Monitoring of large mining induced seismic events - CANMET/MRL's contribution

by

M.Plouffe[1], P.Mottahed[1], D.Lebel[1] and M.Côté[1]

Abstract

CANMET/MRL's contribution to the Canadian Rockburst Research Program is the study of the mining induced seismic events located in the upper range of magnitude, i.e., magnitude 1.0 and above.

To achieve this objective, a remote-controlled macroseismic system was designed and developed which is now operating in four mines across northern Ontario. A menu-driven waveform analysis software was also developed in-house to analyze the waveforms recorded.

To determine magnitude from local mine camps, a network of eight regional seismograph stations is being operated by MRL. The most important part of this network is the Sudbury Local Telemetered Network that includes three uniaxial and one triaxial outstations. Empirical local magnitude scales were developed in order to extend national magnitude values to smaller seismic events.

Keywords

Rockbursts, Macroseismic systems, Waveform analysis, Seismograph stations

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[1] Rockburst Group, Mining Research Laboratories, CANMET, Energy, Mines and Resources Canada

Surveillance des événements séismiques importants générés par l'activité minière
La contribution des LRM de CANMET

par
M.Plouffe[2], P.Mottahed[1], D.Lebel[1] et M.Côté[1]

Résumé

L'étude des événements séismiques, de magnitude 1.0 et plus, générés par l'activité minière est la principale contribution des LRM, de CANMET, au Programme canadien de recherche sur les coups de toit.

Pour atteindre cet objectif, un système macroséismique, contrôlé à distance, a été développé par CANMET et est maintenant en opération dans quatre mines du Nord ontarien. Un logiciel a aussi été développé afin d'analyser les ondes enregistrées.

Les LRM gèrent, de plus, un réseau de huit stations séismographiques afin de calculer les magnitudes des événements séismiques provenant de certaines mines. La partie la plus importante de ce réseau est le Réseau local de télémétrie de Sudbury qui comprend trois stations à senseur uniaxial et une station triaxiale. Des échelles empiriques ont été développées afin de calculer des valeurs de magnitude aux plus petits événements séismiques.

Termes clés
Coups de toit, systèmes macroséismiques, analyse des ondes, stations séismographiques

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[2] Groupe de recherche sur les coups de toit, Laboratoires de recherche minière, CANMET, Energie, Mines et Ressources Canada

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1. Introduction

Rockburst activity in Canadian mines increased significantly during the 1980's, particularly in Ontario. A particularly active year was 1984, that culminated with the largest seismic event in modern Canadian mining history; a magnitude 4.0 event recorded at INCO's Creighton Mine in Sudbury. The high level of rockbursting raised concern from the industry. In response, the Canada-Ontario-Industry Rockburst Project was initiated in 1985 (Hedley & Udd 1987). The objectives of this project were to develop state-of-the-art monitoring systems capable of capturing complete seismic waveforms and investigate the causes and mechanisms of rockbursts. Field trials would also be used to evaluate methods to reduce magnitude and frequency of rockbursts. The final output of this first phase was published in 1992 (Hedley 1992).

Since April 1990, an expanded second phase of the Rockburst Project, the Canadian Rockburst Research Program (CRRP), is in progress. This second, five-year research project involves government agencies, universities and the Canadian & Chilean mining industries. On the basis of the knowledge established from the first phase, the research program will cover five aspects of mining seismicity: the reduction of mining seismicity using stiff backfill, the determination of guidelines in ground support and control, the improvement of mine layout through full waveform analysis, the automation of waveform data analysis, and a better understanding of fault-slip rockburst mechanisms.

CANMET's contribution to the CRRP, through the Mining Research Laboratories (MRL), is the study of the mining induced seismic events located in the upper range of magnitude, i.e., magnitude 1.0 and above. To achieve this objective, a remote-controlled macroseismic system was developed which operates at a lower sampling rate and with the sensor grid being much wider than a microseismic system. This system is now operating in four mines in northern Ontario. A menu-driven waveform analysis software was also developed in-house.

In order to determine the magnitude of small mining induced seismic events originating from some Canadian mine camps, a network of eight regional seismograph stations is now operating. The most important part of this network is the Sudbury Local Telemetered Network (SLTN) that includes three uniaxial and one triaxial outstations. This network was recently upgraded to increase data acquisition of scientifically meaningful data. Empirical local magnitude scales were developed in order to extend national magnitude values for the analysis of these smaller seismic events.

