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ROCKBURST RESEARCH IN CANADA - 1987

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Mining Research Laboratories

January 1987

MINING RESEARCH LABORATORIES
DIVISIONAL REPORT MRL 87-1 (TR)

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by

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ABSTRACT

Rockbursts have occurred in the mines of the Province of Ontario for nearly sixty years. After nearly two decades of diminished rockbursting, however, the problem has once again attained major importance. As a result, research efforts have been intensified in several directions.

In this paper, the authors present an overview of the rockburst research which is in progress in Canada.

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Keywords

Rockbursts, Research, Seismic, Microseismic, Macroseismic, Mine Monitoring, Canada, Ontario, Sudbury, Elliot Lake, Underground Mines

RECHERCHE SUR LES COUPS DE TOIT AU CANADA - 1987

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RESUME

Depuis près de soixante ans des coups de toit se produisent dans les mines de l'Ontario. Toutefois, la fréquence des coups de toit avail diminué depuis deux décennies, mais le problème a de nouveau atteint une importance considéerable. Par conséquent, les efforts consacrés à la recherche ont été intensifiés dans plusieurs directions.

Dans la présente communication, les auteurs donnent un aperçu de la recherche qui se déroule actuellement au Canada sur les coups de toit.

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Mots-clés

Coups de toit, recherche, sismique, microsismique, macrosismique, surveillance minière, Canada, Ontario, Sudbury, Elliot Lake, mines souterraines

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INTRODUCTION

Wherever an underground opening is made in a stressed rock mass the pre-existing stresses are redistributed and concentrated. The speed with which these adjustments to the presence of an opening take place, and the physical results, are dependent upon the strength and deformational properties of the geological materials. In strong, hard, elastic, brittle rocks, it is not uncommon that an instantaneous concentration of stresses beyond the strength of the rock results in an explosive failure. Such events are known to hard rock miners as "rockbursts".

Rockbursts in underground mines result from the practices of extracting ores. The causes include excessively high stress concentrations on the boundaries of openings, sudden failures of supporting pillars, and movements along faults and other weaknesses. In all instances substantial energy may be released. Fault-slip bursts, however, are the most dangerous and damaging because of the larger masses of rock and changes in potential energy which can be involved. At the other end of the scale, the smallest bursts may take the form of "spitting" or "popping" as wall rocks dissipate excessive stored strain energy.

Pillar bursts occur when either increased loading or decreased strength causes a sudden failure. Both strain energy and potential energy are released; the latter being associated with rapid convergence between the hanging wall and footwall.

Of the 217 rockbursts (of magnitude 1.5 to 4.0 on the Richter Scale) which were recorded in Ontario mines during 1984-1985; 5% were classified as strain energy bursts; 81% as pillar bursts; and 14% as fault-slip bursts (1).

A BRIEF HISTORY OF ROCKBURSTING IN ONTARIO MINES

Rockbursts have occurred in Ontario mines since 1929, and possibly earlier (2). It was only in the mid 1930s, though, that the increasing numbers of such events began to cause concern in the mining industry. The Ontario Mining Association, in response to the needs of its member companies, formed a Rockburst Committee and, in 1940, engaged the late Professor R.G.K. Morrison (then Superintendent, Nundydroog Mines Ltd., Ooregum, Mysore State, South India) to study and report on the situation. His report (2), which is equally relevant in many respects to present-day practices, is a classic in the field. Known as the father of rock mechanics in Canada, he is credited with introducing the concepts of "doming" and "sequential mining" into Canadian practice.

At the time that Morrison's report was written, severe and frequent rockbursts were being experienced in the gold mines of Kirkland Lake, Little Long Lac, and the Porcupine District, as well as in the nickel-copper mines of the Sudbury basin. The underlying major causes were given as being: the sizes of mining excavations; the depths of mining; and the local rock types. The same list, with a few additions (to include: the shapes of openings; the pre-mining conditions of stress; and, the rates of mining), would apply today.

