MEASUREMENT OF THE CAVED ZONE ABOVE A LONGWALL PANEL, UNITED COLLIERY

Yvette Heritage[1], Ben Blacka[2] and Damien James[3]

ABSTRACT: This paper presents the results of a targeted goaf borehole program to define the edge of the Longwall 10 caved zone at United Colliery, Hunter Valley NSW. Longwall 10 is an isolated panel with a supercritical panel geometry. Three of the five boreholes defined the edge of caving, while two boreholes characterised the centre of the goaf. The location of the caved zone was depicted from a combination of total water loss during drilling that coincided with a subvertical fracture at the location of total water loss.

The boreholes showed the caving angle from the pillar ribs to be 21 degrees on the up dip side and 19 degrees on the down dip side of the panel. An additional borehole drilled 10 metres (m) towards the goaf centre on the up dip side showed a caving angle increase to 25 degrees from the adjacent borehole, indicating the arc shape of the caved zone.

The caving angle coincided with a high strain fracture zone and connectivity to the goaf. This caving angle information can inform assessments for hydraulic/gas connectivity and geotechnical engineering applications such as multi-seam overmining or opencut/underground interaction. (Note that the caving angle is not the same as the abutment angle, which the latter is a calculated angle based on pillar load.)

INTRODUCTION

A targeted goaf borehole program was implemented to define the caved zone and mining induced fracture network at United Colliery, Hunter Valley New South Wales. The location of United Colliery is presented in Figure 1. United Colliery was a Woodlands Hill Seam longwall and pillar extraction mining operation that is no longer operational. United Wambo Joint Venture implemented a drilling program to characterise the caved zone above Longwall 10 panel to inform open cut hazard identification and assessments.

United Longwall 10 is an isolated panel with a supercritical panel geometry at approximately 120m depth and 180m panel width. Five boreholes were drilled above Longwall 10 to characterise the caved zone above the longwall panel. The boreholes were HQ cored, geotechnically and geophysically logged and tested for hydraulic conductivity with lugeon style packer testing.

The field program provided valuable information in defining the edge of the caved zone, by characterising the high strain zone of fractures at the edge of the caving arc. Geotechnical core logging allowed characterisation of the fractures, while the packer testing and/or water loss observations allowed assessment of fracture conductivity relating to fracture aperture/strain.

[1] *Principal Geotechnical Engineer, SCT Operations Pty Ltd. Tel: +61 2 4222 2777*

[2] *Senior Geotechnical Engineer, SCT Operations Pty Ltd. Tel: +61 2 4222 2777*

[3] *Project Geologist, United Wambo Joint Venture, Glencore. Tel: +61 448 000 524*

This paper presents outcomes of the drilling program relevant to definition of the caved zone and mining induced fracture network.

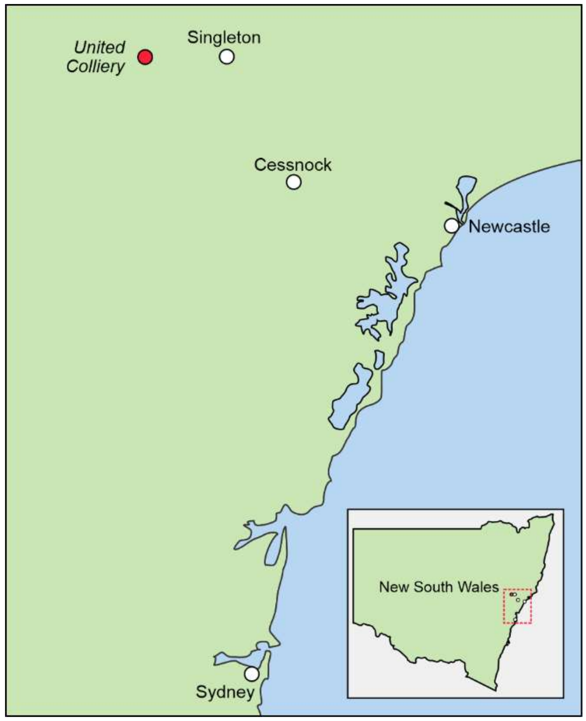


Figure 1: Location of United Colliery.

