INNOVATION IN PROGRESS 2013

CEMI
Centre for Excellence in Mining Innovation

CEMI's strategic focus has resulted in five core research and development project themes: FindMine, DeepMine, ValueMine, ConstructMine and SustainMine. Each is wide-reaching and helps to advance innovation and enrich knowledge for the metal mining industry.

CONTENTS

EXPLORATION | FindMine

Implementation of step-change research, both surface and underground, in the area of exploration (new deposits, expanded mines) and geophysics, that is strategically important to mining sustainability.

DEEP MINING | DeepMine

Research and development of new technologies and processes to ensure safe, profitable mining at depth, with a focus on risk mitigation, mechanized underground excavation, cost reduction, and productivity enhancement.

INTEGRATED MINE ENGINEERING | ValueMine

Strategic research and development in the areas of: Mine Process Engineering and Mine Design to enhance safety and performance, minimize impact and cost risk and emphasize best practices; Enabling Technologies that will result in advances in data and knowledge transfer.

INTEGRATED MINE CONSTRUCTION | ConstructMine

Strategic research and development for safe, rapid, mechanized development of underground mines.

ENVIRONMENT & SUSTAINABILITY | SustainMine

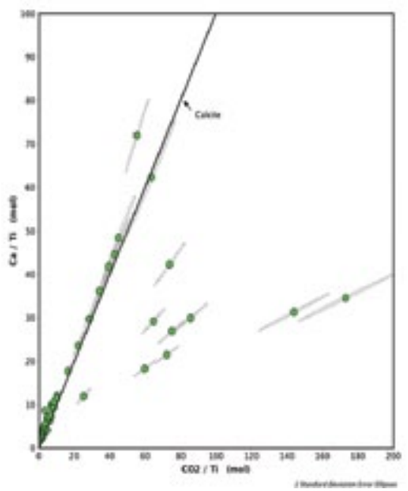
Research is underway to try to identify processes that might lead to more environmentally benign results and better stewardship of mineral resources. Strategic research in the areas of environmentally responsible processes, environmental studies and sustainability is underway. Initiation of novel or reconsideration of previously abandoned techniques for the secondary processing of mine waste.

DEVELOPMENT OF JAVA-BASED MERLIN SOFTWARE TO PLOT MER DIAGRAMS

THE ISSUE: Over the years, molar element ratio (MER) analysis has become both highly adaptable and extraordinarily useful in determining the mineralogical controls in rocks. Pearce element ratio (PER) analysis and general element ratio (GER) analysis are two different but complimentary forms of MER analysis that identify the mineralogical controls in igneous and sedimentary rocks, mineral deposit alteration zones and chemical weathering. As powerful as MER analysis is, it has not gained the following it deserves amongst geoscientists, in large part due to the lack of updated computer software that can plot data in a way that facilitates the interpretation of MER diagrams. These diagrams can clarify the mineralogical history of rocks and help minimize interpretational ambiguity.

THE SOLUTION: Drs. Clifford Stanley and James Diamond of Acadia University designed and developed Java-based software that simplifies the accurate plotting of both PER and GER diagrams, and accelerates their interpretation. Programming the software in Java makes the software available to virtually all laptops, desktops or workstations, including those running MS-windows, Apple OS X, Linux or Unix. The features of the program and the flexibility of Java will make the software more accessible to a wider population of geoscientists with differing skill sets.

THE RESULTS: MERLIN software in Java script is now available. The new program provides a quantitative and objective method to measure data in order to understand the impact and extent of hydrothermal reaction on mineralization, and important step in mineral exploration. It can also be used to examine fractionation processes and so gain a better understanding of the genesis of igneous rocks. MERLIN will be available for download to all geoscientists and to the global mining industry on the CEMI website at www.miningexcellence.ca



Here is a simple graph examining the lithogeochemistry of turbidites from the Castlepoint area of New Zealand (North Island), with information about it below.

This PER diagram tests for compositional control by calcite. Samples plotting on the calcite compositional control line (m = 1) contain calcite; samples plotting with higher ratios along this line contain more calcite. Samples plotting to the right of the calcite compositional control line (m = 1) contain siderite, whereas the sample plotting significantly above the calcite compositional control line (m = 1) contains apatite.

CONTACT:
Cliff Stanley, Acadia University
1-905-585-1344
cliff.stanley@acadiau.ca
www.acadiau.ca

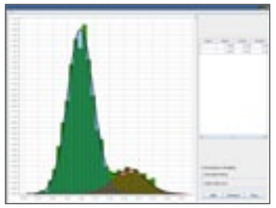
SOLUTION TEAM:
Douglas Morrison, CEMI; Jim Diamond, Acadia University
Kelly Russell, University of British Columbia
Jim Nicholls, University of Calgary
Tony Beswick, Laurentian University (Professor Emeritus)

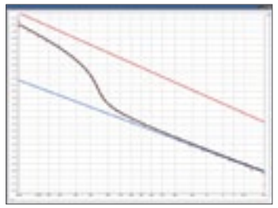
TRANING PROBPLOT SOFTWARE TO A MULTI-PLATFORM APPLICATION

THE ISSUE: ProbPlot analysis of exploration geochemical data is a highly effective means of identifying samples with common geochemical signatures and classifying them into related groups. ProbPlot software was widely used for this analysis and became an industry standard for serious geochemical reports in the 1980's and early 1990's. The ProbPlot software was originally developed for the DOS operating system but was not upgraded to the Windows operating system. As valuable as ProbPlot software was, its use eroded over time, solely due to the discontinuation of DOS software and hardware. As such, ProbPlot geochemical data analysis is no longer commonly used by mineral explorationists.

