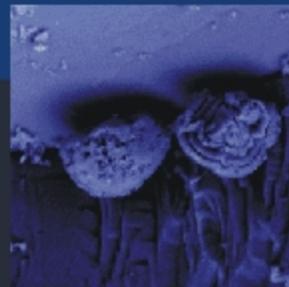


C A N M E T - M M S L

# Annual Report

CANMET Mining and Mineral Sciences Laboratories

## 2003



Natural Resources  
Canada

Ressources naturelles  
Canada

Canada

## Message from the Director

In February of 2004, I assumed the Directorship of CANMET Mining and Mineral Sciences Laboratories (MMSL), succeeding Roy Sage who had accepted an invitation to become the Senior Advisor on Climate Change and International Mining. I am deeply honoured to have been named Director of CANMET-MMSL, a research organization with strong traditions and a long history of providing technical support to the Canadian mining and metallurgical processing industry.

Within Natural Resources Canada, CANMET-MMSL conducts research and develops new technologies related to the economic, safe and environmentally responsible recovery and use of Canada's mineral and metal resources. CANMET-MMSL co-ordinates consortia, and partners with individual companies to carry out specific technical activities related to mining, mineral processing, extractive metallurgy and the environment. CANMET-MMSL also provides technical support to help formulate government policy, and plays a key role in supporting professional activities related to mining and metallurgical processing. For nearly a century, CANMET-MMSL has been a valuable source of technical expertise and professional support for the community which we serve.

CANMET-MMSL's current activities are carried out in laboratories in Ottawa, Sudbury and Val-d'Or. Our research is focused in three principal directions which promote sustainable development in Canada:

- Improving health and safety in the mining environment
- Improving industry competitiveness through enhanced productivity
- Finding technically sound solutions to environmental issues

Within this framework, specific expertise has been developed in a number of fields:

- Mine automation and mechanization
- Mine air quality and ventilation
- Ground control
- Applied mineralogy
- Metallurgical processing
- Mine effluents
- Mine waste management
- Metals and the environment
- Canadian Certified Reference Materials
- Proficiency testing of mineral analysis laboratories



*“For nearly a century, CANMET-MMSL has been a valuable source of technical expertise and professional support for the community which we serve.”*

Details of each of these specific fields of expertise are provided in the remainder of this report, along with the key activities carried out by the teams in 2003. During the year, various publications that were based on these research activities were issued, and these are listed at the end of this report. In addition to the listed refereed publications, CANMET-MMSL staff prepared 72 confidential client reports, 38 technical and internal reports and made more than 130 oral presentations at various conferences, symposia and workshops.

Finally, I wish to thank the CANMET-MMSL management team and the entire staff for their support and assistance in the preparation of our 2003 Annual Report. I hope that this document will be a useful summary of the recent activities of CANMET-MMSL.

A handwritten signature in black ink, appearing to read "Tom Hynes". The signature is fluid and cursive, with a long horizontal stroke extending to the right.

*Tom Hynes*  
Director  
CANMET-MMSL

## Industry Funded Activities

One of CANMET-MMSL's major responsibilities is to support Canadian industry and government departments through revenue generating projects. Such activities demonstrate the relevance of CANMET-MMSL and directly support the technical development of the Canadian mining and metallurgical processing industry. During 2003, major technical investigations were carried out on behalf of a number of companies and government departments, and these studies resulted in 72 confidential client reports. We appreciated the opportunity to work directly with those organizations and we look forward to our continuing collaboration. Our clients in 2003 include:

- Association minière du Québec
- Aur Resources Inc.
- Barrick Gold Corp.
- BHP Billiton Diamonds Inc.
- Breakwater Resources Ltd.
- Cambior Inc.
- Canadian Natural Resources Ltd.
- Carleton University
- Catalytic Exhaust Products Ltd.
- Caterpillar Inc.
- CEZinc
- Canadian International Development Agency
- Collège de Sherbrooke
- COREM
- Cummins Engine Company Inc.
- Department of National Defence
- Environment Canada
- Falconbridge Ltd.
- FedNor, Industry Canada
- Gestion CAMAC 90676214 Québec inc.
- Golder Paste Technologies
- Hilti Corporation
- Hydro-Québec
- Imperial Oil Ltd.
- Inco Ltd.
- Institut de radioprotection et de sûreté nucléaire (France)
- Institut de recherche Robert-Sauvé en santé et en sécurité du travail
- Jacques Whitford Environment Ltd.
- Leslie Investments Ltd.
- MEDATech Engineering Services Ltd.
- Mining Association of Canada
- Millenium Biologix Inc.
- Mitsubishi Engine North America, Inc.
- Nature Works Remediation Corp.
- New Brunswick Power Co.
- Newmont Canada Ltd.
- Nickel Producers Environmental Research Association
- Noranda Inc.
- Placer Dome
- SOREDEM
- Université du Québec en Abitibi-Témiscamingue

To improve the quality of its services, in 2003, CANMET-MMSL upgraded its quality system certification to ISO 9001:2000, passing audits conducted by the British Standards Institution. The Canadian Certified Reference Materials Project maintains separate registration to ISO 9001:2000.

## Awards

The scientific staff of CANMET-MMSL continue to be recognized at the national and international level for their expertise and contributions to the mining and metallurgical processing industry. During 2003, the following staff members were recognized for their significant accomplishments.

The Mine Environment Neutral Drainage (MEND) initiative received a Federal Partners in Technology Transfer (FPTT) Award for “the successful transfer of knowledge and technology developed in federal research laboratories in support of the regulatory and public good mandates that have a significant impact on the socio-economic well-being of Canadians”. The recipients of the award were CANMET-MMSL staff members Gilles Tremblay, Charlene Hogan and Janice Zinck, as well as former staff members Marcia Blanchette, Grant Feasby and Carl Weatherell.

Nand Davé was selected as a Distinguished Lecturer by the Canadian Institute of Mining, Metallurgy and Petroleum (CIM).

John Dutrizac was chosen as the inaugural Mackiw Lecturer in Metallurgy by the University of Alberta. The Mackiw Lecturer Award is sponsored by Dynatec, Sherritt International, Westaim Ambeo and Umicore Canada.



Left to right: G. Feasby, C. Hogan, G. Tremblay, J. Zinck, M. Blanchette, C. Weatherell.

## Road Map for Research and Development in Underground Mining Operations

At the request of the research branch of the Quebec Mining Association, CANMET-MMSL undertook a wide-ranging initiative to define the ten-year vision for R&D for the Canadian mining industry. The objectives of this road map were threefold. The first objective was to define the most pertinent and high priority research directions to improve competitiveness and safety for underground mining operations. The second goal was to quantify the economic benefits of the technological innovations on employment, the creation of new mining operations, communities, and the economic structure of the regional mining industry. The final objective of the project was to evaluate the funding required to achieve a significant impact, and to provide the justification which would be critical to support funding requests submitted to industry, government and other decision makers.

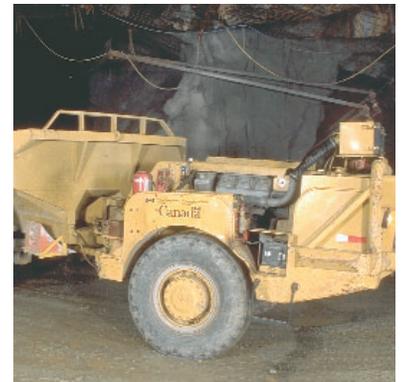
Significant consultations were carried out in 2003 with the Canadian mining industry, universities, research centres, and SMEs to establish a consensus on the main areas of research, where R&D is most likely to have a critical impact over the next ten years. The report will be completed in 2004.

### Mine Air Quality and Ventilation

The Mine Air Quality and Ventilation program is focused on the safety and health of mine workers. This program specializes in mine ventilation automation, diesel engine emission control and certification, and underground contaminant control, sampling and analysis. Of course, success in the application of control technology is intimately linked to the cost of implementation. Initiatives such as ventilation automation allow mine operators to improve air quality while reducing the costs associated with underground ventilation. In this area, CANMET-MMSL collaborates closely with various mining companies, organized labour, and provincial mining regulators to provide technical solutions to industry-wide problems.

