APPLIED RESEARCH - PROJECTS IN PROGRESS AT THE MINING RESEARCH LABORATORIES OF CANMET

by

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ABSTRACT

During the past three years, applied mining research projects have been initiated in several provinces, principally through Federal/Provincial Mineral Development Agreements. Work is now in progress in Manitoba, Ontario, New Brunswick, and Saskatchewan. Other projects are being developed for possible implementation in the Northwest Territories and other political divisions.

All of the projects were started after consultations with industry and/or provincial mining associations and address stated industry needs. The results will, therefore, be directly relevant to the industry. Additional benefits to CANMET/MRL are that a much greater proportion of research is being done externally and that communications with the industry have improved.

In this paper, the author reviews the projects that have been commenced thus far.

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Keywords

backfill, blast design, ground control, heat recovery, Manitoba, microseismic monitoring, mine communications, Mineral Development Agreements, mining research, New Brunswick, Northwest Territories, numerical models, Ontario, recirculation ventilation, research, rock mechanics, rockbursts, Saskatchewan, software

PROJETS DE RECHERCHE APPLIQUÉE - PROJETS EN COURS AU LABORATOIRES DE RECHERCHES MINIERES DU CANMET

by

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RÉSUMÉ

Au cours des trois dernieres années, la recherche minière appliquée fût initiée dans plusieurs provinces, principalement par les ententes Féderale-Provinciales. Des Travaux sont présentement en cours au Manitoba, en Ontario, au Nouveau-Brunswick et en Saskatchewan. D'autres projets sont en développement pour implémentation possible dans les Territoires du nord-ouest et d'autres divisions politiques.

Tous les projets furent entamés après consultations avec l'industrie et/ou les associations minières provinciales et spécification des besoins. Les résultata seront donc directement bénifiques à l'industrie.

De résultats additionnels pour CANMET/LRM sont une plus grande proportion de la recherche faite à l'extérieur et de meilleures communications avec l'industrie.

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Mots-Clés

communications dans les mines, conception de trou de mine, contrôle des terrains, écoute de microséismique, Ententes sur l'exploitation minérale, logiciel, Manitoba, mécanique des roches, modèles numériques, Nouveau-Brunswick, Ontario, recherche, recherche minière, recirculation de ventilation, recuperation de chaleur, Saskatchewan, terre de remblayage, Territoires de nord-ouest,

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INTRODUCTION

Since the recession and depressed metals prices of the early 1980's, the Canadian mining industry has been forced to aggressively seek ways to improve its cost effectiveness and competitive position. While the costs of labour, goods, and services continued to rise, until only recently the prices realized for the end products remained at near historic lows. In this climate, the survival of an enterprise lies in improved productivity and efficiency.

Even now, when the prices of metals are rising on international commodity exchanges, the pressures to maintain a competitive edge will continue (if not increase). Improved prices will inevitably result in increased global production. Maintenance of market share will continue to be a problem.

In recent years, the industry has increasingly converted to large-scale low-cost methods of bulk mining. Because of the exhaustion of near-surface reserves of ore, ore bodies at greater depths and under more adverse geological conditions are now exploited. Methods of mine design have been forced to become much more sophisticated and more solidly based on rock mechanics principles. There is now a much greater awareness of the needs for, and benefits resulting from, mining research. The mining process is probably the only part of the production cycle from which significant improvements in cost-effectiveness can be realized.

Concurrently with the recession in the metals industry, and commencing about 1984, a new delivery vehicle for mining research came into being through Mineral Development Agreements (MDAs) which were concluded between the federal government and many of the provinces. Under the umbrellas of Economic Regional Development Agreements (ERDAs), the MDAs define projects to be implemented in the minerals sectors and the delivery mechanisms for the work.

In some of these agreements, depending on local requirements which had been defined, provision was made for the inclusion of projects relating to the development of technology to enhance the productivity and competitive position of the minerals industry. Many of these projects are defined as "mining research". Others are in the areas of exploration extractive metallurgy, and minerals-related technology.

On another front, mining research was also being expanded through jointly-funded projects with other governments and industry. The best-known of these is the tri-partite project for a major thrust into rockburst research. Jointly funded by the federal and Ontario Governments, and the hard-rock mining industry of that province, the project is aimed at bringing Canadian technology up to world-class standards within five years. Progress to date has been excellent.

Before describing the mining projects and reporting on the progress to date, however, it is worthwhile to explain the processes by which the projects were conceived. Research, under the MDAs, is not in progress in all of the Canadian provinces in which there is mining activity.

When asked the reasons as to why a specific project is being executed in a particular place it is important that one should be aware of the negotiating processes and the sequence in which the agreements were signed. This, together with a federal role of national coordination and avoidance of duplication, provides the answers.

When discussing local needs and potential projects for each of the provinces, the work that has been done and is being done in the other provinces is always an initial item of consideration. CANMET, because of its national mandate and involvement, must be aware of the total research picture. With the amount of interest that is now being generated in mining research, such a national co-ordination of activity is essential.

The most important reason, then, in explaining the pattern which has developed during the past three years, is that all of the projects have been designed to address expressed local needs. This has usually been done through consultative mechanisms involving the governments concerned, and possibly either representatives of provincial mining associations, or of the industry, or all parties.

