2010

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Publication Details

This conference paper was originally published as Trueman, R, Callan, M, Thomas, R and Hoyer, D, Quantifying the impact of cover depth and panel width on longwall shield-strata interactions, in Aziz, N (ed), 10th Underground Coal Operators' Conference, University of Wollongong & the Australasian Institute of Mining and Metallurgy, 2010, 97-107.

QUANTIFYING THE IMPACT OF COVER DEPTH AND PANEL WIDTH ON LONGWALL SHIELD-STRATA INTERACTIONS

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ABSTRACT: Results of a series of back-analyses of the interaction between longwall shields and strata at a number of mines are presented. The purpose of these back-analyses was to quantify the impact of cover depth and panel width on shield performance.

Recently developed shield load cycle analysis theories were used to quantify the interaction between shields and strata. A load cycle is the change in support pressure with time from the initial setting of the shield against the roof until the subsequent release and movement of the support, which typically corresponds to a single shear. Historical shield pressure data from five longwall mines in Australia and Europe were back-analysed, together with strata delay data for the longwall faces. An assessment of the geology of the near-seam overburden was also made for each site. The longwall panels incorporated cover depths ranging from 50 to 770 m and panel widths ranging between 168 to 319m.

Use was made of a modified version of the longwall visual analysis (LVA) software that was specifically extended for this project and provided maps of the critical load cycle parameters implicit to the utilised analysis methodology. The major extension of the software involved presenting the outputs on the basis of individual load cycles for every shield as opposed to a time or chainage basis, thus allowing load cycle analysis to be carried out. In total about 6.5 km of longwall retreat and over 2 000 000 individual load cycles were back-analysed. Together with the strata delay and geological data, this enabled the effects of panel width and cover depth to be quantified within the range of the data.

INTRODUCTION

A number of authors have concluded or inferred the need for a greater powered support capacity with increasing depth of cover and/or panel width (e.g., Medhurst and Reed, 2005; Frith and Creech, 1997; Tsang and Peng, 1994). Nevertheless the impacts of these factors on support loading are still debated. Shield loading is a complex interaction between: shield capacity and set pressure; the composition of the main and immediate roof; the presence or absence of leaking legs; extraction height; cycle time; panel width and depth of cover. It has proven very difficult to isolate all of these factors in the past.

Load cycle analysis theories have been recently developed, which were presented in the Coal 2008 Conference (Trueman, Lyman and Cocker, 2008), that enable the factors influencing shield loading to be isolated and quantified. Commercial software was specifically extended to enable load cycle analysis to be carried out on historical shield monitoring data from five Australian and European longwall mines. These mines represented a range of cover depths, panel widths and strata composition that allows the impact of these factors on shield loading to be quantified.

SHIELD-STRATA ANALYSIS METHODOLOGY

The analysis methodology depends upon both the extraction and visualisation of the critical load cycle features necessary to interpret how the shields are interacting with the strata. An off-line version of the LVA software has been extended to provide and visualise the following critical load cycle features for each leg of each support (where both legs are monitored):

- Time Weighted Average Pressure (TWAP) Map – note: a) the TWAP is calculated between the initial setting of the shields to the roof and the final release at the end of the load cycle, b) a value is calculated for each leg of each shield for every load cycle, c) zones of high loading are shown in red and zones of low loading in blue and d) this map enables a rapid overview to be

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made of the periodic weighting interval, problem areas that have occurred on the face such as roof falls and support maintenance issues.

- Number of Yield Events Map – note: a) the number of yield events in an individual cycle have been colour coded; blue indicates 1 to 3 yields and orange/red >8, b) the number of yield events in a single load cycle is a very good indicator of the intensity of loading and has been shown to correlate well with roof conditions experienced on a face, c) extensive back-analysis at a number of longwalls has indicated that, in general, if there are less than 3 yield events per load cycle then roof conditions do not deteriorate at most sites, d) a deterioration in roof conditions is normally seen between the support tip and the face after >3 yield events, with increasing severity as the number of yields increases and e) this illustrates that it is the number of yield events in a given load cycle that is important and not whether or not a support yields.

- Low Set Pressure Map – note: a) a set pressure which is too low, has been found to lead to roof control problems on the face, because naturally occurring and mining induced fractures are allowed to dilate resulting in a reduction in the mechanical interlock of the strata, b) previous experience shows that a set pressure of <40 t/m2 is the typical threshold value at which roof control problems can result, c) set pressures of >60 t/m2 have been found to ameliorate any potential roof control problems relating to set pressure and d) for each back analysis, maps highlighting set pressures equating to <40 t/m2 have been generated.

- Initial Loading Rate Map – note: a) the map illustrates the loading rate in bar/min calculated in the first ten minutes after the powered support is set, b) previous experience suggests that the initial loading rate is a good indicator of the intensity of the loading conditions and c) loading rates of <10 bar/min in the first 10 minutes after the support is set generally results in relatively benign loading conditions, while loading rates >15 bar/min generally results in heavier loading with the intensity of loading increasing as the loading rate exceeds this threshold.

