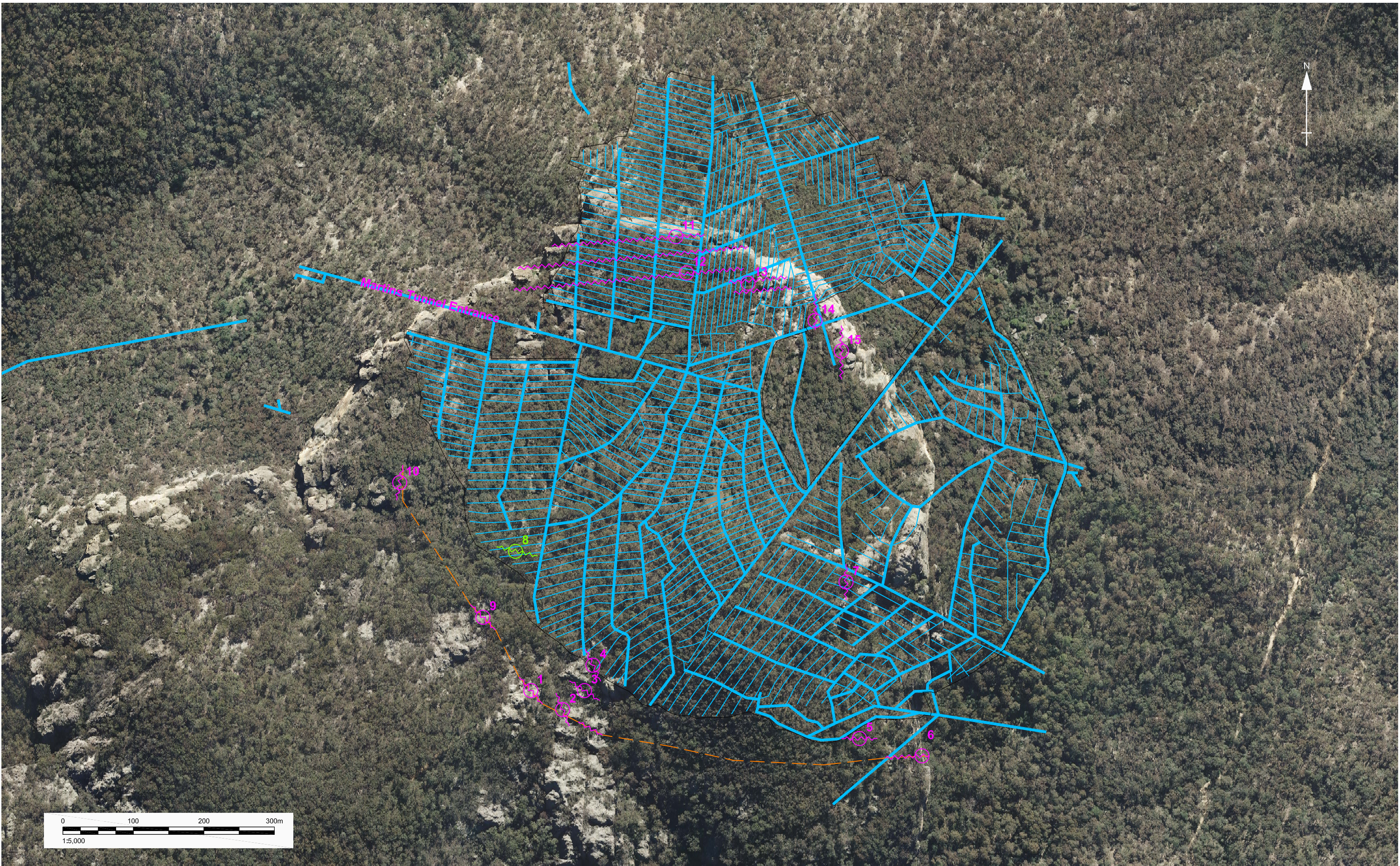
These strains are considered sufficient to initiate surface cracking. Furthermore, recent mapping indicates that the strains at the cliff faces are greater than 10mm/m as these cliff faces are extensively damaged (**Golder, 2013**).

The above said, a surface inspection to assess the current condition of the plateau area and cliff line crests above the old oil shale workings, identified three distinct zones of mining induced damage, namely:

- A significant and persistent tension crack (up to 80mm wide) located 50 to 80m horizontally from the southern edge of the old workings (see **Figures 20 and 21**).
- Significant mining induced cracking and joint dilation within approximately 40 to 70m of the cliff line crests (see **Figures 20 and 22**).
- Importantly, with the exception of the area adjacent to the "Martins tunnel entrance", see **Figure 20**, there is no clear evidence of significant remnant pillars.



Key: - New Hartley Shale Mine old workings production drive ~1.3m height - New Hartley Shale Mine old workings roadways ~2m height - Depth of Cover contour - 0m Depth of Cover contour - 20m Depth of Cover contour - 100m Depth of Cover contour - 200m Depth of Cover contour - Torbane Colliery Lithgow Seam old workings - Cliff line no.	Golder Associates	Engineer: D. Hill	Client: Airly Mine			
		Drawn: B. Richardson	Title: Location of New Hartley Shale Mine Workings and Neighbouring Cliff Line Areas			
		Date: 19.08.13				
		GOLDER ASSOCIATES PTY. LTD. www.golder.com			Ref: 127621105-003	Support Plan No: N/A
					Scale: NTS	Figure No: 19



Key: - New Hartley Shale Mine old workings production drive ~1.3m height - New Hartley Shale Mine old workings roadways ~2m height - Significant subsidence cracks - Photograph locations - Inferred tension cracks - Minor subsidence cracks	Golder Associates	Engineer: M. MacKinnon	Client: Airly Mine			
		Drawn: B. Richardson	Title: Aerial Photograph Showing New Hartley Shale Mine Workings and Surface Features			
		Date: 19.08.13				
		GOLDER ASSOCIATES PTY. LTD. www.golder.com		Ref: 127621105-003	Support Plan No:	N/A
				Scale: NTS	Figure No:	20



Photo: 2151 - Area 1



Photo: 2148 - Area 1



Photo: 2224 - Area 9



Engineer:	M. MacKinnon	Client:	Airly Mine		
Drawn:	B. Richardson	Title:	Surface Photographs from Area 1 and Area 9 Shown in Figure 19		
Date:	19.07.13				
GOLDER ASSOCIATES PTY. LTD. www.golder.com					
		Ref:	127621105-003	Support Plan No:	N/A
		Scale:	N/A	Figure No:	21



Photo: 2235 - Area 12



Photo: 2256 - Area 13



Photo: 2274 - Area 15



Photo: 2294 - Area 15

		Engineer:	M. MacKinnon	Client:	Airly Mine			
		Drawn:	B. Richardson	Title:	Surface Photographs from Area 12, Area 13 and Area 15			
		Date:	19.08.13		Shown in Figure 19			
		GOLDER ASSOCIATES			Ref:	127621105-003	Support Plan No:	N/A
		PTY. LTD.			Scale:	N/A	Figure No:	22
		www.golder.com						



- Generally very limited fracturing (i.e. fractures typically limited to hairline fractures <5mm wide) and no noticeable subsidence depression above the central areas of the shale mine, noting in this area that the minimal rock outcrop and dense vegetation was a limiting factor (see **Figures 20 and 23**).

In order to assess the levels of subsidence that might be associated with extracting the Lithgow Seam beneath the old oil shale workings, a numerical analysis was conducted, again using LaModel. The oil shale workings were represented by a continuous goaf (i.e., full extraction) and the panel and pillar layout was mined beneath at an interburden distance of 25m. At representative depths of 200m to 280m in the Lithgow Seam, cumulative subsidence of 0.6m to 0.7m was calculated, with over 90% of the subsidence reporting after extraction of the upper oil shale horizon, see **Figure 24**. The main weaknesses however of this modelling are that it cannot represent layers with different material properties and it lacks calibration to a reasonable precedent; indeed there is no known precedent for the situation at Airly.

Further to the above, the spanning ability of the Triassic sandstone discussed previously, subsidence in some areas containing pillars could have been limited to well below the 390mm predicted; i.e. there may be areas bounded by remnant pillars where the associated spans are sub-critical. Given the estimated interburden distance, undermining of the workings with panel and pillar mining and partial pillar extraction could however lead to a pillar collapse in the oil shale workings because (as will be highlighted in **Section 7.2.5**) the sub-surface fractured zone located above these panels will intersect the old oil shale workings. This could lead to the fracturing of any remnant pillars and a reactivation of subsidence in the old workings in both the super-critical and (should they exist) sub-critical areas. In such a situation, new subsidence levels well above 100mm are therefore considered possible.

In regard to the assumed sub-critical areas, whilst subsidence may have been limited to below 100mm, with undermining and subsequent pillar collapse, these areas may then be transformed into super-critical areas. In such a situation the effective mining height can be assumed to be the actual mining height with total subsidence from the old shale workings then predicted to be about 520mm. Assuming that the LaModel trends are correct and multi-seam subsidence effects in such a situation is only the addition of the subsidence in the old workings and the subsidence in the Lithgow Seam due to panel and pillar mining (noting again that no precedent exists to validate this result), then total multi-seam subsidence would be of the order of about 600mm. If 100mm of subsidence only had occurred previously in sub-critical areas due to the old shale workings, then this means up to 500mm of new subsidence could end up being related to the proposed panel and pillar mining.

A similar argument could be applied in those areas where the old shale workings are deemed super-critical whereby the effective mining height would be increased to the actual mining height due to the undermining of the remnant pillars, resulting in total multi-seam subsidence of about 600mm and therefore new additional subsidence of about 200mm.

Obviously the above subsidence predictions due to panel mining below the old shale workings are basic estimates given the paucity of information regarding the actual mining situation in the old workings and the lack of precedent of multi-seam mining relating to undermining by narrow panels. Nevertheless, unless it can be proven that no significant remnant pillars exist in the old shale workings and no sub-critical areas exist due to the Triassic sandstone bridging across such remnant pillars, there is potential for levels of new subsidence greater than 100mm. If that were the case, subsidence impacts would include additional surface cracking and continued dilation of existing fractures above the interaction area. In order to prevent further damage to the cliff lines,



