Application of Advanced Technologies to Delineate Ground Hazards in Coal Mines

K.Hanna, D.Conover, & D.Neil
NSA Engineering, Inc., Golden, Colorado USA

ABSTRACT: Early identification of adverse geologic conditions and high stress concentrations during underground excavation using modem mechanized mining systems remains a challenge to cost-effective mining operations. Often, unexpected geologic anomalies and related stress concentrations are encountered more rapidly, leaving the mine operator with insufficient time or information to deal with difficult ground conditions. Two high-tech detection systems developed by NSA Engineering, the RockVision3D™ seismic tomography panel imaging system and the GeoGuard™ shield load monitoring system, allow for continuous assessment of geologic structures and stress conditions ahead of me longwall face without interference to daily mining operations. This paper focuses on the applications of seismic tomography to delineate stress and geologic anomalies for hazard mitigation and full panel shield pressure monitoring to detect high-stress zones, roof caving, shield weighting and periodic loading, and bump occurrences along the face and in adjacent gate roads. Case studies for bump-prone coal mines in Australia, Germany, and the United States where these technologies were used will be discussed.

1 INTRODUCTION

Characterization of geotechnical and geological conditions and responses to high-production demands are essential to mine management to maintain cost-effective mining operations, high mining rates, and workers* safety in today's mechanized mining systems. High-speed longwall mining can cause rapid buildup of ground stress ahead of the face. One common phenomenon in longwall mining, is the periodic occurrence of high loading conditions along the face associated with geostructural conditions in the roof and gateroads, such as caving of cantilevered roof layers at regular intervals and floor heave and pillar yielding in the gateroads. Problems can arise from these conditions in the form of face bumps, spalling and overloading of face supports (shields) leading to severe safety hazards and production delays. Conventional ground hazard detection and mitigation technologies have fallen short in fully addressing both personnel safety requirements and the high-production demands of today's mining. Advances in electronic sensors, computer technologies, and data processing allowed geophysical seismic tomography and shield pressure monitoring techniques to become more popular for identifying potential ground hazards ahead of a mining face (Hanna et al. 1999, Demarco et al. 1997,

& Conover et al. 1994). With appropriate warning of impending high-load conditions, the mine operator can take steps to mitigate these problems, such as removal of personnel, increasing the production rate and inducing caving.

Two high-tech detection systems developed by NSA Engineering-the RockVision3D™ seismic tomography panel imaging system, and the GeoGuard™ shield load monitoring system-have been used successfully in coal mines worldwide. These technologies offer substantial benefits over conventional detection methods by providing continuous assessment of geologic structures and stress conditions ahead of the longwall face without interference to daily mining operations. Results are presented in near-real time and are easy to interpret, allowing mine operators to deal with potential hazards on a day-to-day basis.

RockVision3D™ is a high-tech tomographic imaging method that utilizes seismic energy and processes the information using techniques similar to those used in medical CAT (Computer-Aided Tomography) scans (Rock et al. 1997). The principle behind RockVision3D™ is that seismic energy travels through /different material types with different attenuation and velocity levels. Seismic waves will travel faster through competent or highly stressed rock than through broken or fractured rock

and voids (Westman et al. 1995, & Yu 1992). RockVision3D™ is the only commercially available tomographic imaging system that utilizes mining equipment such as the shearer in coal mines as the seismic source. This allows continuous operation of the Iongwall while images are being generated. In general, RockVision3D™ effectively provides real-time graphic representations of (1) relative stress concentrations as they migrate across an underground rock mass; (2) structural discontinuities, such as faults, joints, or shear zones; and (3) geological anomalies (sand channels or rolls in coal mines).

The GeoGuard™ shield monitoring system is designed to provide warning of high loading conditions on the Iongwall face. The system collects leg-pressure data from the face supports in real-time and provides a variety of tools for displaying and analyzing the data, both in real-time and off-line. The history of face loading conditions is continuously updated and analyzed to identify the development of high-load conditions and anticipate the occurrence of periodic weighting zones.

This manuscript focuses on the applications of seismic tomography and shield pressure monitoring for delineating hazards caused by stress and geologic anomalies. Results from case studies in bump-prone coal mines İn Australia, Germany, and the United States will be presented.

2 THE ROCKVISION3D™ SYSTEM

The RockVision3D™ system consists of commercially available hardware and proprietary software. The system hardware for Iongwall operations is simple and İs designed to measure acoustic noise generated by the shearer cutterhead during coal excavation. In general, the hardware is comprised of an intrinsic safety barrier (for gassy mine applications), geophones that are attached to roof bolts in gate roads, and cables that carry the signal to a seismic data acquisition system. The entire system is located İn the mine, and the data can be easily transferred to the surface or any mine office location through a monitoring and control network.

