Observations of Multi-Seam Subsidence at Ashton Underground Mine

K Mills, SCT Operations Pty Ltd
S Wilson, SCT Operations Pty Ltd

Summary

Ashton Underground Mine (Ashton) is an underground longwall mine located northwest of Singleton in the Hunter Valley of NSW. The mine has extracted longwall panels in three seams, each seam progressively deeper than the last. The mining geometry in each of the seams is regular, parallel and either offset or stacked relative to the panels in the seams above. The high-quality survey monitoring dataset now available from Ashton provides significant insight into the mechanics of ground behaviour in the multi-seam geometry at this site. This paper presents a summary of observations of multi-seam subsidence at Ashton after mining in first two seams and then three seams.

Observations of the characteristics of multi-seam subsidence indicate that although subsidence movements above multi-seam mining are more complex than for single seam mining, the movements are nevertheless regular and predictable. A critical difference from single seam subsidence is that movements are sensitive to the relative panel geometries in each seam and the direction of mining relative to overlying goafs.

Incremental vertical subsidence, as a percentage of incremental mining height, is observed to increase with each additional seam mined. Additional subsidence, referred to as latent subsidence is recovered adjacent to overlying pillar edges and stacked goaf edges when mining in the seam below.

In an offset geometry, remote from pillar and goaf edges, tilt and strain magnitudes are similar or lower than for single seam mining despite the greater vertical subsidence. At stacked and undercut goaf edges, tilts and strains are significantly elevated at locations where fractures were created in the overburden strata during mining in the overlying seam(s).

1. Introduction

A total of eight longwalls in the first seam, six longwalls in the second seam and five longwalls in the third seam have been mined within the same general footprint at the Ashton Underground Mine (Ashton).

The mining at Ashton provides a unique opportunity to study the mechanics and interactions of multi-seam mining in a way that improves understanding of overburden caving behaviour.

The characteristics that make this site particularly useful as a basis to develop understanding multi-seam subsidence behaviour include:

- Longwall mining occurs in a regular, parallel layout with panels and chain pillars of consistent width.
- The seam thickness and seam separation are similar in each seam.
- A comprehensive data set based on well-controlled surveying technique is available for the full period of mining.
- Modern, reliable mine plan records are available in all three seams mined.
- There are no areas of irregular bord and pillar mining or pillar extraction.
- There is no potential for small pillars (or 'stooks') to fail and contribute to risk of pillar run or pillar creep.
- Gradually increasing overburden thickness towards the west provides data for a range of panel width to depth ratios.
- Longwall panels with different starting and finishing positions and goaf edge geometries enable a range of mining scenarios to be studied.

Section 2 of this paper provides a site description and context for the subsidence monitoring observations presented.

Section 3 reviews the subsidence monitoring experience from mining in two seams at Ashton.

Section 4 presents a summary of the experience of mining in three seams.

2. Background and Site Description

Ashton Coal Operations Pty Ltd (ACOL), owned by Yancoal Australia Ltd, operates the Ashton Underground Mine near Camberwell in the Hunter Valley of NSW. The mining approval allows underground longwall mining in four seams. In descending order these seams are the Pikes Gully (PG), Upper Liddell (ULD), Upper Lower Liddell (ULLD) and Lower Barrett (LB).

Figure 1 shows the outline of the longwall voids in the PG, ULD Seams and the five longwalls mined so far in the ULLD Seam superimposed onto a topographic map of the surface area. The positions of subsidence monitoring lines are also shown.

The first longwall in the PG Seam commenced extraction in 2007 with eight longwall panels in the PG Seam sequenced from east to west. Extraction of longwalls in the second (ULD) seam started in 2012 with six longwalls completed to mid-2017. Extraction of longwalls in the third (ULLD) seam started in mid-2017 and five longwall panels were completed by late 2021.

Longwalls in the ULLD Seam are substantially within the footprint of the overlying PG and ULD Seam longwalls, so that the majority of ULLD Seam longwall mining represents three seam extraction with smaller areas of two seam extraction.