During the following four decades, roughly from 1941 to 1981, the occurrences of rockbursts in Ontario mines decreased greatly (Fig. 1) (3). The reasons certainly included improvements in mining practices and ground control measures, but it is also very significant that many of the rockburst-prone mines were closed for economic reasons during this period.

A notable exception in this long, relatively tranquil period, was the severe rockburst of May 5, 1964, which resulted in the closure of the Wright Hargreaves gold mine at Kirkland Lake, Ontario. The same event was also said to have been indirectly responsible for the closure of the adjacent Lake Shore Mine.

With seismic events having become much more frequent again in the early 1980's, however, the rockbursting problem has once again attained serious proportions. The principal reason is that a number of deposits are now in the final, or pillar recovery, stages of extraction. Additionally, however, mining production openings have become larger in order to benefit from economies of scale, and mining has progressed to greater depths. These factors have combined to create, once again, conditions which are favourable to rockbursting.

During the past four years, serious rockbursting has taken place in Ontario in the Elliot Lake, Sudbury, and Balmertown areas. The economic consequences have been very severe as one mine (Falconbridge) and major parts of others have been closed to production. The economic consequences, in Ontario, are estimated by us to be about $200 million per annum.

The most serious recent events have been:

1) <u>Elliot Lake</u>

In March, 1982, a major series of rockbursts occurred at the Quirke Mine, of Rio Algom Ltd., as the result of violent pillar failure. The mine is a room-and-pillar uranium operation in a gently-dipping strong and brittle quartz pebble conglomerate.

After a period of over two years, in which little further bursting took place, seismic activity resumed. Between September, 1984 and April, 1985 over 150 rockbursts were recorded in an area of the mine measuring 1100 m by 600 m. The hangingwall above the ore zone has now become fractured up to the surface - a distance of some 500 m. One of the evidences of this was the disappearance of a beaver pond during the spring of 1986 (Fig. 2). Most of the rockbursts in the Quirke Mine have been of the pillar burst type.

2) Sudbury

In mid-1984, two major series of rockbursts took place in important nickel-copper mines of the Sudbury area. In the first of these, in June, four miners were killed at the Falconbridge Mine when the mat above them collapsed as the result of seismic disturbances caused by slippage along an important fault. The mine, which was in the tertiary stage of mining, through recovery of the shaft pillar by undercut-and-fill methods, was immediately closed.

Just one month later, in July, a similar series of seismic events took place in the Number 5 shaft area of INCO's Creighton Mine. As the operations were in a period of vacation shut-down there were, fortunately, no injuries. Damage to the area of the bursts was substantial, however, and this section of the mine was closed to further production.

Subsequent to 1984, rockbursting has become a problem in other Sudbury-area mines, notably, INCO's North Mine and Falconbridge's Strathcona Mine.

3) Balmertown

In December, 1983, a major series of rockbursts took place in an area of sill pillars at the Campbell Red Lake gold mine. Damage was substantial and the mining of a complete ore zone was suspended.

ROCKBURSTING IN OTHER CANADIAN MINES

Much of Canada's hard-rock underground mining production is derived from the mines of the Province of Ontario. For this reason, and also conditions of local geology and mining methods, the rockbursting problem has, for the most part, been confined to that Province.

Nonetheless, occasional rockbursts occur at the lead-zinc operations of Brunswick Mining and Smelting, in New Brunswick, and in some of the potash mines in Saskatchewan. Isolated rockbursts have also been reported in the Val D'Or gold mining area of northwestern Quebec.

A BRIEF HISTORY OF ROCKBURST RESEARCH IN CANADA

Rockburst research in North America probably commenced with the pioneering work of Obert in the Ahmeek amygdaloidal copper mine of Michigan's Keweenaw penninsula (4). In the following year, he and his colleague, Duvall, studied the problem: at the Sunshine Mine, in Idaho; at INCO's Frood Mine, in Sudbury; and at the Lake Shore Mine, in Kirkland Lake (5). Their work led to the development of test equipment, and testing and analytical procedures (6,7).

On the Canadian side of the Canada-U.S.A. border, the pioneering work was done by Dr. E.A. Hodgson, of the Dominion Observatory, at the Lake Shore mine (8). For a period of about six years, considerable attention was given to the work.