As the process of defining research needs has matured, the communications paths have become much better defined. These have been enhanced by the development of formal mechanisms through which discussions can be formally channelled. The Mining Research Directorate of the Ontario Mining Association (OMA) and the Research Committee of the Saskatchewan Potash Producer's Association (SPPA) are excellent examples of communication channels which have opened within the past two years. As a result, in both of those provinces, mechanisms are now in place which will facilitate continuing discussions with industry on mining research needs. The intent is to direct work in such a way that the greatest possible benefits accrue to the industry.

In the other provinces, the communications paths for formal discussions with the industry are still evolving. To date, these have been less formal in approach than followed elsewhere and have been conducted with representatives of the industry on an "as required" basis. After projects have been defined, initiated, and have started to mature, however, the "ad hoc" format of initial talks have developed into a regular reporting structure. In Manitoba, and Ontario, for example, there are now semi-annual meetings with contractors and representatives of the industry to review progress. This same pattern will probably also emerge elsewhere as progress is made on research projects.

At the national level, the Mining Industry Technology Council of Canada (MITEC), which was recently formed by the Mining Association of Canada (MAC), offers another mechanism for the identification of broad national needs and co-ordination.

In provinces other than those named specifically, the Mineral Development Agreements did not contain a provision for the delivery of mining research. The most important reason for this would probably be that other regional needs were selected as being of higher-priority for research and development in the early discussions. A key point is that the industry must make its needs known to those who negotiate such agreements. It is impossible to proceed without discussion and dialogue.

One of the most important objectives of MDA research is to address the most urgent needs of industry for R&D assistance. If, after the conclusion of the present projects there remain needs which have not been addressed, some of the reasons can be attributed to problems of communications during the early stages of defining possible projects.

The industry is broad and diverse and it is very difficult to obtain consensus; especially regarding needed research. The Communications paths, however, are becoming better defined. It is to be hoped that, in the future, the entire process of determining research needs will be undertaken with a much better awareness of opportunities for funding. In order to address future possibilities for funding, the industry (either provincial or national) would be well-advised to have a "shopping list" of high priority projects, arranged in order of priority for sponsorship and funding, available at "a moment's notice".

The following is a review of the mining research projects presently under way through the federal/provincial MDAs with Manitoba, New Brunswick, Ontario, and Saskatchewan. The majority of these are in the areas of rock mechanics and ground control. This one-dimensional aspect has been of some concern to the writer who has pursued a career as a rock mechanics/ground control specialist.

The reasons, for this, however, are due to the fact that the implementation of rock mechanics and ground control principles and practices is now recognized by the industry as having extremely high potential for returns on investment. Of all of the parts of the mining production cycle, from exploration to production of metallic end products, it is the process of mining which has received the least attention to date from the research point of view. It may well be, in fact, the only part of the production cycle, in which significant reductions in costs and improvements in profitability can be made. In a threatened industry, the focus of attention on mining methods is logical.

Going one step further, improvements in mining methodology necessitate close examinations of the stability implications. Rock mechanics is an essential part of the planning process.

Most of the present MDA's were negotiated in the shadow of the recession which began in 1982. Given the focus on the mining process as a potential "cost-reduction centre" it is hardly surprising that, when asked, nearly all mine operators and provincial associations stated that their immediate needs were for practical rock mechanics and ground control.

Recently, however, because many of the needs for rock mechanics and ground control research are being addressed, it has been possible to expand the scope of MDA work to include such topics as mining environments, ventilation, and mine information systems.

CANADA/MANITOBA MDA - PROJECTS ON ROCK MECHANICS, GROUND CONTROL, AND MINE COMMUNICATIONS

The first of the Mineral Development Agreements involving a mining research component was that which was signed between the federal and Manitoba governments. Nearly all of the mining in that province takes place under hard rock conditions. Thus, the Manitoba projects will produce results which will be potentially applicable to many mines located elsewhere in Canada. The importance of the projects is already recognized on a national level.

There is a distinct Manitoba flavour to the work, however, insofar as many of the projects are being undertaken in small to medium-sized multi-lensed sulphide orebodies, of which there are several in northern Manitoba. Small mines throughout Canada will probably derive the greatest benefits from this research.

Before describing the federally-delivered projects in Manitoba, it must be mentioned that there are also provincially-delivered projects in progress under the supervision of the Department of Minerals and Energy.

The following descriptions refer only to those projects which are being supervised by the Mining Research Laboratories of CANMET.

Project B.2.1.1: "Design Guidelines for the VBM Method for a Steeply-Dipping Deposit in Manitoba". (Also: "Procedures for blasting down hang-ups in ore passes and chutes")

The Vertical Block Mining (VBM) method is thought to be a viable alternative to cut-and-fill mining. There are at present, however, no design guidelines which can be used as a means of selection. The objectives of the project are to consider all of the design parameters, to monitor in-situ conditions, and to

develop a design manual which can provide a rational basis for mine design. Other objectives include the development of guidelines for the conversion of mining from other methods to VBM and guidelines for VBM blast design in order to optimize fragmentation while minimizing overbreak, scaling and dilution. The work is being undertaken by INCO Ltd. at its Thompson operations. The total value of the contract is $362,500.

In the INCO study an assessment is being made of the sizes of production stopes and pillars, the spans, the possible sequences of extraction, the blasting procedures, requirements for ground support, and use of backfill. The intent is that the guidelines should encompass all of the key parameters which are important in the selection of a mining method. An important element of this project is that the work is being done in, and makes special reference to, the particular conditions associated with steeply-dipping orebodies. Up to the present, stability analyses have been made of a number of stopes and several interim reports issued.