The system software combines wavefront and curved ray theories to reconstruct color-coded attenuation or velocity tomograms of the region to be imaged. The velocity and attenuation of seismic waves are directly related to the elastic constants, which characterize the type and condition of the rock medium. The paths followed by seismic waves from a source (i.e. shearer) to individual geophone receivers are represented as velocity or attenuation rays. The ray paths can be straight or curved depending on differentiation of the velocity and

attenuation of seismic waves in the rock. In a uniform rock, the velocity and attenuation ray paths are generally straight. However, the ray paths are not normally straight, but rather bend (refract, curved ray) depending on the physical properties of the medium or the velocity contrasts between various material units (Rock et al. 1997). For example, in mining, as the seismic signals (waves) travel through rock, geological anomalies or highly stressed/ fractured zones ahead of excavation absorb the vibrations, bend the ray, and attenuate me signal. As a result, variations in the measured magnitude of the seismic signals at the sensors are produced. Typically, in Iongwall mining, attenuation tomograms are generated and are related to fracturing and stress under the assumption that an area of higher stress results in microfracture closure and, mus, lower attenuation levels. The results of these tomograms are used to observe stress behavior and ground conditions ahead of mining (Westman et al. 1996).

2.1 Field applications

The RockVision3D™ technology has been used successfully in mines İn the United States, Australia, Germany, Ireland, South Africa, Poland, and Canada for stress and geological mapping, ore deposit delineation, solution cavity location, water migration pathways identification, and characterization of ground conditions within tunnel alignments. The following are some RockVision3D™ applications in coal mines.

2.1.1 RockVisionSD™ monitoring in Germany

At a 1,130-m-deep Iongwall mine in Germany, where high stress zones on the face are known to contribute to severe ground control problems such as face bumps, RockVision3D™ was applied to detect stress concentration zones and to delineate bump-prone areas in the Iongwall panel. The Iongwall panel utilizing the single-entry system was 1,300 m long and 323 m wide. The entries were 5.9 m wide and 4.2 m high. Mining height at the face was approximately 2 m. The panel was oriented approximately S50° E, advancing from SW to NE, and was located between two major fault zones. The immediate roof consists of a massive sandstone layer approximately 20 m thick and contributes to stress concentration along the Iongwall face. The immediate roof is overlain by strong competent shale/sandstone layers of various thicknesses.

After mining 780 m, the Iongwall face approached these two major faults. The first fault had a displacement of 4.3 m and was filled with sandstone. This fault appeared between shields 202 and 205, approximately 12 m from the tailgate rib.
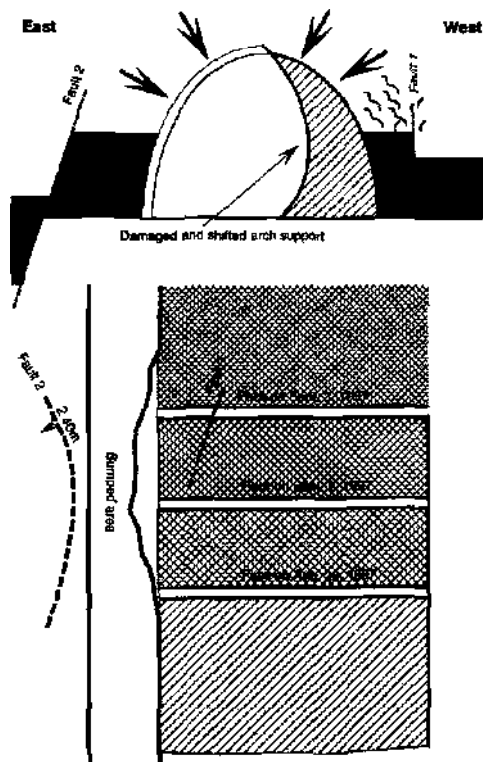
Figure 1 Extent of damage produced by a coal bump after 450-m advance of the longwall panel and location of associated faults.

The second fault, with a displacement of 2.4 m, was located approximately 72 *m* from the headgate rib. Slippage along faults within the coal seam had contributed to significant bumps. For example, after 450 m of advance, when the tailgate was between these two faults at approximately 10 m ahead of the face, a significant bump occurred. The released force pushed the panel rib into the tailgate entry, as shown in Figure 1. "This caused substantial damage to the arch support system. The damage extended approximately 13 m along the tailgate entry.

The factors contributing to structural stability problems m this mine are numerous and present very complicated problems in predicting potential bump locations; however, most of the bump problems are typically associated with high stress conditions and occur on the face. Timely mapping of high-stress concentration zones and geological anomalies ahead of mining can be beneficial to ground control and safety at this mine.

2.1.2 Analysis of roof caving

To evaluate the face bump potential for the mine setting and to characterize roof caving behind the shields, an analytical evaluation was conducted of cantilever and fixed beam span over elastic foundations subject to exponentially distributed abutment stresses. The mined seam and overlying strong roof units configuration were modeled using the Coal Bump Potential Evaluation Program (CBPEP), developed at Virginia Polytechnic Institute and State University, Blacksburg, Virginia (Wu et al. 1995, & Haramy et al. 1988). The program allowed determination of (1) critical roof span, (2) induced foundation stresses, and (3) strain energy stored in the roof and foundations. Dynamic failure potential immediate to the failing span is characterized by local Richter magnitude (ML) and induced maximum stresses in the roof and foundation.

