BYRNES GEOTECHNICAL

BMA

Geotechnical considerations for closure of underground mines at BMA Blackwater.

REPORT: BMA-10 BLACKWATER PRCP

Date: 11/03/2024

Dr Ross Seedsman RPEQ

Byrnes Geotechnical Pty Ltd
39 Stones Road Mount Kembla NSW 2526
Mobile: 0418 266 401
Email: byrnesgeotech@bigpond.com

Executive Summary

The purpose of this report is to fulfill the requirements of the PRCP guideline pertaining to UG mines and identifies geo-technical hazards and provides recommendations which are secondary to any requirements under Queensland mining legislation.

Most of the workings in Laleham and Kenmare should now be in a stable condition given that the end of underground mining was more than 20 years ago. There is a negligible hazard of pot-hole subsidence in the future.

Surface damage in the form of rib parallel tensile cracking is present above both Laleham and Kenmare. The cracks are typically 200 mm wide and several metres deep. Where Quaternary sediments are present at the surface, the cracking that developed during pillar extraction at Laleham has been naturally remediated by slumping associated with rainfall.

The portal entries for Sirius Creek No 2 and Clutha should be rehabilitated by removing the existing steel sets and lagging boards and then backfilling. No earth works are recommended for Sirius Creek No 1.

These recommendations are provided for the purpose of planning closure and rehabilitation of Blackwater mines and further and more specific guidance is to be obtained to the specific areas/mines before conducting any operational activities which may be required as a part of these closure recommendations.

Table of Contents

1 Introduction 1
2 Surficial geology 3
3 Underground Mining Operations 4
3.1 Longwalls 4
3.1.1 General comments 4
3.1.2 Kenmare 5
3.2 Pillar extraction mines 7
3.2.1 General comments 7
3.2.2 Laleham 7
3.3 Bord and pillar mines 7
3.3.1 Sirius Creek Mines 7
3.3.2 Ballamoo Mine 11
4 Stability assessment 12
4.1 Laleham pillars 13
4.2 Flooding Impacts on pillar stability 16
5 Surface deformations 16
5.1 Subsidence prediction and visualisation 16
5.2 Mining subsidence 17
5.3 Surface cracking 20
5.4 Possibility of post-closure subsidence 24
6 Groundwater 25
6.1 Current water level 25
6.2 Flooding of undergrounds 26
6.3 Hydraulic conductivity 27
7 Rehabilitation strategies 28
7.1 Rib parallel cracks 28
7.2 Face parallel or arcuate cracking 29
7.3 Seals and Bulkheads 29
7.3.1 Kenmare 1 30
7.3.2 Kenmare 2 30
7.3.3 Laleham 30
7.3.4 Sirius Creek No 1 30

7.3.5 Sirius Creek No 2 30
7.3.6 Clutha 31
7.4 Shafts 31
7.5 Exploration Holes 31
7.6 Underground service holes (drop holes, pump holes) 32
8 Mine Closure Requirements 32
9 Monitoring 32

List of Figures

Figure 1 Mine plans for Laleham and Kenmare undergrounds. 2
Figure 2 Seam Correlation Diagram of Blackwater Area. 2
Figure 3 Surface geology – Laleham and Kenmare. 3
Figure 4 Surficial geology - Sirius Creek No 1 No 2. 4
Figure 5 General nature of longwall subsidence. 5
Figure 6 Layouts of longwall extraction by mined seam (insert shows location relative to lease boundary). 6
Figure 7 Underground mining by seam at Laleham. 8
Figure 8 Plan view image of a Wongawilli pillar extraction layout with double sided lifting and BLS units (source Galvin: op. cit.). 9
Figure 9 Underground layouts by seam for Sirius Creek Undergrounds. 10
Figure 10 a) Layouts for Sirius Creek No 1 (pit bottom at 320 m depth) and b) No 2 (pit bottom at 200 m depth) 11
Figure 11 Ballamoo pit and underground workings will be buried by backfill. 12
Figure 12 Depth to Pollux Seam and location of pillar stability analyses (larger fonts indicate pillars of marginal stability). 14
Figure 13 Depth to Aries Seam roadways near the entry to Kenmare 1. 15
Figure 14 Subsidence information from a pillar extraction panel at Laleham Colliery (from Wardle 1993). 17
Figure 15 Visualisation of vertical subsidence at Laleham and Kenmare. 18
Figure 16 Visualisation of likely horizontal strain at Laleham and Kenmare.. 19
Figure 17 Frequency statistics on total area exposed to mine subsidence as defined by a prediction of vertical subsidence in excess of 20 mm.. 19
Figure 18 Typical areal distribution of surface cracking, dots indicate noticeable compressive humps (LW4 Cook Colliery ACARP C1311). 20
Figure 19 Mechanism and examples of rib parallel cracks. 21
Figure 20 Mechanism and examples of face parallel cracking. 22
Figure 21 Location of sites inspected in May 2023 relative to the prediction of tensile strain and the surface geology (Qrc boundary moved to better represent observations). 23
Figure 22 Possible additional subsidence if pillars collapse. 24
Figure 23 Location of holes monitoring groundwater in Laleham and Kenmare 1. 25
Figure 24 Framework of the geotechnical model for fracturing. 26
Figure 25 Physical and conceptual models for fracturing between seam and surface. 27
Figure 26 Hydrogeology model – fracturing. 28

Figure 27 Schematic of general strategy to remove safety hazard associated with subsidence cracks in duricrust. 29
Figure 28 Possible areas of face parallel subsidence fractures in the Kenmare and Laleham areas as defined by subsidence greater than 2.0m. 29
Figure 29 Kenmare Aries portal. 30
Figure 30 Kenmare 1 ventilation shaft. 31

List of Tables

Table 1 Pillar stability thresholds 13
Table 2 Kenmare and Laleham Pillar Stability Analyses 15

1 Introduction

The guidelines for Progressive Rehabilitation and Closure Plans (PRCP) as they relate to underground mining require a geotechnical study that must include:

- an assessment of post closure stability of the workings
- proposed methods for sealing-off of surface access to the workings
- the extent of post-closure subsidence
- subsidence modelling to inform rehabilitation strategies and milestones.

The long-term closure impacts are primarily changes in surface topography. Most of these will develop within 1-2 years after mining and need to be considered for progressive rehabilitation.

After mining there will be recovery of the groundwater levels as the ground water stabilises back into the underground voids and reaches equilibrium. This will then represent a significant change in the geotechnical environment within the underground workings and may lead to additional deformations at the surface.

This report has been compiled for the use within the PRCP and presents the underground related geotechnical issues that require consideration for the legacy and abandoned underground mines within the Blackwater Mine operations.

There are multiple underground mines located within the Blackwater mining leases, all of which were never operated by BMA (Figure 1). They are located within the area known as “South Blackwater” and include:

- Kenmare 1 & 2.
- Laleham Mine.
- Sirius Creek No 1 & No 2.
- Ballamoo Mine.
- Clutha Trial Mine.

The area known as the Clutha trial mine in this report has been known under many names in the history of the site. For all purposes in this document, it will be maintained as Clutha Trial mine.

The operations that resulted in surface subsidence are Kenmare (longwall) and Laleham (bord and pillar and pillar extraction). Both mines extracted coal from the Aries Seam and the underlying Pollux Seam (Figure 2).

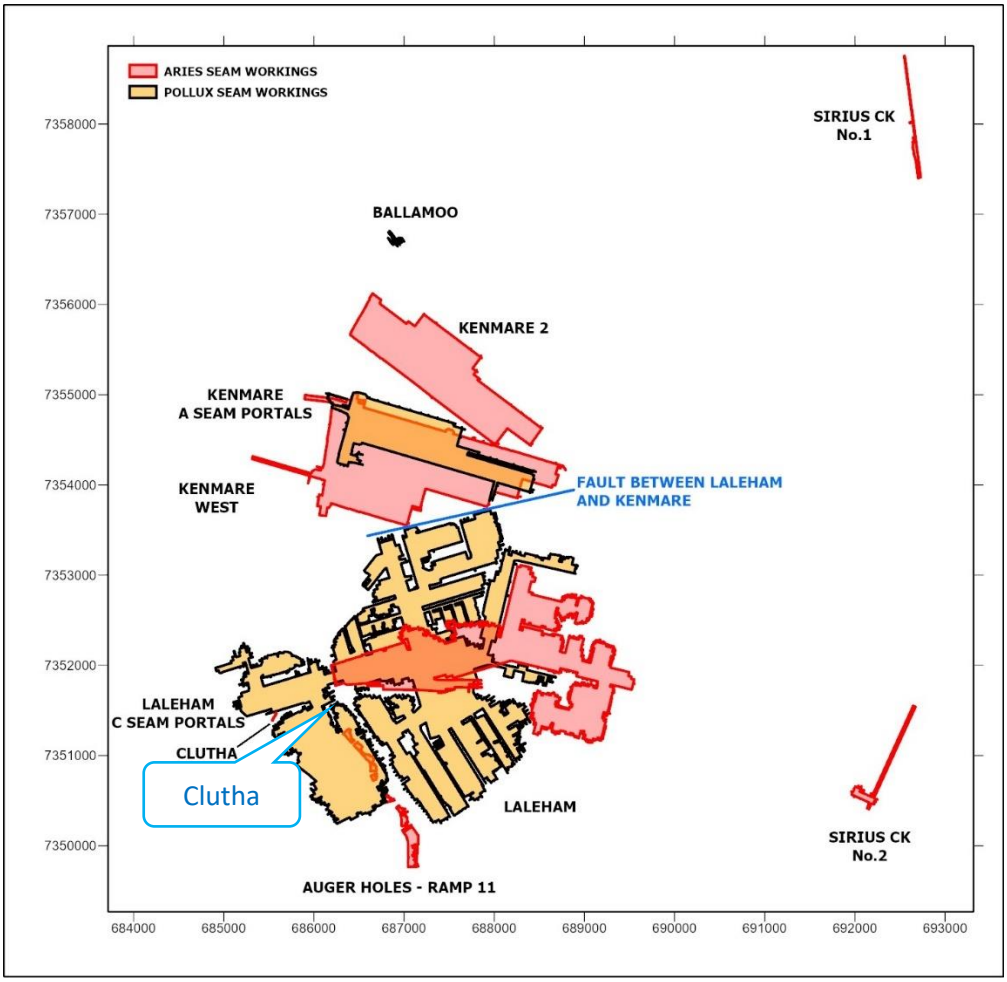


Figure 1 Mine plans for Laleham and Kenmare undergrounds.

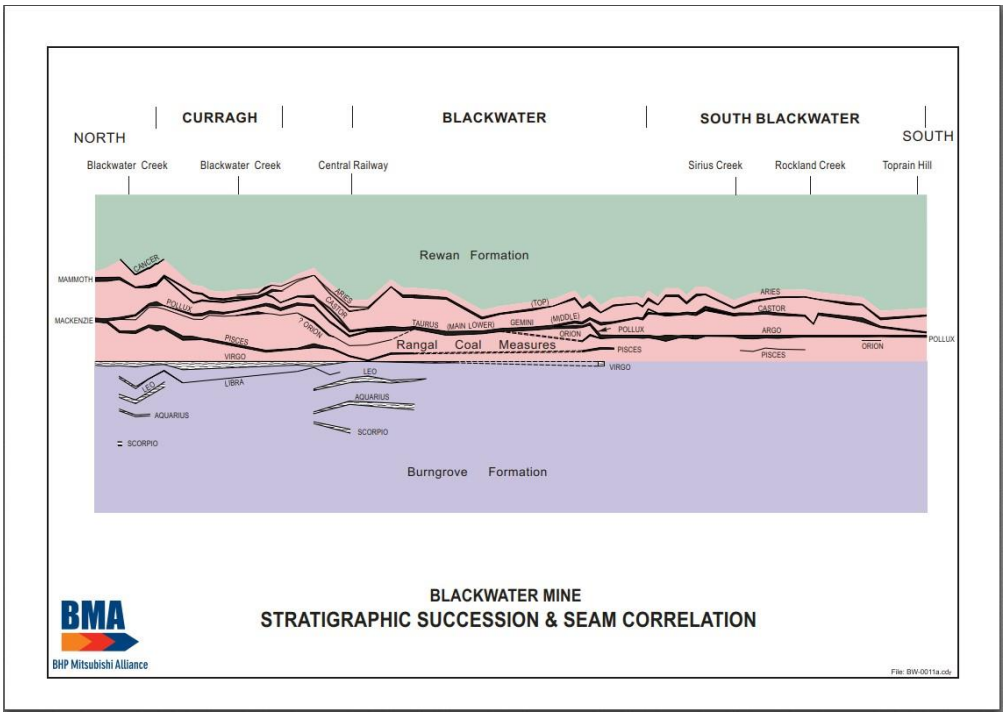


Figure 2 Seam Correlation Diagram of Blackwater Area.

2 Surficial geology

The impact of mine subsidence deformations on post-mining land use depends in part on the nature of the geological materials at the surface. Maps of the surface geology/soils (Figure 3 and Figure 4) indicate the presence of 5 different units.

- Qrc – Quaternary, colluvium and or residual deposits, talus, scree, sheet wash, boulder, gravel, sand.
- Czl – Cainozoic, Ferruginous duricrust, laterite, may include massive to pisolitic subsoil, mottled clays.
- Czoem – Eocene, Emerald Formation – fluviatile and lacustrine claystone and siltstone, quartzose sandstone, pebbly sandstone, gravel, lignite, oil shale, interbedded basalt, all deeply weathered.
- Rsr – Triassic Rewan Group, Lithic sandstones, green to reddish brown mudstone.
- Pok – Permian Blackwater Group, coal measures.

