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Management of subsidence at the Tasman and Abel Mines - issues and outcomes

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MANAGEMENT OF SUBSIDENCE AT THE TASMAN AND ABEL MINES - ISSUES AND OUTCOMES

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ABSTRACT: Tasman and Abel Mines are underground pillar extraction coal mines located to the west of Newcastle, NSW. Tasman mine extracts coal from the Fassifern Seam in the Upper Newcastle Coal Measures and Abel Mine operates in the Upper Donaldson Seam to the north in the Tomago Coal Measures. Each mine apply a range of partial to total pillar extraction techniques depending on allowable impact limits to a broad range of sensitive surface features such as cliff lines, Schedule 2 creeks, Hunter Water lines, public recreation areas and walking tracks, broadcasting and 132/330 kV transmission towers, highly significant aboriginal heritage sites and an operating cattle agistment business. This paper will discuss the mine management responses required to deal with delayed softening of claystone floors, optic fibre cable relocation, irregular surface cracking and how surface and subsurface monitoring techniques were applied to validate subsidence predictions and modify mine design layouts to meet the required performance measures.

INTRODUCTION

This paper discusses the management of mine subsidence control issues and impact outcomes from the development application stage through to the implementation of the Subsidence Management Plans (SMP) at the Tasman and Abel underground coal mines. Both mines are underground bord and pillar mines owned and operated by Donaldson Coal Pty Ltd (a subsidiary of Yancoal Australia Group). The mines are located 20 km west of Newcastle, NSW (Figure 1).

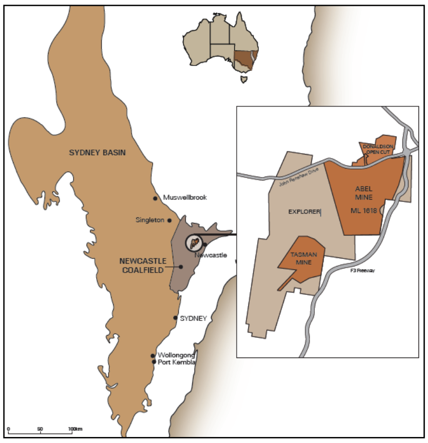

Figure 1 - Location of Abel and Tasman mines

Tasman mine was granted development consent by the Department of Planning in 2004. The mine commenced in 2006 and secondary extraction began in the Fassifern Seam in 2008. The 975 000 t/a consent limit Run Of Mine (ROM) coal is transported by road 20 km to Bloomfield coal preparation plant for processing and subsequent rail transport to the port of Newcastle for export. The Duncan Method of partial pillar extraction commenced in October 2008 with ten out of 14 pillar extraction panels extracted successfully using this technique. Abel mine received project approval in 2007 and is approved to mine up to 4.5 Mtpa. Abel mines the Upper Donaldson seam using predominantly total pillar extraction techniques below semi-developed rural land in the Black Hill area.

The overall successes of both projects have been reviewed in regards to (i) the planned mining layouts and actual extraction layouts approved by the Department of Trade and Investment, Regional

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Infrastructure and Services (DTIRIS), and (ii) the achievement of impact limits defined within the performance measure constraints provided in the project approval. The influence of geological hazards (structure and wind blast), latent soft floor conditions, surface topography and stakeholder issues on the mining layouts is discussed.

TASMAN MINE

Geological conditions

The Fassifern coal seam working thickness is typically 2.2 m to 2.5 m. Seam floor consists of 4 m of coal interbedded with moisture sensitive claystone/carbonaceous shale units. The upper roof is characterised by regular massively-bedded units including a consistent unit of conglomerate greater than 20 m in thickness (Teralba Conglomerate). The immediate seam roof is 0.5 m to 1.4 m of shale overlain by two distinct roof types either side of a NW-SE trending transition zone across the centre of the deposit. On the northeast side of the transition zone the shale is overlain by 1.5 m to 2 m of coal, overlain by 6 m to 10 m of sandy claystone (Awaba Tuff). While on the southwest side of the transition zone, the shale is overlain by 0.1 m to 0.4 m of coal, overlain by 10 m to 15 m of sandstone and conglomerate. In addition, Several NW-SE and NE-SW striking normal faults/dykes traverse the site.

Surface conditions

The Sugarloaf Range is characterised by steep topography, cliffs and forest (Figure 2). The steep slopes range from 18^{o}-35^{o} and generally exist below 5-30 m high sandstone/conglomerate cliff lines and Sugarloaf Recreation Area and walking tracks. Man-made features on the site include three broadcasting towers, AAPT Optical Fibre Cable (OFC) and Telstra copper cabling, four TransGrid tension towers, Ausgrid 11 kV power line, public access road and several highly significant Aboriginal Archaeological sites. The proximity and visibility of the cliff-lines of the Sugarloaf Range State Conservation Area to Newcastle resulted in strict mine approval conditions regarding subsidence outcomes. Under the Tasman Development Consent, there is to be no impact on the high level cliff lines as a result of subsidence.