2. The Macroseismic Networks

Macroseismic systems are being used to investigate the seismic source parameters of rockbursts, which are defined below. These systems have the capability of recording the seismic waveforms of events greater than magnitude 1.0 using triaxial sensors.

MRL developed its own in-house remote-controlled macroseismic system, now operating in four mines in northern Ontario. These systems are located at Falconbridge's Strathcona Mine, INCO's Creighton Mine at Sudbury, Placer Dome's Campbell Mine at Red Lake and Lac Mineral's Macassa Mine at Kirkland Lake. Each system consists of five strong-motion triaxial sensors installed in boreholes underground and/or on surface, usually within a kilometre of the mine workings. They are specifically designed to capture the complete seismic waveforms to allow source location determination as well as seismic parameters. These systems also benefit the mine operators by allowing them to monitor the seismic activity originating from their mine. These in-house systems were commissioned between August 1990 (Strathcona Mine) and February 1992 (Creighton Mine). The macroseismic networks are permanently installed in these mines. Such an installation requires months of labour, software, etc. A Mark I portable version of this macroseismic system is currently being completed and will shortly be undergoing *in situ* trials.

Figure 1. Flow chart of the data acquisition system used by CANMET's macroseismic networks.

Figure 2. Schematic of the waveform analysis software developed by CANMET.

All four networks have basically the same hardware components. All the installations use geophones, except for the Strathcona Mine system which use accelerometers. The differential signals from the transducers are initially amplified and routed via cables in the mine shaft to the data acquisition computer system.

All processing units are located on surface, where the seismic signals are conditioned and passed on to the data acquisition system. After initial signal conditioning and filtering, the signals are then routed to both the trigger detection controller and the data acquisition board. The signals from each channel are digitized by the data acquisition board at a rate varying from 1024 to 4500 samples per second.

2.1 The data acquisition system

Traditionally, high speed data acquisition was only possible using expensive, high powerful computers. However, with the technological advances made by the computer industry, it is now more cost-effective to use microcomputers to perform this task. Although high speed data acquisition hardware is now available, most software packages available operate under the operating system DOS, which lacks the flexibility and power of multi-tasking operating systems. This dictated the use of another system providing this convenience. Hence, CANMET opted for the QNX™ (© Quantum Software Systems Ltd.) operating system. This allows the data acquisition system to be made up of several smaller tasks, which can run concurrently on a priority basis. Tasks not requiring immediate processing can be put on hold and not compete for processor time. Remote access to the system is also possible, simply by having a communication task run in the background, which requires minimal processor time.

The data acquisition software consists of three main modules: primary and secondary acquisition programs and a demultiplexer program. A configuration program, a start batch file and a stop batch program complete the package. Optional program modules are also available to display waveforms and simulate events under software control. The dataflow instructions and interactions which occur between the various program modules is shown on figure 1. Each program runs as a stand alone task on a priority basis, the higher priority tasks being at the top of the flow chart.

The start batch file initiates the acquisition process by starting the primary acquisition task. This primary acquisition task performs all executive functions including creating the secondary acquisition task and the demultiplexer task, which run at lower priorities. The primary acquisition module reads in parameters from the configuration file on disk and then performs a complete hardware and software initialization. It is also responsible for detecting, storing and queuing events in memory. The secondary acquisition module is responsible for transferring the acquired events from the memory buffers to hard disk storage.

A sophisticated triggering controller has also been developed to eliminate the recording of very small seismic events, machine noise or electrical spikes which could saturate the system. The controller has the following features: selectable trigger windows, selectable number of channels for a valid trigger, short-term integration for spike suppression, selectable trigger threshold, individual channel enable/disable switches, event simulator to test the trigger controller, software enable/disable of the triggering, optional hardware selectable retrigger timer and optional sensor amplifier gain control. If the trigger controller determines that a valid event has occurred, then two seconds of seismic data are stored for each channel, including half a second of pre-trigger data. Except for the Creighton Mine system, the acquisition is interrupted for about 200 milliseconds while the data are downloaded to the hard disk.

