Experience of Monitoring Subsidence at Ulan Coal Mine

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Summary

Ulan Coal Mines Ltd (UCML) operates a longwall mine 40km northeast of Mudgee in the Western Coalfield of New South Wales. The operation commenced longwall mining in 1986 and by the end of 2010 had completed 29 longwall panels, with the five most recent panels each 410m wide. Subsidence monitoring has been conducted throughout the life of the mine, but a recent upgrade of the survey control network has added significantly to the understanding of subsidence related ground movements at the mine and the implications of these movements for mining conditions experienced underground. This paper presents a summary of the experience of subsidence monitoring at UCML, the understanding of ground behaviour that has been developed from this monitoring, and the opportunities that have emerged to integrate this understanding for the prediction of underground mining conditions.

1. Introduction

Subsidence monitoring at UCML has spanned a period of significant developments in subsidence monitoring technique. A review of the experience of subsidence monitoring at Ulan is as much a story of the improvements in understanding that come with these developments as it is about the subsidence results themselves. It is also a story about how the understanding developed from a well designed subsidence monitoring program can provide insights into ground behaviour that are of direct benefit to underground operations.

This paper is structured to provide an overview of the UCML longwall operations in Section 2. Section 3 presents a review of the evolution of subsidence monitoring at UCML from levelling and peg to peg chaining used over Longwall 1 through the development of three dimensional surveying using total station surveying by Longwall 23. Section 4 presents an overview of the improved survey control network introduced for Longwall W1 using a far-field survey control network based on Global Position System (GPS) and broadly distributed survey control marks. Section 5 describes the results of the surveying from this network and in particular the characteristics of the horizontal movements that were measured above Longwall W1, the first longwall panel mined in a new area. Section 6 reviews the correlation developed between subsidence monitoring and in situ stress direction at UCML. Section 7 describes the lineaments that have been detected based on subsidence and other monitoring and the correlation of these lineaments with zones of difficult mining conditions observed underground. Sections 8 and 9 present a discussion of the experience and the conclusions that can be drawn from it.

2. Site Overview

Coal has been mined at Ulan since the early 1920’s. The current operation commenced open cut mining in 1982 and Longwall 1 commenced cutting coal early in 1987. The opencut ceased operation in 2008 as the approved resource was exhausted. Continuing operations are planned to include up to 16 further longwall panels at the existing mine and the opening of a second longwall mine nearby called Ulan West.

Figure 1 shows a plan of the site and the location of various subsidence monitoring lines installed over the life of the mine. The surface above the existing mine is mostly owned by UCML and consists of approximately 30% grazing land and 70% undeveloped bushland.

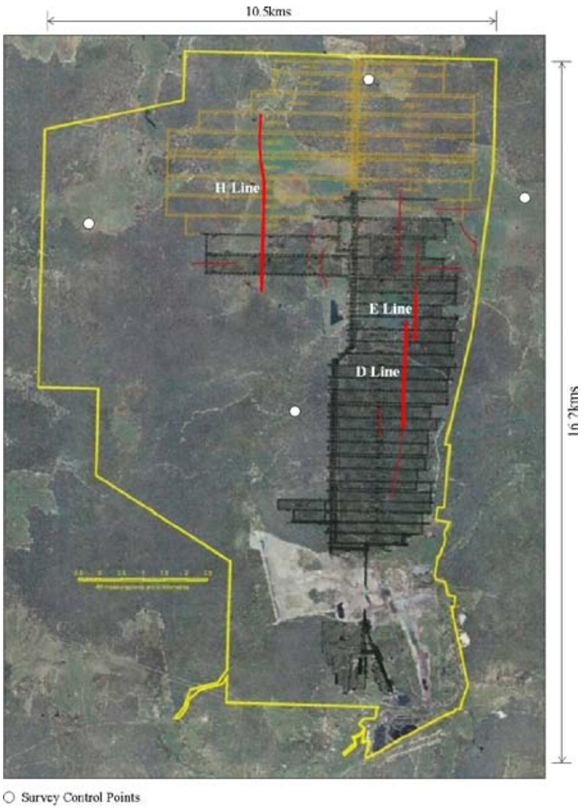

Figure 1: Site Plan of UCML Operations

The UCML underground extracts the lower 3m of the 7-9m thick Ulan Seam. The Ulan Seam dips to the north-east at a grade of 1 in 70. The overburden depth ranges from 100m in the south at Longwall 1 to 320m in the northeast part of the existing mine. The overburden depth above Longwall W1, the first of the 410m wide panels on the western side of the main headings, ranges 210-250m.