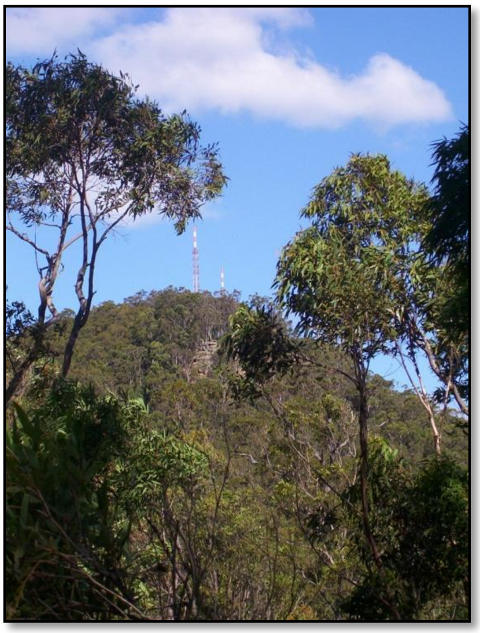


Figure 2 - Cliff lines and Broadcasting towers on the Western side of the Tasman mining lease

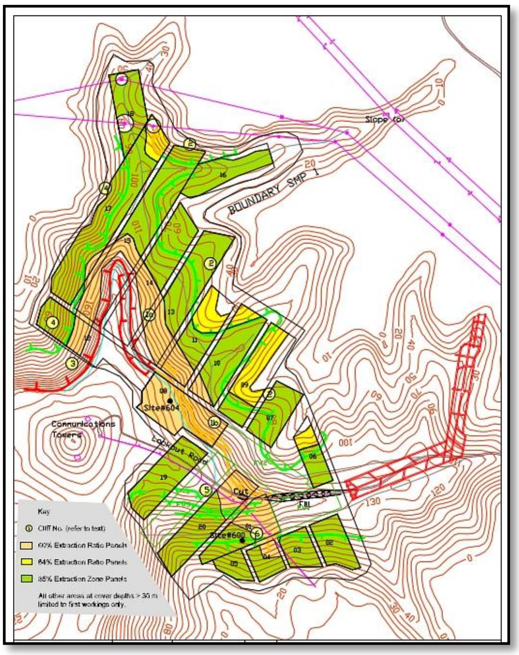


Figure 3 - Subsidence control zones for proposed Tasman mine plan in SMP application

Mine design constraints and proposed mining geometry

The performance criterion for subsidence impact set by DTIRIS was "negligible impact (i.e. no cracking) to the surface below areas with public access".

Level 1 to 4 subsidence control zones were developed for mine planning purposes (Figure 3) in increasing order of subsidence controls required for the existing surface features:

Level 1 - (Green) no mining constraints (total extraction allowed);

Level 2 - (Yellow) subsidence < 150 mm along shallow cover below ephemeral creeks, steep slopes and minor cliffs; Aboriginal Heritage sites; Optical fibre cable.

Level 3 - (Red) subsidence < 100 mm below Sugarloaf area, TransGrid Towers (tension).

Level 4 - (White) Subsidence < 3 mm and horizontal displacements < 20 mm at the Mount Sugarloaf Communication Towers (NBN, TransGrid and Broadcast Australia).

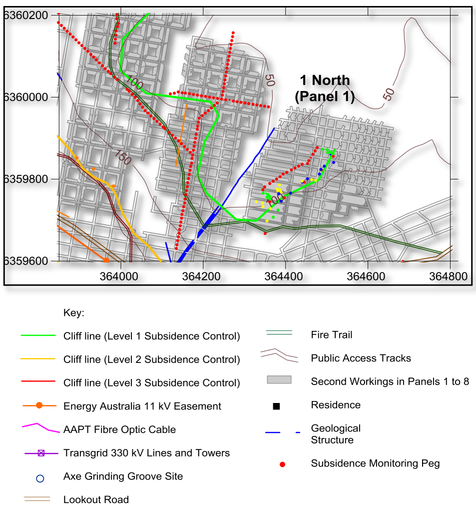
Level 1 areas were considered suitable for total pillar extraction (S_{max} = 60% Mining Height or 1.2-1.3 m). Level 2 and 3 areas required partial pillar extraction techniques that could also support abutment loading from Level 1 areas. Level 2 and 3 had similar subsidence constraints however, remnant pillar FoS ranged from 1.6 to > 2.11 respectively and required squat pillar geometries (i.e. w/h >5) for strain hardening response in yield. Maximum spans between remnant pillars of 27 m and cover depth > 55 m was assessed to avoid plug failures to the surface. First workings were allowed where > 30m of cover existed to minimise the likelihood of plug failures.

Subsidence predictions for the Modified Duncan Method were based on calibrated analytical models of roof-pillar-floor systems and the Voussoir beam analogue presented in Das (1998) and Diedrichs and Kaiser (1999).

Mining conditions encountered and subsidence response

The mining layout has evolved as subsidence data and mining experience was obtained during the course of the panels being mined.

The first panel in Level 1 area (1-North) was a total extraction panel with 106 m x 122 m spans and 60-120 m of cover (Figure 4). The panel was located to the east of the transition zone and subsequently had Awaba Tuff in the immediate roof. There was some initial concern raised by DTIRIS that the Awaba Tuff would fail (despite exploration bore core showing UCS values >40 MPa) requiring coring and testing of the immediate roof before second workings could commence. During mining, the Teralba conglomerate spanned between ribs and Awaba Tuff did not cave up to the Northern Seam (approximately 15 m above) as anticipated. At the completion of Panel 1 the potential for windblast was acknowledged as minimal subsidence was seen on the surface (i.e. S_{max} < 60 mm). This triggered the change in mining method to conventional partial pillar extraction and then the Modified Duncan system (Sutherland and McTyer, 2010).



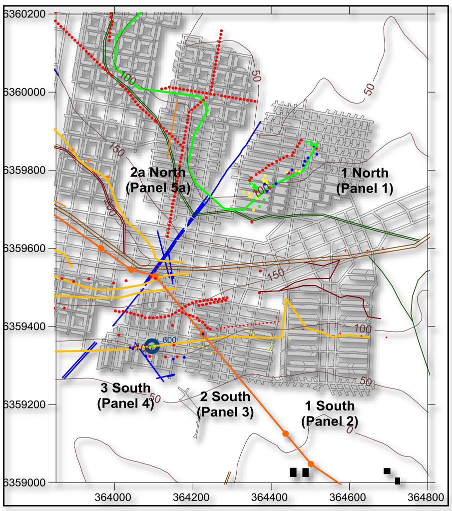


Figure 4 - 1-North total extraction panel in Level 1 area (with subsidence pegs and cover contours)

Figure 5 - 1, 2 and 3-South partial extraction panels in Level 2 area (with subsidence pegs and cover contours)

The next four panels (1-3 South and 2a-North) were located in Level 2 areas (below cliffs, power line, public access track and archaeological sites) and mined using single and double sided lifting partial pillar extraction. The maximum subsidence was < 150 mm for these panels, with tilts < 3 mm/m and strains < 1.5 mm/m. However, extraction ratios were marginal at ~60% (Figure 5).