The ability for subsidence cracks to "self-heal" after rainfall depends on the surface geology and topography. It has been observed throughout BMA sites that where there is a loose surface soil, it becomes more easily rehabilitated and soil can settle into the cracks naturally during rain events. However, where there is a duricrust or rock at the surface (for example Czl), it is less likely that natural self-healing will occur over time, and the rain may increase the erosion risks in these areas.

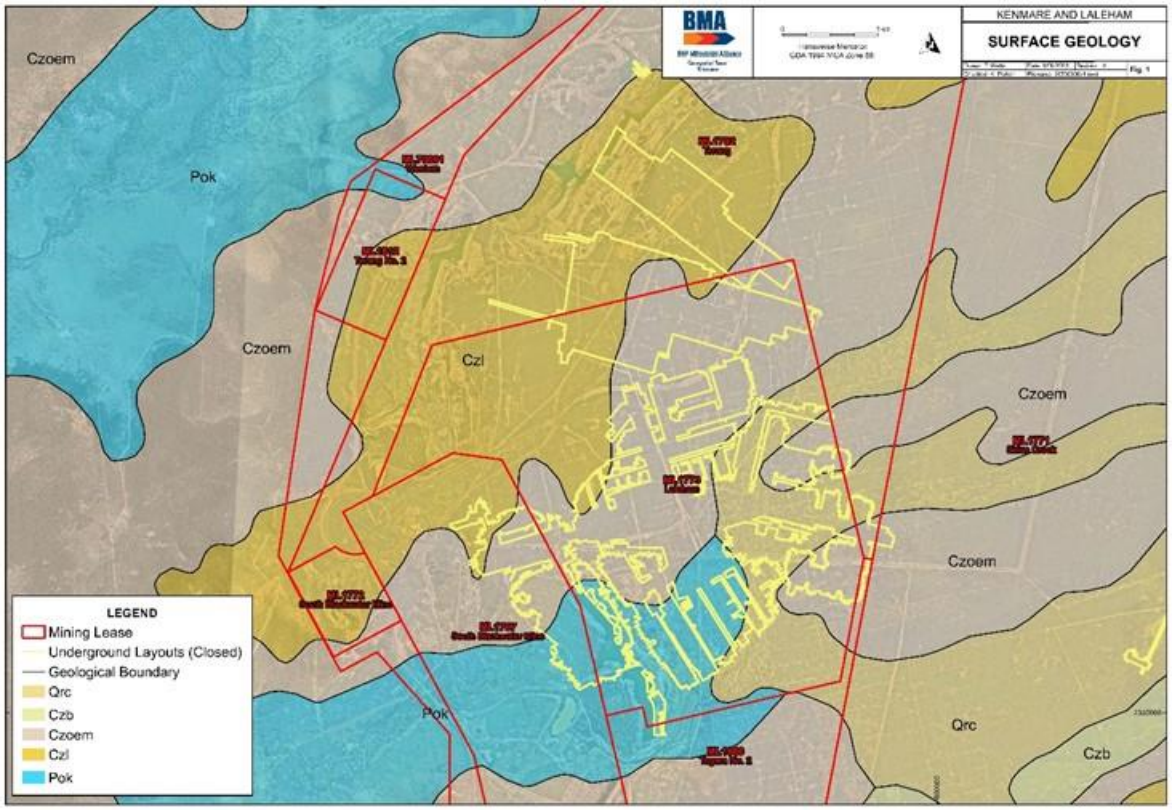


Figure 3 Surface geology – Laleham and Kenmare.



Figure 4 Surficial geology - Sirius Creek No 1 No 2.

3 Underground Mining Operations

A number of different underground mining methods were utilised at BWM:

- Kenmare 1 & 2 – Longwall
- Laleham Mine – Pillar extraction and bord and pillar
- Sirius Creek No 1 & No 2 – Bord and pillar
- Ballamoo – Bord and pillar (headings only)
- Clutha Trial Mine – (single 80m heading in Laleham area)

3.1 Longwalls

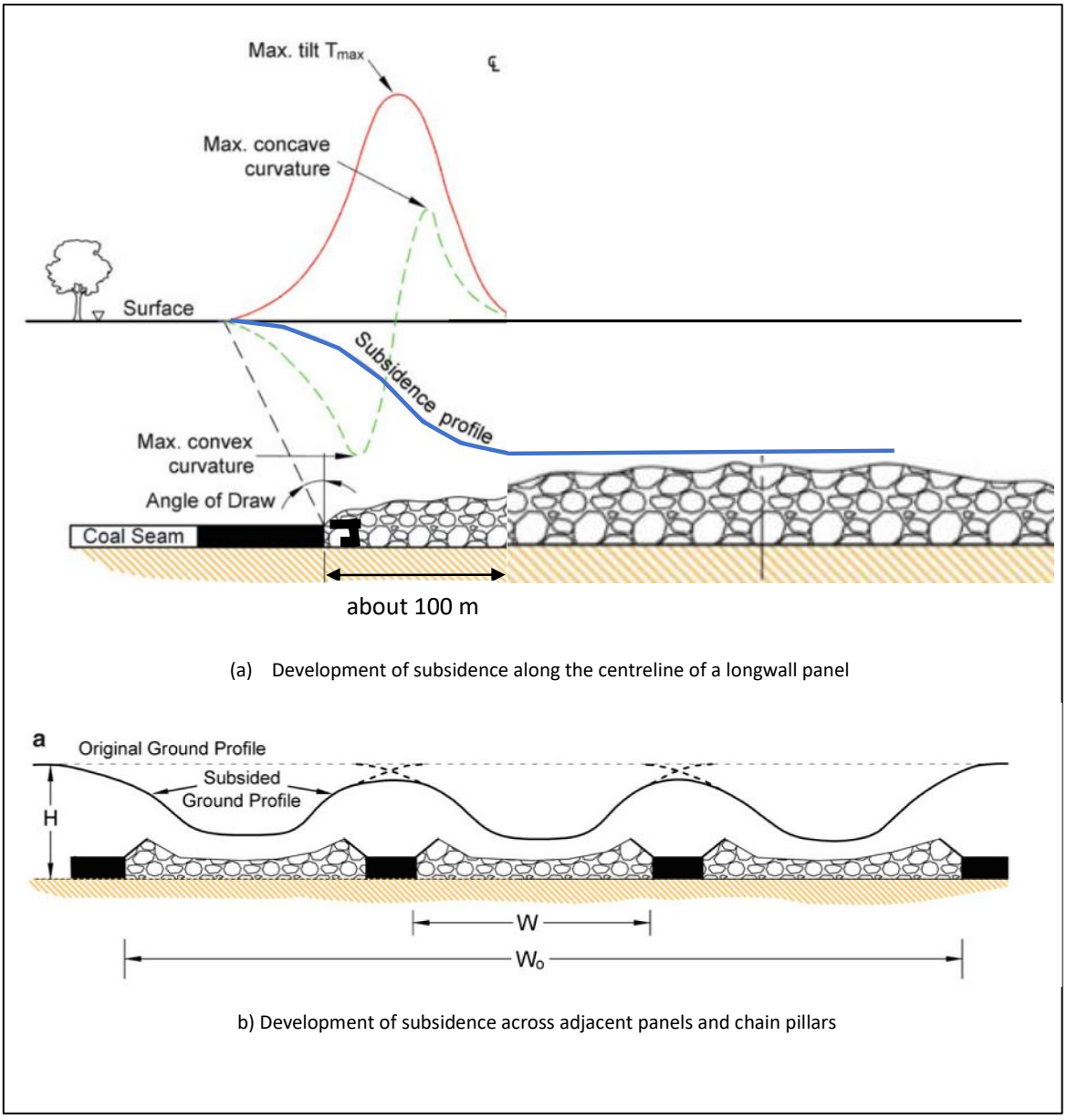
3.1.1 General comments

Inherent in safe and productive longwall mining is the collapse of the rock mass above the extracted coal. This collapse may extend to the surface if the width of the extraction relative to the depth of mining exceeds about 0.5. The width:depth ratio for the Kenmare longwall mine means that substantial vertical subsidence developed progressively as the longwall retreated. Maximum subsidence likely developed above the extraction within about 100 m of the retreating face, there would also have been a lesser amount of vertical subsidence above the chain pillars that developed independently of that above the extraction (Figure 5).

When the underground workings are flooded there may be a small amount of additional vertical subsidence related to the softening of the caved rock above the extracted coal in the presence of water. This flooding can occur as a direct result of the mine being purposefully flooded, or over time as the ground water recovers from dewatering. The subsidence above the chain pillars is unlikely to increase when the groundwater recovers.

The situation with the mains pillars and roadways is different. These are designed to be stable during the operations – both in terms of roof collapse in the roadways and stability of the pillars. Over time, the roof will likely collapse as the support/reinforcement steel members degrade either in the humid mine air or as the mine floods. The possibility that such collapses could extend to the surface at

shallow depths of cover needs to be considered. The mains pillars are typically designed with high stability factors such that failure over the long term is unlikely. Flooding of the mine may temporarily reduce the stability of the pillars, but eventually their stability will be increased due to a buoyancy effect reducing the loads on the pillars.



(a) Development of subsidence along the centreline of a longwall panel

b) Development of subsidence across adjacent panels and chain pillars

Figure 5 General nature of longwall subsidence[1].

3.1.2 Kenmare

Underground drivEage at Kenmare, accessing the Aries Seam from South Blackwater Ramp 66 South, began in November 1994 and the first longwall panel was extracted between November 1996 and April 1997. Longwall panels were about 203 m wide (Figure 6).

Based on discussions with previous mining and geotechnical engineers based at the underground mines prior to abandonment, there was a large amount of historical monitoring information regarding subsidence above both Laleham and Kenmare. However, it is unable to be located, and

[1] Galvin JM 2016. Ground Engineering: Principles and Practices for Underground Coal Mining. Springer.

hence no subsidence information can be used to validate subsidence predictions. This is not seen as a limitation to a Blackwater PRCP as the major identified hazard is subsidence cracking and the predictions are adequate to locate areas of interest. Some information on rock strengths from the Kenmare operation is available for use[2], but it is minimal.

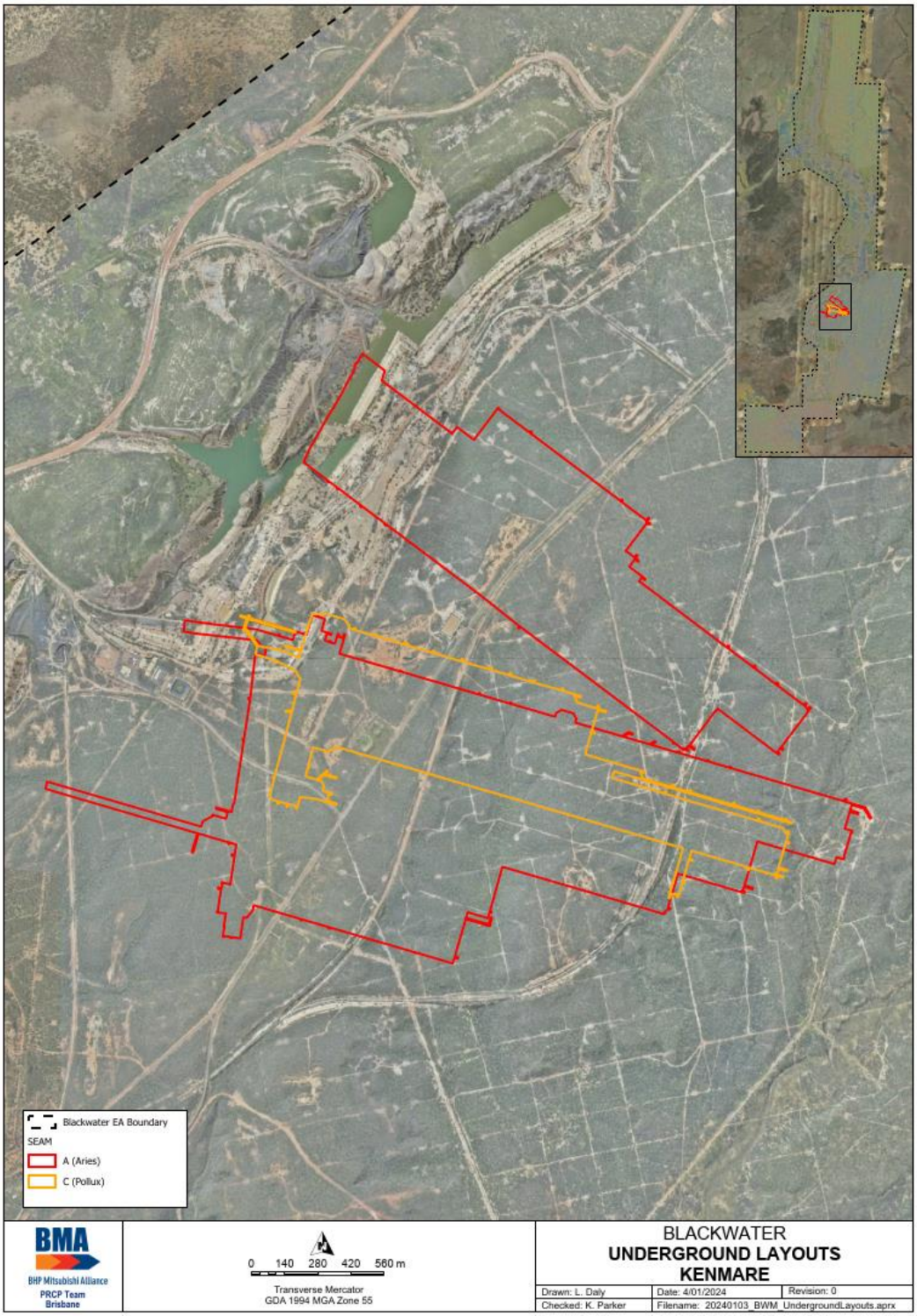


Figure 6 Layouts of longwall extraction by mined seam (insert shows location relative to lease boundary).