- Load Cycle Time Map – note: a) the length of the cycle is of particular importance when the shields are being overloaded or being set too low, b) in such instances the additional cycle time allows more roof convergence and in doing so increases the probability of roof control issues and allows more time for fractures to dilate and c) cycle time is of less importance where the shields are being adequately set and are stabilising the roof.

- Anomalous Leg Pressure Map – note: a) the software identifies differential loading rates between two legs on a single shield and flags the leg with the lower loading rate as potentially having faulty hydraulics, valves or sensors, b) where anomalous legs are grouped together, low set pressures on the anomalous shields and overloading of the adjacent shields can result and c) both scenarios have been found to result in roof control problems.

The data are presented as maps in which the x-axis represents the support number counting from the maingate end of the face. The y-axis represents the shear number in the direction of mining and is therefore proportional to mining advance. Each shear represents a single load cycle for a shield, which enables load cycle analysis to be carried out.

The plotted value is the value of the variable of interest (ie one of the critical load cycle features) and it is coded by colour. Using colour as the third dimension has been found to be the most effective way of enabling a rapid evaluation of the support-strata interaction. These critical load cycle maps are used to characterise the support-strata interaction.

GEOLOGY OF THE CASE HISTORIES

The features of the geology of the longwalls studied that have the greatest potential to influence shield loading are summarised in Table 1.

Table 1 - Geology of longwalls most relevant to shield loading potential

Mine	A	B	C	D	E
Depth of Cover (m)	450-500	500-540	745-770	500-540	50-220
Thickness of Thickly Bedded to Massive Units (m)	30	i) 0-10 ii) 5-10 iii) 0-5	0	i) 5-10 ii) 5-10 iii) 15-22	i) 0-23 ii) 0-17
Height of Thickly Bedded to Massive Units above the roof (m)	50	i) 0-5 ii) 30-50 iii) 60-80	N/A	i) 15-20 ii) 40-50 iii) 55-70	i) 9 ii) 45
CMMR of Immediate Roof	40	55	36	50	35-60

LONGWALL DATA

The relevant longwall data is summarised in Table 2.

Table 2 - Longwall data

Mine	A	B	C	D	E
Shield Capacity (t)	i) 80x750 ii) 23x720	1 000	850	1,000	i) 36x1 240 ii) 117x940
Shield Support Density Before the Cut (t/m2)	i) 100 ii) 81	110	99	106	i) 136 ii) 103
Yield Pressure (bar)	430	430	430	430	465
Tip-to-Face (mm)	650	450	500	500	610
Set Pressure (bar)	330	320 (350)	300	330 (345)	320
Shearer Cutting Method	Uni-Di	Uni-Di	Bi-Di	Uni-Di	Bi-Di
Web Depth (mm)	800	800	800	800	900
Panel Width (m)	168	319.5	305	305	263
Extraction Height (m)	3-3.4	3-3.2	5	2.4-2.8	3.05

SHIELD-STRATA INTERACTION ASSESSMENT

Mine A

Shield pressure and delay data were provided for 885 m of longwall retreat, during which approximately 1 325 shield load cycles were detected by the software. A number of significant roof control delays were recorded by the mine at regular intervals for the full length of the analysed section of retreat. The shield-strata interaction can be quantified from the critical load cycle maps that were developed for this period.

The TWAP map (see Figure 1) clearly shows the periodicity in the loading, with the peaks of the periodic weighting showing up as red (high average pressure) horizontal stripes. The areas where significant roof control problems were experienced are also clearly distinguishable as areas of blue (low average pressures).

The yield count map (see Figure 2) shows that at most of the peaks of the periodic weighting cycles, a significant number of supports yielded. At some peaks, the supports only underwent one or two yield events within the load cycle, but in others several yields were noted. Cases where several yield events were recorded during a single load cycle were in general associated with relatively long cycle times. All of the roof control delays recorded by the mine occurred after a number of the shields recorded several yield events. The yield events shown in Figure 2 are indicative of supports that are experiencing high level periodic weighting. As will be noted later, the number of legs identified as having potential problems with the hydraulics would have contributed to the intensity of the yielding at the peaks of the periodic weighting.

Figure 3 is a map showing where set pressures below 180 bar was recorded, which equates to about 40 t/m2. There are a number of vertical stripes on the map and these are most likely associated with support legs that are either leaking or where the sensors are failing or poorly calibrated. There are additionally a number of clusters of localised low set pressures that correlate to the blue sections in the TWAP map mentioned previously. These areas are associated with cavities and roof falls. The extent of the cavities would undoubtedly have been increased with such low set pressures.

The loading rate in the first 10 minutes after the shield has been set can be observed in Figure 4. Loading rates at the peak of the periodic weighting cycles generally varied between about 10 and 15 bar/ min. The high loading rates corresponded to where periodic yielding was observed.