The following summarizes beam lengths and local Richter magnitudes (ML) calculated for the current longwall panel. If the local Richter magnitude exceeds *2.0,* bump-prone conditions are assumed to exist.

- Fixed beam {first cave) length, m................114.91
- First cave Richter magnitude, (M_L).................5.26
- Periodic weighting cantilever beam length, m 8.96
- Cantilever beam failure Richter magnitude,
    (M_L)...3.31

The above results indicate that, based on the input parameters, the sandstone setting at the mine is bump-prone, and may incur substantial damage from dynamic events associated with die first cave and/or cantilevenng channels "periodic weighting" during panel retreat. Although the existence of a 20-m-thick competent roof layer in close proximity *to the* coal seam contnbutes to bump conditions, a combination of many other factors may act independently or together to promote the following high-stress conditions *on the face:*

   a. High depth of cover;
   b. Presence of geological structures;
   c. Mining of a seam 170 m above;
   d. Massive 20-m-thick sandstone above the seam;
   e. High strength gob-sealing walls built along the tailgate entry, affecting caving of the gob;
   f. Panel orientation with respect to fracture zone in the roof.

2.1.3 Interpretation oftomogfaphic images

The RockVision3D™ system was installed to determine if tomographic images produced on a daily basis could be used to detect zones of high stress concentrations on the longwall face and delineate bump-prone areas in the panel. Sixteen geophones were installed, with eight in the headgate and eight in the tailgate. The geophones were

attached to angled roof bolts at 15- to 20-m spacings, with the closest geophones 10 to 15 m head of the face. The vibration signal produced by the shearer appeared to be transmitted clearly through the rock mass. The data were transmitted through a modem to the surface so that the mine could remotely monitor and analyze data on the surface quickly and cost-effectively.

The tomograms produced over a period of five days showed lower stress zones extending from the middle of the face toward the tailgate. Figure 2 shows tomograms produced on February 10 and 11. The fault present at the tailgate (left) side of the face diverts tbe velocities. This fault does not appear to build strain energy. The fault at shield 50 (right-hand side) had a major effect on how the seismic rays traveled. This fault appeared to contain highly fractured rock to within 25 m ahead of the face. The fractured zone continued to move ahead of the face, and a high-stress zone developed 50 m ahead of the face between shields 1 and 48. The fault, in combination with the overlying massive sandstone, contributes to a high stress concentration between shield 50 and 120. This zone disappears when the roof member caves. The tomograms indicate that the forward abutment extends up to 40 m, widi the highest stress zone occurring between 10 to 15 m ahead of the face (Hanna et al. 1998).

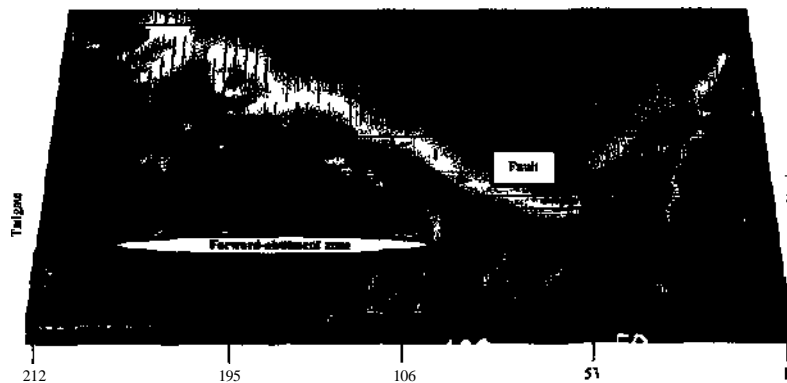**2/10 3:08 pm-3:59 pm**
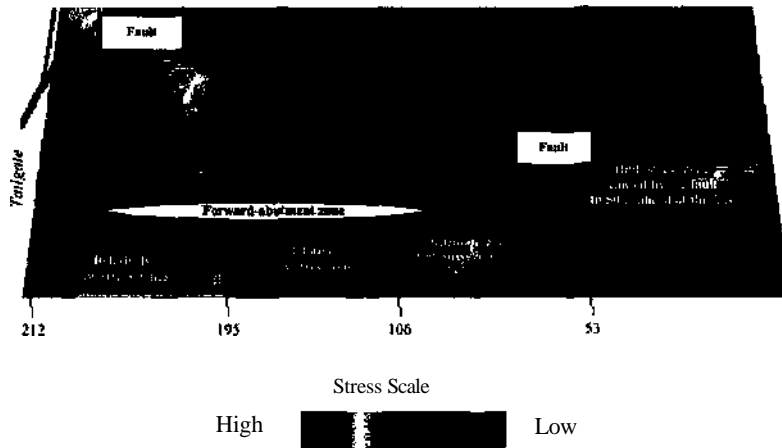
2/11 6:28 pm-10:44 pm

Figure 2. Fault and forward abutment mapping ahead of mining - Germany.