As will be appreciated, there are no unique solutions to the problems of design and prediction of stability in a mining environment. Mining, by its very nature, severely disturbs the surrounding rock mass - especially if full extraction is accomplished. A manual of design guidelines for VBM mining, if readily identifiable with economics and safety, will bring more confidence to design engineers and production staff.

Also included in the project is a sub-project which has major implications concerning the health and safety of underground miners. This work is in connection with the development of procedures for blasting down hang-ups in ore passes and chutes. Every miner recognizes that this is one of the most hazardous of all of the tasks in underground mining. The development of better procedures will have a major impact on safety.

Project B.2.1.2: "Development of a Geomechanical Data-base for Ground Control in Deep Mines"

Increasingly, mining engineers are making use of numerical modelling methods to design underground mine openings and sequences of extraction. To be truly effective such models should, among other features, be able to simulate non-linear and post-failure behaviour of both rock and backfill materials and should be calibrated and verified by reference to actual case history studies.

One of the great benefits of the MDA projects is that their scale, and execution by the industry, makes such practical verifications possible.

In this project, which is the subject of a contract in the amount of $255,500 to INCO Ltd., a numerical model will be produced for the purpose of predicting the ground stresses and deformations induced by mining. In addition to the features mentioned previously, the model will also contain provision for major discontinuities in the rock mass and dynamic effects (such as induced by blasting vibrations). In order to do this a geomechanical model will be developed in order to facilitate data collection and retrieval.

Among the outputs of the project will be software packages accompanied by user's manuals. As with the other MDA projects the intent is to transfer the technology developed to the entire industry as quickly as possible.

After two years of work, the project has now reached the halfway point. Geomechanical data collection procedures have been refined and standardized, and a computerized system for

transferring the data directly into a numerical model has been tested. Mine-wide information on orebody configurations and rock qualities have been entered for future interfacing with numerical models. Significant advances to both two-dimensional and three-dimensional numerical models have also been made.

The three-dimensional model is an iterative package which has been designed particularly for mining applications. It has been designed to be run on both mini and micro-computers. Its use, together with the elements of the geomechanical model (i.e., data collection procedures, data retrieval system, rock mass classification techniques), should provide a useful rock mechanics design tool for use in Canadian mines. Improved efficiency in mine layouts, together with increased safety and productivity, should result.

Project B.2.1.3: "Evaluation of Methods for Delayed Backfill Consolidation"

The use of cemented and consolidated fills in mined out stopes, while now common, has been a feature of Canadian mining practice for only a generation. Previously, unconsolidated alluvial sands, waste rocks, and slags were used. In many areas, depending upon the availability of mill tailings and other considerations, such is still the case.

For such reasons, it is not uncommon for a mining engineer to have to contend with the problem of mining pillars between stopes filled with unconsolidated fill. The alternatives which are available to stabilize such loose fills include pressure grouting and the percolation, by gravity, of cementing mixtures. Stabilization by such methods is necessary for, without it, the dilution by loose fill would soon render further extraction of pillar ores uneconomical.

In this project, which is the subject of a contract in the amount of $100,000 to the Hudson Bay Mining and Smelting Company Ltd., a review is being made of the cost effectiveness of the methods which are available for delayed consolidation of backfills. This will be followed by field trials using preferred methods and the establishment of predictability criteria. There will also be the development of theoretical models and the correlation of field results with these. An objective is to develop practical techniques for the in-situ consolidations of fills. The project is now about 25% completed.

The results of the study should permit the recovery of pillars surrounded by unconsolidated fills to be accomplished with greater stability and safety. Additionally, it might be possible to develop a methodology by which the consolidation of backfills could be deferred to a later stage in the mining process, thereby improving cash flows. This would be a very great benefit to smaller operations. Finally, the technology could improve shrinkage stoping methods in which broken waste is placed on top of the ore being drawn down (through lessening dilution).

Project B.2.1.4: "Ground Stability Evaluation with Particular Reference to En-Echelon Lensed Orebodies"

As mentioned previously, mining engineers are now making increased use of numerical modelling methods in the design of underground openings. Additionally, rock mass structural classification systems are also being used to quantify the properties of rock masses - both for predictive purposes and to provide input data for the models referred to. There is a great need to evaluate the rock mass classification systems which are presently available and to compare the actual stability performances of openings versus predictions as mining progresses. The results should permit an enhancement of presently-available predictive tools.

In this project, which is the subject of a $289,100 contract with Sherritt Gordon Mines Ltd., the currently-available classification techniques will be used to forecast ground conditions in the mine. These forecast conditions will be compared with actual conditions as mining progresses. As the result of these comparisons, the important criteria will be identified and a better predictive methodology will result.

Much has been accomplished to date. A review of rock mass classification systems has been completed and, as a result, both the RMR and Q Systems have been identified as being especially relevant to the particular needs of underground mines. The testing of local mine rocks and backfill has been completed, as have: in-situ determination of stresses, assessments of groundwater conditions and numerical modelling. All of the rock mechanics instrumentation programs have been implemented. Stope design guidelines have been established.

At present, a report is being prepared.

Project B.2.1.5: "Optimization of Blast Design for Blasthole Mining Operations"

Current blasting practices in underground mining are largely based on experience and on trial and error. This approach can be costly and can involve risks. With the trend to large-scale methods of mining, the economic consequences of sub-optimal design can be very great. Clearly, there is a need for a rational process of design by which such key parameters as rock mass characteristics, stope geometry, properties of the explosives, timing, methods of initiation, and induced vibrations, can be incorporated as parameters.