In both the American and the Canadian efforts, attempts were made to apply geophysical methods of seismic monitoring to the rockburst problem. It was hoped that a means might be found of predicting the occurrences of rockbursts. While much progress was, and has been, made in identifying rockburst-prone areas in mines, the goals of prediction remain elusive today.

In fact, because of the speed of failure, prediction in time may never be feasible in the practical sense of being able to give a reliable warning. Prediction in space, however, through the identification of potentially high-risk areas, is thought to be attainable.

In the mid-1940's, the occurrences of seismic events in Canadian mines had decreased substantially. Concurrently, little success had been obtained in the use of geophysical methods for predictive purposes. For both of these reasons, there was little further development for several years.

In the mid-1960's, however, the United States Bureau of Mines undertook to improve the microseismic monitoring technique. The system which was subsequently developed by Blake (9) and others represents the state-of-the-art of the present technology (10). Systems based on the American design have, as the result of the problems of the past four years, now been installed in 13 mines in Ontario as well as one mine in Saskatchewan and one in New Brunswick. The units are manufactured by Electrolab, a firm located in Spokane, Washington.

A basic multi-channel microseismic monitoring system consists of a number of sensors (or, geophones) connected to an automatic monitoring system. This may be pre-set to calculate, through an algorithm, the location of the source of an assumed seismic event once a prescribed minimum number of geophones have received waves of first arrivals within a selected "time window". Once the time window is reopened the system is ready to record the next event.

Geophones, which may either be velocity gauges or accelerometers, are located around the volume to be monitored. The time interval which is usually selected for the "window" is that which would be required for a wave to pass diagonally through the array of monitoring sensors. This is to help ensure that only events which occur within the volume being monitored will cause a calculation sequence to be commenced. An algorithm which is commonly used causes the system to go into a calculation mode once 5 or more geophones have detected first arrival waves within 100 milliseconds. The pre-set values may, and are, adjusted to suit local conditions of installations.

No data goes into a buffer. One of the disadvantages of this type of system is that although the complete waveform signal from each sensor is transmitted to the processing unit only the arrival time of the P-wave is recorded. The rest of the information, which would be valuable for mechanism evaluation, is discarded.

Very large events, which can consist of a succession of several large tremors can cause such systems to become so swamped with data that all information is lost after a certain point. This has happened in 1984 during some of the large events in the Sudbury area. Unfortunately, when this does happen, it frustrates one's efforts to obtain the locations of the sources. From a mine stability monitoring point of view, it is essential that locations of tremors should be established as quickly as possible. Part of the solution to this problem lies in the development of a more powerful and intelligent system with real-time monitoring capabilities.

In the meantime, the large events are normally detected and recorded at at least some of the stations of the Eastern Canada Seismic Network, which is maintained for earthquake monitoring purposes by the Geological Survey of Canada. Data, which is recorded continuously on the drum recorders of the short-period seismographs installed at all such stations, are transmitted regularly to Ottawa for processing. Ultimately, the times and locations of major events occurring in mining localities can be established from these data. Unfortunately, because of the distances between the field stations, the accuracies of locations are not sufficiently precise for mine-monitoring purposes. There is also some delay in obtaining the data.

PRESENT THRUSTS IN ROCKBURST RESEARCH

Government

As the result of the seismic events which took place in Ontario mines, commencing in 1982, it became evident that an intensification of rockburst research was necessary. In May of 1984, at a consultative meeting between CANMET, industry, and representatives of the Ontario Government, this was identified as the highest priority.

The events which took place, in Sudbury, within the following two months emphasized the urgency of the needs.

During the following few months, a large number of meetings were held with representatives of the Government of Ontario and of the companies which had experienced severe rockbursting. The result was a proposal for a major tri-partite research project, in which each of the federal and provincial governments, and the industry would contribute funds and/or services in the amount of $1.4 million (11).