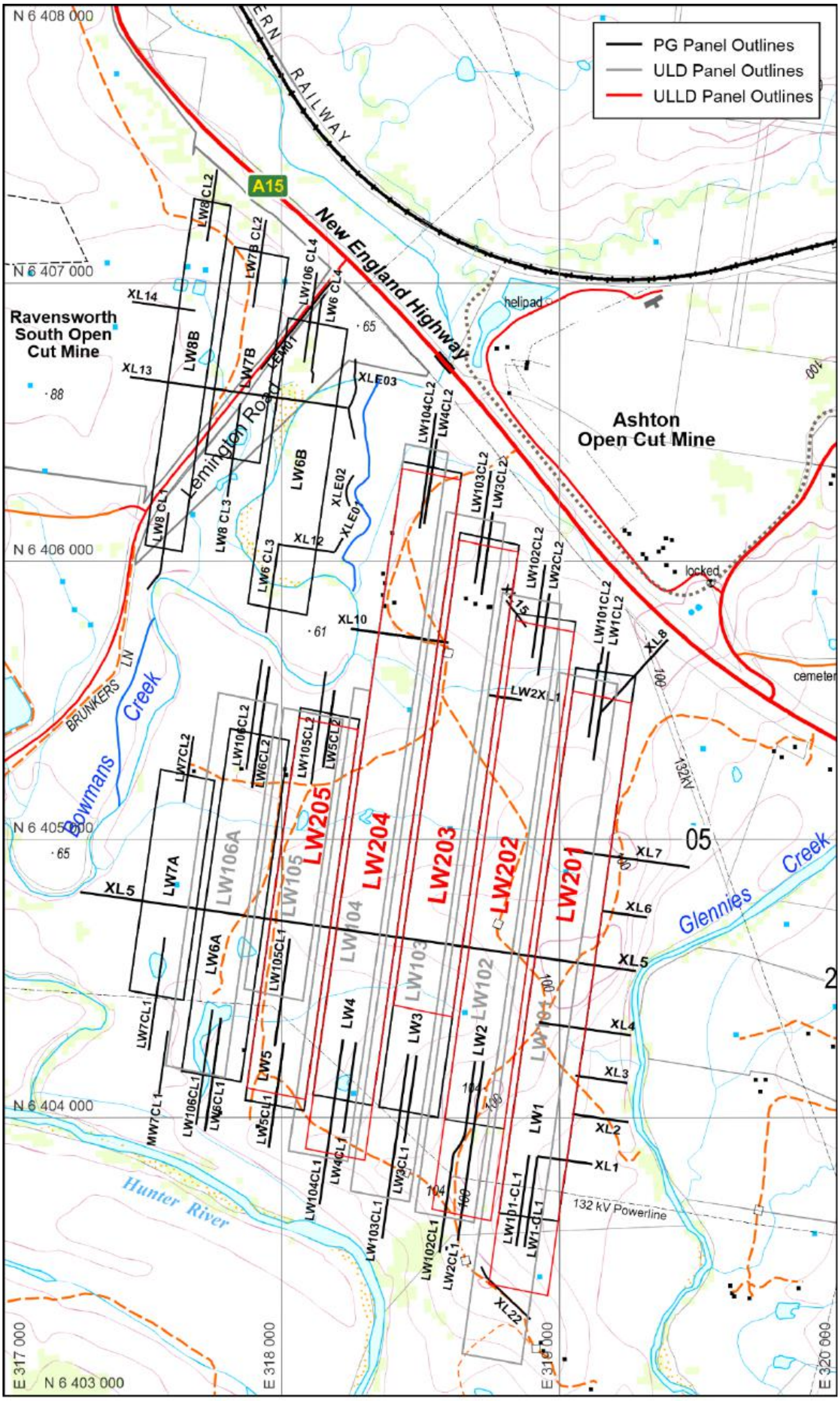

Figure 1 Site plan with location of longwall panel voids and subsidence monitoring lines.

The panels in each of the four seams were originally approved as a regular, parallel, stacked geometry with panels in each seam directly above those in the seam below. The layout design was altered to an offset (staggered) geometry to smooth the overall subsidence profile, to reduce surface impacts, and to take advantage of the potential for reduced stress conditions during gateroad development in the lower seams.

In this offset geometry, longwall panels in the first (PG) and third (ULLD) seams are superimposed. Longwall panels in the second (ULD) seam are offset 60m to the west relative to the PG and ULLD seam longwall panels.

In the regular geometry, longwall panels form a void that is nominally 216m wide and inter-panel chain pillars 24m wide (coal rib to rib). The panels are aligned in an approximately north-south direction with the longwall face retreating from south to north. The naming convention for longwall panels starts with Longwall 1 in the PG Seam, Longwall 101 in the ULD Seam and Longwall 201 in the ULLD Seam.

The mining height in each seam ranges 2.5±0.3m. Longwall mining heights are limited by the seam thickness and the practical operating range of the equipment.

The seams dip to the west at approximately 1 in 10. The gradient of the strata is typically greater than the gradient of the surface topography. The overburden depth to the PG Seam increases from 40m in the northeast corner of Longwall 1 to 180m in the southwest corner of Longwall 7. The interburden thicknesses are typically 35-40m for the PG to ULD Seams and 20-25m for the ULD to ULLD Seams.

The surface topography above the mining area is dominated by a steeply rising ridge line adjacent to Glennies Creek in the east from which the ground slopes west toward Bowmans Creek and the Hunter River to the south.

A comprehensive subsidence monitoring program involving high confidence three-dimensional (3D) survey measurements on conventional monitoring lines has been in place since the start of longwall mining at the Ashton site. Aerial imagery and LiDAR surveys are also regularly captured.

For the PG Seam longwalls, some 35 monitoring lines were installed and regularly surveyed. These subsidence monitoring lines are aligned across the panels and longitudinally near the centre of the panels. The main cross-panel line (XL5) extends over all the southern longwalls.

Sections of the XL5 line are surveyed as each individual panel is mined. The full length of this line was resurveyed at the completion of the PG Seam longwalls and again after completion of mining in the ULD Seam. Sections of XL5 have been surveyed regularly during the mining of the first five longwalls in the ULLD Seam with a survey of the full length after LW204.

A series of 12 additional longitudinal lines were established for the offset geometry in the ULD seam. These lines are adjacent to and offset 30-60m to the PG Seam lines at both the southern and northern ends of each panel. Additional monitoring is conducted at other surface features as required.

3. Subsidence Behaviour from Second Seam of Mining

Contemporary understanding of the mechanics of multi-seam subsidence at Ashton based on two seams of mining is presented in Mills and Wilson (2017).

The results of the ULD Seam monitoring show that subsidence behaviour falls into two categories depending on the relative geometries of the mining in the two seams:

- general background subsidence behaviour for areas remote for pillar edges with tilts and strains of similar magnitude to those observed for single seam mining

- subsidence near goaf edges where temporary or permanent stacked goaf edges are formed and strains and tilts are significantly greater than in single seam mining.

The monitoring dataset provides insight into the mechanics that drive the magnitude and distribution of subsidence movements in the multi-seam environment at the site including:

- the difference in behaviour between strata that is undisturbed by previous mining and strata that has already been subsided (disturbed or modified)

- increased incremental vertical subsidence as a percentage of the second seam mining height

- the concentrating effect of mining near and under overlying goaf edges on tilts and strains

- effect of mining direction on subsidence behaviour above solid/goaf edges

- recovery of latent (extra) subsidence from the overlying seam.

Latent subsidence is a term referring to subsidence which did not occur during mining of the first seam owing to the support provided by nearby pillar or abutment edges. When the second seam mines under the chain pillars and other abutment edges, the strata above and adjacent to the first seam chain pillar and abutment coal edges is disturbed. The supporting effect around the pillar/coal edges is lost and additional subsidence occurs above these edges.

Latent subsidence has a consistent, incremental effect on both vertical and horizontal subsidence movements affecting tilt and strain measured at the surface.

3.1 General Subsidence Behaviour

Figure 2 shows a summary of subsidence monitoring results from XL5 at the completion of mining the sixth longwall (Longwall 106A) in the ULD Seam. The vertical subsidence profile shows the effects of increasing overburden depth and a change from supercritical width caving behaviour to more critical width behaviour with a smoothing of the profile shape and reduction in the magnitude of total subsidence. The areas of latent subsidence are highlighted in the plot of incremental subsidence.