All macroseismic systems are connected via modems to MRL's Elliot Lake Laboratory. At the mines, the data files can be edited and transferred to Elliot Lake or some functions of the trigger controller can be altered.

2.2 Waveform analysis

An in-house menu-driven waveform analysis software was also developed to analyze the recorded waveforms. The schematic of this software system is illustrated in figure 2.

The waveform analysis software is used to calculate seismic parameters of mining induced seismic events, and to estimate their size in the four Ontario mines, or for other research purposes.

The signature of the waveforms can be displayed in acceleration, velocity and displacement modes. Thus, peak particle acceleration and velocity can be determined and used to assess damage. Waveforms can be rotated in order to obtain transverse and radial waveforms for polarization studies and, for source parameter studies, P and S waves are also available. Mine operators can be provided with the seismic energy and equivalent Nuttli (1973) magnitude values in order to quantify the size of the seismic events. Double-couple focal mechanisms can also be analyzed.

In the frequency domain, corner frequencies and low-frequency spectral density levels (plateaus) allow the determination of the source radius, seismic moment and stress drop values.

Currently, new additions to the software is being developed which include automation of seismic parameters computations, polarization analysis, considering surface and mined zone effects, raypath analysis, attenuation, non-double-couple focal mechanisms and near-field/far-field analysis.

This software enables the analysis of more than 250 large mining induced seismic events originating from the four mentioned mines. Of these, 180 were originating from Creighton Mine.

3. Regional Seismograph Station Network

CANMET is responsible for the operation of eight regional seismograph stations. These stations are located in the vicinities of the Northern Ontario and North-West Québec (figure 3) mining camps, in order to provide more detailed information about the source properties of the mining-induced seismic activity in the local mines. Four of these stations are part of the Sudbury Local Telemetered Network

(SLTN).

Figure 3. Location of the seismograph stations operated by CANMET.

Figure 4. Map of the Sudbury Basin showing the location of the active mines and the SLTN seismograph stations.

3.1 The Sudbury Local Telemetered Network

This network is one of the achievements of the Canada-Ontario-Industry Rockburst Project (Hedley and Udd 1987) in order "to increase the range for recorded rockbursts and to improve the source location of previously unlocated rockbursts" (Brehaut and Hedley 1986).

The SLTN was initially a three-station network located around the Sudbury Basin (figure 4). It was established as an initiative of the Canada-Ontario-Industry Rockburst Project in 1984 and has been fully operational since May 1987 (Plouffe 1988).

The three initial outstations, located at Joe Lake, Long Lake and Chicago Mine Road, consisted of a vertical single-component short-period seismometer and a 60 Hz digitizing package. These outstations were linked via dedicated phone lines to a central processing facility at the Science North natural sciences museum in Sudbury. The processor would save triggered events using a simple short-term/long-term average algorithm.

All triggered event files were automatically transmitted, via a dedicated phone line, to the National Seismological Laboratory in Ottawa where they were analyzed along with regional earthquake data.

Using the waveforms recorded by the three original stations, local magnitude scales were developed in order to determine magnitude values for small seismic events, which had not been detected by the National Seismograph Network (NSN) as defined by Munro *et al* (1988). The scales were developed for three seismically active mines in the Sudbury Basin: Strathcona, Creighton and Copper Cliff North Mines. Equivalent Nuttli magnitude values could now be determined down to about 1.0 (Plouffe 1992).

3.2 Upgrading of the SLTN

The SLTN network was recently upgraded in order to: provide a better automatic data transmission and analysis; reduce the volume of data generated by the doubling of the system size; rapidly implement new stations, and centralize the mining induced seismic data analysis at the Elliot Lake Laboratory.

A fourth station has been located close to the Creighton Mine (figure 4). By virtue of the installation of extensive micro and macroseismic monitoring systems and the presence of the new seismograph station above the mine workings, the Creighton Mine will be the best equipped mine for seismic monitoring in Canada. Events could now be recorded from magnitudes ranging between -4 to 4 without interruption, this being a part of the CRRP Source Mechanism Project.

The digital signal, processed at the sites of the four stations, is now recorded at a sampling rate of 100 Hz. It is transmitted through dedicated phones lines to a host computer located at Science North. From there, a communication software, developed by Nanometrics Inc., transmits automatically the triggered events to the Elliot Lake Laboratory. This laboratory includes a seismic analysis centre which could retrieve all seismic data from the SLTN stations. It is planned to transmit the data from all the regional seismograph stations to this central unit.

