Early Warning of Longwall Weighting Events and Roof Cavities Using LVA Software

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ABSTRACT

It is shown that by monitoring longwall leg pressures in real time, warning can be given for significant weighting events and the formation of roof instabilities, such as roof cavities, several hours in advance.

Longwall Visual Analysis (LVA) is a software package that continuously monitors shield pressures and shearer position in longwall mines. LVA has been running on 19 Australian longwalls for up to four years, and as a result a very substantial database of shield pressure trends in a wide range of longwall situations has been collected. This database has been analyzed to develop indicators that will give operators and geotechnical engineers advance warnings of developing conditions such as weighting events and difficult roof conditions.

LVA displays live charts of data, such as shield leg pressures, loading rates, and yield frequencies. Data analysis techniques were applied to historical data records from multiple longwall sites in order to develop a "Cavity Risk Index" (CRI). The CRI indicates the risk of roof cavities developing, and it is based on pressure trends that indicate significant yielding and loading rates spanning a region of relatively low support.

Case studies from different longwalls are given, showing how the CRI can give real-time advance warning of the formation of roof cavities with their anticipated location on the face. The limited number of case studies done so far indicate that the predictions have a high degree of reliability, but more work is required to quantify this.

INTRODUCTION

Longwall Visual Analysis (LVA) is a software package that continuously monitors, analyzes, and displays shield pressures and shearer position in longwall mines. The first version of LVA was installed on an operating longwall in 2006, and the latest version is currently running on 19 Australian longwalls. As a result, a substantial database of shield pressures in a wide range of longwall situations has been collected. These data have been used to develop and test indicators that will give operators and geotechnical engineers advance warnings of developing conditions, such as significant weighting and the formation of roof cavities.

Other researchers have used roof geology in conjunction with leg pressure data to predict areas at risk of experiencing difficult roof conditions (Trueman, 2011; Wiklund, 2011). This paper uses leg pressure data only, which is easier to implement in practice.

LVA MONITORING OF LEG PRESSURES

The LVA software typically connects to the longwall face data via an OPC server (OPC is an industry standard for communication between machines). LVA reads leg pressures and shearer position every 20 to 30 seconds and creates an independent database of these values in a compressed format that allows fast access over networks. This provides sufficient resolution for LVA's data analysis methods to identify individual set-to-release cycles on each shield, from which individual shears across the face can be identified. Various statistics can then be calculated for each leg during each set-release cycle or during each shear. These include time-weighted average pressure (TWAP), set pressures, loading rates, and leaking and calibration issues. Individual users ("clients") can connect to the database via the network to view and analyze the data.

Figure 1 shows a typical LVA screenshot of pressures across the face and back in time over a period of 18 hrs. The black line is the shearer path.

The 3D image in Figure 1 is very efficient for real-time monitoring of a longwall face by operators, but other visualization techniques can be more effective for reviewing larger amounts of data, such as a whole panel or major portion of a panel. LVA can identify individual shears across the face by analyzing patterns of supports setting to the roof, which allows data to be displayed on a shear-by-shear basis. Figure 2 is a "Load Cycle Map" in which each horizontal row of pixels represents the average pressure of each leg across the face during a specific shear.

Figure 2 clearly shows areas of weighting events (horizontal bands of "hot" or red colors), and areas of difficult roof conditions and low-pressure roof cavities (areas of "cool" or blue/green colors). This paper describes a method for determining indicators

