Outburst monitoring using microseismic techniques in the Phalen Colliery, Sydney, Nova Scotia, Canada

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ABSTRACT: The Sydney Coal field in Nova Scotia has experienced outburst activities since the late 70’s and early 80’s. The reported cases of outburst in this field are described as resulting from the ejection of finely pulverized sandstone into the openings. An “intrinsically safe” portable microseismic monitoring system, designed for the Sydney Coal field, was installed in Phalen Colliery at a depth of 695 m. The results of several months of monitoring showed the possibility of detecting different sources and their distinction from their seismic signals. Of particular interest is an outburst recorded in September 94 which we describe in this paper.

1 INTRODUCTION

Sudden failure of rock material close to mine openings has been a major problem to the mining industry for many decades. Such failures fall into several categories, among which rock falls (loosened rock falling under its own weight), rockbursts (violent rock failures causing significant damage), bumps (violent rock failures with minor damage) and outbursts (sudden ejection of rock and/or coal material into an excavation due to rapid release of gas). As mining depths and extraction rates in coal mines increase, the occurrence of outbursts can be expected to increase as well.

Seismic monitoring of outbursts in coal mines provides a unique tool in the investigation of the process of crack propagation leading to catastrophic failures. The origin of such induced failures could be related to stress adjustments within a rock mass following the removal of large volumes of rock, perturbation of the natural hydraulic regime, perturbation of rock temperature or gas pressure, etc. Large mining events in the earthquake range are often called tremors or mine-induced seismic events and are usually monitored using a mine-wide seismic system. Smaller “microseismic” events are usually located close to active workings. The monitoring of such events requires a recording system of a much higher frequency range and sensors located close to mining areas. An abundant literature exists on the use of seismic methods in the monitoring and analysis of coal mine instabilities, e.g. Nakajima et al. 89, Sato et al. 89, Revalor et al. 90, GAL 91, and Coughlin and Wilson 93; etc.

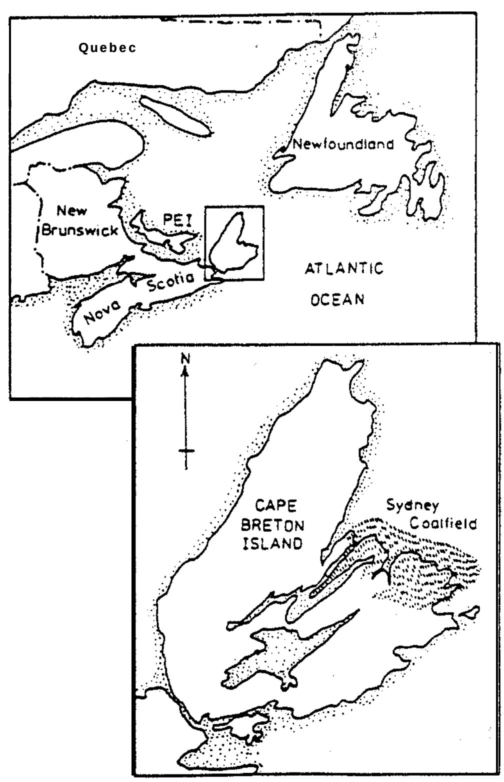

Figure 1 Location of Cape Breton Island and the Sydney Coal field, Nova Scotia.

The two principal underground coal mines in Canada are operated in the Cape Breton Island, Nova Scotia. The Sydney coal field is located on the east coast of the Cape Breton Island and dips gently eastwards beneath the Atlantic Ocean (Figure 1). The mines are owned and operated by the Cape Breton Development Corporation (CBDC), a Federal Crown Corporation. A multi-disciplinary research program undertaken by CBDC on outburst phenomena in the past has covered several aspects: measurements of in situ stresses, simulation of outbursts in laboratory, investigations into the potential for destressing and degassing of sandstones, and development of numerical models to assist in the design of openings in outburst-prone ground. Methods of assessing potential outburst conditions have been primarily examination of probe hole cores for core discing (Corbett et al., 1994).

An intrinsically safety (IS) microseismic monitoring system was developed for the coal mines of Nova Scotia. The design of this system is based on the rockburst monitoring system currently in use by the Canada Centre for Mineral and Energy Technology (CANMET) in hardrock mines of Ontario and Quebec (Figure 2). This system was installed in a development roadway at the deepest extent of the Phalen Colliery, Nova Scotia in 1993. The paper presents a summary of past observations of outburst in the coal mines of the Sydney field, different approaches in dealing with this problem in the past, and the resulting conclusions in terms of further research efforts. The microseismic monitoring system installed at Phalen mine will then be described, followed by the results of the initial observations in this first stage of outburst and microseismic monitoring at this mine.