A Memorandum of Understanding was subsequently signed in September, 1985. Under it, CANMET will provide a team of 5 persons dedicated to the project for 5 years, together with operating funds. The Government of the Province of Ontario, will contribute up to $1.4 million over the five-year period for the purchase of capital equipment and services. The Industry of the Province of Ontario was requested to provide a matching contribution, with a value of up to $1.4 million, through the provision of monies, goods, and services, to the project.

Even at this early stage in the project, it is clear that more will be committed to the research than was originally visualized.

Given the needs of the industry for more rapid and precise mine monitoring, and the technological short-comings which have been identified, the research is proceeding along three lines:

1) To enhance the seismic monitoring capabilities in all mining camps. A very high priority is to develop a seismic monitoring system that will capture wave forms (as compared with triggered first arrivals) and provide information on first motion, peak particle velocity and seismic energy.

Ideally, an "intelligent" real-time system should be provided, with the software to permit automatic differentiation between signals originating from seismic sources and those being generated by other sources such as blasting, drilling, rock tumbling down ore and waste passes, equipment operating, and so on.

Another disadvantage of present technology is that waves arising from any kind of source can arm and activate a microseismic monitoring system. An ability to separate real events from "noise" would improve the operating efficiencies of systems and system operators enormously. We refer to this as an ability to recognize "footprint" signals.

There are many opportunities for research into the characteristics of signals arising from different sources, and in the development of intelligent sensors.

2) Even with the above, however, it is likely that local mine monitoring systems will be saturated by the signals coming from large rockbursts of magnitude 3.0 (Local Richter scale) or greater.

To alleviate that problem, it is planned to provide additional coverage to the Eastern Canada Seismic Network through the installation of seismograph stations in the major mining camps. Through the generosity of Denison Mines Ltd., a short-period seismograph has been installed in the Mining Research Laboratory of CANMET, at Elliot Lake. This is used to monitor events occurring both in Elliot Lake, and as far away as Sudbury.

In Sudbury, two additional stations are being installed in order to provide greater accuracy through finer scale triangulation (Fig. 3). Data from these stations will be transmitted via dedicated telephone lines to a computer located at Science North, in Sudbury, and also to the Geophysics Division of the Geological Survey of Canada, in Ottawa. Provision will be made to enable both of the companies operating in the Sudbury basin, INCO and Falconbridge, to gain access to the data through data ports. Seismograph stations will be installed at Red Lake and Kirkland Lake to provide coverage to these mining camps.

3) Between the seismic stations of the Eastern Canada grid at one end of the scale, and the local mine microseismic monitoring systems at the other, there is a need for an intermediate out-of-mine system having the capability of being able to record the complete waveforms of large seismic events. For such systems a small number of strong motion triaxial sensors are used as the geophones.

At present, macroseismic systems of this kind are being installed; at Falconbridge's Strathcona Mine and INCO's Creighton Mine, both in the Sudbury basin (Fig. 3); at Rio Algoma's Quirke Mine, at Elliot Lake; at Campbell Red Lake Mines, at Balmertown; and at the Macassa Mine, in Kirkland Lake. Waveforms from large local events will be stored on computers at these sites and down-loaded daily to CANMET's Elliot Lake Laboratory via telephone.

The objectives of the Canada/Ontario/Industry rockburst research project are to add to our knowledge of the causes, origins, effects, energy sources, and mechanisms of rockbursts.

The information to be derived from the three levels of monitoring systems mentioned will permit much greater accuracy in locating the origins of mining-induced seismic events. Macroseismic systems, in particular, will be very valuable when events occur outside of existing microseismic sensor arrays.

Likewise, the recording of waveforms will permit determinations of peak particle velocities and seismic energies liberated. This will add considerably to our knowledge of the driving forces and the mechanisms which may be involved.

The Mining Industry

During the past two years there has been a great increase in the number of microseismic monitoring systems installed in Canadian mines. At the time that the Canada/Ontario/Industry project was proposed, in late 1984, there were 6 systems operating and 3 others planned. At the time of this writing there are 15 systems in use: 13 in Ontario, and 1 each in New Brunswick and Saskatchewan. INCO and Falconbridge, in the Sudbury basin, now have systems installed at several of their mines.