THE SOLUTION: Drs. Clifford Stanley and James Diamond of Acadia University have undertaken to redesign/upgrade the ProbPlot software to give it more functionality and make it more accessible. It is being developed in Java so that it is accessible on virtually all laptops, desktops or workstations, including those running MS-windows, Apple OS X, Linux or Unix. As well as having all of the functionality of the original program, it will incorporate many new features (e.g., interactive graphics, consequence-based interpretation) that will significantly increase understanding of cumulative frequency data, the element concentrations used in mineral explorations and its value to mineral exploration and the mining industry in overall.

INNOVATION IN PROGRESS: The development and testing of the software is in progress through the summer and fall of 2013. Beginning in January 2014, this CEMI-funded project will be available for download to all geoscientists and to the global mining industry on the CEMI website in the short term until the means of web distribution are finalized.





Figures 1 and 2 present a probability plot and its corresponding histogram of an element concentration generated by the SOPP software. The program has been used to optimally fit the underlying frequency data with two normal sub-populations (straight lines on the probability plot, blue and red bell curves on the histogram). The resulting frequency model (curved black lines on both plots) can be used to determine the most appropriate thresholds to classify the samples into two categories (e.g., 'anomalous' and 'background', 'sandstone' and 'shale', 'ore' and 'waste', etc.) and thus facilitate accurate geochemical data interpretation.

CONTACT:
Cliff Stanley, Acadia University
1-905-585-1344
cliff.stanley@acadiau.ca
www.acadiau.ca

SOLUTION TEAM:
Douglas Morrison, CEMI
James Diamond, Acadia University
Bruce Downing, New Carolin Gold Corp
Alastair Sinclair, University of British Columbia (Professor Emeritus)

A COMPARATIVE STUDY OF MINERALIZED AND UNMINERALIZED BRECCIAS ALONG THE WHISTLE OFFSET DIKE IN THE NORTH RANGE OF THE SUDBURY IMPACT STRUCTURE

MERC

THE ISSUE: Breccias, such as Sudbury breccia and metabreccia, are preferred hosts to Cu-Ni-PGE mineralization in footwall country rocks and offset dykes of the Sudbury Igneous Complex. The ability to identify and distinguish unmineralized and mineralized metabreccia along offset dikes would help focus exploration efforts.

THE SOLUTION: The main objective of this research project is to develop criteria for discriminating between unmineralized and mineralized metabreccia. By providing tools that aid in the recognition of mineralized metabreccia, exploration efforts and dollars can be focused on the most favourable host rocks.

THE RESULTS: Metabreccia is one of the main hosts of Cu-Ni-PGE mineralization along the Whistle offset dike. Petrographical, modal mineralogical, image analysis, mineral chemistry, and lithogeochemical observations do not suggest any significant differences between mineralized and unmineralized metabreccias.

CONTACT:
Bruno Lafrance, MERC, Laurentian University
1-705 675-1151 x 2264
blafrance@laurentian.ca
www.merc.laurentian.ca

SOLUTION TEAM:
Damien Duff, CEMI; Peter Lightfoot, Vale; Lisa Gibson, Vale
Gregg Snyder and Mike Sweeny, Sudbury Integrated Nickel Operations – A Glencore Company
Andy McDonald, MERC, Laurentian University
Lindsay Bygnes (MSc), Laurentian University; Claire McAneney, NSERC

EXPERIMENTAL STUDIES OF THE ROLE OF Bi, Te, As IN PLATINUM GROUP ELEMENTS (PGE) FRACTIONATION AND REMOBILIZATION DURING THE CRYSTALLIZATION OF A SULFIDE MELT

MERC

THE ISSUE: The Platinum Group elements (PGE) in the footwall ores in Sudbury are typically found as Platinum Group Metals (PGM) that contain arsenic, tellurium, and bismuth (e.g. michenerite, moncheite, froodite, sperrylite). To understand the distribution of PGE in Cu-Ni-PGE systems (and the influence of magmatic vs. hydrothermal processes in ore formation), it is necessary to constrain how these three elements (As, Te, Bi) affect the behaviour of PGE.

THE SOLUTION: Experiments are being conducted in the Laboratory for Experimental Petrology Applied to Ore Deposits at Laurentian University involving the synthesis of sulfide melts, enriched in Bi, Te, As, and PGE to constrain how separation of a Cu-rich sulfide melt from a Fe-rich sulfide residue and separation of a Bi-Te melt from a Cu-rich sulfide residue affect the fractionation of PGE. Synthesis is being done at temperatures ranging from 1200 °C to 550 °C and either at atmospheric pressures (in evacuated silica tubes) or at 5 kbar (in a piston-cylinder press). Synthesized samples were analyzed for distribution and partition-ing of PGE among different phases to determine the temperatures at which Bi-Te melts form and to establish how PGE fractionate in the presence of As, Bi, and Te.