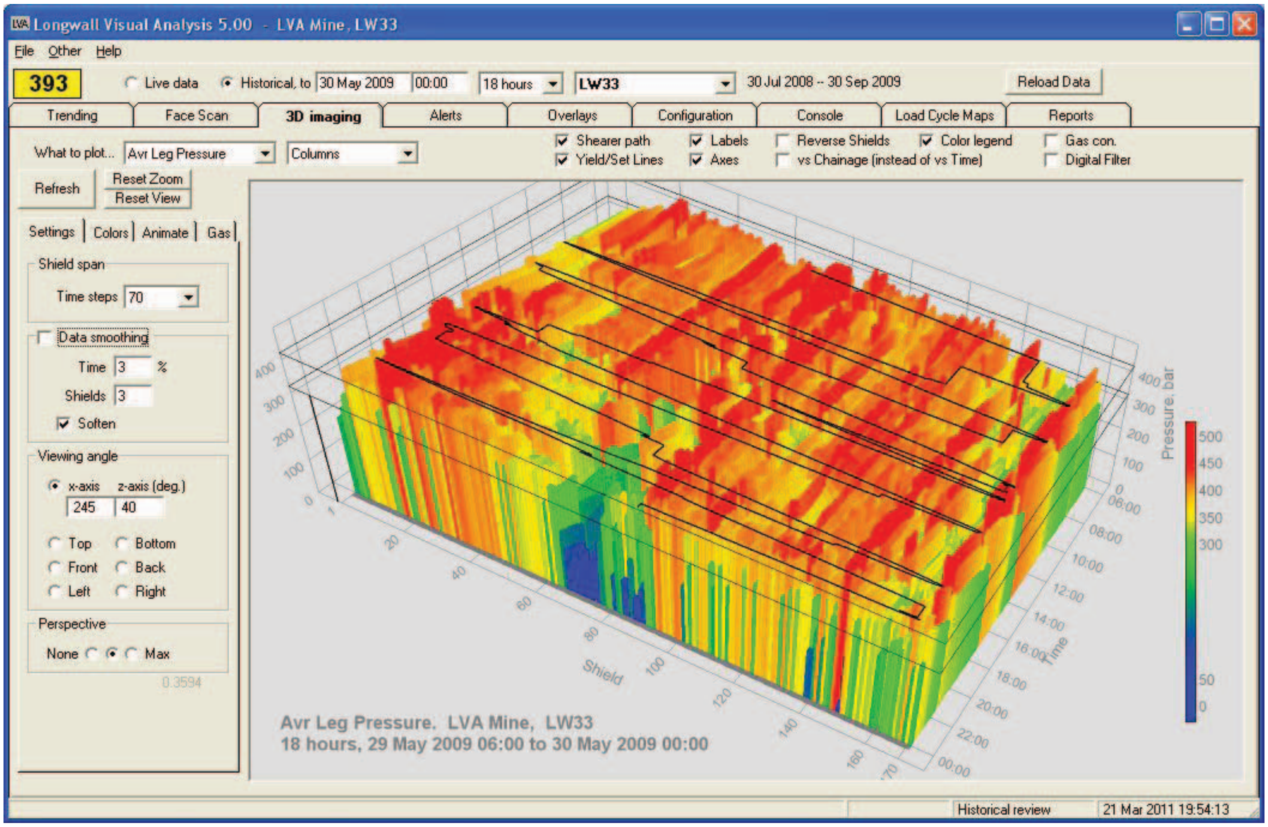

Figure 1. LVA screenshot showing a 3D image of leg pressures across the face and back in time, with shearer path overlaid.

to show operators in real time when there is a higher than normal risk of these roof cavities forming. This would allow the operators to take preventive action such as double-chocking (advancing the shields or chocks in pairs) and not stopping for maintenance, which can reduce downtime and safety hazards.

ALERTS FOR "WEIGHTING DEVELOPING"

The LVA software has an Alert system that logs messages and sends emails when certain events are triggered. One such Alert trigger is called "Weighting Developing." This is currently being used successfully by several mines to provide early warning of the start of unusually high weighting on a portion of the face. According to Moodie and Anderson (2011), "The use of LVA has enabled earlier detection of an oncoming weighting event (several hours) and also a better indication of the potential severity of the event via triggers based around the support average pressure in combination with loading rate and yield counts in a cycle".

This "Weighting Developing" alert system has the following algorithm (see Figure 3). LVA calculates the loading rate during the initial 5- to 10-minute period after the start of each set-to-roof cycle for each shield. During the cycle, LVA also counts yield events by identifying the characteristic rising/falling pattern of leg pressures when yielding. Every few minutes LVA determines which shields have the following properties, where numbers in [square brackets] are configurable by the user:

- The loading rate is at least [2] bar/min during the period 5 to 10 minutes after the shield is set to the roof
- The number of yields is at least [3] during the set-to-roof cycle
- The time-weighted average pressure (TWAP) is at least [380] bar
- A "Weighting Developing" alert is issued when at least [10] shields simultaneously satisfy the three conditions above

An Alert triggered by this algorithm indicates that a significant number of shields across the face are experiencing both high loading rates and substantial yielding. The Alert event is then displayed on screen as a text message and optionally emailed to a list of recipients so that appropriate action can be taken.

ANALYSIS OF PRESSURES, YIELDS AND LOADING RATES

Figure 1 showed how instantaneous leg pressures can be displayed across the face and back in time using 3D graphics. Note, however, that these data are often quite noisy and the signal noise can mask longer-term trends such as periodic weighting and cavity formation. LVA provides a signal filter that smoothes the data. For example, Figure 4 shows similar data to Figure 1, though over 36 hrs instead of 18, with smoothing applied. Both the weighting and cavity events are much clearer when smoothed.

