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HEALTH & SAFETY TRUST OF NEW SOUTH WALES

COAL SERVICES Pty. Ltd.

Demonstration and Proving of the "Acoustic Energy Meter" for Detecting Incompetent Mine Roof as Part of Routine Roof Sounding

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Report No: 00-001-AEM-01

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REPORT ON :

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1.0 INTRODUCTION

The detachment of relatively small pieces of rock from the roof of underground coal mine roadways continues to be a primary safety hazard related to ground instability in coal mining. A significant number of minor to fatal accidents have occurred in Australian underground mines due to this hazard. **Table 1.1,** quoted from **McKensey 1994** and updated by Strata Engineering shows that of sixteen incidents, only one had a height of fall >0.45m.

Even regardless of the level of the injury from rock falls, the associated business costs are substantial and include the cost of low workforce moral, lost production time, rehabilitation and implementing remedial measures. Mining law and workplace safety legislation demonstrate clearly that safety breaches are unacceptable and it is everyone's Duty of Care to take all reasonable steps to prevent them.

In the context of risk management, the issue or hazard associated with small detached pieces of rock cannot be effectively predicted using current strata analysis tools (e.g. rock testing, numerical and empirical modelling etc.). The main reason for this is the location of the instability cannot generally be predicted in advance of mining or occurrence within the rock mass. It is also considered to be a significant operational problem, as the instability cannot always be seen when the roof surface is exposed, as it is often the result of hidden rock defects.

One risk mitigation strategy is to install full mesh over all exposed roof (and occasionally rib) surfaces in order to provide a hard barrier between the hazard and mine workers. For conditions associated with high horizontal stress and laminated to thinly bedded roof strata, this is generally done as the bolts are installed at the face. However where the roof consists of a massive sandstone or conglomerate, which has been supported with relatively low bolting densities (i.e in the order of 4 bolts per 1.5 m of roadway without mesh,) the risk of a detached roof block emanating from approximately the first 0.5m of roof striking mine personnel and machinery still exists.

Traditionally the first 0.5 m of roof has been tested by 'sounding' the roof with a steel rod or bar. This method has often proven effective, but the results can be subjective. The use of a hand held instrument to provide a quantitative value or 'roof stability index' has subsequently been developed. Research done in the UK some 15 years ago when segmental concrete linings were being introduced into deep underground coal mines resulted in the development of the "Acoustic Energy Meter" (AEM). The AEM was developed with the intent of being able to remotely identify voids behind the concrete linings, where backfilling was incomplete.

The physical phenomenon that is utilised by the AEM is the vibration decay rate (dampening) in a material. This characteristic was further investigated by the CSIRO in the early 1990's and was also identified as a possible technique to remotely identify areas of potentially unstable or incompetent roof skin.

This project demonstrates the uses of the AEM by providing details of;

- recent successful work in South African coal mines,
- tunnelling applications in both the UK and Finland whereby the AEM has been used for identifying areas of potentially unstable roof strata and tunnel linings as well as void detection behind tunnel linings.
- the fundamental basis of the AEM,
- site evaluations within the Australian coal mining industry,
- site specific usage and calibration guidelines.

Based on the above information a key outcome from this Coal Services project has been the development of standard operating procedures for Australian underground coal mines, including intrinsically safe accreditation.

Table 1.1: Fatal Accidents (1980-98) and Serious Bodily Injuries (1982-94) due to Falls of Ground under Massive Roof

Taken from McKensey 94 updated by Strata Engineering for cases O and P

Case	Structural Anomaly	Fall at an Intersection	Proximity to a Goaf	Length of Fall (m)	Width of Fall (m)	Area Extent of Fall (m)	Height of Fall (m)	Est. Volume of Fall (m^3)	Est. Mass of Fall (t)	Nature of Fall
A	Fault 2m distant	n/a	n/a	2.7	1.3	3.51	0.3	1.05	2.53	Stone
B	n/a	n/a	20m distant	2.5	2.5	6.25	0.22	1.38	3.30	Stone
C	n/a	3 way	8m distant	2	2	4	0.2	0.80	1.92	Stone
D	n/a	n/a	3m distant	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Sticky Tops
E	Floater	n/a	35m distant	4	3	12	0.2	2.40	5.76	Stone
F	n/a	4 way	n/a	4	4	16	0.25	4.00	9.60	Sticky Tops
G	Washout	n/a	n/a	1	1.5	1.5	0.15	0.23	0.54	Stone
H	n/a	3 way	15m distant	1.4	0.9	1.26	0.13	0.16	0.33	Stone/Coal
I	Floater	n/a	n/a	3.5	1.5	5.25	0.08	0.42	1.01	Stone
J	Sandstone Lense	n/a	n/a	1.5	1.5	2.25	0.2	0.45	1.08	Stone
K	n/a	4 way	n/a	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Sticky Tops
L	n/a	n/a	3m distant	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Coal
M	n/a	3 way	7m distant	1.5	1.5	2.25	0.25	0.56	0.84	Coal
N	n/a	n/a	3m distant	2.2	1.7	3.74	0.4	1.50	2.24	Coal
O	Fault	n/a	n/a	5.5	2	11	0.45	4.95	7.43	Stone
P	*Weak Lamination*	*4 way*	*3m distant*	*20*	*18*	*360*	*2.5*	*900.00*	*1350.00*	*Stone*
Averages	**n/a**	**n/a**	**10.78 / 7.75***	**2.65**	**1.95**	**5.75**	**0.24**	**1.49**	**3.05**	

2.0 LITERATURE SURVEY/DESCRIPTION OF PREVIOUS AEM RESEARCH

The technique of sounding the roof has been used by miners for many years to establish areas of detached and partially detached roof and rib skin. Striking the roof or rib with a steel bar or rod produces a hollow or 'drummy' sound in an area of roof or rib that is partially detached from the rock mass. Scaling or barring the incompetent section down or additional bolting and meshing is usually carried out to reduce the risk of the area of rock detaching completely from the local roof/rib. Over meshing of an area can also be undertaken when confidence in assessing the conditions is low, but particular hazards are also often associated with re-support operations

A problem with roof sounding and the 'qualitative' assessment of the response of the struck object is that operator judgement is required to interpret the outcome. Whilst extreme conditions may be readily identified (eg. almost completely detached rock or fully competent material), marginal conditions (only partially detached) have proven to be more difficult to reliably detect in this manner. Unfortunately, such marginal conditions have also resulted in falls of ground and associated accidents, despite the area being sounded and assessed to be competent. Operator judgement in roof sounding may be compounded by the operators physical condition in regard to hearing, such that an operator affected by industrial deafness or any other hearing condition may interpret the noise response incorrectly.

In order to address the above issues, the development of a non-destructive testing method to provide a safe qualitative assessment of the roof conditions has been attempted through the calibration of the AEM to Australian conditions. Details of the technology and its uses to-date are presented in following sections.

2.1 Vibration characteristic properties of a material

When a surface is struck or sounded, the vibrations created within the material can be characterised in terms of :

- amplitude,
- frequency and
- rate of decay of amplitude and frequency (dampening)

Of these three parameters, various research studies have established that amplitude and frequency of vibration are influenced by several variables, such as the initial impact energy and the velocity of sound in the material (ie. the celerity), which is a function of its elastic modulus and density, refer to **Piper, Le Bron *et. al.* (2002)**.

The amplitude and frequency are therefore difficult/problematical parameters to use as a reproducible and measured output due to:-

- the nature of rock being variable in density and elastic modulus and,
- the small scale being utilised by the AEM.

Figure 2.1 below illustrates the typical amplitude, frequency and decay rate for a vibration, based on relationships derived by **Meriam & Kraige (1993)**.

