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1987 - 1988 ANNUAL REPORT OF THE CANADA-ONTARIO-INDUSTRY ROCKBURST PROJECT

SP88–22E

1987–1988
ANNUAL REPORT OF THE CANADA–ONTARIO–INDUSTRY ROCKBURST PROJECT

C.H. Brehaut
Chairman
Management Committee

D.G.F. Hedley
Chairman
Technical Committee

Sponsors: Denison Mines Ltd.
Falconbridge Ltd.
Inco Ltd.
Lac Minerals Ltd.
Placer Dome Inc.
Rio Algom Ltd.

Ontario Ministry of Labour
Ontario Ministry of Northern Development and Mines

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1987-1988 ANNUAL REPORT OF THE CANADA-ONTARIO-INDUSTRY ROCKBURST PROJECT

FOREWORD

The third annual report of the Canada-Ontario-Industry Rockburst Project illustrates the excellent progress that has been made in developing the technology required to design safer and more economic mining methods in areas prone to rockbursting.

Phase One of the project, which includes the design, building and installation of new seismic monitoring equipment, is almost complete, and Phase Two has begun with the analysis of seismic waveforms to determine rockburst mechanisms and source parameters. In addition, in situ trials to test new design concepts and techniques have been started by most of the companies participating in this project.

As the work proceeds in each area, a significant amount of scientific information is being developed and promptly reported, as illustrated by the list of current publications included in this report. The excellent progress to date is a result of the dedicated efforts of David Hedley and his Rockburst Project Technical Committee and of the many individuals working for the major participants in this project.

C.H. Brehaut
Chairman
Management Committee

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INTRODUCTION

In the third year, 1987-88, of the Canada-Ontario-Industry Rockburst Project, the rationale and objectives remained the same: to develop new seismic monitoring systems capable of capturing complete waveforms, and to investigate the causes and mechanisms of rockbursts using improved source location techniques, first motion studies, peak particle velocity, liberated seismic energy and spectral frequency analysis. These techniques will then be used in conjunction with field trials, in situ measurements and computer models to evaluate methods of alleviating rockbursts or limiting their damaging effects.

The first phase of the project is almost complete. Macroseismic waveform systems have been installed around the Quirke and Strathcona Mines, and additional systems will be located, in the near future, around the Creighton, Campbell and Macassa Mines. A start has been made on the second phase, to analyze the waveform data for cause and mechanism.

Pillar bursting, within the orebody, is the main mechanism for the tabular type orebodies at Red Lake, Elliot Lake and Kirkland Lake. Many of the larger seismic events in the Sudbury mines appear to have been initiated by a fault-slip mechanism, with the source in the wall rocks outside the orebody.

Seismic Events of Magnitude 2.0 or Greater in Ontario Mines 1984-1987

Mining District	1984	1985	1986	1987
Red Lake	18	3	6	0
Elliot Lake	46	74	13	8
Sudbury	15	20	35	31
Kirkland Lake	5	2	3	3
Total	84	99	57	42

During the past four years, 282 seismic events of magnitude 2.0 or greater have been recorded on the Eastern Canada Seismic Network, operated by the Geophysics Division of the Geological Survey of Canada. Over the past two to three years, the number of events at Elliot Lake and Red Lake have declined substantially. Events at Sudbury increased between 1984 and 1986, but remained relatively constant in 1987. Kirkland Lake typically has only a few events per year.

Management and funding of the rockburst project, over a five-year period, is on a tripartite footing. The Government of Canada, through the Canada Centre for Mineral and Energy Technology (CANMET), provides staff to operate the project. The Government of Ontario, through the Ministry of Northern Development and Mines and the Ministry of Labour, provides funds for equipment and services. The Ontario mining industry, through Denison Mines Ltd., Falconbridge Ltd., Inco Ltd., Lac Minerals Ltd., Placer Dome Inc. and Rio Algom Ltd., contributes its existing microseismic systems, assists in the installation and operation of new equipment and provides data on rockbursts at its mines.

The project is overseen by a Management Committee, which consists of representatives from the three sponsoring organizations and is chaired by C.H. Brehaut, Senior Vice-President of Placer Dome

Inc. A Technical Committee, chaired by Dr. D.G.F. Hedley of CANMET, reviews and approves the research plans. During 1987–88, quarterly meetings of the Technical Committee were held in Ottawa, Montreal, Copper Cliff and Toronto. Present membership on both committees is listed in the Appendix.

RESEARCH ACTIVITIES

The research being done by CANMET and the mining companies is reviewed in the following sections along with the research plans for 1988–89.

RED LAKE MINES

The objective of the research at Red Lake is to develop techniques that allow safe and efficient recovery of crown pillars in narrow, steeply dipping orebodies using cut-and-fill and longhole methods with cemented tailings.

The seismograph station at Red Lake was installed in May 1987 at the old Madsen minesite, about 16 km from both the Campbell and Dickenson Mines. Although the station has recorded naturally occurring earthquakes, no mining-induced seismicity has been recorded. Similarly, no large seismic events have been recorded during the same time on Campbell Mine's microseismic system.

During 1987, Campbell Mine upgraded its microseismic system to 64 channels using accelerometers. Under the Rockburst Project, a 16-channel waveform recorder was purchased. While awaiting delivery of the triaxial geophone, this recorder was connected to the microseismic system and provided additional information on first-arrival times.

Overhand cut-and-fill is the main stoping method used in rockburst-prone ground at the Campbell Mine. Local strain bursts frequently occur within 1 to 3 m above the roof. Perimeter blasting, in an arch configuration, is used to alleviate this problem. When the stopes are more than 3 m wide, 5-m long Swellex bolts, in addition to the standard mechanical rockbolts, are installed to provide pre-pinning for the next lift. Trials have also been done using Swellex bolts, wire mesh and steel cables in a lacing pattern. In this case, the steel cable is placed alongside the Swellex bolt in the borehole and anchored in the same operation.

