For the past decade, the underground coal mining industry has been moving toward ‘super panels’ of wider faces and greater lengths. An obvious economy of scale exists: amortisation of setup investments over greater coal volume, and an extension to the time before the longwall must be moved. This enables mine management to reduce fixed cost/t. Face widths have currently reached 350 m (approximately 1200 ft), restricted by equipment considerations because face conveyor chains are at an optimum design. Wider faces would require an incremental step in hardware, which the original equipment manufacturers (OEMs) are now considering at the request of major coal companies. However, panel length has not yet reached a limit; some panels now exceed 4500 m (more than 15,000 ft), with greater length planned for the future. Panel length is more a function of reserve configuration and ventilation requirements or restrictions, including geological anomalies. Super panels have certainly enabled the industry to keep pushing the limits of productivity improvement.

However, an important consideration of panel size now, and especially in the future, will be driven largely by geological factors. While larger panels improve productivity and capture economies of scale, the fact that super panels contain at least four times the area or coal volume, the likelihood of encountering serious geological anomalies is at least four times greater than with the conventional panels. Improved assessment of geology is therefore important for super panels.

The quality of coal reserves is declining, so future mining will be in deeper and more likely thinner seams. These seams appear to contain greater anomalies that threaten efficient operations. To counter the impact of reserve deterioration, the industry is moving towards greater use of geophysical tools and services. To identify and profile the best panels, geologists, engineers and managers need greater intelligence in the form of tomographic or 2-D and 3-D images of panels, using electromagnetic (EM) tools such as the Radio Imaging Method™ (RIM). Important demonstrations have recently been completed in the US and Australia, showing the increased capability of RIM-IV to transmit signals across wider panels, and provide signal phase shift data as well as standard attenuation rates. With phase shift data, greater resolution of images can be developed for 2-D and 3-D images.

**Mine planning**
The coal industry worldwide has been implementing a super panel strategy to improve efficiency and reduce costs. However, while such a strategy can improve economics, a greater degree of risk is introduced because the super panel can contain a greater degree of anomalies. If the face width and panel lengths both double, the area of mining increases four-fold, as does the probability of encountering geological obstacles. In every underground mining field (US, UK, Australia, etc.), interruption of longwall production due to geology has occurred all too often. Such disruptions result in serious financial impacts that can threaten mine viability.

To aid in-mine planning, RIM surveys have been conducted since the early 1980s, with more than 500 such surveys having been conducted to-date. However, as the panel face was widened, the existing RIM hardware was unable to transmit its EM wave across greater length; thus, an upgrade was needed. In addition to strengthening its ability to transmit greater distances, RIM was also improved so that the transmitter and receiver signals are now synchronised, allowing collection of signal phase shift data. Combining attenuation rate and phase shift data, processed by advanced algebraic reconstruction technique models, produce a greater resolution of images.

Most importantly, these improved images enable mine engineers to better plan super panel operations. Identification of anomalies factored into planning yields more accurate predictions of shift and daily output. Better production forecasts result in more accurate financial forecasts, which reduces risk. For example, companies have several ways to measure productivity, such as t/man-shift, t/shift, tpd, and/or distance mined per shift or day. Many factors go into understanding how good productivity might be, but many companies focus on distance advanced or mined as an acceptable proxy for productivity. Whether it is 15 or 30 m/day (50 - 100 ft), if geological obstacles impede the rate of advance, production falls. Due to the large fixed cost of investment, cost/t increases dramatically.
Another measure or proxy for lost productivity is to consider the cost to operations/min lost of production. Again, the specific measure per mine can vary considerably, but it is not uncommon to find management using estimates such as US$ 400 - 500/min of lost cost when longwalls are not producing. In a world where many mines operate continuously, the cost of interruption can be quite imposing. The financial impact is an important consideration with which chief executives must be concerned. The key point is that greater intelligence about geology enables better forecasting of rates of advance or production.