The overburden section comprises approximately 100m of Permian strata above the Ulan Seam, 110m of Triassic Sandstone strata above the Permian, and Jurassic sandstone and mudstone above the Triassic (McElroy Bryan 2007).

The initial longwall panels at UCML were 210m wide, Longwall 6 was 160m wide, Longwalls 7 to 22 were 260m, and last five panels, since Longwall 23, have been 410m wide.

3. Overview of Subsidence Monitoring at UCML

Figure 2 shows subsidence profiles measured over Longwalls 12 to 19 on D and E Lines that are typical of subsidence behaviour at UCML.

Maximum subsidence is typically in the range 0.9m to 1.3m and occurs in the centre of each panel across a narrow band consistent with subsidence behaviour that is marginally subcritical. The subsidence measured over the chain pillars is attributed to elastic strata compression and increases with overburden depth ranging from 200mm at 150m to 600mm at 230m.

Figure 3 shows the sag subsidence normalised with respect to seam thickness and plotted against the ratio of panel width to overburden depth. The sag subsidence is determined by removing any component associated with elastic strata compression from the subsidence profile.

Longwall 1 was located in an area where the Permian strata outcrops on the surface and there is no Triassic Sandstone present. The subsidence behaviour observed in this area is similar to that observed elsewhere in N.S.W. The Triassic sandstone is present in significant thickness in all the other subsidence monitoring data.

The effect of the Triassic sandstone is to reduce the maximum subsidence to between 0.3 and 0.45 times the mining height. The sandstone introduces significant variability into the maximum subsidence for any given panel width and overburden depth geometry

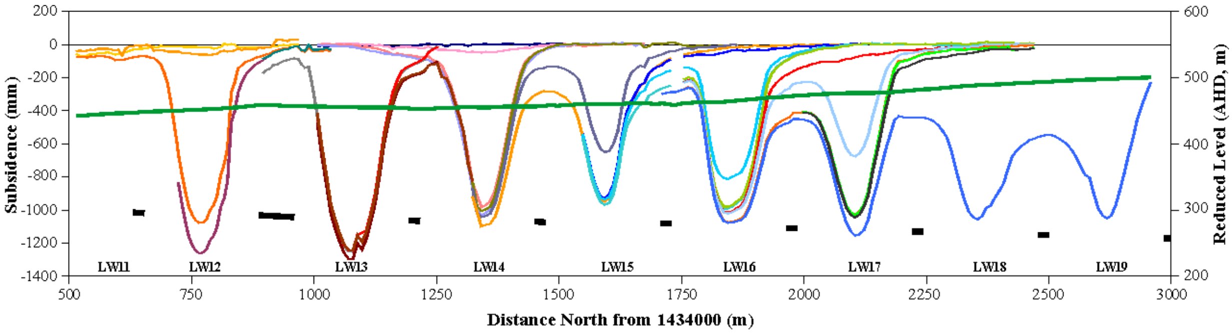

Figure 2: Subsidence profiles measured over Longwalls 12 to 19 at UCML (D and E Line).

so that maximum subsidence ranges from 0.9m to 1.3m along a panel even when there is no change in overburden depth.

Maximum tilt ranges from 10-40mm/m and decreases with overburden depth. Maximum horizontal strains from 3 to 20mm/m and are generally less than 10mm/m.

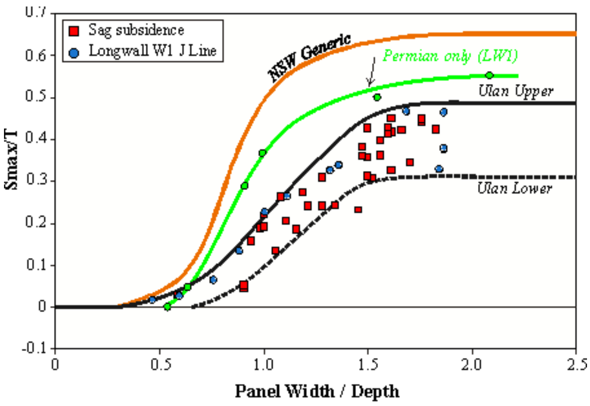

Figure 3: Sag subsidence above each panel.