Figure 5 is a map of those legs that have anomalous pressure readings. From this figure it is evident that approximately 25% of the legs have been identified as anomalous. A manual check of the raw pressure data indicated that all of these legs had potential issues with the hydraulics. This particular longwall operates with guaranteed set which was observed to be constantly topping up the pressure in most of these legs. This would have ameliorated roof control problems associated with low overall support density by maintaining system pressure at all times the pumps were operating, noting that a support density of less than 40 t/m2 before the cut has been observed to result in roof control problems at other sites. Nevertheless, the fact that the maximum support pressures in most of these legs would have been no more than system pressure would have contributed to the yielding on the other neighbouring legs at the peaks of the periodic weighting cycle. This quantity of problematic legs would undoubtedly have contributed to the reported roof control problems.

The estimated cycle times are shown in Figure 6. As mentioned previously, it is noticeable that the periods where several yields were noted on a large number of shields in a single load cycle correlated to relatively long cycle times. It is also noticeable that the roof control problems often occur during or immediately after relatively long cycle times.

The maps indicate that high level periodic weighting is being experienced, which is resulting in yielding of a number of the supports at the peaks of the periodic weighting cycle. Several yield events are occurring at some of the periodic weighting intervals, usually when cycle times are relatively long. Such numbers of yields in a single load cycle has resulted in roof control problems at other sites and is indicative of supports that are being periodically overloaded. A number of roof control problems are noticeable on the critical load cycle feature maps and have been noted in the delay data that occurred immediately after these events. The reason that the supports are being periodically overloaded is probably related to the amount of thickly bedded to massive strata in the roof. Only one sonic log was available to determine the composition of the roof. The interpretation of this log suggested that there may be an up to 30 m thick competent bed located at a height of about 50 m above the seam. Competent beds of this thickness and height above the seam have been demonstrated to result in high level periodic loading at other sites.

The longwall is relatively deep by Australian standards but the marked periodicity of the shield loading points to thick competent beds as the cause of shield overloading rather than the effect of depth. As will be discussed, the fact that much lower shield loading was observed in a longwall that was significantly deeper but had no thick competent units in the immediate or main roof tends to support this argument.

The narrower panel at Mine A has not prevented the supports from being periodically overloaded in some of the peaks of the periodic weighting cycles. Nevertheless the narrow panel means that in general, cycle times will be less than if the panel was wider. This will have likely influenced the number of yields being experienced in some of the high periodic weighting cycles. The narrow panel width in this case would therefore have been expected to have had a positive influence on roof control in many of the weighting cycles. This is confirmed by the fact that roof control issues did not occur following the peak of the periodic weighting cycles in most of the cases but tended to occur when cycle times were long. In narrower panels the number of shields protected from full loading by the chain pillars is proportionally greater and as such, the length of the face that is exposed to overloading is also proportionally less. In the case of Mine A about 50% of the shields went into periodic yield, whereas on other longwalls with wider faces, a higher proportion of the shields were often affected by periodic overloading, as will be discussed later.

Mine B

Shield pressure and delay data were provided for 870 m of retreat. Only minor delays were reported due to roof control issues on the longwall face. Approximately 1,100 load cycles were detected during the period of analysis. As with Mine A, the critical load cycle maps were used as an aid to quantifying the shield-strata interaction. These maps are not presented in the paper, rather a summary of the relevant findings only.

The TWAP map showed a clear periodicity in the support loading. At the peak of the periodic weighting cycles a number of supports yielded and on occasions a large percentage of the supports on the face yielded. However, in general the supports only underwent one or two yield events within the load cycle, even though load cycle times varied. This is indicative of supports that are experiencing low level periodic weighting. When yielding did occur, stabilisation of the roof occurred within the load cycle after less than three yield events.

The only instances of low set pressures that were observed were in the vicinity of faults. Because of the relatively high angle of the faults to the face, only a few shields were set too low in any individual load cycle. Nothing showed up in any of the maps or delay data that indicated any significant roof control problems were experienced in these areas.

Loading rates at the peak of the periodic weighting cycles generally varied between 5 and 10 bar/min. with a few load cycles at the periodic weighting peak in excess of this. The higher loading rates generally coincided to areas where an appreciable number of supports reached yield.

Mine B is relatively deep by Australian standards and is extracting a relatively wide panel. Nevertheless, the analyses indicate that the shields are coping well with the roof conditions with few roof control issues. Few instances of low set pressures or legs with hydraulic problems were identified. Maintenance and support operation were therefore not a contributor to roof control issues on this particular longwall.

Mine C

Shield pressure and delay data were provided for about 700 m of retreat. Approximately 870 load cycles were detected during the period of analysis. As with Mine B, the critical load cycle maps were used as an aid to quantify the shield-strata interaction but most of the maps are not presented in the paper, rather a summary of the relevant findings only. The yield count map has been included because it shows a case study where periodic yielding occurred with only a few yields, even when cycle times were long. Few strata delays were recorded for the period of analysis and these tended to be close to the gateroads.