136

2.1.4 Comparison between tomographic images and drilling

Typically, the drilling-yield method is used by the mine operator to locate the areas of high-stress zones on the longwall face. Once the high-stress zones are identified, the auger drilling method is then used to destress such areas. This method can also give reliable information on the general stress conditions in the coal seam. Results indicate that on the average, the high stress zones occur between 10 and 13 m ahead of mining. The extent of the high-stress zones obtained from the auger drilling method coincides with the measurements obtained from the tomographic imaging data.

To further verify the accuracy of the tomographic images, the mine decided to use the drilling-yield method in areas depicted in the tomograms as "Very High, High, and Low." The results are summarized in Figure 3 and show high accuracy in correlating stress areas obtained from seismic tomography with those obtained from the drilling-yield method. Using the tomogram produced on February 9, the stress results obtained from RockVision3D™ and the drilling-yield method matched perfectly, and the data from February 10 matched at about 80%. Other comparisons were conducted and gave a similar high level of correlation. This information indicates that the technology can be used for real-time detection of stress concentration on longwall faces and the determination of the effectiveness of destressing methods.

2.2 RockVision3D™ monitoring in Australia

At an Australian longwall coal mine, a RockVision3D™ study was conducted to determine if the system could predict periodic shield loading. The mine was experiencing difficulties with face control due to the onset of periodic loading on the shields, possibly caused by the presence of massive sandstone in the roof.

Figure 4 shows the tomograms that were produced from the study. The first tomogram (2/10, 11:12 a.m.-12:34 p.m.) shows an elevated stress zone (red) in the mid-face area, approximately 30-50 m from the face. High attenuation zones (purple to blue) are shown on the outer portions of the area near the tailgate and maingate. The second image (2/11, 4:36-5:38 a.m.), covering a period of one hour early the next day, shows enlargement of the high stress zone from the previous day. The zone is similar in shape to the previous day, but has grown outward as the face approached. The third image (2/18, 5:20-6:25 a.m.), seven days later (the face only advanced a short distance due to production delays during the intervening period), shows that the high stress zone has changed shape slightly and moved closer to the face. The lower left lobe of high

stress has faded away however. The fourth image, showing the situation 11 hours later, indicates a significant stress relief in the mid-part of the face. This suggests that the bridging sandstone had broken, lowering stress on the immediate face line. Areas of high stress developed to the lower left and right, similar to the pattern for the first image, indicating a cyclical pattern of stress development.
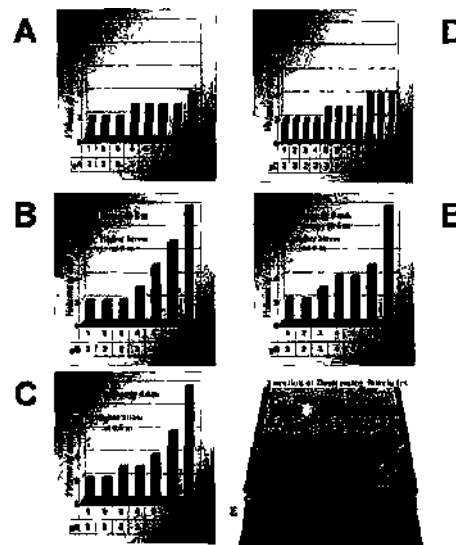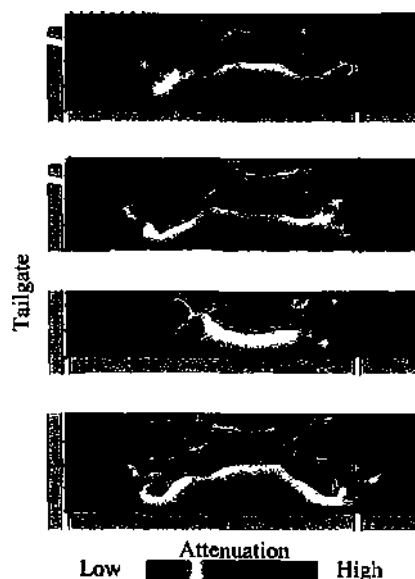

Figure 3 uestressing in a deep coal mine - Germany.

Figure 4. Detection of penodic shield loading - Austrasha.

During the period monitored, failure of fractured roof rock ahead of the face was noted, which corresponded to the blue areas on the tomograms. The blue areas on the tomogram represent high attenuation, indicating that the rock had fractured, and was no longer competent.

The Rock3D™ images obtained during this short demonstration give an indication of the nature of cyclical weighting on the longwall face. A longer period of monitoring would be required to better define the exact nature of the loading.

At another Australian longwall coal mine, fracture zones were causing occasional guttering in front of shield canopies and consequent delays. Several roof falls occurred that extended up to 80 shields along the face. Position and severity of roof falls were typically unpredictable. RockVision3D™ was deployed to determine if roof structural anomalies or fracture zones, along with stress concentrations, could be readily mapped ahead of the face. The longwall panel investigated was 250 m wide by 1,900 m long, with a mining height of 4.2 m and an overburden depth of 170 m. Eight geophones were installed on roof bolts in die tailgate only of the longwall panel at 15-m spacings.