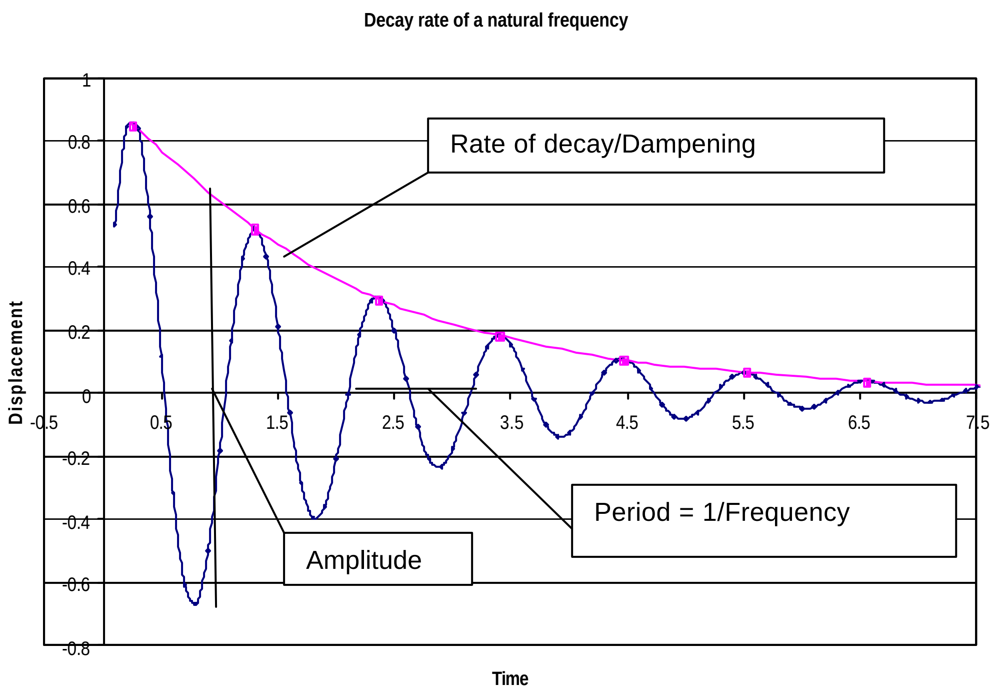

Figure 2.1 Decreasing amplitude, frequency and the rate of decay for a vibration. Based on relationships from Meriam & Kraige (1993).

The rate of decay or dampening attribute is a measure of the rate at which the impact energy is absorbed or dissipated by the material. It depends largely on the geometry of the medium and the internal friction of the material. In general, the greater the amount of material involved, the faster the energy is absorbed or dissipated. However, when a material is vibrated, its natural rate of decay/dampening characteristics will remain the same, despite the initial energy input or the initial difference in amplitude or frequency. Therefore a measure of the dampening is more likely to be reproducible and a relatively consistent characteristic of the material, regardless of initial energy impact to create the vibration.

Piper, Le Bron *et. al*. (2002) show that a change in density effects the velocity of the vibration in a medium and thus the rate of decay of the vibration. Given that the presence of voids will change the density of the medium being vibrated, the rate of decay of the vibration will also change. Hence by measuring the rate of decay at multiple locations, the difference in readings may be interpreted as effective density variations in the rock mass.

In the context of a coal mine roof, a competent section of roof with no partings will have a faster rate of decay (less vibrations) than a section of roof with partings or voids (slower rate of decay, more vibrations). It is this difference in the number of vibrations and the decay rate which the AEM can potentially detect and therefore may be used to indicate the presence of voids or partings between multiple sample locations.

2.2 Available Acoustic Energy Meter – RDL4

The current model AEM is the RDL4, built by Rock Mechanics Technologies Ltd (RMT) in England. The RDL4 utilises a transducer which can be placed in contact with the surface of the medium (rock), a prescribed method of striking the surface close to the transducer (hammer, steel rod etc.) and a detector (geophone). It also has automatic arming and reset functions and features a "traffic light" LED alarm display, as well as a digital readout. A picture of the RDL4 is given in **Figure 2.2**.

Figure 2.2. RDL4 Acoustic Energy Meter

The operation of the AEM requires holding the geophone to the rock surface, either directly or through the use of an extension pole. The surface is then struck with a hammer or equivalent within 0.2m to 0.5m of the geophone and a reading is illuminated on the digital display. A minimum of three readings is usually taken for each sample point then, averaged.

Figure 2.3 shows a schematic diagram of the AEM measurement process. The traces in the figure are expanded below.

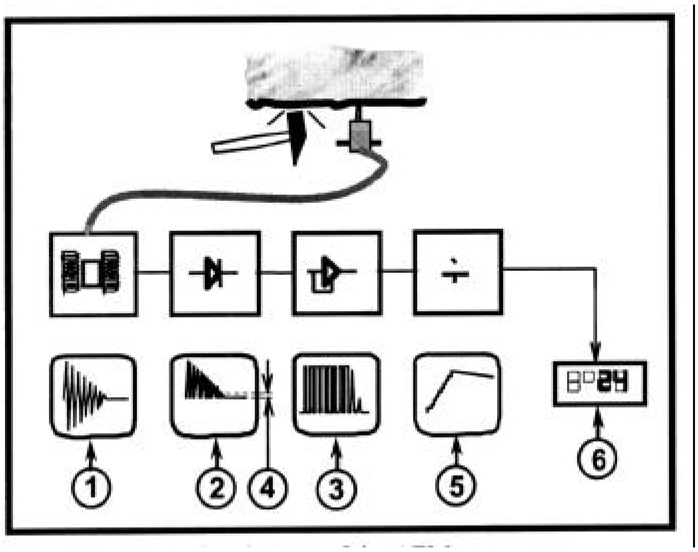

Figure 2.3. Schematic Diagram of the AEM Concept (Taken from Altounyan and Minney 2000)

The analysis steps for the AEM (taken from **Altounyan and Minney 2000**) illustrated in **Figure 2.3** are described below:

1 Geophone output (roof vibration is measured)

2 Rectified geophone output (all negative amplitudes are corrected to positive)

3 Signal is amplified to saturation

4 All pulses above a defined threshold value are converted to square pulses of equal amplitude. The number of pulses is proportional to the decay time of oscillation.

5 Pulse integration (saturated amplitudes above threshold are counted) to give output

6 Visual indicator of output

2.3 Previous Research Field Results

The AEM has undergone several field trials for various applications in recent times, including:

- Establishing the operational performance parameters of the AEM (**Altounyan and Minney 2000**).
- South African coal mines: the detection of incompetent roof (SIMRAC funded research **Altounyan and Minney 2000**).
- UK tunnels to assess the competency and extent of back-filling/voids associated with a number of lining types (eg. steel, brick, shotcrete and concrete segments), **Cartwright *et. al*. (2001).**

Each of the above research projects are described in more detail below.

2.4 Operational Performance Parameters

As stated previously, the AEM provides a numeric value that is related to the rate of decay of vibration in the test material. The values obtained have relative rather than absolute significance, such that on-going calibration and site assessment is a vital part of its use.

Underground proving and calibration trials (refer to **Altounyan and Minney 2000**; **Piper, Le Bon *et. al*. 2002**) indicated that AEM readings are consistent (within an acceptable range) and repeatable for a wide range of surfaces. Intact and loose surfaces result in different outputs with few intermediate readings, indicating discrimination of near surface condition.

The effect on dampening from the operators hand holding the instrument in place has been shown to be negligible (refer to **Altounyan and Minney 2000**; **Piper, Le Bon et. al. 2002**).

Field investigations have been undertaken to check the sensitivity of the AEM to the energy in the hammer blow by varying both the strength of the blow and the position of the blow relative to the geophone (refer to **Altounyan and Minney 2000**).

Figure 2.4 shows a graphical output taken from **Altounyan and Minney (2000)**. The investigation involved utilising three different hammers of various sizes, one being spring-loaded (ie. a Schmidt Hammer).

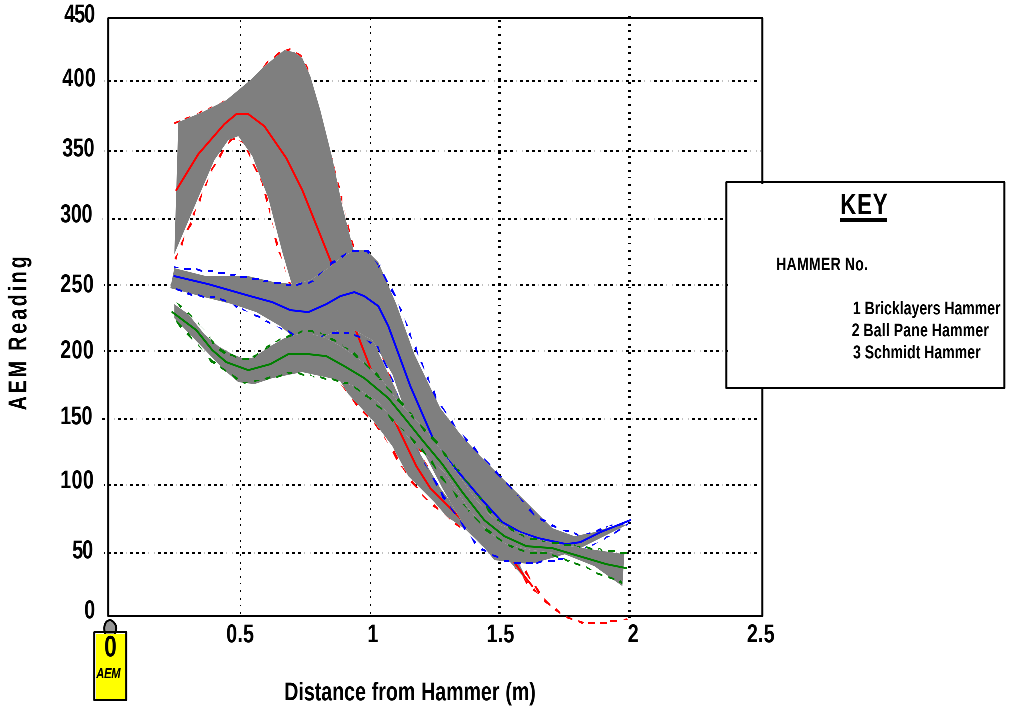

Figure 2.4. Plots of AEM Reading with Respect to Hammer Type and Hammer Impact Point

For a solid sandstone surface, all hammers gave low readings with the largest being obtained using a 2 kg bricklayers hammer.

