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CATALOGUE OF ROCKBURST LITERATURE

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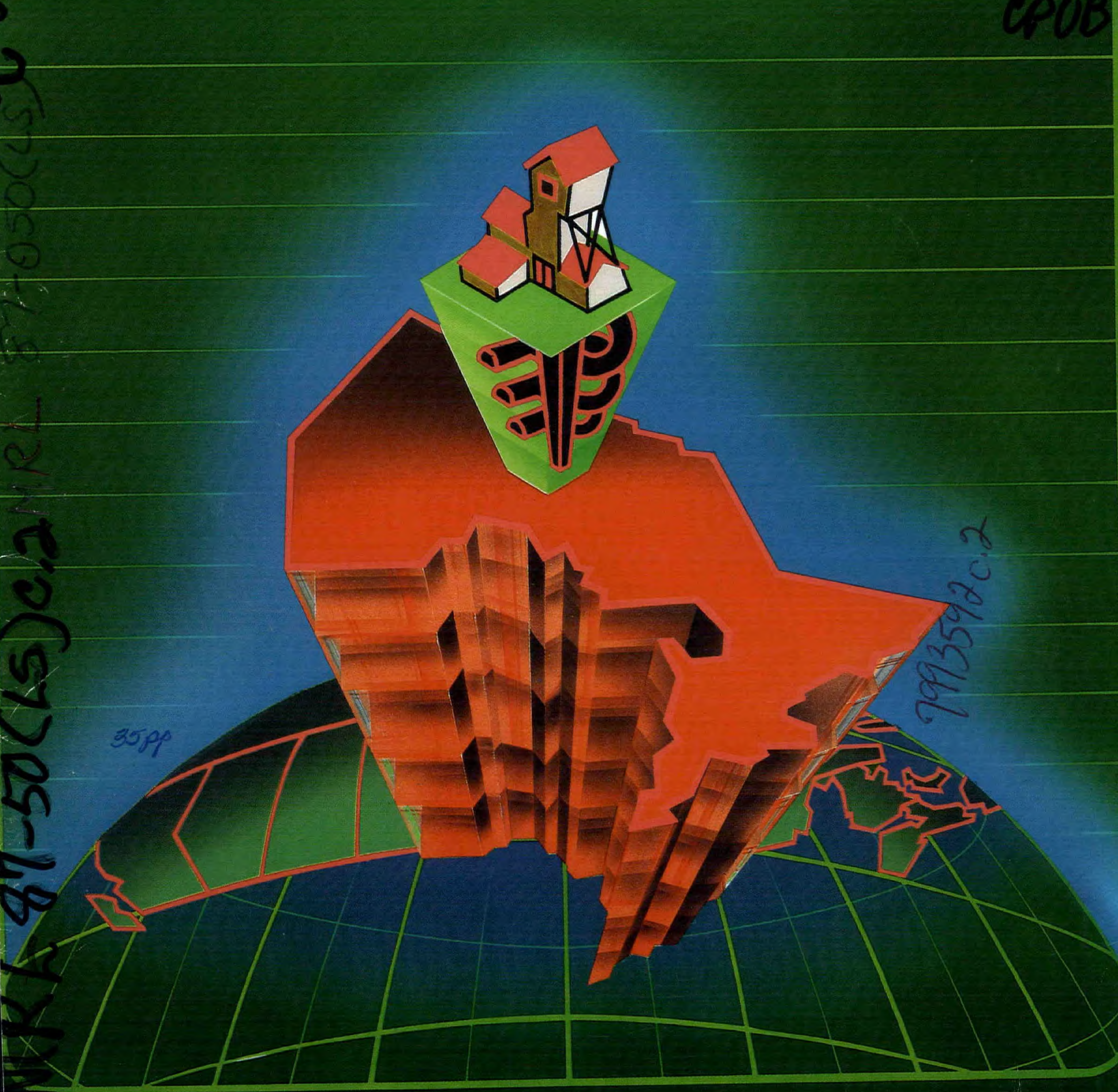

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CATALOGUE OF ROCKBURST LITERATURE

by

D.G.F. Hedley*

ABSTRACT

During the last century rockbursts have become a serious problem in deep hard rock mines. They have caused numerous fatalities and injuries, mine closures and abandonment of ore reserves. Scientific research to reduce the rockburst hazard has been undertaken in many countries including, South Africa, Canada, United States and India. Over 200 papers in the English language press are listed and categorized in this catalogue.