[2] Coutts, R. 2001. Kenmare2 - Longwall2, Hazard management exploration programme, Results of Phase 1 & 2

3.2 Pillar extraction mines

3.2.1 General comments

Legacy pillar extraction mines have mains pillars designed similarly to those for longwalls and also have some areas where pillars may have lesser stability and some areas where the pillars have been extracted. Where the pillars have been extracted surface subsidence may have developed in the same way as for longwalls. There is a possibility that in some areas where the pillars have been extracted the extracted width was insufficient to cause complete subsidence to the surface – such areas may collapse over time.

There may be cases where very high/narrow pillars were formed during the extraction operation resulting in pillars with low stability and the possibility of collapse within a 100-year time frame. Whether such a collapse could extend to the surface needs to be examined.

3.2.2 Laleham

At Laleham, pillar extraction was conducted in the Pollux Seam and only bord and pillar operations were conducted in the Aries Seam (Figure 7).

The Laleham underground bord and pillar mine began in the Pollux Seam in 1969 and was accessed by two drifts, approximately 150 m long. Various methods of pillar extraction were carried out, mostly using timber as ground support, but towards the completion of mining in the Pollux Seam, breaker line supports (BLS) were utilised in a Wongawilli layout (Figure 8) which results in a layout somewhat analogous to a longwall.

At around the same time that Kenmare began operations, Laleham accessed the Aries Seam with an interseam drift from the Pollux Seam and successfully mined several bord and pillar panels using place-change development systems with no pillar extraction.

3.3 Bord and pillar mines

Legacy bord and pillar mines such as the Sirius Creek operations (Figure 9) can be considered in the same context as mains pillars in the longwall mines with regards to stability.

Flooding of the bord and pillar workings will have the same effects as for longwalls.

3.3.1 Sirius Creek Mines

Sirius Creek No 1 (Figure 10a) was a 900 m single entry until it intersected the Aries Seam at about 300 m depth where a line of 18 m wide pillars were formed. Being a single row of pillars, their stability is very high – it is assessed that these will never collapse and there will be no associated surface subsidence.

Sirius Creek No 2 (Figure 10b) utilised 2 of 6 m wide roadways with a 15.2 m wide pillar until it intersected pit bottom at about 200 m depth, at which point pillars were formed on 30 m centres (24 m solids). The limited lateral extent of the pillars, together with their width means that they have high levels of stability – it is assessed that these will never collapse and there will be no associated surface subsidence. The site inspection revealed a pothole has developed through the fill material placed above the original portal canopy.



Figure 7 Underground mining by seam at Laleham.

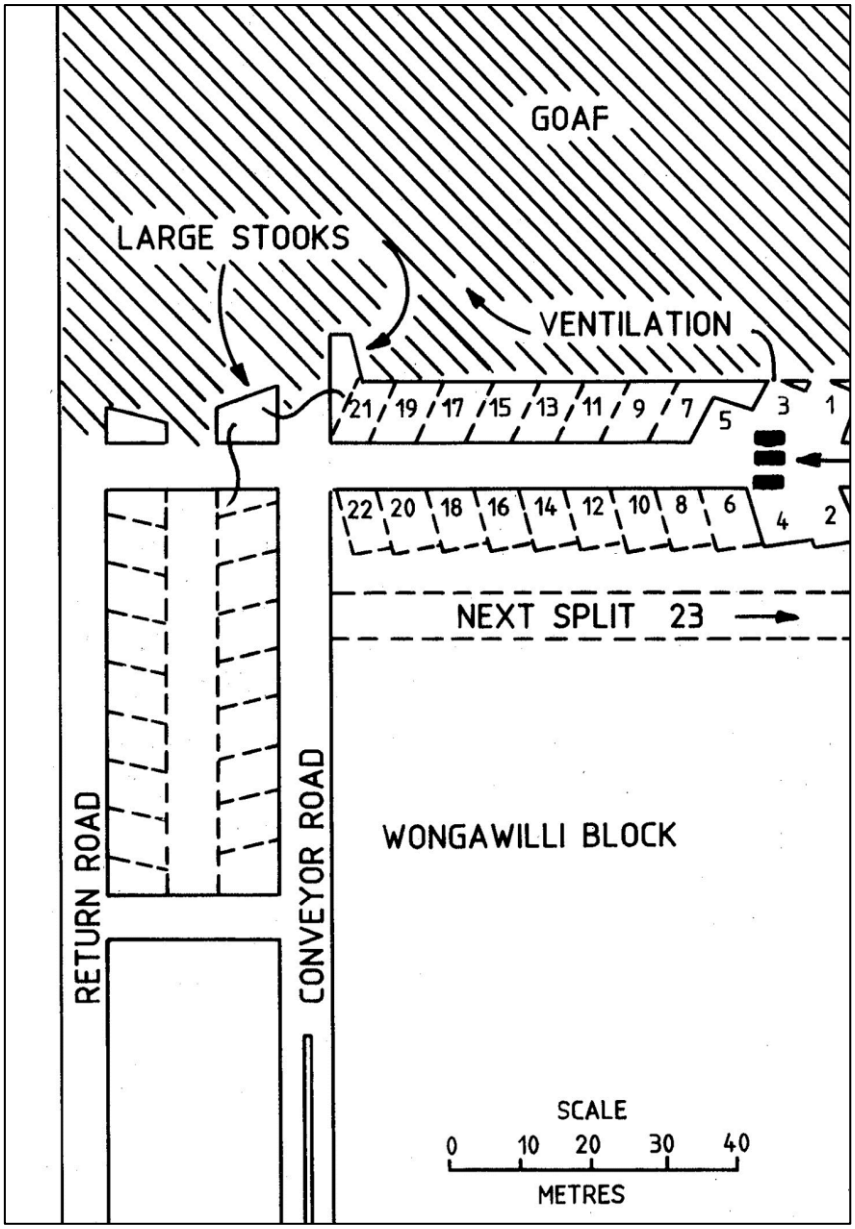
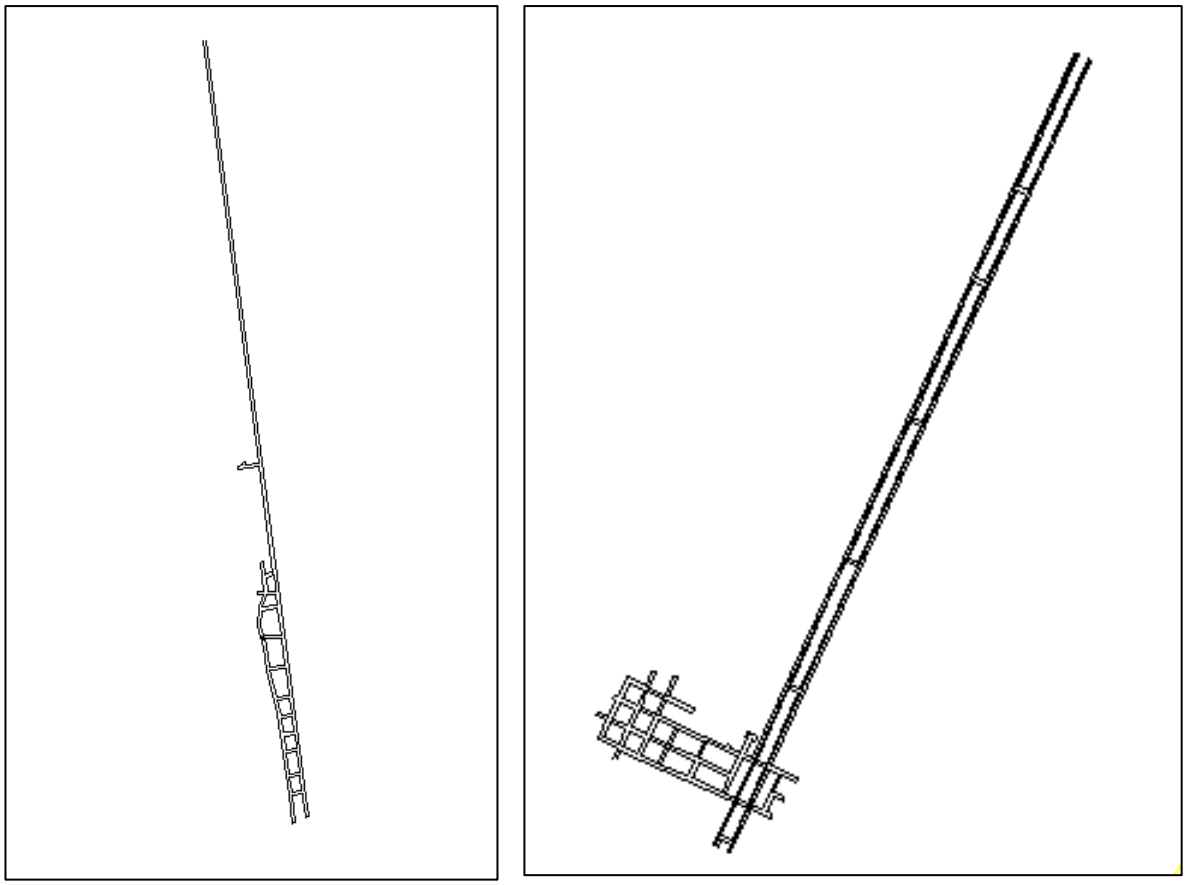


Figure 8 Plan view image of a Wongawilli pillar extraction layout with double sided lifting and BLS units (source Galvin: op. cit.).



Figure 9 Underground layouts by seam for Sirius Creek Undergrounds.



Sirius Creek No 1 Sirius Creek No 2

Figure 10 a) Layouts for Sirius Creek No 1 (pit bottom at 320 m depth) and b) No 2 (pit bottom at 200 m depth).

3.3.2 Ballamoo Mine

The Ballamoo mine extended about 190 m from the Ballamoo highwall and involved 5 headings: no pillars were formed (Figure 11). The headings were located on 30 m centres with 7 m wide roads. The current closure plan is that they will be buried with backfill. The maximum mining depths were in the order of 50 m, no pillar instability is anticipated even when they are buried by backfill.

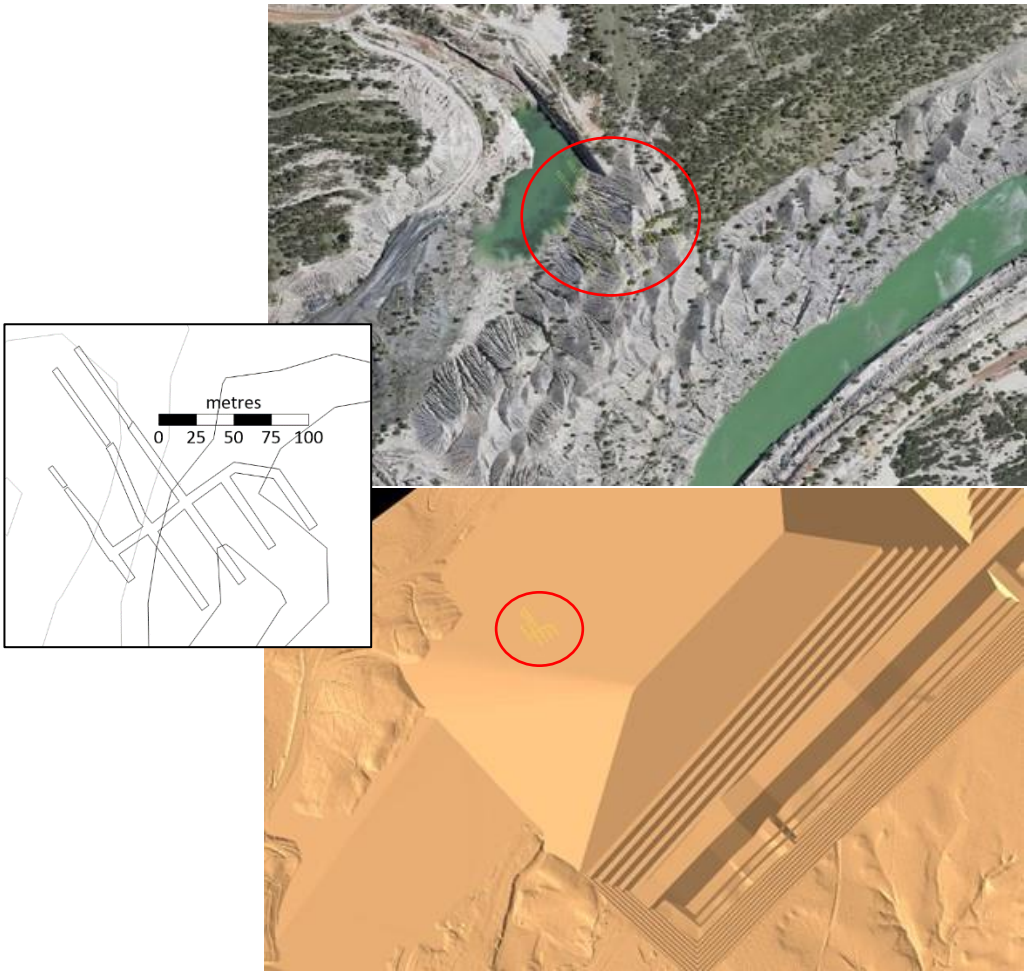


Figure 11 Ballamoo pit and underground workings will be buried by backfill.