The TWAP map indicated that shield loading had a marked periodicity despite the fact that there were no thick competent units in either the immediate or main roof. The periodic weighting interval was observed to be in the range 7 to 14 m. The periodicity was also observed in the yield count map which indicated that at some, but not all, of the periodic weighting cycles the shields across the majority of the face (about two thirds or more of the shields) reached yield pressure. However, in general the supports only underwent 1 or 2 yield events within the load cycle, even though load cycle times varied and a number at the peak of the periodic weighting cycle were quite long, see Figure 7. This is indicative of supports that are experiencing relatively low level periodic weighting, even though some yielding was observed to occur. As noted previously, it is the number of yield events in a load cycle, particularly in long cycles, that indicate the intensity of the weighting not just the fact that yielding occurs.

There was evidence of clusters of low set pressures, although strata delays were not recorded in the vicinity of them. Only one leg of the support was monitored on this particular longwall and the anomalous pressure map depends upon both legs being monitored. A manual check of the raw data did however indicate that there were some legs that appeared to have potential hydraulic problems.

Loading rates at the peak of the periodic weighting cycles generally varied between 5 and 10 bar/minute. The higher loading rates generally coincided to where an appreciable number of supports reached yield pressure.

Mine C is deeper than any existing Australian longwall, has a high extraction height and is extracting a relatively wide panel. Nevertheless, the analyses indicate that the shields were coping well with the roof conditions with few roof control issues. There was evidence of clusters of low set pressures in places and legs with anomalous leg pressures were observed. There was therefore potential for support operation and maintenance to contribute to roof control issues but no such issues were noted in the delay data.

Mine D

Shield pressure and delay data was provided for approximately 1 400 m of longwall retreat and approximately 1 800 load cycles were detected by the software. Numerous roof falls of varying magnitude were recorded during the analysis period, the size and frequency of the falls noticeably increasing over a 600 m length of retreat. The roof falls were clearly distinguished on the TWAP map as was the periodic weighting interval, which was in the range of 10 to 20 m.

At the peak of the periodic weighting cycles a number of supports yielded and on occasions a large percentage of the supports on the face yielded. Over most of the length of the retreat the supports only underwent 2 or 3 yield events with the occasional load cycle experiencing up to 4 yields. In the area of the face where most roof falls were recorded the number of yields increased markedly, with up to 8 in some load cycles. Initial loading rates, at 10 to 20 bar/min, also tended to be higher in this area of the face. Low set pressures were also evident over a number of load cycles in the vicinity of the roof falls. Maintenance issues did not appear to be a significant contributor to the roof falls, with only 3% of the legs showing anomalous pressure readings.

Based upon the above, the face appeared to be experiencing a transition between low and high level periodic weighting over most of the analysis area, with high level periodic weighting over the 600 m length of retreat where the majority of roof falls occurred. The thickly bedded to massive sandstone unit located 55 to 70 m above the workings, had a thickness of between 16 to 20 m over the majority of the panel, increasing to between 20 and 22 m where most of the roof falls occurred. So whilst this longwall is relatively deep by Australian standards and the face relatively wide, the major cause of the roof falls could be attributed to the presence of a relatively thick thickly bedded to massive sandstone in the main roof.

Mine E

Shield pressure and delay data was provided over a length of retreat of 2 625 m and approximately 2 900 load cycles were identified. This longwall is characterised by a large depth range (see Table 1) and a relatively high rate of retreat. Very few roof control issues were noted from the delay data.

Periodic weighting was variable across the panel length. In a number of areas support yielding occurred with the majority of shields across the face being affected. In some areas the supports experienced a large number of yields, up to eight in some cycles, whilst in others either no yielding occurred or where it did, the supports only underwent one or two yield events.

As with yielding, the initial loading rates at the peaks of the periodic weighting cycles were variable. Rates as high as 10 to 15 bar/min occurred in some areas of the face, whilst rates of between 3 and 8 bar/min were recorded in others. The higher and lower initial loading rates correlated to the areas of high and low numbers of yields.

There was evidence of clusters of low set pressures in places and about 4% of the legs were found to have anomalous leg pressures. There was therefore some potential for support operation and maintenance to contribute to roof control issues, although no such issues were noted in the delay data.

The above is indicative of a longwall that is experiencing both low and high level periodic loading of the supports. Although variable, the depth of cover is relatively shallow even at the deepest point (see Table 1). Importantly, there was no correlation between the intensity of the periodic weighting and the depth of cover. Rather there was a strong correlation between the thickness of thickly bedded to massive strata and the periodic loading of the supports. The highest loading rates and number of yields were experienced in the areas where a competent unit in the roof reached a thickness of up to 23 m. Conversely the lowest loading rates and minimal yielding was experienced in areas where no thickly bedded to massive sandstone units existed.