#### Cost-effective Mining at Depth - The Impact of Ventilation Automation

Some mines shut off or reduce ventilation outside of peak demand periods, based on time or activity. However, in some operations, the ventilation infrastructure is designed for highest demand scenarios and is used in that configuration whether or not peak air volumes are required. Although this is costly in conventional mines, it is prohibitively expensive in deep, hot operations. In collaboration with a Canadian mining partner, CANMET-MMSL





undertook a case study which estimated that vertical development of an additional 300 m at depth could result in an overall 70% increase in electricity consumption. This increase is due to a modest 10%-20% increase in the required capacity of the primary ventilation system of the mine. This study identified potential windows of opportunity whereby the primary and auxiliary ventilation systems could operate at reduced capacity. For this mine, it was found that peak ventilation was required for only approximately 50% of a regular working week. With demand-based ventilation control and automation, power consumption and costs could be reduced, resulting in savings up to \$2M per year for the mine.

#### **Fuel Cell Power as a Replacement for Diesel Engines - Cost Benefit Analysis**



One option for the replacement of diesel engines in underground mines is the use of electric motors powered by fuel cells. In addition to the health benefits, cost savings are possible if ventilation volumes can be reduced accordingly. There would also be significant reductions in greenhouse gas emissions (GHG). A cost benefit project sponsored by the Fuelcell Propulsion Institute (FPI) and conducted by CANMET-MMSL showed that significant benefits could be realized because ventilation in a mine represents as much as 40% of the energy costs. In particular, the analysis performed on a cross-section of Canadian mines showed that savings ranging between 24% and 50% in electricity costs were possible for the primary ventilation system (main fans). These modeling exercises also projected reductions in greenhouse gas emissions of 27% to 43%, as a result of replacing diesel engines with fuel cells.

#### **Diesel/Electric Hybrid Load-Haul-Dump (LHD) Vehicle**



The ability to move millions of tons of ore per year in the average mine is a direct result of modern mining methods supported by powerful and reliable diesel powered machines. The LHD vehicle is a low profile loader with a rating as high as 400 HP in 8 yd<sup>3</sup> bucket machines.

Unfortunately, use of the diesel engine comes at a price: contaminants from diesel exhaust are toxic, the engines are a significant source of heat, and the ventilation air required to dilute the contamination is extremely expensive to provide. CANMET-MMSL with the support of l'Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST) is completing a project which evaluates the potential of diesel/electric hybrid vehicles in underground mines. The laboratory-based study investigated the benefits of this technology with respect to reduced emissions. In addition to the obvious health benefits, mine operators would have more flexibility in the management of ventilation air.

### Future Directions

A key direction for the Mine Air Quality and Ventilation program will be deep mining. The Deep Mining Research Consortium (DMRC), of which CANMET-MMSL is an active member, focuses on the cost effective development of deep orebodies. The DMRC is a \$17M research initiative that is investigating techniques and technologies that will facilitate cost effective mining at great depth. Some of the initiatives will include aspects of strata heat control, real-time non-destructive testing of hoist ropes, rapid mine development techniques and a study of the performance of diesel engines.

### Ground Control

The CANMET-MMSL Ground Control program provides applied research for the Canadian mining industry on issues of ground stability. The main focus is to improve the health and safety of workers, to reduce risks to the general public from abandoned mines, and to improve the long term economic viability of mining under highly stressed or weak rock masses. Ground control technologies developed to improve mining have been successfully applied to other areas. An example is the micro-seismic technology used to monitor oil wells and slope stability along railways. Another example is the Time-Domain Reflectometry technology used to monitor the stability of tailing dams and other structures. During 2003, CANMET-MMSL specialists in the fields of geodynamics, geomechanics, modeling, support and instrumentation undertook research to solve the complex ground control problems facing the industry.

#### Micro-seismic Monitoring in Oil Sand Operations

This project had the objective of detecting leaks and failures in well casings as they occurred. The scientific basis for the technology was established over the last decade through collaborative work between CANMET-MMSL, Imperial Oil Ltd. and Canadian Natural Resources Ltd. It involved the development and application of a theoretical model of casing failures and successful in situ pilot experiments for leak detection. Canada's oil sand deposits contain more recoverable oil than all the reserves of Saudi Arabia, but their exploitation is difficult for technical reasons. These companies use thermal methods to extract bitumen, through well casings, from their oil sand deposits in northeastern Alberta. CANMET-MMSL continues to be involved in micro-seismic monitoring of casing failures. This collaboration has helped avoid oil leaks at shallow depths, that would have had substantial environmental consequences.





### **The Slam Jet Sparger Project - Sequestration of CO<sub>2</sub> in Oil Sand Tailings**

The Slam Jet Sparger field project was carried out in 2003 at the Aurora Mine, Fort McMurray, Alberta. The project objectives were to investigate the use of carbon dioxide (CO<sub>2</sub>) instead of gypsum for the production of composite tailings or non-segregating tailings, and to study the possible storage or sequestration of carbon dioxide in the composite tailings. The Slam Jet Sparger project was a joint undertaking of Syncrude Canada Limited and Canadian Natural Resources Limited. CANMET-MMSL participation in the project was made possible by Climate Change Action Plan 2000 funding.

### **Deep In Situ Stress Measurement Survey**

Stress measurement tests were conducted at the Campbell Mine, Placer Dome Ltd., Balmertown, Ontario, to determine the magnitude and the orientation of in situ ground stress in the deepest levels of the mine. Tests were done on Level 36 (1,650 m below surface) and Level 39 (1,785 m below surface), in the context of the on-going exploration and development of the Deep Campbell Zone. Tests were done using the standard doorstopper stress measurement technique developed in South Africa in the mid-1960s. Field tests were done in B-size diamond drill holes, bored in three quasi-orthogonal directions at each test site.

### **Future Directions**

Future areas of R&D for the Ground Control program will include the development of standard in situ tests under permafrost conditions, analysis of composite backfill, and development of risk assessment tools using geomechanical and geodynamical data.

## Mine Mechanization and Automation

The Mine Mechanization and Automation program performs research and development related to drilling, rock fragmentation, underground communication and control systems, transportation, hoisting equipment for personnel and ore, as well as noise reduction.

### Mine Hoists

Throughout 2003, CANMET-MMSL continued to offer hoist inspection services to mining companies. Some 30 machines were inspected in Quebec and three in Tanzania. This involved taking a variety of measurements to determine the technical limits of the hoists. As well, CANMET-MMSL was involved in the adaptation of the South African standards SABS 0293:1996 and SABS 0294:2000 for the Province of Quebec. These standards will enable the evaluation of the condition of the wire rope on hoists, in addition to prescribing the performance, testing and maintenance of the hoist drums.

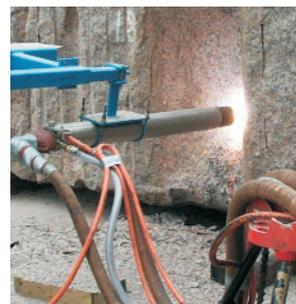
### Application of Fuel Cells to Underground Mining

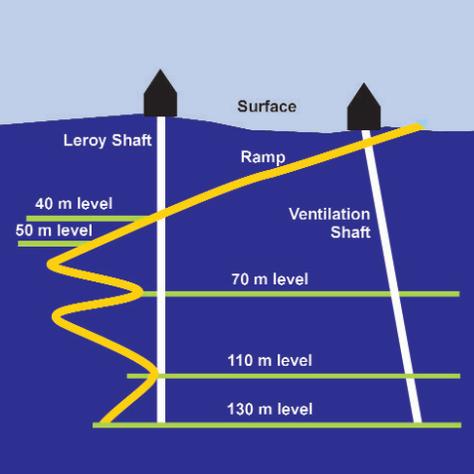
CANMET-MMSL, in collaboration with the Fuelcell Propulsion Institute (FPI), helped to create a North American consortium to do research and development on fuel cells for application in underground mining vehicles. As a partner in FPI, CANMET-MMSL is playing a key role in selecting and planning Canadian projects, and acts as the Project Leader for the demonstration of newly developed fuel cell equipment. In particular, development of the fuel cell loader started in 2002, and will continue for an additional four years. In 2003, the main undertaking was the design of the power system for the loader. In addition, endurance testing of the main components was undertaken using a 4.5 ton fuel cell locomotive.