FIELD INVESTIGATION

The borehole locations were designed to:

- define the edge of the caved zone on the maingate and tailgate sides
- characterise the fracture network above the caved zone
- characterise the fracture network in the caved zone – including two boreholes located in the goaf to investigate potential variability.

The location of the boreholes is presented in Figure 2. Four of the five boreholes form a cross section across Longwall 10. Boreholes SCT07 and SCT10 were located on the north-eastern side of the panel, Borehole SCT09 was located on the south-western side of the panel, and Borehole SCT08 was located in the centre of the goaf. Borehole SCT05 was also located in the goaf centre, approximately 600m south-east of the main cross section to investigate goaf centre variability.

All boreholes were vertical HQ cored boreholes. The first 20m of borehole was not cored due to weaker ground and installation of casing. All core was geotechnically logged. Geophysics was logged where water return was made possible by either a competent borehole, or by a Van Ruth Plug inserted at the base of the hole above the total water loss zone to re-establish water returns. If geophysics was able to be run, the geophysics tools consisted of gamma, density, caliper, Acoustic Televiewer and Optical Televiewer. A borehole camera survey was conducted where possible. Although not specifically presented in this paper, the borehole geophysical logs and borehole camera assisted the authors in characterising and interpreting the caved zone. Key characteristics pertaining to identification of the caved zone are presented in this paper.

The inherent issues of drilling into a goaf including water loss and gas connectivity, meant that boreholes could only be drilled until total water loss was encountered. The panel edge boreholes and one of the centre boreholes were drilled until total water loss, whilst one of the centre goaf boreholes was drilled to 30m above the seam and stopped due to higher risk of goaf connectivity.

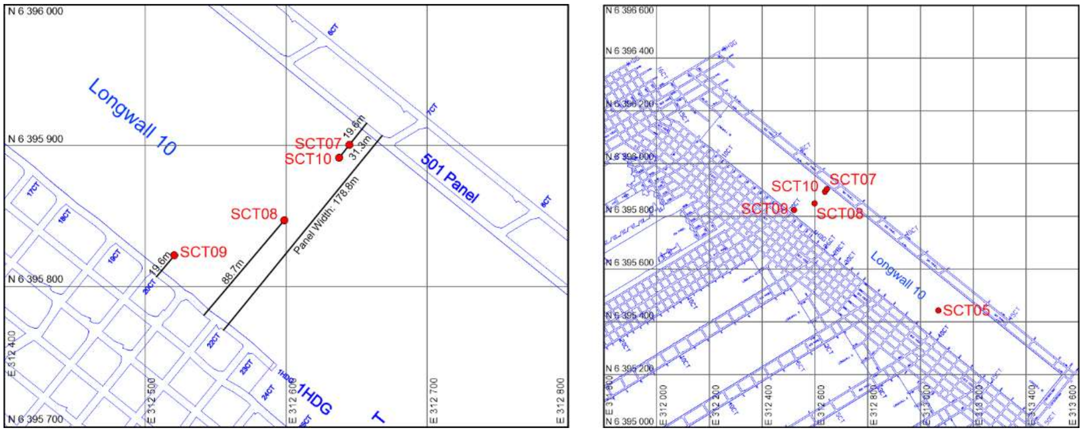


Figure 2: Location of Boreholes over Longwall 10.

DRILLING RESULTS

A summary of the borehole construction and completion for the boreholes aimed to delineate the edge of the caved zone in included in this section. Boreholes SCT07, SCT08 and SCT10 define the edge of the caved zone, while Boreholes SCT05 and SCT08 are located in the panel centre.

SCT07

Borehole SCT07 was located 19.6m from the north-eastern panel edge (solid pillar) and was terminated due to total water loss at 67m depth. The total water loss zone coincided with a high angled fresh fracture and gas make, indicating intersection with the high strain zone associated with the caving arc. A core photo of this fracture is presented in Figure 3a.

Packer testing was conducted throughout the borehole. With the installation of a Van Ruth Plug, geophysical logging was completed. The borehole was grouted on completion of testing and logging.

SCT10

Borehole SCT10 was drilled 31.3m from the north-eastern panel edge and was terminated at a depth of 41.71m due to total water loss. The total water loss zone coincided with a high angled fresh fracture and gas make, indicating intersection with the high strain zone associated with the caving arc. A core photo of this fracture is presented in Figure 3b.