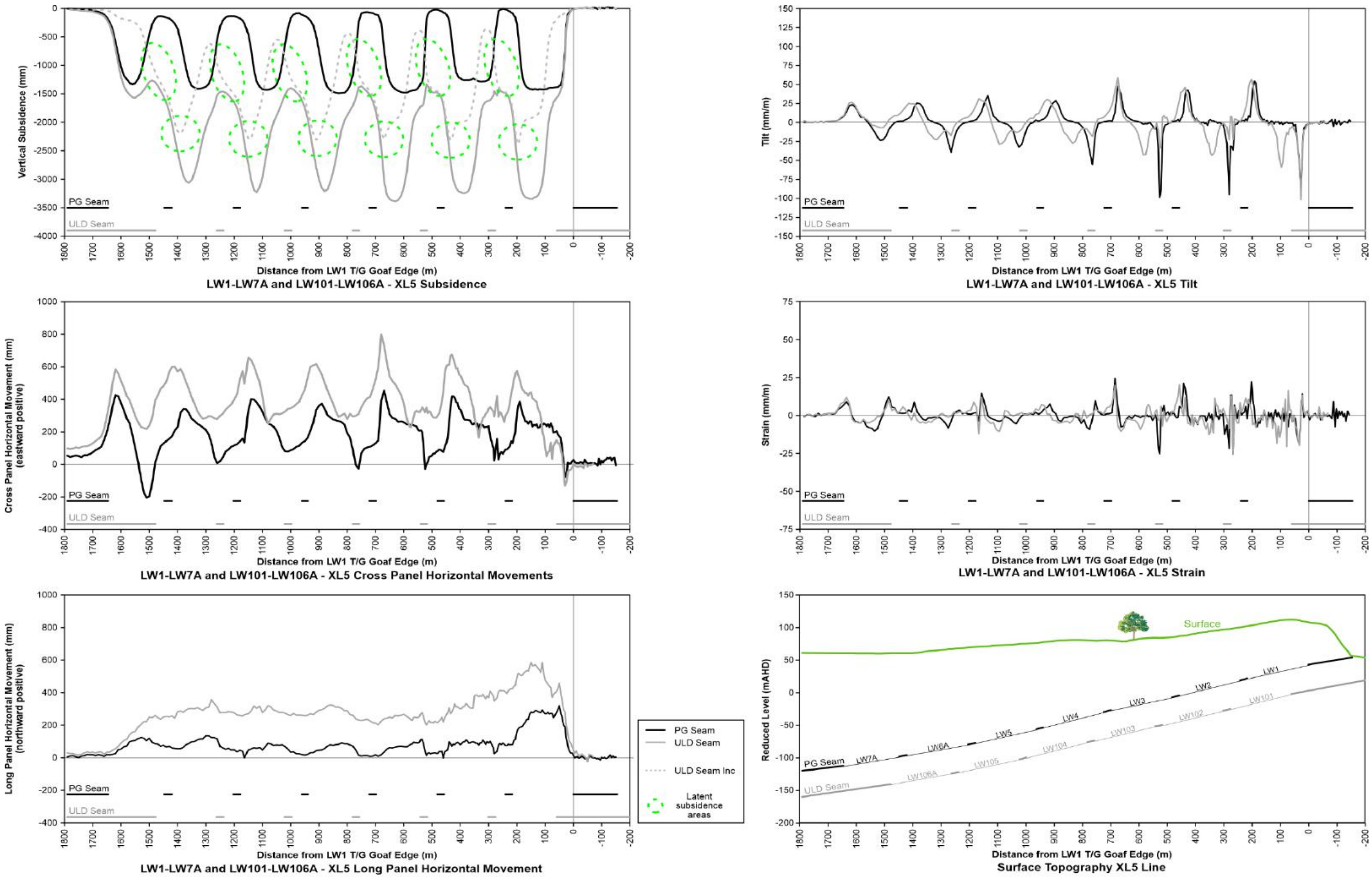

Figure 2 Summary of the subsidence movements measured on XL5 Line for the PG Seam and ULD Seam longwalls.

3.2 Multi-Seam Subsidence Zones Across the Panel Width

Figure 3 shows the cumulative vertical subsidence profiles and the incremental vertical subsidence profiles measured over the first longwalls in the PG Seam and ULD Seam. Several zones of behaviour are apparent: remote from the panel edges, close to the panel edges in the overlying seam and directly below the chain pillars in the overlying seam.

Remote from the edges of both panels, maximum incremental subsidence is 75% of the second seam mining height in this example and typically in the range 70-83%. This increment is higher than the 50-65% more typically observed in NSW for single seam mining remote from the panel edge (i.e., in a supercritical width mining geometry).

Near goaf edges in the overlying PG Seam, incremental subsidence increases by up to 300-400mm where latent subsidence from the first seam is recovered. Vertical subsidence as high as 92% of the second seam mining height is apparent at Ashton. When latent subsidence occurs, the magnitude of this additional subsidence is not a function of the seam mining height in the lower seam, but a function of recovering subsidence that did not occur when the first seam was mined because of the support provided by the chain pillars.

Directly below the chain pillar in the PG Seam, mining in the ULD Seam effectively gives the same subsidence as it would if the ULD Seam was the first seam mined. The ground above the chain pillar is not disturbed by mining in the PG Seam and the subsidence observed during mining in the ULD Seam is equal to single seam subsidence.

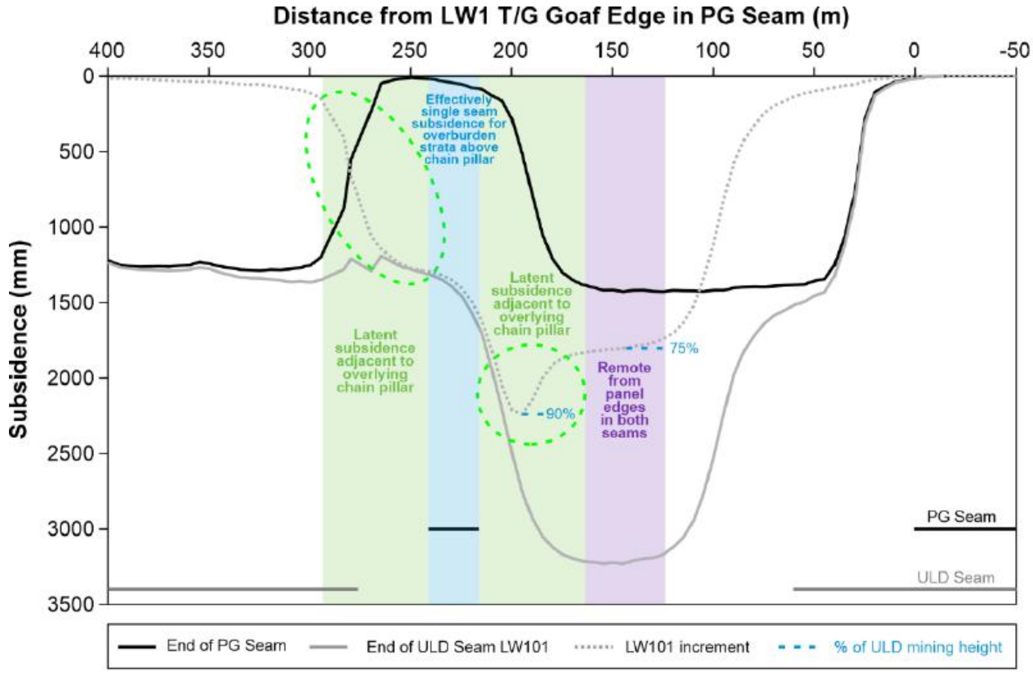

Figure 3 Individual components of incremental subsidence profile.