### Thermal Fragmentation

Thermal fragmentation may provide an innovative method for the economical extraction of ore from narrow vein mines. This process optimizes ore recovery while minimizing dilution with waste rock.

Two alternatives for heat sources are currently being considered for thermal fragmentation, namely, a diesel burner and a plasma torch. In conjunction with its partners in the mining industry during 2003, CANMET-MMSL evaluated the performance and off-gases from the diesel burner, both on surface and underground. As well, a pre-feasibility study was undertaken for thermal fragmentation using the plasma torch.





### Future Directions

The future direction for the Mine Mechanization and Automation program will be to continue to develop technologies in its areas of specialization, in particular, in fragmentation of hard rock without explosives. Success in this area would have important implications relevant to the conventional approaches for the mining of metalliferous veins.



### The CANMET-MMSL Experimental Mine

The CANMET-MMSL Experimental Mine in Val-d'Or, Quebec, is a hard rock mine, which provides an ideal site for research, development and testing of new technologies, as well as the training of mine personnel.

The year 2003 was a very active one for the Experimental Mine. A number of equipment manufacturers and suppliers tested and evaluated their products in the readily accessible and controlled environment of the Experimental Mine. In addition, a collaboration agreement with four universities was signed that provided access to the underground facility for their researchers. An annex is being added onto the surface facilities for their convenience. In total, more than 100 mine industry workers received training in underground mining health and safety at the CANMET-MMSL Experimental Mine in 2003.

## Mineralogy and Metallurgical Processing

The Mineralogy and Metallurgical Processing program applies specialized skills and equipment to improve the productivity, quality and environmental performance of mineral processing and hydrometallurgical operations. Technical advice on major project proposals is also provided to other government organizations. The program activities are: applied mineralogy, base metals, gold processing, high temperature materials, mineral processing, and recycling. In 2003, the program maintained its high level of publications and leadership of scientific activities such as organizing international conferences and workshops.

### Gold Cyanidation Consortia

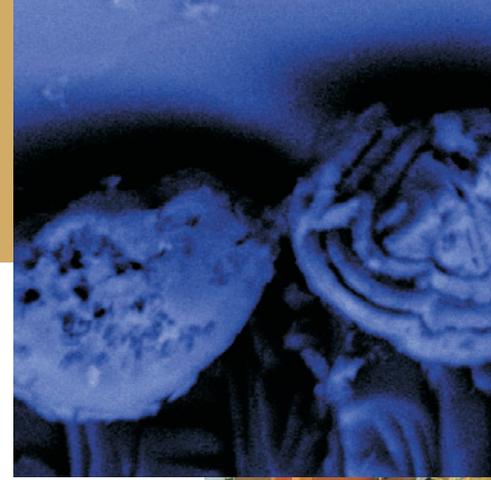
Successful consortia with gold mining operations supported a combination of plant-specific work and shared fundamental research to better understand and improve the operations. These consortia have led to a better understanding of the cyanidation process, with resulting decreases in reagent consumption and reduced losses of gold to the tailings.

### Inco Voisey's Bay Project

Inco Limited is in the process of assessing technologies for the treatment of the concentrates to be produced from the Voisey's Bay nickel sulphide deposit in Labrador. As part of this broad effort, several hydrometallurgical options are being developed and are currently being tested at Inco's facilities. However, some aspects of the proposed processes required additional study which CANMET-MMSL carried out to address specific operational and environmental issues related to the selection of a process and the safe disposal of the autoclave leach residues.

### Fine Particle Project

Fine particles can be problematic in mineral processing circuits, as conventional equipment and processes do not handle them efficiently. This can lead to high mineral losses, increased energy consumption, reduced effectiveness of some operations such as grinding and filtration, and reduced tailings stability. These issues are being addressed by a four-year fine particle project with COREM and Hydro-Québec. In 2003, activities were focused on better identifying the impacts of fines in flotation circuits, and assessing improved or alternative processes for handling the fines. Work is still at the bench test stage; plant trials are planned for the coming year.



## Future Directions

The Mineralogy and Metallurgical Processing program will put an increasing emphasis on developing new or improved processes to reduce or eliminate major environmental challenges. Priority challenges will include reducing cyanide usage while maintaining high gold recoveries, as well as arsenic characterization, processing and stabilization. Other priorities include the identification of hydrometallurgical alternatives to pyrometallurgy, and addressing environmental challenges such as greenhouse gas reductions and recycling. The program is also working with policy groups, federal regional agencies and companies to address the issues and challenges facing Canadian base metal smelters.

## Metals and the Environment



The Metals and the Environment program performs research and development to ensure that environmental policies, regulations and other protection measures pertaining to the mining industry are based on sound science. The program links key scientific data on the fate and effect of metal emissions in the environment to government policies at the domestic and international levels. The program has expertise in aquatic toxicology, biology, environmental chemistry, metals transformation and life cycle assessment of metals. The program generates the science to evaluate the hazards and risks associated with releases of metals and metal compounds to the environment, and provides this expertise to policy and decision-makers.



## Life Cycle Assessment

Life Cycle Assessment (LCA) approaches continue to be developed and applied to environmental assessments. In general, LCA methodologies have been developed for organic substances and their application to metals is often inappropriate. CANMET-MMSL has been actively engaged in identifying alternatives to the inappropriate application of LCA to metals. Following the successful International Workshop on the Life Cycle Assessment of Metals in 2002, CANMET-MMSL continued to promote the application of sound science within LCA. The success of CANMET-MMSL's efforts has resulted in Canada joining the International Life Cycle Initiative (LCI) which functions under the auspices of the United Nations Environment Program (UNEP) and the Society for Environmental Toxicology and Chemistry (SETAC).

## Prediction of Mine Effluent Toxicity to Aquatic Organisms



The CANMET-MMSL aquatic toxicology facilities have continued to develop both acute and chronic testing capabilities, and now include all of the species required under the Metal Mining Effluent Regulations (MMER). Analytical tools to assess metal speciation in standard toxicity test media, effluents and receiving water were also developed and implemented. Testing and field characterization have focused on developing methods for determining site-specific water-quality criteria. This research includes the development and adaptation of biotic ligand prediction models as well as elucidation of the behaviour of other potential toxicants such as thiosalts and flotation reagents. Given the importance of environmental effects monitoring and the associated chronic toxicity testing within the MMER, an improved understanding of mine effluent toxicity and the development of prediction models will make a significant contribution to both the industry and the regulatory community. The work also has significance beyond the MMER, particularly in terms of setting discharge objectives based on site-specific water-quality criteria, and risk assessments.

## Hazard Classification of Metals and Metal Substances

CANMET-MMSL has continued research into hazard identification and classification of metals, and specializes in the transformation and dissolution of metals, sparingly soluble metal compounds and alloys. This work has been a key factor in the development of the Protocol for the Transformation and Dissolution (T/D) of Metals under the OECD Test Guidelines Program. As well, T/D data are an important component of the risk assessments for zinc and nickel within the European Union. In early 2003, the OECD embarked on a project directed at validating the T/D protocol. CANMET-MMSL is an important partner within the validation project and is the lead laboratory for the round-robin test work. The other participating laboratories are based in Chile, Belgium and Italy. Following validation, the T/D protocol may be applied to alloys as well.

## Future Directions

The Metals and the Environment program will continue its efforts to develop sound science on metals and minerals for integration into environmental protection policies. Future initiatives will include an international symposium on LCA, development of metal-specific approaches for hazard and risk assessment, and an improved understanding of mine effluent

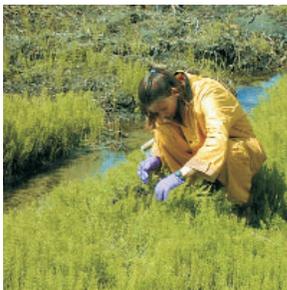


toxicity through a better appreciation of contaminant interactions within aquatic systems.