In this project, which is being performed by INCO Ltd. under a $260,000 contract with the federal government, a study is being made at a number of test stopes. The field work involves: in-situ testing to determine the dynamic properties of a rockmass; evaluations of rockmass characteristics; trials of test stopes; monitoring of ground motion resulting from blasting; analysis of fragmentation achieved; and the development of theoretical and semi-empirical predictive models.

The objectives are to develop a rational blast design process, which incorporates: the important properties of the rock to be blasted, the stability of the resultant opening, the properties of the explosive used, and the blasting methods employed. The design procedures will be prepared in the form of "user-friendly" software packages and manuals suitable for use with IBM PC micro-computers. Interactive graphics will be a feature of the approach.

To date, INCO has completed an extensive search for software which can be used to evaluate blasting, blasting-induced vibrations, damage criteria, and fragmentation. The applicability of some of this software to underground mining has then been evaluated. In the mine in which the studies are being performed, two stopes have been dedicated to the research. Records of blasting procedures and of the results obtained are being documented. A geological study of the areas involved has also been completed. The project is now at a well-advanced stage.

Project B.2.2.1: "Communication Systems for Isolated Areas in Mines, Especially in Ore-bodies Composed of Multi-lenses"

There is perhaps no other MDA mining research project that has generated more interest from the industry than the current research on underground communications systems. There is a strong

consensus in the industry that voice and communications systems are needed urgently if progress is to be made towards effective mine information and monitoring systems. The present technology is seen as being a bottleneck to further development. Beyond any question, new approaches are needed.

The implications for both worker health and safety and efficiency are simply enormous. An improved voice communications system would permit as-required conversations with crews or workers working in isolated areas. It would also permit rapid identification of problems with conditions or equipment and permit speedy solutions to be implemented. No mine supervisor needs to be told of the costs associated with delays in obtaining urgently-needed repairs to equipment.

Likewise, a highly efficient data communications system would accelerate the development of large-scale mine information and monitoring systems.

Against this background, the interest in the awarding of a $429,400 contract to Sherritt Gordon Mines Ltd. (with Falconbridge Ltd. as a sub-contractor) can be appreciated. In the project, the contractor was required to review the state-of-the-art in possible choices of underground mine communications systems, and to select the most suitable and cost-effective of those available for an extended field trial in a Manitoba mine. After a period of evaluation, recommendations were to be made for any research and development that might be needed to improve the system.

The report of the first phase of the work, by Falconbridge Ltd. for Sherritt Gordon, was concluded at the end of 1985. The interest in it was so great that two hundred copies were printed for distribution.

In the conclusions, the contractor stated that a medium frequency frequency-modulated system (FM-MF) is the best choice at present for mine-wide communications. It was also stated that the benefits of installing a system would be such that a payback period of less than two years could be anticipated.

Subsequently, in the second phase of the work, systems were purchased for voice, hoist, data, and rock mechanics monitoring communications. Some of these systems have been evaluated on a pilot-area scale, while others are still under evaluation. Nonetheless, even at this early stage the project has had a tremendous impact on the industry. Systems of the type recommended have already been installed by both Falconbridge and INCO, in the Sudbury basin. Other operators are reported to be considering installations. Seminars on the topic of mining communications have been organized by the Mines Accident Prevention Association of Ontario (MAPAO), the Algoma Branch of the CIM, and the Ontario Ministry of Labour.

From a technology transfer point of view the success to date has been outstanding.

CANADA/ONTARIO MDA - PROJECTS ON MINE BACKFILL AND ANALYTICAL MODELS

In modern large-scale methods, mining panels are extracted in a pre-determined sequence which permits the controlled adjustment of the pre-mining state of stress. Completed panels are usually filled with backfill in order to provide support. Often, cement is added to the backfill as a means of increasing strength.

Mill tailings, as a material for backfill, has been used in the mines of the Sudbury basin for over 30 years. It was in these same mines that much of the original work was done with cemented backfills. Originally, the intent was to provide a hardened floor in cut-and-fill stopes, on which broken ore could be scraped with minimal resulting dilution.

With the advent of large-scale blasthole methods in the past two decades, however, cement has been added to entire pours of tailings in order to improve the free-standing heights of unsupported fill walls. With the fill unsupported during the mining of contiguous panels, the height at which it will stand undisturbed is of vital importance to mine design. Greater heights permit increased level intervals and, consequently, less development and lower unit costs.

The amount of cement required to provide the strengths desired is a key question. Cement is expensive and the amount consumed in large-scale backfilling operations can be enormous. Any optimization in filling technology can have far-reaching benefits for the industry.

It was for this reason that the focus of mining research under the Canada/Ontario Mineral Development Agreement was placed on mine fill. The industry had identified this as one of the most urgent areas for practical research. CANMET responded by recommending a total of $3.55 Million for commitment mostly to field-scale experiments to be performed by the industry. Work is now in progress on projects addressing: the comparative properties of various fills; the development of predictive models; and mining strategies. The contracts were initiated in 1986.

At the same time, provision was made to establish a small laboratory dedicated to studying the engineering and physical properties of fills. Such a highly specialized laboratory, dedicated to the mining industry as a source of technical support, did not yet exist. The laboratory, to be a small highly specialized unit within CANMET's Mining Research Laboratories Division, will be operational on the Laurentian University campus, in Sudbury, before the end of this year.