Photo: 2215 - Area 8



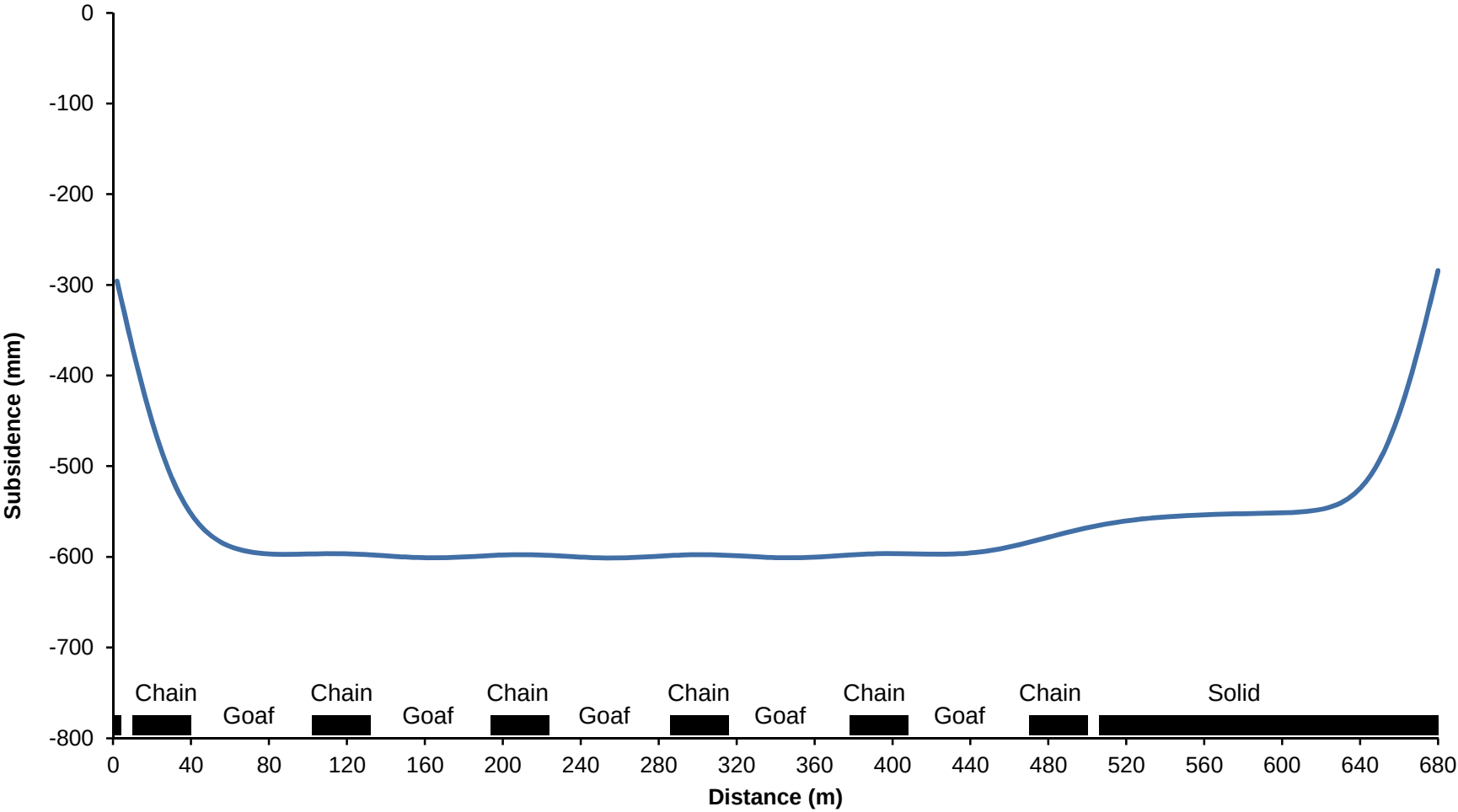
Photo: 2217 - Area 8



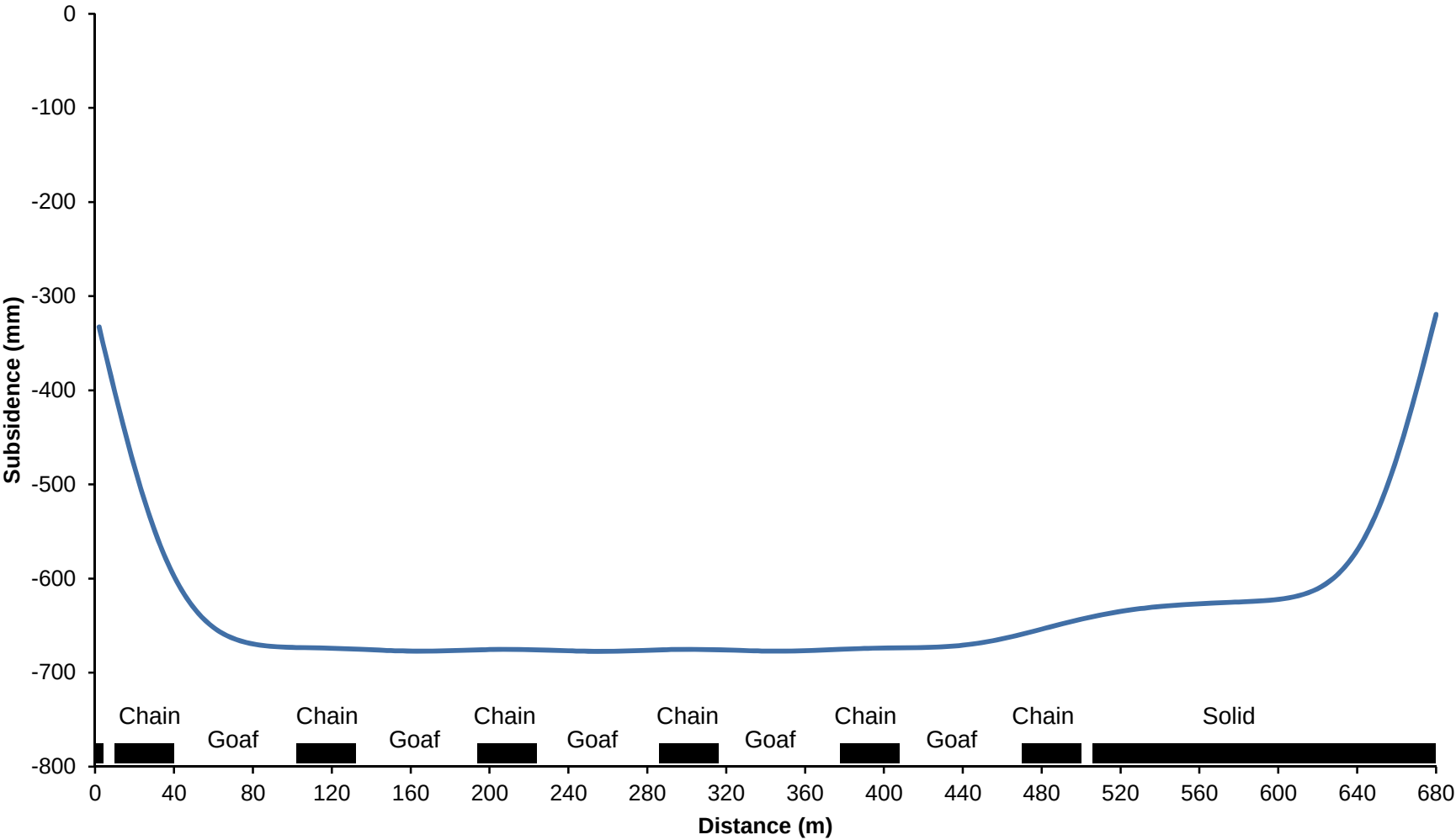
Photo: 2220 - Area 8

		Engineer:	M. MacKinnon	Client:	Airly Mine			
		Drawn:	B. Richardson	Title:	Surface Photographs from Area 8 Shown in Figure 19			
		Date:	19.08.13					
		GOLDER ASSOCIATES						
		PTY. LTD.						
		www.golder.com		Ref:	127621105-003	Support Plan No:	N/A	
				Scale:	N/A	Figure No:	23	

(i) LaModel Output at a Depth of 200m



(ii) LaModel Output at a Depth of 280m



Engineer:	D. Hill	Client:	Airly Mine		
Drawn:	B. Richardson	Title:	LaModel Numerical Output of Subsidence in the Area of Interaction between the New Hartley Shale Mine Workings and Panel and Pillar Mining Proposed in Airly Mine		
Date:	19.08.13	Ref:	127621105-003	Support Plan No:	N/A
GOLDER ASSOCIATES PTY. LTD. www.golder.com		Scale:	N/A	Figure No:	24



the use of increased setback distances for the panel and pillar mining defined by half the depth to the Lithgow Seam is therefore recommended for the interaction area, accepting that this area has already been significantly damaged by the oil shale mining (i.e. rock falls have occurred over approximately 80% of the relevant cliff face area).

Accordingly, in the cliff line area and below the cliff lines, first workings only should be adopted. This recommendation is based upon the current estimate of the interburden distance, in addition to the assumption that there are remnant pillars in the oil shale workings.

6.2.6 Sub-surface Fracturing

The strata above an extracted area that forms the goaf is made of a number of zones. The first is the “Caved Zone”, which comprises loose blocks of detached rock occupying the cavity due to mining. As presented in the Forster and Enever model presented in **Figure 25**, this zone typically extends to a height above the seam of 5 to 10 times the extraction height, or up to a height of 14 to 28m in the case of Airly.

Above this is the “Fractured Zone”, in which the rock sags, with significant bending, fracturing, joint dilation and bed separation. The Forster and Enever model presented in Figure 24 suggests that the combined height of the caved and fractured zones could extend to a height of between 59 and 93. Within the combined caved and fractured zone, large increases in bulk permeability would be expected. **MSEC (2005)** concluded that the height of the combined caved plus fractured zone can be delineated by an “Angle of Break” from the abutments over the extraction area. From a literature review, typical Angles of Break of between 17° and 23° were proposed. For the 61m void width proposed for the panel and pillar layout, this equates to a fractured zone height of 72 to 100m.

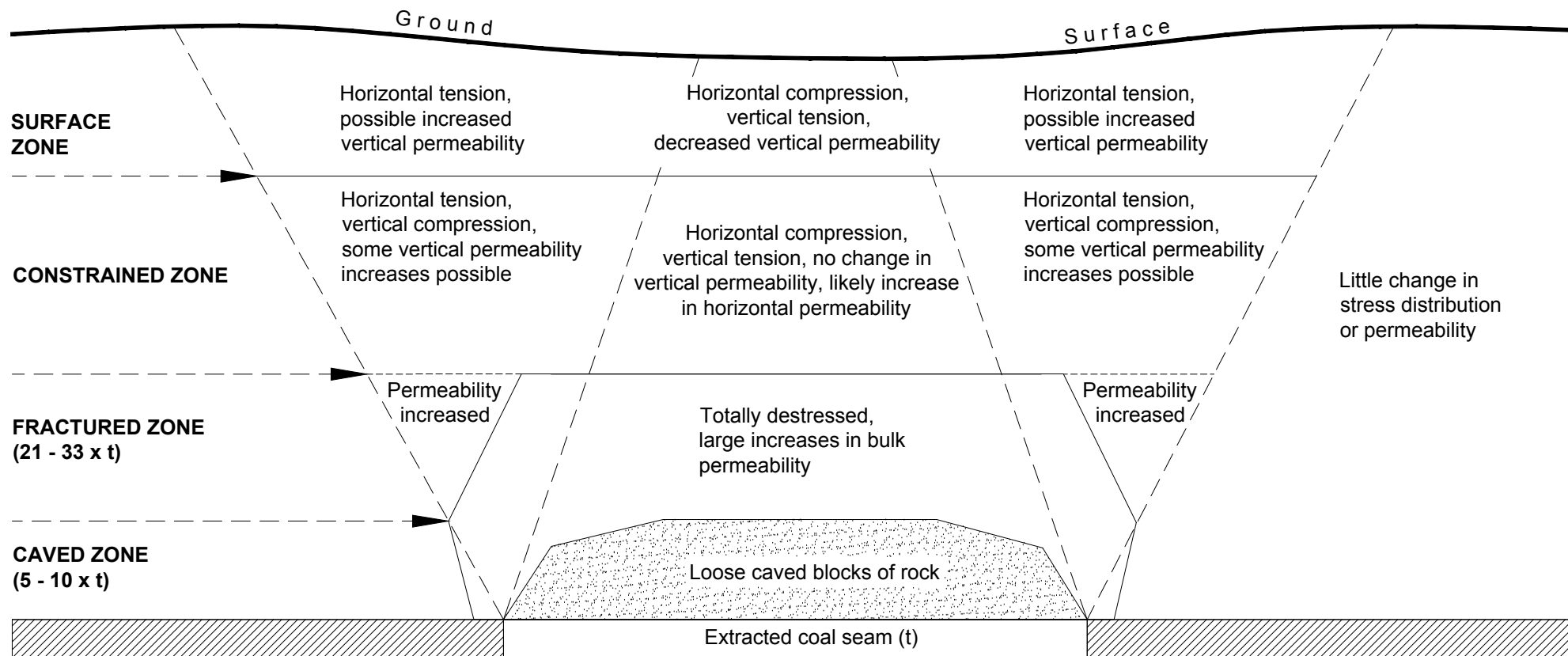
Accepting that the Forster and Enever model was derived from data collected solely from the Newcastle Coalfield, it is nonetheless of note that this range approximates that determined using the MSEC method.

Furthermore, finite element modelling by **Follington and Isaac (1990)** suggested failure zone heights of around 63% of the panel width, which in the Airly case equates to a height of 38m. They also found that for panel widths of 40m to 80m, the failure height ranged between 10 and 18 times the mining height, which in the Airly case equates to a range of 28m to 50m. A failure height of 50m approximates to the lower end of the range suggested using the **Forster and Enever** approach and is considered credible for limited panel spans.

Therefore given:

- the technical outcomes above,
- the adoption of the partial extraction system of mining with limited spans,
- the average thickness of the Permian of 105m,
- the planned working depth of greater than 160m for panel and pillar mining and
- the spanning capability of the Triassic sandstone,

the likely outcome is a fractured zone height approximately equal to the panel width, or 60m to 70m in the case of panel and pillar mining, meaning that sub-surface fracturing will be in most cases limited to the Permian and will not extend as far as the Triassic Sandstone.



Engineer: D. Hill

Drawn: B. Richardson

Date: 24.07.13

**GOLDER ASSOCIATES
PTY. LTD.
www.golder.com**

Client: Airly Mine

Title: Hydrogeological Model above an Extraction Panel
(adapted from Forster and Enever, 1992)

Ref: 127621105-003

Scale: NTS

Support Plan No: N/A

Figure No: 25



A similar logic can also be used to estimate the much more limited fractured zone heights that would be associated with partial pillar extraction mining. The following comments are made in this regard:

- i) For first workings and where pillar splitting and quartering is to be practiced, spans are typically $\leq 6\text{m}$ in roadways and up to 12m in intersections. Experiences with roof falls indicate that heights of greater than 5m in headings and 8m in intersections are rare and overall, fractured zone heights are likely to be typically less than 10m.
- ii) For partial pillar extraction, spans vary between 15.5m and 25.5m. The **MSEC** approach suggests fractured zone heights of 18 to 42m. The **Follington and Isaac** modelling approach suggests fractured zone heights of 10m to 28m. Overall, fractured zone heights are therefore expected to typically range from 20m to 40m.

The abovementioned heights of fracturing have potential implications for any remnant pillars in the old oil shale workings as has been discussed in the previous sub-section. These can be summarised as follows:

- i) For first workings and pillar splitting and quartering, the height of fracturing will not intersect the old shale workings and there will be no damage to any remnant pillars.
- ii) Should partial pillar extraction or panel and pillar mining be adopted in the interaction area, this would mean that the fractured zone would almost certainly impact adversely on the stability of any remnant pillars in the oil shale workings at the expected interburden distances. This could therefore lead to a reactivation of subsidence as discussed in the previous sub-section.

Lastly, above the fractured zone is a “constrained zone”, in which the strata are subject to bending, but without failing. Accepting that this can result in an increase in horizontal permeability if bed separation occurs, a significant increase in vertical permeability is deemed unlikely given the predominance of sandstone in this zone and the limited strains predicted. That said, it is assessed that this zone is likely to form an effective barrier to vertical drainage and prevent hydraulic connection between the surface and the mine opening.

6.2.7 Unconventional Subsidence

Unconventional (or “non-systematic”) subsidence effects, such as upsidence, valley closure and far-field horizontal displacements are generally ascribed to strains associated with large scale redistributions of horizontal stress due to longwall mining. These effects are generally most pronounced in high horizontal stress environments, with many of the known examples accordingly pertaining to the Southern Coalfield (**ACARP, 2002**).

The Airly situation differs from this in two key respects:

- i) The Depth of Cover is a maximum of 280m under Mount Airly, increasing to 310m under Genowlan Point. As discussed, given the topography and the associated potential for horizontal stress relief, it is considered likely that the maximum value of the major horizontal stress would be around 12 to 13MPa. These depths and associated stress levels are low in comparison to those associated with the longwall mines in the Southern and Western coalfields (e.g. greater than 40MPa at Tower Colliery in the Southern Coalfield).



- ii) The Airly partial extraction concept with limited spans and long-term stable pillars is expected to have a relatively minor impact on the distribution of horizontal stress within the overburden in comparison to an extensive longwall operation. Accordingly, concentrations of horizontal stress in the upper overburden (i.e. near surface) are expected to be very limited.

Further to the above, there is no known incident related to unconventional subsidence effects associated with a partial extraction operation. However, accepting that there is little useful precedent, it is nonetheless of note that the Clarence Colliery layout involves negligible caving and that the partial extraction operation at Clarence Colliery has not experienced any appreciable impact that can be attributed to unconventional subsidence.

Reference to the methodologies provided in **ACARP (2002)** suggests the following levels of unconventional subsidence for the Airly panel and pillar layout, assuming typically 50mm to 70mm of vertical subsidence:

- Valley closure of 90mm to 130mm (from **Section 12.1** of the **ACARP 2002** report).
- Upsidence of 20mm to 25mm (from **Section 12.2** of the **ACARP 2002** report).

These values are considered to greatly over-state the likely outcomes at Airly. Nonetheless, the upsidence values appear to be significantly below those associated with buckling and cracking of valley floor rocks (e.g. greater than 300mm in the case of Tower LW14 and the Cataract Gorge, **ACARP 2001**). The abovementioned valley closure figures are therefore deemed incidental in the absence of any surface infrastructure that might be impacted.

Furthermore, as the incised valleys and gorges at Airly are largely associated with cliff lines, a conservative strategy of first workings only is proposed in the vicinity of the great majority of these cliff lines, which by implication means that there will be negligible conventional or unconventional subsidence. However, where panel and pillar mining is planned to cross the upper reaches of incised valleys, it is suggested that a strategy for monitoring stream flow and floor conditions be devised where access is possible and noting that the sections of the streams involved are understood to be ephemeral.

An additional unconventional subsidence effect is far-field horizontal displacement, which again has been attributed largely to the re-distribution of horizontal stress due to extensive longwall mining. Significant displacements (typically 30 to 80mm) have been recorded at sites in the Southern Coalfield, where concern previously arose regarding the potential impacts on infrastructure at gorges (e.g. bridges).

Given therefore:

- the absence of significant infrastructure within the Airly project area,
- that these displacements tend to occur *en masse*, as opposed to generating appreciable relative movements within the rock mass,
- that the steep topography represents a free face for any movement,
- the adoption of a partial extraction layout and
- the moderate horizontal stress environment at Airly,

any such movements at Airly are considered to be negligibly small and insignificant in terms of impact.



Further to the above accepting that, it is possible that additional (i.e. to that already experienced) vertical subsidence in the area of the old shale workings may be higher than that experienced elsewhere, however, a setback distance of half the depth between panel and pillar or partial pillar extraction workings in the Lithgow Seam and the cliff lines will limit the magnitude of contemporaneous valley closure or to negligibly small values in the area of the old shale workings.

There have been instances where faulting has resulted in a transfer of subsidence further than predicted. Angles of draw for the narrow spans being proposed at Airly will be negative to low. For example, commonly at Clarence there is no external angle of draw (**Golder Associates, 2013**). At the spans being planned for Airly the risk of a far field transfer of subsidence through faulting or any other geological feature is regarded as negligible.



7.0 MINING ZONES

Based on the design of the mining system and the subsidence estimations, the project area has been divided into five unique and distinct mining zones, each representing a specific geotechnical environment. The mining system for each of these mining zones was designed to address the specific geotechnical issues and the associated subsidence effects. These mining zones are shown in **Figure 26** and listed as follows:

- i) Cliff Line Zone and Zone of First Workings
- ii) Panel and Pillar Mining Zone
- iii) Partial Pillar Extraction Zone
- iv) Shallow Zone
- v) New Hartley Shale Mine Potential Interaction Zone

The above zones are addressed in turn.