The 2 kg bricklayers hammer was used to investigate the effect of blow distance from the geophone and no effect was found for distances between 0.25 m and 1 m.

It was noted that the energy of the hammer blow had minimal impact upon the measured AEM output, as evidenced by the close correlation of the curves for Hammers 1 and 2 in **Figure 2.4**.

In contrast to the solid surface, the Schmidt Hammer results were inconsistent in character, presumably due to the dynamics of the spring-loaded mechanism affecting the surface in a manner that is not achieved with the use of conventional hammers.

A hammer weight of around 1 kg was preferred to obtain consistent results.

Based on all of the initial proving trials, it was decided that a normal operating mode would consist of Hammer Number 1 (ie. a short-handled 1kg bricklayers hammer) being used to impact the surface at a nominal standard distance of 0.20 m from the geophone.

2.4.1 Detection of Incompetent Roof in South African Coal Mines

Under a SIMRAC funded project, refer to **Altounyan and Minney (2000)**, the AEM was evaluated in eleven (11) underground coal mines. The objective was to assess its reliability in detecting potentially incompetent roof that may have otherwise remained undetected.

Altounyan and Minney (2000) describe the project outcomes in detail as summarised below:

- The AEM output magnitude in stable, competent areas varied according to roof type (i.e. as low as 20 for sandstone and high as 100 for coal). This was as expected, but highlights the need for geological input and site calibration with the use of the AEM.
- Abnormal readings were recorded (up to 1000), but typically twice that of the normal readings for the roof type in question. Intermediate readings between the two conditions were relatively infrequent. No explanation for the abnormal readings was provided.
- For high range abnormal readings, poor roof conditions were usually visible and could be heard when sounding. However, for lower range abnormal readings, poor roof conditions were not generally visibly or audibly apparent. This is the "grey-area" in which it was intended that the AEM would prove to be effective.
- The AEM was highly successful in identifying potential slip planes (i.e. angled joints), the presence of detached laminated slabs within the immediate roof as well as depositional features (known locally as "sandstone drums") that can fall with little or no clear warning.

Variations in AEM readings in different roadways showed good correlation with the known state of *in-situ* stress.

Figure 2.5 shows one of the test areas, demonstrating the difference in AEM readings for different structures and conditions.

Overall, the research study demonstrated that the AEM could identify potentially incompetent immediate roof conditions in underground coal mining operations and provide guidance on a number of other related issues.

As a result, the AEM has been commissioned into full operational use and is already credited with identifying hazards that may have gone undetected or not appropriately controlled in the South African mines that use it.

It is currently being evaluated in the South African metalliferous mining industry as the next step in its use.

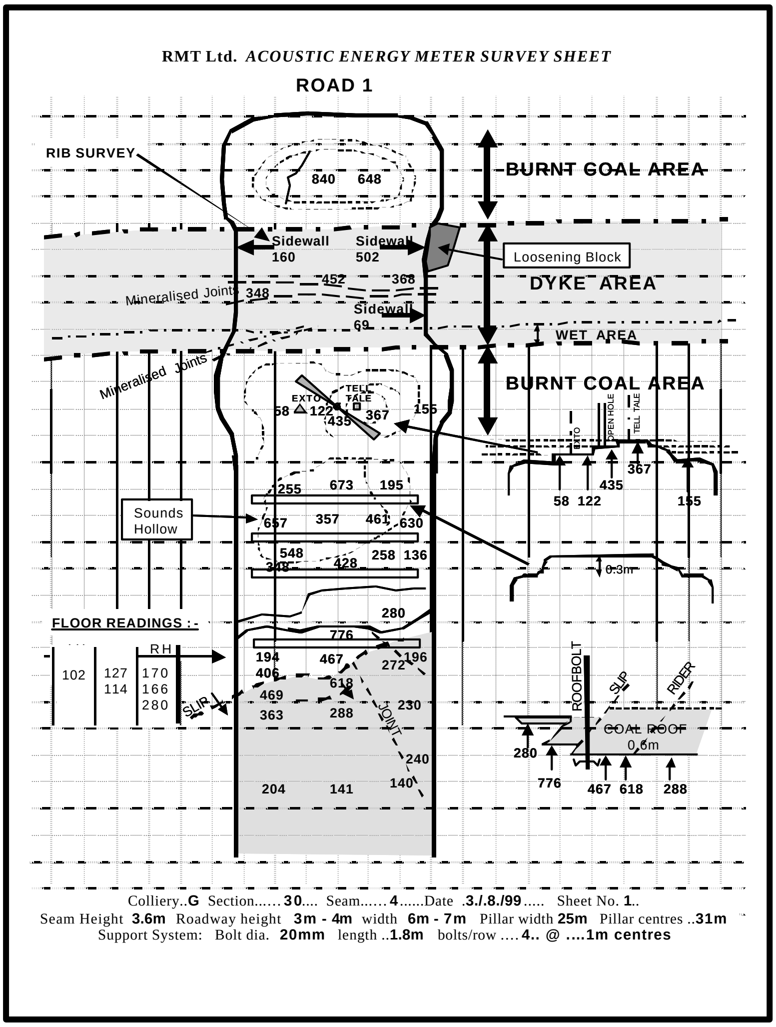

Figure 2.5. Sample AEM Survey Output taken from Altounyan and Minney (2000)

2.4.2 Assessment of Tunnel Linings and Associated Void Backfilling in the UK

The field evaluation conducted by **Cartwright *et. al.* (2001)** involved tunnels which were lined with steel, masonry, reinforced concrete and shotcrete. A summary of the findings for each lining follows.

2.4.2.1 Steel Linings

Figure 2.6 shows the outcomes of an AEM survey in a steel-lined circular water tunnel. The purpose of the survey was to detect voids in the grout behind the tunnel lining.

AEM outputs were found to vary from 3500 for the 45 mm thick steel tube in air to below 50 for a well grouted steel lining.

The results are shown as a contour plot in **Figure 2.6** and areas of potential voids behind the linings are clearly evident. It is noted that in other areas of the same tunnel, AEM surveys were conducted and revealed no reading greater than 50.

It was concluded that the AEM is effective in assessing grout coverage behind steel linings.

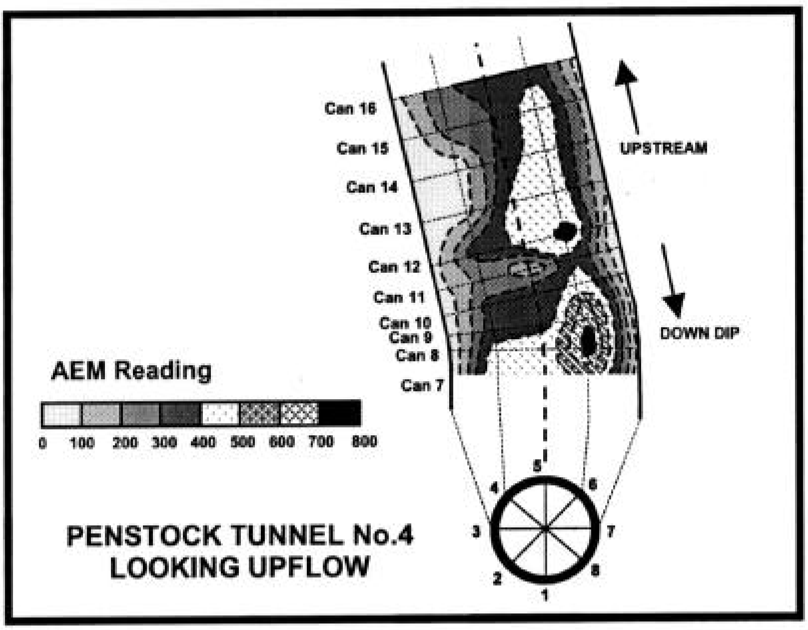

Figure 2.6. Relief Plot in Plan View Showing Contours of AEM Readings

2.4.2.2 Brick Linings

As described by **Cartwright *et. al.* (2001)** the AEM has been used to inspect the brick linings of Victorian era railway tunnels in the UK. Many voids are present behind these linings, either existing since original construction or having developed following movement of the lining or water damage and deterioration of the background rock.