Subsidence monitoring over Longwall 1 comprised levelling of all the pegs on the subsidence line and measuring the change in distance between each pair of adjacent pegs as was the standard for subsidence monitoring at the time. Monitoring of subsidence movements in three dimensions was introduced over Longwall 5 and has been used for all subsequent monitoring.

This three dimensional monitoring has allowed a better understanding of the nature of the horizontal subsidence movements that occur around longwall panels and how these interact with sandstone cliff formations and watercourses in the area.

An intensive program of monitoring was undertaken around the start area of Longwall 11 to develop an understanding of the overburden strata bridging around the starting corner of a longwall panel with a view to being able to better design subsidence barriers to cliff formations.

During subsidence monitoring conducted over Longwall 23, it became clear that the network of survey pegs used to control the subsidence monitoring were moving sufficiently to introduce significant errors into the measurements of horizontal ground movement.

Prior to the commencement of Longwall W1, a widely distributed survey control network was introduced and this change has led to a quantum improvement in the confidence in measurement of far-field horizontal movements and the understanding of horizontal subsidence movements at UCML.

4. Improved Survey Control

The improved survey control network installed at UCML is based on the principals outlined by Anderson et al (2007). They describe the implementation of a widely distributed GPS based survey control network used to integrate the surveying above several collieries at Illawarra Coal.

This approach was adopted at UCML using a ring of survey points around the active mining area.

The four survey control points used to control the subsidence monitoring at UCML are shown Figure 1. These four points are located around the area of current mining activity at distances from each other ranging from 4.6km to almost 10km. These points are surveyed at the commencement of each epoch of monitoring to confirm that there has been no relative movement prior to further analysis of the survey results. The outer ring of control points has pegs located on all four sides of the mining activity, so that any horizontal ground movements that occur toward, or away from, active mining will be apparent as relative movement.

Once the integrity of the outer ring of survey control has been established, the locations of intermediate control points closer to the line and more useful for the actual surveying can be determined. In some of the epochs, some of these intermediate control pegs were observed to have moved, but with the benefit of the outer ring, this movement was able to be identified and allowed for. The intermediate control pegs are distributed at regular intervals on or close to the subsidence line.

Using this approach the location of all the pegs can be established in three dimensions with an accuracy of about 10-20mm relative to their original positions and relative to the outside world. This level of accuracy is similar to normal surveying and is more than adequate for most practical purposes.

The key difference compared to the three dimensional subsidence monitoring previously undertaken at UCML is that all three components of ground movement are able to be measured with confidence to a consistent level of accuracy regardless of their position in the line. There is much less potential for horizontal ground movements to go undetected as a result of horizontal movement of survey control pegs.

5. Horizontal Movements

H Line is the main cross-line over the western longwall panels. In this section, the horizontal ground movements observed on H Line are presented and discussed.

All the pegs on H line were surveyed using the extended survey control network prior to the commencement of Longwall W1, the first 410m wide longwall mined on the western side of the main headings. H Line extended 1660m to the north of Longwall W1 in anticipation of future mining and so as to provide an opportunity to monitor horizontal ground movements well ahead of mining the first panel in a new area.

Figure 4 shows the ground movements measured on H Line in each of the three orthogonal directions. The line was surveyed four times during mining of Longwall W1, as the longwall face passed under the line, soon afterwards, then as full subsidence developed, and finally when the panel finished.

With the combination of the broad area network of survey control, the extended line, and Longwall W1 being the first panel mined in a new area, it was possible to measure the full movements in three dimensions with a high degree of confidence in the result.

Maximum vertical subsidence was 1.3m and within the range expected for a supercritical width panel at an overburden depth of approximately 220m.

Horizontal movement along the axis of the longwall panel were also consistent with expected behaviour. Initial movements were in a direction toward the approaching longwall face with a measured magnitude of approximately 100mm followed by movement in the direction of mining of approximately 260mm. The direction of mining was also locally the downslope direction so the final offset in the direction of mining also includes a small component