Packer testing was conducted throughout the borehole. A Van Ruth Plug was installed allowing for geophysical logging to be completed. A borehole camera survey was conducted prior to grouting.

SCT09

Borehole SCT09 was drilled 19.6m from the panel edge on the south-western side of the panel and was terminated at a depth of 71.75m due to total water loss. The total water loss zone coincided with a high angled fresh fracture and gas make, indicating intersection with the high strain zone associated with the caving arc. A core photo of this fracture is presented in Figure 3c.

At the completion of drilling a Van Ruth Plug was attempted to temporarily allow water returns to block any potential connection with the goaf. Due to high levels of gas encountered at the base of the borehole, the Van Ruth Plug did not completely block the gas from the hole and neither geophysics nor the borehole camera could be logged. Three grouting attempts were required to seal the borehole.

a) SCT07 high angled fracture at hole TD – location of total water loss.

b) SCT10 high angled fracture zone at hole TD – location of total water loss.

c) SCT09 high angled fracture zone at hole TD – location of total water loss.

Figure 3: Fractures at the location of total water loss for three caved zone delineation boreholes.

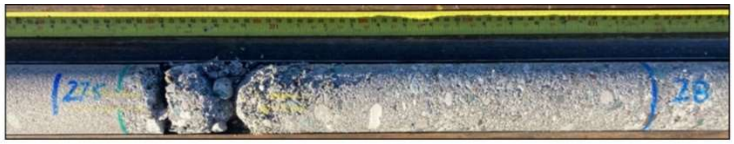
SCT08

Borehole SCT08 was drilled over the centreline of Longwall 10. Borehole SCT08 was fully cored to 89.91m where drilling was terminated at this depth due to anticipation of goaf connection and the potential gas related hazards involved with drilling into the immediate goaf overlying the Woodlands Hill Seam approximately 30m below. Water loss during drilling was observed at multiple stages throughout borehole SCT08, however there was enough water return to surface to continue drilling.

At completion of drilling, geophysics tools were run in the hole. A borehole camera survey was completed prior to grouting the borehole.

SCT05

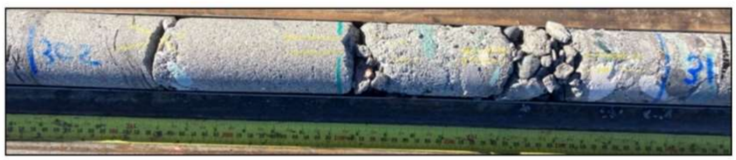
Borehole SCT05 was drilled over the centreline of the Longwall 10 panel. Borehole SCT05 was drilled to a total depth of 32.65m. Total water loss occurred at 29.65m with associated gas make. At this location of total water loss, the borehole was grouted and drilling continued for an additional 3m drill run. Total water loss occurred throughout this drill run with continued gas make observed at the end of the run. The drilling was then terminated at 32.65m. The total water loss zones coincided with fractures, likely intersections with the high strain zones associated with cyclic fracturing from the caving process. The core from these water loss zones are shown in Figure 4.



a) Significant water loss at 27.5m depth.

b) Additional fracture potentially contributing to total water loss at 29m depth.

c) Continued water loss at fractures at 30-30.5m depth.



d) Continued water loss at fractures at 30.5-31m depth.

e) Continued water loss at hole TD fractures at 32.5m depth.

Figure 4: Fractures in water loss zone in borehole SCT05.

At the completion of drilling, installation of a Van Ruth Plug was attempted. Due to high levels of gas encountered at the base of the borehole, the Van Ruth Plug did not completely block the gas from the hole and neither geophysics nor the borehole camera could be logged.

Borehole SCT05 provided a comparison to Borehole SCT08, displaying the variable nature of fracturing and conductivity in the centre of the goaf.

FRACTURE NETWORK

The boreholes were geotechnically logged and found minimal mining induced fractures in the strata above the total water loss zones in the goaf delineation boreholes. A summary of fracture frequency produced from geotechnical core logging is presented in Figure 5. This includes both natural and mining induced fractures. The average fracture frequency in the central goaf borehole is approximately double the fracture frequency for above the caved zone. The average fracture frequency in Borehole SCT05 and SCT08 is 5.04 while the average fracture frequency in Boreholes SCT07, SCT09 and SCT10 is 2.61.