## Mine Waste Management

The Mine Waste Management program develops and assesses long-term, scientifically sound and sustainable options for mine waste disposal, management and rehabilitation. Current R&D activities include the development of innovative acidic drainage prediction models, the assessment of the benefits and risks of marine tailings disposal, and the design and optimization of innovative lime treatment and sludge densification processes. They also include the investigation of the use of alternative treatment reagents, and the development of alternative waste stabilization technologies and monitoring techniques for contaminant transport across the water/tailings interface. The program provides independent review and technical advice for proposals and decommissioning/rehabilitation feasibility studies, and supports environmental capacity-building projects in developing countries.

### Arsenic Research



Studies were conducted to address the issue of arsenic in different mine wastes and its impact on water quality. The mobilization and transformation of arsenic in mine tailings, as well as the speciation and dissolution of arsenic in a neutralization sludge stored under a water cover, were investigated. Studies were conducted to evaluate and understand the leaching characteristics of radium, arsenic and accompanying heavy metals from un-oxidized uranium tailings. Results from these studies will enhance the understanding of the behavior of various residues and will help identify mine waste management strategies to minimize the transfer of arsenic to the environment.



### Mine Waste Management in the North

The development of mineral resources in the North is limited, in part, by the potential for environmental impact to the fragile northern ecosystem. CANMET-MMSL conducted research to develop cold climate technologies for waste management and remediation. Recent work included an assessment of the chemical stability of mine tailings in the North. Parallel field and laboratory studies were completed to address mine sludge stability and densification in cold climates. In addition, a review of passive treatment applications in the North was completed.

### Using Wastes to Treat Wastes



Mining wastes require appropriate disposal and treatment to minimize any potential environmental impact. The program investigated the use of industrial wastes to remediate mine wastes. Supported by funding from the Climate Change Action Plan 2000, the program assessed the environmental and economic benefits of replacing lime with cement kiln dust. In a pilot-scale trial at Britannia Beach, BC, cement kiln dust was found to be effective in treating acidic

mine water. In another study, the application of pulp and paper mill sludge for water treatment was evaluated and was found to be effective for metal removal from the mine water. This supported previous work using pulp and paper mill sludge to revegetate tailings. As an extension of that activity, the microbes present in a pulp and paper mill sludge cover were evaluated with respect to their role as a reducing agent that inhibits the formation of acidic drainage. In another study, a magnesium-based waste rock was used to treat acidic drainage. The waste rock effectively removed metals from the waste stream, and because of its high magnesium content, also generated a sludge with a higher density than that produced using lime. Utilization of wastes to treat other wastes is beneficial both environmentally and economically.

### Future Directions

The Mine Waste Management program will investigate the use of various additives and binders to physically and chemically stabilize sludges and other mine wastes, and will evaluate the chemical stability of paste backfill residues and sludges. It will continue to assess the behavior and disposal of arsenic, and the development of mine waste management techniques for the North.



## Mine Effluents



The Mine Effluents program works directly with industry on the treatment of mining and milling effluents to develop effluent management strategies. Technologies developed include both chemical and biological processes, with the focus being on the area of biotechnology. Successes include the enhancement of natural degradation processes and the development of active biological processes and passive wetlands technology. Contaminant removal processes have been developed for ammonia, cyanide, thiosalts and metals. The program is also involved in the delivery of capacity-building projects for developing countries.

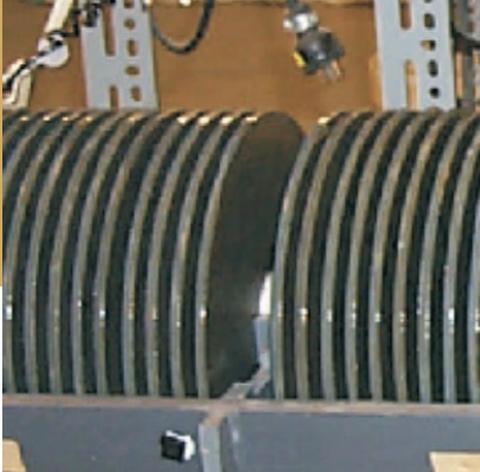
### Natural Degradation of Thiosalts

Natural degradation is the most widely used method to treat thiosalts in mill effluents. However, it is not always an effective treatment method in the spring and fall. By understanding the effects of environmental variables on the chemical and biological processes taking place in a tailings pond, CANMET-MMSL found ways to enhance these natural processes. In 2003, the program performed two studies at an operating mill in northern Quebec. The studies illustrated that the microbes required for thiosalt oxidation were present and that dissolved oxygen and temperature were the limiting factors for promoting their activity. It was found that by implementing a simple and low cost solution, it was possible to decrease the total thiosalt concentration by as much as 30% without the addition of any chemicals.



### Wetlands Work

CANMET-MMSL performed a number of studies in the area of wetlands over the last year. This work involved anaerobic cells, limestone drains and vegetative cells. It examined the inter-relationships between the chemistry and biology that occur within these passive treatment cells. In 2003, some of the projects conducted were field-based sampling and monitoring of an operating field-scale system in British Columbia, operation of a pilot-scale anaerobic bioreactor and Typha cell that successfully treated high loadings of zinc, and bench scale column tests that investigated arsenic removal under anaerobic conditions. In other work, iron oxidizing bacteria and an oxic limestone drain were used to oxidize ferrous ion to the ferric state at acidic pH's and further remove the dissolved iron and aluminium.



### Sediments Project

Natural processes that distribute or redistribute metals in sediments were studied. One of the hypotheses being tested is that metal enrichment at the surface of lake sediments may be the consequence of natural processes, and not a result of industrial activity as is commonly believed. This project is of great interest to regions surrounding large smelting facilities. In this work, sediment samples were taken from two lakes in the Rouyn-Noranda area of Quebec and columns were set-up to determine whether bacterial activity could induce metal resolubilization. Results to date show that some metals may be migrating within the sediment columns as a result of bacterial activity. Further tests are continuing and these could have significant implications for the assessment of the environmental impact of smelters on lakes.

### Brazilian Mine Site Rehabilitation Project

This 5-year project sponsored by the Canadian International Development Agency was successfully concluded. This project achieved its goals of strengthening the institutional technical capability and supporting the establishment of good mine site rehabilitation practices in Brazil. As a result of this project, a mine rehabilitation program has been established and Brazilian mining companies are now using this expertise.

### Future Directions

The integration of chemical and microbial expertise to help provide a better understanding of natural and engineered degradation processes will continue to be the strength of the program. In addition, biotechnological treatment options are being examined with more interest because of their ability to produce non-toxic effluents compared to conventional technologies. Anticipated areas of future work are the biological degradation of nitrogen compounds from gold mill effluents, and the application of advanced biochemical techniques to identify and enhance the activities of specific microbial populations.

## Special Projects

### Mine Environment Neutral Drainage



The year 2003 marked the renewal of the Mine Environment Neutral Drainage (MEND) research program with seven projects in progress. Many of the key priority areas identified by Canadian stakeholders were investigated during 2003. Projects on sludge management, neutral leaching, underground paste backfill, permafrost use in mitigation, case studies, and a dry cover design manual are nearing completion. The Mining Association of Canada, Environment Canada and Natural Resources Canada provided funding for the projects.



Technology transfer is a well-recognized function of MEND, and continues to play a strong role in the program. An international alliance among the regional groups involved in acidic drainage - MEND, ADTI (Acid Drainage Technology Initiative, USA), ACMER (Australian Centre for Mining Environmental Research) and INAP (International Network for Acid Prevention) - was formalized to enhance technology transfer. This partnership co-sponsored the successful 10th Annual British Columbia Metal Leaching and Acid Rock Drainage Workshop in Vancouver in December 2003.