Maximum values of tilt and strain are typically less in areas remote from pillar and goaf edges than for the first seam mined despite the greater total vertical subsidence. This behaviour is attributed to a general softening and reduction in shear stiffness of the overburden strata overlying the upper seam that has been previously subsided.

3.3 Strata Compression Above Chain Pillars

Incremental vertical subsidence above the ULD Seam chain pillars is much greater than the elastic strata compression observed above chain pillars when the PG Seam was mined. This increase in subsidence is a result of non-elastic compression of the ground above the lower seam chain pillar and the reduced stiffness of this ground caused by mining in the PG Seam.

3.4 Behaviour at Stacked Goaf Edges

The ULD Seam longwalls formed stacked or almost stacked edges at several locations. The measured tilt and strain near the stacked goaf edges are significantly elevated compared to tilt and strain observed in areas remote from overlying goaf edges. The greatest tilt and strain are observed when the deeper seam undercuts the upper seam goaf edge.

The direction of mining in the second seam under an existing goaf edge has a significant influence on the surface effects that develop. Mining from a goaf under solid leads to a stacked goaf edge that produces very high tilts and strains and much higher than the general background values. Mining from solid to under a goaf produces en-masse subsidence with tilts and strains that are comparable to levels remote from goaf edges.

3.5 Mining from Under Goaf to Under Solid

At a stacked goaf edge where the lower seam is mined into solid from below an existing goaf in the upper seam, maximum tilts are observed to be approximately double the maximum tilts observed elsewhere. Horizontal strains are observed to peak at about four times the background levels measured more generally along the panel. These maxima are observed when the goaf edge in the upper seam is undercut to a distance where the caving of the goaf in the lower seam intersects the goaf edge in the upper seam.

The presence of the pre-existing fractures in the overburden from the upper seam mining acts as a preferred separation point to localise deformations from the lower seam mining. Deformations become concentrated on these pre-existing fractures with the result that tilt and strain magnitudes are significantly elevated.

Figure 4 illustrates the retreat of a ULD Seam longwall under the PG Seam goaf edge/solid coal and how the subsiding strata interacts with the overlying goaf edge as the panel retreats.

3.6 Mining from Under Solid to Under Goaf

Different subsidence behaviour is observed where a longwall proceeds in the opposite direction. Where a longwall transitions from mining in a single seam to mining below an overlying goaf, the subsidence profile involves a large wedge of undisturbed strata above the start of the overlying panel subsiding en-masse. Tilt and strain magnitudes are of similar magnitude to single seam mining.

Figure 5 illustrates the geometries involved and shows how the disturbance caused to the ground by mining longwall panels in the two seams leaves a triangular wedge of largely undisturbed ground above the start of the PG Seam longwall. This triangle of rock subsides gradually en-masse as mining in the underlying ULD Seam progresses.

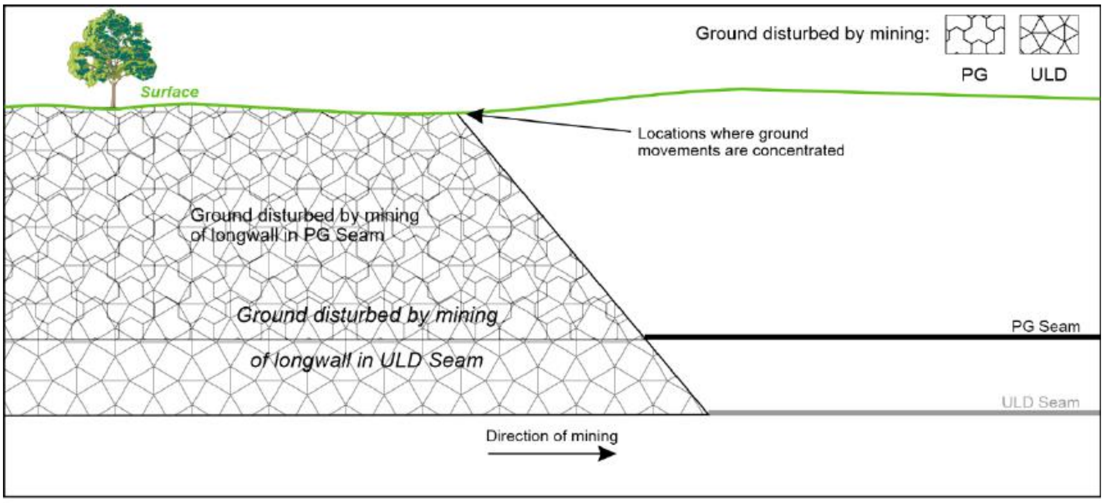

Figure 4 Sketch illustrating the mechanism that concentrates the strata movements during mining in the ULD Seam at the same location as they were concentrated during mining in the PG Seam.

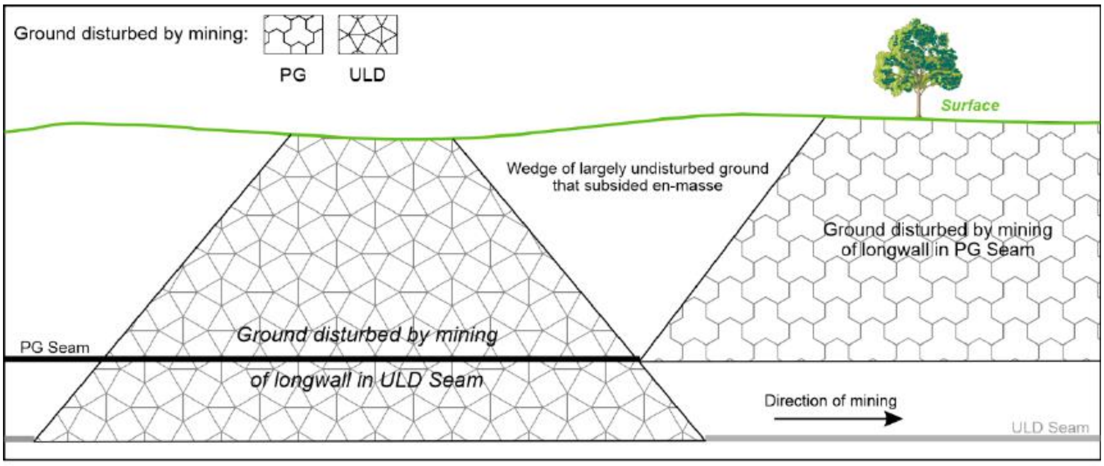

Figure 5 Sketch illustrating the mechanism by which a wedge of undisturbed strata subsides as the ULD Seam longwalls mine under the start of the PG Seam longwalls.