Surveys were carried out at selected locations by obtaining mean AEM readings from 13 positions, equally spaced around the tunnel section at intervals of 5 m along the tunnel length.

Figure 2.7 is an example output from a 250 mm thick brick lined tunnel in South Wales in which both known and suspected voids behind the lining were confirmed.

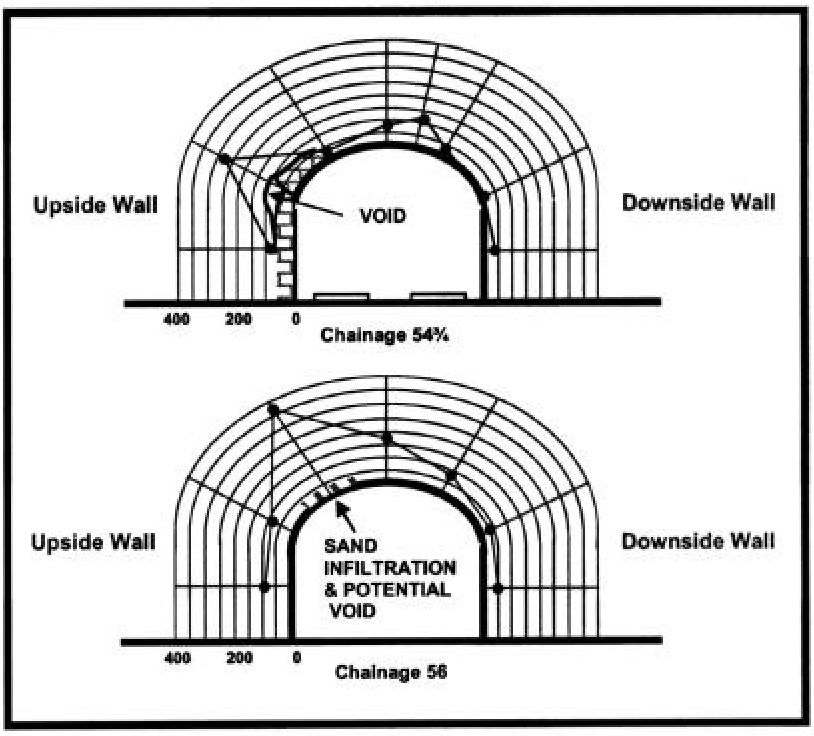

Figure 2.7. AEM Survey Results – Brick Lined Tunnel

It was concluded that the AEM accurately detected the presence of voids behind the lining and/or bulging or loose brickwork.

2.4.2.3 Concrete Segmental Linings

The original AEM prototype was used extensively by British Coal between 1987 and 1992 to inspect 240 mm thick concrete segmental linings in 5 m diameter tunnels.

The AEM was successful in detecting voids behind such linings after grouting and additional grouting of these areas prevented further stability problems occurring. **Figure 2.8** shows an example of a segmental lining survey with a void clearly indicated at the left-hand shoulder position. The AEM values ranged between 30 and 50 for no void locations and 200 at void locations.

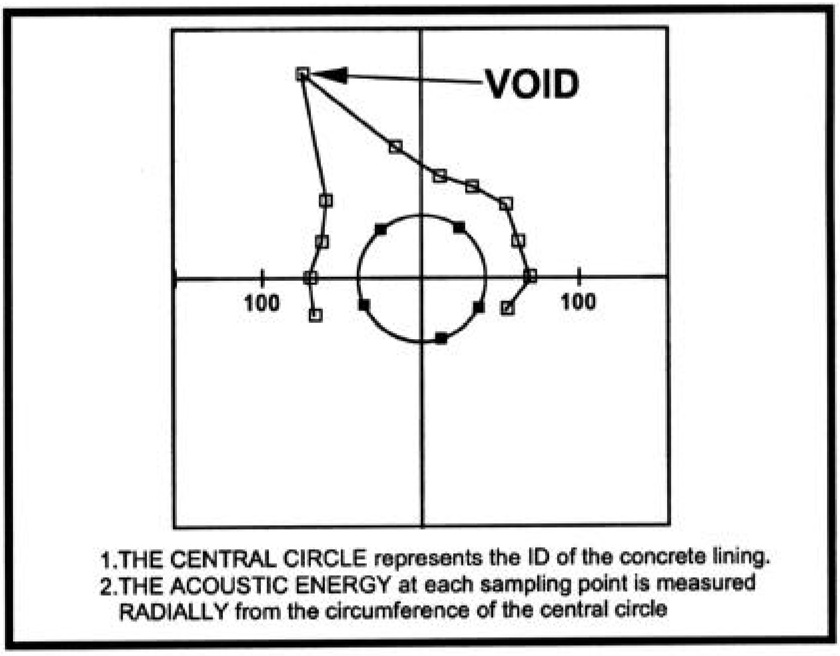

Figure 2.8. AEM Survey Result – Concrete Segmental Lining

2.4.2.4 Application to Shotcrete Linings

In Finland, the use of the AEM to examine shotcrete tunnel linings has been investigated by Geotek Oy during enlargement excavations of the Viikinmaki underground municipal wastewater plant in the Helsinki area.

The integrity of a 75 mm thick shotcrete lining was evaluated using the AEM after the lining had been subjected to blasting vibrations and deformations. Initial test measurements were followed up by further tests after four months to reveal any changes in shotcrete lining quality caused by subsequent excavation work.

Test configuration and average results of the initial and repeated tests are shown in **Figure 2.9**.

The results indicated that detached shotcrete areas, which were surrounded by visible fractures and later confirmed by drilling, could be revealed by the AEM which gave a high output value (average around 150). In contrast, intact shotcrete gave a very low measurement or no triggering of the instrument at all (i.e <50).

Two hidden drain pipes in the shotcrete could also be located by the AEM (see **Figure 2.9**).

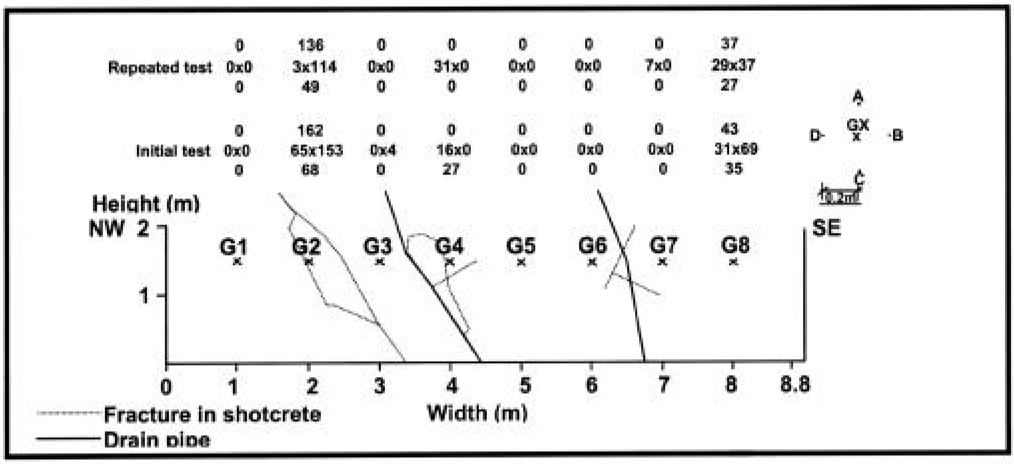

Figure 2.9. Test Configuration and Results from the AEM Test Profile in a Pillar with a Shotcrete Lining

The repeated tests confirmed the shotcrete lining was unaffected by the blasting vibrations. It was also found the detached side of any given fracture could be identified by comparing the readings taken on either side of it (as was also the case for slips within the roof of coal mine roadways).

3.0 PROJECT ASSESSMENT METHODOLOGY

As stated earlier one of the main objectives for this project in Australian underground mining conditions was to establish working parameters to provide base guidelines for the operation of the AEM, not to repeat nor prove how the physical process of the AEM works. The assessment method was therefore required to link the changes in the physical condition (open partings, lithology change etc.) of the rock to a change in response from the AEM.

AEM data would need to be gathered from a number of different roof conditions and the results compared to identify patterns or characteristics of the AEM. The different conditions were as follows:

- Lithological: sandstone, siltstone, conglomerate, coal, claystone.
- Working conditions; inside the hazardous zone at the working face and outside the hazardous zone.
- Visibly poor roof conditions and visibly good roof conditions.

The data was collected by geologically and geotechnically mapping the area and where necessary, borescope holes were drilled in to the roof and inspected to identify partings (width and height into roof) within the roof. The borescoping was able to link an open fracture in the roof with the AEM reading and identify the depth into the roof at which the partings occurred.