4 Stability assessment

An assessment of the current and ongoing stability of the underground workings is critical to understanding the subsidence risk at closure. Specifically, there is a need to consider possible impacts on the post mining land use related to further pillar collapse or further roof collapse.

For operational reasons the pillars in the main access roadways (Mains pillars) were designed with high levels of stability and a design life in excess of 50 years. Typically, Mains pillars are dimensioned with a factor of safety in excess of 2.0 and there is an industry conjecture that the probability of failure is better than 1:1 000 000. It is valid to conclude that these Mains pillars have not and will not collapse.

In both legacy pillar mines and the longwall mines there are pillars that were designed to collapse as an integral part of the mining system, for example longwall chain pillars and some pillars in pillar extraction mines. These will have already collapsed and any associated surface subsidence developed.

There are also pillars that have intermediate levels of stability. Typically, during mining operations the heuristics applied to pillar stability relate to a ratio of pillar strength: pillar load. Typical thresholds used for mine design are presented in Table 1:

Table 1 Pillar stability thresholds

Stability	Factor of Safety	Implied probability of collapse within a nominal 50-year periods
Immediate collapse	<1.0	1:1
Short term	>1.2	1:10
Pillar formed on advance	>1.6	1:1 000
Long term	>2.11	1:1 000 000

It is important to emphasise that these factors of safety are derived from a statistical analysis of small databases (n<100) in which there are no collapse cases with a pillar width to height ratio greater than 5.0.

From a rock mechanics perspective, the ultimate strength of a pillar relates to the frictional restraint that can be developed once any cohesive strength is lost (for example by overstressing or weathering). If a very much lower-bound frictional strength of 12° is adopted for coal it would follow that the width to height ratio of a coal pillar would need to be 4.7 for the pillar to completely collapse (by lateral displacement) assuming that the loading is purely vertical; this is similar to the upper bound in the database of failed pillars. From this discussion, our assessment is that for the for bord and pillar workings at Laleham and Kenmare long term stability will be present if the Factor of Safety is greater than 1.6 and/or the aspect ratio of the pillars is in excess of 4.7.

4.1 Laleham pillars

There are pillars at Laleham with stability factors less than 2.0, therefore based on the previous discussion there could be a risk of further collapse. These pillars are located in production panels where only first workings development (beyond the Mains) or pillar splitting was undertaken (Figure 1213). A series of pillar stability analyses have been conducted on these pillars. The pillars examined in the stability analysis, are located in either the Aries or Pollux seams with their specific locations shown in Figure 12. Seam thickness in both the Aries and Pollux Seams ranged from 3.4 m – 3.8 m. A roadway height of 3.6 m has been assumed for this analysis.

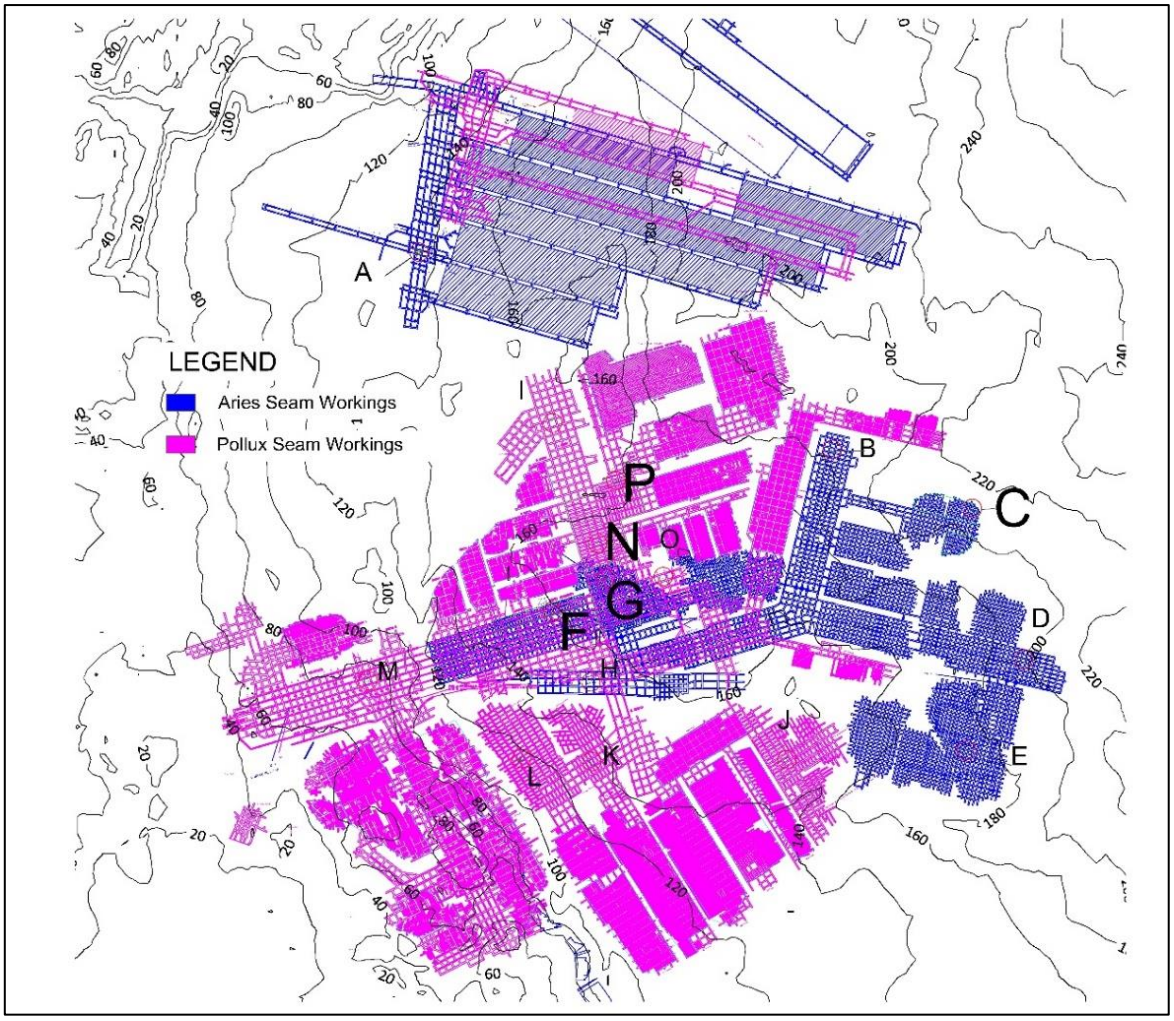


Figure 12 Depth to Pollux Seam and location of pillar stability analyses (larger fonts indicate pillars of marginal stability).

The stability of these pillars has been assessed using either the UNSW power (width to height ratio <5) or UNSW squat (width to height ratio >5) pillar formulae (Table 2). Pillar's C, F, G, N, and P have marginal long-term stability as indicated by low factors of safety results as shown in Table 2. These results indicate that there may be a hazard of further subsidence in these areas within a nominal time frame of 100 years (Section 5.4).

Table 2 Kenmare and Laleham Pillar Stability Analyses

Location	Depth (m)	Width to Height Ratio	Factor of Safety
Pillar A Kenmare Mains	110	5.5	3.58
Pillar B Laleham Aries First Workings 1	150	5.0	2.19
Pillar C Laleham Aries First Workings 2	**170**	**3.1**	**1.14**
Pillar D Laleham Aries First Workings 3	160	4.4	1.70
Pillar E Laleham Aries First Workings 4	140	3.9	1.69
Pillar F Laleham Aries First Workings 5	**120**	**2.8**	**1.58**
Pillar G Laleham Aries First Workings 6	**130**	**2.5**	**1.27**
Pillar H Laleham Aries Mains	130	9.2	5.08
Pillar I Laleham Pollux 1 North Mains	170	9.0	3.48
Pillar J Laleham Pollux 303 Panel Split Pillars	150	3.8	1.69
Pillar K Laleham Pollux 3 South Panel Split Pillars	140	3.8	1.99
Pillar L Laleham Pollux 4 South Panel	120	3.8	2.30
Pillar M Laleham Pollux East Headings	80	8.1	6.13
Pillar N Laleham Pollux 111 Panel Split Pillars	**165**	**3.5**	**1.39**
Pillar O Laleham Pollux 1 East	170	8.1	3.03
Pillar P Laleham Pollux 100 Panel Split Pillars	**160**	**2.8**	**1.16**

Due to the depths of cover being mostly in excess of 30 m for both the Laleham and Kenmare 2 portal areas, pot-hole risk is highly unlikely to occur. There is only a small section of Kenmare 1 that has a lower depth of cover than this (Figure 13) which means that there is a hazard of pot holing occurring near the mine's entrance and this should be addressed in the plans for the surface mine void.

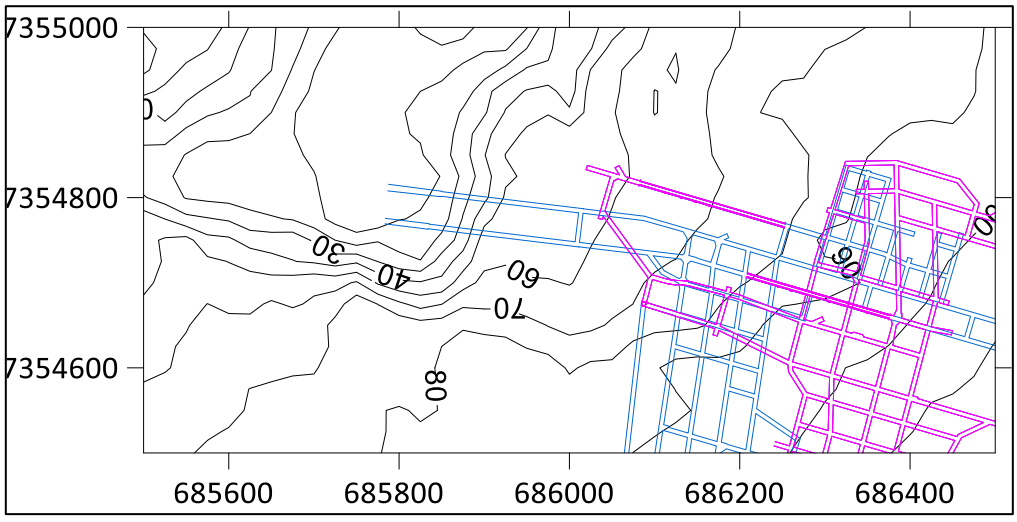


Figure 13 Depth to Aries Seam roadways near the entry to Kenmare 1.

4.2 Flooding Impacts on pillar stability

In the laboratory there is a measurable decrease in uniaxial compressive strength on saturation of coal measure rocks (about 20%). The impact of this on the stability of narrow pillars is in the order of 11% for pillars with width to height ratios of less than four but has not been studied for wider pillars. It is assessed that this strength loss will not add materially to the consideration for the stability of the pillars in Laleham.

There is a possibility of reduction in the floor strength of the roadways which would result in a reduction in the bearing strength of the pillar floor system (Figure 16). The reduction in roadway floor strength may be relatively small so the impact on pillar stability will be minor unless the impacted layer is very thick and initial floor stability was low. The available information on the Aries and Pollux seams[3] suggests that the floor strengths are well in excess of those that could be associated with this type of failure mechanism.

In contrast to these reductions in strength, there will be an overall trend for an increase in stability related to a buoyancy effect as the water level rises above the coal seam. The result is that any decrease in stability will be temporary while the material at or below seam level softens and the water level is such that there is no buoyancy effect. Over time as the water level rises above the coal seam level, buoyancy will dominate and stability will increase beyond that at mine closure. It is valid to include consideration of buoyancy when using the available method to estimate pillar loading.

5 Surface deformations

Mining subsidence results in the following deformation and associated impacts at the surface:

- Downward vertical movements.
- Change in surface slope angles.
- Vertical steps and compression humps.
- Surface cracking.

It is noted that the remediation of vertical steps, humps, and cracking is addressed as part of progressive rehabilitation and forms a part of the operational mining activities.

5.1 Subsidence prediction and visualisation

There are many tools for visualising the distribution of vertical subsidence, tilt, and curvature, all require a prediction of the maximum vertical subsidence which can only be derived from surveys of mines in the same geological regime. In this report the SDPS influence function method[4] has been used.

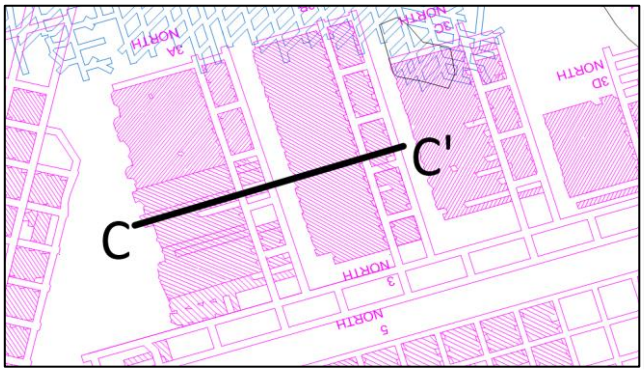
Documented subsidence information has been located, related to a 110-125 m wide pillar extraction panel at Laleham mine at a nominal 150 m depth[5]. This survey was conducted before Panel B was fully extracted; the information from Panel A is consistent with other subsidence results in the

[3] Gordon N. Optimisation of strata reinforcement at Kenmare Colliry. Coutts R 2001. Kenmare 2 – Longwall 2. Hazard Management Exploration Programme, Results of Phase 1 & 2.