INNOVATION IN PROGRESS: Experiment results indicate that gold, palladium, and platinum can be mobilized away from a main mass of sulfides without the need of hydrothermal fluids, at temperatures down to 600 °C. Below 600°C, any PGE mobilization will likely be hydrothermal. Main results were presented at the GAC-MAC conference in May 2013 and a paper will be submitted for publication by end of 2013. Additional experiments on different aspects of the system are in progress.

Platinum, palladium, and gold arsenides synthesized experimentally at 900 oC. Light grey grains with square and trapezoidal sections is sperrylite (PtAs2). The lighter (almost white) rounded grains are Au-Pd arsenides (likely from immiscible arsenide melt droplets). Darkest grey areas are Fe-Ni sulfides. The intermediate-grey region in the right-hand side are Cu-Fe sulfides (from a Cu-rich sulfide melt).

CONTACT:
Pedro Jugo, MERC, Laurentian University
1-705-675-1151 x 2106
pjugo@laurentian.ca
www.merc.laurentian.ca

SOLUTION TEAM:
Damien Duff, CEMI; Peter Lightfoot, Vale; Lisa Gibson, Vale
Gregg Snyder and Mike Sweeny, Sudbury Integrated Nickel Operations – A Glencore Company
Andy McDonald, MERC, Laurentian University; Fabio Cafagna (PhD), Laurentian University
Claire McAneney, NSERC

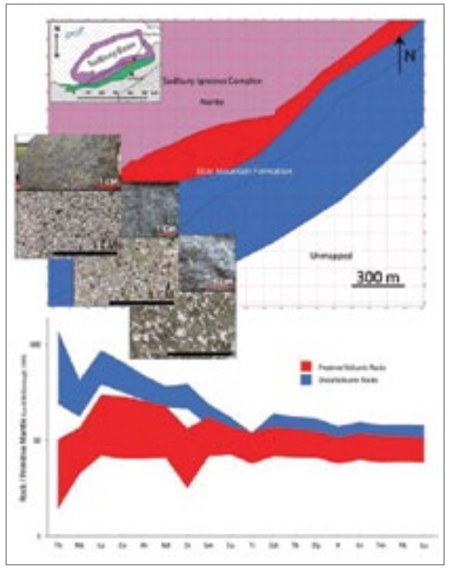
EVOLUTION OF THE SUDBURY IGNEOUS COMPLEX CONTACT METAMORPHIC AUREOLE AND CONTROLS ON ANATEXIS

MERC

THE ISSUE: Much of the Ni-Cu-PGE mineralization in the Sudbury Structure was generated and modified within the anatectic and contact metamorphic aureole of the Sudbury Igneous Complex (SIC). To increase our chances of exploration success in this complex environment, new and novel exploration techniques are needed, yet few studies have been conducted that show how to identify the presence of a contact metamorphic aureole around the SIC. This is critical for a deeper understanding of the thermal architecture during the development of some types of contact and footwall ore deposits.

THE SOLUTION: Defining field, microscopic and geochemical criteria to establish the nature and extent of partial melting, metamorphic devolatilization, and fluid interaction within the SIC contact metamorphic aureole and the overprint of the aureole by regional metamorphism will provide the context to understand the thermal structure and evolution around the SIC.

THE RESULTS: Field observations indicate that large portions of the South Range metamorphic aureole surrounding the SIC can be resolved despite complications due to post-metamorphic events, primary lithologic heterogeneities, and the geometry of the SIC contact. Geochemical data has proven useful in establishing fingerprints to distinguish rocks that are highly affected by contact metamorphism compared to similar rocks in the more distal part of the metamorphic aureole. This is extremely useful as new and existing geochemistry databases can now be studied to see if similar rocks outside the study area show the same characteristics. Finding rocks with matching characteristics would indicate their proximity to the SIC during cooling and solidification of the SIC melt sheet.



CONTACT:
Douglas Tinkham, MERC, Laurentian University
1-705.675.1151 x 2270
dtinkham@laurentian.ca
www.merc.laurentian.ca

SOLUTION TEAM:
Damien Duff, CEMI; Peter Lightfoot, Vale; Lisa Gibson, Vale
Gregg Snyder and Mike Sweeny, Sudbury Integrated Nickel Operations – A Glencore Company
Michael Lesher, MERC, Laurentian University; Taus Joergensen (PhD), Laurentian University
Claire McAneney, NSERC

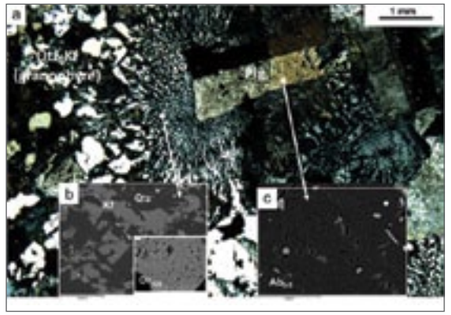
THE ROLE OF FLUIDS IN THE FORMATION AND MODIFICATION OF FOOTWALL Cu-Ni-PGE SYSTEMS

MERC

THE ISSUE: The Sudbury Igneous Complex (SIC) and its footwall rocks constitute one of the most significant centres of Ni-(Cu)-PGE mineralization globally. Previous work indicates that fluids have contributed to the low-temperature evolution of the footwall mineralization, but details remain poorly defined. Similarly, there has been relatively little work done to assess the role of the hydrothermal system process in the formation, upgrading and mobilization of ore zones in the SIC and what aspects of these alterations are conducive to mineralization.