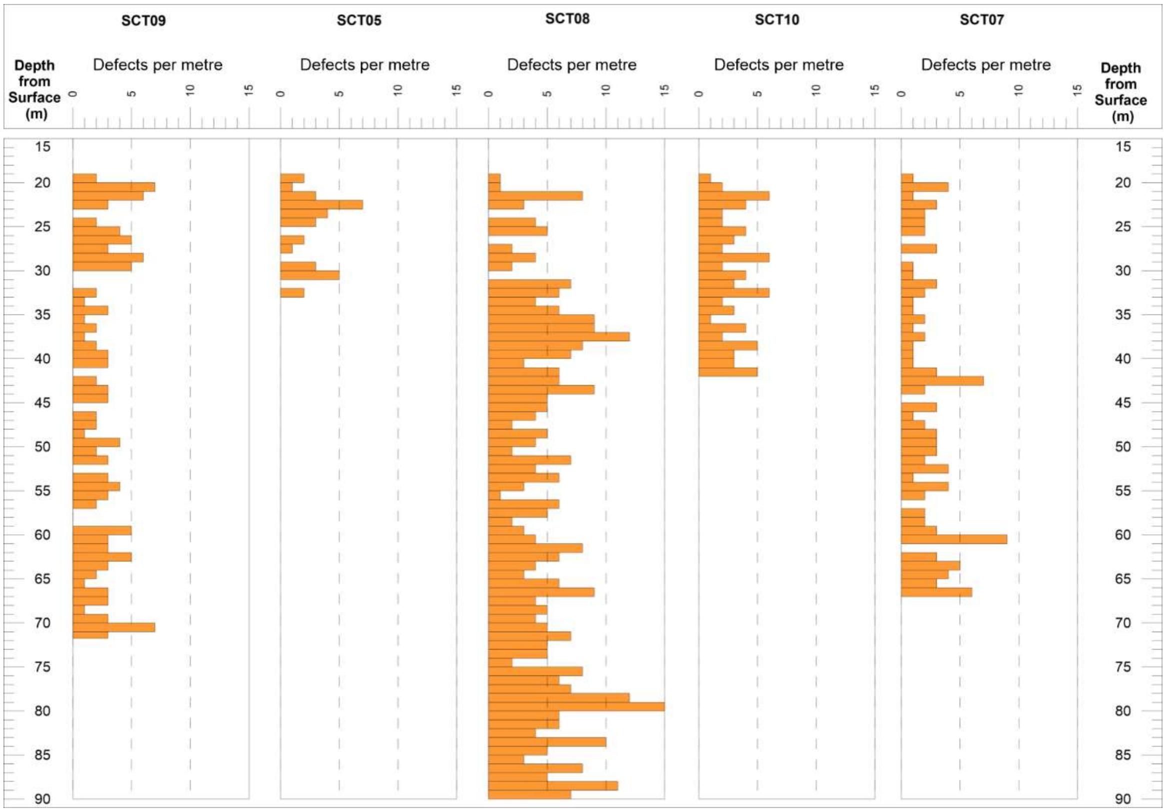


Figure 5: Defects logged per metre.

In the goaf boreholes, there is also an increase in fracture frequency below the D Seam horizon (See Figure 8 for Seam horizons). This is also consistent with site experience where there was no surface to goaf connectivity observed through long term mine gas monitoring of the closed underground mine.

Geophysical logs of Boreholes SCT07, SCT08 and SCT10 provided for structural interpretation from optical televiewer (OTV) and acoustic televiewer (ATV) images. Rosette plots of the panel edge holes (SCT07 and SCT10) showed a northwest strike subparallel to the panel edge (Figure 6). Rosette plots of the goaf centre Borehole SCT08, show a northeast strike. This northeast strike orientation is consistent with anticipated mining induced fracture orientation parallel with the longwall face and also aligns with the strike of local faults mapped at Woodlands Hill Seam level.