Tomograms developed from the data showed a pattern forming when roof falls occurred. A high-stress zone developed at approximately 50 m ahead of the face, which created a high shear zone close to the face. Due to the weakness of the roof rock, failure then occurred. After the fall, the high-stress zone moved closer to the face, and a smaller fracture zone was detected. Figure 5 shows four consecutive tomograms indicating the partem Üıat developed. The first, at 3:55 to 4:09 pm shows areas of high attenuation (dark blue) indicating areas of fractured rock not under appreciable stress. An area of light green, indicating low attenuation and high stress, is developing around this blue region. In the next tomogram for the period between 6:08 and 6:23 pm, the area of high stress that probably represents the front abutment is further developing and looping around the fractured material toward the tailgate.

The third tomogram at 6:59 to 7:17 pm shows the beginning of. a second high-stress zone, and the fourth tomogram at 10:32 to 11:14 pm shows the high-stress zone expanding and spreading across the face. During the period of these tomograms, sporadic hard cutting and yielding of shield legs occurred.

Subsequent tomograms show an increase in stress, which then migrates toward the maingate side of the face, and the cycle appears to terminate. For the two days following this, difficult face conditions were encountered, with significant spalling and guttering, and failure of most of the mid-face zone.

Over the following days, tomograms were produced that confirmed the pattern of stress abutment development, with stress circumscribing the tailgate corner. The elevated stress zone appears to migrate toward the face until me rock became fractured and developed high attenuation, ultimately leading to failure on the face.

Image analysis and underground observation indicate that the extent of the mining-induced stress zone extended 45 to 50 m ahead of the face with significant mining-induced loads at 18 m. The most critical zone is approximately 2 m from the face in the tailgate area. This agreed well with the RockVİsion3D™ results. At this mine, RockVisiorßD™ was considered a reliable tool in mapping patterns of stress buildup ahead of the mining face.
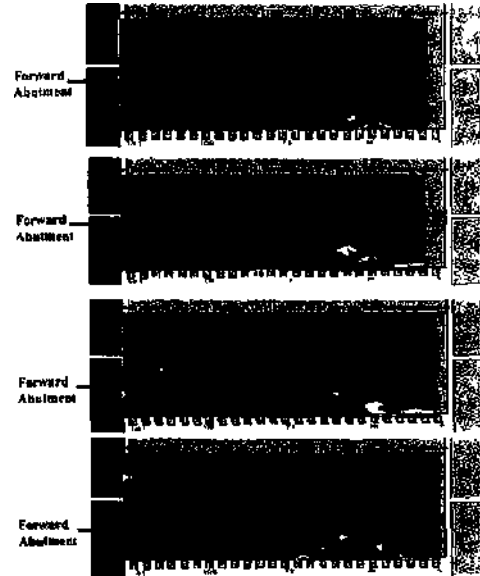

FigureS. Detection of a pattern developing prior to roof failure - Australia.

3 THE GEOGUARD™ SYSTEM

The principal goal of the shield monitoring implementation is to provide an early warning system to alert the operator to an imminent occurrence of severe periodic weighting events. The average loads and/or load increments experienced by the face supports during each cycle have been shown to provide a reliable indicator of weighting conditions. Automated analyses of historical data provide estimates of the weighting interval, and warnings are generated when the face approaches a predicted weighting zone and when loads became unusually high.

Earlier research in this area (Conover et al. 1994) had success using support loads to predict ground conditions; however, a separate monitoring system was required, and the software analysis functions were performed off-line, requiring significant operator time to process and interpret. Modem installations include the necessary interfaces to permit collecting and transmitting the support data through existing monitoring and control networks. To obtain maximum advantage from existing installations, NSA modified the various software components into an integrated application that combines the functions of monitoring, analysis, interpretation, prediction, and warning.

3.1 GeoGuard™ components and system layout

Although GeoGuard™ is a software system that accesses real-time monitored data, the interface to the monitoring hardware is an integral part of the system and significantly influences the capabilities and performance of the software. Data from the supports are accessed using hardware and software components supplied by the support manufacturer, including an interface between the support controller and an Allen-Bradley monitoring and control network. The support data are periodically scanned and transferred to a PLC using custom, system-specific control programs. These data typically include the pressures of both support legs and possibly support convergence. Also, the shearer position Is normally captured and stored in a separate PLC location. Typically, updated data are collected every few minutes and whenever each support is reset.

GeoGuard™ connects to an Allen-Bradley network using the RS-Linx software bridge, available from Rockwell Software. RS-Linx permits accessing the network via a data highway, serial, or Ethernet connection. GeoGuard™ communicates with the RS-Linx program using software calls to set up data pathways and initiate the transfer of data to and from specific PLC memory locations. The GeoGuard™ and RS-Linx software are installed on a dedicated PC, and the system runs continuously, capturing data in real time.

Data are read at a user-specified scan interval (normally 1 minute) and are written to daily files to provide a permanent record. At the end of each support cycle, the time-weighted average pressure (TWAP) is calculated and written to a file. This loading history is analyzed to identify the pressures accompanying peak (periodic) loading zones and the intervals between zones.