Where there were no competent units in the roof the initial loading rates at the peaks of the periodic weighting cycles on this longwall were noticeably less than for the much deeper Mine C, which likewise lacked competent units. This indicates that depth of cover is of some, albeit limited significance, in terms of shield loading.

IMPLICATIONS FOR SHIELD LOADING

The most significant impact on shield loading was found to be the presence or absence of thickly bedded to massive units in the immediate or main roof. High level periodic weighting leading to periodic shield overload was observed once thickly bedded to massive sandstone unit thicknesses exceeded 20 m. A transition between low and high level periodic weighting appears to occur once the thickly bedded to massive sandstones thicknesses exceed about 16 m. The height above the roof that these units influence shield loading can be quite high. Beds whose bases were up to 70 m above the roof were observed to be causing high level periodic weighting in this study.

The initial loading rate at Mine C at the peak of the periodic weighting cycles was higher than the areas in the much shallower Mine E that also lacked thick competent beds in the near-seam overburden. This is despite the fact that the shields at Mine E would have been appreciably stiffer, having a larger leg diameter and lower operating height. This indicates that in general supports in deeper deposits will carry a higher pressure, everything else being equal. Nevertheless the shields used at Mine C, which have a support density slightly below the average of the five mines in this study (see Table 2), were not being overloaded to a depth of 770 m. This indicates that, at least within the range of the data presented in this study, depth on its own does not appear to be a major factor in shield loading.

The potential for shield overload was observed at all the panel widths in this study – 168 m to 319.5 m. It must be noted that in none of the case histories did the strata bridge across the panel. Bridging longwalls have been found in previous studies to result in reduced shield loading (e.g., Frith and Creech, 1997; Bigby, 1988). Nevertheless a reduced panel width can have a significant impact upon roof control if periodic support overload occurs, as the reduced cycle time associated with narrower panels will reduce the number of yields and subsequent roof degradation. In addition, the number of shields on the face affected will be less as a greater percentage of them will be protected from full loading by the chain pillars located at either end of the face.

The analyses have also indicated the importance of shield maintenance and operation on the shield loading environment. Inadequately maintained shields can increase the load on adjacent legs and supports. Low set pressures when set conditions deteriorate can have a similar effect and can destroy the mechanical interlock of the strata above the supports, leading to roof control problems.

CONCLUSIONS

The greatest impact on shield loading has been found to be the presence or absence of thick units of thickly bedded to massive strata in the immediate or main roof. Although an increased depth of cover will generally result in higher shield loading, everything else being equal, modern capacity supports are capable of adequately controlling the roof in deep longwalls. Once full caving is initiated on or about a longwall face, narrowing the panel width cannot be relied upon to prevent shield overload. Nevertheless, where shield overload does occur there are benefits to narrower panels. Maintenance and support operation have both been found to potentially significantly influence the shield loading environment.

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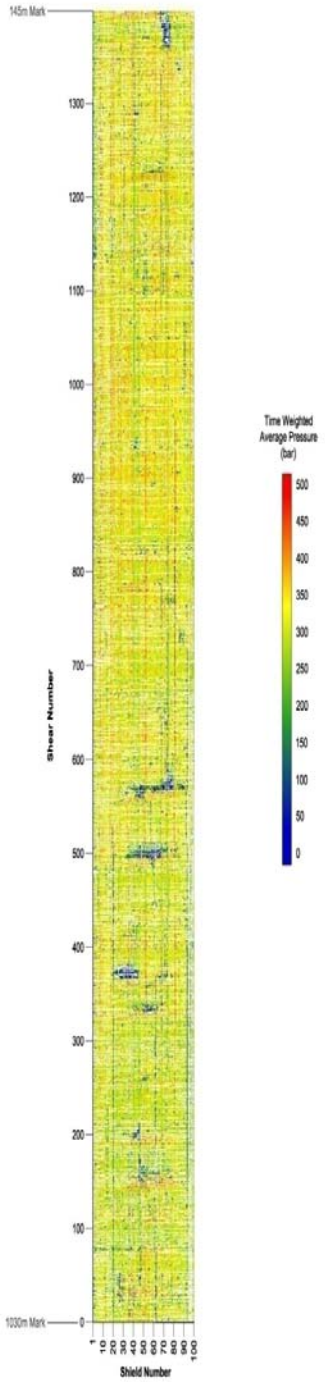