THE SOLUTION: Conduct a characterization and evaluation of fluid-related alteration within both the granophyre unit and footwall setting (Nickel Rim South) by integrating field observations, petrography, whole-rock and mineral chemistry, stable isotopes, and chemistry of fluid inclusions. These data will be used to address several fundamental issues regarding the role of fluids in the SIC and mineralized settings. This project links directly with two other projects currently underway that are focusing on the generation of melts in the contact aureole of the SIC and the role of trace metals in mobilization of sulfide ores and PGE.

INNOVATION IN PROGRESS: Data collected in this study, using a wide variety of analytical methods, suggest that the granophyre interacted extensively at high fluid:rock ratios with two thermally distinct, but chemically similar fluids in terms of their bulk chemistry. These two fluids record the initiation and subsequent collapse of hydrothermal fluid circulation related to the SIC. The early high-T fluid may be internally derived and was responsible for the pervasive metasomatism observed in the granophyre. The later lower-T fluid records the ingress of an external fluid as the hydrothermal system collapsed. This latter fluid, fuelled by the cooling SIC, gave rise to massive sulfide mineralization (Zn-Pb-Ag) found at the top of the Onaping Formation which overlies the granophyre. Ongoing study will compare and contrast the characteristics of the hydrothermal alteration documented in the granophyre with that associated with the footwall system of the large Nickel Rim South Ni-Cu-PGE deposit. These results are underway and will be presented in 2014.



Dissolution-reprecipitation texture (Figure 1a) from granophyre unit, SIC. K-feldspar (Figure 1b) and plagioclase (Figure 1c) grains contain pitted textures, produced by dissolution-precipitation reactions at ~300-350°C. Some pits contain secondary phases.

CONTACT:
Daniel J. Kontak, MERC, Laurentian University
1-705-675-1151 x 6575
dkontak@laurentian.ca
www.merc.laurentian.ca

SOLUTION TEAM:
Damien Duff, CEMI; Peter Lightfoot, Vale; Lisa Gibson, Vale
Gregg Snyder and Mike Sweeny, Sudbury Integrated Nickel Operations – A Glencore Company
Robert Craig Stewart (PhD), Laurentian University
Doreen Ames, Geological Survey of Canada; Jacob Hanley, St. Mary's University
Claire McAneney, NSERC

METAMORPHIC, STRUCTURAL, AND GEOCHRONOLOGICAL EVOLUTION OF THE SOUTH RANGE OF THE SUDBURY IMPACT STRUCTURE

MERC

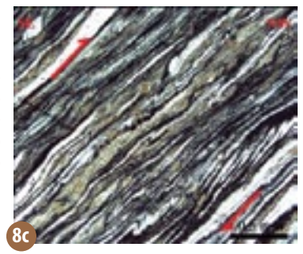
6b

Fig6b staurolite: Photomicrograph of syn-kinematic staurolite porphyroblast.

THE ISSUE: The South Range of the Sudbury impact structure has been affected by several orogenic events that have displaced and folded Huronian footwall rocks and Ni-Cu massive sulphide deposits at the base of the Sudbury Igneous Complex. New and novel exploration approaches are needed to increase exploration success.

THE SOLUTION: A 4-D interpretation of the tectonic evolution of the South Range before and after the Sudbury impact event has been developed. This integrates structural geology, metamorphic petrology and geochronology, and provides further clarity and understanding of the geology of the nickel-rich south rim of the Sudbury Igneous Complex.

Fig8c think section GF: Photomicrograph showing micro drag folds showing southeast-sid-up reverse thrusting towards the northwest, Grenville Front.



8c

THE RESULTS: A new interpretation of the tectonic evolution of the South Range has been developed and multiple deformational phases postulated, providing a new framework for evaluating the present shape and distribution of Ni-Cu massive sulphide deposits along the south rim of the Sudbury Igneous Complex.

CONTACT:
Douglas Tinkham, MERC, Laurentian University
1-705-675-1151 x 2270
dtinkham@laurentian.ca
www.merc.laurentian.ca

SOLUTION TEAM:
Damien Duff, CEMI; Peter Lightfoot, Vale; Lisa Gibson, Vale
Gregg Snyder and Mike Sweeny, Sudbury Integrated Nickel Operations – A Glencore Company
Bruno Lafrance, MERC, Laurentian University
Tsilavo Raharimahefa (PDF), MERC, University of Regina; Claire McAneney, NSERC

UPDATING MOFRAC: DISCRETE FRACTURE NETWORK MODELING SOFTWARE

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THE ISSUE: Underground fractures in the earth's crust pose a number of problems for the mining and nuclear waste management industries. For the mining industry, determining the composition of the earth's crust – the structure and nature of the rock, the concentration and distribution of stresses and where the rock is fractured is important for safe and effective mine design. For the nuclear waste disposal industry, it is critical to understand the location of fractures and faults when burying nuclear waste because of the risk of ground water contamination and other dangers such as leeching.

MOFRAC software models fracture networks in the earth's crust by heavily relying upon known actual geological controls. However, it was initially developed in Fortran, a now outdated computer language and not user friendly.