The high angled fractures above the caved zone in Boreholes SCT07 and SCT10 are located within the horizon 0-15m above the caved zone (total depth of borehole). These fractures are likely to be mining induced fractures based on the location of these fractures and strike parallel with the panel edge.

Extraction of the open cut above Longwall 10 started after the drilling program was completed. A batter face approximately 65 m to 100 m above the gateroad of Longwall 10 has exposed a number of high angled joint planes with strikes subparallel to the highwall. These fractures are above the identified caved zone located between the D and E Seams. These features are not consistent with previous open cut experience. The high angle dip and orientation of these fractures, together with the inconsistency with site experience, suggest that these fractures may be mining induced fractures from Longwall 10 extraction.

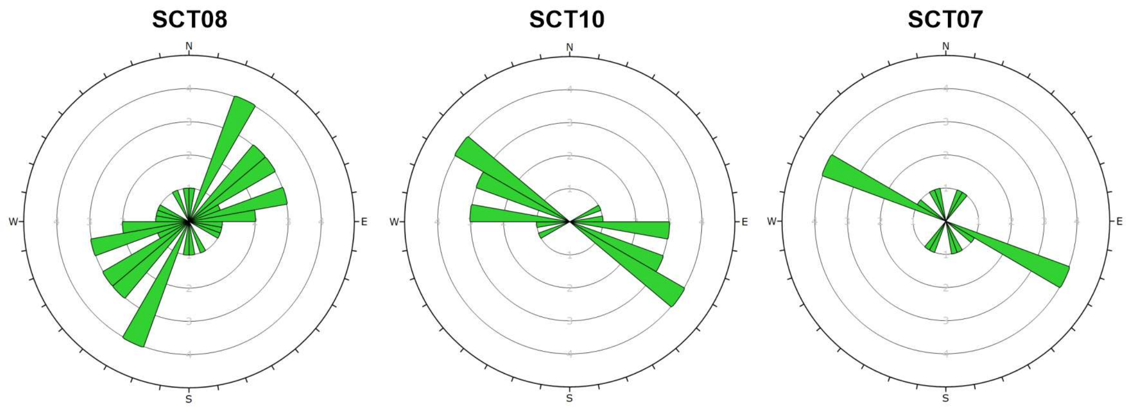


Figure 6: Structural rosette plots of interpretated OTV and ATV images for Boreholes SCT07, SCT08 and SCT10.

HYDRAULIC CONDUCTIVITY

Hydraulic conductivity was tested using Lugeon style straddle packer testing at 6m intervals. The hydraulic conductivity results test results are presented in Figure 7, together with water loss observations whilst monitoring drilling returns. The range in hydraulic conductivity for the caving delineation holes (SCT07, SCT09 and SCT10) was in the order of 1x10^{-10}m/s to 1x10^{-7}m/s. This increased to 1x10^{-6}m/s in some intervals that included coal seam horizons.

At the total water loss horizons, a minimal hydraulic conductivity of 1x10^{-4}m/s was estimated from the maximum pump rate (100L/min) and assuming 10m of water head in the drill string.