7.1 Cliff Line Zone and Zone of First Workings

The features of the cliffs that characterise the plateaus in the project area and the potential impacts of mining thereon were addressed in **Golder (2013)**. Cliff lines were defined as being at least 20m in height and having slope angles of greater than 2:1. The tolerance of the cliff lines and associated landforms in the study area to subsidence was assessed using the methodology developed by Waddington Kay and Associates and presented in **ACARP (2002)**. The methodology has been used successfully for assessing the potential impacts due to partial extraction at Clarence Colliery since 2005.

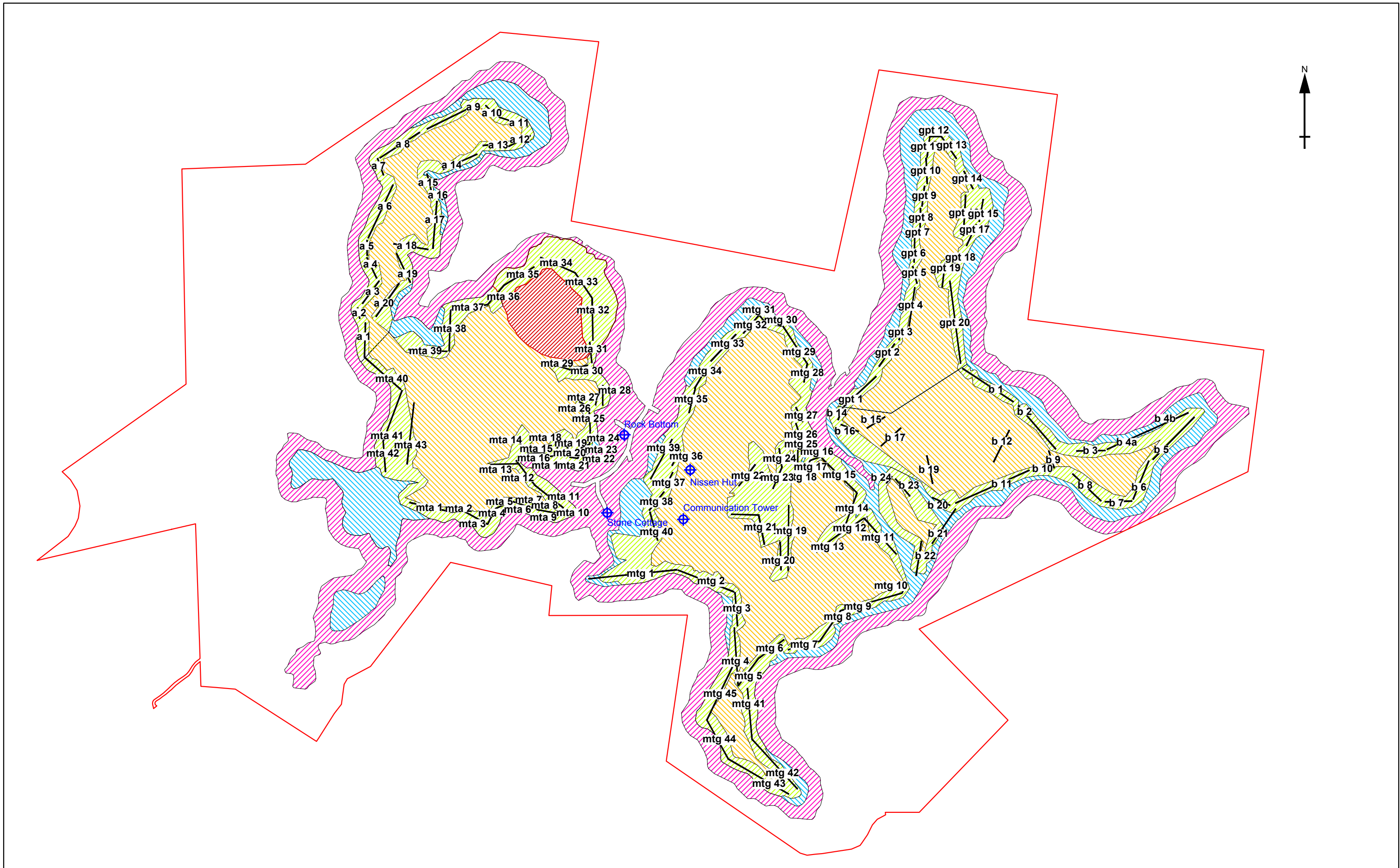
The methodology provides a framework for the categorisation of cliffs according to the following groups of criteria:

- Extent of mining-induced ground movements.
- Aesthetic quality and degree of public exposure / access.
- Natural instability of the cliff formation.

The cliffs vary in height across the project area from typically 40 to 50m in the west at Mount Airly to an average of 100m at Genowlan Point. Pagodas and/or slender spires up to 10m high are present along approximately 50% to 60% of the crest length. Cliff line development is controlled by two very widely spaced, sub-vertical, persistent, orthogonal joint sets. The strike of the first set ranges from 340° to 360° (i.e. NNW to N) and the second from 050° to 080° (i.e. NE to ENE).

Figure 27 and **Figure 28** are examples of typical cliff lines in the Airly project area.

The cliffs are comprised of moderate to high strength, fine to coarse grained sandstone, with occasional low strength mudstone beds up to 1m thick. The mudstone bed spacing varies between 10m and 40m down the cliff faces. The 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 typically up to 2m deep. The cliff crests slope at 45° to 60° on the pagodas;



Key: Panel and pillar mining zone Cliff line zone and zone of first workings Partial pillar extraction zone Shallow zone New Hartley Shale Mine potential interaction zone mta 1 Cliff line no. Project application area ⊕ x Nissen Hut, Communication Tower, Rock Bottom and Stone Cottage		Golder Associates	Engineer:	D. Hill	Client:	Airly Mine			
			Drawn:	B. Richardson	Title:	Proposed Mining Zones in Airly Mine, Associated Cliff Line No.s and Location of Nissen Hut, Communication Tower, Rock Bottom and Stone Cottage			
			Date:	30.06.14					
			GOLDER ASSOCIATES PTY. LTD. www.golder.com			Ref:	127621105-003	Support Plan No:	N/A
						Scale:	NTS	Figure No:	26



Engineer: M.MacKinnon

Drawn: I.Meek

Date: 19.08.13

GOLDER ASSOCIATES
PTY. LTD.
www.golder.com

Client: Airly Mine

Title: Photograph of Typical Cliff Line from Airly Project Area
(Photo No.: MG_1905)

Ref: 127621105-003-R

Scale: N/A

Support Plan No: N/A

Figure No: 27



Engineer: M.MacKinnon

Drawn: I.Meek

Date: 19.08.13

GOLDER ASSOCIATES
PTY. LTD.
www.golder.com

Client: Airly Mine

Title: Photograph of Typical Cliff Line from Airly Project Area
(Photo No.: MG_2445)

Ref: 127621105-003-R

Scale: N/A

Support Plan No: N/A

Figure No: 28



pronounced notches and recesses are associated with the development of spires and columns. The cliffs are shear at 80° to 90° on the main faces.

Due to preferential weathering of the mudstone beds, iron induration and iron leaching of the sandstone beds, mid-face caves / hollows estimated at up to 4m deep have formed on a number of the cliff lines. Prominent joint and bedding controlled overhangs have also occasionally developed; the major overhangs are estimated at up to 8m deep and 20m long. Although many of the cliffs are visually superb, they are generally difficult to access, due in part to the presence of large, highly vegetated talus slopes at angles of typically 20° to 30° from the horizontal and commonly of the order of 90m high.

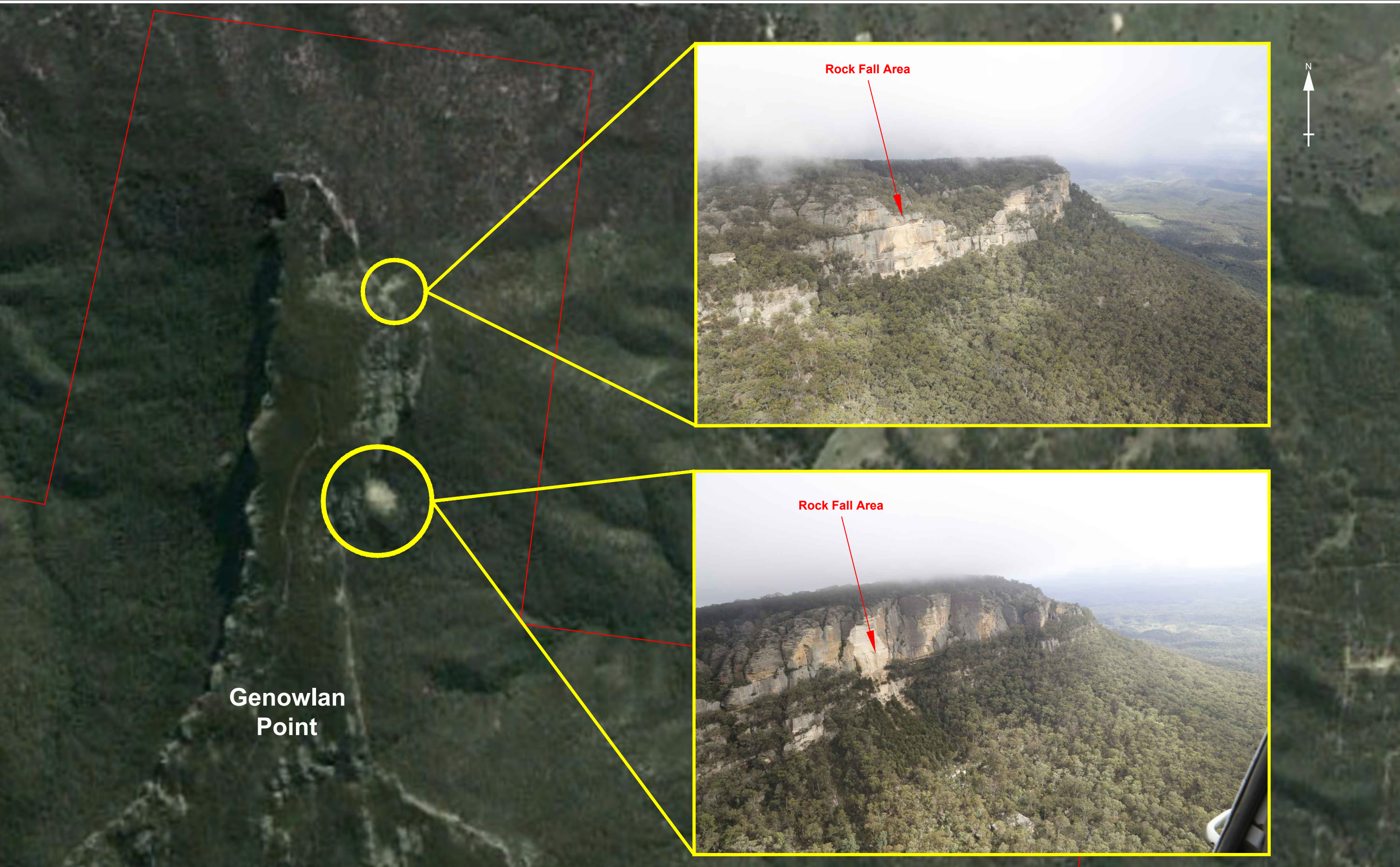
The key issue regarding potential cliff behaviour relates to the fact that many of the cliffs have overall impact assessment ratings of high to extremely high, driven largely by the aesthetic value and natural instability components of the adopted assessment process. The question is the response of typically large, relatively sensitive cliffs to very small movements and in this regard, it is of note that aerial photographs indicate that across the resource area as a whole, three major natural cliff collapses have occurred in recent years (see **Figure 29 and 30**). Accepting that these falls are less obvious in the 2010 imagery, because the skree material has become overgrown, a more recent fall is apparent at the northern end of Genowlan Mountain (see **Figure 30**). Photographs taken from the 2013 helicopter survey depicting these fall areas are also included in the associated figures.

A previous study of cliff falls elsewhere in the NSW coalfields associated with total extraction mining found that (**ACARP 2001**):

- i) The majority (88%) of cliff falls were associated with surface cracking on the plateau areas above the cliffs.
- ii) The great majority of falls occurred when the cliff face was directly undermined to a maximum distance equivalent to half the panel width and only a small percentage (4%) of falls occurred over un-mined coal.
- iii) The proportion of the cliffs damaged increased with the extent of mining and associated subsidence. Cliff line damage was negligible for highly sub-critical panels with limited subsidence (i.e. at a panel W/H ratio of 0.25, similar to the typical value for the Airly panel and pillar layout, see **Figure 31**).

Therefore, on the basis of the above, the strategy adopted by Airly Mine is to limit panel and pillar mining largely to the plateau areas above the cliff faces and to restrict mining to first workings only at the cliff faces. The area of first workings about the cliff faces being defined on the basis of a setback or offset distance of 30m from both the crest and base of the cliffs, 30m approximating to half the panel width and being also consistent with Angles of Draw of less than 8° for the panel and pillar partial extraction system, see **Figure 32**. An exception to this is in the vicinity of the old shale workings where the cliff lines have already been damaged and as such, it is considered that a more conservative approach should be used in this area and a stand-off distance of half the mining depth is considered more appropriate.