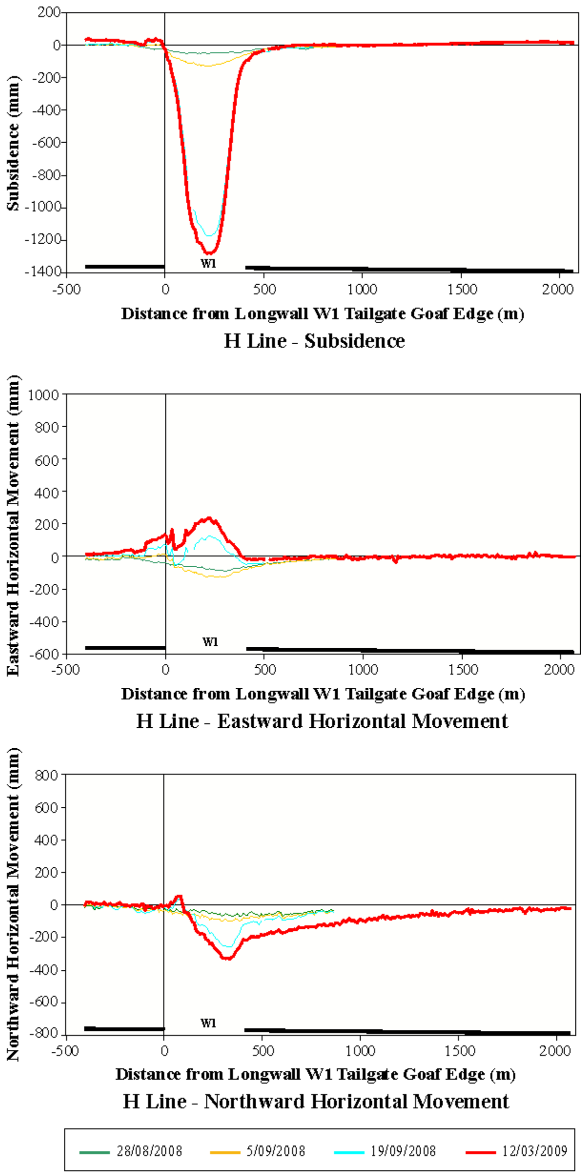

Figure 4: Subsidence movements measured on H Line at completion of Longwall W1.

(approximately 100mm) of downslope movement in addition to the systematic ground movements expected.

The measurements of horizontal ground movements measured on H Line provide the first direct measurements of all ground movements associated with the first panel mined in a new area at UCML.

Within the panel boundaries, the horizontal movements are similar to ground movements observed elsewhere above longwall panels. The ground on both sides of the panel moves toward the centre.

Immediately outside the panel, the ground movements are also similar to those previously measured at UCML and elsewhere. There is initial movement toward the approaching longwall face and then a deviation in direction toward the retreating longwall face with the main movement being in a direction toward the centre of the panel. The magnitude of the final horizontal movement at the panel edge is approximately 200mm which is slightly greater, but nevertheless consistent with subsidence behaviour previously observed at Ulan and elsewhere.

The characteristic that has not previously been identified at UCML is the significant distance to which the horizontal ground movements extend outside the panel and the nature of these movements as shown in Figure 5.

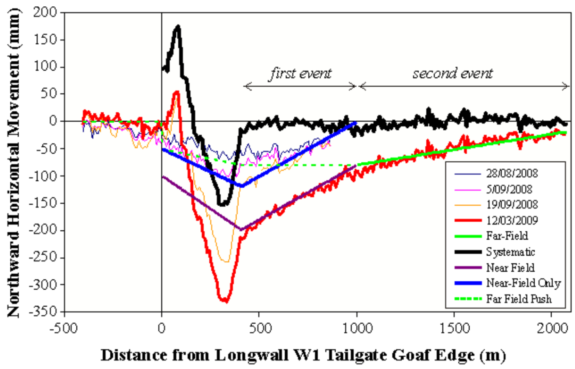

Figure 5: Components of horizontal movement inferred from measured subsidence profile.

Soon after full subsidence had developed, horizontal ground movements extended to a distance of approximately 600m from the northern goaf edge of Longwall W1 (approximately 1000m from the southern goaf edge used as a reference in Figure 4). The ground movements vary along the line as a linear function of distance from the goaf edge.

By the end of the panel, a second stage of horizontal movement is evident. This second stage is also toward the goaf but additional movement extends to a distance of 1.6km from the northern goaf edge of Longwall W1. The second stage of movement is bilinear with the ground out to 600m from the goaf edge showing no further differential movement along the line, but rather a mass translation of about 80mm, while the next 1km of ground shows a linear expansion of 80mm between 600m and 1600m from the northern goaf edge.

The ground movements observed are occurring in a direction opposite to the dip of the seam and opposite to the general dip of the surface topography so they do not appear to be related to downslope movement.