THE SOLUTION: In a project lead by CEMI, in partnership with Ontario's Nuclear Waste Management Organization (NWMO), MIRARCO as well as R. Mohan Srivastava - the original developer of the computer code, the software is being upgraded so that it can be used more broadly and effectively by the mining and nuclear waste management industries. MOFRAC is unique because it pays strict attention to fundamental geology principles, respecting geological input data better than any other tool of its kind. It is expected that this application will produce a more accurate representation of the geological structures in the rock than other tools which claim to do the same thing. This will reduce uncertainty and increase safety for both the mining and nuclear waste management industries.

INNOVATION IN PROGRESS: This project is being managed in two phases. The first phase, which is now complete, has updated the computer language and developed a rudimentary graphical user interface (GUI) for the software. Initial validation exercises were also done in which data was input from known fracture networks and the results from the application were compared to the actual structures. Phase two, currently under development, will include the development of a more comprehensive GUI as well as more complex testing and validation of the program at real sites (a nuclear waste site in Finland and at possibly at a Glencore mine in Sudbury).

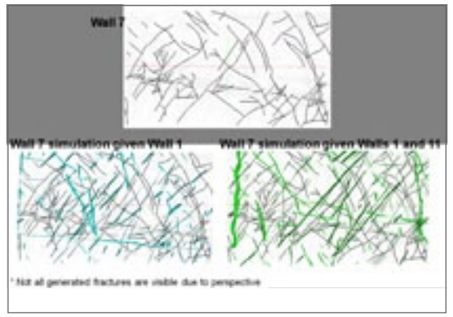

Photo Courtesy of Lorrie Fava

CONTACT:
Damien Duff, CEMI
1-705-673-6568 x 3
dduff@miningexcellence.ca
www.miningexcellence.ca

SOLUTION TEAM:
Mohan Srivastava, Benchmark Six
Lorrie Fava, MIRARCO
Eric Sykes, Nuclear Waste Management Organization (NWMO)
Monique Hobbs, Nuclear Waste Management Organization (NWMO)

INTEGRATED PERSONAL PROTECTIVE EQUIPMENT (IPPE) – A NEW IMAGE OF THE UNDERGROUND MINER IN THE 21ST CENTURY

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THE ISSUE: Due to the financial unpredictability/risk of finding and developing new mines, there is an increasing emphasis on extending the life of existing mines by digging deeper. The deeper a mine, the harsher the environment for the people and machines working at those depths for a variety of reasons (e.g., increased heat, physical protection due to rock wall instability, fresh air, contaminants in the air, communication, navigation, etc.). Mitigating those risks is expensive, with almost half of the cost of ultra deep mining being attributed to the cost of maintaining an environment in which humans and machines can function. The current solution is to provide traditional support gear (helmets, air, etc.) and then strap on devices as necessary to provide additional capabilities, which can in fact, impede productivity and even safety. As yet, there is no integrated protective solution that enables workers to function safely, comfortably and efficiently at these extreme depths.

THE SOLUTION: CEMI is leading a project to develop the next generation of IPPE that will integrate many of the "add-on/strap on" functions available current technology and that will also integrate with other protective gear components that is required for ultra deep mining (e.g., thermal control, comms, navigation). It is anticipated that this IPPE will manage or be a part of an integrated system that ergonomically manages and enhances the wellbeing/safety of miners working at ultra deep levels, including cooling, filtered breathing, air quality monitoring, position tracking (RFID), noise reduction, medical monitoring (e.g., heart rate, breathing) and mine alerts. In addition, IPPE will enhance miner efficiency with features such as lighting, power supply, computerized heads-up display, communications, navigation/mapping, recording (still and video images) and operations manuals on demand.

Photo courtesy of Omer Hacomenoglu Design

INNOVATION IN PROGRESS:
Development of the Integrated Personal Protective Equipment (IPPE) is underway. Functional requirements specified in the design phase will focus on individualized environmental control, and ergonomic and safety components that will make mining in ultra-deep environments far more efficient. The improved level of protection will increase the value proposition of an optimized human-driven production system, highly effective people underground, generating significantly higher value than at present. It addresses the critical operational health and safety risks to facilitate Ultra Deep Mining. This will lower the cost of creating and maintaining a safe work environment at these extreme levels. More broadly, it will be easier for mining companies to expand production, and maintain investor confidence, because more is being extracted from existing mines rather than taking on the financial risk of developing new mines.

CONTACT:
Allan Akerman, CEMI
1-705-673-6568 x 41
aakerman@miningexcellence.ca
www.miningexcellence.ca

SOLUTION TEAM:
Wayne Ablitt, Jannatec
Dale Boucher, Deltion Innovations
Sylvie Nadeau, École de Technologie Supérieure (ETS)
Gary Potts, Sudbury Integrated Nickel Operations – A Glencore Company