The locations of future weighting zones are predicted using the average of past weighting intervals. A multi-stage alarm is generated based on the proximity of the face to the predicted weighting zone and the current support loading intensity relative to a pre-set threshold. The weighting interval predictions and pressure threshold values are automatically updated in order that the warning system adapts to changing ground conditions.

A variety of graphical displays are provided to evaluate the data visually. A real-time graphics display (Fig. 6) shows the current leg pressures and other parameters for the entire face. A two-dimensional trending function permits trending any of the monitored data points versus either time or face position, as shown in Figure 7. Three-dimensional plots permit viewing the support loading data superimposed on base maps of mine layout or geology to identify correlations between loading behavior and any conditions that may contribute to excessive weighting occurrences.

3.2 GeoGuard™ monitoring in the United States

GeoGuard™ was installed at a longwail operation In the western United States (Hanna & Conover, 1998). Support leg pressures were monitored on 12 shields, evenly spaced along the face, during die mining of five panels. An independent monitoring system transmitted the data in real-time to the main office, 240 km from the mine. Processing was conducted off-line and correlated with mine geologic maps and reports of ground control conditions.

The coal seam was 320 m deep, 3 m thick, and had a slight dip oblique to the panel layout. The seam and surrounding strata were relatively uniform throughout the monitoring area. The roof consisted of three strong sandstone layers extending approximately 14 m above the seam. The main ground control problems were bumps that occurred in the tailgate, resulting In significant floor heave and subsequent down-time required for cleanup. Some rapid shield-loading events associated with the bumps were also observed.

Review of the TWAP data revealed a pattern of periodic loading, with pressure peaks of different intensities occurring at different intervals. It was determined that the pattern was indicative of the caving behavior of the tiiree main roof layers. Figure 8 shows an idealized plot of TWAP versus face position and a diagram of the roof strata. The low-intensity pressure peaks, at intervals of 2.5 m, coincide with caving of the immediate, lowest roof layer (A). As mining progresses, the upper layers form cantilevers extending behind the shields and fail when the underlying layers cave and their support is removed. The middle layer (B) caves at intervals of 7.5 m accompanied by somewhat higher support pressures, and the upper layer (C|) caves at intervals of 30 m and produces the largest pressure peaks.

The current version of GeoGuard™ contains an automatic system for identifying pressure peaks, calculating the periodic weighting interval between peaks, and alerting the operator when the face approaches periodic weighting zones.
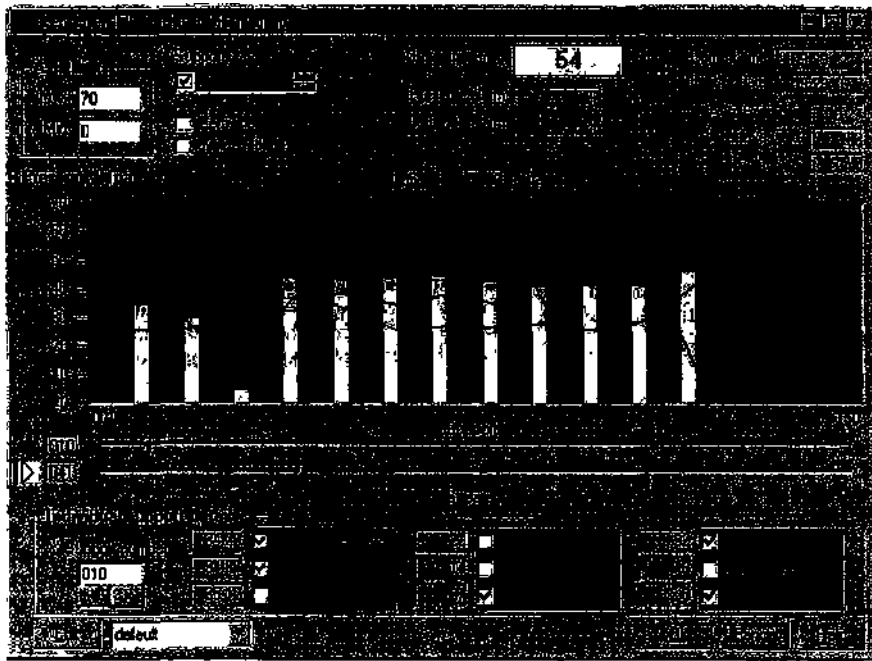
Figure 6. GeoGuard™ real-time monitoring display showing shield leg pressures, alarm state, and other parameters related to detection of penodic weighting pressures and intervals.
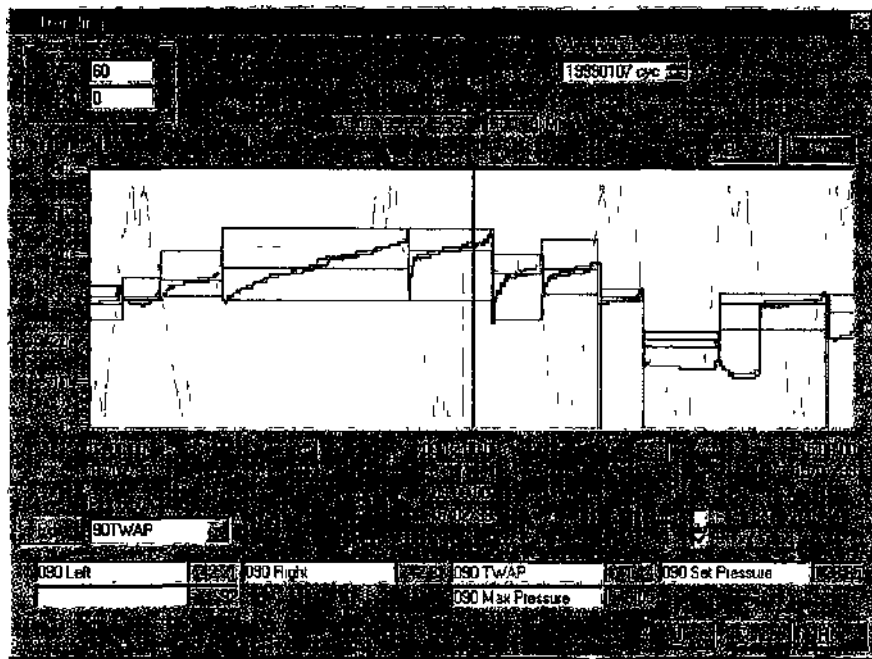