All of the projects are now in progress. These are as follows:

Projects C.1.0(a) and (b): "In-Situ Determination of Dewatered Tailing Fill Properties"

Mill tailings are emplaced as backfill in the form of a slurry. As a result, the water which was used to transport the solid particles to the stopes being backfilled must be pumped from the mine as the fill consolidates and ages. Cement, added to increase the strength of the fill, is leached away as the water percolates downwards.

The successful use of higher-density paste-type fills would offer a number of improvements to mine operators. First, with much less water being used, there would be significant reductions in pumping costs and cement losses. Second, because of the increased retention of cement and higher density, the fill would attain higher strengths more rapidly. Third, this in turn, would simplify the methods which are used to design the structures used to contain the fills (i.e., bulkheads and fill fences). Fourth, there would be an improvement in the handling of slimes and in costs of clean-up underground.

Two projects, involving alternative technologies are in progress:

(a) At INCO Ltd., in the Sudbury basin, work has been in progress for some time at the Levack Mine, to design a system which will permit the delivery of high-density fills directly through pipelines. A CANMET contract, in the amount of $112,000, is in place to accelerate this work.

At INCO a surface mixing plant and a gravitational system is used to deliver the paste fill to a test stope. The initial results, at depths at less than 1,200 feet, have been very successful. Monitoring instrumentation has been installed and the trial stope filled. Undercutting has now begun.

Based on the early successes, consideration is being given to extending the technology to openings at greater depths.

A final report on the project is expected about the beginning of 1988.

(b) At Dome Mines Ltd. an alternative approach to the delivery of paste fill is being investigated. Through a CANMET contract, in the amount of $152,580, the company is evaluating the potential use of a device known as the "tailspinner". Operating much like a centrifuge, the tailspinner receives liquid backfills at normal pulp density (about 60% solids by weight). On delivery, the water is spun from the fill and removed. An extruded paste is emplaced.

At Dome, in-situ monitoring of fill behaviour is now in progress. Laboratory studies of the behaviour of paste fill are nearly complete. As with the INCO study, a final report is expected early in 1988.

Project C.2.0: "In-Situ Monitoring and Computer Modelling of a cemented sill mat and confines during tertiary pillar recovery"

In cut-and-fill mining, the intervening pillars between previously-mined stopes are recovered during secondary extraction. Sill pillars, between the mining blocks and the levels, are recovered during a final, or tertiary, stage. The entire process of extracting all of the ore between levels may involve several years.

During this process, however, mining practices and economic conditions are constantly changing. The results can be great departures from original plans and large variations between the properties of fills in contiguous openings.

In order to provide increased confidence in both design methodology and extractive practices, a project, involving both in-situ monitoring of ground conditions during the extraction of sill pillars and computer modelling for predictive and back-analytical purposes, was initiated with Falconbridge Ltd. The contract, under the Canada/Ontario MDA is valued at $154,720.

The study is now almost complete and a final report is in preparation.

Project C.3.0: "Use of Cemented Fills for Controlling Violent Failure in Pillars"

In the room-and-pillar mines in the near-horizontal tabular uranium deposits of Elliot Lake, backfill has not been used. Until recently, this has not been considered to be necessary, since the vast mined out areas have remained quite stable. Within the past two years, however, there has been much increased rockbursting and failures of the rib pillars in the area near the boundary pillar between the Denison and the Rio Algom mining

operations. The area affected has been more-or-less in the centre of the previously mined part of the ore-bearing conglomerate reef.

The experience at the Quirke Mine at Elliot Lake has shown that the area affected by rockbursting in a room and pillar mining operation can grow rapidly and become extensive. The only practical remedial action may be to pour backfill around the pillars. This seems to be a method of increasing post-yield strength and, consequently, of limiting the growth of the failure zones.

To study the use of mill tailings backfill as a means of stabilizing an area which is in the process of fracturing, a project, with a contract value of $610,000, was initiated with Denison Mines Ltd. In this research, the stabilities of pillars are being monitored as a selected area is backfilled. Monitoring involves both stress measurement and microseismic techniques. A microseismic system, belonging to CANMET, has been installed in the designated area of the mine for the purpose of the study.

In the project, a trial panel at the Denison mine has been rehabilitated. With the completion of bulkheads and drainage systems, and the installation of monitoring equipment, filling is in progress.

Project C.4.0: "Computer Program Specifications for the Ontario Mining Industry"

The industry, and particularly the smaller mining operations, are in great need of computer software packages which can be used to improve operating efficiencies and productivities and to reduce costs. The needs have been expressed to CANMET on many, many occasions. At the same time, the lack of standardization and compatability of software has been mentioned as a serious concern. The industry is in need of a systems approach.

Originally, during the conception of the Canada/Ontario MDA projects, it was planned to identify a number of specific requirements for software and to sponsor the development of the packages.

With the foregoing concerns in mind and at the urging of specialists, however, it was decided that the best, and necessary, first step would be the design of a protocol. Accordingly, a contract, in the amount of $50,000 was signed with Mining Resource Engineering Ltd., of Kingston, Ontario. The firm was charged with the responsibility of determining the computing capabilities and needs of the industry and of recommending specifications which would ensure a high degree of universality of approach over the next few years (i.e., 3 to 5 years). Recommendations concerning the choice of an operating system and a computer language were also required. The intent was to develop specifications which could be used as a standard.