2 BACKGROUND

Outbursts of rock and gas in coal mines are often associated with the destruction of strata around an excavation and release of large amounts of gas. The resulting cavity is formed by the ejection of flaked or powdered rock displaced into the workings. The cavity walls are often described as having an “onion skin”appearance. Such outbursts were experienced in No. 26 Colliery in the Sydney Coal field in the late 70’s and early 80’s. The strata between the coal seams in this coal field are sandstones, siltstones, mudstones, with minor shales and non-marine limestones. In all reported cases of outbursts in the Sydney Coal field the

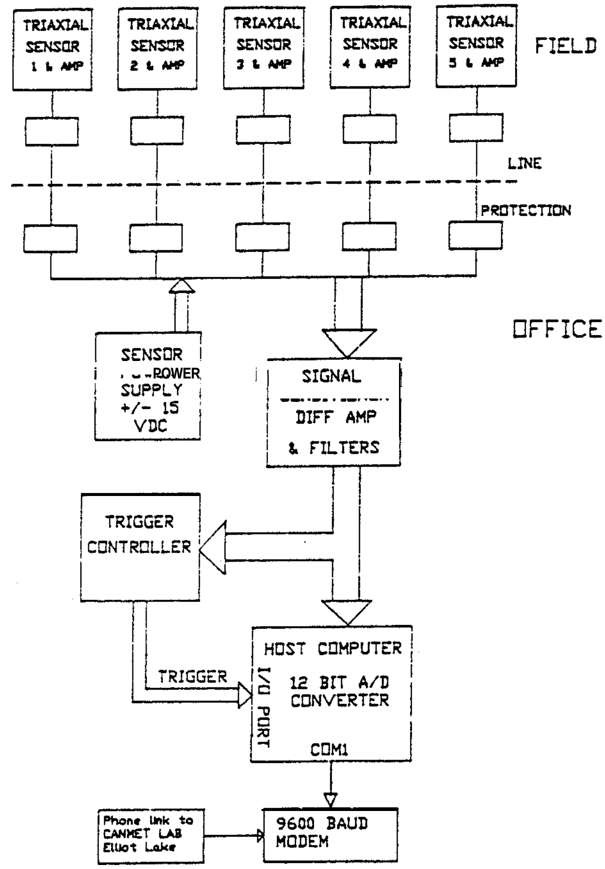

Figure 2 - Schematic diagram of the macroseismic system of CANMET (after Hedley, 1992).

ejected material has been described as predominantly finely pulverized or “flaky” sandstone chip and flake size particles. Where coal was ejected, this appeared to be a subsequent phenomenon due to rapid stress redistribution (GAL 1991).

The CANMET’s Cape Breton Coal Research Laboratory, in collaboration with the CBDC, has initiated a major research effort to investigate the causes of the outburst phenomena in the Sydney Coal field and safe mining methods in prone ground. In this section, we review some of the results of these investigations.

2.1 *Review of outbursts at No. 26 Colliery*

Between 1977 and April 1984 the No. 26 Colliery, the deepest mine in the Sydney Coal field at the time, experienced 37 rock/gas outbursts. An investigation of these events indicated that the majority of the outbursts took place in development headings driven in virgin coal, that they were initiated by blasting and occurred whenever a sandstone erosion channel was present either in the face, close to it and/or within 2.7 m of the top of the coal seam (GAL 1987). Sandstone channels are often observed within the seams or in their close proximity. All of these outbursts occurred between 703 m and 790 m below sea level. The frequency and intensity of the outburst increased with depth.

The last two outburst events in the No. 26 Colliery (November 83 and January 84) resulted in the destruction of 18 m of roadway, the release of considerable quantities of methane into the workings, and the ejection of volumes of rock of about 316 m3 and 145 m3 respectively (GAL 1990). The outburst cavity created by the events were conical in shape. At the time of the closure of No. 26 Colliery, as a result of an unrelated fire, these outbursts were the subject of intensive investigation.