### National Orphaned/Abandoned Mines

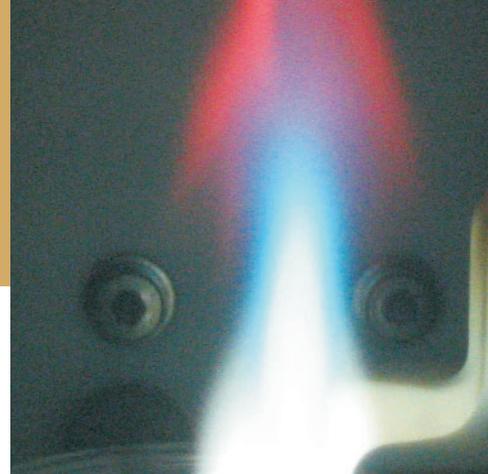
The assessment and remediation of orphaned and abandoned mine sites across Canada has received increased national attention in recent years. The National Orphaned/Abandoned Mines Initiative (NOAMI), established in 2002, is well positioned to address the issues related to this problem. In 2003, a workshop examining the "Legal and Institutional Barriers to Collaboration (LIBC)" was held, and a report on funding approaches was released. Recommendations from these activities were integrated into a multi-year Action Framework, which will involve stronger linkages with the provinces as guidelines and funding mechanisms are developed. As technology transfer is an integral part of the initiative, a web site was launched in 2003 ([www.abandoned-mines.org](http://www.abandoned-mines.org)), which lists publications and information about current activities.

### Canadian Certified Reference Materials

The Canadian Certified Reference Materials Project (CCRMP) provides certified reference materials, and co-ordinates the operation of the Proficiency Testing Program for Mineral Analysis Laboratories (PTP-MAL).

For over thirty years, CCRMP has continued to prepare and certify reference materials. These are finely powdered Canadian ores, rocks, concentrates, tailings, exploration-grade materials, soils, sediments and radioactive materials for which the concentrations of specific elements have been accurately determined. Analytical laboratories in the mining industry assess the accuracy and precision of their own results by using these reference materials. Recent developments in CCRMP include the release of two new copper anode certified reference materials, CUAR-1 and CUPD-1. CUAR-1 has certified values for arsenic, gold, iron, lead, silver, tin, and tellurium, whereas CUPD-1 has certified values for antimony, arsenic, bismuth, gold, iron, lead, nickel, selenium, silver, and tin. Certified reference materials for a lead-zinc-tin ore, a lead concentrate and a gold ore, with analyses for the elements of environmental interest, are expected to be released within the year.

PTP-MAL completed its sixth year of operation with approximately fifty participating laboratories from Canada, the United States, Peru, Chile, Argentina, Brazil, Ireland, South Africa, Tanzania, Guinea, Morocco, Australia, and Indonesia. PTP-MAL provides laboratories with exploration-grade samples to assess their proficiency. Successful participants earn a certificate, which indicates their proficiency as compared to other laboratories. A final report summarizes all of the results, and preserves the anonymity of the participants. PTP-MAL is operated in full accordance with ISO/IEC Guide 43-1 and CAN-P-1579 to meet the needs of Canadian analytical laboratories. Participation in PTP-MAL is obligatory if a laboratory wishes to be, or to remain, accredited to ISO/IEC 17025.





## CANMET Mining and Mineral Sciences Laboratories Publications

### Books

Barbosa, J.P., Soares, P.S.M., Dixon, B. and Tisch, B., editors (2003): Brazil-Canada Seminar on Mine Rehabilitation-Technological Innovations, Desktop Publishing, Rio de Janeiro, Brazil, 301 pp.

Dutrizac, J.E., Negre, P., Paquette, L.A. and Solozabal, R., editors (2003): Environmentally Clean Technologies for Sustainable Production and Consumption, Natural Resources Canada, Ottawa, Ontario, 474 pp.

Dutrizac, J.E. and Clement, C.G., editors (2003): Copper Electrorefining and Electrowinning, Canadian Institute of Mining, Metallurgy and Petroleum, Montreal, Quebec, 658 pp.

Price, W.A., Gardiner, W. and Howell, C., editors (2003): Proceedings of British Columbia Mine Reclamation Symposium - Remediation Work at Closed Mines Where Molybdenum is an Issue, Bytech Publishers Ltd., Richmond, British Columbia.

Riveros, P.A., Dixon, D., Dreisinger, D. and Menacho, J., editors (2003): Hydrometallurgy of Copper, Canadian Institute of Mining, Metallurgy and Petroleum, Montreal, Quebec, 819 pp.

Udd, J.E. and Bekkers, G., editors (2003): Mining in The Arctic: Proceedings 7th International Symposium on Mining in the Arctic, Canadian Institute of Mining, Metallurgy and Petroleum, Montreal, Quebec, 425 pp.

### Patents

Papavinsam, S.S., Gould, W.D., Revie, R.W., MacLeod, F.A. and Attard, M. (2003): Biological activity probe, United States Patent No. 6,673,222.

## Refereed Journal Publications

Beauchemin, S., Hesterberg, D., Chou, J., Beauchemin, M., Simard, R. R. and Sayers, D. (2003): Speciation of phosphorus in P-enriched agricultural soils using XANES spectroscopy and chemical fractionation. *Journal of Environmental Quality* 32, 1809-1819.

Beauchemin, S., Simard, R.R., Bolinder, M.A., Nolin, M.C. and Cluis, D. (2003): Prediction of phosphorus concentration in tile-drainage water from the Montreal lowlands soils. *Canadian Journal of Soil Science* 83, 73-87.

Bétournay, M.C., Desrivières, G., Laliberté, P., Laflamme, M., Miller, A. and Barnes, D. (2003): The fuel cell mining vehicles development program: An update. *Canadian Institute of Mining, Metallurgy and Petroleum (CIM) Bulletin* 96(1074), 72-76.

Bétournay, M.C., Laflamme, M., Miller, A.R. and Barnes, D.L. (2003): Future mining opportunities for fuel cell applications. *Canadian Institute of Mining, Metallurgy and Petroleum (CIM) Bulletin* 96(1074), 77-79.

Cabri, L.J., Sylvester, P.J., Tubrett, M.N., Peregoedova, A. and Laflamme, J.H.G. (2003): Comparison of LAM-ICP-MS and micro-PIXE results for palladium and rhodium in selected samples of Noril'sk and Talnakh sulfides. *Canadian Mineralogist* 41, 321-329.

Chen, T.T. and Dutrizac, J.E. (2003): A mineralogical study of the effect of the lead content of copper anodes on the dissolution of arsenic, antimony and bismuth during copper electrorefining. *Canadian Metallurgical Quarterly* 42(4), 421-432.

Chen, T.T. and Dutrizac, J.E. (2003): Characterization of the calcines produced by the roasting of zinc sulphide concentrates in a TORBED reactor. *Canadian Metallurgical Quarterly* 42(1), 1-16.

Chen, T.T. and Dutrizac, J.E. (2003): Filter press plugging in zinc plant purification circuits. *Journal of Minerals, Metals and Materials (JOM)* 55(4), 28-31.

Dutrizac, J.E. and Chen, T.T. (2003): Synthesis of the vanadium analogue of potassium jarosite. *Canadian Metallurgical Quarterly* 42(2), 187-198.

Dutrizac, J.E. and Chen, T.T. (2003): The synthesis and properties of V(III) analogues of jarosite family minerals. *The Canadian Mineralogist* 41, 479-488.

Förster, H.-J., Cooper, M.A., Roberts, A.C., Stanley, C.J., Criddle, A.J., Hawthorne, F.C., Laflamme, J.H.G. and Tischendorf, G. (2003): Schlemaite,  $(\text{Cu},\square)_6(\text{Pb},\text{Bi})\text{Se}_4$ , a new mineral species from Niederschlema-Alberoda, Erzgebirge, Germany: description and crystal structure. *The Canadian Mineralogist* 41, 1433-1444.

Francis, M.M. and Gould, W.D. (2003): Microbial production of isoquinoline from indene. *Canadian Journal of Microbiology* 49, 699-706.

Geller, L.B., Leung, K., Udd, J.E. and Kitzinger, F. (2003): Electromagnetic testing of wire ropes - new developments. *Canadian Institute of Mining, Metallurgy and Petroleum (CIM) Bulletin* 96(1074), 65-71.

Gould, W.D., Koren, D., Bédard, P., Molnar, R. and Riveros, P.A. (2003): Removal and destruction of ammonia from a uranium plant effluent. *Canadian Institute of Mining, Metallurgy and Petroleum (CIM) Bulletin* 96(1075), 72-77.