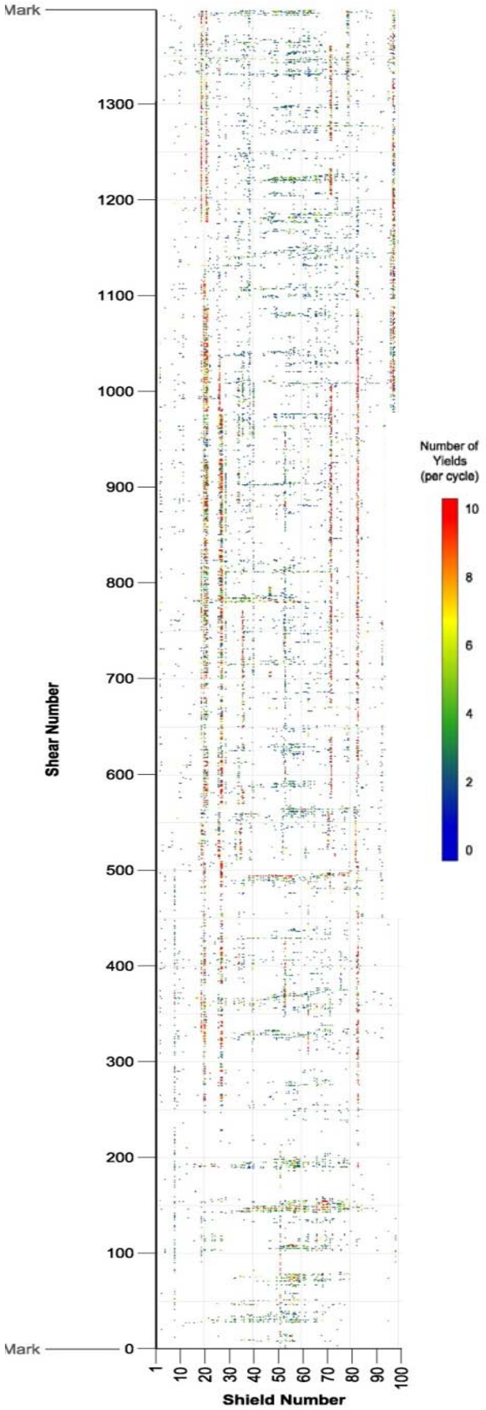

Figure 1 - Time weighted average pressure map, Mine A	**Figure 2 - Yield count map, Mine A**