Overall, restricting mining to first workings in the cliff line zone is expected to reduce the impact to between “low” and “insignificant” according to the methodology outlined in **ACARP (2002)**, such that the expected damage is reduced to theoretically less than 10% of the expected cliff i.e., according to the rock fall incidence graph provided by this methodology, see **Figure 33**. Practically, given the favourable outcomes with respect to both first workings and partial extraction elsewhere,

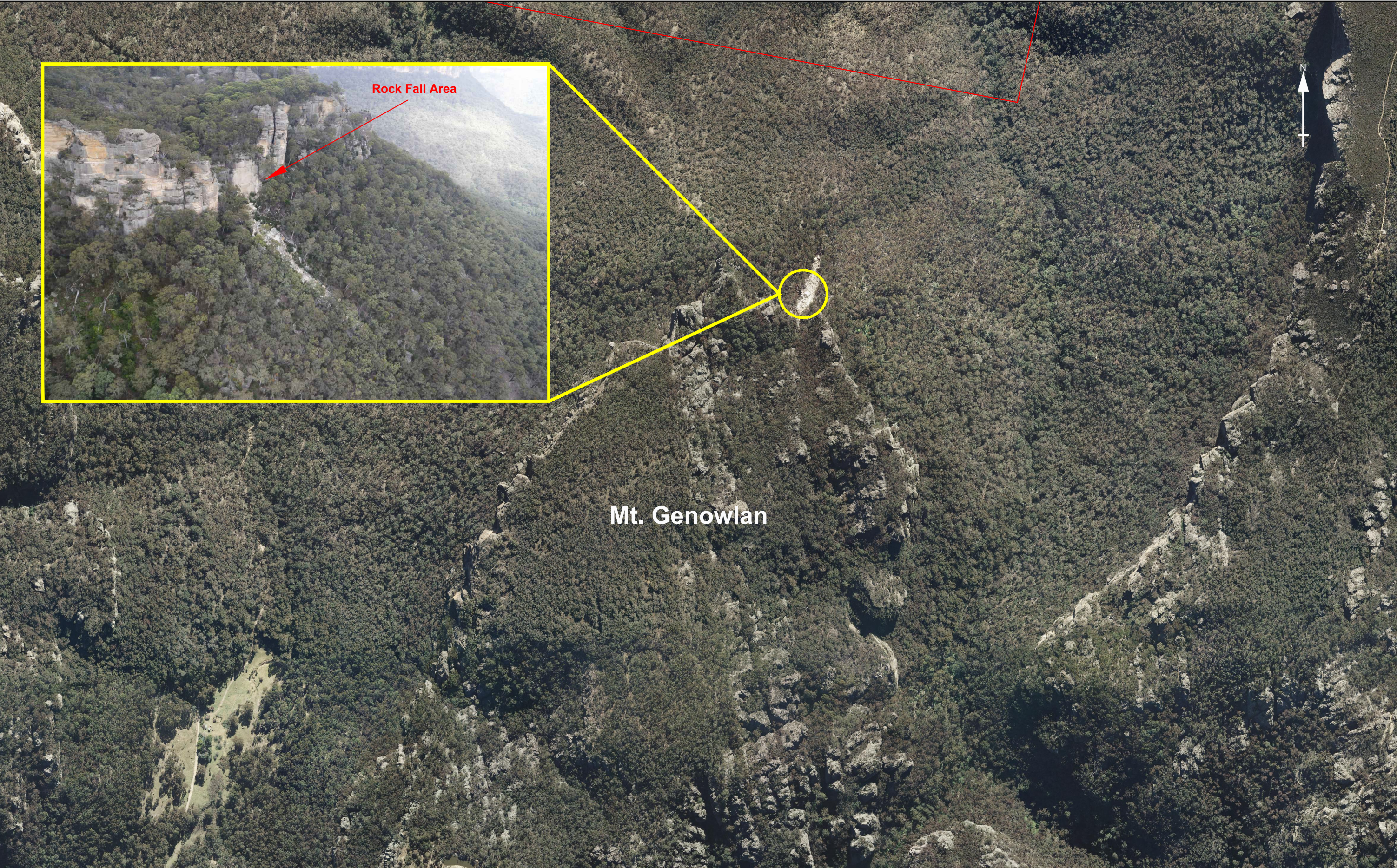


Key:

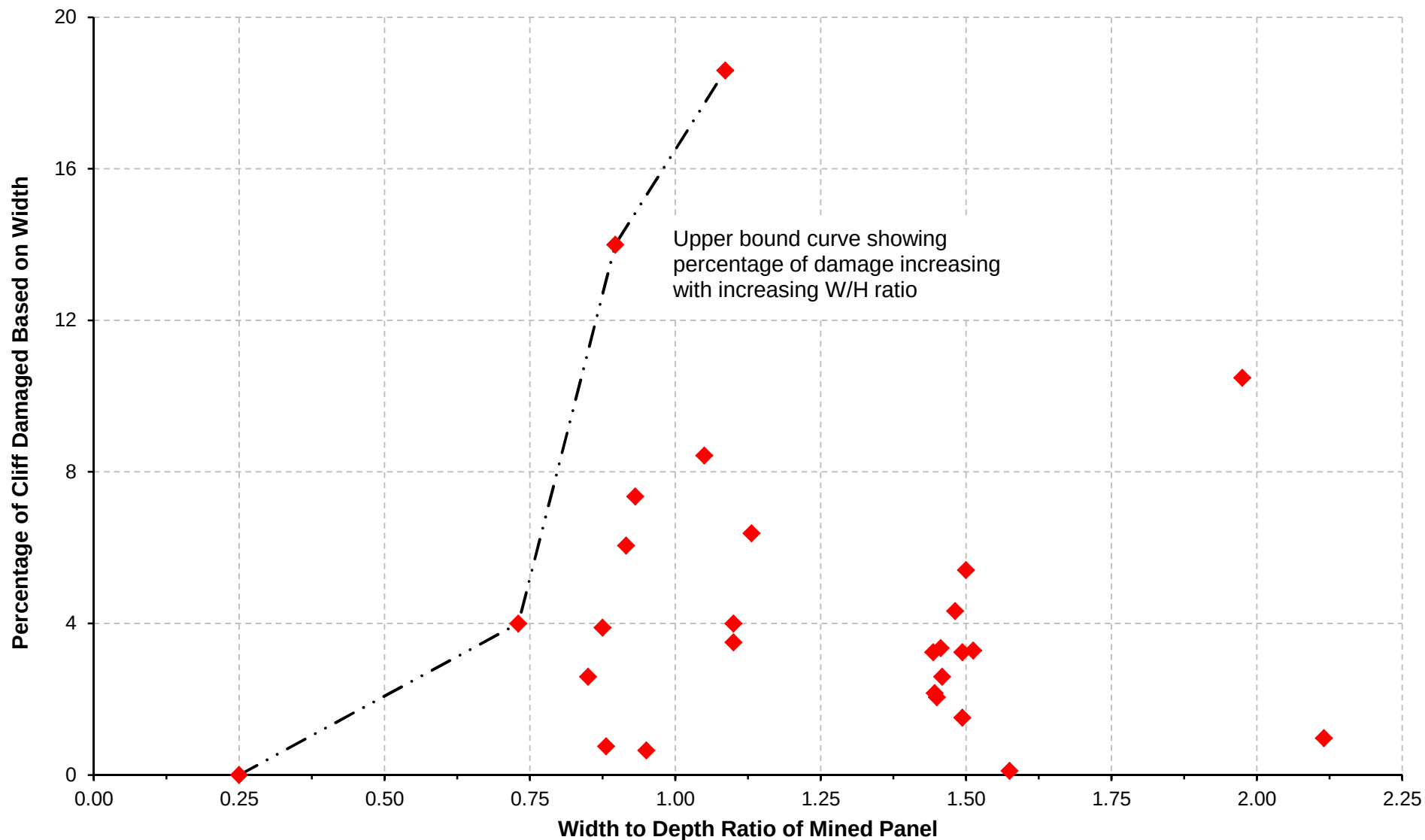
-  - Significant natural rock fall
-  - Project application area



Engineer:	M. MacKinnon	Client:	Airly Mine		
Drawn:	I.Meek	Title:	Areas of Interest and Natural Rock Falls Using Google Earth Imagery from 2006 and Cliff Line Photographs from 2013 Helicopter Survey		
Date:	19.08.2013	Ref:	127621105-003	Support Plan No:	N/A
GOLDER ASSOCIATES PTY. LTD. www.golder.com		Scale:	NTS	Figure No:	29



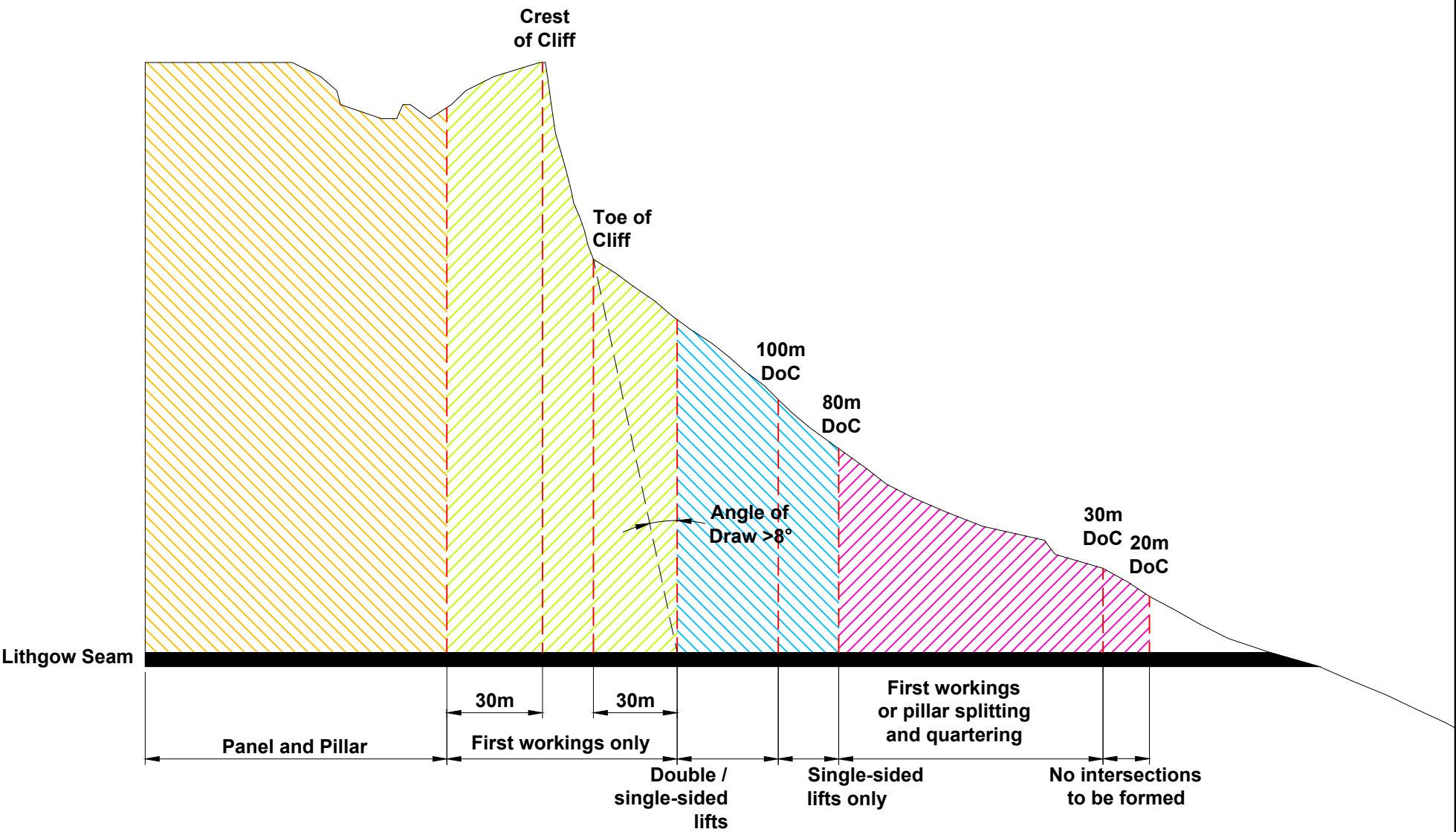
Key: - Significant natural rock fall - Project application area	Golder Associates	Engineer:	M. MacKinnon	Client:	Airly Mine		
		Drawn:	I.Meek	Title:	Areas of Interest and Natural Rock Falls Using Imagery from 2010 and Cliff Line Photographs from 2013 Helicopter Survey		
		Date:	19.08.2013				
		GOLDER ASSOCIATES PTY. LTD. www.golder.com		Ref:	127621105-003	Support Plan No:	N/A
				Scale:	NTS	Figure No:	30



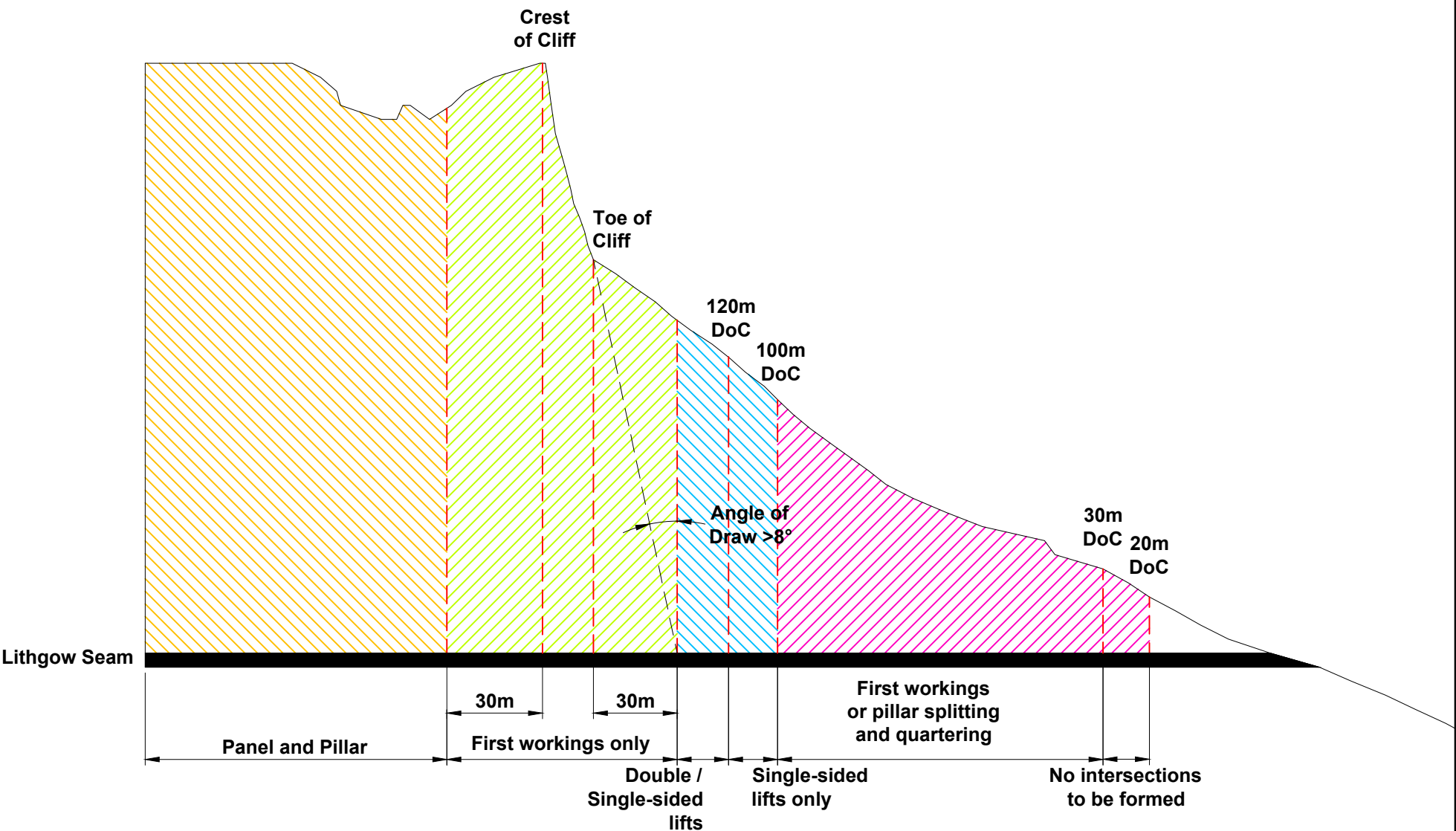
Engineer: D.Hill
Drawn: B. Richardson
Date: 19.08.13
GOLDER ASSOCIATES
PTY. LTD.
www.golder.com

Client:	Airly Mine		
Title:	Graph Showing Percentage of Cliffs Damaged with Regard to Panel Width to Depth Ratio (Reproduced from ACARP 2001)		
Ref:	127621105-003	Support Plan No:	N/A
Scale:	N/A	Figure No:	31