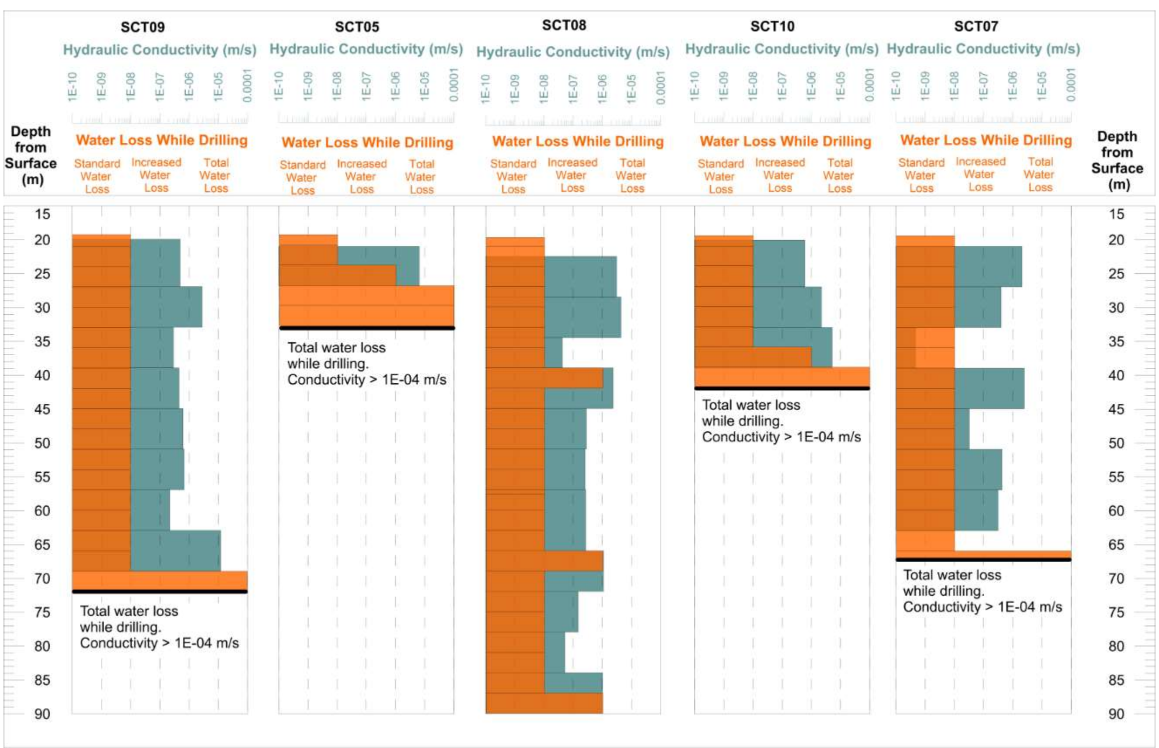


Figure 7: Hydraulic conductivity results and water loss observations over Longwall 10.

The two goaf boreholes (SCT08 and SCT05) showed significantly varied outcomes. Borehole SCT05 experienced total water loss at 30-32m from surface. Borehole SCT08 was able to be drilled to 90m depth, 30m above the extracted Woodlands Hill Seam, without total water loss occurring. Hydraulic conductivity in Borehole SCT08 ranged in the order of $1x10^{-8}$m/s to $1x10^{-6}$m/s.

The total water loss in Boreholes SCT07, SCT09 and SCT10 indicate intersection of the high strain zone associated with the edge of the cave zone. The water loss trends in Borehole SCT05 suggests the borehole intersected a cyclic high strain zone that forms during the dynamic retreat process. The increase in water loss in the run above the total water loss zone in Borehole SCT05 is comparable to the experience in Borehole SCT10 above the water loss zone of the caving arc. The low conductivity in Borehole SCT08 suggests that it may not have intersected a high strain cyclic caving zone, or if it did, it may have been at depth and the aperture reduced by goaf confinement.

The hydraulic conductivity of fractures above the high strain zone are in the order of $1x10^{-10}$m/s to $1x10^{-7}$m/s. This indicates that mining induced fractures that may occur above the high strain zone, are less conductive than fractures in the high strain zone.

CAVED ZONE DEFINITION

The edge of the caved zone was defined by the high strain zone inferred by total water loss and the intersection of one or more high angled fractures. Figure 8 shows a cross section of the caved zone inferred from the water loss zones and the intersected high angled fractures.