The Modified Duncan (MD) partial extraction system was developed to maximise the number of extraction tonnes for each metre of panel development (Figure 6). Subsidence was expected to be < 150 mm for the cover depth range provided the FoS was > 1.6. The MD Pillar extraction method achieved greater extraction ratios (70-80%) with minimum remnant pillar width of 18 m (w/h >7.5) set by Continuous Miner (CM) length at cover depths < 110 m. Remnant pillars stripped on 4-sides were proposed to be increased up to widths of 27 m as cover depth and subsidence level controls increased below Mount Sugarloaf.

Floor heave and rib spall started to occur in the deeper panels on first workings to west of the transition line (light blue hatching in Figure 6). Claystone beds, 0.1 m to 0.4 m thick exist between moderate to high strength carbonaceous shales units in the first 4 m of floor. It was assessed that the claystone units in the first 1.2 m of floor had softened from 2-3 MPa to 0.15-1 MPa, based on underpass exposures, floor core and windy borer tests (Figure 7). Laboratory tests (Atterberg limits, moisture content and slake durability) indicate the claystone is highly sensitive to moisture and has similar plasticity/smectite minerology of Awaba Tuff in the floor of Cooranbong and Awaba collieries.

No deterioration of Awaba tuff in the roof has occurred in any of the partial extraction panels, with moderate strength tuff continuing to span 16 m to 27 m between remnant pillars above Panels 1-4 east of the transition.

First workings pillar stresses of 5-8 MPa in 3-North and 4-South Panels resulted in floor heave of 300 mm to 500 mm and rib spall up to 400 mm on one to four sides. Subsidence was measured at < 50 mm in heaved areas. Second workings were completed and subsidence was still < 150 mm for pillar stress between 8 and 19 MPa.

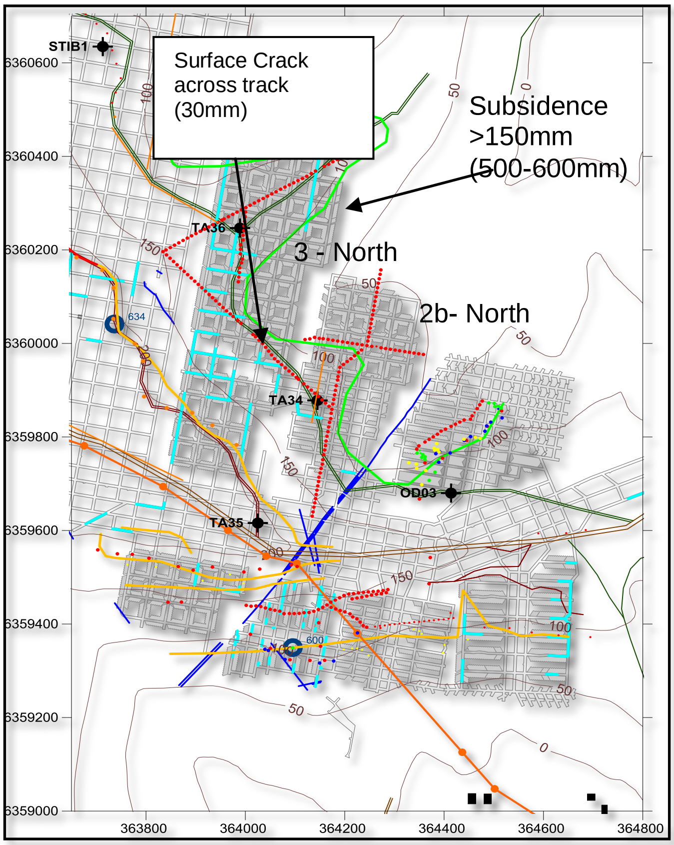


Figure 6 - Modified Duncan panels (2b-North, 3 North & 4 South) to west of transition zone and cover contours

3-North Panel was in a Level 1 Control area with 110 m of cover. The panel was commenced as a 4-heading 203 m wide panel and widened to 5-headings or 250 m where cover depths ranged from 60 m to 110 m. Over-wet floor conditions resulted in grubbing and belt road relocation. Subsidence was measured at 120 mm (12 months after extraction was completed) and 300 mm at 18 months after completion. Remnant pillar stress was 16 to 19 MPa based on Full Tributary Area Loading. Two years since panel completion, subsidence reached 521 mm (Figure 8) and subsidence development rates had slowed to < 5 mm/week from a peak of 12 mm/week. A surface crack of 30 mm width developed above the rib line and across a public access path after subsidence was >300 mm. No remediation was considered necessary and no slope instability or other impacts have occurred to-date above the panel.

Groundwater flows also increased in shallow areas of North-East and 4-West Panel (H=60 m to 110 m), which resulted in excessive floor heave and panel abandonment where grubbing failed to control affected roadways. 4-West Panel is in a Level-1 Control Area and has also developed subsidence > 150 mm six months after panel completion.