The primary function of a mine microseismic monitoring system is to provide the locations and relative magnitudes of seismic events in real-time. After a rockburst has occurred the immediate concern of management is to determine the location and if there has been injury and/or damage. From an operator's viewpoint, understandably, research needs are secondary.

All of the mine operators are involved to greater or lesser degrees in the development of software and the addition of hardware which will improve the accuracy of calculations and facilitate the graphical portrayal of data. In the future, perhaps using CAD (Computer Assisted Design) technology, the location and magnitude of an event will be shown on monitor images of plans and sections (or isometrics) shortly after it occurs. For the present, however, because of the difficulties with the algorithms that have been mentioned, there is much checking of data and plotting to be done. Most mine operators are making efforts to improve the operating efficiencies of their systems.

The Canada/Ontario/Industry Rockburst Project, which has been described, is having a significant effect on this through providing an on-going forum by which systems operators can meet regularly and exchange information on both problems and solutions. The Project is guided by a Technical Advisory Committee, which includes as members representatives of the federal and Ontario governments and all Ontario companies operating mine microseismic monitoring systems. Meetings are held quarterly, and provide an invaluable opportunity for operators to compare their data and approaches to interpretations.

With a number of algorithms available, and numerous possibilities as regards computing systems and software, it can be appreciated that, without some standardization there would be little ability to compare results. The Technical Committee provides an opportunity to discuss matters of common concern and to obtain a consensus. In addition to CANMET/MRL and the Ontario Ministries of Labour and Northern Development and Mines, the mine operators participating in Ontario at present are: Campbell Red Lake Mine Ltd., Denison Mines Ltd., Falconbridge Ltd., INCO Ltd., Lac Minerals Ltd., and Rio Algom Ltd.

An important objective of the research is to relate rockburst activity to: mine design, the mining methods used, the sequencing of extraction, the local rock types, the depth of operation, and other factors.

Through understanding the causes of rockbursts the industry will be able to develop strategies which will minimize risks.

Equipment Designers and Manufacturers

Two Canadian organizations are presently involved in the design of improved systems for mine monitoring. These are completely complementary inasmuch as one system is intended for macroseismic monitoring applications, while the other is intended for use in underground mine microseismic monitoring. Both involve improved sensors and recent advances in communications, such as fibre-optics technology.

The first system mentioned, for out-of-mine local macroseismic monitoring is being developed by the Noranda Research Centre of Noranda Mines Ltd. An installation of the newly-developed system will be field tested at the Quirke Mine in Elliot Lake. The system will permit the recording of complete waveforms of large seismic events.

The second system, for in-mine monitoring, is being developed by Instantel Inc., of Kanata, Ontario. Involving tri-axial sensors with local microprocessors, fibre optic data transmission, more intelligent triggering algorithms, and dedicated computers, the system is intended to be the next generation of monitoring equipment. The installation of a prototype unit at an Ontario mine should take place in the not-too-distant future.

Both systems are being developed with financial assistance from the Government of Canada - the former through the Unsolicited Proposals Program of the Department of Supply and Services; the latter through the Projects for Industry/Laboratory Participation (PILP) program of the National Research Council. The first-mentioned author is the Scientific Authority on the Instantel project, while his co-author author is Scientific Authority for the Noranda work.

Academia

Research into some of the various aspects of rockbursting is underway at two Canadian universities; Queen's at Kingston, Ontario, and the University of Saskatchewan, at Saskatoon. At the former, there are projects in each of the Departments of Mining Engineering and Geological Sciences.

In the Queen's Mining Engineering Department, a team is studying the waveforms emitted from rock subjected to increasing loads. The intent is to determine, both in the laboratory and in the field, if the waveform characteristics can be used to establish load levels. Field work, to date, has consisted of monitoring at different locations which were known to have been subjected to different stresses. The initial results have been encouraging and point towards a different approach to monitoring.

In the Department of Geological Sciences at Queen's an attempt is being made to apply the principles of tomography to determining the integrity of a rock structure, such as a supporting pillar. If successful in detecting and permitting the mapping of fractures in large in-situ structures, the method might permit periodic rapid assessments of rock mass integrity. This would permit one to study the degradation of a rock mass, and to relate this to other factors such as loading, changes in conditions, and rockbursting.