The outbursts at No. 26 Colliery were observed to have the following common attributes (Corbett et al. 1994):

- All outbursts were associated with Paleo river channels of sandstone roof where the rock dipped to within a height of 2.7 m of the seam.
- Sandstone interbedded with dark gray siltstone was most prone to bursting.
- The majority of outbursts occurred while driving development roadways in virgin ground.
- All known outbursts occurred at a depth of greater than 700 m.
- All but one outburst were initiated by shottiring.
- Outburst incidence did not appear to be related to direction of drivage.

2.2 *Review of the Lingan Colliery*

Following the closure of the No. 26 Colliery, investigations intensified in the case of Lingan Colliery which was approaching the 700 m depth. Based on the available information on the in situ stress field, it was concluded that outbursts were more likely in Lingan Colliery than they were in No. 26 if a critical mine geometry and gas pressure were encountered (GAL 1991). The report concluded that outburst triggering mechanisms should be investigated using seismic techniques. Seismic research at Lingan Colliery consisted of baseline blast monitoring during the limited number of drill and blast operations. The objective was to address several key issues such as the existence of any microseismic activity during or immediately following test blasts and the significance of such an activity from the point of view of outburst occurrence.

Monitoring was accomplished using a multi-channel BMX blast monitor and an MS-3 single channel event counter during development blasts and machine cutting operations (GAL 1992). No microseismic activity was recorded within the six second recording window of the blast monitor. Events monitored by the event counter seemed to correlate with level activity such as moving conveyors or setting arches. This experiment showed the limitations of the equipment used for outburst monitoring, i.e. monitoring window being too short, memory being too limited, and particularly the equipment not being approved for use in coal mines. Although the equipment was operated under special exemption from the Coal Mine Regulations, the unit had to be shut down and removed from the section whenever the methane concentration exceeded 0.5%, which happened several times during the monitoring. The blast monitor revealed to be simply inadequate because it could not be used when and where outbursts were most likely to occur.

The fundamental result of this investigation was ‘that a more sophisticated continuous monitoring seismic equipment was needed to study the potential outburst phenomena. Unfortunately, Lingan Colliery was also closed before any further work could be done. Attention was shifted to Phalen Colliery which was quickly approaching the critical depth of 700 m (Corbett et al, 1994).

2.3 Phalen Colliery

Phalen Colliery, the newest colliery in the Sydney Coal field, lies directly under the Lingan and No. 26 workings and currently its deepest extent, No. 3 Slope development, is at a depth of 695 m. The geology of the mine is similar to that of No. 26 and Lingan Collieries. The method of slope development drivage at Phalen is by road header as in Lingan.

A review of the available microseismic monitoring systems around the world concluded that no single system would adequately fulfii the requirements of outburst monitoring in the Sydney Coal field (GAL, 1990). Systems developed for coal mines in other parts of the world tended to be “one of a kind” and usually constructed on an “ad hoc" basis by research groups. The report concluded that such an approach could be adopted for the Sydney Coal field.

A portable microseismic system, specifically designed by CANMET's Rockburst group at the Sudbury Laboratory for outburst monitoring in the Sydney coal field, was commissioned in 1993 and is currently operating at the bottom of No. 3 Slope. This system is the product of cooperation among the CBDC and CANMET's Cape Breton Coal Research Laboratory, the Canadian Explosive Atmospheres Laboratory, and the Sudbury Laboratory.

3.0 THE PORTABLE MICROSEISMIC SYSTEM

In this section, we describe the Intrinsically Safe (IS) microseismic system installed at Phalen mine. The system was installed at the bottom of No. 3 slope at a depth of 695 m in November 1993. Following a period of adjustment, the enhanced prototype of this system began to record microseismic waveforms in March 1994.

3.1 *System Design Criteria*

The design of the system was based on several fundamental considerations. It is accepted generally that highly stressed rocks, such as those associated with outburst phenomena, generate microseismic/acoustic activity, as shown by the abundant literature on the subject. However, within coal bearing strata where rock may be broken considerably, high-frequency microseismic emissions may not be able to travel long distances or to traverse minute fractures within the strata around mine opening because of the attenuation phenomena. Such a system had to record full-waveform signals in order to allow further research studies on the causes and mechanisms at the origin of outbursts.

