DETECTING ADVERSE COAL-SEAM GEOLOGY AHEAD OF MINING USING ADVANCED RADIOWAVE GEOPHYSICS AND RECENT LONGWALL APPLICATIONS

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Understanding and Mitigating Adverse Coal Seam Geology

- Since easy-to-access natural resources are at historic lows, future mining in metaliferous deposits, ore bodies and coal seams will be deeper and more geologically complex.

- Better exploration methods must now be adopted in the geological and geotechnical evaluation of reserves ahead of mining.

- In coal mining, geological anomalies are prevalent in nearly all of the world’s coal deposits. Coal production can come to an abrupt halt in bad geology where the seam becomes partially discontinuous or contains in-seam structure.

- The good news: Coal is a perfect radio-frequency waveguide and radiowave detection and mapping is a proven exploration technique. Tomographic radiowave mapping around geological anomalies areas can assist in mitigation, mine planning and production operations.
Instrumentation: Radio Imaging Method (RIM)

- The general function of RIM equipment is to send radio waves from a transmitter, across the area-of-interest to a receiver, reacting to geology between the two systems.
- RIM leverages natural waveguide effects of signal propagation in layered strata to produce wave-front absorption, refraction, and scattering from anomalous structure.
- Signal analyses allows for the detection of conductivity changes and material boundaries, while the geometric distribution of signal vectors, or ray paths, allows for the generation of reconstructed images through tomography.
- RIM applications go beyond coal mining, and have proven to be powerful tools in metaliferous mining, engineering, environmental research, & security-defence applications.
- This paper describes current RIM-6 instrumentation and processes, and presents several recent case studies confirming the benefit of radio-geophysics to exploration and mining processes to detect and scale geologic conditions well ahead of mining.
Background: Radio Imaging Method

- (1970’s) Medium-frequency mine-wide radio communications discovered that mining formations, particularly layered formations such as coal seams, act as a radio waveguide for the transmission of electromagnetic.
- Years of experimentation showed that signals traveling through bad geology, such as faults or conductive structures, exhibited reflections and amplitude loss in the radio signal that could be a powerful tool for evaluating anomalous geological structures.
- (1980’s and 1990’s) Within a decade, dedicated RIM instrumentation and survey practices had validated radio geophysics’ capabilities in mapping palaeo-channels, faults, fracture zones, intrusions, and seam thinning. Longwall mapping in particular had become standard practice in the USA and Australia.
- (2000’s) Existing RIM systems had not grown with the scale and complexity of mining. Longwall blocks had quadrupled in size and the need for better instrument performance was critical. Advanced research and development into newer and more capable RIM systems began in earnest around 2001.
- (2011) RIM-6 is the culmination of a decade of R&D and ongoing field testing, and has demonstrated improved transmission range and enhanced image resolution.
- RIM-6 is both man-portable and borehole-capable, and provides a tool/service to reduce risk and adds value to continuous and efficient mining production.
Rock-n-Coal Radio

Hard ROCK Exploration and COAL Seam Mapping
with RADIO-wave Imaging Technology

Deep 1500-m System

Shallow 150-m System

New Handheld System

Shallow Drillhole Systems

600-m System
Rock-n-Coal Radio Applications

Coal Seam Mapping
➢ Longwall: Geologic Structures Detection - Entry to Entry
➢ Longwall: Structures Detection - Borehole to Borehole
➢ Old Mine Works: Void Detection and Barrier Confirmation

Hard Rock Mining
➢ Heap Leach Pile Rafinate Mapping
➢ Exploration - Sterilization
➢ Ore Body Delineation
➢ Void Detection – Natural and Mine Voids

Environmental, Civil Engineering and Construction
➢ Void Detection – Natural and Mine Voids
➢ Bed Rock Mapping
➢ Contamination Plumes
➢ Ground Water Monitoring
➢ Earthen Dam Stability Monitoring
➢ Conduit Locating
Underground Mapping with In-Mine RIM

- 2-D Mapping From Underground Drifts
- Establishes Areas of Normal Geology
- Maps In-Seam Structure and Poor Geology
- Rapid Surveys and Data Processing
RIM Data Collection Methods

**Detect In-Seam Anomaly Position along Longwall**

**Direct Reconnaissance – 4000-m per day**

**Detect and Confirm General Scope and Severity**

**Sweep Reconnaissance – 3000-m per day**

**Map Detailed Position, Shape and Seam Condition**

**Full Grid Tomography – 1500-m per day**
Multi-Stage RIM Survey

Stage 1: Full-Panel Reconnaissance (1-D RECON)

Preliminary detection of significant anomalous structures using rapid direct-ray scanning

Stage 2: Focused Entry-to-Entry 2-D Tomography

Refined 2-D Image of In-Seam Anomaly
Exploratory Borehole (optional technique)

Stage 3: Supplemental Imaging – Entry-to-Borehole

Exploratory Borehole (optional technique)
Multi-Stage RIM Survey

Stage 4: Full-Grid Hole-to-Hole Tomography

Regions of greatest fracture-zone severity

Stage 5: Final Imaging – Entry-to-Borehole

Image used to plan grouting and bolting prior to mining

Final longwall map before mine-through
Recent Longwall Survey on 400m-Wide Block

Face-Mapping Notes:
• The first dyke encountered was 10cm in thickness and died quickly.
• Second dyke averaged about 30cm thickness as mapped.
• The dyke thinned out and disappeared where the seam roll was predicted.
• A secondary finger appeared about mid-face.
• Red area consistent with dyke increasing in thickness from ~30cm to 50cm.
Recent RIM-6 Case Study
Predictive Dyke Mapping

Predicted Dyke Characteristics Correlate to Exploratory Drillhole and “Grunching” Observations
Recent RIM Case Studies- 3 Coal Seam Longwalls