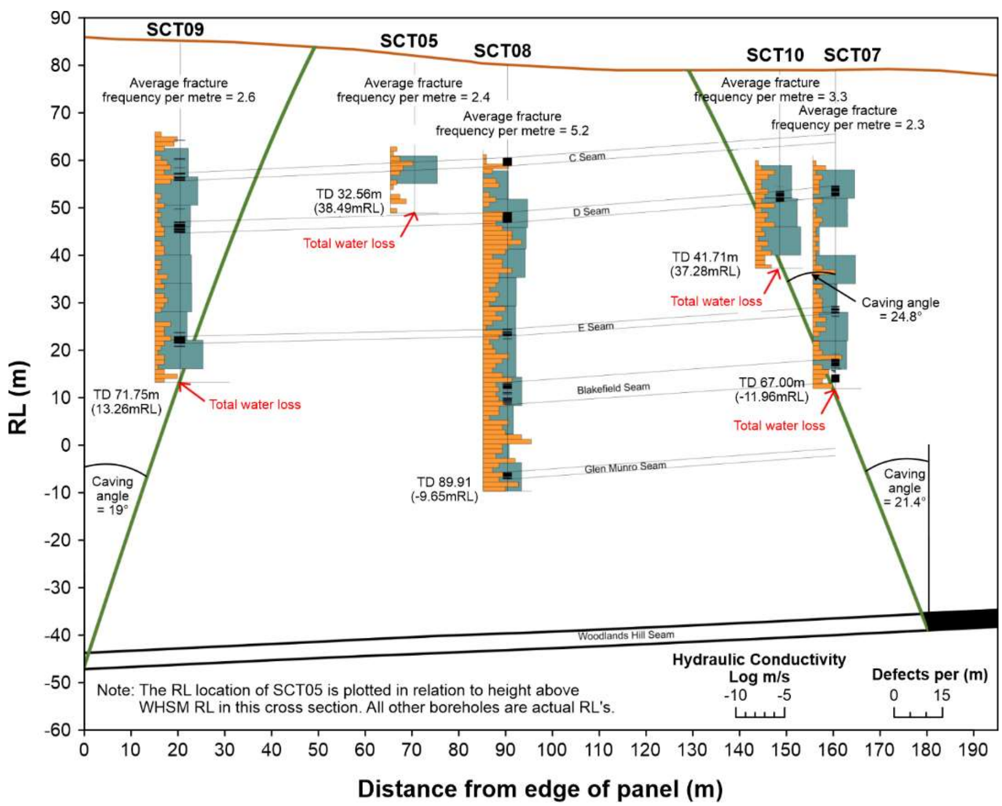


Figure 8: Longwall 10 panel cross section showing edge of caved zone interpreted from borehole drilling.

The location of water loss at the base of the boreholes depicts the caving angle from the pillar ribs up to the first boreholes 50-60m above the seam. On the up dip panel edge, the caving angle is interpreted to be 21 degrees between the pillar rib and the total water loss at the base of borehole SCT07. Between SCT07 and SCT10, the caving angle between the water loss zones at the base of each borehole increases to 25 degrees, indicating the arc shape of the caved zone. On the down dip side of the longwall panel, the angle between the pillar rib and the water loss zone at the base of Borehole SCT09 is 19 degrees.

The interpreted caving angle is the high strain zone at the edge of the goaf. This does not necessarily correspond with the extent of mining induced fracturing, nor does it correspond with the abutment angle (which the latter is a calculated angle based on pillar load). This angle defines the edge of high strain caving fractures with high connectivity for Longwall 10.

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If the caved zone arch was to continue in the same shape as drawn in Figure 8, it would create a height of caving of approximately 160 m (or 0.9 x panel width). This supports the supercritical geometry of this longwall panel and is also consistent with the zone of large downward displacement measurement to be 1.0-1.1 times panel width at Clarence Colliery (Mills and O'Grady, 1998) which has later been summarised at approximately 1 times panel width in Mills (2012).

SUBSIDENCE

The United Longwall 10 subsidence survey Line 10T closely matches the location of the borehole section line across Longwall 10. A comparison of the defined caved zone and the subsidence survey data is presented in Figure 9. The caved zone extrapolation corresponds with the transition between the tensile and compressive surface strains on the up dip side of the panel and the compressive zone on the down dip side of the panel. This is a noteworthy observation as the surface panel edge tensile cracks that are often observed above longwall panels are located in the tensile zone, which is outside the caved zone. This indicates that panel edge surface tensile cracks may not be directly connected to the caved zone high strain fractures due to their location outside of the caved zone.

CONCLUSIONS

United Wambo Joint Venture successfully conducted a goaf drilling program to define the caved zone above Longwall 10. Three of the five boreholes defined the edge of caving, while two boreholes characterised the centre of the goaf. The location of the caved zone was depicted from a combination of total water loss during drilling that coincided with a subvertical fracture at the location of total water loss.

The boreholes showed the caving angle from the pillar ribs up to the first boreholes 50-60m above the seam is 21 degrees on the up dip side and 19 degrees on the down dip side of the panel. An additional borehole drilled 10m towards the goaf centre on the up dip side showed a caving angle increase to 25 degrees from the adjacent borehole, indicating the arc shape of the caved zone.