The subsidence increases observed above 3-North and 4-West panels are considered to be indicative of claystone floor unit softening that has resulted in pillar punching and lateral squeezing failures within the first 1.5 m of floor strata (Figure 9). The development of the 'time-dependant' subsidence behaviour (Figure 10) appears to have been driven by (i) pillar load increases from yielding conglomerate spans and (ii) reduction of floor strength due to softening of exposed claystone units and lateral strata confinement above 27 m wide roadways between remnant pillars. Marino and Choi (1999) discuss a similar mechanism in US bord and pillar mines after mine water ponding occurs for a period of time above moisture sensitive claystone).

The two-layered floor strength formula for lateral 'squeezing' failures below square pillars by Brown and Meyerhoff, (1969**)** was applied as follows:

$q_u = N'_{square} \times UCS_1/2 = [0.33(w/t) + 5.14]\ UCS_1/2$

where, N'_{square} = Modified bearing capacity coefficient for a square footing;
w = proposed stripped widths
UCS_1= weak claystone strength = 2 MPa (unsoftened) and 1 MPa (softened)

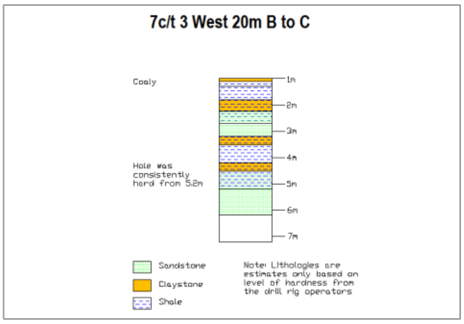


Figure 7 - Claystone units in first 4.5 m of floor

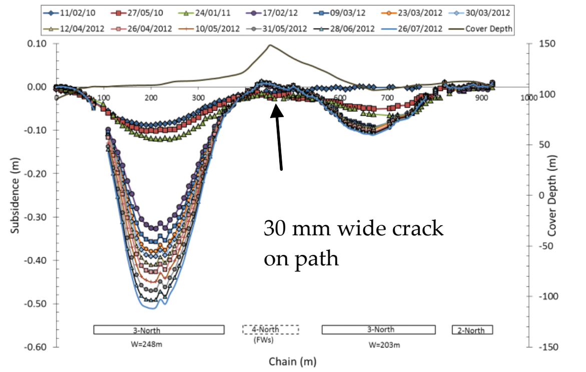


Figure 8 - Delayed subsidence above 3-North in Level 1 Area

Figure 9 - Moderate floor heave in 3-North panel (outbye)

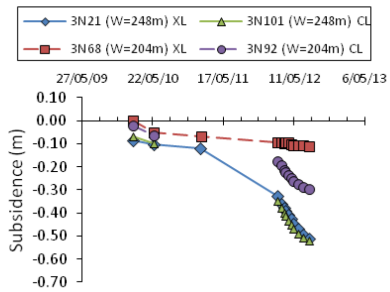


Figure 10 - Subsidence development above 3-North panel

The response to the floor softening was to reduce the remnant and barrier pillar stress in the last three panels within the Level 2 and 3 Control Zones as follows:

- Panel spans limited to 4-headings or 185.5 m to maintain spanning capability of Teralba Conglomerate.
- Pillar loads were estimated two ways (i) 0.8 x Full Tributary Area (FTA) loading on remnants and Effective Double Abutment (DA) loading on Inter Panel Barriers and (ii) FTA on all pillars.
- Increase remnant pillar widths by limiting stripping to single or double sided under worst case loading.
- Inter panel barrier pillars are not to be stripped to provide load sharing redundancy if remnant pillar floor yields.
- Minimum softened floor FoS of 2 in Level 3 Areas and 1.5 in Level 2 Areas.
- Maximum pillar stress of 9 MPa in Level 3 Areas and 12 MPa in Level 2 Areas.
- Bearing capacity of softened floor assessed to range from 16 to 18 MPa for FoS Calculation.
- Effective floor stiffness after softening reduced from 1.5 GPa to 0.7 GPa to estimate subsidence when floor FoS>1.5. Floor stiffness reduces to 0.15 GPa through back analysis when lateral squeezing occurs.

In regard to Level 3 subsidence control beneath the TransGrid towers, after several Modified Duncan panels were completed (and before the softened floor event in 3-North), confidence in the subsidence control method was high. It was considered unnecessary to modify the panels beneath the TransGrid towers or OFC if maximum subsidence was < 150 mm, tilts < 3 mm/m and tensile strains < 1.5 mm/m. The approach was initially accepted by TransGrid and Telstra.

As the TransGrid tower were tension towers, DTIRIS required that at least four first workings pillars with 39.5 m widths be left beneath each tower in partial pillar extraction panels (Figure 11). This decision was probably the correct one in light of the subsequent softening event above 3-North and 4-West Panels. To-date, the TransGrid Towers have performed well, with < 50 mm of subsidence and strains < 1 mm/m (Figure 12) measured under pillar stresses of 2 - 5 MPa.