At the University of Saskatchewan, a team is involved in the development of better monitoring systems for use in the local potash mines. Improvements include triaxial sensors, and approaches to the design of monitoring systems and analysis of waveform records.

SUMMARY

In this paper, a review has been made on the research into rockbursts which is presently in progress in Canada. The listing is impressive, including work by governments, the mining industry, the manufacturing industry, and academia. It is clear that the state of technological development has increased rapidly in a very short period, and that further very substantial gains can be anticipated. Much of the research in progress is the "world-class" level and is directed at developing the next generation of equipment and approaches.

The work is essential, for Canadian mines are progressing to greater depths. The economics of scale and mass production are dictating that openings must be larger and productions (or sites of mining advance) greater. All of these factors are forces towards rockburst-prone conditions.

Knowing this, some of the fundamental concerns must be addressed now.

ACKNOWLEDGEMENTS

The authors are grateful for the cooperation and assistance which they have received from their colleagues in industry, government, and academia during the evolution of new thrusts in rockburst research in Canada. In particular, the mining industry and the Government of the Province of Ontario must be thanked for their enthusiastic support of, and collaboration in, the major tripartite project which has been mentioned.

REFERENCES

1) Brehaut, C.H. and Hedley, D.G.F., "1985-1986 Annual Report of the Canada-Ontario-Industry Rockburst Project", CANMET Special Publication SP86-3E, ISBN 0-662-14984-X, Minister of Supply and Services, Canada, 1986.

2) Morrison, R.G.K., "Report on the Rockburst Situation in Ontario Mines", Transactions CIM, Volume XLV, 1942, pp. 225-272.

3) Pakalnis, Victor, "Strengths and Limitations of Microseismic Monitoring for Rockburst Control in Ontario Mines", Proc. 3rd Conf. on Acoustic Emission/Microseismic Activity in Geologic Structures and Materials, the Pennsylvania State University, October, 1981, Trans Tech. Publications, Clausthal, Germany, 1984, pp. 549-558.

4) Obert, Leonard, "Use of Subaudible Noises for Prediction of Rock Bursts", U.S Bureau of Mines, R.I. 3555, January 1941.

5) Obert, Leonard and Duvall, Wilbur, "Use of Subaudible Noises for the Prediction of Rock Bursts, Part II", U.S. Bureau of Mines, R.I. 3654, July, 1942.

6) Obert, Leonard and Duvall, Wilbur, "Microseismic Method of Predicting Rock Failure in Underground Mining, Part I, General Method", U.S. Bureau of Mines, R.I. 3797, February, 1945.

7) Obert, Leonard and Duvall, Wilbur, "The Microseismic Method of Predicting Rock Failure in Underground Mining, Part II, Laboratory Experiments", U.S. Bureau of Mines, R.I. 3803, March, 1945.

8) Hodgson, E.A., "Dominion Observatory Rock Burst Research 1938-1945", Vol. XX, No. 1, Publication of the Dominion Observatory, Ottawa.

9) Blake, W., "Microseismic Application for Mining - A Practical Guide", Final Report, U.S. Bureau of Mines, Contract No JO215002, July 1982.

10) Leighton, Fred, "Growth and Development of Microseismics Applied to Ground Control and Mine Safety", Mining Engineering, August, 1983, pp. 1157-1162.

11) Udd, John E., "A Proposal for a Major Research Project on Rockbursts", CANMET Division Report MRP/MRL 84-84(TR), December, 1984, 18 pages.