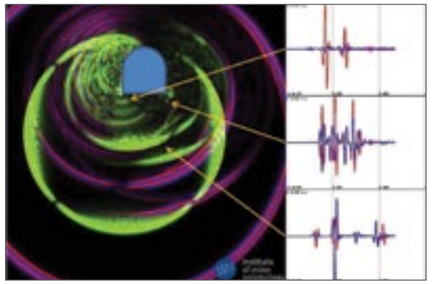
S-GMAT GROUND MOTION ASSESSMENT TOOL

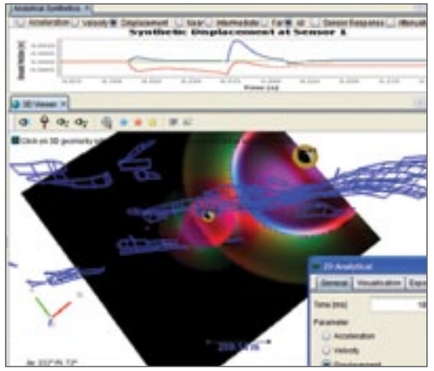
institute of mine seismology

THE ISSUE: Existing methods for estimating ground motions resulting from mine seismicity near potentially vulnerable excavations are currently too simplistic and do not reflect today's more advanced understanding of microseismic monitoring capabilities. Furthermore, ground motions can only be monitored at selected points and conditions in between are unknown.

THE SOLUTION: CEMI, working with the Institute of Mine Seismology (IMS) in South Africa and Australia, developed a Synthetic Ground Motion Assessment Tool (S-GMAT). The tool permits estimation of the ground motions produced near potentially vulnerable excavations located at varying distances from a seismic source. Tool outputs are in 3-D format capable of being incorporated into existing modeling and visualization platforms at mines. S-GMAT also provides input for forensic analyses of excavation damage. This is now being utilized for case studies to improve excavation stability.

THE RESULTS: First Phase work on the S-GMAT tool is now complete. For more information, contact the IMS at www.imseismology.org. The next phase of this project will be to validate and then integrate the S-GMAT with BurstSupport, a tool developed by MIRARCO to help deal with dynamic rock support element selection in burst prone mines.

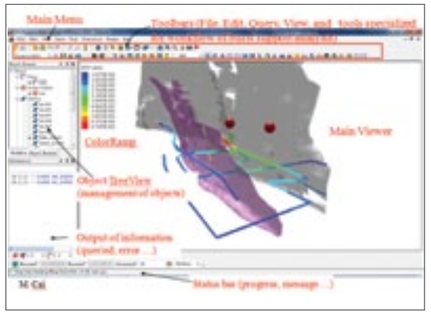


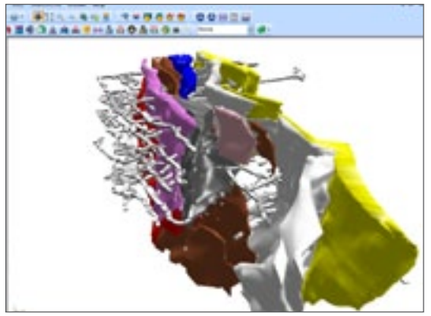


CONTACT:
Aleksander J. Mendecki, IMS - Institute of Mine Seismology
+27(-21) 809 2074
aleksander.mendecki@imseismology.org
http://www.imseismology.org

SOLUTION TEAM:
Ernest Lötter, IMS
Damien Duff, CEMI
Peter K. Kaiser, CEMI, RTC-UMC

BURSTSUPPORT TOOL





THE ISSUE: While huge progress has been made to increase safety in burst prone ground, there is an ongoing need to develop more reliable approaches for dealing with dynamic ground support requirements and formulating appropriate ground support strategies in underground burst prone mines.

THE SOLUTION: The development of BurstSupport, a new software tool released in 2013 for use by rock mechanics engineers at mines, improves rock support design strategies in areas of a mine affected by large seismic event, by enabling the selection of appropriate ground support elements when dealing with dynamic loading conditions from fault-slip events in underground mines.

This powerful, user-friendly, Windows-based 3D tool, provides mining and civil engineers the ability to conduct rock support design in deep underground mine drifts or civil tunnels. Users can visually assess load, displacement and energy demands at multiple drift locations by considering anticipated seismic event magnitude and location, stress, drift orientation and rock mass quality simultaneously. BurstSupport allows safety and geo-risk management through integration of all relevant engineering design components. It is envisioned that rockburst risk management can be significantly improved using this tool.

THE RESULTS: This tool greatly improves the utility of the Canadian Rockburst Support Handbook (to be published in an updated guide). The next phase of this project will aim at validating and then integrating BurstSupport with S-GMAT, a synthetic ground motion modeling tool used to estimate ground motions produced in response to fault rupture. The BurstSupport Tool is now available for licensing. For more information contact Ming Cai.

CONTACT:
Ming Cai, MIRARCO, Laurentian University
1-705-675-1151 x 5099
mcai@laurentian.ca
www.laurentian.ca

SOLUTION TEAM:
Damien Duff, CEMI
Simon Nickson, Vale
Lars Malmgren, LKAB
Peter K. Kaiser, CEMI, RTC-UMC
Claire McAneney, NSERC

STRAINBURST POTENTIAL IDENTIFICATION AND MITIGATION

THE ISSUE: New research data suggests that it is time to re-think standing assumptions made when assessing rockburst damage and by implication when designing support in burst-prone ground.