Figure 3 shows how loading rates and yield counts can be calculated by LVA from the leg pressure trending data. The same smoothing and 3D presentation methods can be applied to yield

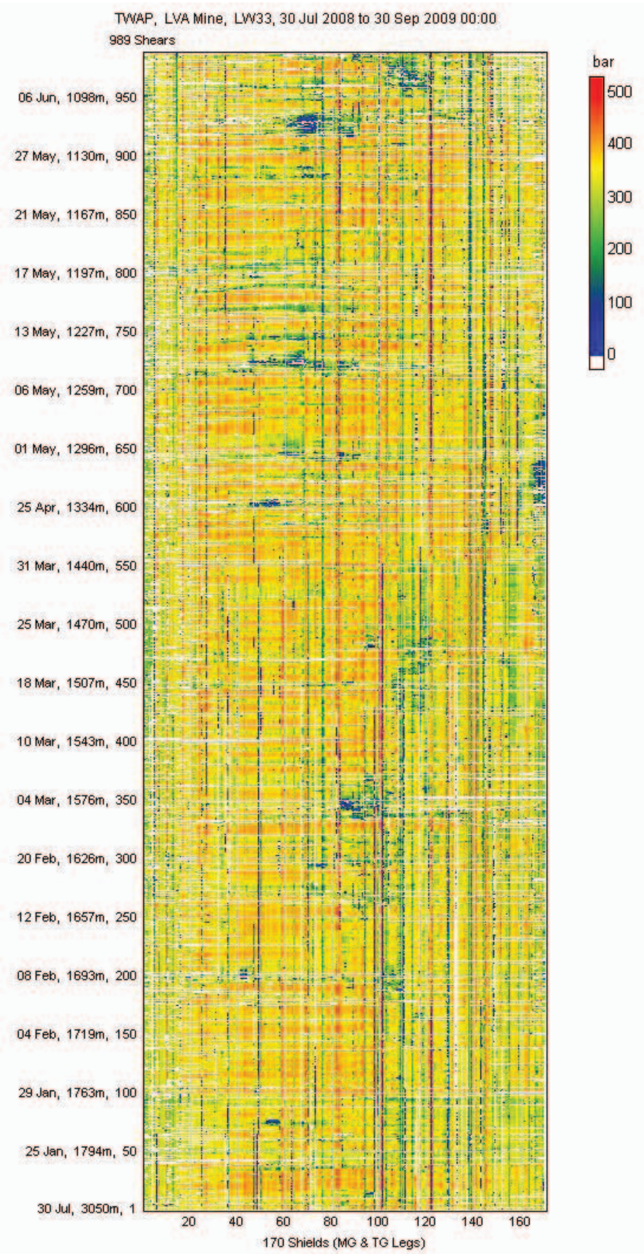

Figure 2. Load Cycle Map showing time-weighted average pressure (TWAP) on individual legs across the longwall face for 989 individual shears over about 12 months. Weighting events show as horizontal bands of "hot" or red colors. Areas of difficult roof conditions and roof cavities show as "cool" or blue/ green colors.

count and loading rates, as shown in Figures 5 and 6. These are the data formats that will be used in the next section to develop a cavity risk alert system. In particular, compare Figures 4 and 5. Note how in Figure 5 showing Yields in a Cycle, there are two "mountain peak" areas that form on each side of where the cavity formed in Figure 4. Note also that these peaks can be identified *before* the cavity forms.

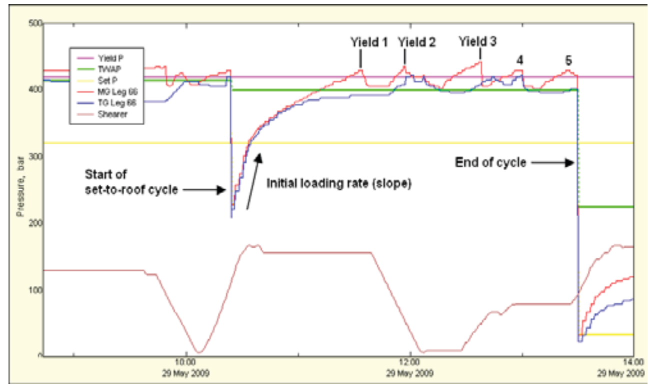

Figure 3. Leg pressure trend showing start and end of a set-to-roof cycle, and illustrating the calculation of loading rate and number of yields in a cycle. This cycle had five yields on the Main Gate leg (red) and three on the Tail Gate leg (blue).

WARNINGS OF POTENTIAL ROOF CAVITY EVENTS

The "Weighting Developing" Alert system described above has proved useful at several longwall sites. The primary concern when responding to weighting alerts is to try to reduce the occurrence of actual roof cavity events, namely complete loss of support pressure over a portion of the face and a section of the roof collapsing. This situation often results in loss of production and increased safety hazards. However, if an operator gets a Weighting Developing alert, they still do not know if the situation may develop into a cavity, which is a much worse condition. It was speculated that it should be possible to develop a "Cavity Risk" indicator by modifying the weighting alert algorithm. Additionally it was considered that a real-time display system with continuous visual feedback would be more useful to operators than a text-based Alert system when heading into potentially difficult roof conditions.