3.6.1 Horizontal Movements

The magnitude, direction, and form of horizontal movements observed during mining the ULD Seam are consistent with the horizontal movement observed during mining of the PG Seam. Total horizontal movements measured for mining in the ULD Seam are typically in the range of 20-30% of the vertical subsidence.

There is a strong similarity in the characteristics and distribution of cross-panel horizontal subsidence movements associated with each longwall panel indicating a consistent mechanism driving horizontal movements. The influences of the offset geometry and latent subsidence recovered from the PG Seam are seen as a regular pattern of incremental horizontal movements associated with mining in the ULD Seam.

There is also a strong influence of strata dilation or bulking in the development of horizontal movements. This strata dilation generated by the creation of subsidence fractures within the overburden strata causes a general shift in an uphill direction. The mechanics of this process are described in Mills (2001).

Incremental long-panel horizontal movements are characterised by movement toward the approaching longwall face, followed by movement in the reverse direction after the longwall face has passed. This behaviour is similar to the ground movements commonly observed above supercritical width longwall panels in a single seam mining geometry.

3.6.2 Incremental Subsidence Movements

Figure 6 shows the incremental vertical subsidence and incremental cross-panel horizontal movements measured above Longwalls 101 to 106A. The horizontal distance is plotted relative to the tailgate or eastern ULD Seam goaf edge. A slight, downdip side-shift, with increasing depth is apparent.

Figure 6 shows:

- the vertical subsidence profile has a regular, repeatable form, with a general smoothing and reduction in peak values with increasing overburden depth
- the maximum vertical and horizontal movements occur substantially within the footprint of the active panel
- the influence of the recovered latent subsidence from the PG Seam extends over the disturbed ground of the next panel
- movements over previous panels are small and insignificant for most practical purposes.

4. Subsidence Behaviour from Third Seam of Mining

Monitoring data from XL5 Line and the longitudinal lines at the start of finish of Longwalls 201-205 in the ULLD Seam provide insights into the mechanics of multi-seam mining in three seams.

Figure 7 shows the subsidence effects along XL5 Line after the mining of Longwalls 201-205.

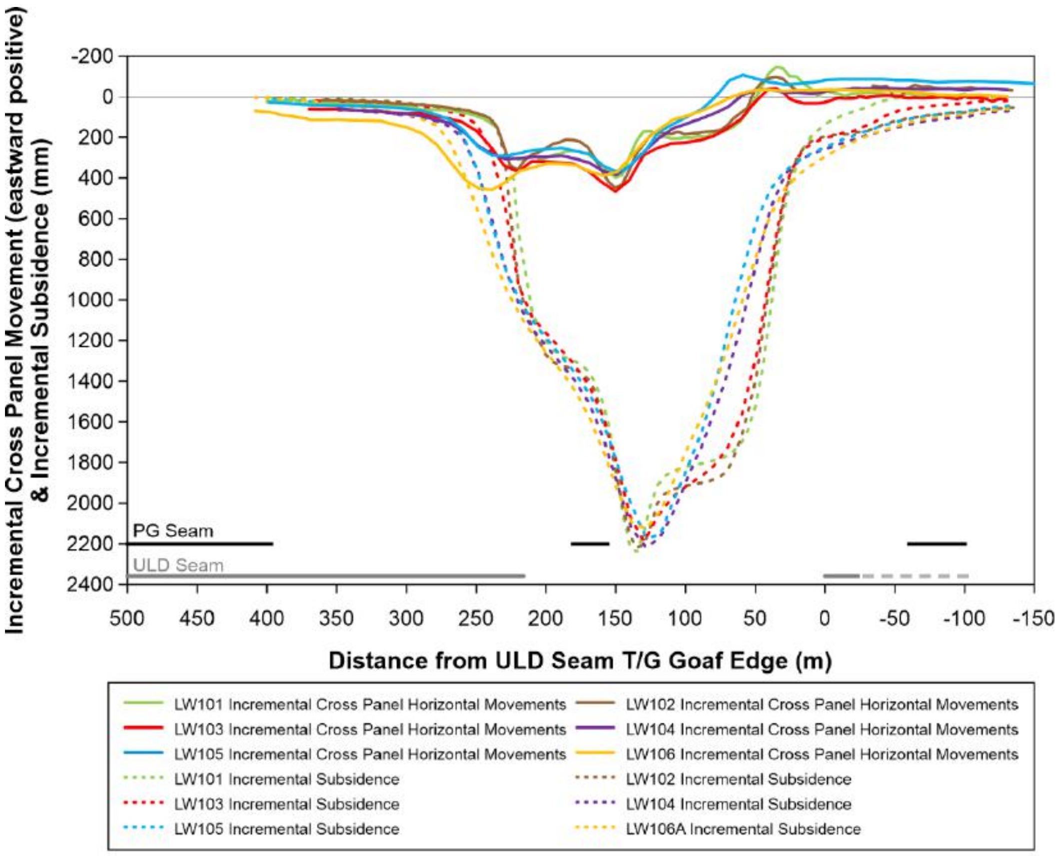

Figure 6 Incremental Cross Panel Horizontal Movements and Vertical Subsidence for LW101 - LW106A.

The panels in the ULLD Seam are offset relative to the ULD Seam panels in the opposite direction to the offset of the ULD Seam panels relative to the PG Seam panels. As a result, the incremental vertical subsidence profile is the mirror image of the incremental profile for the ULD Seam. The latent subsidence recovered adjacent to each overlying chain pillar is clearly evident.

After three seams of mining at Ashton, maximum cumulative subsidence has reached 5.8m. Cumulative subsidence ranges 72-78% of the combined mining heights in all three seams.

Remote from chain pillars and goaf edges in overlying seams, incremental subsidence ranges 82-88% of ULLD Seam mining height. Maximum values of tilt and strain are similar or of a lower magnitude than those measured for the PG and ULD Seams despite the increased vertical subsidence.

Close to chain pillars and goaf edges in overlying seams, incremental subsidence ranges 96-105% of the height of the seam being mined when the latent subsidence from the overlying seam is included. Maximum incremental subsidence from the ULLD Seam mining is 2.7m (105% of ULLD Seam thickness) which includes latent subsidence from the ULD Seam.