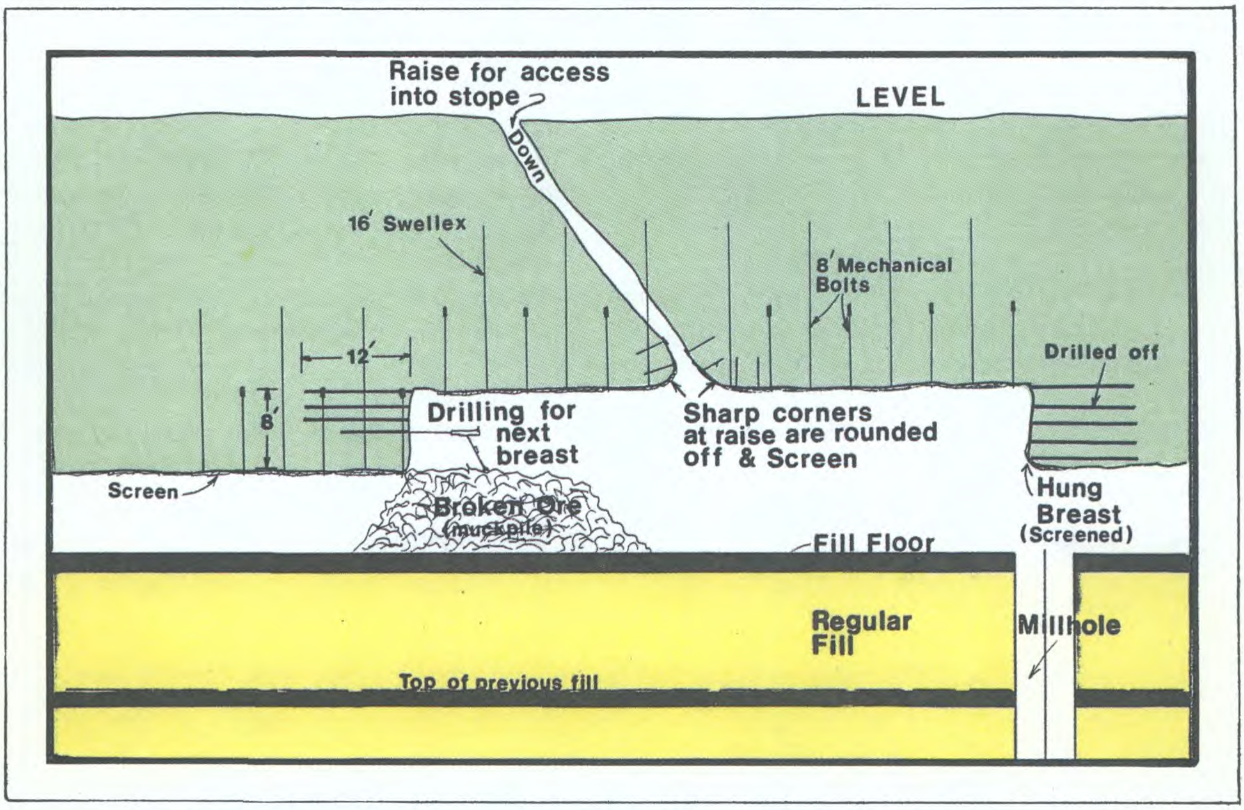
Through back analysis of previous pillar rockbursts, it was determined that the critical pillar thickness is about 6 m for mining above the 20 level (1000 m) and will increase with increasing depth. Conventional overhand cut-and-fill is stopped when the crown pillar is 10 to 13 m thick. A pillar mining scheme is then developed to take the remaining ore by either longwall, longhole or undercut-and-fill techniques. Pillar destressing has been applied effectively at the Campbell Mine.

Research Plans 1988–89

a) Install five triaxial geophones at the Campbell Mine connected to a Gould waveform recorder and computer. This system is designed to record complete waveforms of the larger seismic events.

b) Conduct field trials on the response of various types of support systems to impact loading. The first trial will compare peak particle velocity imposed on various supports by explosive charges at

Trial installation of Swellex bolts with steel cables at the Campbell Red Lake Mine.



Support practices in wide stopes at the Campbell Red Lake Mine.

fixed distances. The second trial involves supporting sections of a drift with two to three support systems and subjecting the drift to close-in explosive charges. These trials are also part of the Mining Research Directorate program.

ELLIOT LAKE MINES

The objectives of the research at Elliot Lake are to establish whether the hanging wall is caving above the rockburst area at Quirke Mine and to monitor the spread of seismic activity at both the Quirke and Denison Mines. Also of interest is the contract research being done by Denison Mines Ltd. on the use of backfill to control violent pillar failure.

During 1987, the seismograph station at Elliot Lake was calibrated against the Eastern Canada Seismic Network, operated by the Geophysics Division of the Geological Survey of Canada. Thirty-one seismic events of known magnitude at Quirke and Denison Mines were used. Correlation is based on the time duration (coda) of the seismic signal. This coda relationship is now used to assign magnitudes of seismic events in the range of 1.0 to 1.9 at Elliot Lake, while still relying on the regional network for magnitudes 2.0 and greater. In 1987, there were 46 events of magnitudes between 1.0 and 1.9 and 8 events of magnitude 2.0 and greater. About 70% of these events occurred at Quirke Mine and the remainder at Denison Mine.