Cavity Risk Index Algorithm

Several different algorithm types were trialed on historical roof cavity events from different longwalls across Australia. Roof cavity events can be clearly identified from the Load Cycle Maps of TWAP, like the example shown in Figure 2. The LVA databases from each longwall site were used to replay conditions leading to cavity events, in order to test the effectiveness of various algorithms. It was found that cavity events are frequently preceded by the type of Yield bridging shown in Figure 5, and this was used as the basis of the Cavity Risk algorithm in conjunction with loading rates. Note that the bridge is neither a physical bridge nor a pressure bridge, it is a conceptual "yield and loading rate" bridge, which begins forming several hours before the pressure bridge of a roof cavity.

The algorithm finally selected to quantify cavity risk is as follows:

- Each individual shield is considered a "cavity risk trigger" if
  - its loading rate is at least [2] bar/min during the period 5 to 10 minutes after the shield is set to the roof
  - the number of yields is at least [3] during the set-to-roof cycle
- The pattern of cavity risk triggers across the longwall is analyzed to determine whether a bridge exists somewhere

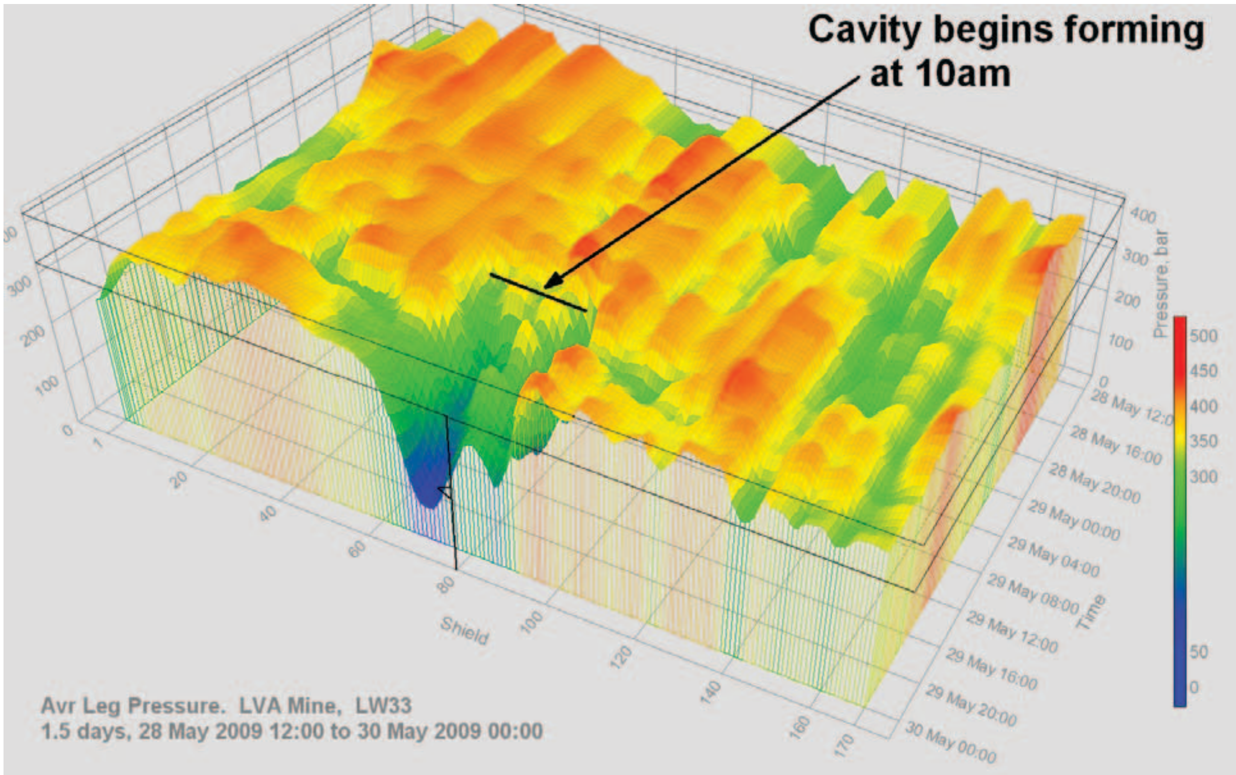

Figure 4. Similar data to Figure 1, but with the shearer path removed and with a smoothing filter applied. Note the appearance of a substantial roof cavity near the middle of the face (blue area at front of image).

on the longwall. A bridge in this context is a region of non-triggered shields (low yielding and loading rate) straddled on each side by a region of triggered shields (high yielding and loading rate). For example, a bridge may be said to exist when a region at least [10] shields wide has no triggers, and the region is straddled by regions on each side that have at least [4] out of [12] shields in a trigger state. The numbers given here (10, 4 and 12) have proven satisfactory in the cases studied so far. Further work is required to see whether these may need to be tuned specifically for different sites.

- A "Cavity Risk Index" (CRI) is calculated from the size of the bridge, from 0% when no bridge exists to 100% when [4] or more out of [12] shields on each side of the bridge are in a trigger state.
- The calculated CRI can actually decrease before a cavity event as the roof begins to weaken. For this reason, the displayed CRI is taken to be the peak CRI value over the previous [12] hours when implemented in a real-time warning system.
- Filtering is applied to the CRI trending, in order to reduce the effect of anomalies such as isolated spikes.