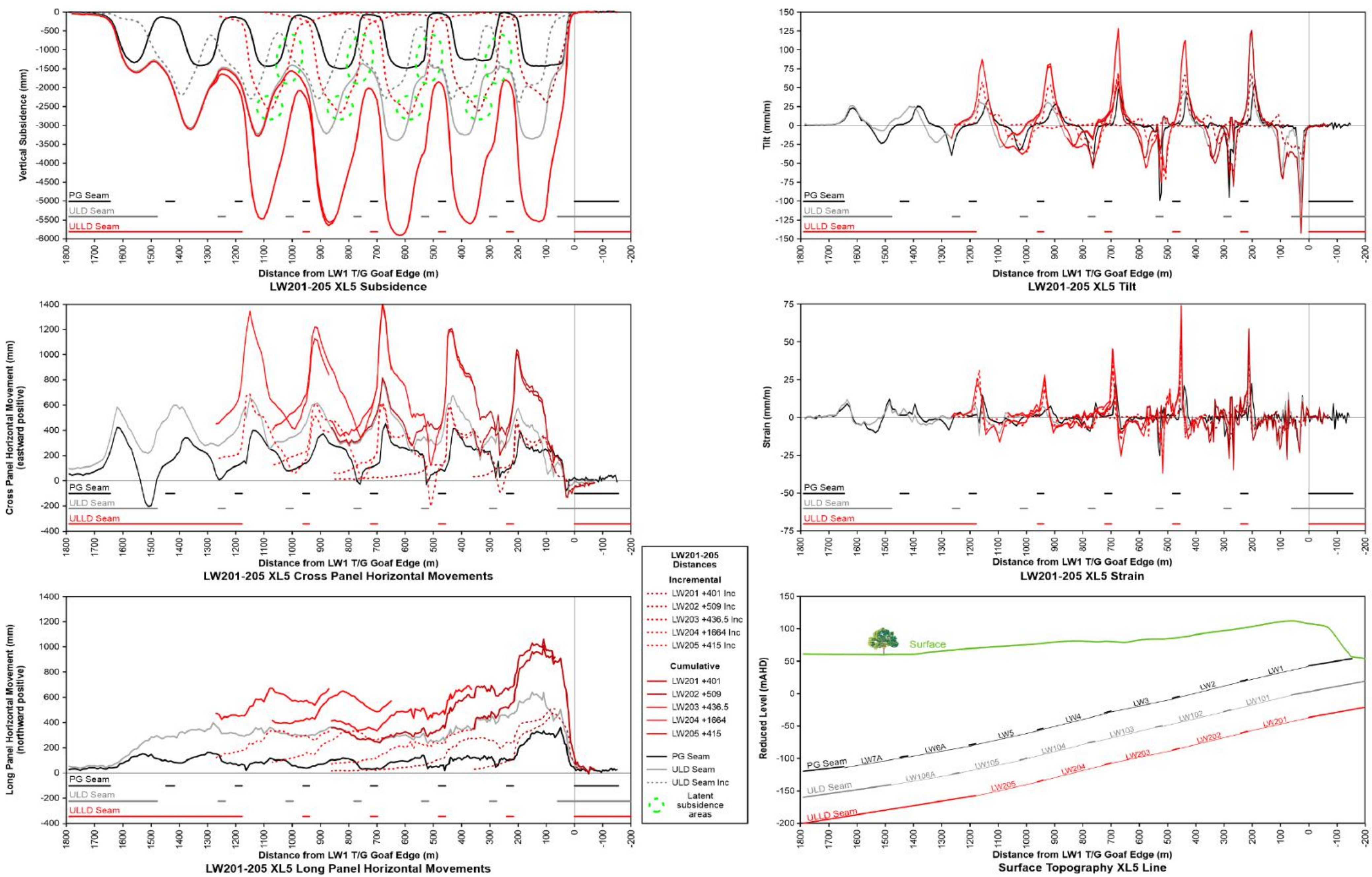

Figure 7 Summary of the subsidence movements measured on XL5 Line to the end of LW205.

The areas of latent subsidence adjacent to pillar edges are similar in extent to those observed during the ULD Seam mining. The magnitudes are also similar. The additional vertical displacement from latent subsidence is estimated at 300-500mm, the same as that observed when the PG Seam goaf edges were mined under.

Maximum tilt and strain near the panel edges are higher than over the centre of the panel.

4.1 Behaviour at Stacked Goaf Edges

Stacked goaf edges associated with mining from goaf to solid were avoided in Longwalls 201-203 to improve longwall conditions during start-up and take-off. However, Longwalls 201 and 202 created a variation of mining direction effects at stacked goaf edges not previously observed. Both panels mined from below a single seam goaf to under goaf in two seams. Mining in the third seam progressed from solid to under a goaf edge at the same location for a second time. During the first episode of mining, a triangular wedge-shaped block of overburden subsided en-masse as illustrated in Figure 5. This block remained substantially undisturbed by incremental mining effects.

Figure 8 shows the mining geometry and the overburden strata impacted by mining in each seam. The second episode of mining in the third seam led to fracturing and dilation of the undisturbed strata in the wedge for the first time.

Another observation from three seams of mining relates to stacked goaf edges formed by mining in the first and third seams, albeit with mining in the second seam between the edges.

The mining layout in the ULLD Seam is directly below the PG Seam goaf leading to stacked edges along both sides of each panel.

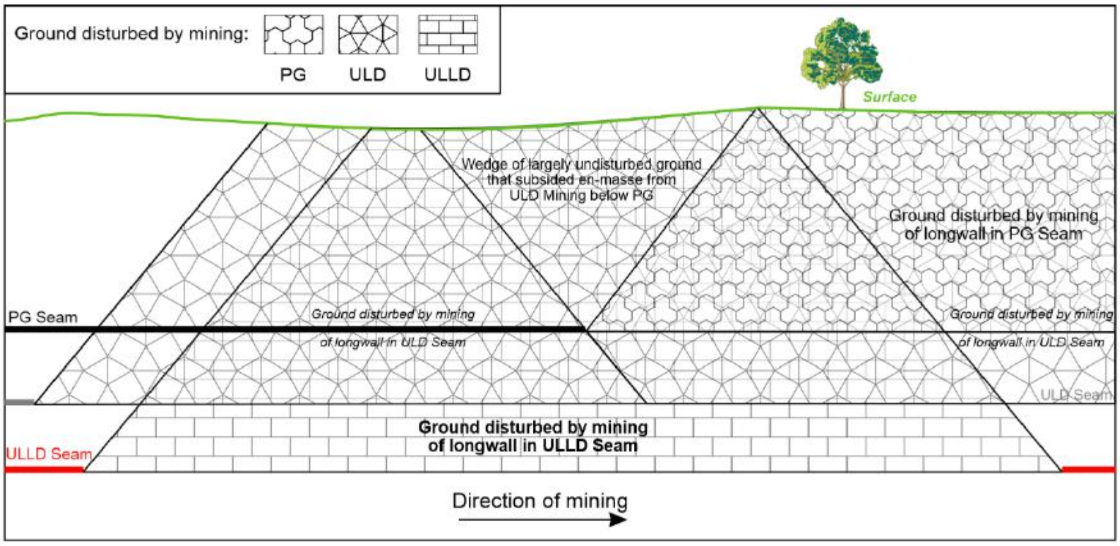

Figure 8 Sketch illustrating the geometry and the mechanisms driven by mining direction at start of panel and vertical subsidence profile.