THE SOLUTION: A critical assessment of the current mine support design guiding principles led to the conclusion that the primary damage mechanism to an excavation site is often a seismically triggered strain-burst or self-initiated strainburst and damage is often not rooted in momentum or dynamic shaking from a remote source. For example at the Jinping II tunnel in China, over 500 strainbursts were encountered without any triggering earthquakes or fault slip events. As a result, rockburst damage is primarily related to the state of stress and the local mine stiffness at the potential damage location and only indirectly related to the seismic ground motion. A reliable means of identification of mining induced strainburst potential will lessen vulnerability of an excavation. Further, once strainburst potential is identified, failure may then be mitigated by using methods of hydraulic fracturing that allow for the creation of fracture networks, thereby damaging the rockmass prior to mechanical excavation.

INNOVATION IN PROGRESS: Research is underway to build a strainburst database with related excavation vulnerability assessment parameters and a methodology to assess deformation potential as a strainburst trigger is under development. Forensic analysis to review the damage to an excavation or its support will aid in better understanding the cause of failure and necessary design parameters. The BurstSupport Tool - created through earlier related research projects - will then be updated to assist in strainburst support analysis. Related step-change innovations are being explored to overcome existing deficiencies of hydraulic fracturing technology, namely the use of stimulation and solids injection for application in mining. It is anticipated that the results will also find application in the oil and gas sectors. Two keynote industry lectures by P. K. Kaiser at Support'13 in Perth, Australia, and at Rasim8 (rockburst and seismicity in mines) in Russia (2013) address the need to re-think standing assumptions made when assessing rockburst damage and by implication when designing support in burst-prone ground.

Photo courtesy of Brad Simser

Photo courtesy of Kidd Creek Mine

CONTACT:
Damien Duff, CEMI
1-705-673-6568 x 3
dduff@miningexcellence.ca
www.miningexcellence.ca

SOLUTION TEAM:
Peter K. Kaiser, CEMI, RTC-UMC
Ming Cai, MIRARCO, Laurentian University
Simon Nickson, Vale
Sami Talu, Rio Tinto
Claire McAneney , NSERC

A GUIDE TO ROCKBURST SUPPORT SELECTION

THE ISSUE: The Canadian Rockburst Support Handbook (Kaiser et al., 1996) presented an engineering approach to selecting rock support for burst-prone mines by systematically assessing both support demands and support capacities. Since its publication, technology of rockburst support has seen many new developments. A number of key insights, changes in thinking, and new concepts have emerged over the last two decades. In some cases, the practical implications have been immediately apparent, whereas in other cases, the full implications are only now emerging with the development of new methods of analysis and new design approaches. Development of "The Canadian Rockburst Support Selection" is an update of the handbook. It addresses the fundamental principles, methodologies and procedures in rockburst support design, and will assist practicing engineers in following systematic design procedures.

THE SOLUTION: Intended for ground control engineers with a sound background in engineering design, rock mechanics, stress modeling, and static ground control principles, *A Guide to Rockburst Support Selection* (Cai & Kaiser, 2014), focuses on aspects that are most important for rock support in burst-prone ground, particularly within the context of the current situation in hard rock mines and civil tunnels in Canada, Australia, Chile, South Africa, China, and many other countries. Extensive field and laboratory testing of support elements and systems under both static and dynamic conditions have generated key data for design, and have led to new insights concerning the mechanisms or behaviour by which rock support dynamically interacts with the ground. In addition to the conventional grouping of rockburst types into strainburst, pillar burst, fault-slip burst, a distinction between static-load-induced or dynamically triggered and dynamically loaded strainbursts is essential for the support demand estimation. As well, identification of three distinct rockburst damage mechanisms involved in most of the damage caused by rockbursts in deep underground mines form the fundamental basis for the design approach presented in this Guide:

- Sudden volume expansion or bulking of the rock due to fracturing of the rockmass around an excavation
- Rockfalls (or falls of ground), which have been triggered or loaded by seismic shaking
- Ejection of rock caused by: (1) momentum transfer from violently bulking (larger) blocks or slabs of rock to smaller blocks that are free to eject (e.g., between bolts), and (2) energy transfer from large remote seismic events to fractured rock near a stressed excavation

For each of these mechanisms, the Guide presents detailed methods of analysis for support design. The guide treats support design as a two-stage engineering process: determining the expected loading conditions or demand on support; and integrating the various elements into a support system to achieve a support capacity that exceeds demand.

INNOVATION IN PROGRESS: The *Guide to Rockburst Support Selection* is scheduled for publication in 2014. Workshops and short courses will be offered in support of the guide. In addition, a software tool (BurstSupport) has been developed in tandem to assist in applying the design methodology to a computer aided design package that rapidly executes design calculations at all affected tunnel locations.

CONTACT:
Ming Cai, MIRARCO, Laurentian University
705-675-1151 x 5099
mcai@laurentian.ca
www.laurentian.ca

SOLUTION TEAM:
Damien Duff, CEMI
Simon Nickson, Vale
Lars Malmgren, LKAB
Peter K. Kaiser, CEMI, RTC-UMC
Claire McAneney, NSERC

USING HYDRAULIC FRACTURING TO HELP SHED STRESSES IN DEEP UNDERGROUND MINES

THE ISSUE: Rock instability in deep mines can potentially create two problems: 1) the possibility of rock bursts and strainbursts, which can compromise the safety of personnel and capital assets; 2) significant disruptions to production schedules. Hydraulic fracturing, the mechanical process of fracturing rockmass, can be used to induce changes to its characteristics which may be helpful for stress management in underground mining operations. Traditionally used in large block cave mines for cave inducement and fragmentation purposes, hydraulic fracturing can also be used for stress re-distribution, including in conventional stoping operations.