(i) Typical Section Showing Mining Zones



(ii) Typical Section Showing Mining Zones with Potential Flooding

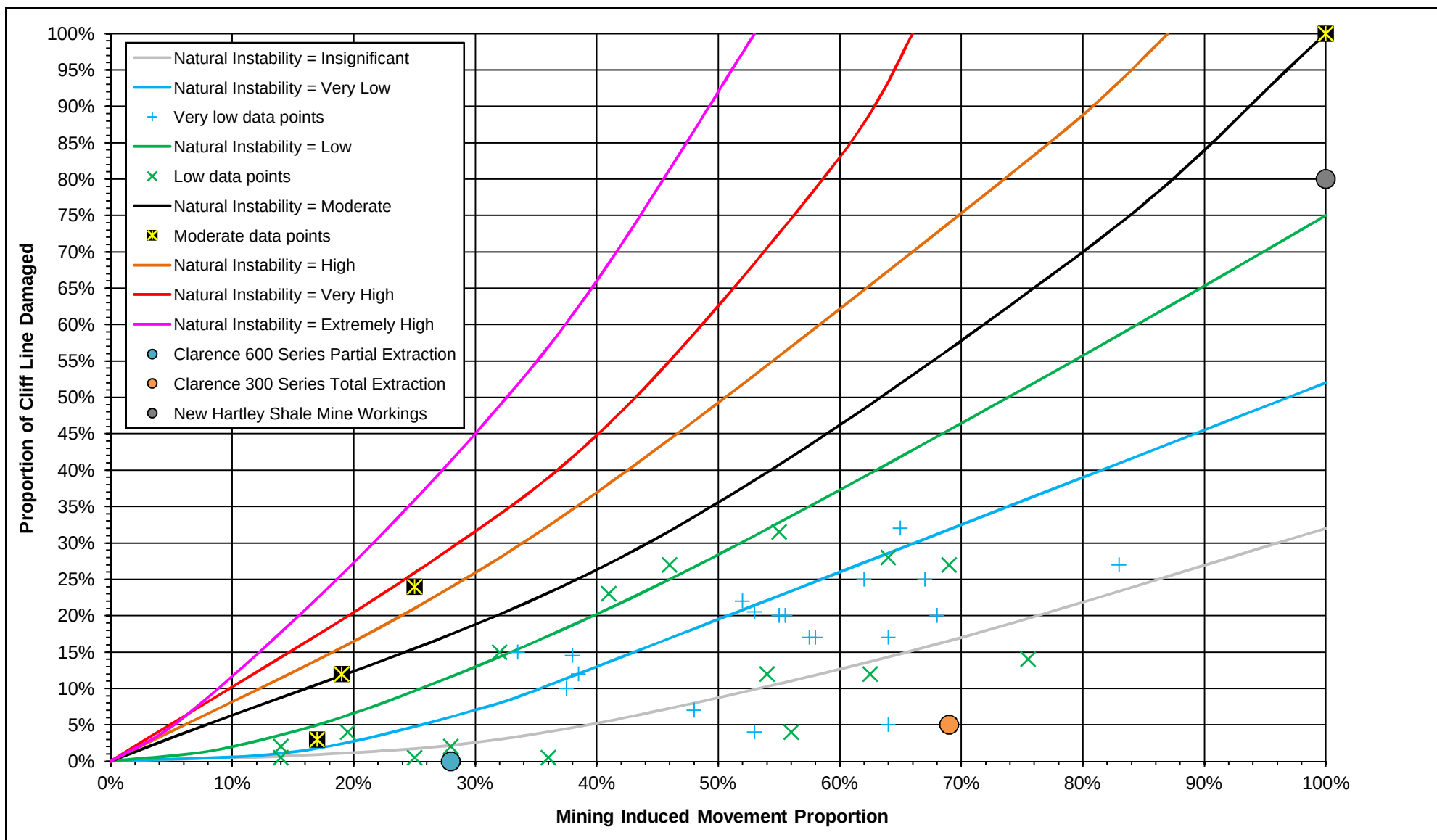


Key:

	Panel and pillar mining zone
	Cliff line zone and zone of first workings
	Partial pillar extraction zone
	Shallow zone



Engineer:	M. MacKinnon	Client:	Airly Mine		
Drawn:	B. Richardson	Title:	Typical Sections Showing Proposed Mining Zones		
Date:	04.11.13				
GOLDER ASSOCIATES PTY. LTD. www.golder.com		Ref:	127621105-003	Revision No:	N/A
		Scale:	NTS	Figure No:	32



Engineer: D. Hill
Drawn: B. Richardson
Date: 19.08.13
GOLDER ASSOCIATES
PTY. LTD.
www.golder.com

Client: Airly Mine
Title: Graph Showing the Likely Incidence of Cliff Falls for Different Levels of Mining Impact and Different Levels of Natural Cliff Line Instability
Ref: 127621105-003
Scale: N/A
Support Plan No: N/A
Figure No: 33



favourable outcomes with respect to both first workings and partial extraction elsewhere, the actual damage proportion is however expected to be less than 5% of the cliff line area and probably zero.

Apart from covering the main area of the external cliff lines, this cliff line zone also extends into the main internal drainage area of Genowlan Mountain (including as seen in **Figure 34** the Grotto area) and as such, subsidence in this area is expected to be similarly negligible. Within the Grotto area, apart from the natural landforms of interest, there is one heritage site identified by RPS (2013); this is a rock shelter known as “Genowlan Creek 1” and by its Aboriginal Heritage Information Management System (AHIMS) Number: 45-1-0167, see **Figure 35**. Depth of Cover in the area of interest is in the order of 140m and it is assessed that the first workings proposed for this area would have no appreciable impact upon the site.

In summary, this is an area of first workings to isolate the main cliff lines. It is defined by setback distances of 30m from both the crest and toe of the cliffs. The exception is in the vicinity of the cliffs affected by subsidence due to previous oil shale mining; for these cliffs, the lateral distance from the crest of the cliff to the commencement of the Panel and Pillar Zone is conservatively defined by half the depth (i.e. an Angle of Draw of 26.5°).

Subsidence effects in this zone can be summarised as follows:

• Subsidence	:	10 to 65mm
• Tilt	:	0.6 to 1.1mm/m
• Tensile Strain	:	0.2 to 0.3mm/m
• Compressive Strain	:	0.2 to 0.5mm/m
• Fractured Zone Height	:	<10m above the seam
• Surface Cracking	:	Not expected

Predicted tilt and strains in this zone are less than for the partial pillar extraction zone (see **Section 8.3**) even though subsidence levels are predicted to be similar. This is because the system is essentially elastic in this zone and subsidence is predicted to be greater as depth increases. In the partial pillar extraction zone caving will occur and the system will be non-elastic. As a result subsidence is predicted to be greater as depth decreases in the partial pillar extraction zone. Tilt and strains are predicted to be inversely proportional to the depth, hence the differences between the two zones.

7.2 Panel and Pillar Mining Zone

The panel and pillar mining zone largely occupies the plateau areas above most of the cliff lines. As such, Depths of Cover range from 160m to a maximum of 280m over Mt. Airly and up to 310m over Genowlan Point. These plateau areas encompass significant areas of pagodas and rock shelves. However, given that tensile strains are predicted to be less than 1mm/m and compressive strains less than 2mm/m (with the exception of the oil shale mining interaction zone), no surface cracking and / or appreciable impacts are expected. Furthermore, the associated tilts of less than 2mm/m represent angles of less than 0.1°, which are not expected to impact on any of the pagoda slopes.

The panel and pillar mining zone does however encroach on a small number of cliff lines, as shown in **Figure 26**. The following comments are made regarding these specific cliff lines.

- i) Cliff line “Mta 43” is located along the western margin of Mount Airly. This cliff reduces in height to between 20m and 30m in the north, where approximately the northernmost 175m



horizontal extent of the cliff line falls within the panel and pillar mining zone. In this area the cliff line takes the form of a dissected rounded landform with multiple pagodas. Depth to the base of the cliff in the affected northern section is of the order of 180m and subsidence of 60mm is expected, with tilts and strains of less than 2mm/m. Using the previously discussed classification standards, this equates to a borderline low to moderate mining induced impact rating (i.e. a score of 0.31, noting that a low score is ≤ 0.3 and high ≥ 0.4) and ranks as moderate in terms of natural instability, such that from **Figure 33**, the predicted upper bound for the proportion of cliff line damage is 18% of its length. In practice, the proportion of cliff line damaged in this area is however expected to be significantly lower (i.e. less than 10%). Damage to say 10% of the length of the cliff line does not mean that this percentage will likely fall en-masse. At worst, only isolated falls are likely to result.

- ii) Cliff lines “B9” and “B12” are located in an extensive area of dense rounded landform and pagoda country near the south-east end of Genowlan Mountain (defined as “Area B” in the cliff line survey referenced in **Figure 26**). The cliffs are relatively low at around 20m and Depth of Cover to the base of the cliffs is favourable, at around 220m to 270m. Accordingly, subsidence of 50mm is expected, with tilts and strains of less than 2mm/m and 1mm/m respectively. The cliffs both rank very low in terms of mining induced impact rating, B9 having a score of 0.14 and B12 a score of 0.11. These cliff lines also rank low in terms of natural instability, such that their overall ranking is very low. The predicted upper bound for the proportion of cliff line damage is 2 to 3% and in practice it is considered probable that zero damage would occur due to undermining of these cliffs.
- iii) Cliff line “B15” is an internal cliff approximately 20m high, located in the southern end of Genowlan Mountain (again, cliff line survey “Area B”). Depth of Cover to the base of the cliff is favourable, at around 250m. Accordingly, subsidence of 50mm is expected, with tilts and strains of less than 2mm/m and 1mm/m respectively. The cliff ranks very low in terms of mining induced impact rating, with a score of 0.17. The cliff line ranks low in terms of natural instability, such that the overall ranking is very low. The predicted upper bound for the proportion of cliff line damage is 5% and in practice it is considered probable that zero damage would occur due to undermining of this cliff.
- iv) Cliff line “B17” is an internal cliff up to 60m high, located in the southern end of Genowlan Mountain (again, cliff line survey “Area B”). Depth of Cover to the base of the cliff is favourable, at around 210m. Accordingly, subsidence of 50mm is expected, with tilts and strains of less than 2mm/m and 1mm/m respectively. The cliff ranks very low in terms of mining induced impact rating, with a score of 0.14. The cliff line ranks low in terms of natural instability, such that the overall ranking is very low. The predicted upper bound for the proportion of cliff line damage is 3% and in practice it is considered probable that zero damage would occur due to undermining of this cliff.
- v) Cliff line “B19” is an external cliff approximately 50m high, located in the southern end of Genowlan Mountain (again, cliff line survey “Area B”). Depth of Cover to the base of the cliff is around 190m. Accordingly, subsidence of 50mm to 60mm is expected, with tilts and strains of less than 2mm/m and 1mm/m respectively. The cliff ranks low in terms of mining induced impact rating, with a score of 0.28. The cliff line also ranks low in terms of natural instability, such that the overall ranking is low. The predicted upper bound for the proportion of cliff line damage is 13% and in practice it is considered probable that damage due to undermining of this cliff would be minimal (i.e. less than 5%).



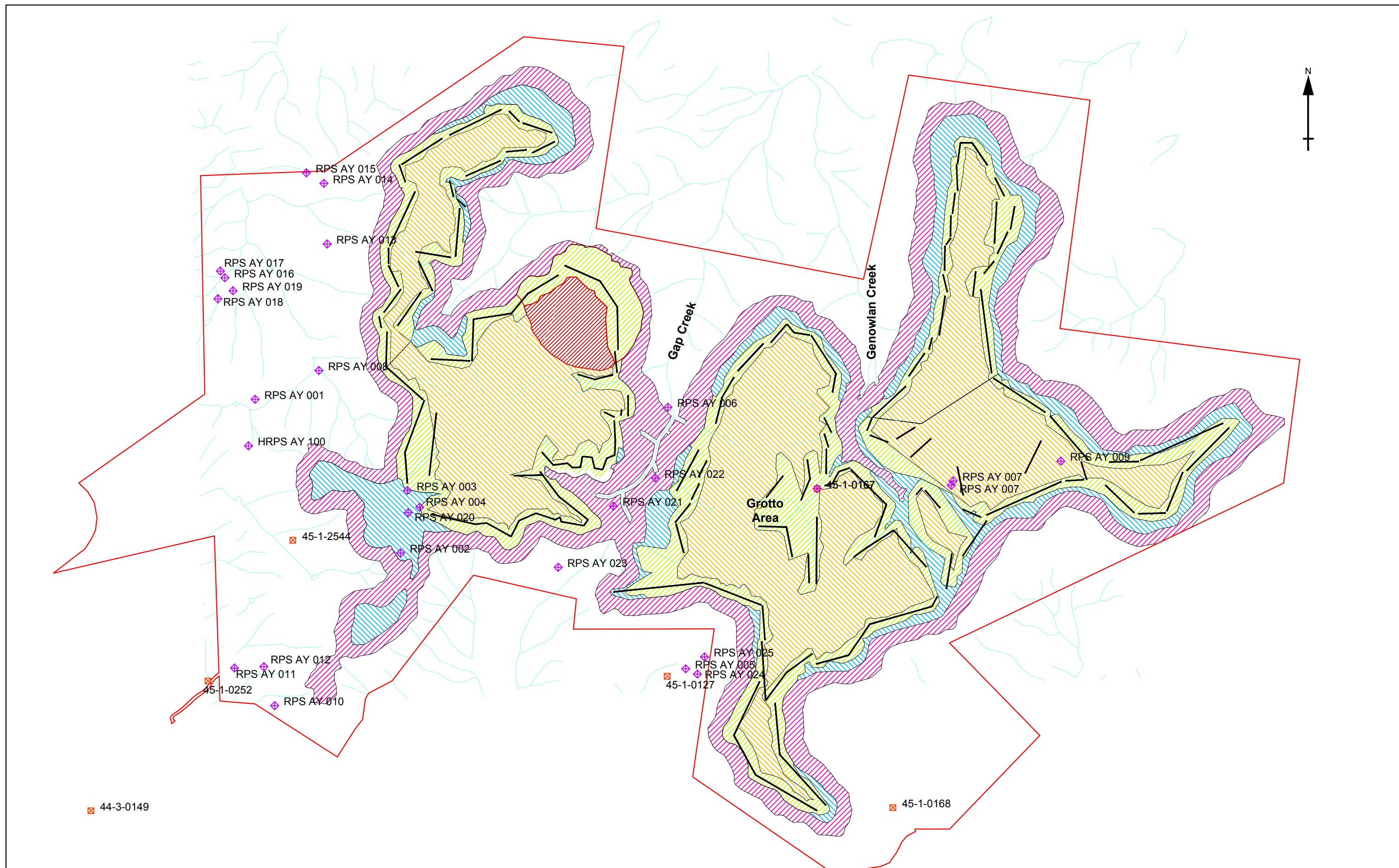
Two heritage sites RPS AY 007 and RPS AY 009 are located within the panel and pillar mining zone, see **Figure 34**. The first is an art site plus rock shelter, the second is an artefact scatter plus rock shelter. Both are ranked high on the local scale for overall archaeological significance. Depth of Cover is 190m at RPS AY 007, increasing to 220m at RPS AY 009. Strains are expected to be less than 1mm/m and tilts to be less than 2mm/m in both areas and as such, surface cracking is not expected.