The project has now been completed and the final report is available. In summary, UNIX has been selected as the recommended operating system, and Fortran and C as the programming languages.

At present, because all of the funds available for mining research in the Canada/Ontario MDA have been committed, it is not likely that this particular project will be continued through the development of specific software packages. Nonetheless, through the specifications which have been established, the results of the research should be of benefit to the industry through the provision of guidelines for the acquisition and development of software.

As is elaborated elsewhere in this report, software packages are under development in some of the other MDA projects.

Project C.5.0: "In-Situ Properties of Backfill Alternatives in Ontario Mines"

In spite of the fact that a wide range of materials has been used as backfills in mines (i.e., alluvial sand, waste rock, mill tailings, slags, and mixtures of these), very little is known concerning the relative merits or demerits of these. There is a need to determine the properties of various backfill alternatives and to establish general engineering specifications.

To accomplish this, a contract, in the amount of $470,000 was signed with Falconbridge Ltd. Much of the work is being carried out at the Kidd Creek operations.

In the research, which commenced a short while ago, various types of backfill will be emplaced in openings which have been surrounded by monitoring instrumentation. The results of this large-scale comparative study should permit a quantification of the support characteristics of fills. Further, the relationships between laboratory and field properties, once established, will permit the establishment of specifications.

At present, both labortory testing of various binder alternatives (including slags and flyash) and physical modelling trials are proceeding according to schedules. The installation of instrumentation and field trials are also underway. It is anticipated that the project will be completed early in 1990. The results should be reliable specifications for various filling materials. Additionally, less expensive alternatives to present methods and approaches may result.

Project C.6.0: "3-D Numerical Models for simulation of Bulk Mining at Depth"

During the past decade, especially, there have been rapid advances in the analytical tools which are available to rock mechanics specialists. Numerical modelling techniques have taken the place of experimental stress analysis and are now used for engineering design purposes.

The computing requirements for the larger models, however, can be far beyond the capabilities of most organizations. For this reason "mine wide" models are very rare and are mostly the property of large international-scale consulting organizations.

There is a need, both to advance the technology which is available and to investigate ways in which it can be transferred to smaller scale computers. By doing so, it would become available to the smaller organizations which do not presently possess the specialized skills necessary.

In order to develop a sophisticated three-dimensional model, applicable on a very broad scale, and suitable for simulating a wide variety of mining conditions including non-elastic and post-failure behaviour of a rock mass, a contract in the amount of $1,000,000 was signed with INCO Ltd. The contractor will not only develop the highly sophisticated model but will also calibrate it and refine it by making frequent reference to actual in-situ conditions and measurements.

The project has now commenced and is progressing on schedule. It will require several years to complete. The result should be one of the finest numerical models in the world.

Project C.7.0: "Liquefaction Potential of Dense Backfill"

One of the greatest concerns of any mine operator using mill tailings as a backfilling material relates to its liquefaction potential. Fine-grained materials, with a high moisture content, can liquefy under dynamic loading conditions. In a worst case scenario, a seismic disturbance could cause the fill in a recently-filled stope to liquefy, break the bulkheads due to the resulting sudden increasing pressure, and to flood out into the openings below. The results, as at Belmoral (but with overburden rather than fill) could be catastrophic.

In order to define the engineering parameters involved, and to study such behaviour of fill, and particularly densified fill, a contract in the amount of $125,250, was signed with Dome Mines Ltd. The objectives are to study the liquefaction potential of dense backfill, and to develop procedures for determining the safe limits for various types of fill materials.

The project is now at a well-advanced stage. Laboratory determinations of fill properties are nearing completion, while field measurements to establish in-situ behaviour are in progress. The results of the research should assist the industry in establishing safe limits for evaluating the liquefaction potential of dense backfills.

CANADA/ONTARIO/INDUSTRY ROCKBURST RESEARCH AND RELATED PROJECTS

Government

As the result of the seismic events which took place in Ontario mines, in the early 1980's, an intensification of rockburst research became 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 for research.

During the following months, a 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 to the value of $1.4 million (1).

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 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 is being committed to the research than was originally visualized. The industry, in particular, is making a major commitment to the installation and upgrading of local mine monitoring systems.

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.

2) To alleviate the problem of local mine monitoring systems being saturated with the signals coming from large rockbursts additional coverage is being incorporated into the Eastern Canada Seismic Network. 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 have been installed in order to provide greater accuracy through finer scale triangulation. Data from these stations are being transmitted to Science North, in Sudbury, and also to the Geophysics Division of the Geological Survey of Canada, in Ottawa. Seismograph stations will also 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.

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 Balmerton; 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.

Related Projects

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 is now being 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, has been 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 will take place in the not-too-distant future.

Both systems have been 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.

CANADA/NEW BRUNSWICK MDA - PROJECTS ON POTASH MINING, MINE SERVICES SOFTWARE SYSTEM, AND CO2 SURROGATE

Nearly all of the sectors of the Canadian mining industry with the exception of gold, suffered terribly from recent depressed metals prices. In New Brunswick, because of a narrower resource base, the problem was especially acute. In the base metals category only Brunswick Mining and Smelting is operating at present.

As elsewhere in the industry, the key to continued operations lies in improved efficiency and productivity. Costs of operations continue to rise while the prices realized for output remain at low values. Long-term viability will depend, in large measure, on a continuing ability to reduce the unit costs of production.