This report is a draft chapter of a "Rockburst Handbook for Canadian Hardrock Mines" being produced under the Canada/Ontario/Industry Rockburst Project.

Key words: Rockbursts; Seismology; Microseismic monitoring; Bibliography.

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CATALOGUE DE LITTÉRATURE SUR LES COUPS DE TOIT

par

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RÉSUMÉ

Depuis les cent dernières années, les coups de toit posent de sérieux problèmes dans les mines de roche dure profondes. Ces coups de toit sont la cause entre autres de nombreux accidents mortels, de blessures, de fermeture de mines et enfin, de l'abandon de gisements de minerai. Par conséquent, plusieurs pays dont l'Afrique du Sud, le Canada, les États-Unis et l'Inde font de la recherche scientifique dans le but de réduire les dangers de coups de toit. Le catalogue contiendra plus de 200 rapports publiés en langue anglaise et classés par catégorie.

Le présent rapport est un brouillon de l'un des chapitres du manuel sur les coups de toit dans les mines de roche dure au Canada "Rockburst Handbook for Canadian Hardrock Mines" préparé dans le cadre du projet de recherche conjoint Canada/Ontario/Industrie sur les coups de toit.

MOTS-CLÉS: Coups de toit; séismologie; surveillance microsismique; bibliographie.

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INTRODUCTION

Although mining has been carried out for at least a couple of millenia, rockbursts have occurred only over the last century. Improvements in mining technology, especially in explosives, hoisting, pumping and ventilation, allowed mines to go deeper into an ever increasing stress environment. Scientific articles on rockbursts are even more recent and are mainly confined to the last thirty years.

In this review only readily available English literature has been consulted, and only in respect to hard rock mines (i.e., coal and potash mines are not covered). Consequently, most of the literature is concerned with South African gold mines, metal mines in Northern Ontario, Canada, the Kolar Gold Fields in India, and the Coeur d'Alene mining district in Idaho, United States.

About 200 articles in the literature have been divided into several categories as follows:

a) General reviews and text books.

b) Rockburst mechanics.

c) Seismic monitoring and source location.

d) Rockburst seismology.

e) Rockburst alleviation.

f) Controlling rockburst damage and destressing.

g) Rockburst prediction.

h) Case histories.

For each category the literature is listed chronologically, then alphabetically within each year.

There have been a number of symposia dealing exclusively with rockbursts and seismic activity. The most noteworthy are as follows:

Rockbursts and Seismicity in Mines, Johannesburg, 1982. Published by the South African Institute of Mining and Metallurgy, Symposium Series No. 6, 1984.

Rockbursts: Prediction and Control, London, 1983. Published by The Institute of Mining and Metallurgy.

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GENERAL REVIEWS AND TEXT BOOKS

The first known study on rockbursts was by a committee, appointed by the South African Government in 1908, to investigate tremors being felt on surface. This committee established that the tremors were not naturally occurring (i.e., earthquakes), but were caused by mining operations and specifically the 'shattering of support pillars'. Subsequent government committees were appointed in 1915, 1924 and 1964 to study the ever increasing rockburst incidents in South African gold mines. In 1977, a high-level committee appointed by the South African Chamber of Mines reviewed the findings of these earlier committees, as well as presenting the latest state-of-the-art for reducing the rockburst hazard. Additional overviews have been published in recent years.

Rockbursts on the Kolar Gold Fields in India started at about the same time as those in South Africa. Much of the information was published in a local mining society, but more readily available reviews on rockburst research have been published at regular intervals in recent years (1963, 1972, and 1983).

Rockbursts in Ontario mines started during the 1930's, mainly in the

Sudbury and Kirkland Lake mining camps. The Ontario Mining Association set up an industry rockburst committee in the mid-1930's which was active until the late-1940's. This committee retained R.G.K. Morrison to report on the rockburst situation in Ontario mines in the early 1940's. With the closure of many of the rockburst prone mines the problem decreased. However, in the 1980's the problem reappeared with significant rockburst activity in Red Lake, Elliot Lake, Sudbury and Kirkland Lake mines. An Ontario provincial inquiry was commissioned in 1984 to investigate the problem. In 1985 a tripartite rockburst research project was initiated between the governments of Canada and Ontario and the Ontario Mining Association.