**Conducting a RIM survey**

The process for surveying a longwall panel includes the following five steps:

- **Plan the survey.**
- **Collect the field data** (which include equipment calibration to the specific seam, a reconnaissance scan, and tomographic scan as needed).
- **Analyse the data**, including construction of 2-D or 3-D images.
- **Confirm geological anomalies** as required (in some cases drilling into anomalies to confirm a target is prudent).
- **Integrate geologic intelligence into mine planning**. Given the high cost of super panel longwall systems, it is important to factor into mine plans whether or not there are serious mining obstacles.

It goes without saying that the better one plans a survey, the greater the opportunity for achieving meaningful results. Using specific maps of panels to plan a RIM survey enables planners to correctly estimate the time it will take to collect the relevant data. An accurate estimate of time enables or ensures budget control.

The underground teams that collect data consist of four or five people. Two are required to handle the antennae; one for the transmitter, the other for the receiver. Each can ensure efficient operations if assisted, and it is important to have someone supervising the effort.

Each seam is unique and, thus, the RIM team must calibrate the equipment to establish baseline attenuation rates. Once established, it is fairly efficient to send a signal directly across the panel every 15 m (50 ft) along the panel length. If no anomalies are present, the attenuation rates of the signals should be fairly consistent.

However, if an anomaly is encountered, there is a general loss of energy in the signal with an increase in the attenuation rate. Once encountered, a more in-depth evaluation can take place. Diagonal scans across the panel can be made to increase the intensity of signals, generating more data and yielding greater resolution. Not only are the attenuation rates collected, but anomalies cause reflections in the signals, and with the new RIM-IV’s ability to measure signal phase shift, a rich database can be achieved to provide meaningful and high-resolution images. Such images provide the mine planner with important intelligence about thinning seams, sandstone channels, etc., that could impede longwall advancement. Factoring this information into production forecasts provides management with the necessary tools to better estimate financial performance to meet profit objectives. Eliminating surprises greatly reduces risk and enables greater productivity.

Given the need for creating greater intelligence about coal geology, industry organisations in the US and Australia have funded trials or demonstrations of RIM-IV for longwall panels. The US trial was sponsored under the Department of Energy (DOE)/National Mining Association (NMA) Mining Industry of the Future (MOF) programme. Several companies participated and partnered in the effort. West Virginia University’s mining engineering department was a key participant to help verify results as an independent third party. The trial took place at a mine in western Pennsylvania.

The Australian trial was sponsored by the Australian Coal Association Research Program (ACARP). Backed by many of the leading mining houses, the ACARP structured an underground trial at known targets to confirm RIM-IV’s new capabilities.

**US trial**

The DOE/NMA MOF programme has been successfully bringing new technology to the forefront in the mining industry. Identified by the chief executive officers of the mining industry as one of the top five needed technologies, the MOF sponsored a demonstration of RIM-IV at a large longwall mine in western Pennsylvania. The Pittsburgh seam contains sandstone channels that can and have stopped longwall production. The preliminary analyses of the collected data in the case demonstration site show that the RIM-IV technology is capable of identifying and delineating the geological anomalies that affect longwall operations.

The demonstration survey area was...
within a 1082-ft-wide panel with approximately 600 ft of overburden. Normally, the main bench, the draw slate and some of the roof coal are mined. Based on experience in previous panels and observations in the nearby entries, it was expected that a sandstone (paleochannel) intrusion into the coal seam could cross the panel in the survey area.

A standard RIM tomography survey was conducted along a 1400 ft section of the longwall panel. The RIM-IV transmitter and receiver were deployed along the head gate and tail gate of the panel, respectively. Radiowave measurements of 80 kHz were recorded at 50 ft intervals throughout the survey grid. These measurements, including signal magnitude and phase, were used to create a tomographic image of the survey area (Figure 1). This image (a tomogram) is comprised of colour contours representing radiowave attenuation rates for the coal block in two dimensions. The zones of higher attenuation rate in the tomograms appear to result from a combination of the three main measurable factors: thickness of waveguide, distance to nearest sandstone, and the seam undulation factor.