The horizontal movements observed are interpreted as being caused by horizontal stress relief that occurs in response to the overall panel geometry when a longwall is mined in a new area. The direction of movement is restrained by the solid ground at either end of the panel and so the net movement is predominantly in a direction toward the goaf rather than in the major principal stress direction.

The first stage of stress relief extends to a distance of approximately 600m to the north. The linear change with distance from the goaf edge is characteristic of a system where the displacements are caused by stress relaxation with no significant frictional resistance on the basal plane below the zone of relaxation.

The second stage of movement has a similar linear characteristic beyond 600m from the goaf edge that continues to 1600m (at the 20mm resolution of the surveying and may extend to 2km). The second stage of stress relief does not cause further either relief or recompression of the ground out to 600m that relaxed during the first stage of movement. This observation implies there is a very low resistance on any basal plane with both frictional and cohesive properties close to zero.

The presence of basal shear planes with such low strength or perhaps low stiffness or both implies that it is possible for stress relief over large areas to become concentrated by mining activity or geological structure into small areas. Horizontal stresses are then locally increased in these areas well above background levels.

The horizontal ground movements observed about Longwall W1 are not equally distributed on each side of the panel. Indeed on the southern side of the panel the north-south horizontal movements are close to zero. This asymmetrical distribution suggests that stress relief and the overall panel geometry are not alone in controlling the ground movement because these are both essentially symmetrical processes.

The implication of the asymmetry in horizontal movement is that something else that existed prior to mining and does not relate to the mining geometry is able to influence horizontal ground movement to the extent that the ground on one side of the panel is mobilised to a distance of at least 1.6km while on the other side there is no detectable horizontal ground movement at all. The most likely cause of asymmetrical behaviour is considered likely to be geological structure.

6. Stress Direction

The in situ stressfield at Ulan has been observed using a range of different techniques over the life of the mine. In this section, these measurements and in particular the in situ stress directions indicated by subsidence monitoring are reviewed and their implications for underground mining conditions are discussed.

In coal measure strata in eastern Australia, the largest of the three principal stresses is typically horizontal with the magnitude of the order of twice the magnitude of the vertical stress. The secondary horizontal stress typically has a magnitude similar to the magnitude of the vertical stress (Nemcik et al 2005).

As the magnitude of the in situ stresses approaches and exceeds the strength of the rock strata adjacent to underground roadways, typically with increasing depth of mining, the differential in the two horizontal stresses is apparent as a bias in the behaviour of these roadways depending on the direction in which they are driven. The phenomenon of biased roadway behaviour is widely accepted and has for many years been used to determine in situ stress direction from observation of the behaviour of underground roadways (Gale et al 1992, Rixon 1996).

A similar stress induced bias occurs above longwall panels and is apparent as an offset in the location of the point of maximum subsidence in panels that are of, or close to, subcritical width. At UCML, this bias is apparent even though the panels are typically of supercritical width, because of the significant thicknesses of Triassic sandstones that exhibit a pseudo-subcritical behaviour.

Figure 6 shows the in situ horizontal stresses observed above each of the longwall panels based on the bias in the point of maximum subsidence. Other observations and measurements of in situ stress direction available from borehole breakout, underground observations, stress change monitoring underground, and overcoring stress measurements conducted at the surface and underground are also shown.

In general, the bias in subsidence behaviour indicates the background horizontal stress direction is in the northeast-southwest quadrant, coincident with the regional horizontal stress direction typically observed in eastern Australia. However, there are several locations where the bias indicates a stress direction in the orthogonal direction. These apparent swaps in stress direction are often associated with difficult mining conditions underground.

In the main headings adjacent to Longwalls 13 and 14, the in situ stresses were measured using ANZI stresscells and the overcoring method of stress relief at three locations in and on either side of an area where particularly difficult mining conditions were experienced. The behaviour observed at this site is characteristic of behaviour at numerous other sites in the Western Coalfield of N.S.W. The magnitude of the minor horizontal stress is locally elevated so that it becomes the major horizontal stress and causes much higher than normal roadway deformations within a relatively narrow zone, typically less than, and often much less than, a few hundred metres wide.

There is no rotation in the direction of the two horizontal stresses, but rather a local increase in the magnitude of the secondary principal stress which then dominates the roadway deformation behaviour. In mines where the background horizontal stresses are not sufficient to cause biased roof failure, there has been a tendency to interpret the deformations that occur in these high stress zones as reflective of the background in situ stress, but in situ stress measurements such as those conducted in the main headings at UCML confirm that the phenomenon relates primarily to a local elevation of the, normally secondary, horizontal stress.