CAVITY RISK – CASE STUDY A

This case study was taken from an Australian longwall mine with 170 shields of capacity 875 tonnes, with a yield pressure of 430 bar (6,237 psi) (the same data shown above in Figures 3 to 6). The immediate roof is sandstone conglomerate, with thick massive sandstone conglomerate channels from 60 m (197 ft) above the seam. The case study shows how the CRI changed from low to moderate about 7 hrs before a roof cavity formed, and to extreme about 3 hrs before the cavity formed.

Figure 7 shows how the calculated CRI varies between close to 0% and 100% over a period of 36 hrs. The CRI went into the "high" range, above 80% at 3:28 a.m., and reached 100% at 7:26 a.m. Figure 8 shows a sequence leading to the roof cavity forming at 10:40 and becoming more pronounced by 13:55. The sequence of seven snapshots, labeled A to G, shows the state of the longwall leg pressures at different times. The x-axis shows shield number, in this case from 1 to 170. The blue dots along the bottom edge mark those shields that satisfy the trigger conditions of high yielding and high loading rate. The CRI is calculated from the pattern of these dots as described earlier. The sequence progresses as follows:

1. 28 May at 13:04. Leg pressures across the face are within the low to normal operating range. The thick black line is a smoothed profile drawn through the leg pressures. The blue dots along the bottom section of the graph mark those individual shields that are in a "cavity risk trigger" state, meaning they have experienced high loading rates and multiple yields. The Cavity Risk Index (CRI), shown in the gauge to the right, is calculated from the pattern of individual shields in the cavity risk trigger state – specifically identifying when the longwall face is in a bridging state. At this stage the CRI is low, as the algorithm applied to the pattern of blue dots indicates a weak degree of bridging.
2. Four hours later, 17:02. Leg pressures across the face are still within the low to normal operating range. The Cavity Risk

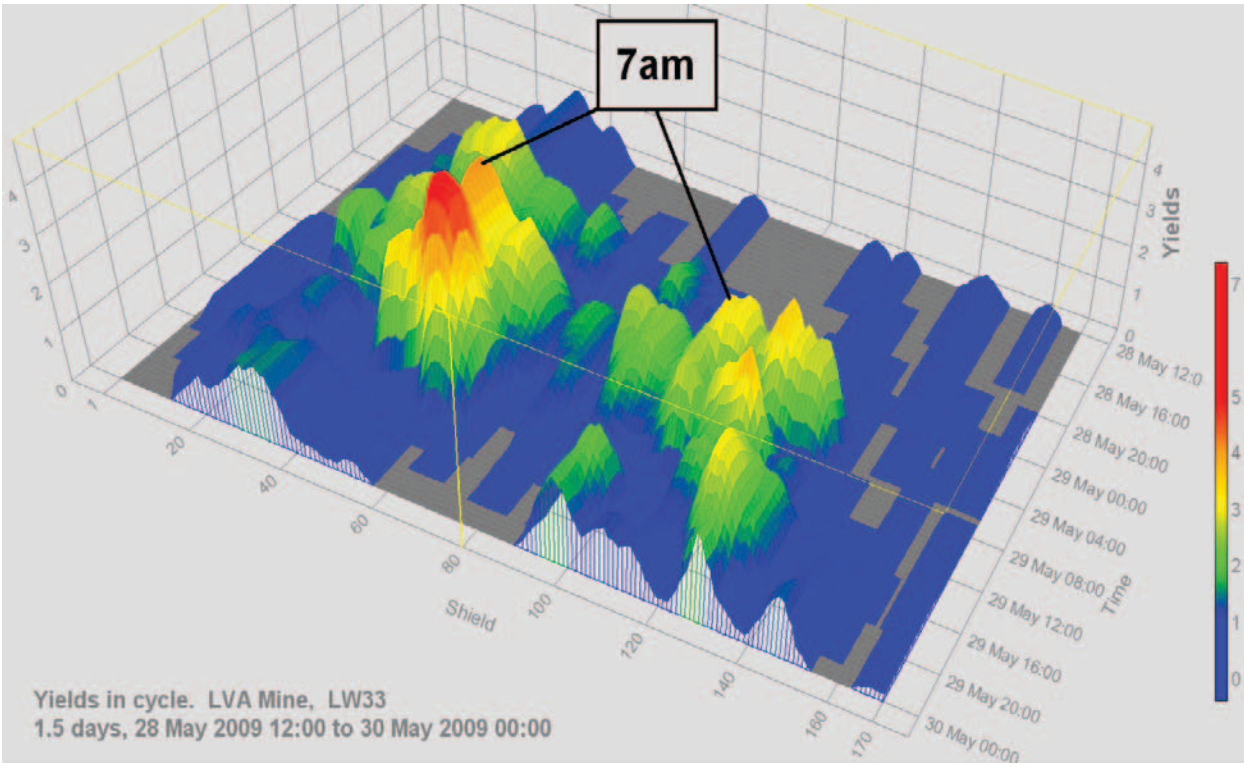

Figure 5. Smoothed image of yield count for each shield across the face and back in time. Note the formation of a significant "bridge" to each side where the cavity formed (cf. Figure 4). This bridge was prominent for several hours prior to the cavity forming.