Other man made features in the panel and pillar mining zone include a communications tower and associated buildings on Genowlan Mountain and a Nissen hut and out building in the old diamond mining complex, see **Figure 26** for the locations. Depth of Cover is approximately 280m for all of these structures. The underlying workings are predicted to flood post-mining and the empirical upper bound subsidence (applicable for post-mining flooding as noted previously) is estimated at 61mm. The empirical upper bound tensile and compressive strains are estimated at 0.4 mm/m and 0.6 mm/m respectively. Tilt is likewise estimated at 1.2 mm/m post flooding. Based upon studies carried out by the National Coal Board in the UK, **MSEC (2007)** concluded that tilts of <5mm/m will cause no damage to surface structures. **MSEC (2007)** also concluded that critical tensile strain in the range 0.5 to 1.0mm/m is the threshold value range for the onset of cracking for brickwork and blockwork. Only one small shed at the communications tower site is constructed of concrete blocks. The remainder of the structures are constructed of steel or steel and timber, which would require greater tensile strains to result in damage. Transgrid give horizontal tensile strain threshold values of between 1.2 and 1.5mm/m as trigger levels (these values being below that at which damage would occur) for their steel towers for example (**Strata Engineering, 2003**). Additionally the length of the structures are limited (the Nissen hut with a plan area of 11m x 5m is the longest), so strains well above the threshold values noted above would be needed to cause more than negligible damage. Also, in practice not all of the horizontal ground strain will be transferred to the structures. The predicted subsidence, tilt and strains post-mining flooding at these sites are therefore well below those that are expected to cause damage to the structures.

In summary, the plateau area is located above the cliffs at cover depths of $\geq 160\text{m}$ and at the proposed void width of 61m, the 29.5m wide long-term stable pillars left between the voids will support the overburden and significantly limit subsidence impacts on the surface.

Subsidence effects in this zone can be summarised as follows:

- Subsidence : 40 to 106mm
- Tilt : Typically 1 to 2mm/m (lower bound 0mm/m and upper bound 3mm/m)
- Tensile Strain : 0 to 1mm/m
- Compressive Strain : 0 to 2mm/m
- Fractured Zone Height : 60 to 70m above the seam
- Surface Cracking : Not expected



Key: Panel and pillar mining zone Cliff line zone and zone of first workings Partial pillar extraction zone Shallow zone New Hartley Shale Mine potential interaction zone Cliff line Project application area Creeks Aboriginal heritage site	Golder Associates	Engineer: D. Hill	Client: Airly Mine			
		Drawn: B. Richardson	Title: Location of Known Aboriginal Heritage Sites and Proposed Mining Zones			
		Date: 30.06.14				
		GOLDER ASSOCIATES PTY. LTD. www.golder.com			Ref: 127621105-003	Support Plan No: N/A
					Scale: NTS	Figure No: 34



7.3 Partial Pillar Extraction Zone

The partial pillar lifting zone occupies the foot slopes below the cliff line zone to the 80m depth contour (100m in areas subject to post-mining flooding). This is an area of densely vegetated, talus covered slopes with angles of typically 20° to 30° to the horizontal. Slope height and angle varies widely across the project area; the slopes tend to be concave in shape with steeper upper portions.

Review of the literature notes that whilst landslides elsewhere in NSW have been triggered by total extraction mining, there are no known failures above first workings (**ACARP, 2001**). This indicates that significant subsidence, tilt and strains are required to destabilise talus slopes. Large pillars and limited extraction spans are employed in the partial pillar lifting zone to limit subsidence to less than 70mm and typically to between 20mm and 50mm. Strains are expected to be less than 2mm/m and typically much less than 1mm/m. Tilts in the range 0.5 to 2.6 mm/m are predicted. The very small strains will not result in surface cracking and the maximum predicted tilt represent localised changes in slope angle of around 0.15°, such that the subsidence impacts on the stability of these slopes are considered negligible.

The other key features of the partial pillar lifting zone are the streams that cross the zone, most notably Genowlan Creek and Gap Creek. Although limited Fractured Zone heights of 20m to 35m have been estimated for this zone, it is recommended that the creeks be protected by maintaining a minimum Constrained Zone thickness of twelve times the mining height beneath the creeks, see **Figure 25**. This is the equivalent of 34m of additional cover, resulting in a combined fractured plus Constrained Zone height of 54m to 69m. Allowing for a weathered surface zone thickness of 10m to 15m, it is recommended that mining beneath the creeks at depths of less than 80m be therefore limited to first workings and pillar quartering (noting the high FoS of the remnant quarters) only. The partial pillar extraction zone has been limited to a minimum depth of cover of 80m.

Furthermore, there are four aboriginal heritage sites that fall within this zone: RPS AY 002, 003, 004 and 020, see **Figure 34**. They are located at depths of between 110m and 150m in an area where no flooding post-mining is predicted. Subsidence is predicted to be <50mm, with tilt at <2mm/m and strains <1mm/m. No surface impacts are therefore anticipated at these locations.

In summary, this is a zone of pillar stripping, creating limited spans (15.5m to 25.5m) and leaving long-term stable pillars. This zone extends from the Cliff Line Zone to the 80m depth contour where no flooding post-mining has been predicted and to the 100m depth contour where flooding is predicted.

Subsidence effects in this zone can be summarised as follows:

- | | | |
|-------------------------|---|--------------------------|
| • Subsidence | : | 25 to 65mm |
| • Tilt | : | 0.5 to 2.6mm/m |
| • Tensile Strain | : | 0.2 to 1.1mm/m |
| • Compressive Strain | : | 0.2 to 1.9mm/m |
| • Fractured Zone Height | : | 20 to 35m above the seam |
| • Surface Cracking | : | Not expected |



7.4 Shallow Zone

The shallow zone extends from the 80m depth contour to a minimum depth of 20m where no flooding post-mining is predicted. The shallow zone will extend to a depth of 100m in areas where flooding is predicted. Within this zone, first workings and pillar splitting and quartering are proposed, with associated subsidence of less than 26mm as noted previously. In recent times, the mine has worked to the proposed 17.5m centres at depths of between 20m and 110m, with subsidence estimated at less than 20mm and no known subsidence impacts. It is noted that no flooding post-mining had occurred during past mining and the upper prediction of subsidence is for areas where flooding is predicted to occur post-mining. As noted previously this leads to a minimum FoS of 2.2 and the pillars are considered long-term stable, noting also the squat w/h ratio of 4.1 and the effective roadway width of 6m.

A particular consideration for the shallow zone however is the prevention of sinkhole-type subsidence at very shallow depths. Previous analysis (**Strata Engineering, 2011a**) suggested the following minimum guidelines for a mined height of 2.8m:

- No roadway drivage at a depth of less than 20m.
- No intersection formation at a depth of less than 30m.

These guidelines have been applied to the existing workings of the mine without incident whereby the mining lease is confined to those areas where the Depth of Cover is $\geq 20\text{m}$. The planned cut-off depth of 20m for the shallow zone is therefore consistent with these guidelines.

Natural and man-made features in the shallow zone can be summarised as follows:

- i) There are two Aboriginal heritage sites in the shallow zone, both located within Airly Gap. Referring to **Figure 34**, these are RPS AY 021, an artefact scatter, and RPS AY 022, an isolated find. These sites are ranked low on the local scale for overall archaeological significance. Depth exceeds 30m at both sites and no subsidence impact is expected.
- ii) The northern and north-eastern sides of Mount Airly are the location for the European heritage sites associated with Airly village and the old oil shale workings. A total of 37 sites have been identified (**RPS, 2012**), see **Figure 35**. Depth of Cover at these sites varies between approximately 21m and 60m. For the sites with a Depth of Cover $>30\text{m}$ no subsidence effects are anticipated with the subsidence, tilt and stains predicted. Exceptions are sites 14, 17 and 18 which are located in the zone of first workings beneath the cliff lines associated with the old oil shale workings and no subsidence impacts are expected at these locations. There are two sites that involve cover depths of less than 30m; Site 3, a dwelling (depth around 21m), and Site 24, a cave house (depth around 25m). It is recommended that these sites not be undermined, with protection zone widths again defined by half the depth and as such, these have been excluded from the shallow zone and will not therefore be impacted by subsidence (see **Figure 35**).
- iii) "Rock Bottom" is a cottage within Airly village, situated adjacent to Gap Creek. Depth of Cover to the seam is only around 20m at this location. It is recommended that no mining be undertaken in the vicinity of this site and it has been excluded from the shallow zone workings (see **Figure 35**). There is also a stone cottage at Airly Gap where the seam is located at a depth of about 45m. Accepting that this is included in the shallow zone workings, no subsidence impacts are expected at this depth of mining.

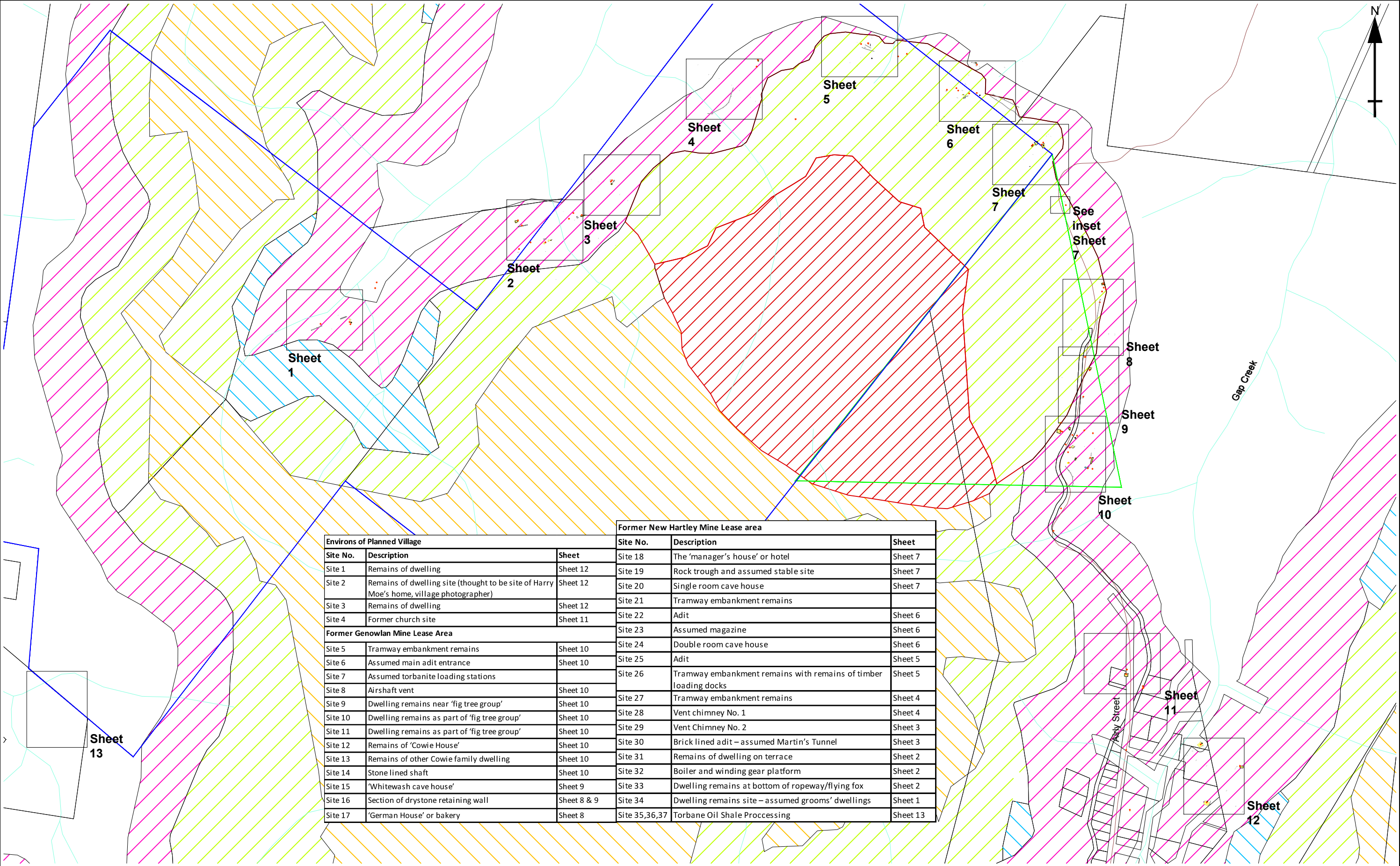


- iv) The shallow zone is characterised by numerous creeks, including the main Gap Creek and Genowlan Creek. Fractured zone heights above first workings are likely to be less than 10m, based on experiences with roof monitoring and failures in bord and pillar workings. However, consideration also needs to be given to the maintenance of adequate constrained zone thicknesses, recognising that the larger creeks, in particular, are liable to be associated with zones of geological structure and an associated increase in rock mass instability and permeability. On this basis it is therefore suggested that a minimum mining depth of 40m beneath creeks be adopted based on a criterion of ten times the mining height (28m), plus an allowance of 12m for the thickness of the weathered zone. This minimises mining in the vicinity of creeks in the shallow zone. Appropriate setback distances from the Gap and Genowlan creeks should also be defined by an Angle of Draw equivalent to half the depth. The areas that have been excluded from the shallow zone workings adjacent to these creeks are shown in **Figure 34**.
- v) A Telstra copper cable (the only subscriber to which is Centennial) follows the old tramway to Rock Bottom (see **Figure 26** for the location). Tensile strains of up to 4mm/m are considered tolerable for Telstra Copper cables (**Oceanic Coal Australia Ltd, 2013**). As a 'rule of thumb', normal copper communications cables can generally accommodate tensile strains up to 20mm/m without damage (**Strata Engineering, 2006**). As such, with the relatively low values of tensile strains predicted for the shallow zone, no subsidence impacts on this cable are expected.

In summary, this is a zone of first workings and pillar splitting and quartering between the 20m and 100m Depth of Cover contours.

Subsidence effects in this zone can be summarised as follows:

- | | | |
|-------------------------|---|---------------------|
| • Subsidence | : | 3.5 to 25.5mm |
| • Tilt | : | 0.6 to 1.1mm/m |
| • Tensile Strain | : | 0.1 to 0.4mm/m |
| • Compressive Strain | : | 0.2 to 0.6mm/m |
| • Fractured Zone Height | : | <10m above the seam |
| • Surface Cracking | : | Not expected |



Environs of Planned Village			Former New Hartley Mine Lease area		
Site No.	Description	Sheet	Site No.	Description	Sheet
Site 1	Remains of dwelling	Sheet 12	Site 18	The 'manager's house' or hotel	Sheet 7
Site 2	Remains of dwelling site (thought to be site of Harry Moe's home, village photographer)	Sheet 12	Site 19	Rock trough and assumed stable site	Sheet 7
Site 3	Remains of dwelling	Sheet 12	Site 20	Single room cave house	Sheet 7
Site 4	Former church site	Sheet 11	Site 21	Tramway embankment remains	
Former Genowlan Mine Lease Area			Site 22	Adit	Sheet 6
Site 5	Tramway embankment remains	Sheet 10	Site 23	Assumed magazine	Sheet 6
Site 6	Assumed main adit entrance	Sheet 10	Site 24	Double room cave house	Sheet 6
Site 7	Assumed torbanite loading stations		Site 25	Adit	Sheet 5
Site 8	Airshaft vent	Sheet 10	Site 26	Tramway embankment remains with remains of timber loading docks	Sheet 5
Site 9	Dwelling remains near 'fig tree group'	Sheet 10	Site 27	Tramway embankment remains	Sheet 4
Site 10	Dwelling remains as part of 'fig tree group'	Sheet 10	Site 28	Vent chimney No. 1	Sheet 4
Site 11	Dwelling remains as part of 'fig tree group'	Sheet 10	Site 29	Vent Chimney No. 2	Sheet 3
Site 12	Remains of 'Cowie House'	Sheet 10	Site 30	Brick lined adit – assumed Martin's Tunnel	Sheet 3
Site 13	Remains of other Cowie family dwelling	Sheet 10	Site 31	Remains of dwelling on terrace	Sheet 2
Site 14	Stone lined shaft	Sheet 10	Site 32	Boiler and winding gear platform	Sheet 2
Site 15	'Whitewash cave house'	Sheet 9	Site 33	Dwelling remains at bottom of ropeway/flying fox	Sheet 2
Site 16	Section of drystone retaining wall	Sheet 8 & 9	Site 34	Dwelling remains site – assumed grooms' dwellings	Sheet 1
Site 17	'German House' or bakery	Sheet 8	Site 35,36,37	Torbane Oil Shale Processing	Sheet 13

Key:

Panel and pillar mining zone

Cliff line zone and zone of first workings

Partial pillar extraction zone

Shallow zone

New Hartley Shale Mine potential interaction zone



Engineer:	D. Hill	Client:	Airly Mine		
Drawn:	B. Richardson	Title:	European Heritage Sites in the Shallow Zone (adapted from RPS, 2012a)		
Date:	04.11.13				
GOLDER ASSOCIATES PTY. LTD. www.golder.com		Ref:	127621105-003	Support Plan No:	N/A
		Scale:	N/A	Figure No:	35



7.5 New Hartley Shale Mine Potential Interaction Zone

A surface inspection of the plateau area and cliff lines above the old oil shale workings and a review of the old mine plan did not indicate that significant pillars remained in the old oil shale workings. Nevertheless, given the age of the workings and the mining method employed, it is considered at least possible that some areas containing pillars are in existence. Should such pillars be in existence, both panel and pillar, and partial pillar extraction methods in the Lithgow Seam could lead to their collapse at the expected interburden distances. This in turn would result in a reactivation of subsidence in the oil shale workings with subsidence, and tilt and strains above the limits being proposed in the remainder of the deposit. Given the uncertainty with respect to the location and extent of pillars in the oil shale workings, first workings only are recommended in the Lithgow Seam for the cliff lines and below the cliff lines. As noted earlier, this recommendation can be revisited if the interburden distance is found to be different with further investigation. Determining the existence and location of pillars in the old workings is not considered practically possible and on this basis, a set-back distance for pillar and panel mining of half the depth is recommended for the cliff lines.