This correlation between elevated horizontal stress and the change in direction of the major horizontal stress provides an opportunity to identify and map zones based on the changes in direction of the major horizontal stress where stresses are likely to be elevated, and by implication mining conditions are likely to be more difficult.

These changes in stress direction have been able to be mapped across multiple panels at UCML using the results of routine subsidence monitoring.

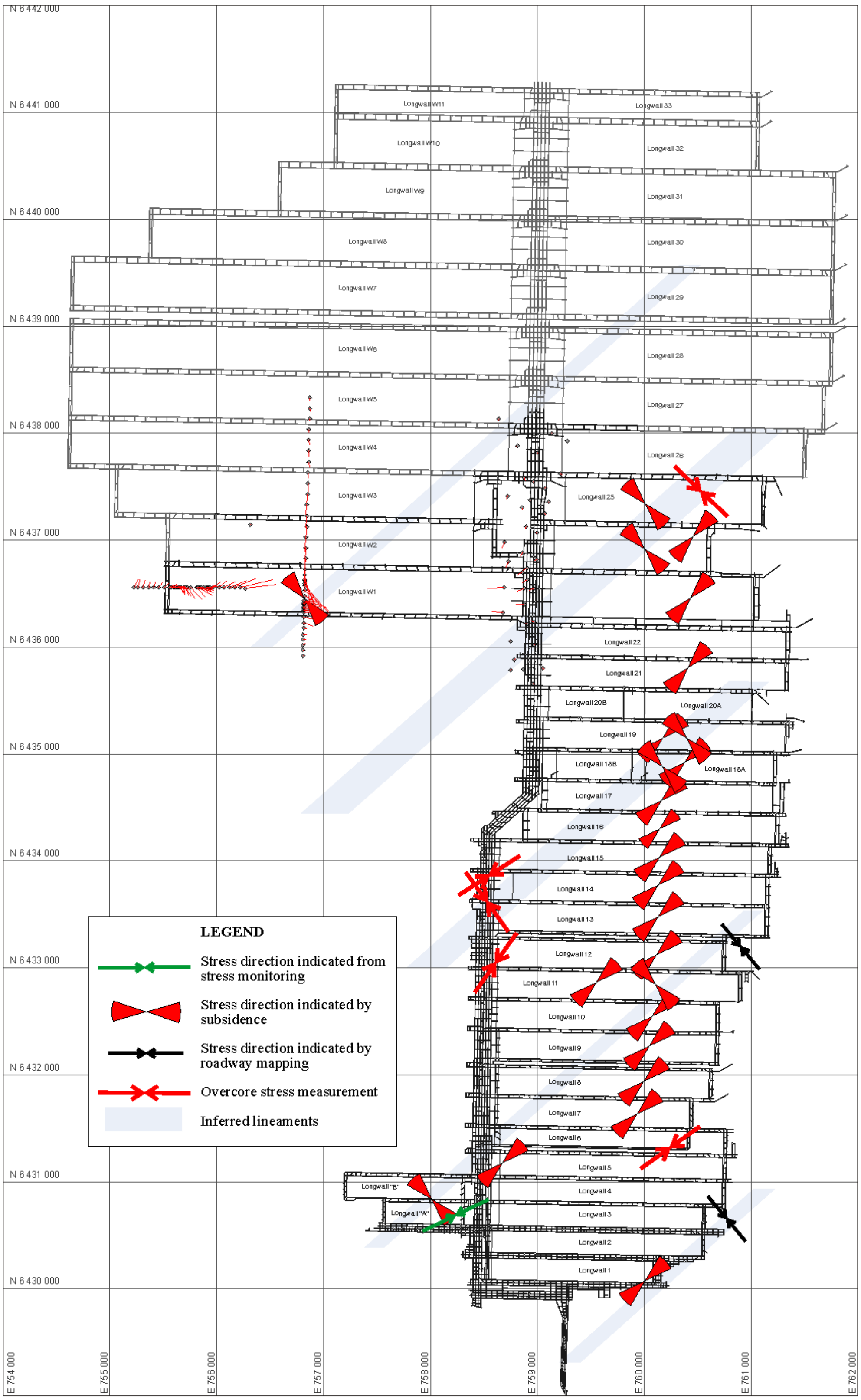

Figure 6: Stress directions and inferred lineaments based on subsidence observations and other measurements.