Rio Algom Mines

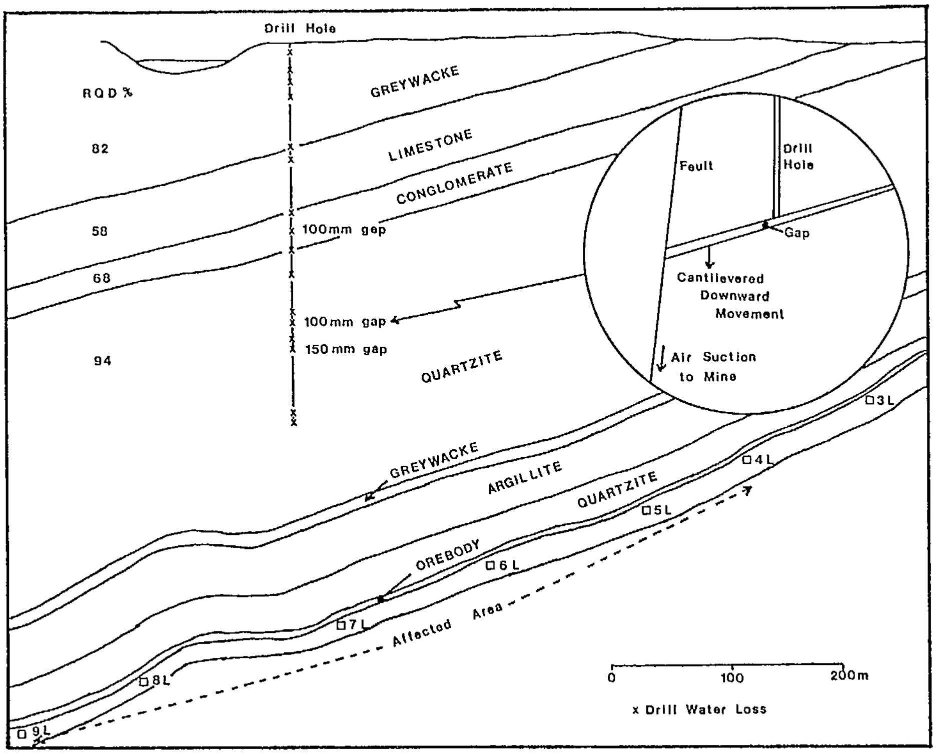
In 1984 and 1985, Rio Algom's Quirke Mine was the most seismically active mine in Ontario. Pillar failures were occurring over an area 1100 m on strike by 600 m on dip. Eventually, the hanging wall could no longer span the affected area and fracturing progressed through to surface. Subsequently, seismic activity decreased dramatically, and there has been no significant increase in the size of the affected area. In 1987, the mine's microseismic system averaged only one event per day compared to more than 100 events per day in September 1984. Only two events of magnitude greater than 2.0 were recorded.

The manner in which the hanging wall has fractured, whether by physical caving or movement along major structural planes or a more general fracturing of the rock mass, is of interest. A previous attempt at diamond drilling in 1986 indicated that lateral slippage was occurring along the bedding plane contacts.

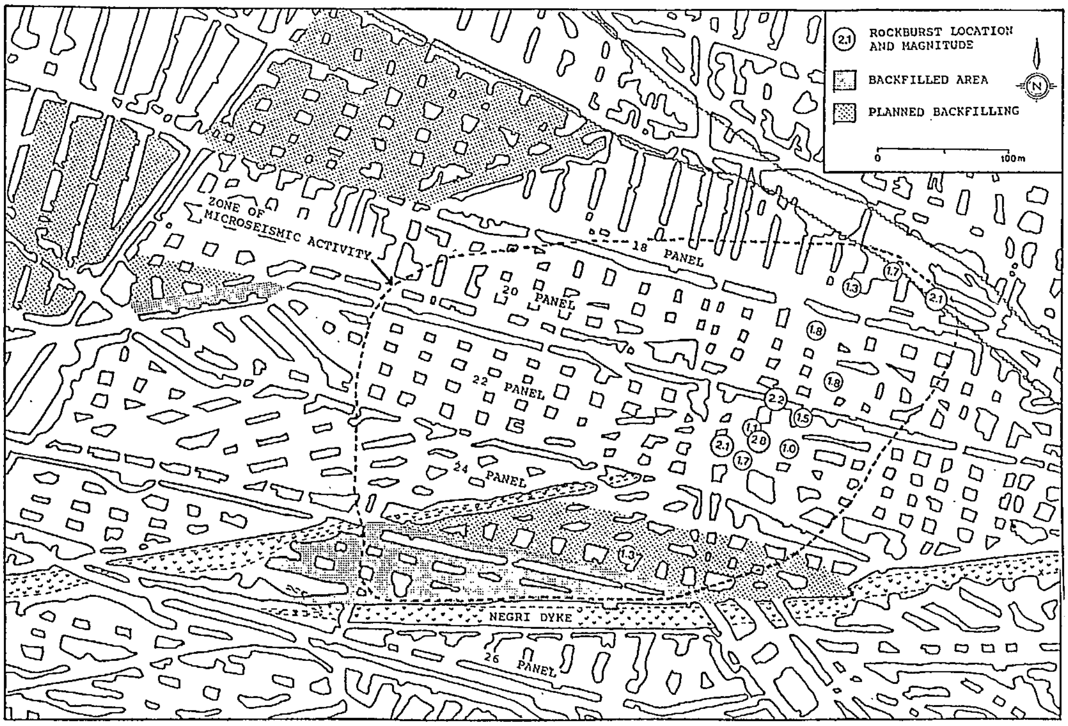
A new diamond drill hole, directly over the centre of the affected area, was drilled from surface in February 1988. Drilling progressed to a depth of 317 m, about 170 m above the orebody, before the hole was abandoned because of water-loss problems.

Two types of open fractures were encountered. Down to a depth of 150 m, water circulation was lost at eight locations, which were mainly minor open fractures on bedding contacts. At a depth of 155 m, a 100-mm wide gap was encountered. Also, air was being sucked down the borehole with sufficient force to produce a howling sound. This established the presence of an open vertical fracture(s) between the mine workings and the beds 355 m above. Similar open gaps of 100 mm and 150 mm were encountered at depths of 234 m and 255 m, as well as six minor fractures.

It is postulated that caving is confined to the first few metres of the hanging wall. For the next 350 m, extremely large slabs are moving down along vertical faults in a cantilever fashion. The top 150 m is subsiding without major vertical fractures.