It became obvious from the above considerations that any microseismic system sensor array would have to be placed near the emission source, preferably ahead of the development face. Because of the high advance rate of the mining machine, the sensors had to be remountable and the system itself had to be mobile to allow the sensor array to follow the mining face. Therefore, the system had to be portable, compatible with existing coal mine equipment and able to operate continuously. Also, the intelligent triggering system had to be remotely programmable. Finally, the system had to be Intrinsically Safe (IS) for use in hazardous environments and rugged enough to operate in demanding coal mine conditions.

3.2 Array of sensors

The array of sensors at Phalen consisted of five triaxial accelerometers installed in five 6.1 m deep.. boreholes drilled at different angles in one section of the excavation tunnel (Figure 3).The sensors installed in the rock are triaxial piezoelectric accelerometers with a nominal sensitivity of 980 mV/g and a flat frequency response range of 0.5-2000 Hz. Accelerometers were chosen because of their sensitivity, frequency range and ease of use. Three triaxial accelerometers were deployed in the roof stone while two were mounted in the coal - one on each side of the heading. The present design of the sensor array was partly due to the limited capabilities of drilling large diameter boreholes at acute angles at Phalen. Moreover, poor ground conditions and operational difficulties made it impossible to install any sensors ahead of the face, as originally planned. Five multi-pair cables connect the sensors to preamplifiers, mounted outside the boreholes. As the mining machine passes the boreholes, cabling would follow behind the machine until the sensors would have to be redeployed in new boreholes. This approach ensures that sensors would never be located farther than 100 m from possible sources in front of the mining machine.

3.3 Hardware

The portable microseismic system installed at Phalen is a derivation of the CANMET permanent macroseismic system originally developed as part of the Canadian Rockburst Program and currently being used in a number of hardrock mines in Ontario and Quebec (Hedley 92, Talebi et al. 94). The system was modified to make it Intrinsically Safe for coal mines according to Canadian standards.

The heart of this full-waveform 16-channel system is a 386 or higher dedicated PC computer. **The triggering** board, A/D board, and a standard modem are all housed in a single flame-proof

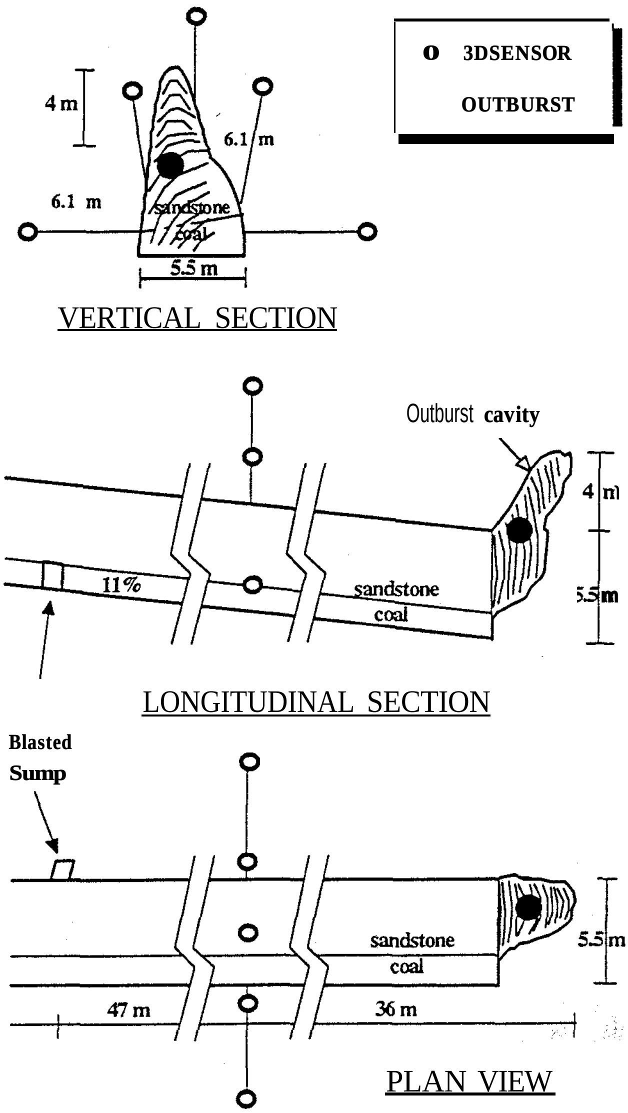

Figure 3 - Location of the microseismic sensor array and the "schematic" outburst cavity within the No. 3 Slope at the Phalen Colliery.

enclosure. Connections to external amplifiers and sensors are made through shunt diode IS barriers. The external amplifiers and sensor power level is maintained IS by voltage clamping techniques. Data transfer is accomplished through a single pair dedicated phone line to a host computer on surface. Another modem connection on the surface allows the users to call the system directly from a remote computer. The system is powered by a standard coal-mine rated 110 V switched power supply. The system runs continuously and stores events on an internal hard drive.