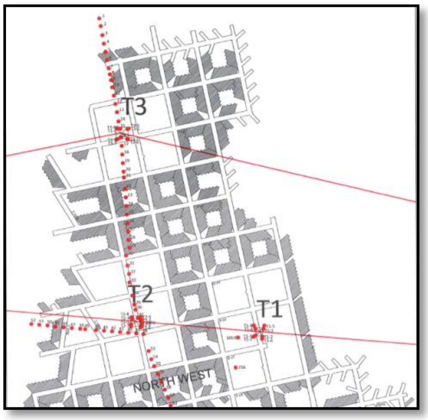


Figure 11 - North West panel extraction under the TransGrid towers

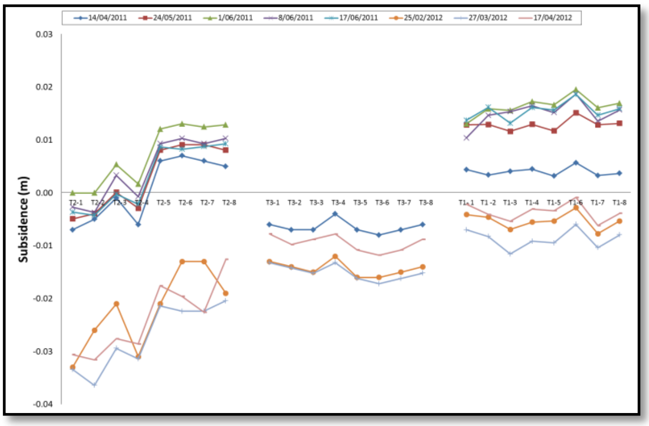


Figure 12 - TransGrid tower subsidence above NE/NW

Review of mine planning and subsidence

In hindsight, the over confidence in the Modified Duncan method was due to the focus on the Awaba Tuff and massive, spanning conglomerate in the roof, and the belief in the robustness of the pillar design by all parties involved. The floor heave and subsequent rib spall was generally ignored as subsidence above the first seven panels did not indicate any anomalous subsidence behaviour immediately after panel completion.

The proposed partial pillar extraction panels beneath the towers had remnant pillars with pillar stress 7.5-9.5 MPa and were unlikely to have resulted in the same magnitude of subsidence that has occurred above 3-North. To-date subsidence and strain below the OFC has been < 150 mm and < 1.5 mm/m with no signal losses incurred (Figures 13 and 14).

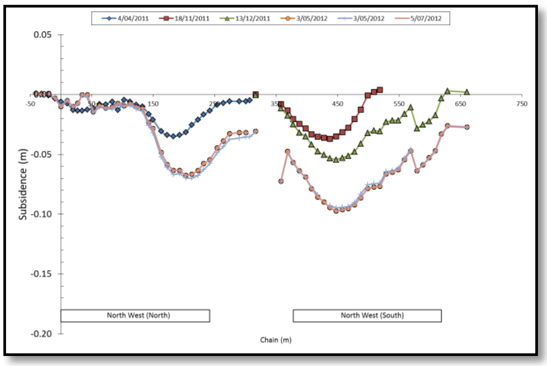


Figure 13 - OFC subsidence above NW panel

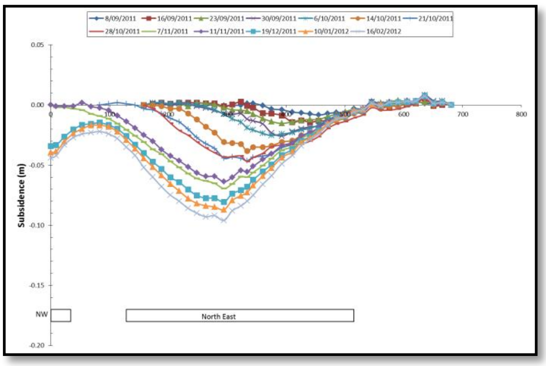


Figure 14 - OFC subsidence above NE panel

Subsidence exceedance response

The ramifications of the softening claystone floor in the shallower areas of the mine has resulted in significant adjustments required below the Level 2 and 3 Control areas beneath Sugarloaf Mountain (steep slopes, cliff lines and public recreation areas) where cover depth ranges from 150 m to 230 m.

Mining outcomes

Review of the potential softening and strength loss of the claystone units in the first three to four metre below the floor has required the remnant pillar stress in Level 3 Areas to be reduced to 8 MPa with a FoS of two against lateral squeezing failure of claystone beds. Level 2 Areas pillar stresses were reduced to 10-12 MPa with a FoS of 1.5.

The bearing strength for the multi-layered floor was estimated to range from 16 to 18 MPa with measured claystone unit thicknesses of 0.31 m to 0.44 m and softened UCS strengths of 1 MPa. This has significantly reduced the extraction ratios with only single sided stripped allowed beneath the Level 3 areas. The 39.5 m wide inter panel barriers between the 150 m wide panels have also been limited to first workings with no stripping allowed (see Figure 15).

A comparison between the originally proposed and approved SMP Panel remnant pillar FoS, pillar w/h and extraction ratios using the Modified Duncan Method are summarised in Table 1.

Table 1 - Tasman proposed v. approved mining outcomes using Modified Duncan method

Subsidence Control Area	Remnant Pillar Extraction Ratio (%)		Remnant Pillar Stress (MPa)		Remnant Pillar FoS		Remnant Pillar Floor FoS	
	Proposed	Approved	Proposed	Approved	Proposed*	Approved	Proposed^	Approved
1	75 - 85	75 - 85	9 - 19	9 - 19	1.27-3.51	1.20-2.54	0.64-1.95	0.64-1.95
2	69 - 78	57 - 75	12 - 18	8.3 - 9.8	1.60-1.90	2.57-3.10	1.11-1.81	1.51-1.79
3	64 - 69	46 - 48	12 - 16	8.4 - 8.6	2.14-2.24	4.54-4.78	1.15-1.25	2.06-2.12

* - 0.4 m of rib spall included. ^ - Based on softened floor conditions.

Far-field effects at the broadcasting towers have not been detected outside the proposed buffer zone defined by a 45^{o} Angle of Draw. Far Field Displacement (FFD) monitoring is conducted at the NBN tower after the completion of each panel. Post processing GPS has been utilised to provide the best possible accuracy on horizontal movements. Numerical modelling of yielded partial pillar and total pillar extraction panels (worst-case scenario) by DgS, 2007 indicated that far-field effects are likely to be < measureable survey tolerances.