Cross section through the rockburst area at Quirke Mine showing locations of open fractures in the hanging wall and possible mechanisms of movement.



Plan of Denison Mine in the Negri Dyke area showing the location of large seismic events and the zone of microseismic activity. Backfill is being placed to confine the affected area.

The macroseismic system, developed under contract by the Noranda Research Centre, was installed on surface above the rockburst area of Quirke Mine in March 1987. During the summer of 1987, all the triaxial accelerometer sensors were destroyed by lightning. They were replaced by triaxial velocity gauges, which were given improved lightning protection. About 30 seismic events, in both Quirke and Denison Mines, have been recorded by this system. The waveform data have been analyzed to give peak particle velocity, seismic energy, seismic moment and source parameters.

Denison Mine

Two areas of Denison Mine are seismically active: one directly down-dip from the main rockburst area at Quirke Mine and another north of the Negri Dyke about 2 km to the east.

The boundary pillar area with Quirke Mine has been extensively backfilled with deslimed tailings and cementitious slag, in a ratio of 30:1. As in the previous year, all the seismic activity is occurring at the edge of the backfilled area. This provides additional confirmation of the stabilizing effect of the backfill.

Recovery of rib pillars between backfilled stopes is being conducted down-dip of the boundary pillar area. Some seismic activity has accompanied this pillar recovery, especially during the last few cuts. Denison Mines Ltd., in conjunction with the Mining Department of Queen's University, is measuring pillar stresses and monitoring ultrasonic emissions in this area.

The area north of the Negri Dyke was mined in the mid-1970s using a room and pillar layout. The first recorded rockburst was in September 1984. It was observed that the slender panel pillars were deteriorating. This pillar deterioration has subsequently intensified and expanded in areal extent. Broken rock bolts, floor cracks up to 5 cm wide, floor heave and the occasional roof fall have also been observed. An interesting phenomenon is the apparent slippage of the hanging wall in an up-dip direction relative to the footwall.

At the end of October 1987, the area became seismically active. Over a two month period, microseismic activity averaged 10 events per day, and 13 events were recorded by the Elliot Lake seismograph; the largest event had a magnitude of 2.8.

Computer models used to assess pillar stresses and stress transfer in the affected area indicated the potential of pillar failures. Because of the success of pillar stabilization with backfill in the boundary pillar area, this method was implemented. Pours of backfill with slag were started in January 1987, directly up-dip of the Negri Dyke. Also, a 32-channel microseismic system was installed around the area. This system greatly assisted in determining seismic source location and trends in the expansion of seismic zones.

The affected area, about 300 m in diameter, is bounded to the south by the Negri Dyke, and to the northeast by a relatively large fault-zone pillar. Denison Mines Ltd. has started to backfill the stopes on the northwest side of the area to create a backfilled corridor about 120 m wide.

Panel pillar at Denison Mine. The hanging wall appears to have moved up-dip relative to the footwall.

Stabilization of pillars with backfill in the Negri Dyke area of Denison Mine.

Research Plans 1988-89

a) Continue to monitor seismic activity using the surface macroseismic system above Quirke Mine. Using waveform analytical techniques, evaluate the mechanism and attenuation characteristics of these events.

b) Monitor seismic activity in the Negri Dyke area of Denison Mine and the effect of backfill on areas of seismic activity. The Mining Department of Queen's University is investigating ultrasonic emission as a method of determining stress levels in pillars and their rockburst potential.

SUDBURY MINES

The objective of research at Sudbury is to determine the causes and mechanisms of rockbursts using waveform analysis techniques, and to evaluate methods of alleviating or limiting their damaging effects.

The third seismograph station was installed in May 1987 on the north rim of the Sudbury Basin. A direct data link connects Science North in Sudbury to the Geophysics Division of the Geological Survey of Canada for continuous transmission of seismic data. A person was hired to run the network operating out of the Geophysics Division.

About 250 events per month originating within the Sudbury Basin are recorded by this network. Blasting accounts for 84% of the events; the remaining are mining induced, although only about half of these events can be accounted for by the microseismic systems at individual mines. Preliminary evaluation of first motion, on some of the very large seismic events, has been carried out using the Sudbury network and other stations in the Eastern Canada Seismic Network. In one particular case, first motion was consistent with a thrust fault mechanism driven by eastwest compressive stresses.

Falconbridge Mines

A thorough study of the 1984 fault-slip rockbursts at the Falconbridge No. 5 shaft was planned for 1987. However, the imminent closure of the adjacent East Mine (access via No. 5 shaft) and significant "overprinting" of subsequent slippage on the original faults led to the abandoning of this project.

At the Lockerby Mine, microseismic activity, including three rockbursts, increased significantly in early 1988. This activity was centred in the north wall granites near an ore pass. Minor damage was contained by the previously installed cable lacing. This ore pass has been the source of seismic activity over the past few years and has enlarged to about 16 m in diameter in some places.

Microseismic activity associated with mining a blasthole stope at the Strathcona Mine was monitored by the Geological Sciences Department of Queen's University. Geotomographic imaging and whole waveform microseismic systems were used. A period of about 24 hours of increased activity was observed after each production blast, and the area became more active as mining advanced. Hypocentres clustered generally above the stope in the footwall gneiss, rather than along prominent structures in the vicinity. First motion data indicated that the recorded events were generated by a shear mode of failure at the source.

The macroseismic system was installed around the Strathcona Mine in 1987. Three of the triaxial accelerometers are on surface, and the other two are underground on the 2375 and 2750 levels.

Seismic data are stored in a computer on surface and transferred, via modems, to CANMET's Elliot Lake Laboratory for analysis. This system is designed to record only the larger seismic events of magnitude 1.0 and greater. So far, 12 events have been recorded. Preliminary analysis indicates a slippage mechanism.