Hulsof, A.H.M., Blowes, D.W., Ptacek, C.J. and Gould, W.D. (2003): Microbial and nutrient investigations into the use of in situ layers for treatment of tailings effluent. *Environmental Science & Technology* 37, 5027-5033.

Jambor, J.L., Dutrizac, J.E., Raudsepp, M. and Groat, L.A. (2003): Effect of peroxide on neutralization-potential values of siderite and other carbonate minerals. *Journal of Environmental Quality* 32, 2373-2378.

Kapoor, A., Bédard, P., Kuiper, A. and Gould, W.D. (2003): Use of a rotating biological contactor for removal of ammonia from mining effluents. *The European Journal of Mineral Processing and Environmental Protection* 3, 88-100.

Kocsis, C. and Hardcastle, S. (2003): Ventilation system operating cost comparison between a conventional and an automated underground metal mine. *Mining Engineering* 55(12), 57-64.

Kwong, Y.T.J., Swerhone, G.W.D. and Lawrence, J.R. (2003): Galvanic sulfide oxidation as a metal leaching mechanism and its environmental implications. *Geochemistry-Exploration, Environment and Analysis* 3, 337-343.

McGeer, J.C., Brix, K.V., Skeaff, J.M., DeForest, D.K., Brigham, S.I., Adams, W.J. and Green, A. (2003): Inverse relationship between bioconcentration factor and exposure concentration for metals: implications for hazard assessment of metals in the aquatic environment. *Environmental Toxicology and Chemistry* 22, 1017-1037.

Paktunc, D. and Dutrizac, J.E. (2003): Characterization of arsenic substitution in synthetic potassium jarosite using X-ray diffraction and X-ray absorption spectroscopy. *The Canadian Mineralogist* 41, 905-919.

Pane, E.F., McGeer, J.C. and Wood, C.M.. (2003): The effects of chronic waterborne nickel exposure on successive generations of the freshwater cladoceran, *Daphnia magna*. *Environmental Toxicology and Chemistry* 23, 1051-1056.

Pane, E.F., Smith, C., McGeer, J.C. and Wood, C.M. (2003): Mechanisms of acute and chronic waterborne nickel toxicity in the freshwater cladoceran, *Daphnia magna*. *Environmental Science & Technology* 37, 4382-4389.

Poirier, S., Fecteau, J.M., Laflamme, M. and Brisebois, D. (2003): Thermal rock fragmentation-Applications in narrow-vein extraction. *Canadian Institute of Mining, Metallurgy and Petroleum (CIM) Bulletin* 96(1071), 66-71.

Pratt, A.R. and Duke, N. (2003): Characterizing the distribution of gold in pyritic sulphide ore. *Journal of Minerals, Metals and Materials (JOM)* 55; 51-54.

## Refereed Conference and Workshop Proceedings

Aubé, B and Zinck, J.M. (2003): Lime treatment of acid mine drainage in Canada. *Brazil-Canada Seminar on Mine Rehabilitation - Technological Innovations*, Barbosa, J.P., Soares P.S.M., Dixon, B. and Tisch, B., editors, Desktop Publishing, Rio de Janeiro, Brazil, 23-39.

Bellefontaine, K. and Price, W.A. (2003): Environmental management plans: A key tool in ensuring successful long-term environmental management at closed mine sites with ML/ARD. *British Columbia Mine Reclamation Symposium*, Kamloops, BC, September 15-18, 2003, Price, W.A., Gardner, W. and Howell, C., editors, Publisher, BC Technical and Research Committee on Reclamation, Distributor, Bytech Publishers Ltd. Richmond, British Columbia.

Bétournay, M.C. (2003): The Canadian manual for decommissioning of shallow stopes of hard rock mines. *Proceedings 39th U.S. Rock Mechanics Symposium*, Boston, MA, USA, Culligan, P.J., Einstein, H.H. and Whittle, A.J., editors, Verlag, Essen, Germany, 2811-2818.

Bétournay, M.C., Boyle, R. and Udd, J.E. (2003): Long-term stability considerations and engineering applications for a decommissioning mine in permafrost. Proceedings 7th International Conference on Mining in the Arctic, Udd, J.E. and Bekkers, G., editors, Canadian Institute of Mining, Metallurgy and Petroleum, Montreal, Quebec, 369-380.

Beyak, J.C. (2003): Emerging issues in ecotoxicology. Brazil-Canada Seminar on Mine Rehabilitation - Technological Innovations, Barbosa, J.P., Soares P.S.M., Dixon, B. and Tisch, B., editors, Desktop Publishing, Rio de Janeiro, Brazil, 107-124.

Chen, T.T. and Dutrizac, J.E. (2003): The behaviour of tellurium during the decopperizing of copper refinery anode slimes. Copper Electrorefining and Electrowinning, Dutrizac, J.E. and Clement, C., editors, The Canadian Institute of Mining, Metallurgy and Petroleum, Montreal, Quebec, 287-308.

Davé, N.K. (2003): Management of metal bearing neutral drainages in northern Canada. Proceedings 7th International Conference on Mining in the Arctic, Udd, J.E. and Bekkers, G., editors, Canadian Institute of Mining, Metallurgy and Petroleum, Montreal, Quebec, 139-150.

Davé, N.K. (2003): Uranium mine waste management, rehabilitation and decommissioning- A Canadian perspective. Proceedings Uranium Mine Remediation Exchange Group (UMREG) 2002, Freiberg, Germany, Jakubick, A.T., Mager, D. and Metzler, D.R., editors, WISMUT GmbH, Chemnitz, Germany, 41-58.

Duquet-Harvey, N. and Deschênes, G. (2003): Control of lead nitrate at New Britannia Mine. Proceedings of the 35th Annual Meeting of the Canadian Mineral Processors, Wilson, S. editor, Canadian Institute of Mining, Metallurgy and Petroleum, Montreal, Quebec, 263-274.

Dutrizac, J.E. (2003): The behaviour of cobalt and nickel during jarosite precipitation. EMC 2003, Vol. 1: Copper and Nickel, GDMB, Clausthal-Zellerfeld, Germany, 45-67.

Dutrizac, J.E. (2003): The behaviour of the lanthanide elements during jarosite precipitation. Hydrometallurgy 2003, Vol. 2: Electrometallurgy and Environmental Hydrometallurgy, Young, C.A., Alfantazi, A.M., Anderson, C.G., Dreisinger, D.B., Harris, B. and James, A., editors, The Minerals Metals and Materials Society, Warrendale, PA, USA, 1755-1771.

Dutrizac, J.E. and Chen, T.T. (2003): The control of antimony and bismuth in copper electrolytes by lead additions to the anodes. Copper Electrorefining and Electrowinning, Dutrizac, J.E. and Clement, C. editors, The Canadian Institute of Mining, Metallurgy and Petroleum, Montreal, Quebec, 249-272.

Dutrizac, J.E., Pratt, A.R. and Chen, T.T. (2003): The mechanism of sphalerite dissolution in ferric sulphate-sulphuric acid media. Yazawa International Symposium on Metallurgical and Materials Processing, Kongoli, F., Itagaki, K., Yamauchi, C. and Sohn, H.Y., editors, The Minerals, Metals and Materials Society, Warrendale, PA, USA, 139-162.

Fiset, J.F, Zinck J.M. and Nkinamubanzi, P.C. (2003): Chemical stabilization of metal hydroxide sludge. Tailings and Mine Waste'03, A.A. Balkema Publishers, Lise, The Netherlands, 329-332.

Fiset, J. F., Zinck, J.M. and Laflamme, J.H.G. (2003): Mine sludge stability in cold climates. Proceedings 7th International Conference on Mining in the Arctic, Udd, J.E. and Bekkers, G., editors, Canadian Institute of Mining, Metallurgy and Petroleum, Montreal, Quebec, 151-160.

Gould, W.D. (2003): Applications of passive biological systems for the treatment of acid mine drainage. Brazil-Canada Seminar on Mine Rehabilitation - Technological Innovations, Barbosa, J.P., Soares P.S.M., Dixon, B. and Tisch, B., editors, Desktop Publishing, Rio de Janeiro, Brazil, 91-105.