At another location in the province a new potash mine, owned by the Denison Potacan Potash Company is now in production. This came into production concurrently with the decline in the prices paid for potash. The same considerations of improving efficiency and productivity, therefore, also apply.

It was against this background that the conception of mining research projects took place. Unlike the discussions in the other provinces, however, there were two stages in project implementation. In the first, during the original planning cycle, research was to be directed exclusively towards potash. Later, as additional funding became available, the projects were expanded to include metal mining. As will become clear after reading the next section of this paper, on the Canada/Saskatchewan MDA, the reason that the initial focus was on potash was to maintain a momentum of research that had been developed in the mines of Saskatchewan and which was in danger of flagging because of the completion of research projects in that province. The MDA with New Brunswick, and a mutual interest in potash mining technology, offered a timely opportunity for the research thrust to be maintained.

The potash-related project now in progress in New Brunswick is:

Project II.5: "Use of Backfill in New Brunswick Potash Mines"

Potash mining in Canada is essentially a "one-pass" type of operation. Rooms are mined in a series of passes using highly mechanized boring machines. The rate of advance is very rapid and total extraction of mineral probably averages about 40%. The intervening pillars between rooms are not mined, nor is backfill used. The present economics of potash mining are said to preclude the use of fill. The extraction ratio is low by design in order to provide long-term stability both of the rooms and of the overlying strata.

In the long-run, however, the low extraction ratio will result in a loss of reserves.

A second problem is that the potash is interbedded with salt. Because of contamination with other minerals this salt is not usable for any purpose. After separation during milling, therefore, it is transported to storage piles on the surface. In the future the ultimate disposal of the waste salt will pose a number of environmental concerns.

The project in New Brunswick was designed to address both of these concerns. Under a $214,740 contract with the federal government the Denison Potacan Potash Company is evaluating the stabilizing effect of waste salt as a backfill in mined openings.

In the first phase of the work, now completed, a study was made of the engineering properties of waste salt backfill, and of the effects of additives on strength. The costs and benefits of alternative stowing procedures have been assessed. Finally, using numerical methods of stress analysis, determinations were made of the effects of backfilling upon convergence and the creep of mine openings. The results have shown that at least ten years are required before backfill provides roof support.

A debriefing session for the first phase of the project was held on September 4, 1987.

At present, discussions are taking place concerning a field scale demonstration trial, which would comprise a second phase of the study.

Project: "CO_2 Surrogate"

In the next section of this paper, on the Canada/NWT EDA, a short report will be made of a study on recirculation ventilation which will be initiated in a northern mine. Recirculation ventilation offers the possibility of achieving substantial savings on the costs of heating mine air. One of the key concerns, however, is the extent to which air can, and should, become polluted.

Previously, in a cooperative project on diesel emissions (involving Canadian and American scientists), it was demonstrated that the concentration of all of the major exhaust pollutants were functions of CO_2 concentations. The measurement of carbon dioxide concentrations, therefore, offers the possibility of simple and less expensive systems for mine monitoring and, eventually, automated control. Measurements of all of the pollution constituents is laborious, costly, and expensive.

In this study, which is the subject of a $107,000 contract with Brunswick Mining and Smelting through the Canada/New Brunswick MDA, the pollutants in the air in a mine level on which several machines are operating will be characterized. The objective is to determine the limits of the relationships between concentrations.

As a second stage, assuming that positive results are obtained, an automated ventilation system will be designed. The results and the technology will be applicable to many Canadian mining operations - and especially to those in the north in which the conservation of heat is a key issue.

CANADA/NORTHWEST TERRITORIES EDA - PROJECTS ON RECIRCULATION VENTILATION AND HEAT RECOVERY

Likewise, it is too early to report on progress being achieved through two projects which will be implemented in the Northwest Territories. The Canada/NWT EDA was signed only recently, in July, 1987.

Prior to the agreement, discussions with industry regarding research needs were held at meetings which had been organized by the NWT Chamber of Mines. Those needs are particular to mining operations in cold climates. Both of the projects identified have the potential of signficantly reducing the consumption of energy - which is especially expensive in Canada's north.

In the first project, an evaluation will be made of potential applications of recirculation ventilation systems. The study will involve the development of appropriate monitoring and remote ventilation control technology. Both are necessary to ensure that the quality of mine air is maintained within acceptable limits. The cost of the project has been estimated at $675,000.

The second project will involve the design of a heat recovery system for an existing mine. It will include an analysis of the heat energy which can be reasonably expected to be recoverable together with the actual design. It must be emphasized that the work will involve the application of known principles to an actual problem. The objective is not to extend theoretical knowledge, but, rather to enable the participating operator to begin construction as soon as possible. The cost of the project has been estimated at $300,000.

CANADA/SASKATCHEWAN MDA - PROJECTS FOR POTASH MINING

The federally-funded mining research which has taken place in recent years in the Saskatchewan potash mines can be divided into two phases. In the first of these, which preceded the Mineral Development Agreements by about two years (i.e., 1983 to 1985), approximately $443,000 was committed to mining research through the START (Short-Term Assistance for Research and Technology) program. Many of the immediate needs of the industry were perceived as having been met, therefore, when the discussions leading to an MDA took place. As a consequence, the amount allocated through the MDA was much reduced from the previous level.