[4] Surface Deformation Prediction System (SDPS) Software | Office of Surface Mining Reclamation and Enforcement (osmre.gov)

[5] Wardle, LJ. 1993. The use of numerical modelling for underground coal mine design. Chapter 28 in Volume 2, Analysis and Design Methods, Comprehensive Rock Engineering, pp 733-948

Bowen Basin allowing more recently derived generic parameters to be applied when predicting these values.



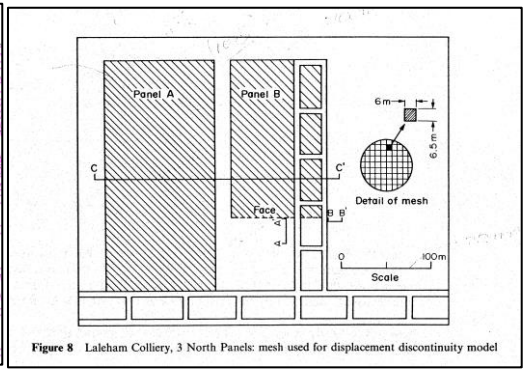


Figure 8 Laleham Colliery, 3 North Panels: mesh used for displacement discontinuity model

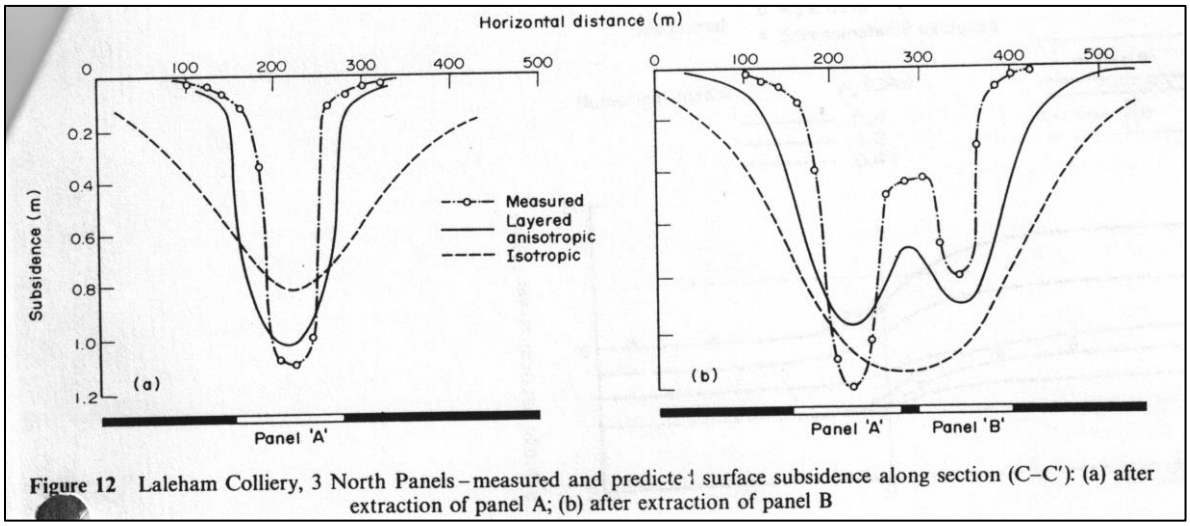


Figure 12 Laleham Colliery, 3 North Panels – measured and predicted surface subsidence along section (C–C'): (a) after extraction of panel A; (b) after extraction of panel B

Figure 14 Subsidence information from a pillar extraction panel at Laleham Colliery (from Wardle 1993).

5.2 Mining subsidence

The modelled distribution of vertical subsidence is shown in Figure 15 and the horizontal strains shown in Figure 16. For the Laleham Pollux Seam workings it was necessary to make assumptions on the collapse of some of the shallower (early) panels where extensive extraction of bord and pillars workings was completed and likely to have been sufficient to cause surface subsidence.

The maximum vertical subsidence is 2.5 m for single seam extraction and 3.5m for dual seam extraction. The 3.5 m applies only to a small area of Kenmare 1 where mining of both the Aries and Pollux seam was undertaken.

For the vertical subsidence, a cut-off deformation of 20 mm was adopted to define the onset of displacement. Using this definition, there is an estimated area of 3.2 km^2 subsided ground above Laleham and 2.9 km^2 above Kenmare.

For horizontal strain (Figure 16), the presented contours are those in excess of 5 mm/m in either tension or compression to give an insight into areas where visible localised surface deformations may be seen (cracking).

Figure 17 presents frequency plots of the level of vertical subsidence, change in slope, and tensile/compressive strains expressed relative to the area defined by the 20 mm vertical subsidence level. The maximum change in slope is 4.8° (8%). It is anticipated that 20% of the subsided area may

have tensile strains in excess of 5 mm/m and a similar percentage will have compressive strains in excess of 5 mm/m.

The modelling of horizontal strain and inferences on surface deformations was validated by the observed cracking during the May 2023 site inspection.

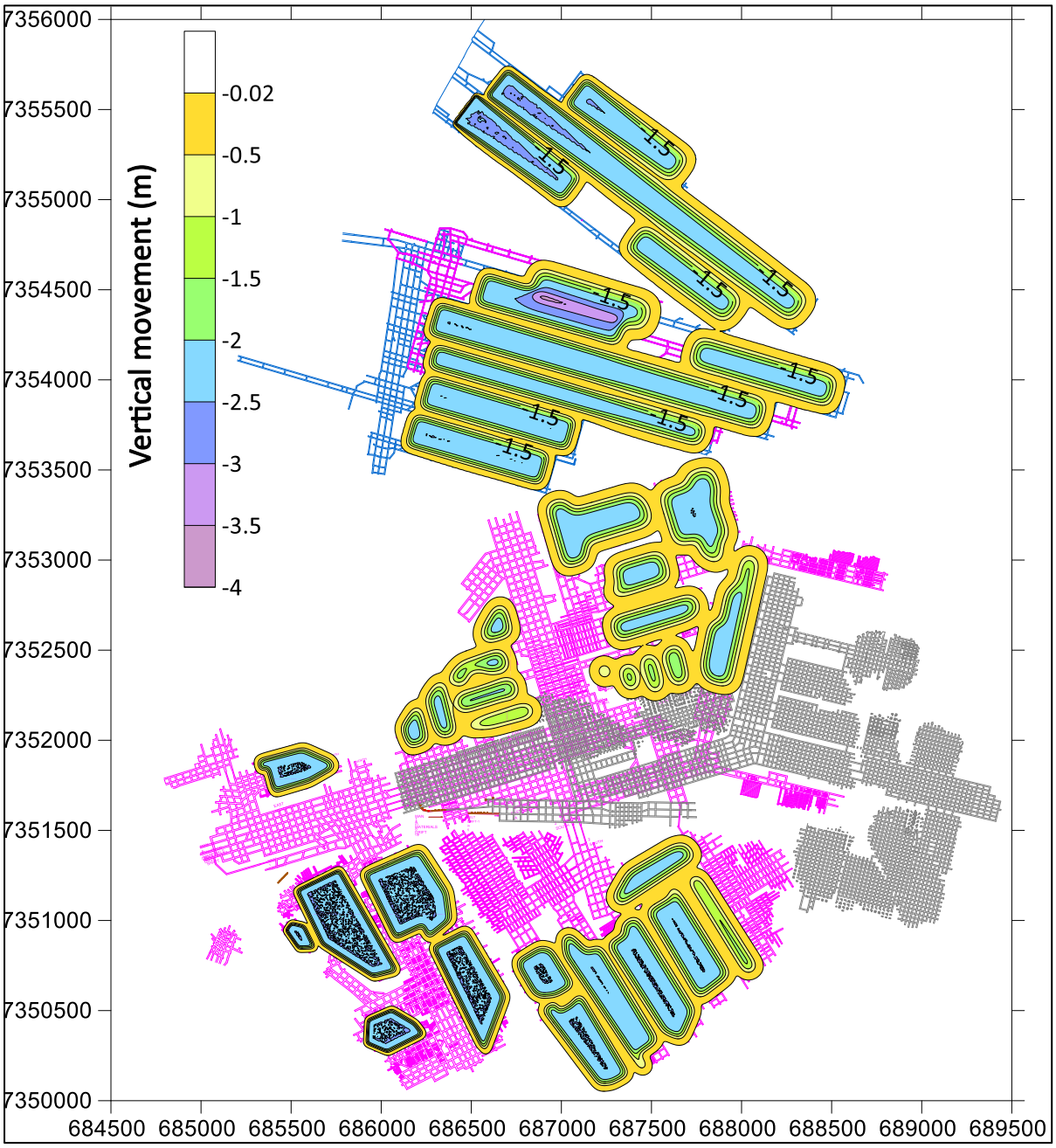


Figure 15 Visualisation of vertical subsidence at Laleham and Kenmare.

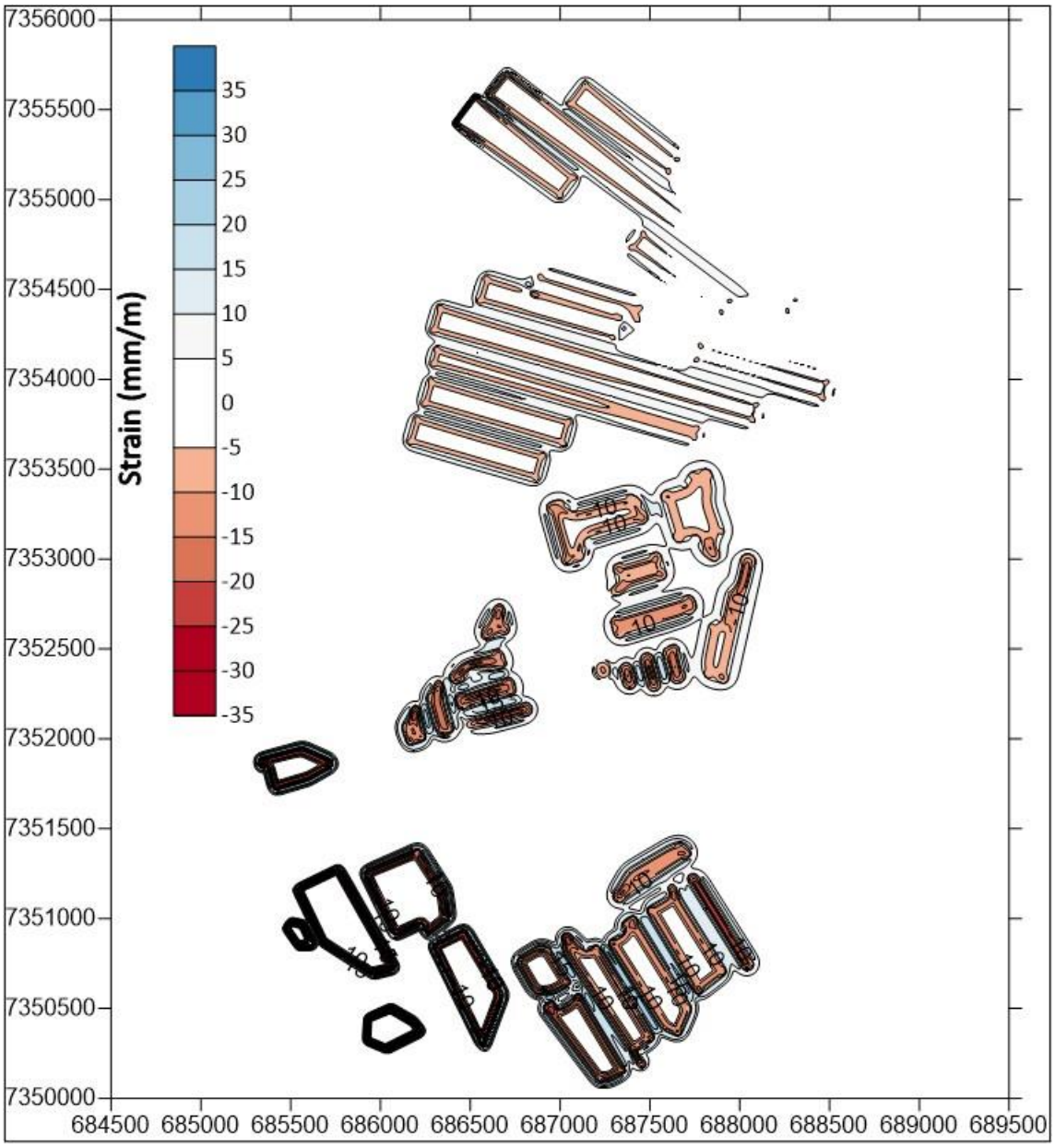


Figure 16 Visualisation of likely horizontal strain at Laleham and Kenmare..

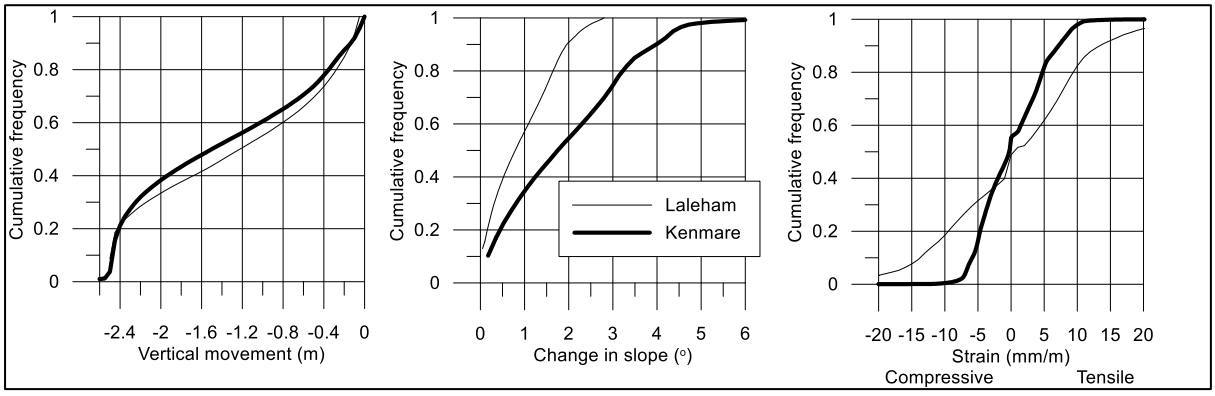


Figure 17 Frequency statistics on total area exposed to mine subsidence as defined by a prediction of vertical subsidence in excess of 20 mm..