The mode of operation is configurable to cover a variety of sampling rates from 600 to 20,000 samples per second per channel. The system features remotely programmable "intelligent" triggering detection circuitry minimizing the need for on site configuration or maintenance.

3.4 *Software*

The operating system of the acquisition computer, QNX, provides a multi-user multi-tasking platform. It incorporates a user-set time slice parameter which allocates processor time to tasks or programs according to the priority set by the user. Event acquisition is held at the highest priority.

The data acquisition software consists of three main modules: the primary and secondary acquisition modules, and the demultiplex module. These modules are auto enabled at start-up ensuring that acquisition is running unless it is terminated by the user. Other associated tasks are also included and run as required by the user. A display utility is also included. Three acquisition modes are available. These software-configurable modes manage memory buffers on the A/D board and work in conjunction with the trigger board to provide an efficient, intelligent seismic recording platform. In modes 1 and 2 real-time acquisition is interrupted for a period of 250 msec following each event. Mode 3, however, is unique in that it can achieve continuous real-time data acquisition. In this mode two events, very close in time to each other, can be chained into one single file including both of them.

4 RESULTS

4.1 *Observations*

The No. 3 Slope heading at Phalen colliery where the portable microseismic system was installed was idle for several months following the installation. Except for the road header being partially dismantled in the expectation for a refit before the heading advances, there was no other mining activity within a distance of 100 m of the sensors. Consequently, the microseismic monitoring system did not record any significant events for a while, the area being acoustically quiet. Some adjustments to the hardware and the recording parameters (e.g. gains of preamplifiers) were made during this period in order to insure efficient recording of outburst activity, should it occur.

On September 1994 at approximately 10:00 a.m., Phalen Colliery experienced a rock/gas outburst in No. 3 Slope at a depth of 697 m. As a result of this incident, one miner was seriously injured, several meters of roadway were destroyed and an estimated 1350 m3 of methane was released. The event made a loud bang which sounded like a sharp rifle shot and was followed almost immediately by an air blast, flying dust and small fragments of rock. The force of the air blast was sufficient enough to knock over some mine workers close to the mining face. The air in the tunnel immediately following the outburst had a very heavy smell, like diesel fuel, and contained a line gray dust making breathing difficult. At the time of the outburst, the sensor array was about 30 m from the face, the location of the sandstone/gas outburst. Due to operational difficulties, only one of the sensors was functioning at that time.