New subsidence effects in the zones of first workings can be summarised as follows:

- Subsidence : 10 to 65mm
- Tilt : 0.6 to 1.1mm/m
- Tensile Strain : 0.2 to 0.3mm/m
- Compressive Strain : 0.2 to 0.5mm/m
- Fractured Zone Height : <10m above the seam
- New Surface Cracking : Not expected

If panel and pillar mining is practiced beneath the plateau in this area, the expected new subsidence effects (accepting that subsidence affects have already occurred) can be summarised as follows where panels are super-critical (this maybe the entire area) in the old shale workings:

- New Subsidence : 200mm
- Tilt : 2.5 to 6.7mm/m
- Tensile Strain : 1.0 to 2mm/m
- Compressive Strain : 0.7 to 3.3mm/m
- New surface Cracking : Expected

Should there be sub-critical areas in the old shale workings that become super-critical with remnant pillar collapses with pillar and panel mining, the expected new subsidence effects can be summarised as follows:

- New Subsidence : 500mm
- Tilt : 6.2 to 16.7mm/m
- Tensile Strain : 2.4 to 5mm/m
- Compressive Strain : 1.8 to 8.3mm/m
- New surface Cracking : Expected

Clearly, panel and pillar mining beneath the old workings has the potential to induce new subsidence, tilt and strains that are above the threshold values that have been set for the remainder of the deposit. The indications from the surface inspection are that significant surface damage has already occurred at the cliff lines but the proposed panel and pillar mining set-back



distance will ensure that no further damage will occur above the old shale workings. The only other area of significant visible damage is at the southern margin of the old workings. Significant surface damage in other areas of the plateau area does not appear to have occurred, although the limited rock outcrops and dense vegetation may mean that damage may not be visible.

Should the old oil shale area be super-critical over the whole plateau area, then the extent of additional surface damage is not likely to be significant, despite the fact that the estimated subsidence, tilt and strains exceed the threshold values set for the Airly deposit. The threshold values are known to be conservative, as noted earlier. However, the analyses do indicate that significant additional surface damage is possible if areas exist that are sub-critical in the old shale workings.

To this end, it must be noted that there is considerable uncertainty in the conclusions relating to subsidence and its effects with panel and pillar mining beneath the old shale workings that cannot be quantified at this stage. The subsidence estimates are dependent upon an estimate of the extent of remnant pillars and the results of an un-calibrated numerical model that indicates that total multi-seam subsidence is the addition of the two single extraction subsidence levels with the Lithgow Seam geometries. There is insufficient information to ascertain the extent of remnant pillars in the old shale workings or indeed if any at all are in existence and there is currently no precedent by which to calibrate the numerical model. That said, the subsidence assessments for this area noted in this report do not constitute the very worst case possible. If there are more remnant pillars than the 75% extraction assumed, then new subsidence could be even greater should those pillars be fractured by undermining. Further to this, the analysis has also assumed that multi-seam subsidence is merely an addition of the individual subsidence in the mining geometries proposed for the Lithgow Seam. Given that there is no precedent to validate this assumption it is possible that the multi-seam subsidence will be greater than just the addition but it is not possible to estimate by how much.



8.0 SUGGESTED MONITORING PROGRAMME

Given the negligible expected subsidence, rugged topography, commonly dense woodland and the high conservation value of this catchment area, the potential use of conventional survey techniques (i.e. surface lines for the measurement of subsidence, strain and tilt) is considered limited. A system of cross-lines and longitudinal survey lines should therefore be devised that minimises the impact on the environment. Consideration should therefore be given to remote station monitoring and/or space borne repeat-pass InSAR monitoring.

Monitoring should also focus on recording the physical condition of cliff lines and rock features such as pagodas and rock shelves, with the aim of confirming that the impacts of mining-induced movements are negligible. Systematic photographic records should be compiled of cliff lines and other major features, with consideration given to the use of photogrammetry techniques. In the panel and pillar mining zone, selected accessible rock features should also be mapped prior to mining for pre-existing joint patterns and post-mining for any joint dilation or fracture development.

Mount Airly has landforms and vegetation communities that are less sensitive to the installation of conventional subsidence monitoring lines than the Genowlan Mountain complex. Fortuitously it is also the first location for pillar and panel mining. There is therefore the opportunity to install conventional surface subsidence monitoring over the first series of extraction panels and to use these results to demonstrate the level of accuracy of remote monitoring (such as InSAR or similar).

There is also considerable value in installing stress and deformation monitoring instrumentation in the underground pillars, similar to that done at Clarence Colliery. These have included rib extensometers and hydraulic borehole stress cells. This instrumentation can provide valuable confirmation with respect to the stability of pillars, which are an essential component in minimising subsidence in the mining geometries being proposed at Airly. Additionally in the case of Airly, the stress cells can confirm the share of the overburden load being carried by pillars and the caved waste (which is represented by an abutment angle). This is also an essential component of pillar design in mining methods associated with caving. The results of pillar monitoring and surface subsidence monitoring have also been a valuable input into calibrating and validating empirical, numerical and analytical models at Clarence and that would also be the case at Airly. Once a calibration between underground monitoring, surface subsidence monitoring and remote monitoring is established, the intention should then be to use underground monitoring and remote monitoring (in combination with visual inspections on surface) to better estimate the level of surface subsidence being experienced. This in turn would eliminate the reliance upon conventional subsidence survey lines. The extent and methodology of underground and remote monitoring required to achieve this would need to be established as mining progresses.



9.0 PERFORMANCE MEASURES AND ADAPTIVE MANAGEMENT

The systems of partial extraction and first workings proposed for Airly Mine are intended to result in subsidence that is nominally limited to 100mm but shall not exceed 125mm, with strains that are insufficient to induce surface cracking and significant tilts. Experiences of partial extraction elsewhere in the Western Coalfield under similar land forms (in particular at Clarence Colliery) at equivalent subsidence levels indicate that the associated surface subsidence impacts are negligible and a similar outcome is expected for Airly. Although the cliff line assessment suggests limited levels of damage are possible (i.e. low rock fall percentages as a proportion of the cliff areas), the results are regarded as conservative at the very low levels of subsidence involved in this case and as stated earlier, no adverse impacts are considered likely.

Further to the above, a feature of the Airly mining layout is that mining will generally take place in the vicinity of the lower western cliffs first, prior to progressing eastwards to the higher cliffs of Genowlan Mountain. An opportunity therefore exists to monitor the performance of less sensitive cliffs in the early stage of the project, with mining proceeding as planned, given ongoing negligible impact.

In this regard, four levels of impact should be defined as part of the assessment, namely:

- i) Nil, defined as “*none whatsoever*”.
- ii) Negligible, defined as “*small and unimportant, so as not to be worth considering*”. Indicative impacts would be the occasional displacement of boulders, hairline fracturing and the isolated detachment of slabs from overhangs that in total do not impact on more than 0.5% of the total cliff line length and would not therefore stand out amongst the natural and inevitable deterioration of the exposed surfaces.
- iii) Minor, defined as “*relatively small in quantity, size and degree*”. Indicative impacts would be isolated rock falls of less than 30m³ that do not impact on aboriginal heritage, EEC's or public safety and affecting less than 5% of the total length of cliffs.
- iv) Significant, defined as “*relatively large in quantity, size and degree*”. Indicative impacts would be rock falls of > 30m³ that may impact on aboriginal heritage, EEC's or public safety and affecting > 5% of the total length of cliffs.

It is suggested that in the case of Airly, minor impacts would warrant reconsideration of setback distances from cliff lines to the extraction areas associated with panel and pillar mining. It is also recommended that the definition of “mining-related” incorporate a time cut-off of two years post extraction in a given location (i.e. impacts occurring within two years of mining in an area are considered potentially mining-related, but impacts beyond that period are not).

Attached in **Tables 15, 16 and 17** are the proposed Trigger Action Response Plans (TARP's) relating to measurable survey techniques, underground pillar monitoring and visual observations. Subject to further review and optimisation, this type of TARP would be included as part of the ongoing monitoring program at the mine. A similar TARP has been successfully used at Clarence Colliery to restrict subsidence and surface damage to the limits required under the mines' subsidence management plan.

TABLE 15 - TRIGGER ACTION RESPONSE PLAN FOR PANEL & PILLAR MINING

Monitoring Element	Trigger / Response	Condition Green	Condition Yellow	Condition Red
Void Width/Chain Pillar Width	Trigger	Void width <62m Chain pillar >28.5m solid width	Void width 62-64m average over 100m Chain Pillar 26.5-28.5m average solid width over 100m	Void width >64m average over 100m Chain pillar <26.5m average solid width over 100m
	Notification	N/A	Notify: Senior Mining Supervisor Senior Mining Engineer Geotechnical specialist	Notify: Senior Mining Supervisor Senior Mining Engineer Principal Subsidence Engineer Geotechnical Specialist
	Action / Response	Nil	Review pillar stress monitoring and subsidence data. Review development operational procedures and rectify issues leading to over width or off line driveage for subsequent panels. Assess impact on chain pillar stability Assess likely impact up on subsidence. Install additional support or modify extraction plan if appropriate	Review pillar stress monitoring and subsidence data. Review development operational procedures and rectify issues leading to over width or off line driveage for subsequent panels. Assess impact on chain pillar stability Assess likely impact upon subsidence. Principal Subsidence Engineer in consultation with expert geotechnical engineer to review panel design and extraction plan for current and subsequent panels.Stop extraction if appropriate. Install additional support or modify extraction plan if appropriate.
Roadway Height	Trigger	Rib Height < 3.0m on average and rib spall <0.5m	Rib Height > 3.0m but ≤ 3.3m on average, rib spall depth >0.5 to 1m over 100m	Rib Height > 3.3m, rib spall depth > 1.0m over 100m
	Response	Mining officials to monitor and report height	Review development operational procedures and rectify issues leading to over height driveage. Assess impact on chain pillar stability Assess likely impact on subsidence.	Assess impact upon chain pillar stability. Assess likely impact on subsidence. Review pillar stress monitoring data. Principal Subsidence Engineer in consultation with expert geotechnical engineer to review panel design and extraction plan for current and subsequent panels. Review development and lifting operational procedures and rectify issues leading to over height. Consider additional rib support if applicable.
Pillar Stress Monitoring	Trigger	Pillar stresses <15% above predicted values	Pillar Stresses 15 to 25% above predicted values	Pillar stresses >25% above predicted values
	Response	Mining officials to monitor and report pillar stresses	Review stress cell monitoring information. Review predictions with all relevant technical parties. Assess likely impact upon chain pillar stability. Assess likely impact on subsidence. Notify Senior Mining Engineer and Principal Subsidence Engineer of monitoring results and planned response.	Assess likely impact upon chain pillar stability. Assess likely impact on subsidence. Stop extraction if appropriate. Principal Subsidence Engineer in consultation with expert geotechnical engineer to review panel design and extraction plan for current and subsequent panels. Consideration of additional rib support and standing support if appropriate.
Subsidence Confirmation Survey Monitoring after secondary extraction	Trigger	Subsidence results are ≤ 100mm	Subsidence results are 100mm - 125mm	Subsidence results are > 125mm
	Notification	Nil	Notify Senior Mining Engineer and Principal Subsidence Engineer and arrange inspection. Notify all relevant land owners.	Cease extraction in the affected area and notify Principal Subsidence Engineer and Senior Mining Engineer Notify all relevant land owners.
	Action / Response	Continue subsidence monitoring at designated frequency in accordance with subsidence monitoring plan	Conduct further surface inspections to validate results. Review both subsidence and stress cell monitoring information. Review predictions with Principal Subsidence Engineer and all relevant technical parties. Develop response plan which may include modifying extraction plans as required.	Conduct further surface inspections to validate results. Undertake detailed review of subsidence model, panel design and extraction plan for current and subsequent panels with Principal Subsidence Engineer and all relevant technical parties. Consider modifying current extraction plan in current and subsequent panels.
Surface Cracking / on Roads, Tracks or Impacting buildings or heritage sites	Trigger	Surface cracking <10mm	Surface cracks 10-50mm wide	Surface cracking > 50mm wide
	Notification	N/A	Notify - Senior Mining Engineer - Principal Subsidence Engineer - All relevant land owners..	Notify immediately - Senior Mining Engineer - Principal Subsidence Engineer - All relevant land owners.
	Action / Response	Continue monitoring and surface inspections in accordance with subsidence monitoring plan	Review public safety aspect. Consider erecting warning signs and barriers in affected areas Undertake review of subsidence model, panel design and extraction plan for current and subsequent panels with all relevant technical parties. Consider modifying current extraction plan in current and subsequent panels. Develop and implement remediation plan in consultation with Principal Subsidence Engineer and land owner	Stop extraction mining if appropriate Review public safety impacts Erect warning signs and barricades as required Undertake detailed review of subsidence model, panel design and extraction plan for current and subsequent panels with Principal Subsidence Engineer and all relevant technical parties. Consider modifying current extraction plan in current and subsequent panels. Develop and implement remediation plan in consultation with Principal Subsidence Engineer and land owner
Cliffline / Pagoda or rock out-crop damage or increased instability	Trigger	No surface cracking or notable changes following secondary extraction.	Surface cracking up to 50mm, evidence of increased instability due to mining induced movement, or rock fall > 30m³ .	Surface cracking > 50mm wide, significant notable damage to cliff face or pagoda, or rockfall > 100m³ .
	Notification	N/A	Notify - Senior Mining Engineer - Principal Subsidence Engineer - All relevant land owners	Notify immediately - Senior Mining Engineer - Principal Subsidence Engineer - All relevant land owners
	Action / Response	Continue subsidence monitoring and surface inspections in accordance with subsidence monitoring plan	Review public safety aspect. Consider erecting warning signs and barriers in affected areas Undertake review of subsidence model, panel design and extraction plan for current and subsequent panels.with all relevant technical parties. Consider modifying current extraction plan in current and subsequent panels. Develop and implement remediation plan in consultation with Principal Subsidence Engineer and land owner	Stop extraction mining until reason for damage is determined Review public safety impacts Erect warning signs and barricades as required Undertake detailed review of subsidence model, panel design and extraction plan for current and subsequent panels with Principal Subsidence Engineer and all relevant technical parties. Consider modifying current extraction plan in current and subsequent panels. Develop and implement remediation plan in consultation with Principal Subsidence Engineer and land owner. Develop remediation plan in consultation with Principal Subsidence Engineer and land owner