In a strict sense the purpose of this paper is to review the work in progress under the various federal/provincial MDA agreements. By doing so, however, without reference to the major commitment of funding to the START projects which immediately preceded the MDAs, one could give the wrong impression that a major area of research needs is not being addressed. Thus, for purposes of record, a list of the START mining research projects is given in Table 1. No descriptions are provided in this paper as doing so would involve considerable space. For further details, the reader is referred to the proceedings of a technology transfer seminar which took place, in Saskatoon, in 1984 (2).

The two projects now in progress were implemented after discussions with, and on the recommendations of, the Research Committee of the Saskatchewan Potash Producers' Association (SPPA). During the past year that group has achieved consensus on the needs and priorities for research in the potash mines of their province. Discussions are now taking place regarding a possible third phase of research for the not-too-distant future.

The present projects under the MDA are:

Project: "Research on Microseismic Technology"

As mentioned earlier, the problems of rockbursting have been acute in the hard rock mines of Ontario in recent years. Research has also taken place in Saskatchewan, with a microseismic monitoring system having been installed at one of the Potash Corporation of Saskatchewan (PCS) mines.

In this project the objectives are to participate in the important microseismic research projects which are currently in progress at McGill and Queen's University and at the University of Saskatchewan. These address research into low frequency microseismics (Saskatchewan), geotomography (Queen's), and high-frequency acoustic emissions (McGill). The research is in progress.

The federal contract in support of this work, in the amount of $40,000, is in place with the Potash Corporation of Saskatchewan. This funding is matched by the SPPA.

Project: "Regional Subsidence Related to Potash Mining"

The objectives of this project are to update the analysis methodology applied to subsidence data from the potash mining fields and to improve the capabilities in prediction. Current methods of collecting subsidence data are very labour-intensive and require long traverses over mining areas. Simultaneously, there is a need for a predictive model applied specifically to potash mining.

TABLE 1

CANMET/MRL Mining Research Projects Completed in Saskatchewan Under the START Program

1983-1985

Title	Contractor	Value of Contract
Alternatives to Present Potash Mining in Canada	MONENCO	$ 52,040
Assessment of Possible Problems in Regional Mine Stability with Future Mining of Saskatchewan Potash	Potash Corp. of Saskatchewan	$ 89,879
Creep Cell Evaluation and Laboratory Testing of Large Evaporite Samples	Saskatchewan Research Council	$39,938.50
Numerical Modelling Package to Design Underground Openings in Potash	RE/SPEC Ltd.	$ 47,579
Determination of Engineering Properties of Waste Salt for Backfilling Underground Potash Mines	RE/SPEC Ltd.	$ 25,250
Dust Measuring Techniques and Dust Levels in Potash Mines	The Cambrian Eng. Group Ltd.	$ 27,000
Absolute Convergence Measurements in Potash Mine Openings	Cominco, Ltd.	$ 41,717
A Field Test Program to Evaluate the Use of Waste Salt Backfill in Saskatchewan Potash Mines	Central Canada Potash	$ 120,000

The work has commenced, through a federal contract, in the amount of $50,000, with Central Canada Potash. The funding is also matched by the SPPA. Progress on the project is reported to be proceeding according to plans with computer programs having been successfully modified for "friendliness" and interactiveness.

CONCLUSIONS

The entire process of conceiving and implementing mining research projects through the federal/provincial MDA agreements cost-sharing arrangements has had several significant effects on both the pattern and quality of mining research in Canada. It is to be hoped that the trend will continue because change in direction has been highly desirable. Some of the key features have been:

1) The projects have, usually been designed through a consultative process involving two levels of government and representatives of either provincial mining associations or industry, or both.

   The process of determining research priorities has improved with each successive agreement. Increasingly, consultations commence earlier and involve more people.

2) Because of this, the work that is initiated is in direct response to the needs of industry. Relevance of the work and applicability of the results is virtually guaranteed.

3) The work itself is mostly being accomplished by industry through government contracts. During the past three years this has meant that the percentage of MRL's financial responsibilities allocated to extramural research have increased from about 5% to about 50%.

4) Further, the scale of the typical research project has changed. Not so long ago, research contracts of the order of $10,000 to $20,000 were the norm. From an inspection of the projects listed in this paper it can be seen that there has been an almost tenfold increase (on the average). Many of the projects listed are in the vicinity of a quarter to a half of a million dollars each. The first million dollar contract has now been signed (under the Canada/Ontario MDA, for the development of a large-scale numerical model).

5) Largely as the result of the MDAs, mining research has come out of the laboratories and into the mines. Bench-scale projects have been replaced by full-scale field demonstration projects. The impact of this is bound to be colossal.

6) The consultations involved in designing, implementing, and monitoring of the projects has led to vastly improved communications between government and industry. Communications with industry have generally been good in the past. At present, however, in many areas these are now outstanding.

7) These communications have led to an increased collaboration and partnership in research. This is financial as well as physical. Nearly all of the projects mentioned in this paper involve not only federal funding but also substantial commitments on the parts of the companies involved. "Dollar matching" is common; in many cases companies are contributing substantially more.

8) The MDA agreement discussions have created a new framework within which research needs can be defined and priorities attached to these, and then followed with project implementation. This has instilled confidence and trust in working with government. The MDA process has been spectacularly successful. It is to be hoped that the model will be continued.

REFERENCES

(1) "A Proposal for a Major Research Project on Rockbursts", J.E. Udd, CANMET Division Report MRP/MRL 84-84(TR), December, 1984, 22 pages.

(2) "Seminar on Canadian Potash Mining and Ground Control", Mining Research Laboratories Division Report MRP/MRL 85-1 (INT), January, 1985.