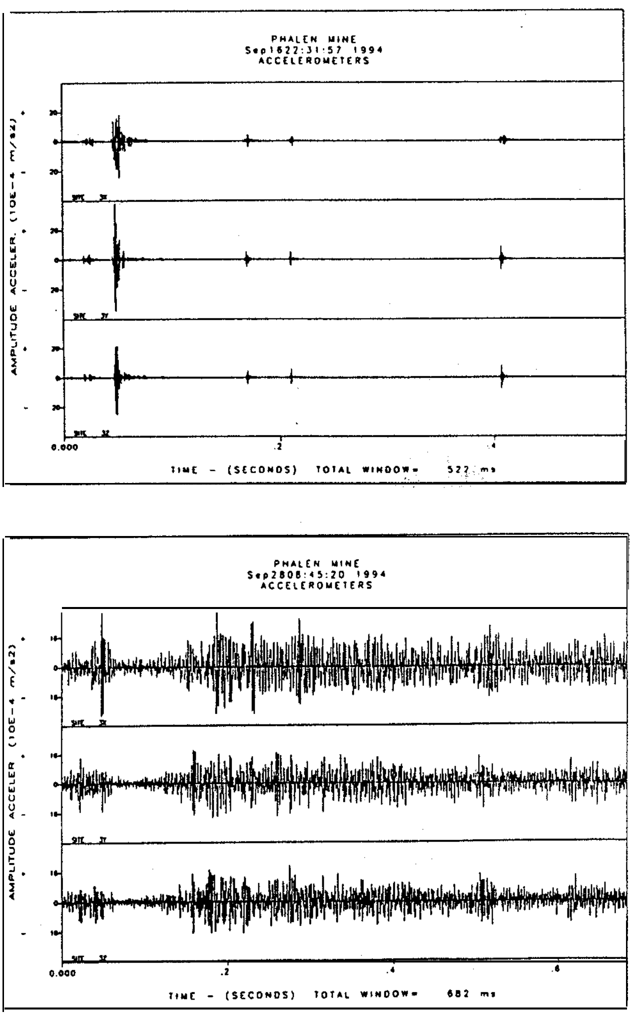

Figure 4 - Signals recorded from the triaxial sensor 3 due to microseismic activity (top traces) and the outburst (bottom traces). The high level of noise in the latter case is due to the cutting machine operating when the outburst occurred. The total window time is 522 and 682 milli-seconds respectively.

4.2 *Signal processing*

For the time period between March and September 1994, 55 files were recorded by the microseismic system at Phalen, of which 27 were due to electrical spikes and were thus rejected. The remaining 28 files formed five different categories: 12 files were due to noise caused by the operation of the cutting machine, 2 were caused by hammer strikes to the tunnel wall for test purposes, 7 files were induced by blasting operations and 2 files were known seismic events. The origin of the remaining 5 files is not clear and investigations are on-going.

The recorded signals were analyzed using their time and frequency contents. A Fast Fourier Transform (FFT) algorithm included in the CANMET waveform processing package was used for this purpose. The parameters used in this analysis in the time domain were the signature of the signals, their duration and amplitude. In the frequency domain, the dominant frequency range, the presence of amplitude peaks and the ratio of signal to noise were compared between different types of events.

All types of events showed their characteristic signatures. Figure 4 shows signals from micro-seismic activity recorded while the monitored area was seismically quiet since no mining equipment was operating in the tunnel. The arrivals of P and S waves are clear, as it was also the case when signals from transient sources such as hammer strikes on the tunnel wall or blasts were examined. In the latter cases, signal saturation was observed sometimes because of the large energy content of the blasts and the closeness of the hammer strikes to sensor locations. Figure 4 also shows signals recorded because of the outburst. The noisy aspect of these signals is due to the cutting machine still operating at the face when the outburst occurred. The fact that this noise is similar in nature to the background noise made further analysis of the outburst signals difficult.

Displacement spectra of the above signals using a Fast Fourier Transform (FFT) algorithm are shown on figure 5. The event recorded while the mine was quiet shows a high signal to noise ratio and a clear separation between the ambient noise and the signal. The energy is concentrated in the 100-1000 Hz frequency range. As expected, no particular peak of energy manifests itself in this case. The examination of the other figures shows, however, distinct concentration of energy around 100Hz and 300Hz in the spectra of the noise caused by the cutting machine. The spectra for the outburst shows similar features as those of the previous seismic event, but a low signal to noise ratio is observed and the separation between the signal and the noise is not very distinct. A clear difference between the signals from seismic events and artificially-induced sources of noise reveals to be the presence of distinct peaks of energy in the spectra of the latter while seismic events have a rather broad frequency content, with a concentration of energy in the 100-600 Hz frequency range. Signals from blasts show similar features, except for the fact that they contain energy below 100 Hz as well.

5 CONCLUDING DISCUSSION

The implementation of the CANMET portable microseismic system in the Sydney Coal field represents the first of its kind in Canadian coal mines. This system, like most of its counterparts in other parts of the world, is site specific. The design of the prototype system has fulfilled the requirements of the project: i.e. an intrinsically safe portable microseismic monitoring system with a frequency range of monitoring, sensor sensitivity, detection capability and other relevant recording parameters adequate for the site. The system is flexible enough to be able to be moved to other locations within the mine and to follow the excavation face. This portable system allows easy set up in any coal mine utilizing standard coal mine power supply and its rugged design is perfectly suited to the coal mine environment.

The ability of this system to continuously monitor the microseismic activity, record full wave forms and source locate the events is extremely important to the understanding of coal mine acoustic phenomena. Although the source location procedure is not automatic for the time being, event files are easily transferable from the portable system to surface for in-depth analysis of the nature of recorded events.