Note:

Subsidence Predictions	Single-sided lifting	Double-sided lifting
Subsidence (mm)	<125	<125
Strain (mm/m)	<2.0	<2.0
Tilt (mm/m)	<2.0	<2.0

TABLE 16 - TRIGGER ACTION RESPONSE PLAN FOR PARTIAL PILLAR EXTRACTION ZONE

Monitoring Element	Trigger / Response	Condition Green	Condition Yellow	Condition Red
Roadway Width / Lift Width	Trigger	Roadway Width 5.5-6.0m average across panel as mined Lift depths average 10m	Roadway Width 6.0 – 7.0m on average across panel as mined. Lift depths 10 to 11m average as mined	Roadway Width > 7.0m on average across panel as mined. Lift depths >11m
	Notification	N/A	Notify: Senior Mining Supervisor Senior Mining Engineer	Notify: Senior Mining Supervisor Senior Mining Engineer
	Action / Response	Mining official to monitor roadway and lift depths	Reduce lift depths to ensure total extraction span does not exceed: 15.5m for Single-sided Lifting 25.5m for Double-sided Lifting Review development and lifting operational procedures and rectify issues leading to over width	Review panel design and modify extraction plan to suit changed pillar dimensions. Reduce lift depth to ensure total extracted width does not exceed: 15.5m for Single-sided Lifting 25.5m for Double-sided Lifting Review development and lifting operational procedures and rectify issues leading to over width
Roadway Height	Trigger	Rib Height < 3.0m on average and rib spall <0.5m	Rib Height > 3.0m but ≤ 3.3m on average, rib spall depth >0.5 to 1m	Rib Height > 3.3m, rib spall depth > 1.0m
	Response	Mining officials to monitor and report height	Restrictions to lifting to be assessed by Senior Mining Engineer. Review development and lifting operational procedures and rectify issues leading to over height.	Principal Subsidence Engineer to review panel design and extraction plan. Review development and lifting operational procedures and rectify issues leading to over height. Consider additional rib support if applicable and leaving a row of un-lifted pillars.
Pillar Stress Monitoring	Trigger	Pillar stresses <15% above predicted values	Pillar Stresses 15 to 25% above predicted values	Pillar stresses >25% above predicted values
	Response	Mining officials to monitor and report pillar stresses	Review stress cell monitoring information. Review predictions with all relevant technical parties. Notify Senior Mining Engineer and Principal Subsidence Engineer of monitoring results and planned response.	Principal Subsidence Engineer in consultation with expert geotechnical engineer to review panel design and extraction plan. Consider leaving rows of pillars un-lifted
Subsidence Confirmation Survey Monitoring after secondary extraction	Trigger	Subsidence results are ≤ 100mm	Subsidence results are 100mm - 125mm	Subsidence results are > 125mm
	Notification	Nil	Notify Senior Mining Engineer and Principal Subsidence Engineer and arrange inspection Notify all relevant land owners.	Cease extraction and notify Principal Subsidence Engineer and Senior Mining Engineer Notify all relevant land owners.
	Action / Response	Continue subsidence monitoring at designated frequency in accordance with subsidence monitoring plan	Conduct further surface inspections Review both subsidence and stress cell monitoring information. Review predictions with Principal Subsidence Engineer and all relevant technical parties. Develop response plan which may include modifying extraction plans as required.	Undertake detailed review of predictions with Principal Subsidence Engineer and all relevant technical parties. Consider modifying current extraction plan in current panels. Review subsidence model. Modify future panel design as required.
Surface Cracking / on Roads, Tracks or Impacting buildings or heritage sites	Trigger	Surface cracking <10mm	Surface cracks 10 - 50mm wide	Surface cracking > 50mm wide
	Notification	N/A	Notify - Senior Mining Engineer - Principal Subsidence Engineer - All relevant land owners.	Notify immediately - Senior Mining Engineer - Principal Subsidence Engineer - All relevant land owners.
	Action / Response	Continue monitoring and surface inspections in accordance with subsidence monitoring plan	Review public safety aspect. Consider erecting warning signs and barriers in affected areas Undertake review of subsidence model, panel design and extraction plan for current and subsequent panels with all relevant technical parties. Consider modifying current extraction plan in current and subsequent panels. Develop and implement remediation plan in consultation with Principal Subsidence Engineer and land owner	Stop extraction mining if appropriate Review public safety impacts Erect warning signs and barricades as required Undertake detailed review of subsidence model, panel design and extraction plan for current and subsequent panels with Principal Subsidence Engineer and all relevant technical parties. Consider modifying current extraction plan in current and subsequent panels. Develop and implement remediation plan in consultation with Principal Subsidence Engineer and land owner
Cliffline / Pagoda or rock out-crop damage or increased instability	Trigger	No surface cracking or notable changes following secondary extraction.	Surface cracking up to 50mm, evidence of increased instability due to mining induced movement, or rock fall > 30m ³ .	Surface cracking > 50mm wide, significant notable damage to cliff face or pagoda, or rockfall > 100m ³ .
	Notification	N/A	Notify - Senior Mining Engineer - Principal Subsidence Engineer - All relevant land owners.	Notify immediately - Senior Mining Engineer - Principal Subsidence Engineer - All relevant land owners.
	Action / Response	Continue subsidence monitoring and surface inspections in accordance with subsidence monitoring plan	Review public safety aspect. Consider erecting warning signs and barriers in affected areas Develop remediation plan in consultation with Principal Subsidence Engineer and land owner	Stop extraction mining until reason for damage is determined Review public safety impacts Erect warning signs and barricades as required Undertake detailed review of subsidence model, panel design and extraction plan for current and subsequent panels with Principal Subsidence Engineer and all relevant technical parties. Consider modifying current extraction plan in current and subsequent panels. Develop and implement remediation plan in consultation with Principal Subsidence Engineer and land owner

Note:

Subsidence Predictions	Single-sided lifting	Double-sided lifting
Subsidence (mm)	<125	<125
Strain (mm/m)	<2.0	<2.0
Tilt (mm/m)	<2.0	<2.0

TABLE 17 - TRIGGER ACTION RESPONSE PLAN FOR MOUNT AIRLY SMP (SHALLOW ZONE)

Monitoring Element	Trigger / Response	Condition Green	Condition Yellow	Condition Red
Roadway Width / Panel Width	Trigger	Roadway Width 5.5m -6.0M average across panel as mined	Roadway Width 6.0 – 7.0m on average across panel as mined.	Roadway Width > 7.0m on average across panel as mined.
	Notification	N/A	Notify: Senior Mining Supervisor Senior Mining Engineer	Notify: Senior Mining Supervisor Senior Mining Engineer
	Action / Response	Nil	Reduce roadway width during quartering or pillar splitting to ensure total extraction span does not exceed 5.5m and final pillar size is >120m ²	Review panel design and modify extraction plan to suit changed pillar dimensions. Reduce roadway width during quartering or pillar splitting to ensure total extraction span does not exceed 5.5m and final pillar size is >120m ²
	Mitigation / Remediation	N/A	Refer to Strata Management Plan Review mining process Improve consultation with development crews.	Stop Mining Refer to Strata Management Plan Review Mining Process.
Roadway Height	Trigger	Rib Height < 3.0m and no significant rib spall	Rib Height > 3.0m but ≤ 3.3m, rib spall depth > 300mm but ≤ 500mm	Rib Height > 3.3m, rib spall depth > 1m over a height of ≥ 2m
	Response	Nil	Restrictions to lifting to be assessed by Senior Mining Engineer. Refer to Strata Management Plan.	Senior Mining Engineer to review panel design and extraction plan. Refer to Strata Management Plan.
Pillar Size	Trigger	Remnant pillar size >120m ²	Remnant pillar size >110m ² but <120m ²	Remnant pillar size <110m ²
	Response	Nil	Review subsidence predictions with Principal Subsidence Engineer and all relevant technical parties.	Senior MiningEngineer to review panel design and extraction plan. Refer to Strata Management Plan.
Subsidence Confirmation Inspection After Final Pillar Formation	Trigger	No visible cracking in the surface. No sink holes.	Minor cracking <50mm wide. No sink holes.	Cracking >50mm wide Sink hole in land surface
	Notification	Nil	Notify - Senior Mining Engineer - DPI – Mineral Resources Principal or representative - Land owner	Stop splitting and quartering work. Notify - Senior Mining Engineer - DPI – Mineral Resources Principal and arrange inpection by Principal Subsidence Engineer or representative - Land owner
	Action / Response	Continue subsidence monitoring at designated frequency in accordance with subsidence monitoing plan	Conduct further surface inspections Review both subsidence monitoring information. Modify mining sequence, reduce width of roadway formation to provide adequate final pillar size as required	Undertake detailed review of predictions with Principal Subsidence Engineer and all relevant technical parties. Consider modifying current extraction plan in current panels. Review subsidence model. Modify future panel design as required. Review public safety Erect warning signs and barricades as required Suitably qualified personnel to inspect and assess need for further action / remediation. Implement remediation plan.

Note:

Subsidence Predictions	First Workings
Subsidence (mm)	<30mm
Strain (mm/m)	<1.0
Tilt (mm/m)	<1.0



10.0 CONCLUSIONS

This report provides estimates of subsidence and pillar stability above proposed future mining areas at Airly Mine and assesses the likely impacts on surface and sub-surface features within the assessed zone of influence of the mine workings. Surface features have also been identified along with any required subsidence impact control measures. Mining systems appropriate to different areas of the mine have been devised that will result in “negligible subsidence impact” over the majority of the mining lease. A possible exception to this is the plateau area above old oil shale workings where surface damage has already occurred. A programme for monitoring subsidence and pillar stability has been suggested. Performance measures and adaptive management have been defined with a proposed Trigger Action Response Plan. In this way, management will be able to respond timely to situations that could potentially lead to adverse surface impacts.



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Report Signature Page

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APPENDIX A

GLOSSARY OF GENERAL SUBSIDENCE AND MINING TERMS



GLOSSARY OF GENERAL SUBSIDENCE AND MINING TERMS

Angle of Draw

The angle from the vertical of the line drawn between the limits of extraction at seam level to the 20mm subsidence contour at the surface (20mm is an industry defined limit and represents the practical limit of subsidence).

Chain Pillar

The unmined pillar of coal left between adjacent panel and pillar mining blocks to promote improved underground conditions (e.g. in terms of ventilation and/or ground control), which also assists with controlling subsidence at the surface.

Compressive Strain (see also Strain)

Indicates that the distance between two points on the surface has decreased and can cause shear cracking, buckling or steps at the surface. Compressive strains are usually associated with concave bending (curvature) near the middle of the panels.

Cover Depth

The depth from the surface to the mine workings.

Critical Panel Width

A term used to describe a panel width where maximum subsidence for a given mining height is reached.

First Workings

The tunnels, roadways or bords which are driven by a continuous mining machine to provide access to the production panels in a mine. Subsidence above first workings pillars is generally negligible or < 20mm.

Factor of Safety

Commonly used to design underground coal mine pillars. The Factor of Safety (FoS) is the ratio between the strength of a pillar and the design load applied to the pillar.

Goaf

The extracted area that the immediate roof or part of the overburden collapses into. The overlying rock then sags and re-compresses the collapsed rock or 'goaf', which subsequently results in a subsidence 'trough' at the surface.

Horizontal Displacement

The horizontal movement of a point after subsidence has occurred above an underground mining area.

Mining Height

The height at which the seam is mined or extracted.

Panel Width

The width of an extracted area between the chain pillars.

Production Panels

Refers to panels of coal, which are subject to second workings or within which pillars are extracted, stripped or lifted.

Secondary Extraction or Second Workings

The extraction or stripping of production panel coal pillars in a controlled manner, which may or may not result in the formation of 'goaf' as the support to the immediate roof is removed.

**Stook**

The relatively small portion of a stripped or secondary workings pillar which provides support to the mine workings roof during mining and expected to collapse as the mining face retreats away from it. Some reduction in subsidence is expected to occur above second workings pillars due to the presence of stooks.

Strain

The change in horizontal distance between two points on the surface after mining, divided by the pre-mining distance between the points.

i.e. $\text{Strain} = ((\text{post-mining distance between A and B}) - (\text{pre-mining distance between A and B})) / (\text{pre-mining distance between A and B})$ and is usually expressed in mm/m.

Sub-Critical Panel Width

A term used to define secondary extraction panel widths that have lower width (and hence less subsidence) than the critical panel width.

Subsidence

The difference between the pre-mining surface level and the post-mining surface level at a point, after it settles (vertically) above an underground mining area.

Subsidence Control

Reducing the impact of subsidence on a feature by reducing the amount of coal extracted so that the impact is within safe, serviceable and repairable limits (normally applied to sensitive natural features or residential structures that can't be protected by mitigation or amelioration works).

Subsidence Impact

The effect that subsidence has on natural or man-made surface and sub-surface features above a mining area.

Subsidence Management Plan

Refers to the approval process for managing coal mine subsidence impacts in accordance with the Department of Primary Industry Guidelines. The mine must prepare a Subsidence Management Plan (SMP) to the satisfaction of the Director-General prior to the commencement of operations which will potentially lead to subsidence of the land surface. Individual stakeholder SMPs are then usually developed between the mine and the stakeholders after consultation with the DPI.

Subsidence Mitigation/ Amelioration

Modifying or reducing the impact of subsidence on a feature so that the impact is within safe, serviceable and repairable limits (normally applied to moderately sensitive man-made features that can tolerate a certain amount of subsidence).

Super-critical Panel Width

A term used to define secondary extraction panel widths that are wider than the critical panel width and will have subsidence equal to the critical width, regardless of the width of the panel.

Tensile Strain (see also Strain)

Indicates that the distance between two points on the surface has increased and can cause cracking at the surface. Tensile strains are usually associated with convex bending (curvature) near the sides (or ends) of the panels.

Tilt

The rate of change of subsidence between two points (A and B) that are measured at a known distance apart (usually 10 m). The tilt is plotted at the mid-point between the points.

i.e. $\text{Tilt} = (\text{subsidence at point A} - \text{subsidence at point B}) / (\text{distance between the points})$ and is usually expressed in mm/m.

At Golder Associates we strive to be the most respected global company providing consulting, design, and construction services in earth, environment, and related areas of energy. Employee owned since our formation in 1960, our focus, unique culture and operating environment offer opportunities and the freedom to excel, which attracts the leading specialists in our fields. Golder professionals take the time to build an understanding of client needs and of the specific environments in which they operate. We continue to expand our technical capabilities and have experienced steady growth with employees who operate from offices located throughout Africa, Asia, Australasia, Europe, North America, and South America.

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