The demonstration study results showed a good correlation between the reconstructed tomogram and the mapped geological anomalies that affect longwall mining operation. The distribution of the three main factors studied matched fairly well to the locations of the high attenuation rates.

A distinguishing characteristic of RIM is that the imaging energy predominantly travels in the coal bed. The EM wave is highly sensitive to geologic anomalies that intersect the coal measure, which makes RIM technology cost-effective in detection of anomalies. RIM tomography improves detection by forming silhouettes of faults, dykes and paleochannels. The geologic anomaly interference with mining cannot be determined from the RIM data. Often the margin of the paleochannel locates where the roof rock will fall when the coal is cut. Scouring into the coalbed occurs in the cut bank region of the channel. RIM tomography can be used to locate an anomaly that can be confirmed by horizontal directional drilling with measurements-while-drilling (MWD) radar. The MWD radar can determine seam height, relative dielectric constant, and roof/floor sedimentary rock type along the borehole.

**Australian trial**

Stolar Horizon, Inc., was invited to participate in a demonstration of RIM-IV instrumentation under the auspices of the ACARP. The primary objective of the ACARP field trial was to evaluate the operational procedure, performance capabilities, and imaging resolution of the prototype RIM-IV in-mine system. The trial survey was performed at BHP Billiton’s Crinum coal mine. It was intended to image a pillar known to contain a diatreme that could be seen in the rib of the entry. This diatreme had been exposed from development work (the only known such feature in the area).

Transmitter and receiver stations were set up in such a way as to transmit the radio signal through three coal pillars of 30.2 m in width, separated by two roadways of 4.8 m (total transmission distance 100.2 m). The survey was conducted at 70 kHz. The attenuation rates at this mine were also expected to be relatively high for Australian coal.

The target imaged was a diatreme that was known to exist in the centre of the middle pillar. Diatremes can be a major disruption to a longwall panel. They are a product of an igneous intrusion, which in the molten phase collapses under gravity, drawing the overlying clastic material back into the void. Hence, the Crinum diatreme is a mélange of broken up roof material, and there is no igneous material left in the coal seam area. Figure 2 shows the resulting tomographic image of the complete data set obtained during the Crinum survey. The tomogram shows the diatreme as an area of high signal attenuation rate (red colour contour) in its exact known position within the normal coal seam (blue colour contours).

The survey at Crinum established that RIM-IV possessed a significantly improved range over previous RIM systems (estimate 30% plus increase in range for a given frequency), and is capable of generating higher resolution and target definition than ever before.

**Conclusion**

The results of both trials confirmed that an advanced RIM system provides additional intelligence on the coal geology of a longwall panel. The 2-D or 3-D images are not an end in themselves. Once produced, graphical presentation of the seam needs to be integrated into mine planning and production forecasting. If serious anomalies are identified, management must then chart a course to deal with the challenge. Knowing that geological obstacles lie ahead can improve the chances of positive outcomes. Surprises, especially ones that are severe, are more difficult to deal with and usually leave little time for adjustment.

In addition to developing an upgraded RIM system, Stolar is moving forward with its virtual organisation, the Stolar Global Center for Geological Interpretation. As reported in a previously published *World Coal* article,¹ the virtual organisation enables collaboration on projects from each corner of the world. Proprietary modelling can provide sharp images.

**References**

Mr. Glenn G. Wattley (Chief Executive Officer of Stolar Horizon, Inc.) has 28 years of experience including his initial assignment in the industry as a maintenance engineer for Consolidation Coal Company (CONSOL). His engineering responsibilities at CONSOL included field demonstration of new safety technology such as the spray fan for better face ventilation and "hands-off" drilling equipment for safer roof bolting. He was product line manager for Mine Safety Appliance Company specializing in rock dust machines and chemical/mechanical fire-fighting systems for the mining industry. He was a corporate officer and headed the mining and electric utility practice at Arthur D. Little, Inc. He has also been a partner at Accenture in the Resources Group.

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