5.3 Surface cracking

High levels of tensile strain can lead to the onset of cracking at the surface. There are two end members of cracking – ribs-parallel tensile cracking and face-parallel/arcuate steps (Figure 19).

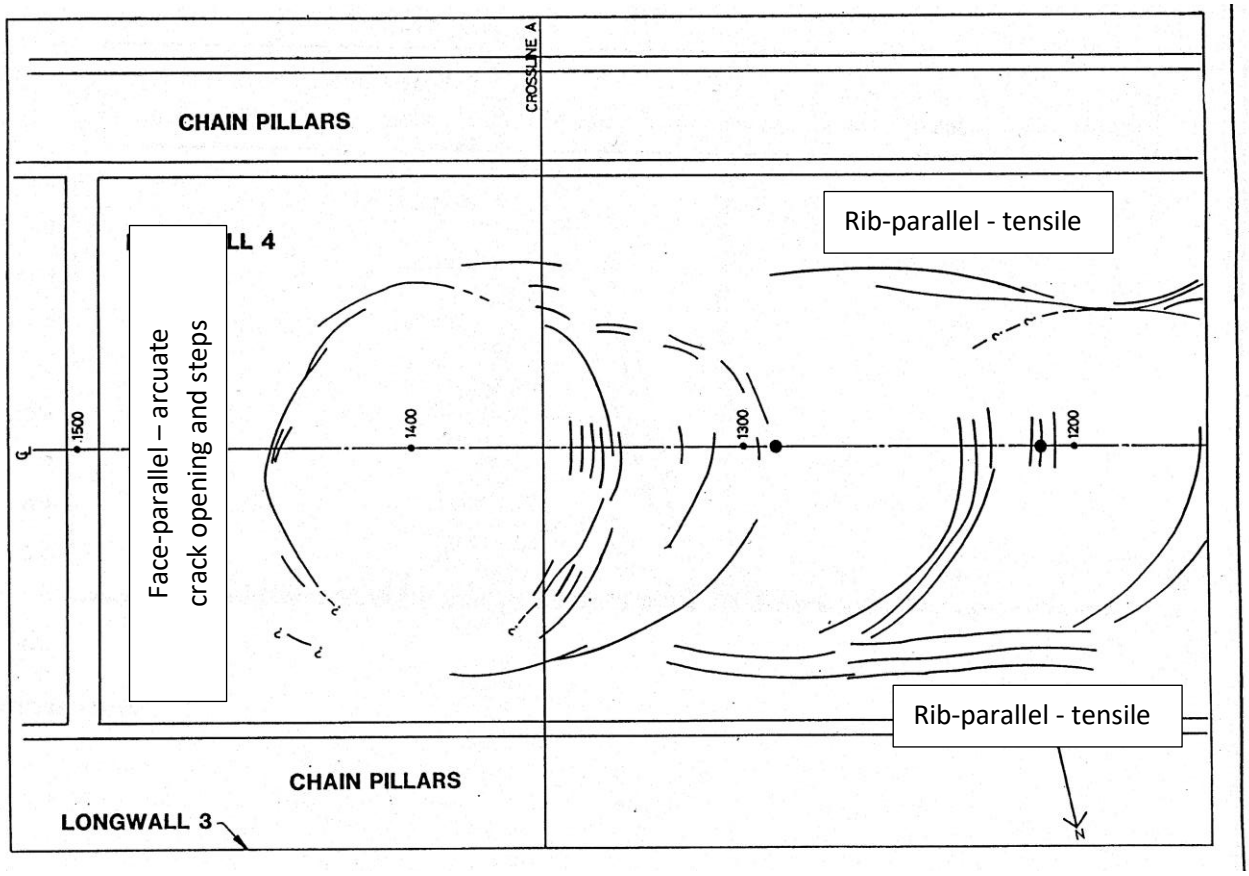


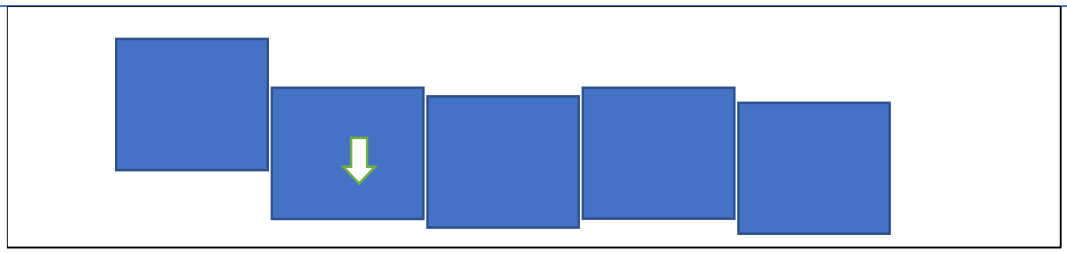
Figure 18 Typical areal distribution of surface cracking, dots indicate noticeable compressive humps (LW4 Cook Colliery ACARP C1311).

The rib-side cracking is perhaps the most obvious and is typically the focus of progressive rehabilitation regimes on most mine sites. Rib cracking is the result of overburden blocks' rotation at the edge of the extraction panel (Figure 19). Both a tensile opening and a compression strain associated with block rotation is experienced. The tensile opening (crack) becomes easily visible at the surface, where the compression strain is usually not clearly discernible.



Figure 19 Mechanism and examples of rib parallel cracks.

The face-parallel deformations are related to periodic vertical collapse (Figure 20) with the collapse somewhat akin to the periodic weighting events experienced at the longwall mining face but at a much smaller scale. As the longwall face retreats the rocks near the surface may temporarily "hang up" but then collapse vertically. The roughness of the interface between the blocks will mean that the blocks will not match perfectly - hence the steps and some opening. As for the rib-parallel cracks, the face-parallel deformations will be apparent through the soil cover but may be ameliorated by rainfall.



Longwall centreline – blocks move downwards (and to a lesser degree sideways) at discrete intervals



Figure 20 Mechanism and examples of face parallel cracking.

Rehabilitation of rib-parallel cracks and face-parallel cracks near the longwall end lines is standard practice at mines in the Bowen Basin.

A reconnaissance survey of subsidence cracking was conducted in May 2023 by inspecting areas of predicted high visualised tensile strain that could be readily accessed on foot. Figure 21 shows the location of observed cracking relative to the visualised tensile strain and the surface geology.

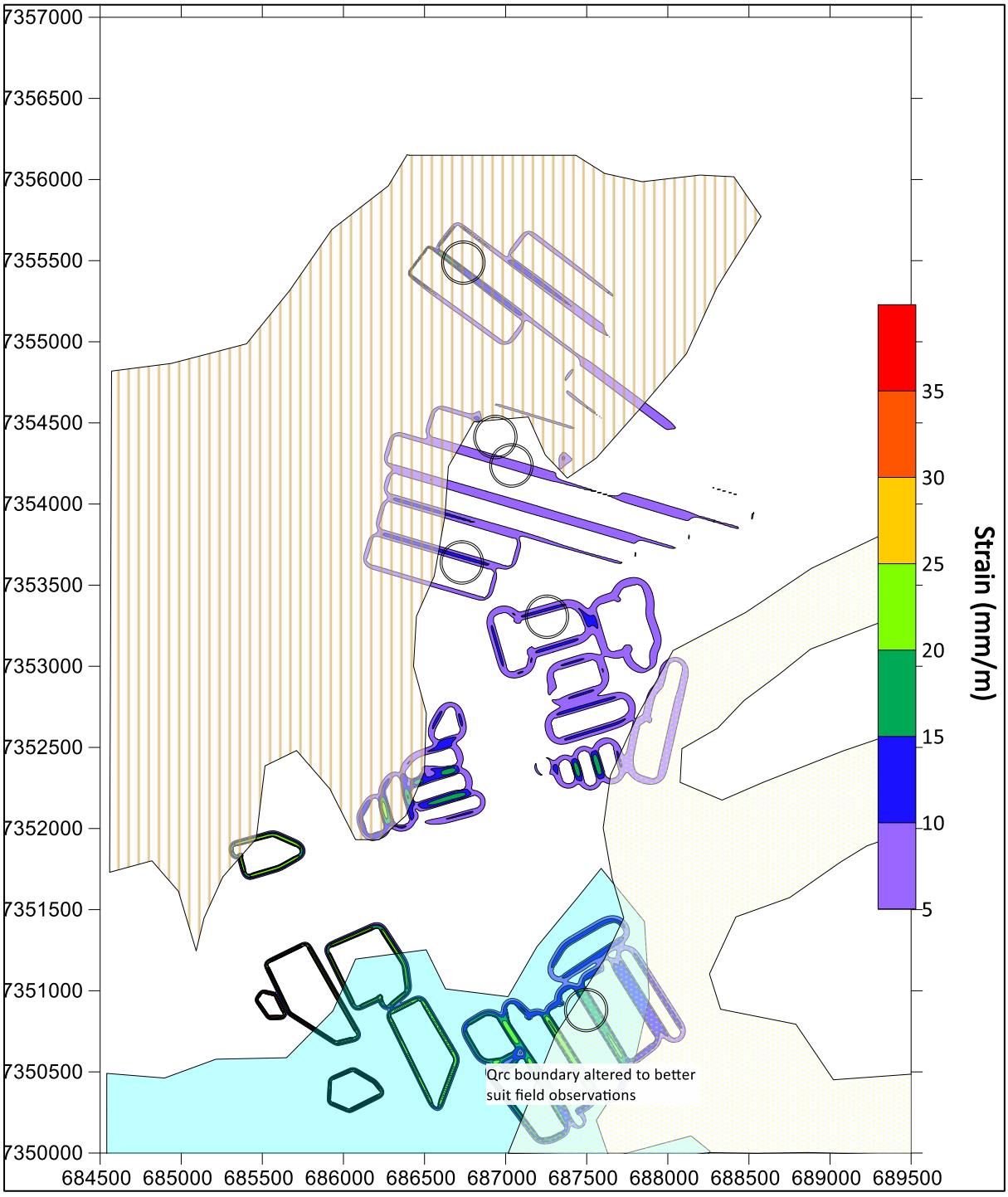


Figure 21 Location of sites inspected in May 2023 relative to the prediction of tensile strain and the surface geology (Qrc boundary moved to better represent observations).

The nature of the rib parallel cracking associated with both, longwall and pillar extraction show cracks up to 200 mm – 250 mm wide with depths sometimes in excess of 2 m.

It was observed during the inspection that the cracking does not appear to have adversely impacted vegetation growth. The mining was concluded in excess of 20 years ago but there is no obvious natural remediation of the cracking; this is attributed to the surface geology – duricrust (Czl) or sandstone/mudstones of the Emerald Formation (Czoem).

The surface above Laleham extraction panels where the surface geology appears to be Quaternary (Qrc) are shallow linear "trenches" which are interpreted to have been large tensile cracks that have "self-healed" over the years through rainfall and sediment migration. Note that the Qrc boundary presented in Figure 21 has been moved to reflect the observations made in May 2023.

5.4 Possibility of post-closure subsidence

Most of the workings in Laleham and Kenmare should now be in a stable condition given that the end of underground mining was more than 20 years ago. Figure 22 indicates the potential for additional vertical subsidence that may develop if additional pillars within the Laleham Aries seam workings collapse (Section 4.1).