In the United States, rockbursts have been experienced in two regions; the copper mines in northern Michigan (now closed), and in the Coeur d'Alene district of Idaho. The mines in Idaho have been the subject of many field trials by the United States Bureau of Mines, universities, consultants and mining companies, involving microseismic monitoring, destressing and rock pre-conditioning.

A number of rock mechanics text books contain chapters specifically on rockbursts. The earlier text books were mainly descriptive of the mining conditions favouring rockburst incidents and methods of reducing the hazard. Those by Jaeger and Cook, and by Salamon, incorporate the theory of elasticity, stiffness concepts and an energy balance approach to explain rockburst occurrences.

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ROCKBURST MECHANICS

Prior to the 1950's a traditional engineering approach of observation, experience and trial-and-error methods was used to combat the rockburst hazard. Since that time scientific research has been used in an attempt to understand the causes and mechanisms of rockbursts. First the theory of elasticity was applied, for simple geometries, to estimate the redistribution of stress as a result of mining.

In the 1960's three important advances were made, noteably by N.G.W. Cook. The first multi-channel microseismic monitoring system was installed in a South African gold mine. This system gave relatively accurate locations for both small and large seismic events. An energy balance approach was used to evaluate the source of energy liberated in a rockburst. All sources of energy entering the system as a result of mining were balanced against how the energy could be dissipated. The excess energy would be liberated as seismic energy. It was also discovered that the post-failure behaviour of brittle rock was either violent or non-violent depending on the stiffness of the loading machine.

The concepts of an energy balance and pillar stiffness versus loading stiffness were further refined by Salamon in a number of publications. Computer models incorporating energy and stiffness concepts were developed soon after.

In recent years research has been concerned with the mechanisms involved with various types of rockbursts. This has included the fracture patterns around longwall faces and shearing through intact rock (i.e., development of new faults) in South Africa. In Canada attention has been focused on pillar bursts that are occurring in the Elliot Lake, Red Lake and Kirkland Lake mines, and the fault-slip type bursts that are occurring in mines at Sudbury.

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SEISMIC MONITORING AND SOURCE LOCATION

The first single channel microseismic system was developed by the United States Bureau of Mines in the early 1940's and tested in both United States and Canadian mines. The number of microseismic events in a given time was the main parameter, which was subject to equipment noise problems.

Apparently, the first multi-channel microseismic system was used by N.G.W. Cook in a South African gold mine in the early 1960's. This system gave source location and a measure of the seismic energy liberated. Additional microseismic systems were installed in South African gold mines, followed by mines in the Coeur d'Alene, United States, in the 1970's and Canadian mines in the 1980's. The commercially available Electrolab system, with up to 64 channels, is used predominantly in North American mines.

Regional seismic networks have also been installed in South African mining areas. These systems have widely spaced geophones covering several mines and are used for detection and source location of the major rockbursts.

A number of source location techniques have been developed. Most use the arrival times of the compression wave to successive geophones. The so-called 'direct solution' uses a series of linear equations to solve for the three-dimensional coordinate plus the velocity. Least squared versions of this method have been developed by the United States Bureau of Mines and Mt. Isa in Australia. The so-called 'block' and 'simplex' methods use a series of non-linear equations. When the complete seismic waveform is recorded the separation of the compression and shear waves is used to calculate source location. A number of papers have been published comparing the accuracy of the various methods.

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ROCKBURST SEISMOLOGY

Scientific observations on earthquakes has taken place over a much longer time period than rockbursts, consequently literature on seismology is much more vast. Only those papers on seismology which have a direct application to mining or involving source location techniques have been reviewed.

Rockburst magnitude scales are the same as those used for earthquakes. Most countries use a local magnitude scale developed by Richter, except for eastern North America, where a scale developed by Nuttli is used. However, Hasegawa has developed a relationship between the two scales for the Canadian Shield.