7. Geological Lineaments

The observations of in situ stress direction shown in Figure 6 indicate that the rotations in stress direction occur on northeast-southwest trending zones referred to as lineaments. Five such lineaments have so far been intersected in underground roadways and identified from changes in stress direction using a range of techniques of which subsidence monitoring has been the most laterally extensive. The lineaments so far identified occur in a regular pattern at a separation of 2km from each other.

The lineaments do not appear to be associated with geological structure that are readily identifiable within the Ulan Seam such as monoclines or geological faults. The hypothesis of small steps in the granite basement located a short distance below the Ulan Seam that act as stress risers in the secondary stress direction as a result of mining induced horizontal movements has not been confirmed but would appear a likely mechanism.

The far-field horizontal ground movements observed on H Line, both the bias to the northern side of the panel, and the point at which horizontal stress relief movement ceases are consistent with the locations of already identified and suspected lineaments in the regular pattern.

Such far-field subsidence monitoring with a broad area network of survey control on the western side of the mine is expected to allow further lineaments to be identified in advance of their being intersected in the main headings and in the eastern longwall panels.

An array of subsidence monitoring points has been surveyed over the main headings in advance of longwall retreat to help identify if there are any differential movements apparent along the lineaments as adjacent longwall panels mine back toward the main headings. To date, the ground movements observed on this array have not indicated any irregular or differential movements on geological structures but it is recognised that some movement may already have occurred prior to installation of this array.

The lineaments observed to date in subsidence monitoring and surface stress measurement are characterised by behaviour that is apparent on the surface directly above each lineament encountered at seam level.

This characteristic means that the lineaments and in particular the associated stress signatures can be detected well ahead of mining through measurements of the in situ stresses in exploration boreholes or even shallow holes designed for the purpose.

8. Discussion

Subsidence monitoring at Ulan has developed from a process that was initially required only for compliance with government approvals into a tool that is being used to determine the likely conditions of underground roadways well ahead of mining.

With the implementation of a GPS based broad area survey control network, the horizontal ground movements that occur out to several kilometres ahead of mining can be used to identify the location of geological lineaments that have potential to significantly influence underground mining conditions.

In effect, the subsidence associated with longwall mining is being used to unload the ground, while the far-field surveying is being used to see how the ground responds to this unloading, much the same as a laboratory specimen is subjected to a change in load in order to determine its elastic properties. Any geological structures within the unloaded ground show up as steps or changes in gradient in an otherwise uniform continuum.

9. Conclusions

Subsidence monitoring at UCML has developed with the improvements in surveying technique that have occurred over 23 years of longwall mining activity at the mine.

Initially subsidence was monitored using levelling and peg to peg chaining. This system was upgraded to measure subsidence movements in three dimensions from Longwall 5 onwards.

This subsidence monitoring and the deformation bias imposed by differential horizontal stress magnitudes have allowed the in situ stress direction to be determined across the full area of the mine.

Changes in magnitude of the secondary horizontal have been identified from direct measurement to be associated with difficult, high stress mining conditions underground at UCML and other sites in the Western Coalfield of N.S.W. The swap in major horizontal stress direction determined from subsidence monitoring has enabled the location of geological lineaments to be determined across the broad area of those panels that have already been mined.

In 2008, a review of the subsidence monitoring led to the installation of a GPS based broad area survey control network at the mine. This network was successfully used to control subsidence monitoring of the first 410m wide longwall in a new area on the western side of the main headings.

The main cross-line over this panel was installed some 1660m north of the northern goaf edge of this panel and all horizontal ground movements were able to be measured to an accuracy of approximately 20mm.

The ground movements that were observed indicated horizontal stress relief has occurred to a distance of approximately 1.6km from the panel causing horizontal movements of 200mm at the goaf edge decreasing to 20mm at 1.6km.

The differential nature of the ground movements observed by subsidence monitoring confirms the influence and location of geological lineaments. These lineaments can be used to identify locations ahead of mining where difficult mining conditions are anticipated.

The experience at UCML confirms the benefits of well controlled subsidence monitoring for not only compliance monitoring, but also for strategic monitoring of ground movements to determine likely ground conditions well ahead of mining.

10. Acknowledgements

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All views expressed in this paper are those of the authors and not necessarily those of UCML.

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