Rockbursts associated with sill pillars in the narrow-vein mining of Strathcona's copper zone have been investigated using numerical models. Severe bursting (Mn >2.5) appears to correlate with pillar stresses in the range of 135 to 165 MPa. Microseismic activity also showed an increasing number of events with these predicted stress levels. At stresses in excess of 165 MPa, mine pillars appear to shed load, assuming that the subsequent decrease in their microseismic activity is an indication of a yielded state. Post-failure models may be needed in the late extraction stages of mining (i.e., after 85% extraction).

Since fault-slip appears to be the dominant rockburst mechanism in Falconbridge Mines, a preliminary study on induced "controlled" slip by pressurized fluid injection was initiated. Numerical modeling of the Strathcona sill pillar extraction and prominent structures indicated a possible theoretical advantage in applying this technique: stress regimes can be modified significantly by pressures of about 20 MPa over a 100-m radius. The practical feasibility of injection will be investigated.

Inco Mines

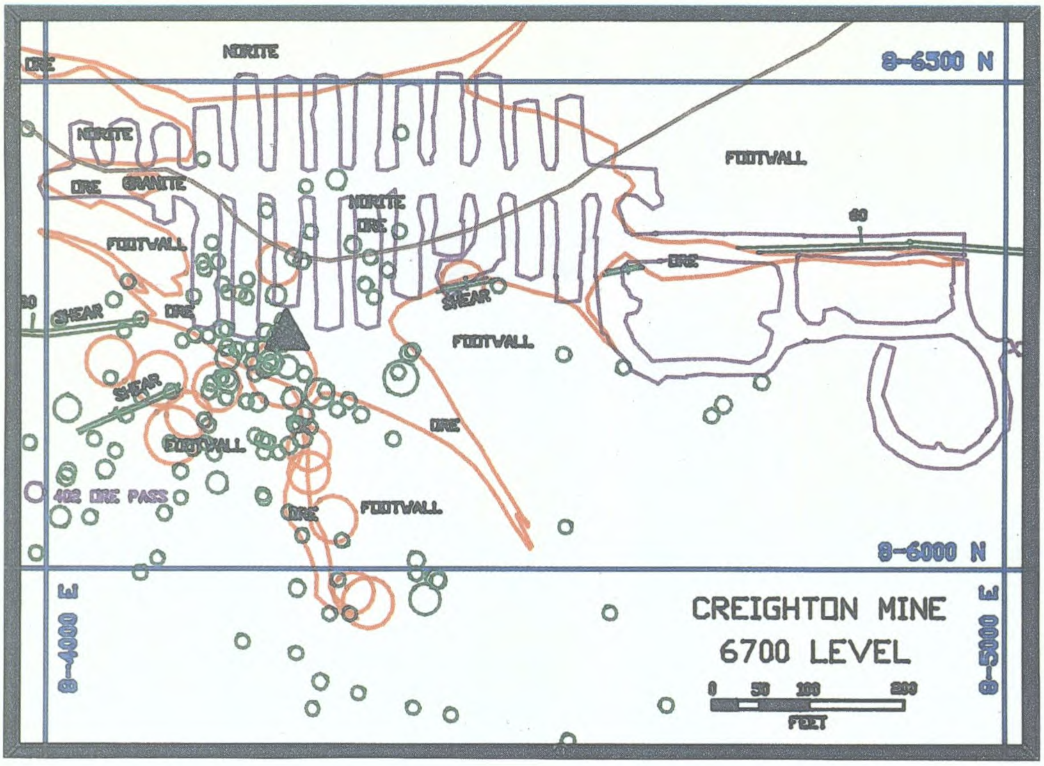
During 1987, four microseismic systems were in operation at Inco's mines (Creighton, Copper Cliff North, Garson and Stobie).

Creighton Mine is the most seismically active mine. During 1987, there were 14 events of magnitude 2.0 and greater. Over the last few years, the area of seismic activity has moved progressively to greater depth, reflecting present mining activity. It is becoming increasingly clear that the large events are often occurring on geological structural planes such as shears and dykes, and more often than not in the wall rocks. The largest event in 1987 had a magnitude of 3.6 and was located about 15 m in the footwall on a prominent shear zone.

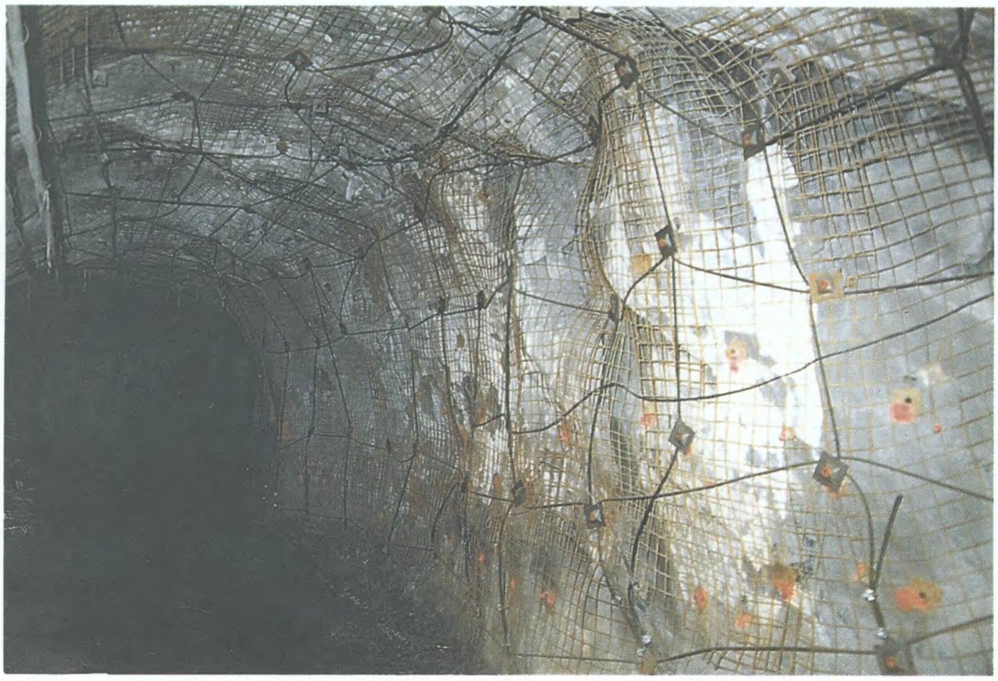
In view of the increased seismic activity at depth, a tightly clustered microseismic system is being deployed between 6600 and 7200 levels, and within the existing microseismic system. Funds for this dense array are being provided by Inco and the Rockburst Project. Also covering the same area will be the five-station macroseismic system, although at a greater distance (i.e., 500 to 1000 m) from the orebody. In 1987, this system was designed and the components ordered; the installation is scheduled for 1988-89.