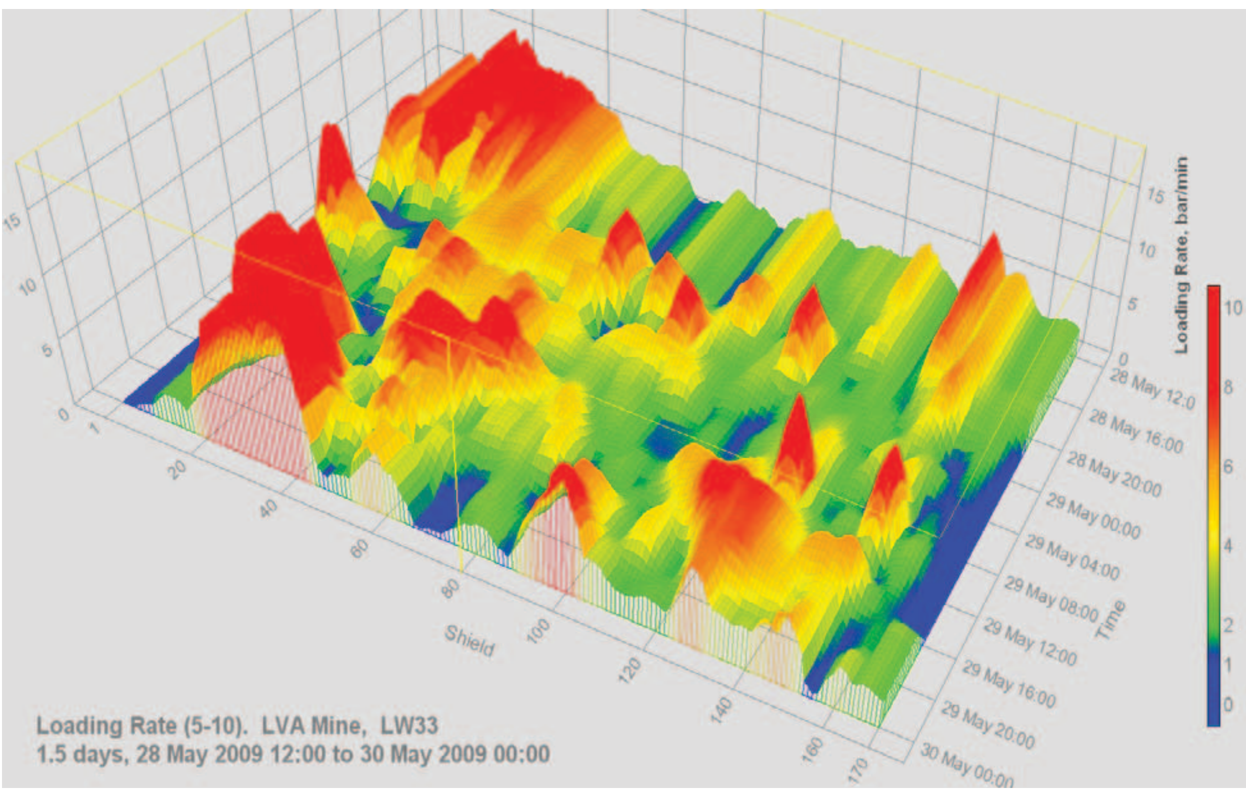

Figure 6. Smoothed image of loading rates for each shield across the face and back in time. These are used in conjunction with yield count to determine cavity risk.

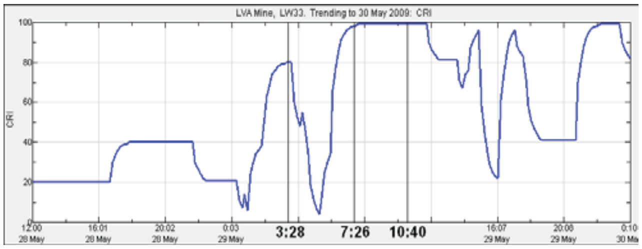

Figure 7. Case Study A. The trending graph over 36 hours of the Cavity Risk index, rising from low at 12:00 on 28 May to high at 3:28 on 29 May and extreme at 7:26. A roof cavity began forming at 10:40.