Hollow, J., Deschênes, G., Guo, H., Fulton, M. and Hill, E. (2003): Optimizing cyanidation parameters for processing of blended Fort Knox and True North ores at the Fort Knox Mine. Hydrometallurgy 2003, Young, C., Alfantazi, A., Anderson, C., James, A., Dreisinger, D. and Harris, B., editors, The Minerals, Metals and Materials Society, Warrendale, PA, USA, 21-34.

Judge, K.J. and Udd, J.E. (2003): Development of an on-line geotechnical instrumentation system for monitoring over the internet. Proceedings 7th International Conference on Mining in the Arctic, Udd, J.E. and Bekkers, G., editors, Canadian Institute of Mining, Metallurgy and Petroleum, Montreal, Quebec, 285-291.

Kapoor, A., Gould, W.D., Bédard, P. and Morin, K. (2003): Treatability study of gold mill effluents by biological wastewater treatment methods. Proceedings of the 35th Annual Meeting of the Canadian Mineral Processors, Wilson, S., editor, The Canadian Institute of Mining, Metallurgy and Petroleum, Montreal, Quebec, 669-684.

Kocsis, C., Hall, R. and Hardcastle, S. (2003): The integration of mine simulation and ventilation simulation to develop a "life-cycle" ventilation system. 31st International Symposium on Computer Applications in the Minerals Industry - APCOM 2003, Camisani-Calzolari, F.A., editor, South African Institute of Mining and Metallurgy, Marshalltown, South Africa, Section 6 Mine Planning.

Kwong, Y.T.J. (2003): Characteristics of impounded tailings at Mount Nansen - implications for remediation. Proceedings of the Third Biennial Workshop on Assessment and Remediation of Contaminated Sites in Arctic and Cold Climates, May 4-6, 2003, Edmonton, Alberta, Nahir, M., Biggar, K. and Cotta, G., editors, Department of Civil Engineering, University of Alberta, Edmonton, Alberta 57-62.

Kwong, Y.T., Kapoor, A. and Fiset, J.F. (2003): Assessment of chemical stability of the impounded tailings at Mount Nansen, Yukon Territory. Proceedings 7th International Conference on Mining in the Arctic, Udd, J.E. and Bekkers, G., editors, Canadian Institute of Mining, Metallurgy and Petroleum, Montreal, Quebec, 355-369.

Li, G.G. and Qi, L. (2003): Analysis of geostress and its influences on foundation stability in a hydropower project. Proceedings of 12th Panamerican Conference on Soil Mechanics and Geotechnical Engineering and 39th U.S. Rock Mechanics Symposium, Boston, MA, USA, Culligan, P.J., Einstein, H.H. and Whittle, A.J., editors, Verlag, Essen, Germany, 1139-1144.

Paktunc, D. (2003): Speciation of arsenic in metallurgical wastes by synchrotron X-ray absorption spectroscopy. Environmentally Clean Technologies for Sustainable Production and Consumption, Dutrizac, J.E., Negre, P., Paquette, L. and Solozabal, R., editors, CANMET-CARI- European Commission Workshop, Vancouver, Canada, Natural Resources Canada, Ottawa, Ontario, 407-415.

Price, W.A. (2003): Metal leaching and acid rock drainage challenges at closed mine sites. British Columbia Mine Reclamation Symposium, Kamloops, British Columbia, September 15-18, 2003, Price, W.A., Gardner, W. and Howell, C., editors, Publisher, BC Technical and Research Committee on Reclamation, Distributor, Bytech Publishers Ltd. Richmond, British Columbia.

Sage, R. and Bétournay, M.C. (2003): Use of fuel cells in underground mining. Proceedings 18th International Mining Congress, Antalya, Turkey, Ozbayoglu, G., editor, The Chamber of Mining Engineers of Turkey, Ankara, Turkey, 129-133.

Tisch, B. and Tremblay, G. (2003): The legacy of abandoned Mines in Canada. Brazil-Canada Seminar on Mine Rehabilitation - Technological Innovations, Barbosa, J.P., Soares P.S.M., Dixon, B. and Tisch, B., editors, Desktop Publishing, Rio de Janeiro, Brazil, 125-141.

Udd, J.E., Judge, K.J. and Auer, L.J.F. (2003): A case history on the development of a geotechnical monitoring system at the Nanisivik Mine, Baffin Island. Proceedings 7th International Conference on Mining in the Arctic, Udd, J.E. and Bekkers, G., editors, Canadian Institute of Mining, Metallurgy and Petroleum, Montreal, Quebec, 275-283.

Van Huyssteen, E. (2003): Mining with environmental quality - The Canadian experience. Brazil-Canada Seminar on Mine Rehabilitation - Technological Innovations, Barbosa, J.P., Soares P.S.M., Dixon, B. and Tisch, B., editors, Desktop Publishing, Rio de Janeiro, Brazil, 143-178.

## Electronic and Other Publications

Aota, J., Morin, L., Lastra, R., Zhuang, Q. and Clements, B. (2003): Alternative iron making process using cold-bonded pellets. Iron and Steel Exposition and AISE Annual Convention, September 29 - October 1, 2003, Association of Iron and Steel Engineers, Pittsburgh, PA, USA (CD format).

Bétournay, M.C. and Mitri, H.S. (2003): Laboratory simulation of the behavior of highly stressed mining fronts. Proceedings 10th International Rock Mechanics Congress, Sandton, South Africa, Handley, M. and Stacey, D., editors, South African Institute of Mining and Metallurgy, Marshalltown, South Africa, 113-119 (CD format).

Bétournay, M.C., Desrivières, G., Laliberté, P., Chan, J.R., Replogle, B., Miller, A.R., Barnes, D.L., Burse, H., Sprott, D. and MacKinnon, T. (2003): Design, testing and performance of the world's first fuel cell mine vehicle, a mine production locomotive. Proceedings 105th CIM Annual General Meeting, Montreal, May 4-7, 2003, Canadian Institute of Mining, Metallurgy and Petroleum, Montreal, Quebec (CD format).

Bétournay, M.C., Laliberté, P., Lacroix, R., Kocsis, C., Hardcastle, S., Desrivières, G., Mousset-Jones, P. and Righettini, G. (2003): Fuel cell versus diesel loader operation: cost-benefit analysis study. Proceedings 105th CIM Annual General Meeting, Montreal, May 4-7, 2003, Canadian Institute of Mining, Metallurgy and Petroleum, Montreal, Quebec (CD format).

Bétournay, M.C., Laflamme, M., Miller, A. and Barnes, D. (2003): Future mining opportunities for fuel cell applications. Proceedings 105th CIM Annual General Meeting, Montreal, May 4-7, 2003, Canadian Institute of Mining, Metallurgy and Petroleum, Montreal, Quebec (CD format).

Bétournay, M.C., Desrivières, G., Laliberté, P., Laflamme, M., Miller, A. and Barnes, D. (2003): The fuel cell mining vehicles development program: an update. Proceedings 105th CIM Annual General Meeting, Montreal, May 4-7, 2003, Canadian Institute of Mining, Metallurgy and Petroleum, Montreal, Quebec (CD format).

Bétournay, M.C., Bonnell, G., Edwardson, E. and Lidkea, W. (2003): Suitability of PEM fuel cells for underground mining vehicles. Proceedings 105th CIM Annual General Meeting, Montreal, May 4-7, 2003, Canadian Institute of Mining, Metallurgy and Petroleum, Montreal, Quebec (CD format).

Davé, N.K., Krishmappan, B.G., Davies, M., Reid, I. and Lanteigne, L. (2003): Erosion characteristics of underwater deposited mine tailings. Sudbury 2003 Mining and the Environment, Spiers, G., Beckett, P. and Conroy, H., editors, Centre for Environmental Monitoring, Laurentian University, Sudbury, Ontario (CD format).

Davé, N.K. and Paktunc, D. (2003): Surface reactivity of high-sulphide copper mine tailings under shallow water cover conditions. The 6th International Conference on Acid Rock Drainage, Cairns, Australia, July 12-18, 2003, The Australasian Institute of Mining and Metallurgy, Carlton South, Victoria, Australia, 241-251 (CD format).