This caving angle information can inform assessments for hydraulic/gas connectivity and geotechnical engineering applications such as multi-seam overmining or opencut/underground interaction.

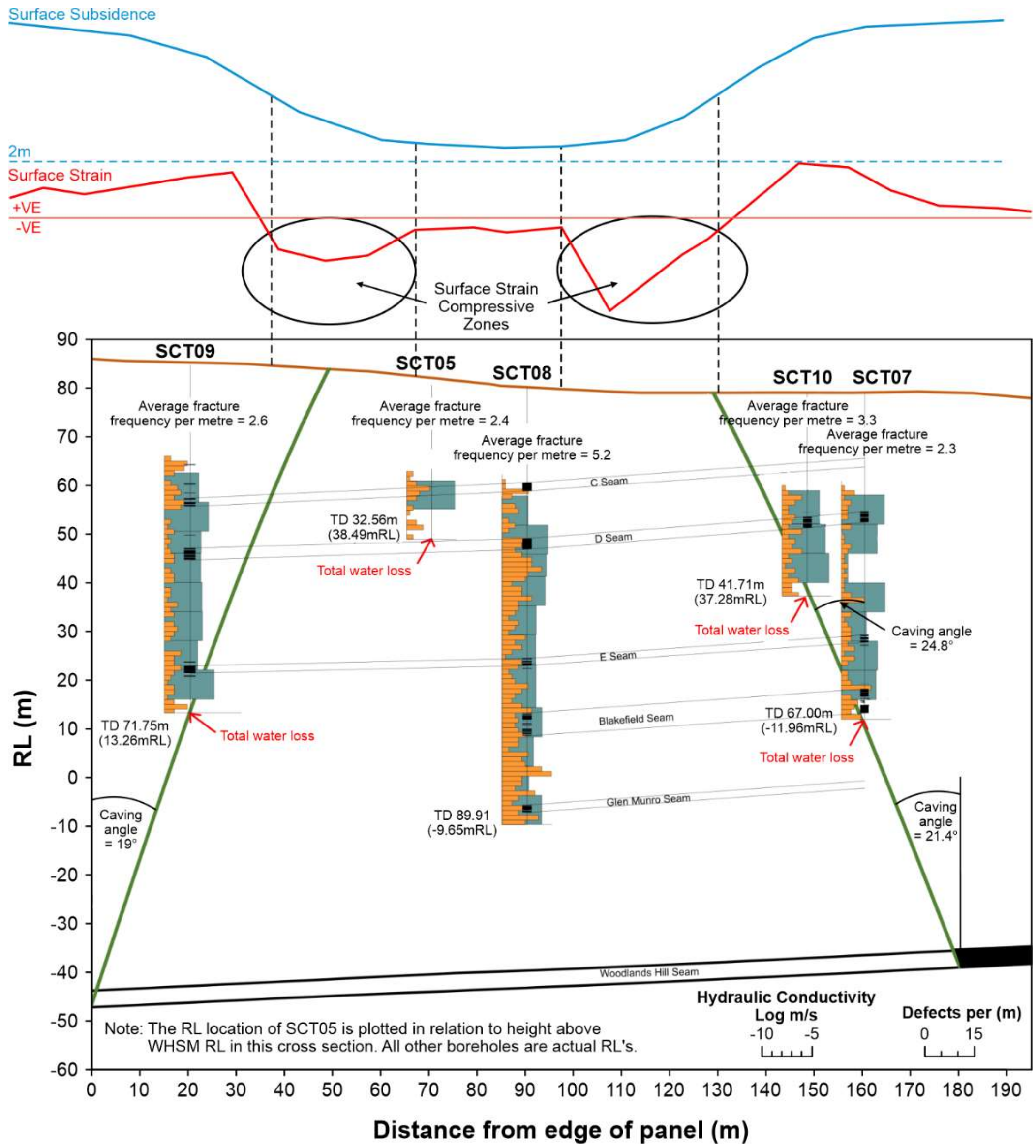

Figure 9: Surface subsidence data and comparison to defined caved zone.

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