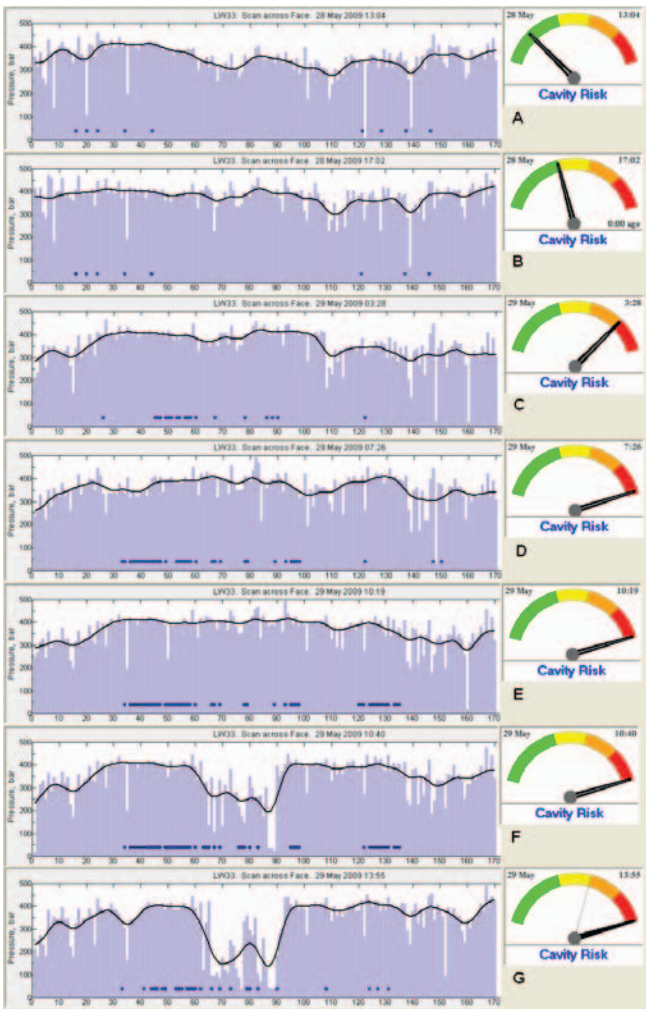

Figure 8. A sequence of seven snapshots (A to G) of the state of the longwall leg pressures, leading to the cavity formation. The CRI becomes high several hours before the cavity is fully formed.

Index is low but just touching on yellow (moderate). Note that the black gauge needle represents the peak CRI value over the previous 12 hrs, not necessarily the value from the exact pattern of dots shown in this image.

3. Eight hours later, 29 May 03:28. Leg pressures across the face are still within the normal operating range, but the Cavity Risk Index is high, just touching on red.
4. Four hours later, 07:26. Leg pressures across the face are still within the normal operating range, but the Cavity Risk Index has just jumped to extreme.
5. 10:19. The Cavity Risk Index has been extreme for 3 hrs, while leg pressures across the face remain within the normal operating range.
6. 10:40. After the Cavity Risk Index has been high for 7 hrs and extreme for 3 hrs, major loss of roof pressure occurs between shields 65 to 95, indicating formation of a roof cavity.
7. Three hours later at 13:55 the cavity is more pronounced. Mining stops for two days.

CAVITY RISK – CASE STUDY B

This case study was taken from an Australian longwall mine with 181 shields of capacity 913 tonnes and yield pressure 420 bar (6,092 psi). The case study shows how the CRI changed from low to moderate about 3 hrs before a roof cavity formed, and to extreme about 2 hrs before the cavity formed. Figure 9 shows the smoothed leg pressures across the face and back in time, developing to a cavity at the front of the graph.

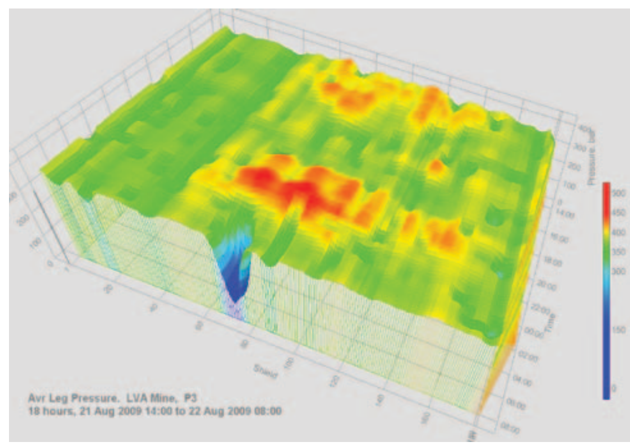

Figure 9. Case Study B. Smoothed leg pressures across the face and back in time. Note the appearance of a substantial roof cavity near the middle of the face (blue area at front of image).

Figure 10 shows how the calculated CRI varies between 0% and 93% over a period of 18 hrs. The CRI was in the "high" range of 60 to 80% at 2:46 a.m., and reached the "extreme" range of 80 to 100% at 3:30 a.m. Figure 11 shows a sequence of smoothed face pressure profiles and CRI readouts leading to the roof cavity forming at 5:28.