Delabbio, F., Eastick, D., Graves, C., Sprott, D. and Bétournay, M. C. (2003): A risk assessment and regulatory compliance of the world's first fuel cell-powered mining equipment. Proceedings 105th CIM Annual General Meeting, Montreal, May 4-7, 2003, Canadian Institute of Mining, Metallurgy and Petroleum, Montreal, Quebec (CD format).

Dixon, B., Tisch, B. and Kangama, G.K. (2003): Mining in Zambia: Challenges to effective regulation. Sudbury 2003 Mining and the Environment, Spiers, G., Beckett, P. and Conroy, H., editors, Centre for Environmental Monitoring, Laurentian University, Sudbury, Ontario (CD format).

Djivre, M.M., Kitzinger, F., Leung, K., Udd, J.E. and Geller, L. (2003): Electromagnetic testing of wire ropes - new developments. Proceedings 105th CIM Annual General Meeting, Montreal, May 4-7, 2003, Canadian Institute of Mining, Metallurgy and Petroleum, Montreal, Quebec (CD format).

Drexler, J., Fisher, N., Henningsen, G., Lanno, R., McGeer, J. and Sappington, K. (2003): Issue paper on the bioavailability and bioaccumulation of metals. Invited Issue Paper under the US EPA Metals Action Plan. Posted at <http://cfpub.epa.gov/ncea/raf/recordisplay.cfm?deid=59052>, 119 pp.

Frostad, S., Price, W.A. and Bent, H.G. (2003): Operational NP determination - accounting for iron manganese carbonates and developing a site-specific fizz rating. Sudbury 2003 Mining and the Environment, Spiers, G., Beckett, P. and Conroy, H., editors, Centre for Environmental Monitoring, Laurentian University, Sudbury, Ontario (CD format).

Giziewicz, E., editor (2003): RNet Recycling Technology Newsletter, Natural Resources Canada, Ottawa, Ontario.

Gorski, B. and Bétournay, M.C. (2003): The application of time domain reflectometry to monitor tailings embankment movements. The 3rd Tailings Dam Symposium, Montreal, Quebec, International Commission on Large Dams, Paris, France (CD format).

Gould, W.D. and Kapoor, A. (2003): The microbiology of acid mine drainage. Environmental Aspects of Mine Wastes, Jambor, J.L., Blowes, D.W. and Ritchie, A.I.M., editors, Mineralogical Association of Canada Short Course, Volume 31, 203-226.

Gould, W.D., Stichbury, M., Francis, M., Lortie, L. and Blowes, D.W. (2003): An MPN method for the enumeration of iron-reducing bacteria. Sudbury 2003 Mining and the Environment, Spiers, G., Beckett, P. and Conroy, H., editors, Centre for Environmental Monitoring, Laurentian University, Sudbury, Ontario (CD format).

Hardcastle, S. and Kocsis, C. (2003): The ventilation challenge - to maintain a tolerable working environment in deep mines. Proceedings 105th CIM Annual General Meeting, Montreal, May 4-7, 2003, Canadian Institute of Mining, Metallurgy and Petroleum, Montreal, Quebec (CD format).

Kapoor, A., Dinardo, O., Gould, W.D., Kuiper, A., Kawaja, J. and Bédard, P. (2003): Application of rotating biological contactor technology for mine effluent treatment and metal bioleaching operations. Sudbury 2003 Mining and the Environment, Spiers, G., Beckett, P. and Conroy, H., editors, Centre for Environmental Monitoring, Laurentian University, Sudbury, Ontario (CD format).

Kwong, Y.T.J. (2003): Thoughts on practical tools for early identification of environmental challenges associated with a mining project. Proceedings of the 6th International Conference on Acid Rock Drainage, Cairns, Australia, July 14-17, 2003. The Australasian Institute of Mining and Metallurgy, Carlton South, Victoria, Australia, 601-604 (CD format).

Kwong, Y.T.J. and Hynes, T.P. (2003): Benefits and risks of submarine tailings disposal - Lessons learnt from two historic mine sites in Newfoundland and other Canadian case studies. Proceedings of the 6th International Conference on Acid Rock Drainage, Cairns, Australia, July 14-17, 2003. The Australasian Institute of Mining and Metallurgy, Carlton South, Victoria, Australia, 719-724 (CD format).

Langmuir, D., Chrostowski, P., Chaney, R. and Vigneault, B. (2003): Issue paper on the environmental chemistry of metals. Invited issue paper under the US EPA Metals Action Plan. Posted at [http://oaspub.epa.gov/eims/eimscomm.getfile?p\\_download\\_id=379035](http://oaspub.epa.gov/eims/eimscomm.getfile?p_download_id=379035), 114 pp.

Lastra, R., Cabri, L.J. and Weiblin, P.W. (2003): Comparative liberation study by image analysis of Merensky Reef samples comminuted by electric-pulse disaggregation and by conventional jaw crusher. XXII International Mineral Processing Congress, September 28 - October 3, 2003, Cape Town, South Africa, South African Institute of Mining and Metallurgy, Marshalltown, South Africa (CD format).

Li, G., Bétournay, M.C. and Boyle, R. (2003): Examination of rockbursts around deep mine excavations by using linear and non-linear FEM analysis. Proceedings 5th Computer Applications in the Mineral Industries, Calgary, Alberta, Singhal, R., Fytas, F. and Chiwetelu, C., editors (CD format).

Ludgate, I., Coggan, A and Davé, N.K. (2003): Performance of shallow water cover on pyritic uranium tailings. Proceedings of the 6th International Conference on Acid Rock Drainage, Cairns, Australia, July 14-17, 2003. The Australasian Institute of Mining and Metallurgy, Carlton South, Victoria, Australia, 287-296 (CD format).

Miller, A. and Bétournay, M.C. (2003): Applications and benefits of the hydrogen fuel cell mining program. Proceedings 5th Computer Applications in the Mineral Industries, Calgary, Alberta, Singhal, R., Fytas, F. and Chiwetelu, C., editors (CD format).

Okonski, A., Levin, S., Tisch, B., Beckett, P. and McCreath, D. (2003): Changes in chemical and biological properties of paper sludge used for revegetation of copper tailings. Sudbury 2003 Mining and the Environment, Spiers, G., Beckett, P. and Conroy, H., editors, Centre for Environmental Monitoring, Laurentian University, Sudbury, Ontario (CD format).

Paktunc, D. and Davé, N. (2003): Pyrite oxidation rates determined based on quantitative mineralogy of long-term column leaching tests. The 6th International Conference on Acid Rock Drainage, Cairns, Australia, July 14-1, 2003, The Australasian Institute of Mining and Metallurgy, Carlton South, Victoria, Australia, 1095-1097 (CD format).

Price, William A. (2003): The mitigation of acid rock drainage: Four case studies from British Columbia. Sudbury 2003 Mining and the Environment, Spiers, G., Beckett, P. and Conroy, H., editors, Centre for Environmental Monitoring, Laurentian University, Sudbury, Ontario (CD format).

Tisch, B., Volchek, K., Okonski, A., Raskin, M. and Black, C. (2003): Lignin and lignin derivatives to promote vegetative growth and metal uptake in mine tailings. Sudbury 2003 Mining and the Environment, Spiers, G., Beckett, P. and Conroy, H., editors, Centre for Environmental Monitoring, Laurentian University, Sudbury, Ontario (CD format).

Tremblay, G., Hogan, C. and Gardiner, E. (2003): Mine Environment Neutral Drainage (MEND) initiative. The 6th International Conference on Acid Rock Drainage, Cairns, Australia, July 14-1, 2003, The Australasian Institute of Mining and Metallurgy, Carlton South, Victoria, Australia, 5-8 (CD format).

Udd, J.E. (2003): An international review of the use and testing of the wire ropes used in mine hoisting. Proceedings 105th CIM Annual General Meeting, Montreal, May 4-7, 2003, Canadian Institute of Mining, Metallurgy and Petroleum, Montreal, Quebec (CD format).

Zhuang, Q., Clements, B. and Aota, J. (2003): CANMET direct reduced iron process. Combustion Canada '03, September 21-24, 2003 Vancouver, British Columbia (CD format).