Much has been learned from this initial experience with the system. Improvements are, however, required and planned. The sensor array will be improved to allow easier mounting and

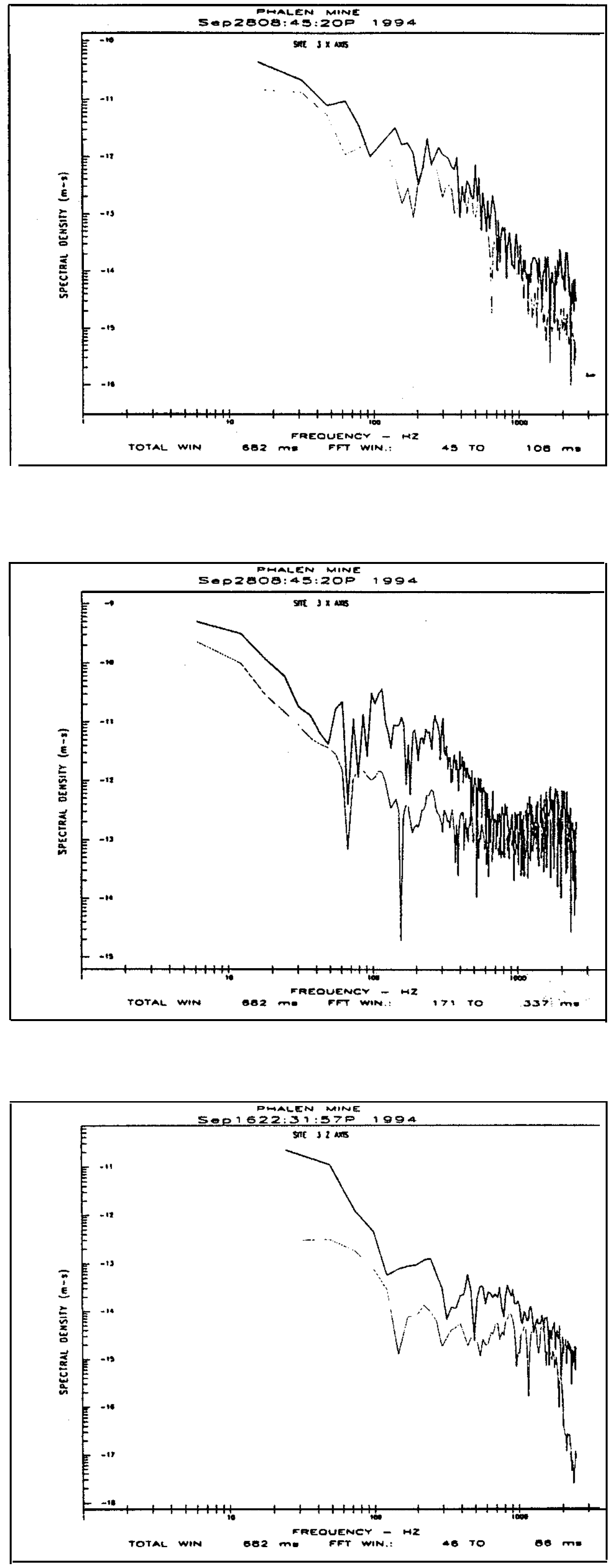

Figure 5 Displacement spectra of recorded signals of the outburst (top), the noise caused by the cutting machine (middle) and a microseismic event (bottom).

retrieval of the sensors and a better coverage of seismically active areas within the Colliery. On the other hand, a new design of the array of sensors is needed to improve source location and seismic parameters determinations. An ideal array would include some sensors in front of the development face. The number of sensors can also be increased to provide a better analysis of the seismic activity. Future plans are to place the amplifiers on one IC board within the flameproof enclosure minimizing the possibility of damage to the amplifiers, lowering the possibility of electrical noise, and making it easier to guarantee that IS is maintained.

The different types of events recorded at Phalen show different signatures, allowing for a strategy to be developed for discrimination between different types of events in situ. The present waveform analysis shows clearly the potential benefit of the seismic data processing for further in-depth analysis to increase the understanding of sandstone/gas outburst phenomena at Phalen. A routine analysis process will be implemented in order to increase the speed of the response provided to concerned parties.

Acknowledgments

The authors would like to thank the Cape Breton Development Corporation for their financial support of this project and their permission to publish the results. Thanks are due to the personnel of the Phalen Colliery for their collaboration in the installation and operation of the portable microseismic system. We would like to thank our colleagues of the rockburst group who contributed to different aspects of this work: L. Laverdure, D. Lebel, M. Cote, M. Plouffe and P. Rochon, as well as the CBCRL staff involved in this project: P. Cain, D. For-rester and D. Payne.

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