The AEM data sample points were generally laid out in a grid style for each area, with a minimum of three AEM readings recorded at each sample point. The AEM readings were then averaged for each sample point. Where the AEM did not record a value, due to the decay rate being so fast the AEM was unable to detect enough vibration to give a value, a 'No Trigger' (NT) was recorded. An NT was treated as a zero when calculating an average AEM reading for that sample point.

On occasion the AEM was incorporated into a borescope survey. In these cases only one AEM sample point was recorded, within 0.4 m of the borescope hole. Again a minimum of three AEM readings were recorded at each sample point. This was able to provide large amounts of borescope data relating directly to an AEM reading.

Where visible lithology contacts were, present such as is illustrated in **Figure 3.1**, a traverse of the lithology contact was conducted with AEM readings sampled on all sides of the contact. This information was used to classify the AEM response to differing lithologies and the effect of rapid changes in lithology.

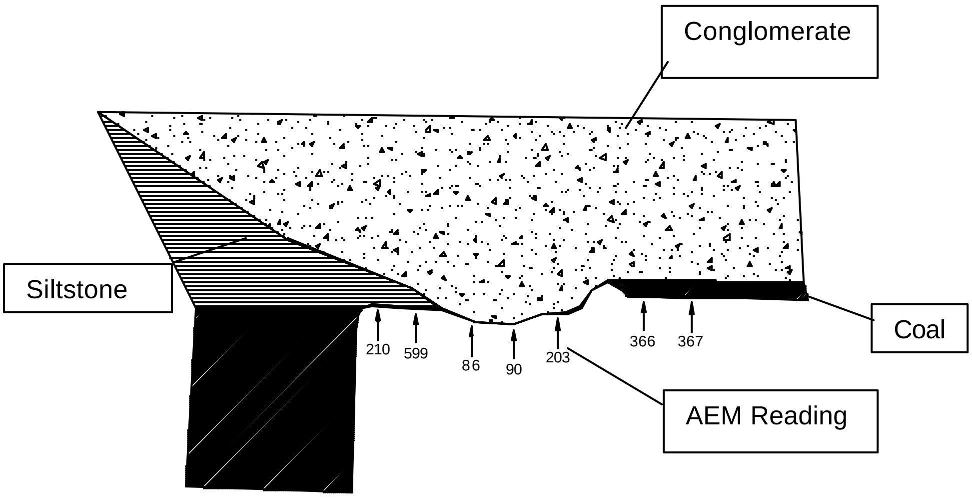

Figure 3.1 Lithological contacts with an AEM traverse.

4.0 SUMMARY OF FIELD SITES

A total of nine (9) underground coal mines in New South Wales, Queensland and Tasmania provided sampling sites for the study.

Table 4.1 summarises the field results gathered. The results include mining technique, roof lithology, geological structure in the test area, borescope analysis (where applicable) and the AEM result for the sample point. Details for each site are presented in the appendices.

5.0 SUMMARY OF ASSESSMENT OUTCOMES

Each of the general lithologies from the test areas of the AEM study have been classified into five main lithologies as illustrated in **Figure 5.1** ***Average AEM readings for roof lithology***. **Figure 5.1** also classifies the percentages of readings taken within each range. The trend of the graph indicates the relative reverberation characteristics of :-

- **Conglomerate:** a consistently faster rate of vibration decay than the other geological units. 96% of the AEM values are =100. A change in rock mass competency and therefore reverberation characteristic is likely to be identified by higher AEM values. Total number of sample points in conglomerate was 121. The minimum and maximum readings were 0 and 286 respectively.
- **Coal and siltstone:** relatively slower and more variable rates of vibration decay. Changes in vibration characteristic is less likely to be distinguishable by higher AEM values. Total number of sample points in coal was 108 and laminated siltstone 8. The minimum and maximum readings for coal were 0 and 1048 respectively; siltstone were 58 and 321 respectively.
- **Sandstone:** has a relatively fast rate of vibration decay. Changes in rates of vibration decay may be identified by higher AEM values, depending on the sandstone unit characteristics. Total number of sample points in sandstone was 215. The minimum and maximum readings were 0 and 676 respectively.
- **Claystone:** shows a relatively moderate rate of vibration decay. Total number of sample points in claystone was 5. The minimum and maximum readings were 0 and 278 respectively. Given the small sample size the data can be considered inconclusive.
- **Laminated and thinly bedded material:** i.e material with bedding = 0.1m: a relatively slow and variable rate of vibration decay. Changes in rock mass competency and therefore rates of vibration decay are less likely to be distinguishable by higher AEM values. Total number of sample points in laminated material was 31. The minimum and maximum readings were 0 and 286 respectively.

Figure 5.2 is an example showing a localised high AEM reading associated with a discontinuity in a conglomerate roof **Figure 5.2**. In the test area, a feather edge/fracture is highlighted by a high (204) AEM reading, whereas the remaining

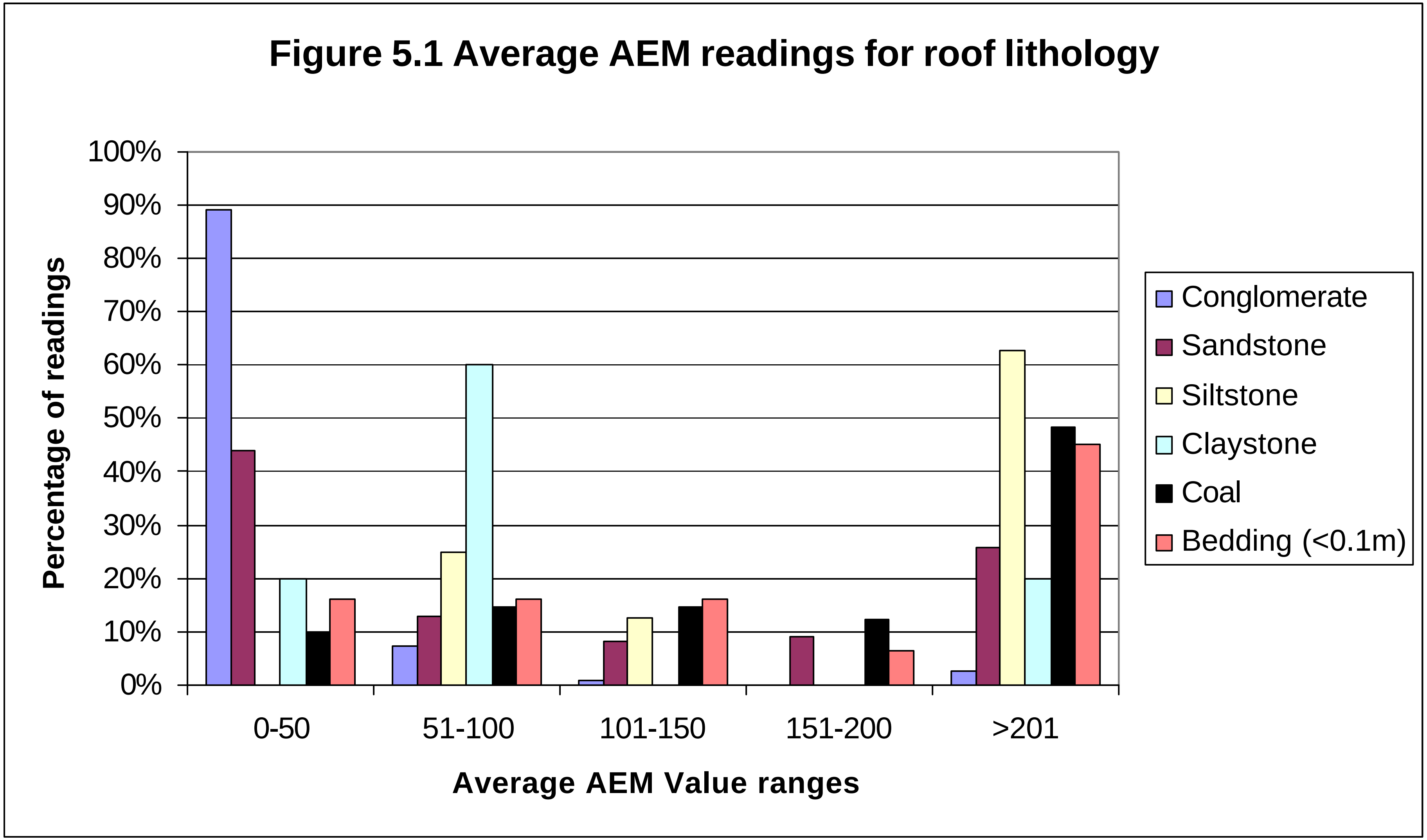
Figure 5.1 Average AEM readings for roof lithology
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percentage of readings
0-50
51-100
101-150
151-200
>201
Average AEM Value ranges
Conglomerate
Sandstone
Siltstone
Claystone
Coal
Bedding (<0.1m)

readings in the conglomerate test area are below 35. No other geological structure was visible nor indicated by the AEM results for the area.