At the Copper Cliff North Mine, 11 events of magnitude 2.0 and greater were recorded in 1987. These events tended to occur in swarms, specifically in early September 1987 and again in December 1987. In general, seismic activity is associated with active vertical retreat stoping between the 3400 and 3600 levels. Lacing is being used at the mine to support the development openings from rockburst damage. In this case, welded wire screen is held against the rock using 2-m long split sets. Steel cable in a square pattern is tensioned against the wire screen by driving a short 45-cm long split set inside the longer split set.

Microseismic activity continued at a low level at Garson after the mine ceased production in 1986, but no major events have occurred. In June 1987, the processing unit was used to replace a damaged unit at the Creighton Mine.



Seismic activity around the 6700 level at Creighton Mine on October 27, 1987, showing events associated with structures. The triangle marks the location of the 3.6-magnitude event, and the various sized circles indicate the relative magnitude of the associated events.



Lacing support of development drifts at the Copper Cliff North Mine. The steel cables are anchored by driving a short split set within the original longer split set.

Research Plans 1988-89

a) Continue to operate the seismograph network in the Sudbury Basin, primarily to determine event magnitude and location; and use the data in conjunction with the macroseismic system to evaluate source mechanisms.

b) Continue to monitor seismic activity using the macroseismic systems around the Strathcona Mine, with waveform analysis.

c) Conduct tomography studies at the Strathcona Mine and record three-dimensional waveforms on small seismic events. This will be done by the Geological Sciences Department of Queen's University.

d) Complete installation of the macroseismic system around the Creighton Mine at depth. Being a new system, it will require debugging and calibration.

e) Complete installation of a dense geophone array around the destress slots in the crown pillars of the 6800 and 7000 level stopes at Creighton Mine. This research will be carried out by Inco Ltd.

KIRKLAND LAKE MINES

The objective of the research at Kirkland Lake is to develop techniques that allow safe and efficient recovery of crown pillars in narrow, steeply dipping orebodies, using cut-and-fill methods with waste rock backfill and cemented rockfill. As such, it complements the research at the Red Lake mines, although the backfill material is different and the mine workings are at a much greater depth (down to 2200 m).

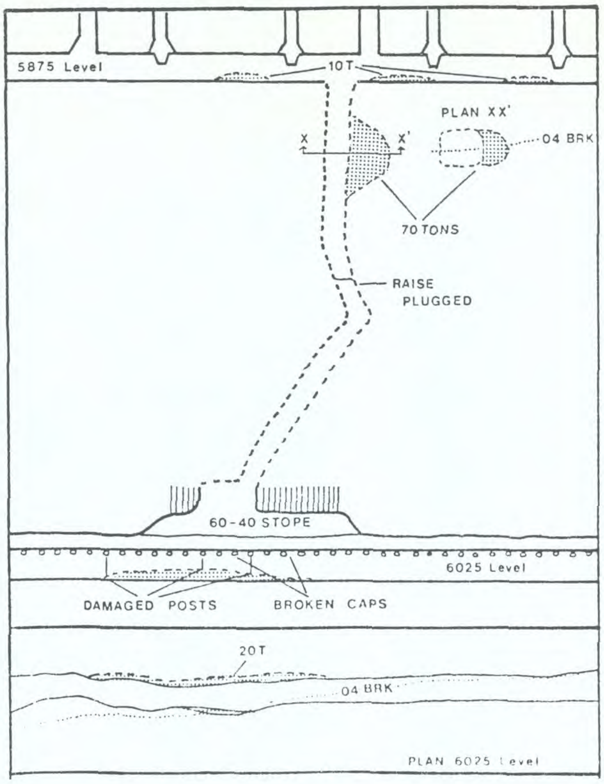
The seismograph station at Kirkland Lake was installed in June 1987, next to the airport, some 12 km from the Macassa Mine. However, there was a one-year delay in connecting the dedicated phone line to the mine.

In 1987, Macassa Mine installed a microseismic system with a capacity of up to 48 channels. This system provides coverage between the 4750 and 6450 levels at the west end of the mine around the new No. 3 shaft. One of its prime functions is to monitor any seismic activity in the shaft pillar.

Over a six-day period in April 1987, five rockbursts occurred at the Macassa Mine. Most of these events were in the pillars surrounding a previous destress blast, and considerable damage was reported. In 1987, the mine introduced cemented rockfill, having a cement content of 5%, initially in selected stopes and then in the majority of active stopes. It is felt that the major advantages of cement rockfill are that it limits sidewall convergence and reduces the magnitude of a burst, which in turn reduces the dynamic loading and damage of ground support. The need for extensive rehabilitation of timber sets supporting previously unconsolidated rockfill is eliminated. In addition, cemented rockfill has allowed the mine operators to introduce new mining methods, such as underhand cut-and-fill and a modified Avoca-type longwall method, for recovery of rockburst-prone crown pillars.