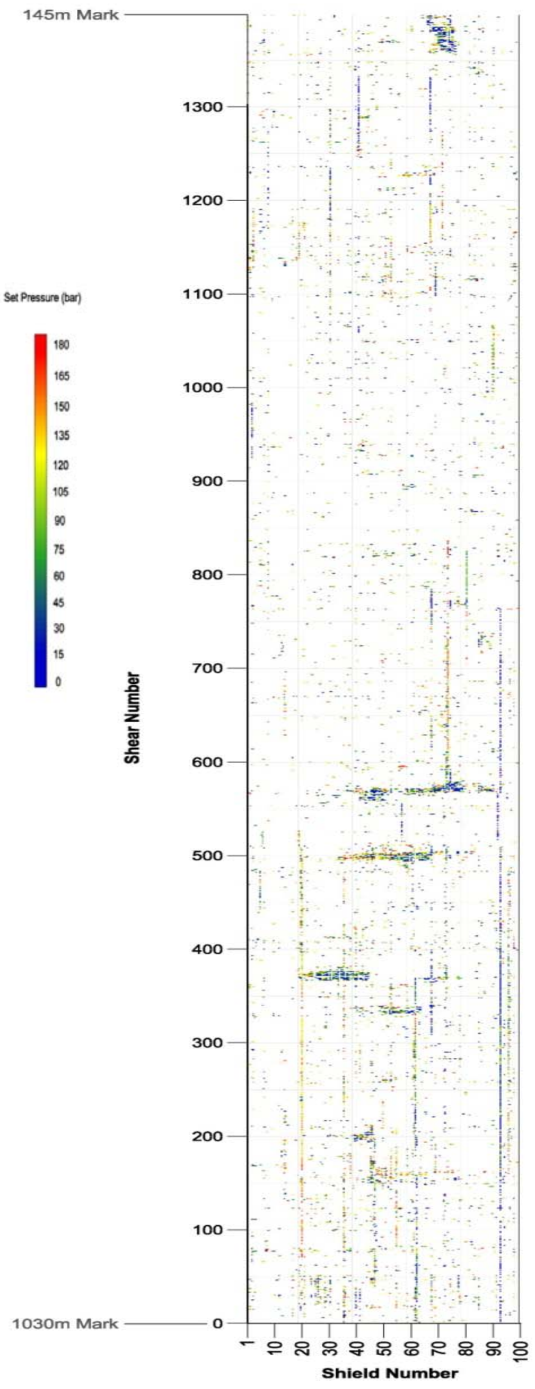

Figure 3 - Low set pressure map, Mine A

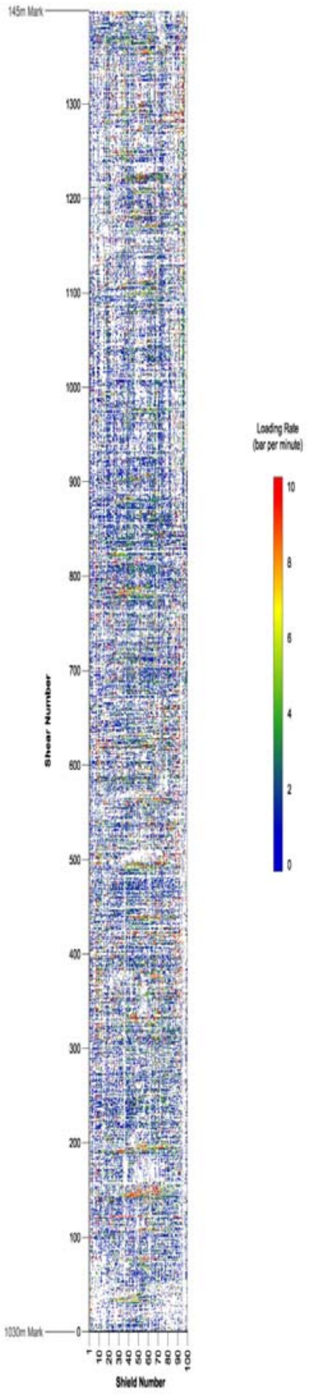

Figure 4 - Loading rate map, Mine A

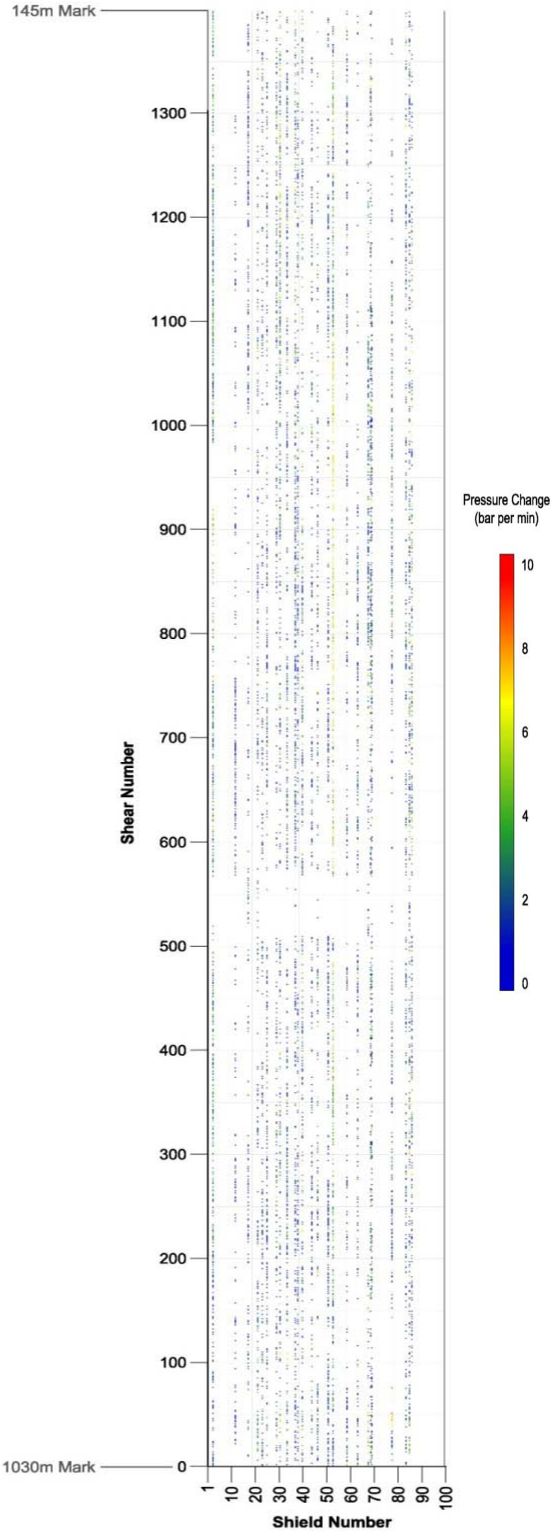