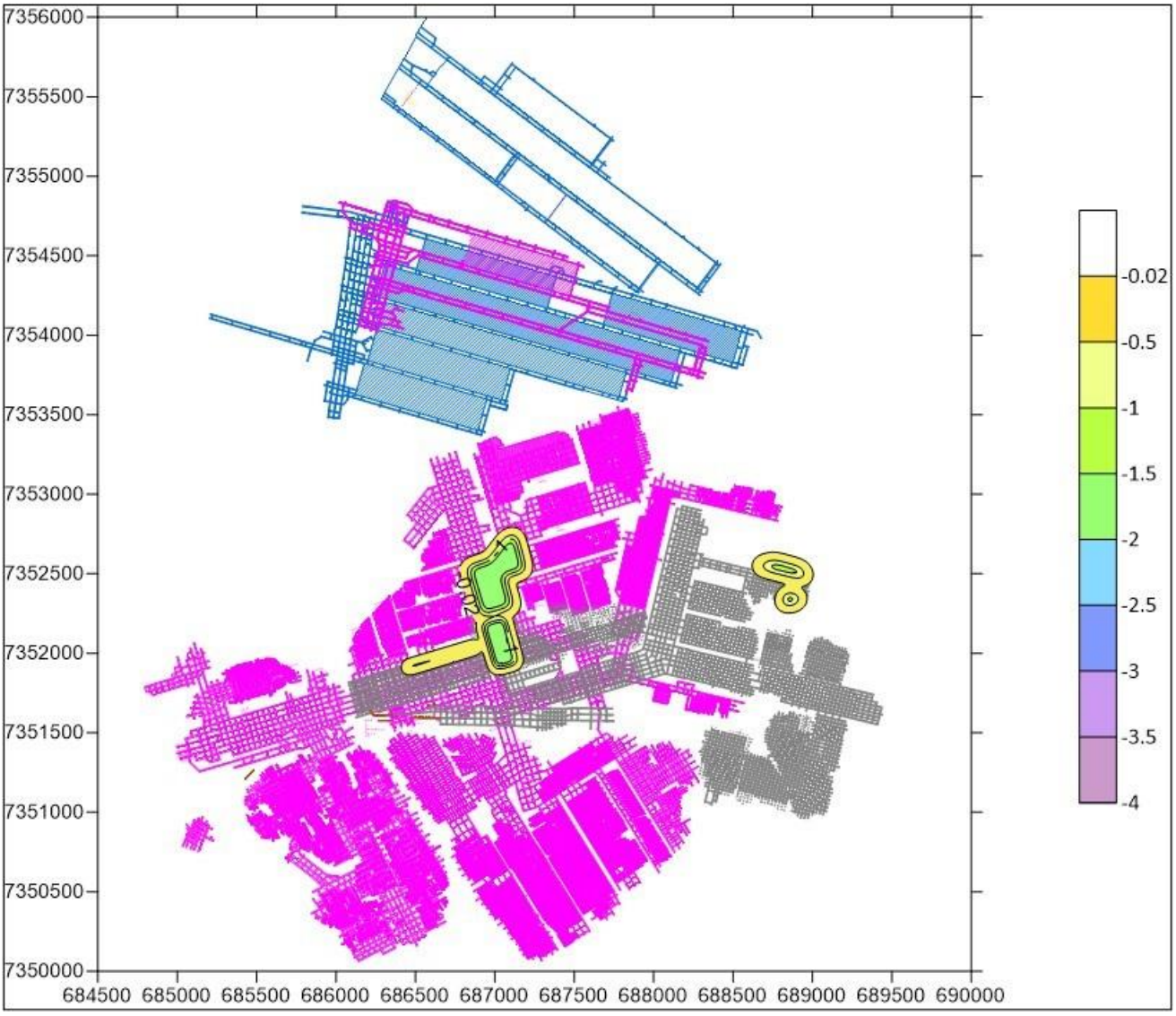


Figure 22 Possible additional subsidence if pillars collapse.

6 Groundwater

6.1 Current water level

In the first week of September 2023, the water level recorded in the pump hole at the inbye end of Kenmare 1 Aries Seam workings (Figure 23) was 21 m below the top of the casing and at an RL of 277.5 m. Assuming that the standing water level is horizontal and that the two seams are interconnected either by longwall caving or cross measure drifts, the standing water level is 3 m below and 37 m east of the Kenmare 1 portal. MB16 is located above the Laleham workings and the water level in this hole is 37.76m below the top of the casing indicating that these working are flooded. From a geotechnical perspective this means that any strength losses due to inundation have already developed and hence no hazard off additional collapses.

Kenmare K2 retreated into an existing surface mine void and there was no attempt to create a hydraulic seal between the surface and underground voids. The minimum separation between K1 and K2 is in the order of 18 m (at E687878, N7354266). It is assessed that K2 can be considered to be flooded.

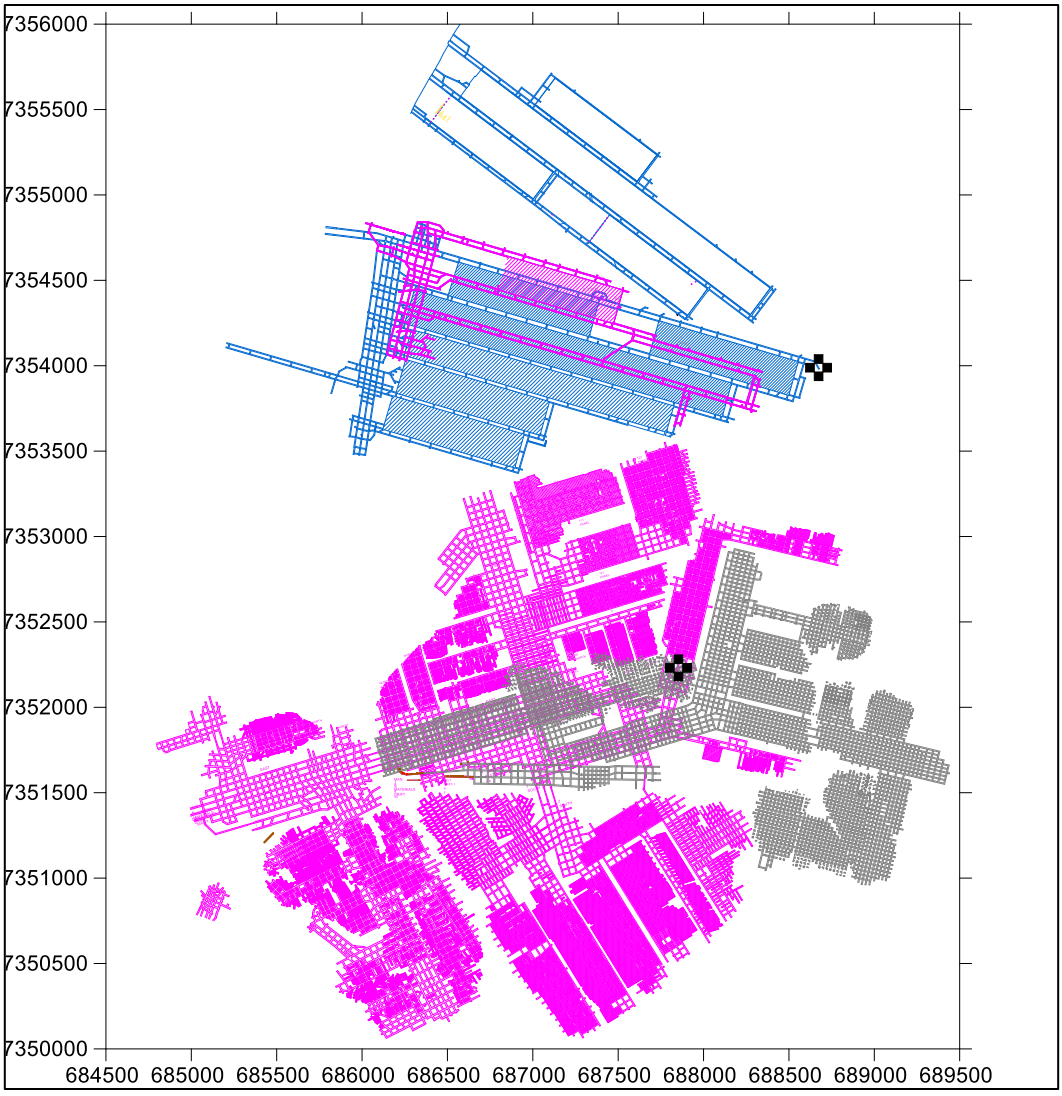


Figure 23 Location of holes monitoring groundwater in Laleham and Kenmare 1.

No standing water data is available for the Sirius Creek, Clutha or Ballamoo mines but it is assessed that they are now flooded to the regional groundwater level. It is noted that there is no pillar collapse hazard in these mines as they had no or very few pillars.

6.2 Flooding of undergrounds

Flooding an underground mine will result in the saturation of the bottom of the goaf (the Potential Consolidation or Caved Zone in Figure 24) and this will cause a softening of the fragmented immediate roof with consequent consolidation. This consolidation may be reflected in additional surface subsidence. Based on the discussion above, it is assessed that this softening and consolidation has already developed.

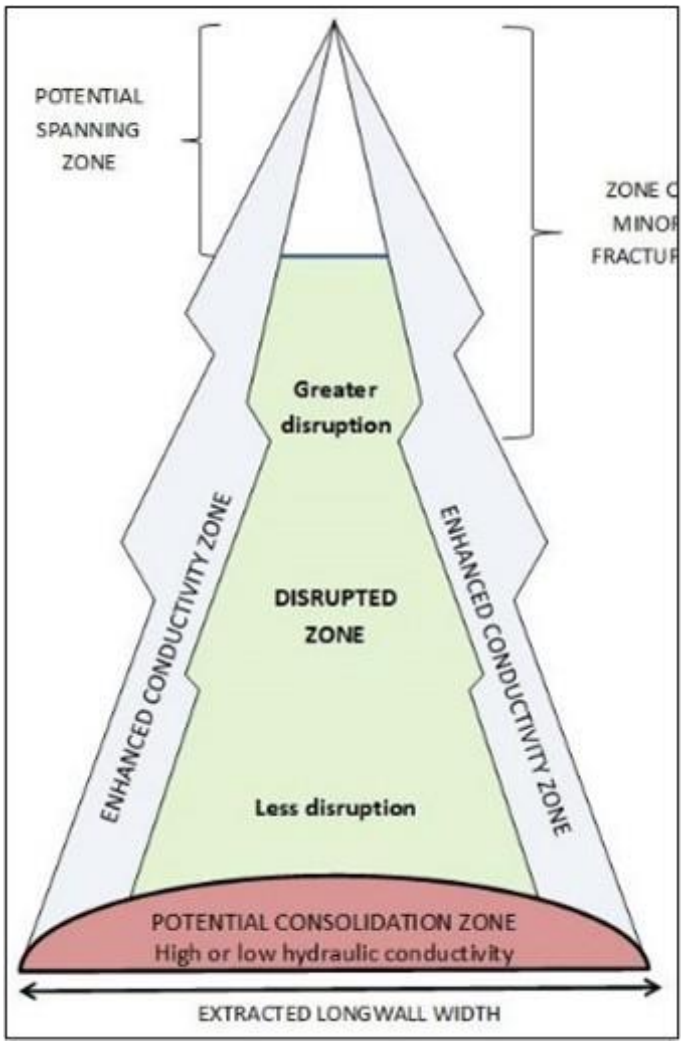


Figure 24 Framework of the geotechnical model for fracturing.

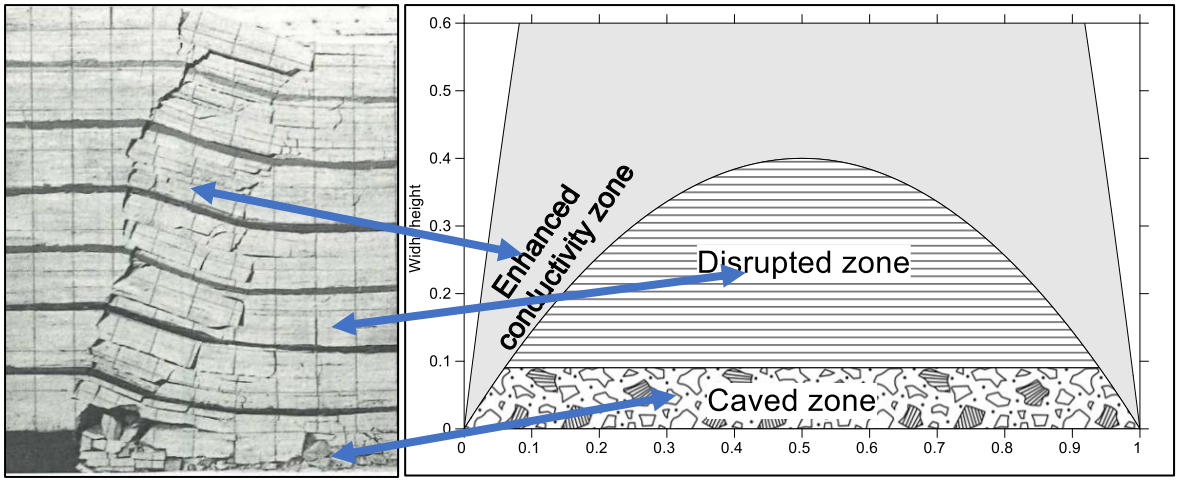


Figure 25 Physical and conceptual models for fracturing between seam and surface.

6.3 Hydraulic conductivity

Collapse or fracturing of the rock mass above the extracted coal is an intrinsic feature of extraction or longwall mining, except in some specific geological environments. Subsidence results in large scale fracturing of the overburden and subsequently, disruption to the overburden above the mined seam. This means that groundwater systems are unlikely to be returned to pre-mining condition. Importantly, if the differential surface subsidence above any extraction panel is in excess of about 500 mm there will be fracturing through to the surface.

Following work done at Crinum Mine, then owned by BMA in 2014, there has been a revision in the model for longwall fracturing and hydraulic conductivity. The largest changes in hydraulic conductivity are now recognised to be in the "Enhanced Conductivity Zones" (Figure 24 and Figure 25).The Impact on the overburden above the extracted area is not homogenous in its extents. An estimate of the resulting hydraulic conductivity (based on one scenario of how cracking develops in the overburden) is presented in Figure 26.