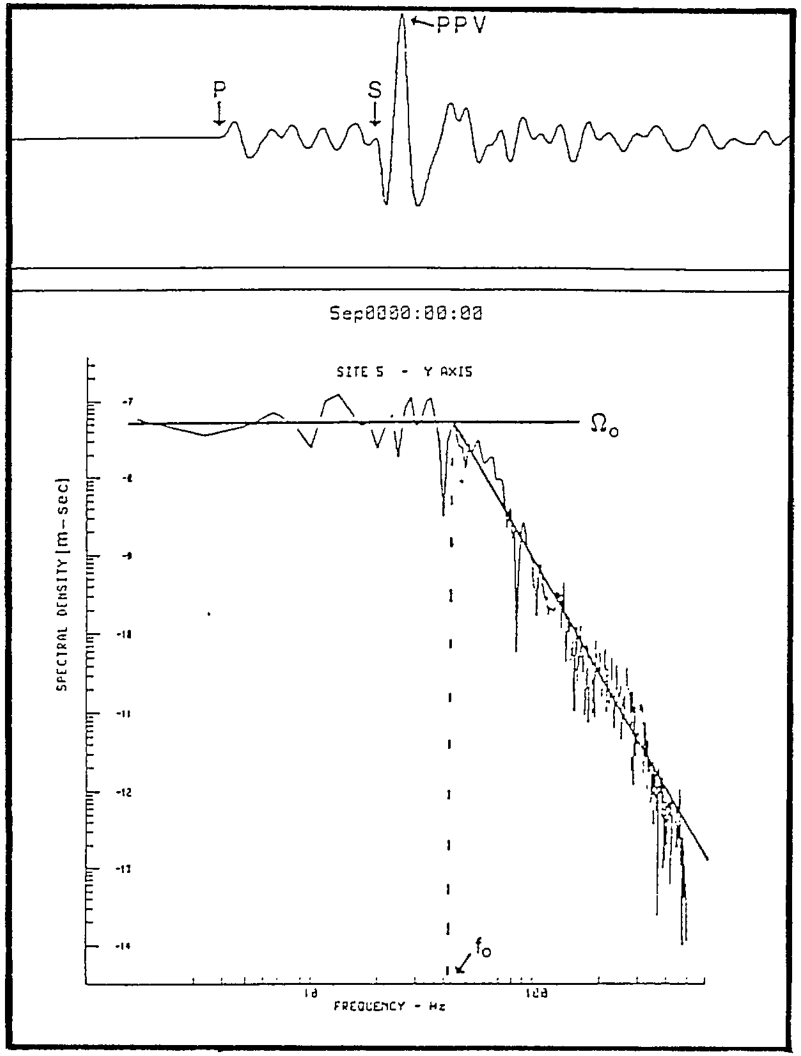
Research Plans 1988-89

a) Connect the previously installed seismograph at Kirkland Lake to the Macassa Mine with a dedicated phone line.

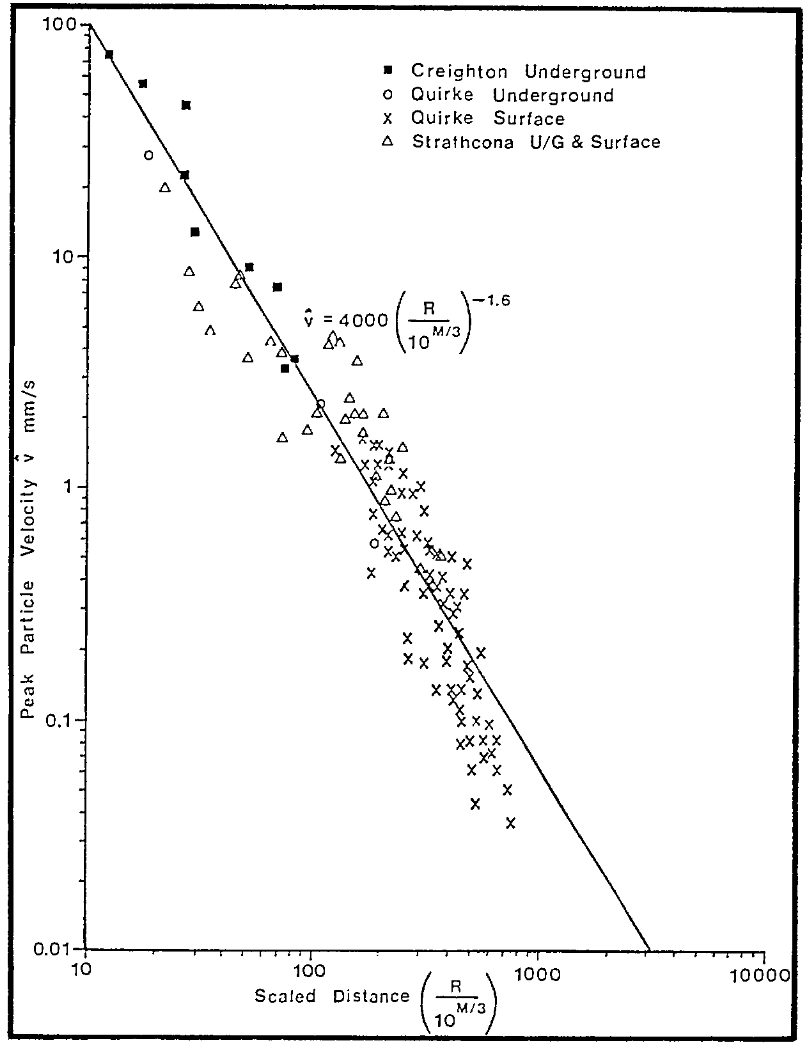


Damage caused by a 2.2-magnitude rockburst, during early stages of stope development at Macassa Mine.

Effects of a 2.5-magnitude rockburst in a waste pillar on the 5600 level at Macassa Mine. More than 400 t of rock were displaced and the drift closed over a distance of 15 m. Note: linked-wire mesh and 2.4-m mechanical bolts held.