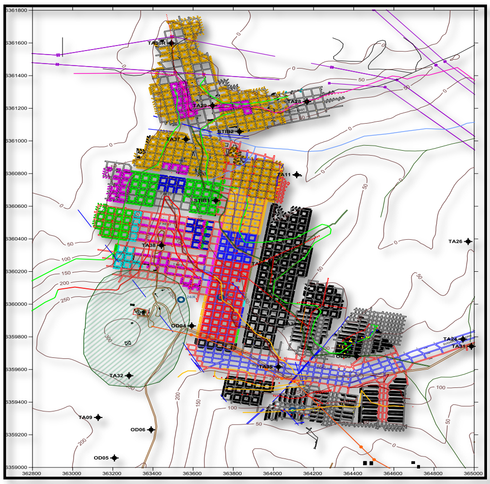


Figure15 - Final approved Tasman Mine layout

ABEL MINE

Mining at Abel has taken place in the first two SMP areas under a combination of land owned by Black Hill Land Pty Limited, the Catholic Diocese of Maitland - Newcastle, a narrow strip traversing the area owned by Hunter Water Corporation and ten private rural residential land holdings. A Boral Asphalt plant exists in the north eastern corner of the site. The current application seeks approval to mine coal by the pillar extraction method from the Upper Donaldson Seam at depths of cover ranging generally from 50 to 150 m.

Geological conditions

The Upper Donaldson Seam mined at Abel ranges in thickness from 1.6 m to 3.8 m. The mining height on first workings is typically 2.5 m with additional coal taken where possible when lifting off. The overburden comprises medium bedded sandstone and siltstone with a moderate strength mine workings coal roof and non-moisture sensitive carbonaceous shale floor. Several N-S striking faults exist within the mining area that were a significant hazard in regards to underground strata control.

Surface conditions

The surface conditions in the SMP Areas 1 and 2 include mild to moderate slopes (2^{o}-15^{o}), Schedule 2 Viney Creek and its tributaries, Optus OFC and Telstra copper cabling, One TransGrid tension tower and several TransGrid suspension towers (Figure 16) - the towers were already fitted with cruciform footings in the early 1980's in anticipation of future underground mining). There are also three significant Aboriginal Archaeological sites, Ausgrid 132 kV and rural 11 kV power lines and private access roads. Previous land use was a Steggles Chicken Battery Farm with several clay-capped areas of contaminated fill located around the site.

Figure 16 - Cruciform footings installed under the TransGrid 330 kV suspension towers in the early 1980's

Current land use is predominately cattle agistment with three rental properties (Catholic Diocese Land). The stakeholder requested protection for a cattle loading ramp and yard, with remediation of fences, access roads and water supply lines in a timely manner. A commercial/industrial subdivision is proposed after 2013 by Black Hill Land Pty Ltd. A primary or secondary school was initially proposed by the Catholic Diocese during the EA stage, however, no development application for it has been presented to Council at this stage.

Mine design constraints and proposed mining geometry

Under the project approval, effective subsidence (deemed to be 95% of predicted) as a result of secondary extraction had to be completed by June 2013. Therefore, the majority of panel extraction in SMP Area 1 and 2 had to be completed prior to this date. The potential for subsidence development due to standing pillar instability beyond this date was also required to be minimised.

Surface constraints to mining included Viney Creek and the TransGrid tension tower, both of which needed to be protected from subsidence impacts using an appropriate buffer zone.

Under the Project Approval, mining is limited to first workings under all Principal residences & commercial structures (Boral Asphalt Plant) above the mining areas.

All subsidence impacts were to be remediated to the satisfaction of the stakeholder unless an alternative compensation agreement was negotiated prior to subsidence development. Total extraction panels were proposed outside subsidence control buffers to Viney Creek, TransGrid tension tower and principal residences.

The extraction panels in SMP Areas 1 and 2 were originally all total extraction panels with widths of 120 m (Panel 1) and 160 m (Panels 2 to 26) with 25 m wide barrier pillars (Figure 17).

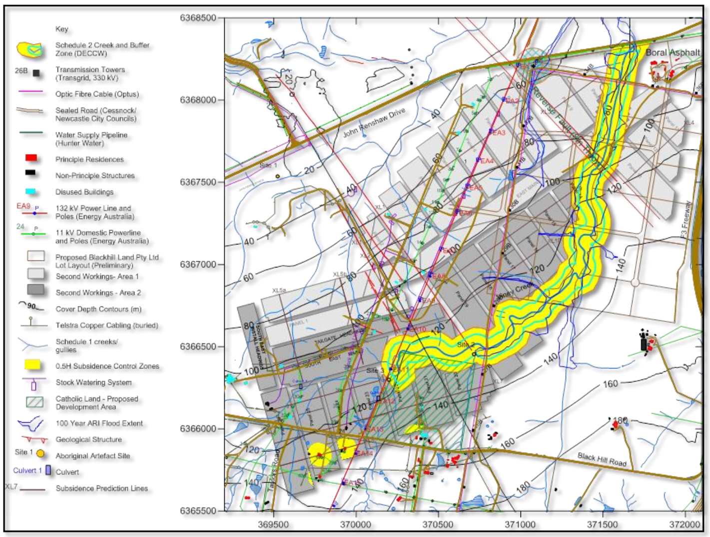


Figure 17 - Proposed SMP area 1 and 2 panels at the Abel Mine

Review of subsidence predictions and impacts

Subsidence predictions were estimated based on ACARP, 2003 empirical Longwall model and an effective mining height (i.e. assumed mining height x extraction ratio). Measured subsidence has ranged from 0.82 to 1.25 m with original predicted subsidence values from 0.87 to 1.76 m for assumed mining heights of 2.0 to 3.2 m and an extraction ratio of 95%. The predicted subsidence was significantly higher in places due to differences in assumed mining heights and the sizes of stooks left to control roof adjacent to the fault structure.