3.3 The other regional seismograph stations

In addition to the SLTN stations, MRL operates four other regional seismograph stations. They are located at Elliot Lake, Kirkland Lake and Red Lake, Ontario, and Val d'Or, Québec, (figure 3).

These seismograph stations consist of a vertical single-component Teledyne-Geotech S13 seismometer, which usually records in a frequency range of 1 to 16 Hz.

At all the stations, the analog signal was initially recorded on a helicorder; the paper chart was changed once a day and sent to Elliot Lake once a month. Presently, at Red Lake, the signal is now added to the data recorded by the local macroseismic system. For Elliot Lake and Val d'Or, the signal is now digital only, using a new generation of seismograph stations, manufactured by Nanometrics Inc.

Duration magnitude relationships were developed for these regional stations located close to the mines. These local magnitude scales allow a quantification of the size of the mining induced seismic events for these mines, at a much lower level than the one given by the National Seismograph Network. Presently, a local magnitude scale has been developed for the Quirke/Denison Mines seismic events (Rochon and Hedley 1987) recorded by the Elliot Lake seismograph; a second preliminary scale was developed for the Macassa Mine at Kirkland Lake (Plouffe 1992). These local magnitude scales enables the magnitude determination for seismic events as low as 0.7 and 1.1 respectively.

These duration magnitude values are equivalent to the national Nuttli magnitude values given by the Eastern Canada Telemetered Network (ECTN) (Munro *et al.* 1988).

4. Conclusion

Mining Research Laboratories of CANMET's involvement with the rockburst research in Canada, first in the phase I (COIRRP) and later as a partner in the Canadian Rockburst Research Program, which is to last until 1995, has contributed to the better understanding of the problems in rockburst engineering. This has been achieved through the co-ordination of the research efforts of the various mining camps, project management, research in hardware and software technology for monitoring and analyzing of rockbursts/micro/macroseismic data and technology transfer seminars.

These efforts and endeavour, augmented by the financial contribution from the industry, the provincial government and their agencies, and the research efforts from the Canadian institutions of learning have brought the Canadian mining industry to the edge of the state-of-the-art of rockburst technology. Today, it could be claimed that the Canadian mining industry, after a quantum leap since

1984, has become the leader in the forefront of rockburst research in the world.

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6. References

Brehaut, D.H. & D.G.F. Hedley 1986. 1985-1986 Annual Report of the Canada-Ontario-Industry Rockburst Project. CANMET, Energy, Mines and Resources Canada. Special Report SP86-3E.

Hedley, D.G.F. 1992. Rockburst Handbook for Ontario Hardrock Mines. CANMET, Energy, Mines and Resources Canada. Special Report SP92-1E.

Hedley, D.G.F. & J.E. Udd 1987. The Canada-Ontario-Industry Rockburst Project. *Proc. 6th Int. Rock Mech. Congr., ISRM*: 115-128. Montreal.

Munro, P.S., R.J. Halliday, W.E. Shannon & D.R.J, Schieman 1988. Canadian Seismograph Operations - 1986. Geological Survey of Canada, Energy, Mines and Resources Canada. Paper 88-16.

Nuttli, O.W. 1973. Seismic wave attenuation and magnitude relations for eastern North America. *J. Geophys. Res.* 78:876-885.

Plouffe, M., M.G. Cajka, R.J. Wetmiller & M.D. Andrew 1988. The Sudbury Local Telemetered Seismograph Network. *Proc. 2nd Int. Symp. on Rockbursts and Seismicity in Mines*: 221-226. Minneapolis, Minnesota.

Plouffe, M. 1992. Preliminary local magnitude scales for mining-induced seismicity at some mines in the Sudbury Basin. CANMET, Energy, Mines and Resources Canada. Technical Report MRL92-109.

Plouffe, M. 1992. Preliminary report on scaling of mining induced seismicity at Kirkland Lake, Ontario. CANMET, Energy, Mines and Resources Canada. Technical Report MRL92-113.

Rochon, P. & D.G.F. Hedley 1987. Magnitude scaling of rockbursts at Elliot Lake. CANMET, Energy, Mines and Resources Canada. Division Report MRP87-156.