Typical waveform with associated displacement spectral density illustrating peak particle velocity, P- and S-wave arrival, first motion, corner frequency and plateau.



Peak particle velocity from seismic events at Quirke, Creighton and Strathcona Mines. Particle velocity is adequately represented as a function of cube root scaled distance, using a blasting format.

b) Complete the installation of five triaxial geophones at Macassa Mine connected to a Gould waveform recorder and computer. This system is designed to record complete waveforms of the larger seismic events.

c) Carry out seismic velocity calibration using a waveform recorder.

d) Install fill pressure cells and convergence meters to measure the in situ properties of cemented rockfill.

BASIC STUDIES

The purpose of these studies is to provide an overview of rockburst activity in Ontario mines, to be aware of rockburst research in other organizations and other countries, and to conduct fundamental research on methods of source location, measurement of seismic energy and mechanisms of rockbursts.

With the installation of the new macroseismic systems, which have triaxial sensors and capture complete waveforms, a standard method of analysis was developed based on techniques used in seismology.

Both velocity gauges and accelerometers are used in these systems. Raw data from the latter are first integrated to obtain velocity. Vector sum peak particle velocity for each triaxial sensor is obtained from these waveforms. Integration of the squared velocity signal gives the seismic energy liberated. The direction of first motion, whether towards or away from the source, is also obtained from the velocity waveform.

The analysis is then switched from the time to the frequency domain. The spectral density of the displacement waveform is plotted against frequency in a log-log format. Two important parameters are obtained from this graph. The plateau at low frequencies is related to the seismic moment, which is a measure of the size and magnitude of a seismic event. The corner frequency, between the plateau and the sharp drop in spectral density at high frequencies, is related to the size of the source. A simple circular fault model is used to calculate radius of movement, stress drop and average slippage. All these parameters are obtained by the operator working interactively with the computer.

The peak particle velocity of seismic events at Quirke, Creighton and Strathcona Mines has been correlated with magnitude and distance from source. An adequate relationship exists using a common blasting format with a cube root scaling factor. Prediction of peak particle velocity is the first step in assessing the damage caused by rockbursts.

The first analysis using seismic waveforms to evaluate source parameters has been done for seismic events at Quirke and Denison Mines. Relationships between seismic energy and magnitude, for those events close to the sensor array, are in agreement with South African experience. The seismic moment-magnitude relation is similar to that for earthquakes in the Canadian Shield. Stress drop values are in line with those obtained elsewhere.

A historical review of rockburst occurrences and research in Ontario mines was completed in 1987-88. In the 1940s, an understanding of the rockburst problem and the development of practical means of dealing with it were achieved. The key elements missing in understanding the rockburst problem were the presence of high horizontal stresses, the change in potential energy of the rock mass as the driving force and fault-slip as a source mechanism.

Research Plans 1988-89

a) Because the evaluation of waveform data from rockbursts in Ontario mines is still in its infancy, establish relationships between source parameters observed in other parts of the world as well as the consistency, reliability and usefulness of the data.

b) Prepare four more draft chapters of the Rockburst Handbook for Canadian Mines. These would cover destressing techniques, rockburst seismology, seismic monitoring systems and rockburst predictions. Contributions will be made by Placer Dome, Lac Minerals, Inco and Falconbridge as well as CANMET. The chapter on rockburst prediction will likely be contracted out.

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APPENDICES

APPENDIX A

Rockburst Project Management Committee

C.H. Brehaut – Placer Dome Inc., Chairman
C. Barsotti – Inco Ltd.
M. Musson – Falconbridge Ltd.
J.B. Gammon – Ontario Ministry of Northern Development and Mines
P.V. Kivisto – Ontario Ministry of Labour
M.D. Everell – Energy, Mines and Resources Canada
J.E. Udd – Energy, Mines and Resources Canada

APPENDIX B

Rockburst Project Technical Committee

D.G.F. Hedley – Energy, Mines and Resources Canada, Chairman
C.G. Graham – Mining Research Directorate, Secretary
D. Ames – Ontario Ministry of Labour
W.J. Logan – Ontario Ministry of Northern Development and Mines
P. MacDonald – Inco Ltd.
A. Makuch – Placer Dome Inc.
S.N. Muppalaneni – Rio Algom Ltd.
W.J.F. Quesnel – Lac Minerals Ltd.
G. Swan – Falconbridge Ltd.
P. Townsend – Denison Mines Ltd.

APPENDIX C

Energy, Mines and Resources Personnel Involved in the Project

*Dr. J.E. Udd, Director, Mining Research Laboratories (MRL), CANMET
Dr. D.G.F. Hedley, Research Scientist, MRL, CANMET
*Dr. B. Arjang, Research Scientist, MRL, CANMET
Dr. J. Niewiadomski, Post-doctorate Fellow, MRL, CANMET
Mr. P. Rochon, Ground Control Engineer, MRL, CANMET
**Mr. D.S.G. Hanson, Ground Control Engineer, MRL, CANMET
Mr. T.J. Semadeni, Ground Control Engineer, MRL, CANMET
Mr. W. Ropchan, Electronics Technologist, MRL, CANMET
Mr. D. Lebel, Electronics Technologist, MRL, CANMET
Mr. M. Plouffe, Seismology Analyst, MRL, CANMET (attached to Geophysics Division, Geological Survey of Canada)

*Part time
**Now with Falconbridge Ltd.

APPENDIX D

Equipment and Services Ordered in 1987-88 (Funds provided by the Ontario Ministry of Northern Development and Mines)

Accessories for Strathcona macroseismic system	$ 32,810
Dense microseismic array for Creighton Mine	113,000
Macroseismic system for Creighton Mine	122,000
Computers and triaxial sensors for Campbell and Macassa waveform recorders	90,650
Electronic equipment	4,200
Diamond drilling at Quirke Mine	60,000
Software programs	12,000
Computer service account	40,000
	$474,660

Canada