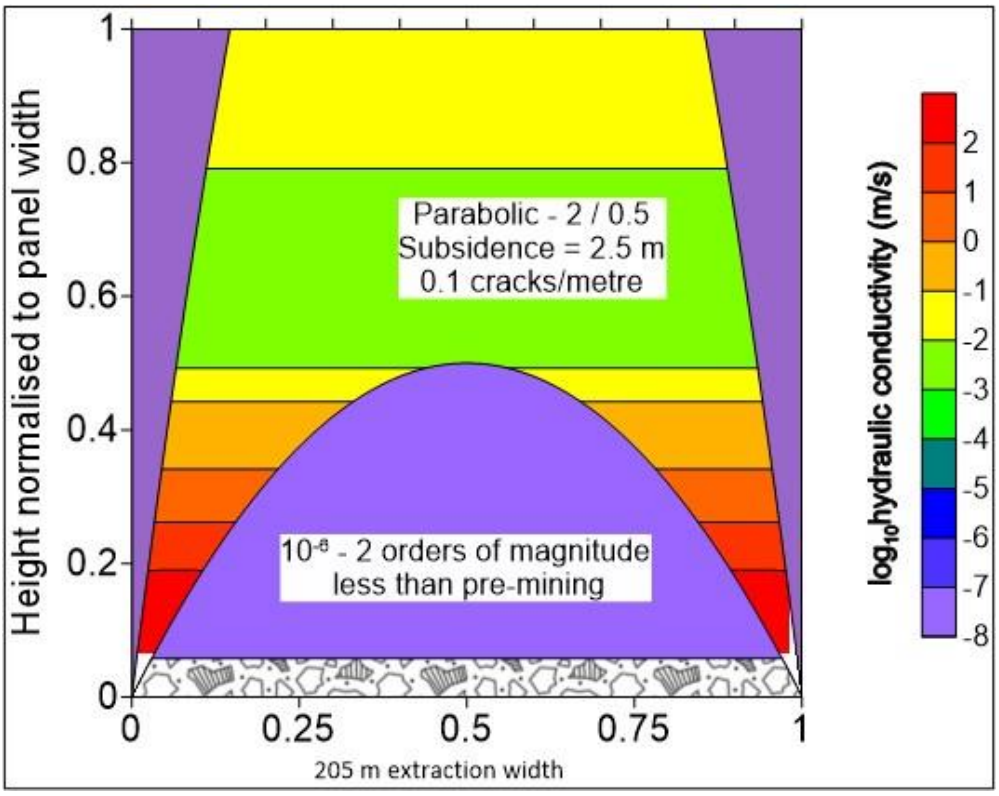


Figure 26 Hydrogeology model – fracturing.

7 Rehabilitation strategies

7.1 Rib parallel cracks

Up to 20 % of the subsided ground may be exposed to rib parallel cracks. Areas of high predicted tensile strain (Figure 21) indicate likely locations. Any cracking that has occurred in the Qrc surface geological will show evidence of self-healing, and no further subsidence or cracking is expected.

If rehabilitation is considered for the cracking in the non Qrc area, then earthworks to flatten the sides will be required or material will need to be imported. The general strategy of rehabilitation for this type of movement should be based on removing the slip/trip hazard at the surface by ripping/breaking the vertical faces to a 1 m depth and then compacting/grading (Figure 27). A nominal 3 m wide rounded gutter shape will result.

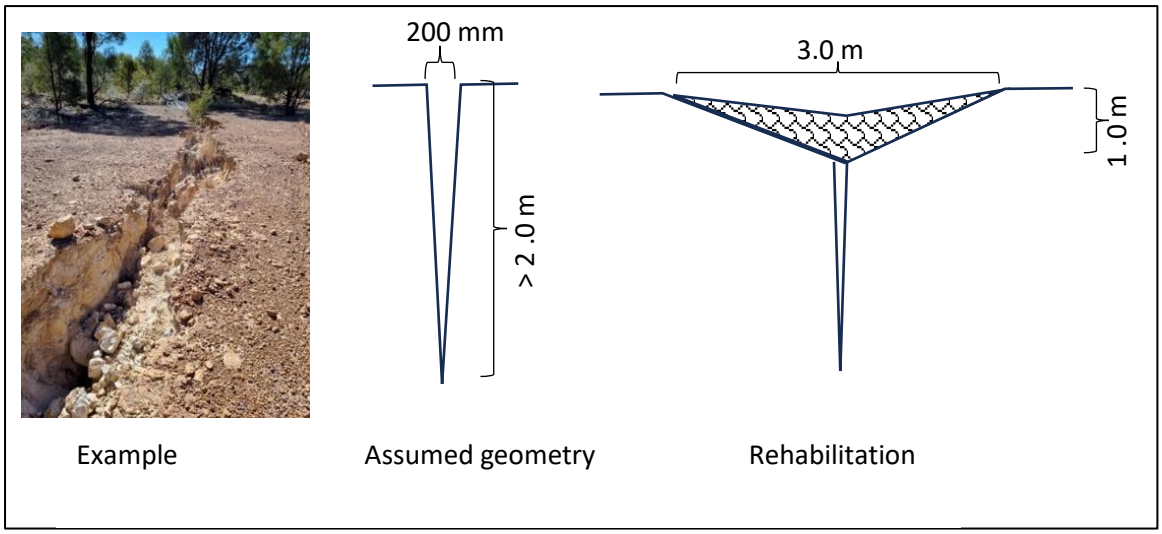


Figure 27 Schematic of general strategy to remove safety hazard associated with subsidence cracks in duricrust.

7.2 Face parallel or arcuate cracking

Face parallel cracking was not observed during the site reconnaissance. It should be assumed that these cracks may be present where the surface subsidence is greater than 2.0 m (Figure 28).

Rehabilitation would be to remove the edge with a grader or similar.

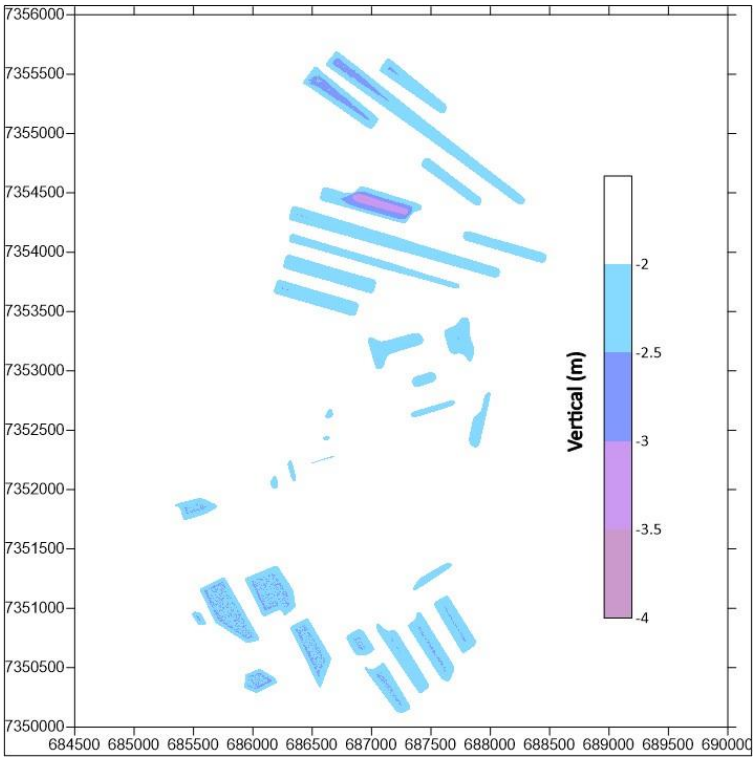


Figure 28 Possible areas of face parallel subsidence fractures in the Kenmare and Laleham areas as defined by subsidence greater than 2.0m.

7.3 Seals and Bulkheads

Mine seals are used to manage or limit water and gas flows as well as to control physical access to parts of the mine.

7.3.1 Kenmare 1

The Statutory Mine Plan (Plan of Abandonment) submitted to the Mines Department in 2001 shows seals at about 142 m from the portal entrance in both the "Man & Materials" & "Conveyor" drifts. A survey of the "Man & Materials" drift that was conducted on 19th of October 2023 showed that the drift has filled (floor to roof) with silt to a distance of about 70m from the entrance (Figure 29).

The current landform designs for closure of the surface mine has the Kenmare pit backfilled to surface.

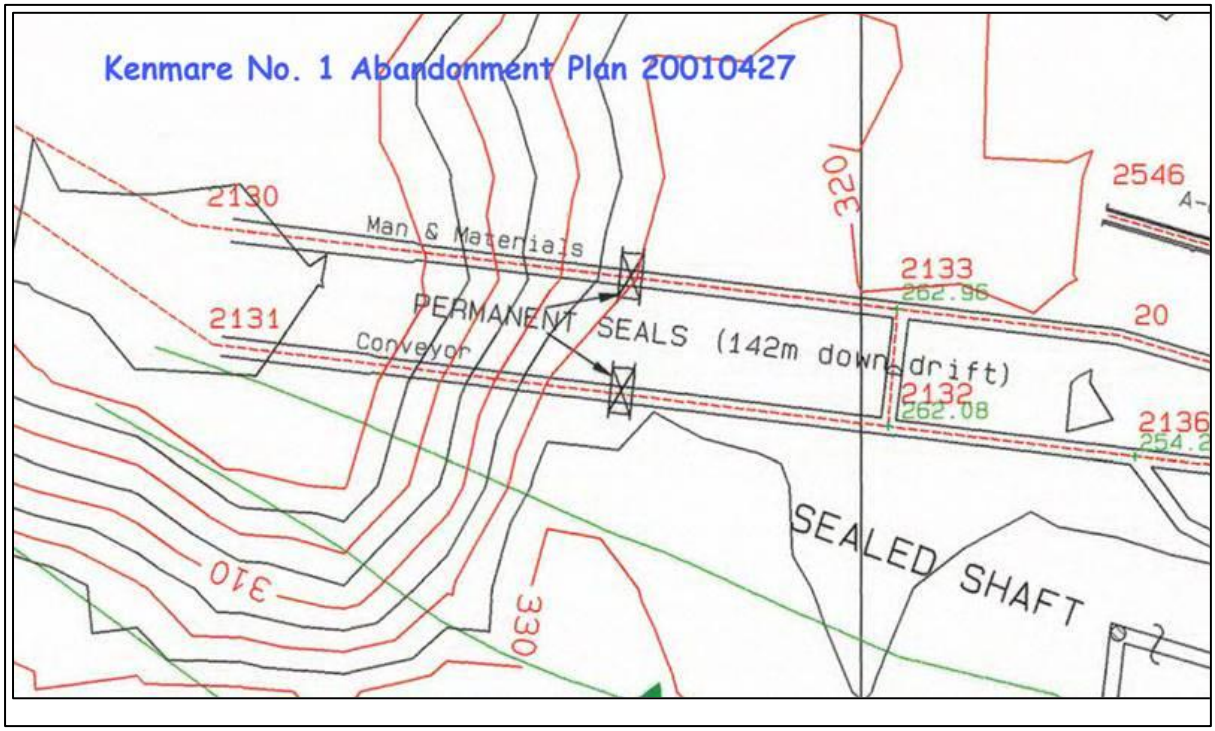


Figure 29 Kenmare Aries portal.

7.3.2 Kenmare 2

Kenmare 2 retreated the longwall face into an existing surface excavation which has since been incorporated into the surface operation.

7.3.3 Laleham

The Laleham portals have been either dozed-in or dumped-over.

7.3.4 Sirius Creek No 1

Sirius Creek No 1 was closed soon after opening and the portal entries are not visible. Re-excavation is not recommended. The current surface should be regraded and revegetated.

7.3.5 Sirius Creek No 2

Permanent seals appear to have been installed at about 1150m from portal entrance in both the Man & Materials and Conveyor drifts. The symbols appear to indicate an "Explosion Proof Stopping" on the statutory mine plans submitted to the Mines Department in 1976.

There has been a recent collapse at the Sirius Creek # 2 portal. It is assessed that timber lagging bords and/or the steel arches have deteriorated over time and a pothole has developed

A solution for closure would be to excavate the steel arches and lagging bords and backfill with a coarse-grained fill. An indicative specification would be:

- UCS>30 MPa
- 150 mm topsize
- 20 mm minimum size
- free draining
- not acid forming.

It is noted that a potential for remote installation of a grout seal may be required. This is also relevant for Clutha below.

7.3.6 Clutha

The Clutha portal is located at the outcrop of the Aries Seam. It was a single entry only, approximately 80 m long. Recommendations for closure include removal of the arches and lagging bords and then backfill using fill sourced from the immediate area.

7.4 Shafts

The main ventilation shaft for Kenmare 1 is annotated as sealed on the statutory mine abandonment plan and there is a plaque glued to the concrete plug on top of the shaft (Figure 30).



Figure 30 Kenmare 1 ventilation shaft.

Shafts should be fully backfilled with any locally sourced material. The shaft collar should be removed to allow removal of weathered/soil like material and then backfilled and compacted.

7.5 Exploration Holes

All open exploration holes previously completed as part of the exploration works of the mine development will require, as per legislation, the hole to be located, the casing to be removed and the hole to be cleaned out and grouted to surface.

7.6 Underground service holes (drop holes, pump holes)

Open holes to surface that are not defined as geological in nature will also need to be grouted to surface and sealed. All mine plans should be reviewed for these holes to ensure that no open access to the underground workings is maintained at closure.

8 Mine Closure Requirements

Mine subsidence results in permanent changes in the relative level of the surface and the generation of small-scale disruptions to the surface (cracks, steps, and humps).

The tensile cracks and steps discussed in Section 8 present a hazard to fast moving vehicles and possibly to wildlife. Over time there would be a lesser hazard if the surficial geology allows “self-healing” during rainfall events but where there are duricrusts or rock exposures the hazards will continue to exist for an unspecified duration.

Specific rehabilitation strategies should only be developed after an appropriate risk assessment is conducted based on the final land use and its impacts.

9 Monitoring

No further monitoring of the undergrounds at Blackwater Mine is recommended once it is established that the mines are flooded.

Where flooding has not occurred, there is potential for an additional subsidence of up to 250 mm; this is unlikely to change the current surface conditions.