The PG Seam panel edges had previously been remediated. They were then mined under by a ULD Seam longwall which is offset 60m to the west before being mined under again by the ULLD Seam longwall.

Tilt and strain measured on XL5 Line at the panel edges of the PG Seam approach the levels observed at stacked goaf edge levels at other locations where only two seams are mined. Even though the panel edge had subsequently been mined under by a ULD Seam longwall without forming a stacked edge, movements continue to be focussed on the original fractures in the overburden when a stacked edge is subsequently formed with the first seam by mining in a third seam. Fracturing in the overburden from the first seam of mining appears to be reactivated with further movements concentrated and localised at the original fractures. Surface cracks along the PG Seam panel sides opened again during mining of the ULLD Seam longwalls.

4.2 Multi-Seam Subsidence Zones cross the Panel Width

Incremental subsidence in the centre of the panel, maximum incremental subsidence with latent subsidence effects, and cumulative subsidence from the third seam of mining are all generally 5-10% greater, as a proportion of mining height, than the equivalent values after two seams of mining at the same location.

Figure 9 shows a comparison of the increment profiles against the cumulative profiles for the ULD and ULLD Seams. The areas where latent subsidence is recovered are shown. The magnitudes of incremental subsidence as a percentage of the mining height are also shown for each of the main zones of ground behaviour highlighted in Figure 3.

4.3 Multi-Seam Incremental Subsidence Observations

Figure 10 shows the incremental vertical subsidence profiles super-imposed for Longwalls 201-205. A regular pattern of behaviour is observed similar to the regular pattern shown in Figure 6 above the ULD Seam panels.

The slight variations are consistent with patterns of increasing depth also observed for mining in the ULD Seam.

When compared to two seams of mining, the cross-panel incremental profiles indicate a further ‘softening’ of the overburden from the third episode of mining. This softening results in a slightly wider, slightly steeper subsidence trough and greater subsidence as a proportion of mining height in the third seam.

4.4 Horizontal Movements

Figure 10 also shows the incremental cross-panel horizontal movements for Longwalls 201-205. The magnitude, direction and form of horizontal movements observed are consistent with the horizontal movements observed during mining of the PG and ULD Seam longwalls.

The influence of the offset geometry and latent subsidence are seen in the profile as a regular pattern of incremental horizontal movements.

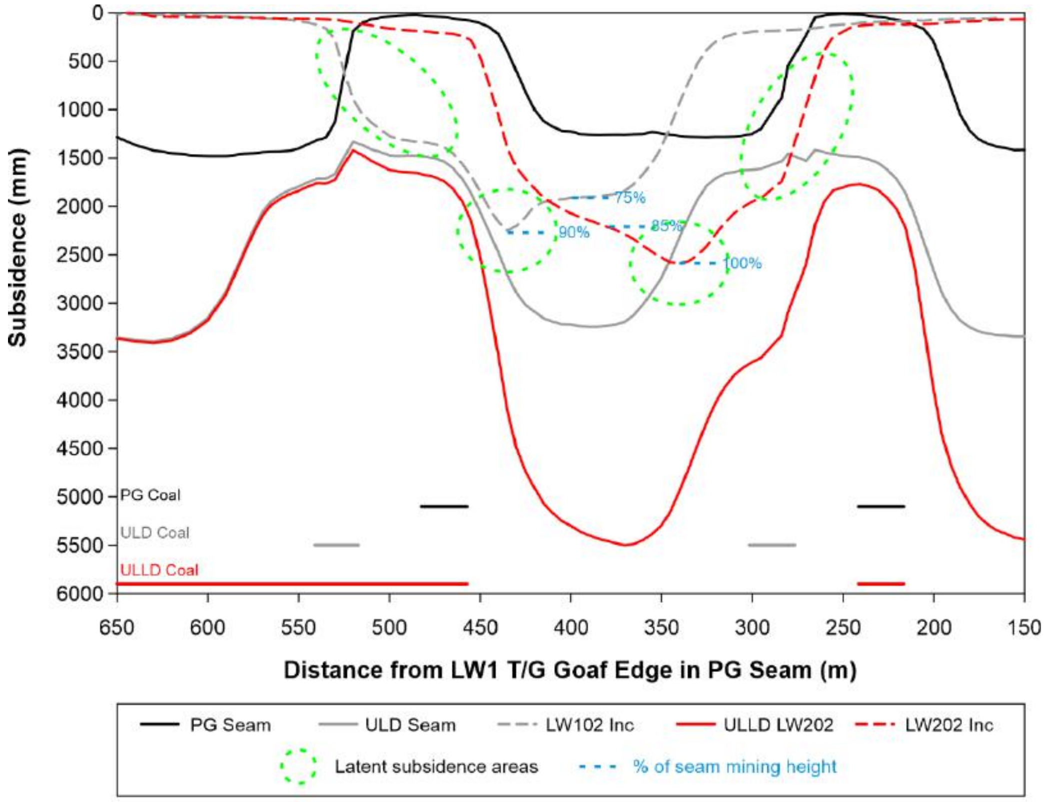

Figure 9 XL5 Subsidence - LW102 and LW202 with second and third seam increments.