The relatively high and inconsistent AEM readings associated with a coal roof are illustrated by **Figure 5.3**. Readings in this area vary from 51 to 1048. No visible discontinuities have been mapped.

Changes in AEM readings in sandstone are illustrated in **Figure 5.4**. Readings vary from 0 to 410 AEM units. The high AEM readings (>100) are consistently associated with geological structure. The sandstone roof lithology in this test varied between fine grained laminated sandstone, medium grained sandstone with coal inclusions and massive sandstone.

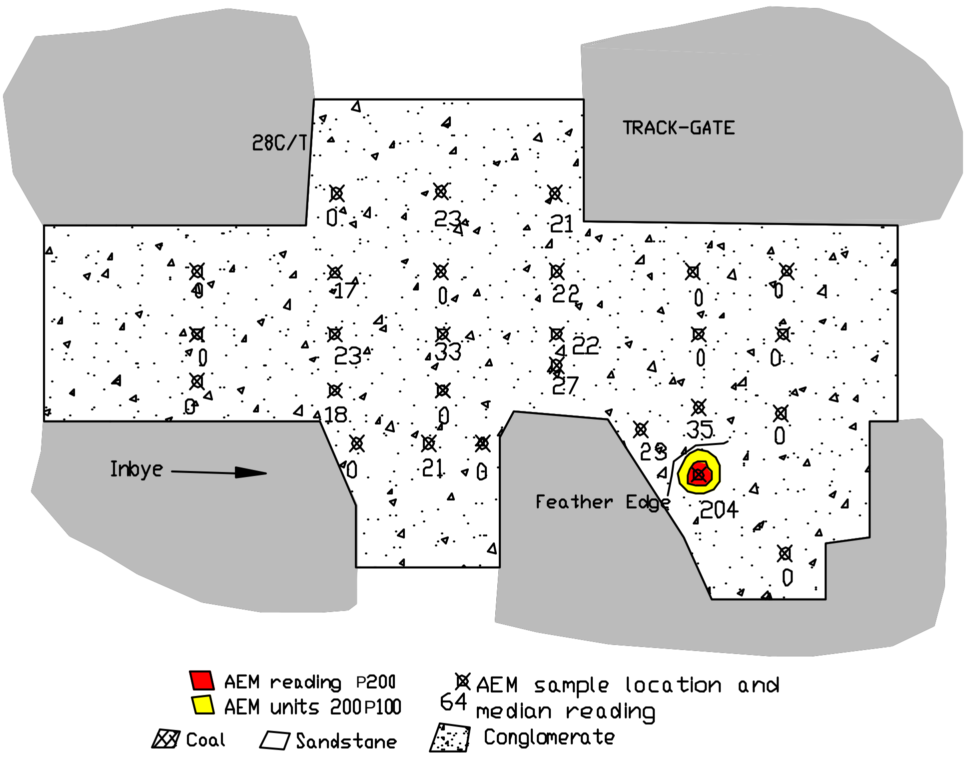

Figure 5.2 Conglomerate roof test area with feather edge/fracture.

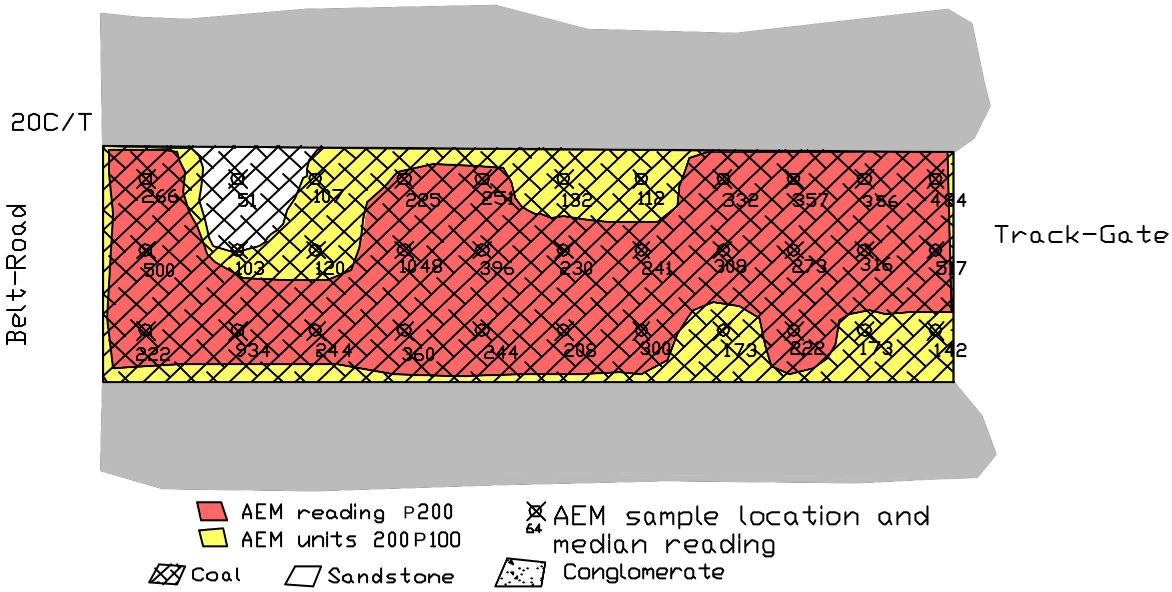

Figure 5.3 Coal roof test area.

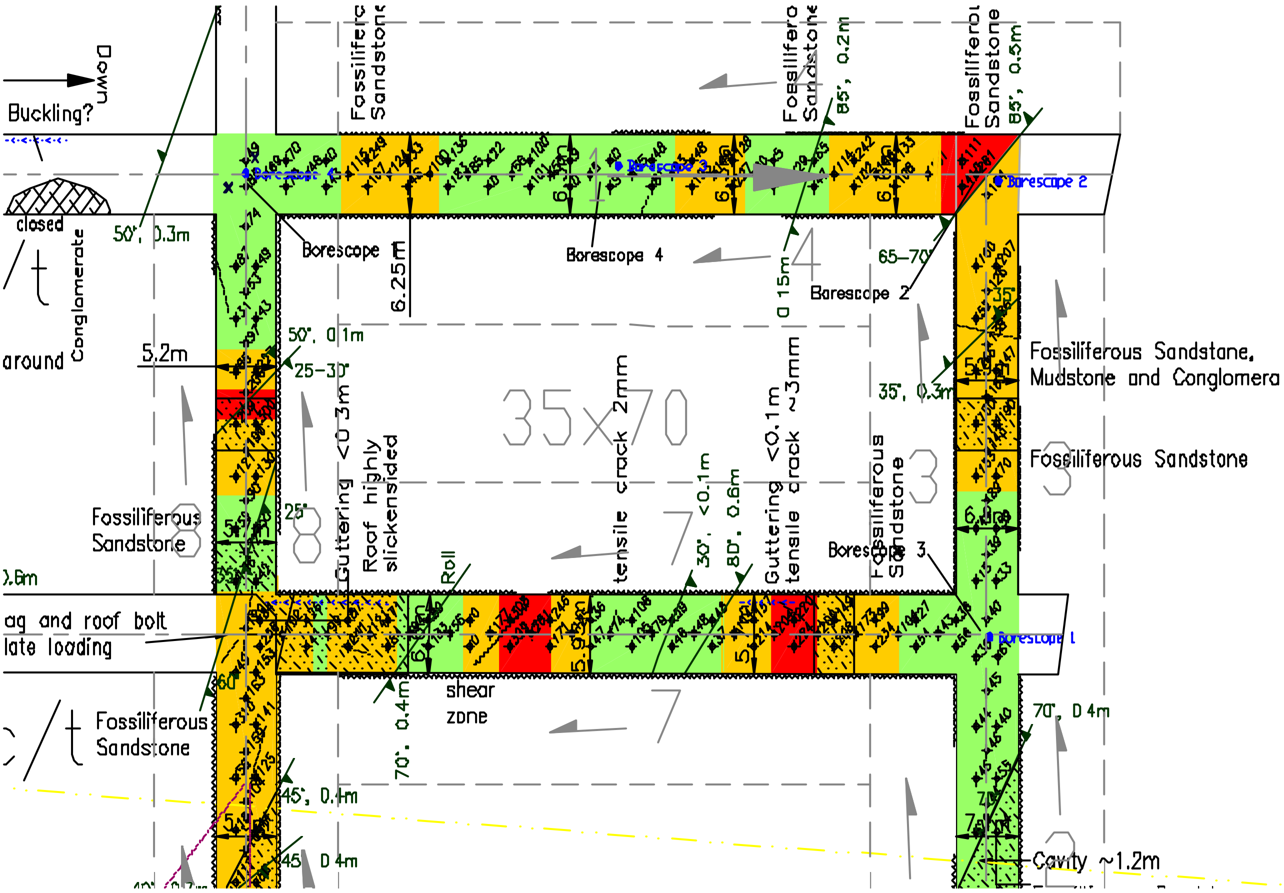

Figure 5.4 Sandstone roof lithology with geological structure

Limited data was gathered from claystone (5 sample points) and laminated siltstone lithologies. The results of the borescoping with the AEM results, indicate a possible link between high AEM values and partings in the claystone. Given the small data set this link would require confirmation, see **Figure 5.5**.