Figure 7. Two-dimensional GeoGuard™ trend plot of let pressures including calculated cycle parameters and shearer position
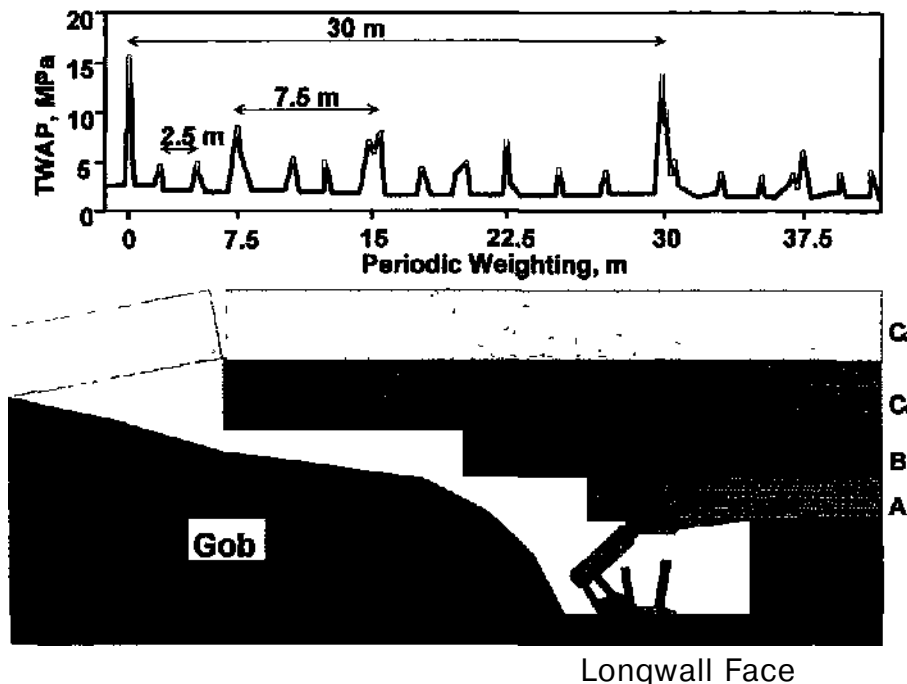
140

Figure 8. Correlation of periodic shield weighting with roof caving sequence Layer A caves every 2 5 m, layer B every 7.5 m and layer Ci every 30 m.

3.3 GeoGuard™ monitoring in Australia

GeoGuard™ was installed at a longwall operation in New South Wales, Australia (Conover & DeMarco, 1999). Transducers were installed on every support, and convergence meters were installed on several supports. The data were accessed from the surface through an existing Allen-Bradley control network.

The longwall panels were located under a 24-m-thick sandstone unit immediately overlying the coal seam, which resulted in several sudden and severe face weightings, three of which resulted in severe overloading of the supports, with significant equipment damage and several weeks of downtime. During these weighting events, vertical convergence of up to 200 mm was measured along the panline.

The strata overlying the seam were generally characterized by a strong, massive sandstone residing immediately above the seam, overlain by moderately strong sandstone and shale sequences, with interbedded weak coal and shale layers. The primary contributors to the weighting behavior were determined to be the existence of the massive sandstone unit, minimal cover depth, and a lack of significant jointing in the roof.

The first face-stopping weighting event involved approximately 30 shields toward the tailgate end of the face. Operational delays caused the face to stand idle for more than 90 minutes, during which time the face converged to such a point that the shearer could no longer travel the face. Mining was suspended for two weeks while the collapsed shields were cleared and repaired.