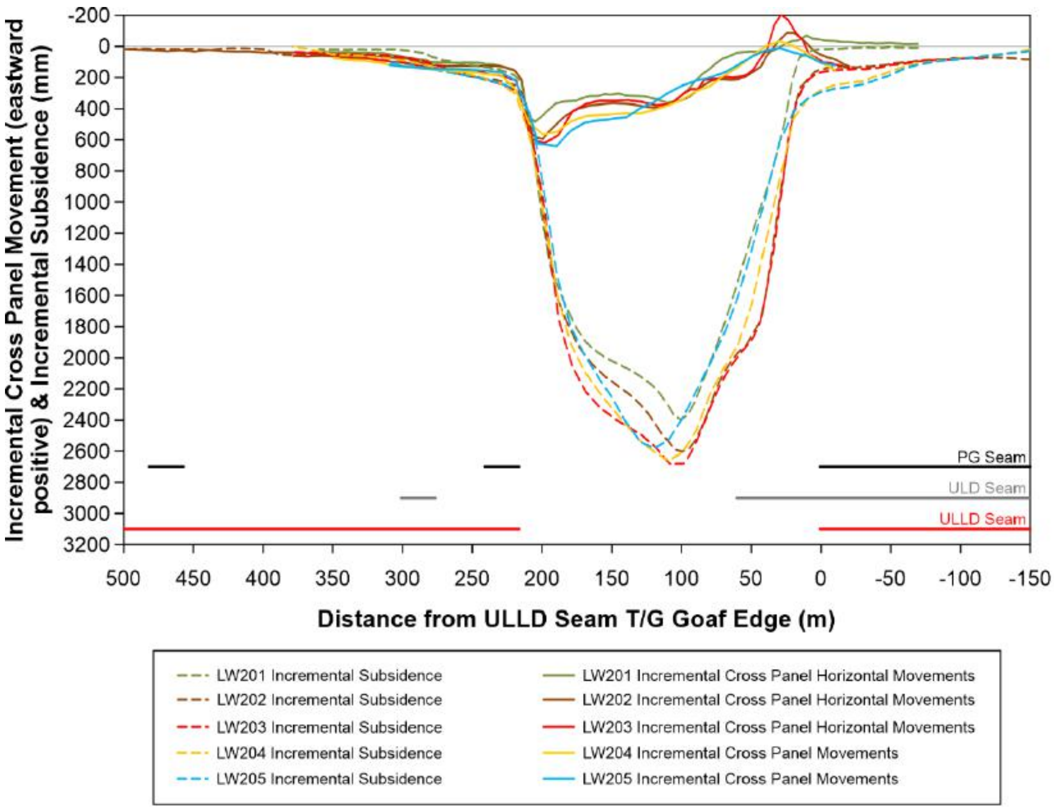

Figure 10 Incremental vertical subsidence and cross panel horizontal movements for LW201-LW205.

The characteristics and distribution of horizontal subsidence movements indicates a consistent mechanism driving the horizontal movements.

Cumulative horizontal subsidence movements of 1.4m have occurred in an upslope or easterly direction during the period of mining three seams. These movements represent 20-30% of the cumulative vertical subsidence consistent with the experience of the previous mining in the upper seams.

4.5 Angle of Draw

In a multi-seam environment, the extent of subsidence varies depending on the geometry of the extracted panels in all the seams and the angle of draw to 20mm of subsidence becomes dependent on this geometry.

The angle of draw outside of the outermost goaf edge is the same as for single seam mining even when the outermost goaf edge is not associated with the panel being mined. The angle of draw for the second and third seam being mined extends further when the overlying strata has been disturbed or modified by previous mining.

The angle of draw from the outer edge of multi-seam panels based on the depth to the seam of the outer panel edge is similar to single seam mining. Where panels start or finish within the boundary of overlying panels changes to the angle of draw for the upper seam(s) are imperceptible for all practical purposes. No significant change in angle of draw has been observed where multiple panels are aligned at a stacked goaf edge and additional goaf edge subsidence is measured.

Where panels start well below an established goaf, the subsidence and angle of draw at the start line is greater, consistent with a general softening of the overburden strata from the previous episode of subsidence.

Subsidence across panels is observed to extend above overlying goaf areas to the next load bearing pillar or solid coal. These low magnitude movements are a secondary effect from the low-level subsidence or compression of the previously disturbed ground.

Although this low-level subsidence is generally insignificant, consideration of multi-seam interaction effects is helpful in determining study areas for impact and environmental assessments as required by the mining approval process.

4.6 Comparison of Predicted and Observed Subsidence

Monitoring data indicates the methodology used to forecast the subsidence behaviour for the third seam based on an understanding of the subsidence mechanics is providing a reasonable estimation of the measured subsidence effects for impact assessment purposes.

The maximum incremental and cumulative vertical subsidence measured on XL5 Line to date is consistent with forecast. The difference between predictions and measured are well within 15%, recognising that natural variation expected in single seam mining is usually of the order of 15%.

Observed tilt and strains are able to be estimated using the Holla approach (Holla 1991) and site specific K values derived from monitoring for each of general background, stacked goaf edges, and undercut goaf edge areas (Mills and Wilson 2017).

The main variation from predictions occurs where areas of maximum latent subsidence are located slightly further to the west than forecast. This variation is attributed to dipping strata but is of no practical consequence.

With multi-seam mining geometries, there is potential for measurements of incremental subsidence to be misleading as performance indicators of subsidence magnitude. For instance, longitudinal lines can be located in areas where incremental subsidence includes latent subsidence. The resulting maximum incremental subsidence can be interpreted as indicating greater than predicted subsidence when the increment is added to previous maximum subsidence.

Performance indicators should be based on measured cumulative subsidence movements and not the calculated incremental subsidence to avoid this issue.

5. Conclusions

The monitoring dataset from Ashton provides insight into the mechanics of ground behaviour that drive the magnitude and the distribution of subsidence movements in the multi-seam environment at the site.

Subsidence behaviour from the second and third seam of mining are consistent and predictable once the various geometry effects are recognised and considered. The patterns of incremental subsidence movements are regular and repeatable.

Ongoing softening of the overburden with each episode of subsidence and recovery of latent subsidence from previous episodes is evident as:

- incremental subsidence increasing as a proportion of mining height with each additional seam mined
- slightly wider and slightly steeper subsidence troughs.

The maximum incremental and cumulative vertical subsidence measured is consistent with forecast and the actual levels of incremental and cumulative tilt and strains are generally less than the maxima forecast for compliance reporting.

The understanding of latent subsidence effects should also be considered in the design of future subsidence monitoring programs to ensure the maximum subsidence movements are captured. Assessment of compliance against performance indicators should be based on measured cumulative subsidence movements and not the calculated incremental subsidence to avoid the subject nature of deriving incremental subsidence magnitudes.

6. Acknowledgements

The authors wish to thank Yancoal Australia Ltd - Ashton Coal Operations Pty Ltd for permission to present this data. The views expressed are those of the authors and not necessarily those of Yancoal Australia Ltd.

7. References

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