Revised predictions were subsequently based on data from the first four panels and revised from 0.92 to 1.31 m for mining heights of 2.35 to 3.0 m and extraction ratio of 85% (to allow for bulking of goaf/stooks). Tilts and strains were generally within predictions with maximum measured tilts ranging from 23 to 63 mm/m, tensile strain from 4 to 23 mm/m and compressive strain from 2 to 17 mm/m.

Cracking was predicted to range between 40 - 260 mm above panels where cover depths were < 80 m (i.e. W/H > 2) and < 150 mm for cover depths > 80 m. Measured crack widths (bold represent exceedances) above Panels 1 to 4 were 180 mm, 50 mm, 260 mm and 300 mm respectively for cover depths of 100 m, 75 m, 55 m and 55 m. The distribution of cracking was erratic in places, however, and could be explained by biased strain distribution towards the high side of sloping ground and the presence of compacted clay fill. The direction of mining or goaf development may also have contributed (Figures 18 and 19). The exceedances represented < 5% of all measured crack widths.

Subsidence mitigation works that were agreed to before mining were carried out in a timely manner. The works included:

- Ripping and regrading cracked ground, drainage earthworks along gravel access road and out of channel ponded areas.
- Extraction panels were set back from cattle ramp and race and temporary fences installed above cracked areas so as not to injure livestock or disrupt cattle agistment while repair works to fences were carried out (wire strands broke or sagged).
- Loss of clearance to ground above sagging 415 kV powerlines were repaired by Ausgrid.
- Timely repairs to damaged buried water supply pipes used to water cattle.

The surveying program also used Feno survey markers to minimise injury potential to the cattle.

Figure 18 - Typical tension crack above total extraction panels with cover depths of 60-80 m

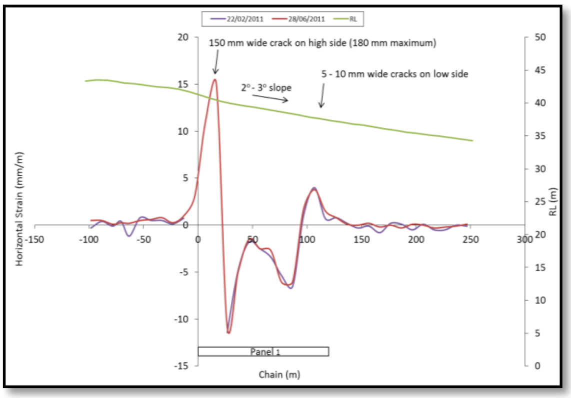


Figure 19 - Strain profile bias towards high side of gentle slope for Panel 1 (100 m of cover)

Deep borehole extensometers and multi-vibrating wire piezometers were placed over the panel centres and chain pillars respectively of Panels 1 and 2 and successfully identified heights of fracturing (A Zone) and constrained or strata dilation (B Zone) zone thickness for cover depths of 76 m and 95 m (Table 2). Shallow slotted standpipe measurements confirmed shallow groundwater levels had been lowered due to strata dilation. Further monitoring data required to assess if leakages occurring directly to the workings from B Zones.

Table 2 - Measured fracture and dilated zones above total extraction panels 1 and 2

Panel No.	Width W (m)	Cover H (m)	Effective Mining Height T_e (T) (m)	Fractured Zone (A Zone)			Constrained Zone (B Zone)		
				Thickness (m)	Anchor Displ. (mm)	Vertical Strain (mm/m)	Thickness* (m)	Anchor Displ. (m)	Vertical Strain (mm/m)
Panel 1	120	95 - 99	2.55 (2.6)	45 (18T_e)	734-1351	120	40 (15T_e)	14-33	0-3
Panel 2	150	73 - 76	1.88 (2.5)	46 (24T_e)	78-298+	11	20 (11T_e)	-13- -18	-1-0

e =extraction ratio for panel at instrument location. * - Constrained zone thickness extends from A to <10 m below surface.

The extensometer and piezometer data for Panel 2 is shown in Figures 20 and 21.

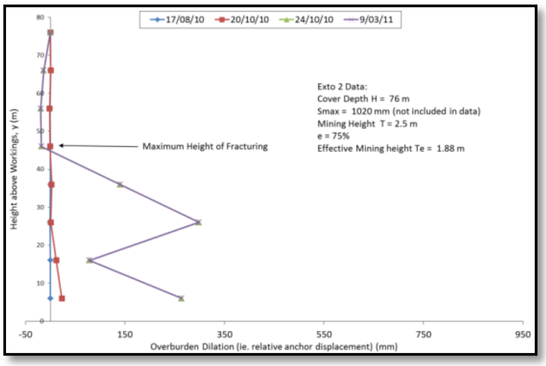


Figure 20 - Borehole extensometer for panel 2

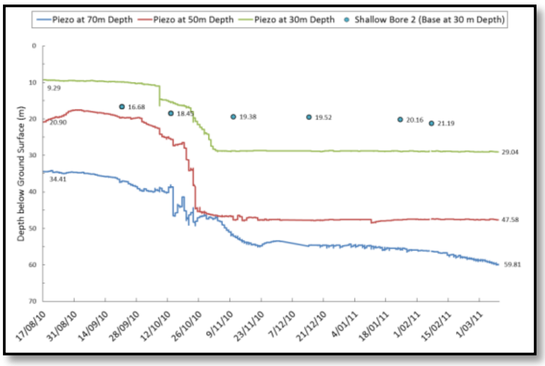


Figure 21 - Piezometer and standpipe for panel 2

Three panels were changed from total extraction to partial pillar (Modified Duncan) extraction panels in the south-western area of the SMP Area 2 to meet the practical subsidence completion deadline (Figure 22). The proposed panels will be developed on a 3 and 5-heading layout with 50 m and 45 m centre-centre square pillar spacing respectively and 5.5 m wide headings and cut-throughs. The mining height has been assumed to equal the seam thickness and ranges from 2.85 m to 3.3 m for pillar stability assessment and subsidence prediction purposes.