A second face-stopping event occurred approximately 200 m outby the first event. Once again, operational delays in excess of one hour contributed to the eventual stoppage of the face, and another week of downtime.

Face width is another factor that contributes to difficulties in mining through weighting events. Wider faces require additional shearer tramming per pass, thereby extending the time required to advance the wall through a weighting area. Over the course of a major weighting, 60 to 90 mm of closure can take place per shearer pass, with a rapid-onset event experiencing more than 200 mm per shearer pass.

GeoGuard™ can alert the operator when the face approaches weighting areas and when pressures increase prior to weighting events. Review of three-dimensional plots of the support loading history, such as Figure 9, can quickly identify patterns of loading that accompany periodic loading and panel advance through specific geologic conditions. With this knowledge, the operator can take steps to ensure that the area is mined-through rapidly, before excess convergence can occur.
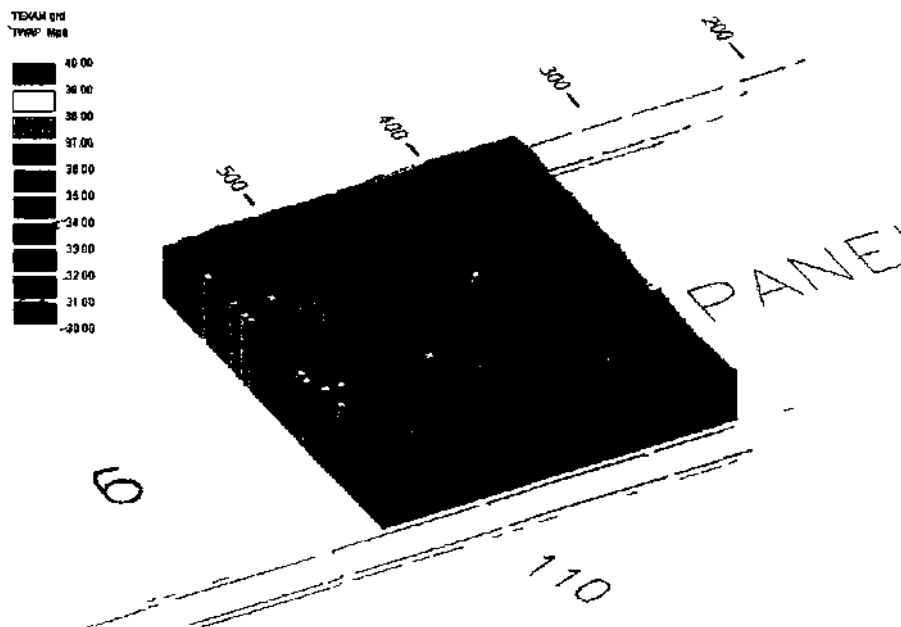
141

Figure 9 Three-dimensional GeoGuard™ plot of Time-Weighed \\i.rage Pressure (TWAP) over a penod of 22 days (210 m)
Gale road shown at top is the headgate and race advance is toward the right

4 CONCLUSIONS

The conventional ground hazard detection methods to delmeate high stress areas and geologic anomalies have fallen far short of meeting both personnel safety requirements and the high production demands of today's mechanized mining operations The RockVision3D™ seismic tomographic technology and GeoGuard™ shield monitoring system have evolved into powerful predictive tools for continuous non intrusive assessment of ground conditions without interference to daily mining operations, and without putting mine personnel at risk

REFERENCES

Conover, DP, & DeMarco, M J 1999 Shield Monitoring to Forecast Severe Face Weightings at the South Bulga Colliery *Proc of W Internationa! Conference on Ground Control in Mining,* Morgantown, WV

Conover, D P, McDonnell, J P , & Hanna, K. 1994 Computer assisted ground control management system USBM 1C 9408 25 pp

DeMarco M J & Haramy, K.Y 1997 New technologies for coal bump hazard detection and mitigation assessment Pres 28th Ann Inst On Mining Health, Safety and Research, Salt Lake City, UT, 15 pp

Hanna, K & Conover, DP 1998 Shield Pressure Monitoring A Key to High-Production Longwall Mining Systems *Proceedings of Advanced Toob & Monitoring Techniques for Mechanized Longwall Mining Conference,* Poland

Hanna, K. & Haramy, K- 1998 Ground control and geologic assessment in mining through the use of geophysical tomographic imaging *Proc Geomechantcs/Ground Control m Mining and Underground Construction Conf Wollongong NSW Australia 543 pp*

Hanna, K & Haramy, K- 1999 RockVision applications to delineate hazardous geologic and stress conditions in coal mines Case histones SME Preprint 99 94

Haramy K Y Magers J A & McDonnell JP 198S Mining under strong roof Proc of 7th International Conference on Ground Control in Mining Morgantown WV pp 179-194

Westman, E, Haramy, K & Rock, A 1996 Seismic tomography for longwall stress analysis *Proc 2nd North American Rock Mechanics Symposium Montreal Quebec Canada*

Wu, X, Karfakis, M G , Haramy, K. V & Brady, B T 1995 Ground motion parameters associated with coal mine tremors SME Preprint No 95-49