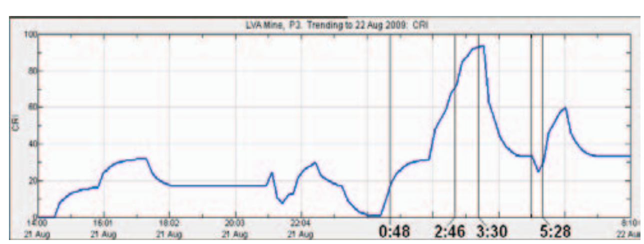

Figure 10. Case Study B. The trending graph over 18 hours of the Cavity Risk Index, rising from low at 0:48 to high at 2:46 and extreme at 3:30. A roof cavity began forming at 5:28.

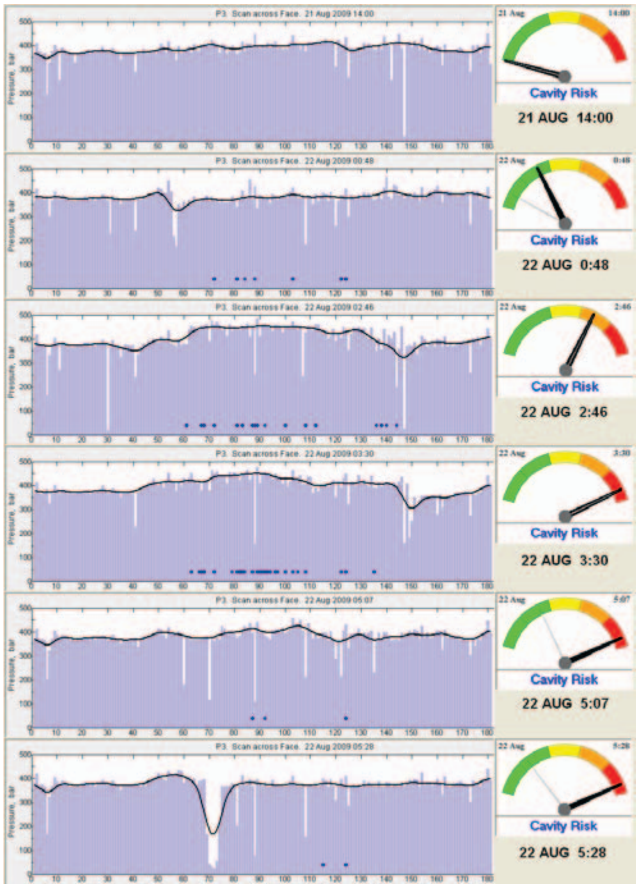

Figure 11. Case Study B. 21 Aug at 14:00 to 22 Aug at 5:28. Showing how the CRI varies from low to extreme as leg pressures across the face change, leading to the roof cavity at 5:28.

IMPLEMENTATION OF REAL-TIME CAVITY RISK INDICATOR INTO LVA

Figure 12 shows a prototype of how the CRI has been integrated into the LVA software for continuous real-time feedback on the future risk of roof cavities forming.

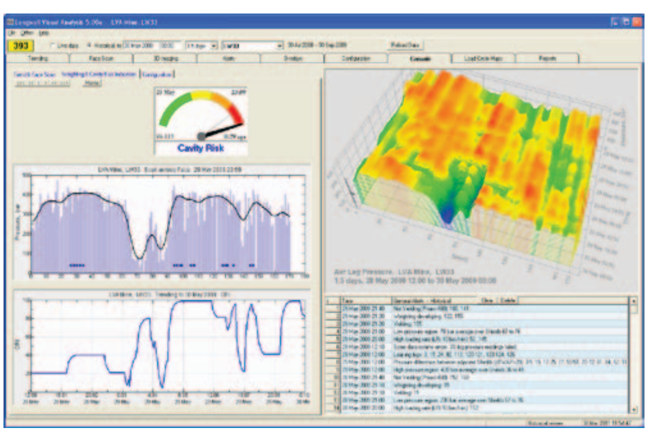

Figure 12. Integration of the CRI into the LVA software.

CONCLUSIONS

The LVA shield monitoring software calculates a Cavity Risk Index (CRI) from patterns of yielding and loading rates across a longwall face. This CRI warns of developing poor roof conditions including roof cavities – often giving several hours more warning than might be gained from looking at leg pressure trends alone. This advance warning allows operators to take preventive action such as double-chocking and not stopping for maintenance, which in turn can reduce downtime and safety hazards.

The CRI will be implemented in the LVA software program to provide real-time warnings of cavity risk to longwall operators. Two case studies were presented in this paper. The frequency of occurrence of roof cavities on the mines using LVA has not yet been comprehensively studied. Approximately ten additional roof cavity events have been identified and studied to date. In all but one the CRI was triggered several hours before the cavity formed. The confidence that a cavity can be predicted with several hours notice is therefore high. The frequency of false cavity predictions has not yet been established; this will be a focus of future work.

ACKNOWLEDGEMENTS

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