The panels will typically have final mined widths (W) of 118 m and 211 m with cover depths (H) ranging between 100 and 130 m. The panels will have *super-critical* to *critical* W/H ratios of 1.91 to 0.94, indicating the maximum pillar loads will be close to or equal to full tributary area magnitudes.

The pillars will then be 'stripped' or reduced in width along four sides on retreat, leaving square remnant pillars with factors of safety (FoS) > 2.11 (under the assumed design loading conditions) and w/h ratios >7.

The roof between the remnant pillars is expected to cave readily and the floor comprises moisture insensitive shales and sandstone of moderate strength. The pillar stress will range from 9.7 to 11.6 MPa with maximum subsidence expected to be < 150 mm. The remnants will also have strain hardening properties that will limit subsidence to < 300 mm in the unlikely event that they go into yield. The potential for significant impact to future surface features or developments is very low.

Mining outcomes

The mining outcomes for SMP Areas 1 and 2 for Abel are summarised below:

- The proposed panels east of a large reverse fault had to be abandoned due to the cost of mining through the structure.
- Panels have been extracted with minimal subsidence effect (any mitigation work conduced as per the various Property/Infrastructure Management Plans).
- No injuries to cattle were reported.
- No loss of creek or surface water flows. Surface to seam connection not detected below total extraction panels with cover depths ranging from 73 to 99 m. Fracture heights ranged from 18 to 24 x Effective Mining Height.
- No impact to TransGrid Tension or suspension towers. Tilt meters were installed for real time monitoring and Infrastructure Management plans were prepared in consultation with TransGrid and approved by DTIRIS.
- Mitigation works have restored the function of infrastructure (power lines, roads and buried water supply system).
- Optus optic fibre cable was relocated with assistance from MSB around the extraction areas of SMP Areas 1 and 2.
- Existing residences were not undermined by total or partial pillar workings due to mine layout adjustment.

- Consultation with the local community has been extensive with SMP Area Stakeholder days held and regular updates to the Abel Mine Community Consultative Committee.
- Three panels have been changed to the Modified Duncan Method to meet the June 2013 subsidence development completion deadline. The extraction ratio for the partial extraction panels will range from 72% to 75%.
- The proposed panel locations and extraction ratios of > 95% were achieved, with Panels 1 and 2 requiring additional stooks at several locations to support structure affected roof. The extraction ratios were reduced to between 83% and 93% where additional stook support was required.

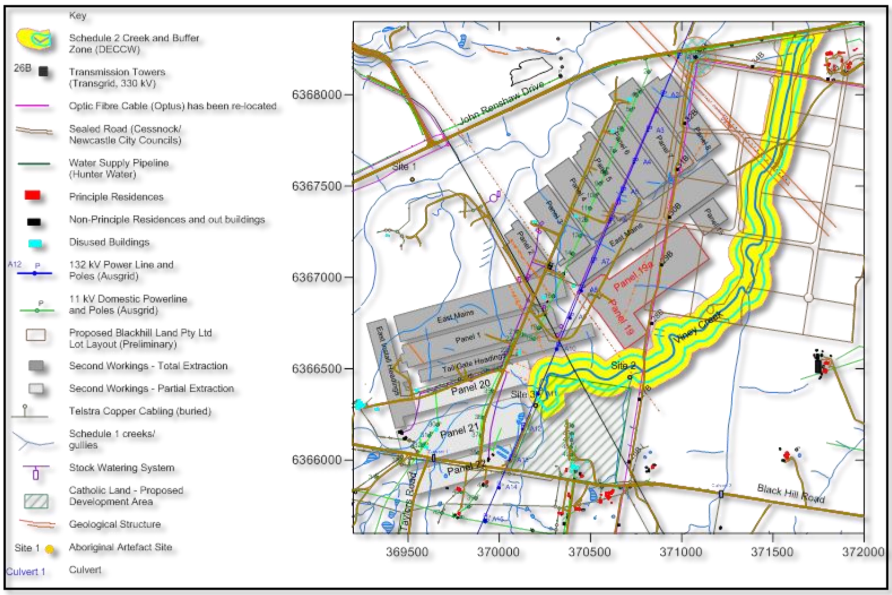


Figure 22 - Final approved Abel Mine SMP area 1 and 2 mining layout

CONCLUSIONS

Overall, it is assessed that maximising the extraction ratios in non-sensitive areas and reviewing subsidence responses at the Abel and Tasman Mines and has enabled good mine design efficiency outcomes to be achieved despite significant mining constraints in highly sensitive areas. Negligible impact to steep surface topography, infrastructure and public safety has also been achieved.

The Modified Duncan Method of partial pillar extraction has been used successfully at the Tasman mine where the control of surface subsidence is a critical mining constraint. The method has allowed a high degree of flexibility in regards to adjusting mining layouts in response to latent floor heave conditions. The deterioration of the floor occurred after higher than normal groundwater inflows were encountered during mine development in the shallower areas of the mine.

Total pillar extraction mining at relatively shallow depths (60 m to 130 m) at the Abel Mine has also allowed a high degree of flexibility to mine plan layouts where a range of surface subsidence constraints and hazardous underground geological conditions exist. The Modified Duncan method of partial pillar extraction has also recently been approved to meet Stakeholder expectations in regards to subsidence development at the Mine. Other factors, such as communicating impact expectations with stakeholders can be a difficult and on-going process, despite reasonable impact predictions being provided beforehand. The thorough monitoring of subsidence effects and review of impacts allow timely (and transparent) explanations to be made when problems arise, which is important for fair and productive outcomes to be achieved.

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