Longwall “C”

Red – Seam Intrusions

Blue – Clean Coal

Longwall Tomogram at 552-kHz

Frequency vs. Resolution

Longwall “A”

300-kHz

700-kHz

Longwall “B”

300-kHz

700-kHz

Dyke Projections
RIM Tomography Images
Composite: 3 longwall panels mapped over 3 years

- Washout Zone
- Wide Boggy Zone
- Long Vertical Intrusions
- Dykes
RIM Images
Composite: 3 longwall panels mapped over 3 years

Multiple intrusion planes are tracked into a third longwall panel in the area. This region was re-imaged with horizontal borehole-to-borehole RIM-6. Resulting high-resolution image illustrates the various intrusion planes, geologic complexity, and local density changes important to mining difficulty.
Borehole RIM Methods in Dam Monitoring
(Earthen, Tailings, Impoundment)

- Characterize Earthen Dam Geology and Structure
- Monitor for Seepage or Stability Problems Before Dam Failure
- Provides Emergency Reconnaissance for Remediation Ahead of Failure
- Allows Continuous and Time-Lapsed Evaluation of Moisture Changes
- RIM Imaging Technique Requires Boreholes with 50mm PVC Liner
- Borehole Spacing is Geology-Dependent, Averages 50 meters

Boreholes Are Used to Perform Hole-to-Hole Tomographic Radiowave Imaging

Resulting Images can LOCATE and SCALE all Regions of Moisture within the Dam
RIM Methods in Leach Pile or Dam Monitoring
(Example of Borehole-to-Slope Mapping)
Standard RIM Methods in Old Mine Workings
(Water or Air-Filled Voids)

**Technique #1: RECON**
Proving Solid-Pillar and Detecting the Void-Spaces
Fence-Line Confirmation of Barrier

**Practical Technique:**
Real-Time Detection of Void-Spaces Near Active Mining
Image Ahead of Current Workings

**Technique #2: TOMO**
Provides Location and Shape of Void-Space
Tomographic Imaging of Voids

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**Stage 1:** In-Mine to V-Borehole

**Stage 2:** V-Borehole to V-Borehole

Increasing Complexity
Detecting Old Mine Workings in Coal Seams
(Water or Air-Filled Voids)

Transmitter Hoist and Fiber Optic Cable
Receiver Hoist and Fiber Optic Cable

RIM Survey Trailer, Truck or ATV

Depth to Coal Seam is Irrelevant

Transmitter Antenna in the Coal Seam

Transmitted Signal
Air or Water-Filled Void
Signal Absorbed and Reflected within Void-Space

Received Signal
Receiver Antenna in the Coal Seam
Fence-Line Case Study for Barrier Pillar Confirmation

Two unexpected voids encountered

Rapid Borehole RIM Deployment

Old and Abandoned Mine (water and air-filled voids)

Planned Location for Future Mining

Fence Line Survey Plan:
- 20 Boreholes
- 20 Ray Paths
- 19 Fence Line Shots
- 1 Mine Void Calibration Shot
Case Study of Old Mines Delineation (Void-Space)
590-kHz Tomogram of a 2-meter Void Space (Tunnel)

590-kHz Average Attenuation Rates:
Background Geology = 0.8 dB/ft
Void Space Related = 2.0 dB/ft
Old-Tunnel Imaging with Drillhole Confirmation

High-Frequency Tomogram between Closely-Spaced Boreholes

This “Void-Space” Anomaly was Imaged in 2-D and Selected for Confirmation Drilling

This “Void-Space” Anomaly was Drilled from Surface, Intersected at the Predicted Depth, and Video Confirmation was provided with Borehole Camera
Massive Iron-Nickel Ore-Body Tomography
RIM Borehole Mapping During Drilling Operations

Crosswell Tomogram of Disseminated Copper Deposits
Mineralization Conductivity Tomography

Pod of Mineralization between Boreholes in Resistive Host Rock (200-meter separation)

Crosswell Tomogram of Conductivity Changes

500m borehole depth, collar at 500m depth below surface 60C groundwater temp
Porphyry Copper Ore-Body Tomography
Borehole and Handheld RIM

Image Plane between Borehole and Open Entry

Image Plane between Boreholes in Section Fan

Mobile U/G Instrumentation Platform Allows 2 to 6 Image Planes Daily
Deep Borehole RIM-6 Signal Range

Recent Testing at Hard Rock Mine Provided 90-kHz Signal Range Estimates versus Borehole Depth (Hole-to-Hole Separation)

Signal Range Increased with Depth
Due to Layered Resistivity Increases in the Formations with Depth.

Applications with Shorter Separations would Benefit from Allowable Frequency Increases (improving Sensitivity and Resolution).
Conclusion: Radio Imaging Method is more than Core, and more than conventional E-Logging

- Advanced Radio Imaging Method (RIM) equipment: Generates images of the geology between adjacent drillholes; better detecting areas of high geological risk or delineating areas clean coal.
- RIM instruments send radio waves through the rock/coal, reacting to geologic layering, composition, structure and void-space.
- Applicable to most geological or geotechnical imaging applications include coal mining, hardrock and metaliferous mining, environmental remediation, and civil engineering.
- Can improve resource evaluation and mine planning by:
  - imaging between exploration boreholes, better delineating structure
  - navigating around areas of geologic anomaly or mining hazard
- Recently RIM surveys have added value to exploration drilling by imaging ahead of mining and with fewer drillholes.
- RIM should be used to augment existing drilling operations in conjunction with core and e-logging. This provides better information, fills in the gaps between drillholes.
Thank you for your attention, and your questions!

Please stop by and visit with us at the German Pavilion in Building 8, Row C (Booth B8M4)

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