Lithological contacts that are intact with no visible parting may not show a significant change in AEM reading depending on the typical response characteristics of the material. **Figure 5.6** has a large contact area between sandstone and conglomerate. The AEM readings along the lithological contact, are relatively unchanged, where the contact surface is closed and intact. **Figure 5.6** also links the scaling characteristic of drummy/hollow sounding roof to higher AEM readings.

Regular lithology changes are common in laminated (bed thickness =0.01 m) and thinly bedded (bed thickness =0.1 m) material. Also common from the data tabled from Colliery D in **Table 4.1** are partings of 1mm along bedding contacts. The small openings or 1mm partings are readily identified in the data and linked to high AEM readings (>100). The depth for which the AEM readings are reliable in laminated material appears to be no greater than 0.5m, as demonstrated in the borescope data presented in **Appendix D,** where the average AEM reading for the sample point is >50 when the partings are below a Height of Fracturing (HoF) of 0.5 m.

The AEM was used to target geological structures to assess if the structure was intact. A test area that identifies a geological structure with closed and open regions in conglomerate is **Figure 5.7**. AEM readings in the surrounding conglomerate are <100, whereas directly below the parting the AEM reading is 286. This example also demonstrates the AEM can potentially identify partings associated with geological structure, principally on the ‘footwall’ or ‘weak’ side of an inclined structure.

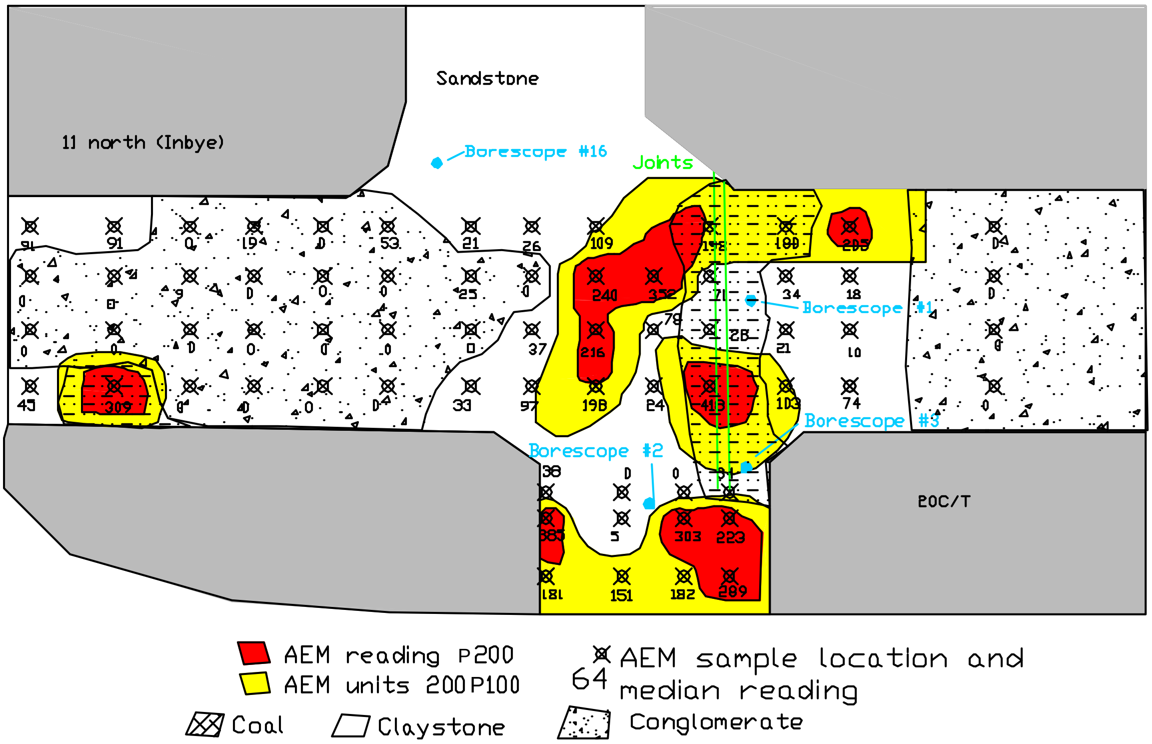

Figure 5.5 Claystone/sandstone roof lithology with geological structure

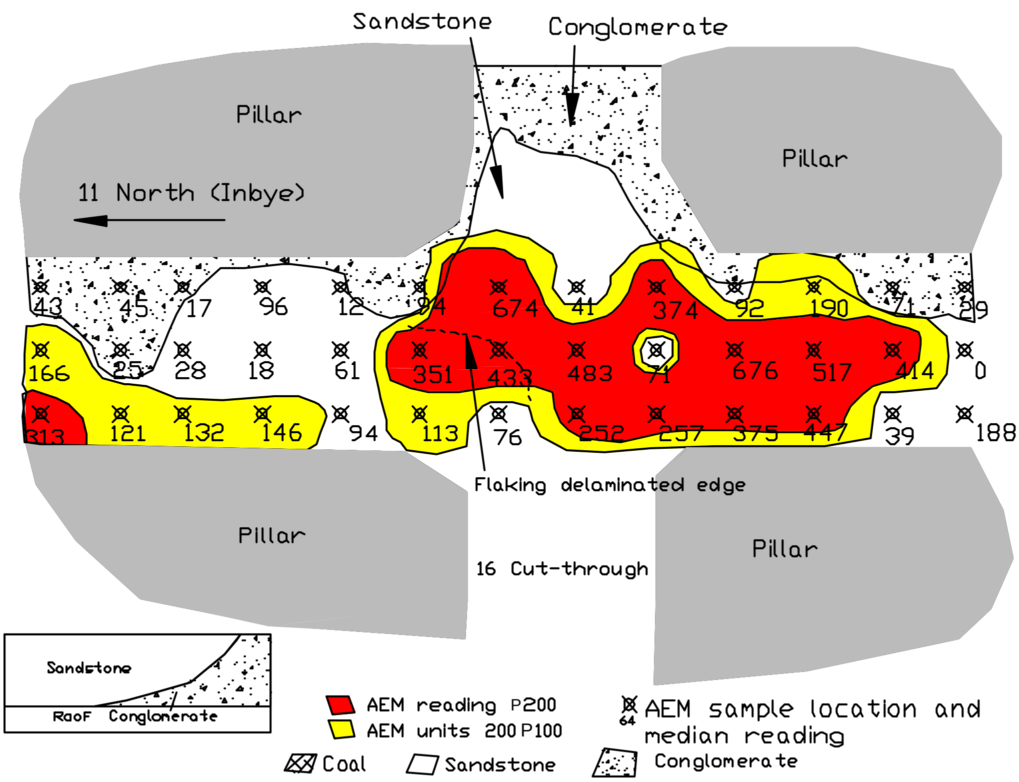

Figure 5.6 Sandstone roof lithology with geological structure

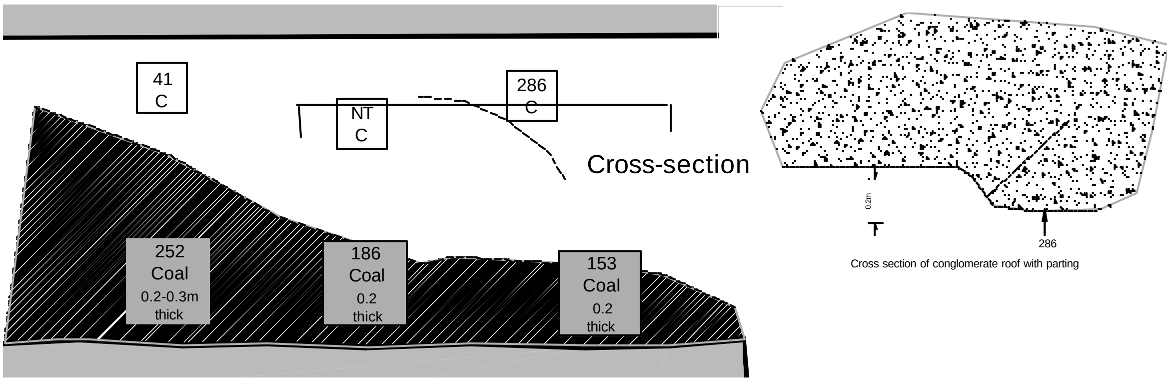

Figure 5.7 Conglomerate roof with open geological structure

It is clear from the above examples that where an open parting exists in the strata below 0.8 m into a massive geological unit, the AEM reading will be considerably higher for that sample point than in the surrounding intact rock. **Table 5.2** below illustrates for the given geological conditions AEM reading ranges for identifying open partings and the associated background (intact rock).