Figure 5 - Anomalous pressure reading map, Mine A

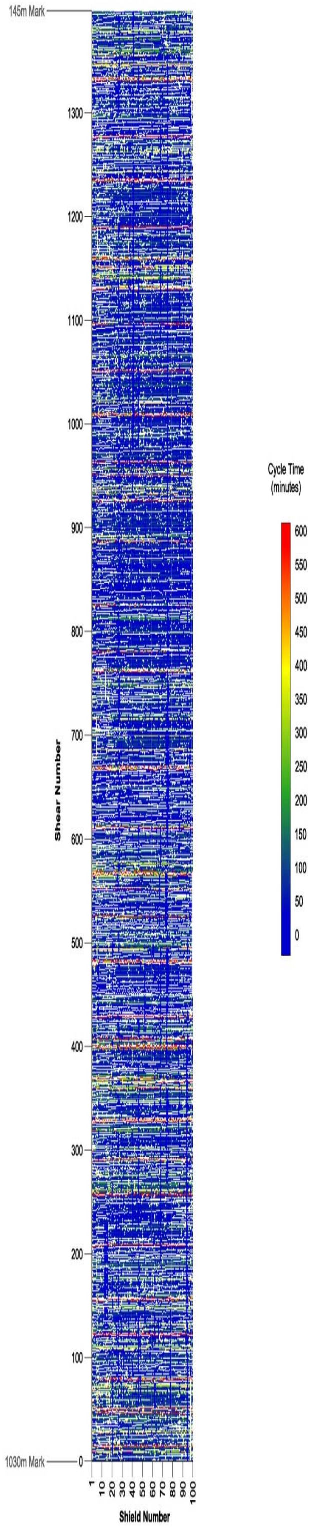

Figure 6 - Load cycle time map, Mine A

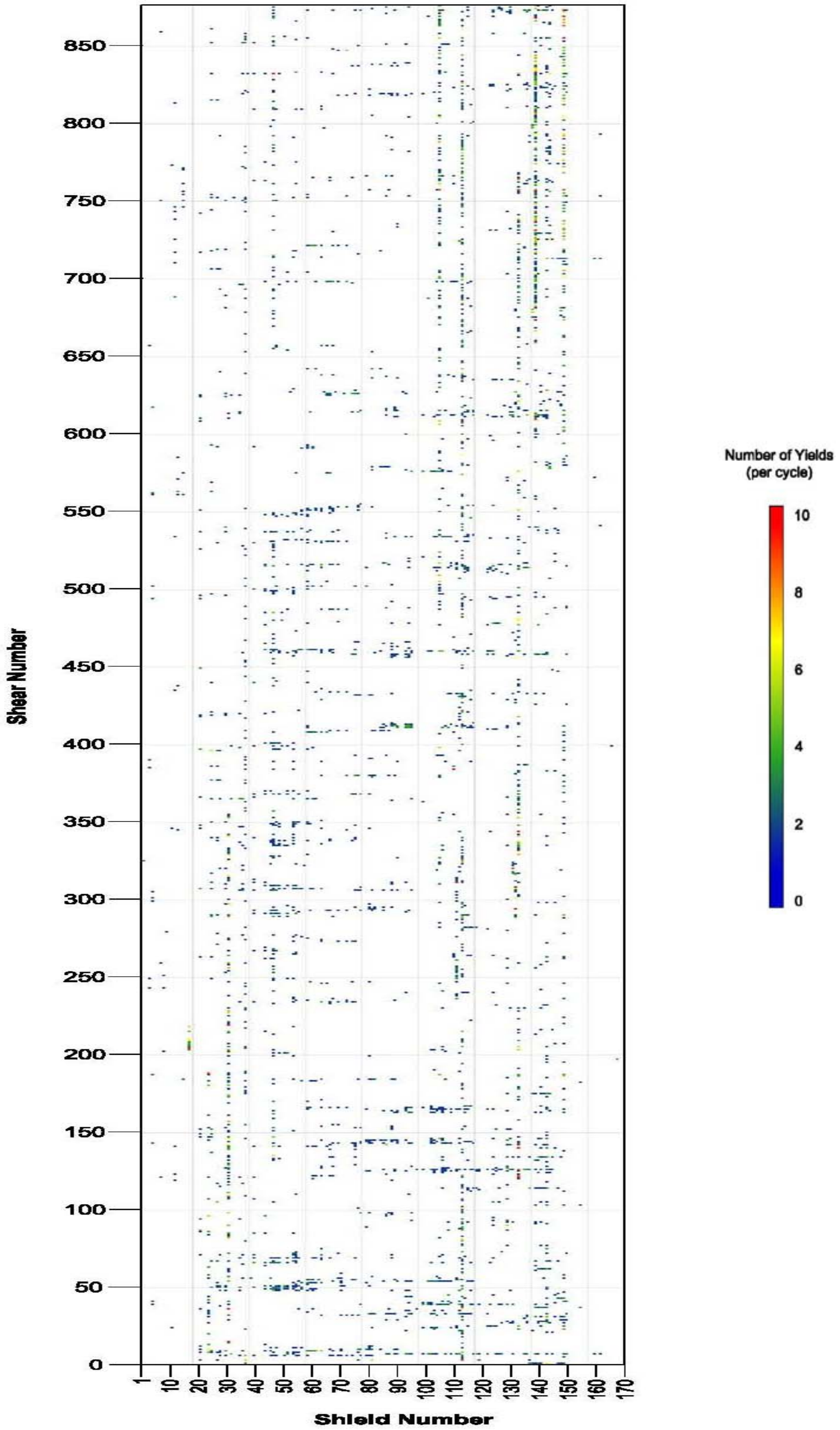

Figure 7 - Yield count map, Mine C