Comprehensive reviews on the application of seismology methods of analysis to rockbursts and mining related problems have been presented at two rock mechanics conferences: by A. Nur in Denver in 1974, and by M. Bath in Johannesburg in 1982.

One of the first applications of seismology techniques to rockbursts was by E. Hodgson in the Kirkland Lake mining camp, Ontario during the 1930's to 1940's. Since that time most of the investigations have been carried out in the South African gold mines, noteably by A. McGarr and S.M. Spottiswoode.

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ROCKBURST ALLEVIATION

There are two approaches to the alleviation of rockbursts, which can be termed 'strategic' and 'tactical'. The strategic approach is to diminish the possibility of encountering rockburst-prone ground or to diminish the severity of the rockbursts. Many of the recommendations of the early committees in South Africa and Canada were along these lines. For instance avoiding remnant pillars, longwall face configurations and mining away from, rather than towards, a major weakness plane were strategic approaches based on experience and observation.

A more scientific approach became available with the introduction of energy balance equations to mining operations. The concept of energy release rate was introduced based on the premise that if the released energy could be reduced, the seismic events would be starved of energy. Although this reasoning was found to be erroneous (Salamon, 1983), a strong empirical correlation was found between energy release rate, frequency, magnitude and damage of rockbursts for the South African gold mines. These concepts were incorporated into computer models which allowed comparison of energy release rate for different mining layouts and sequence of extraction.

The energy balance equations also showed that the one parameter over which the mining engineer had any control was the volumetric closure in a stope. If the closure could be reduced, then all the energy components were reduced. Backfill or other support systems between hanging wall and footwall both limit stope closure and absorb energy otherwise liberated as seismic energy. In recent years large permanent stabilizing pillars have been left at regular intervals to reduce stope closure in thin tabular deposits, such as the gold mines in South Africa and at a uranium mine in Elliot Lake, Ontario. Especially in South Africa it has been shown that these stabilizing pillars reduce the frequency and magnitude of seismic events.

The benefits of the strategic techniques are only realized in the long-term.

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CONTROLLING ROCKBURST DAMAGE AND DESTRESSING

The tactical approach to rockburst alleviation is to accept that some rockbursting is inevitable, but seeks either to limit the extent or the timing of the damage.

The peak particle velocity is the cause of the damage to conventional support systems which usually tend to be rigid. This led to the development of rapid-yielding support systems in South African gold mines of which the rapid-yielding hydraulic prop is a good example. In access drifts the concept of lacing was introduced which consists of mild steel grouted rebar, wire mesh and flexible steel cable over the mesh and connected to the rebars in a diamond pattern. It was found that this type of support system, when subjected to a nearby rockburst, allowed the wall rocks to rapidly converge inwards while still maintaining the integrity of the drift. Friction type (e.g., spit sets and swellex) support systems with wire mesh have been found to be effective in rockburst conditions in Canadian mines.

Although some form of destress blasting was practised in the Kirkland Lake mining camp in the 1940's, the first systematic destressing trials took place on longwall faces in South African gold mines in the 1950's. Although initial results were encouraging the practice was discontinued when it was found that no excess energy was being released other than that of the explosive. However, destress blasting was continued in North American mines (Coeur d'Alene, Red Lake, Sudbury and Kirkland Lake) with apparent success.

The concept of destressing is to fracture highly stressed pillars with explosives thereby reducing the deformation modulus and the stress they can support. This in turn allows the hanging wall and footwall to converge with the resultant change in potential energy. In many mines, rockbursts occur shortly after destress blasts and large production blasts, due to stress transfer. In some cases it may be possible to control the timing of a rockburst by such blasting.

The benefits of these tactical techniques are realized in the short-term.

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ROCKBURST PREDICTION

There are two components to rockburst prediction: location and time. At many mines microseismic systems indicate those areas of the mine which are rockburst-prone and a build up in microseismic activity sometimes precedes a large rockburst. Computer models also indicate locations which are highly stressed and rockburst-prone. However, consistent prediction of time has been much more elusive.

Some of the precursor phenomena that have been evaluated include, microseismic count rate, average energy per seismic event, and change in waveform frequencies.

Much of the original research on rockburst prediction was done by the United States Bureau of Mines. In recent years a large research effort has been underway at Western Deep Levels in South Africa.

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