FIGURE 1

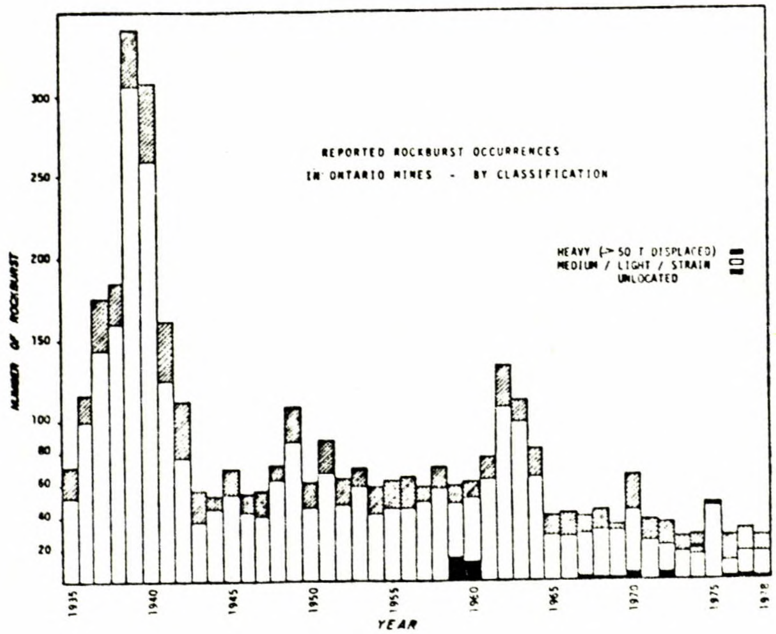
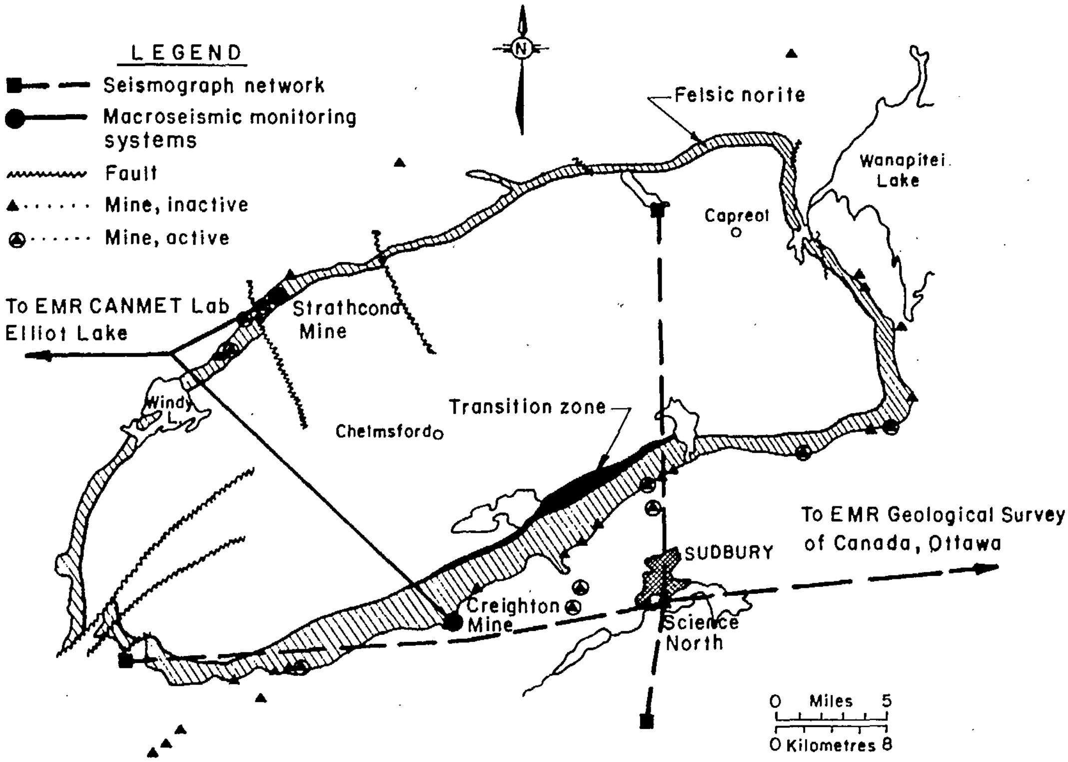


FIGURE 2

Hanging wall above a rockburst area fractured through to surface causing disappearance of a small lake.

FIGURE 3



Mine Locations in Sudbury Basin