Table 5.2 Possible AEM Ranges and Geological condition

Lithology/Geological Condition	Background AEM Units (Intact rock)	AEM units (Possible open fractures present)
sandstone, conglomerate, thickly bedded strata (>0.1m beds)	0-100	>100 (lower 0.8m of roof)
claystone, siltstone. laminated material (<0.1m beds)	0-150	>150 (lower 0.5m of roof)
Coal	0-1000	>200

6.0 INTRINSICALLY SAFE ACCREDITATION

Another main objective of the study was to achieve certification of explosion protected electrical equipment in accordance with standards *AS/NZS 60079.0:2000*, *AS/NZS 60079.11:2000* and *AS1939-1990*. Testing was conducted by TestSafe Australia. The RDL4 AEM has also already received hazardous area approval from *Mine Safety and Health Administration* in the United States of America and intrinsically safe classification from *South African Bureau of Standards* (SABS).

The certificates are presented in **Appendix K**.

7.0 GUIDELINES FOR USE

7.1 General applications

The AEM could be utilised in some of the following generic applications: (i) roof assessment that requires a quick response, (i) long term monitoring and (iii) as one element of a strata management process.

During panel development the AEM could be utilised by a suitably trained person to check the integrity of the roof in an operating panel, specifically areas in and around the miner, before and during bolt up, to assist with identifying unstable ground. The operator could then utilise the AEM progressively outbye of the face to monitor and identify unstable rock conditions should conditions deteriorate. All this would aid in providing an increase in safety and reduction in potential risk from skin failure and slabbing from the roof, depending on the applied level of roof support.

Similarly the AEM could be utilised in non working sections of mines where inspections are required. The AEM could be utilised to target areas of concern and also as a means of comprehensive survey of roadways that were originally driven on very low densities (or no) primary support. The AEM could then be used to monitor the areas of concern for deterioration and provide notification that action to prevent further deterioration may be required.

7.2 Conditions of use

Where low roof bolting densities are used (ie. <4 bolts/m with no mesh) the potential for detachment of thin pieces of rock between bolts and straps represents a credible safety threat to the work force, therefore improving the identification of detached roof pieces would provide information to help eliminate the hazard. Low bolting densities therefore can provide effective working conditions for the AEM.

Thickly bedded sandstone and conglomerate roof does not typically have bed separations or rock detachment within the first 0.5m of roof. Therefore, on the occasion when this does occur, it is an anomalous event that may go undetected, resulting in potentially an uncontrolled safety hazard in the mining environment.

Consequently detection of the safety hazard, subsequent monitoring and remediation are vital in attempting to provide a safe working environment.

7.3 Mechanics of use

The operation of the AEM requires holding the geophone to the rock surface, either directly or through the use of an extension pole. The surface is then struck with a hammer or equivalent at a recommended 0.2m to 0.5m of the geophone and a reading illuminated on the digital display. A minimum of three readings is taken for each sample point, then averaged.

As is the case for most instruments, calibration is required. Calibration of the 'internal' functioning of the instrument is required on an ongoing basis to ensure that the AEM continues to operate according to the manufacturer's standards. Also calibration to local conditions is required in the form of a hazard or strata management plan (SMP) that identifies under which circumstances the AEM readout is identifying a hazard outside of normal controlled operating conditions. The SMP AEM triggers would also be required to be updated on a regular basis to identify when a change in geology (eg. roof type) may affect the AEM results.

The AEM could be effective around a miner bolter operation with the crews being able to inspect the roof in their working area. Similarly in a place changing operation the AEM could be effective in identifying potential hazards between bolting rows and testing areas in-front of the last row of bolts before installation of the next support row. A sampling density similar to four sample points per metre of advance could prove effective, depending on bolting densities.

When the AEM is utilised for monitoring and investigation of roof competency outbye a sampling density similar to four sampling points per metre would be typical, however a final sampling density would depend on the installed support and the sampling density necessary to acquire a suitable coverage of the roof. Also marking each sampling point with spray paint would provide a record of the sampling point for repeatability and monitoring purposes.

7.4 Use within a formal SMP

The most effective operational use of the AEM would involve utilising AEM results in an SMP. As with all triggered response plans, it should not rely on just one trigger, but link the AEM results to geological mapping to identify if the hazard is related to geological structure, lithology contacts etc. The AEM would provide suitable information to warrant further investigation to identify the most effect response from the SMP.

The consistent use of the AEM with the SMP would eventually provide information to assist with increasing or decreasing bolting densities and also to assist in refining the SMP to provide a more efficient decision making process for roof support.

Localised use of the AEM would provide feedback regarding a direct hazard which could be barred down, effectively used in the same process as sounding.

The SMP would also provide guidelines for AEM sampling density at the face and outbye to monitor and investigate hazards.

The use and interpretation of the AEM should only be conducted by persons who have received sufficient training to be considered a competent person and this process of accreditation would need to involve how the AEM is incorporated into the SMP.

The AEM is not intended to replace sounding as a primary tool for identifying and remediating hazards in the mining environment from loose rock fragments. The AEM is intended to provide another tool for identification of hazards that removes possible interpretation of a hazard and results into a consistent, repeatable process.

When using the AEM it should be operated by two people; one person to hold the AEM/geophone to the roof and one person to strike the roof within an acceptable distance of the roof to provide the reading. This is especially relevant when operating in a thick seam environment. Suitable personal protective equipment should be worn, primarily safety glasses to prevent eye injury from possible splintering rock when struck.

Some initial data has been gathered to investigate the stability of ribs. From the initial results presented in **Appendix G** the volume of data sets for the coal ribs would need to be large to give the AEM survey statistical credibility. As seen in the coal roof data, the AEM values from coal are high, thus identifying anomalies and changes in rock condition would seem to require a significant change in AEM output.

8.0 CONCLUSIONS

It is evident that the AEM concept has undergone a significant amount of testing and evaluation in a wide variety of applications and geotechnical settings worldwide. Following on from previous research, this study was able to demonstrate consistency with the overseas trials. The consistency was the reliable identification of open partings and discontinuities within the lower 0.8m of the roof. This study has added to the AEM knowledge by identifying a common range of readings for different roof lithologies (laminated siltstones, sandstones and conglomerates) and indicating types of rock (coal, laminated/thinly bedded material) where the range of AEM readings appear too broad and imprecise to recognise open partings.

The significance of establishing open partings or discontinuities within the 0.8 m horizon is particularly relevant, for as stated in **McKensey 1994 (Table 1.1 updated by SEA)**, of the 14 fatalities in NSW between 1980 to 1994 involving roof falls, all of them involved pieces of rock <0.4 m thick emanating from the skin of the roof. Therefore a fast and effective instrument to detect open partings within this depth range into the roof could improve mine safety.

A summary of the range of AEM values that have correctly identified voids behind tunnel linings or partings/semi-detached blocks in mining roof are presented in **Table 5.2**.

The outcomes of this study show the AEM may have a valuable role to play in assisting the identification of potentially unstable strata within the skin of the roof. A common method used for many years in mining to detect unstable ground is sounding. The AEM is able to take much of the subjective ‘guess-work’ out of roof sounding by providing a repeatable and relevant number to relate to the local roof conditions. Sounding is and remains the quickest method of assessing roof for short term, small scale stability, the AEM adds to this as follows:

- It is able to monitor areas of concern regularly, without being open to interpretation from one operator to the next.
- Data can be gathered, stored, updated and interrogated to identify areas that are deteriorating.
- In areas where operators are unsure of the sounding results the AEM can provide a more definitive response and monitoring of the area in question.

The AEM can simply be used as another tool for mining personnel to identify, monitor and remediate a hazard effectively.

The most effective application of the AEM in controlling roof conditions would be in areas of relatively low primary support, eg. 4 bolts per 1.5m with straps, no mesh, in conglomerate or massive sandstone roof. Under these conditions the AEM could potentially identify delaminations or partings that may not be detected visually and allow remediation to eliminate the associated safety threat. The AEM would not be used effectively unless it was used in conjunction with a Strata Management Plan.

The project has gained full intrinsically safe approval for use in the hazardous zone of underground coal mines. Therefore the AEM can be used in both active development operations or as an outbye tool for assessing existing old roadways especially those that may be subject to rehabilitation for future use and contain minimal amounts of primary support or suspect (eg. corroded) support.

As outlined above, the study has provided general guidelines for the operational use of the AEM and should be linked to a SMP to realise the full benefit to the mining operation.

9.0 REFERENCES

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