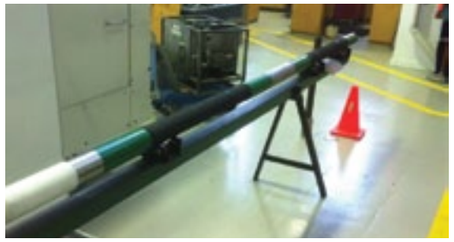
THE SOLUTION: CEMI and a consortium of companies and research institutions have initiated a 3-year research program to investigate hydraulic fracturing as a means to re-distribute stress in deep mines away from where it can potentially cause harm. Fracture network creation technologies as well as the characteristics of the created networks will be examined by undertaking a series of drill-through and mine-back experiments in active mines.

This research aims to better understand how to use hydraulic injection to manage stresses locally, and potentially at a block scale; improve our understanding of the processes during hydraulic fracturing in tight shale formations; better able to relate geophysical observables (e.g., micro-seismicity, stress change, tilt etc.) to the created fracture networks; and better able to optimize numerical modeling approaches for simulating hydraulic fracturing and hydraulic stimulation.

INNOVATION IN PROGRESS: Three hydraulic fracture case studies have been identified, with expected completion and results in 2015. These are:

1) Experimental design and execution of drill through trial at Newcrest's Cadia East mine in Australia, and extending at least one borehole to the production level at 1,425m to execute stimulation and hydraulic fracturing tests.
2) Low level injection trial, including a mine through.
3) Large production-scale application and technology transfer for eventual usage in conventional stoping operations.

It is anticipated that hydraulic fracturing will make mines safer and potentially render unmineable ore reserves mineable. It also has applications for the energy (oil and gas and geo-thermal) industry, in terms of validating existing models. interpretations will allow for better predictability and planning, thereby reducing operating and capital costs.



Courtesy of Newcrest Mining Limited and CSIRO-Integrated HF Tool

CONTACT:
Damien Duff, CEMI
1-705-673-6568 x 3
dduff@miningexcellence.ca
www.miningexcellence.ca

SOLUTION TEAM:
Peter K. Kaiser, CEMI, RTC-UMC; Benoît Valley, Eidgenössische Technische Hochschule Zürich (ETHZ)
Sean Maloney, MIRARCO; Erik Eberhardt, University of British Columbia
David Eaton, University of Calgary; Mirko van der Baan, University of Alberta
Doug Schmitt, University of Alberta; Maurice Dusseault, University of Waterloo

LOW OR ZERO CARBON CRYOGENIC VENTILATION FOR DEEP MINES

THE ISSUE: To develop a new air cooling technology for underground mining that will decrease the overall carbon footprint and reduce operating costs, especially as mines deepen and their cooling loads increase.

THE SOLUTION: CEMI is working with MIRARCO to design a system that uses the shaft work from a wind turbine rotor to drive the compressor in an air liquefaction plant. The motivation is that if utilizing wind energy to drive the liquefaction process is practical, work from such a wind turbine would be available at very low marginal cost and with very low CO2, eq emissions – in contrast to liquefaction by means of grid electricity powered liquefaction plants. The research will include determination of the feasibility of using wind powered liquefaction plants to produce liquid air used to cool underground workings (as deep as 2-3 kilometres) and compare this approach with that of conventional mine cooling practice.

INNOVATION IN PROGRESS: Wind turbines and liquefaction plants are established, commercial technologies. It is the integration of these two technologies where innovation arises. An important distinction between conventional liquefaction approaches and the CryoVent approach is the variability and intermittency of wind energy resources that dictate the rate of work input delivered by a wind turbine, versus the steady input delivered by an electric motor. Can a CryoVent wind turbine system be designed to accommodate the intermittent and variable work input and still produce a relatively steady output rate of cryogen? Development of a numerical model of the liquefaction process to assess system performance has been completed. Predicted performance will be verified using a proof-of-concept laboratory scale rig assembled at Laurentian University. SCADA data from two Vestas V52s wind turbines, held by the Camborne School of Mines at the University of Exeter, UK, will be used to characterize the variability in torque and rotational speed from direct observations to drive the rig variably, while the output cryogen production rate is monitored.

This project has the potential to deliver a compact, renewable energy technology to the mining industry that will result in lower overall operating costs as well as a cleaner operation. CEMI has provided funding to support Saruna Kunwar's work on the project; funding for equipment has been secured from the Canada Foundation for Innovation and the Ontario Research Fund.

The liquid air in the Dewar Flask is at minus 190°C and atmospheric pressure. If it was at atmospheric pressure and temperature instead, the same amount of air as in the flask would occupy around 1m³.

CONTACT:
Dean Millar, MIRARCO, Laurentian University
1-705-675-1151 x 5071
dmillar@mirarco.org
www.mirarco.org

SOLUTION TEAM:
Saruna Kunwar, MIRARCO
Paul Ballard, The Fluid Power House, Lively, Sudbury
Patrick Foster, Camborne School of Mines, University of Exeter
Canada Foundation for Innovation – Leaders opportunity fund
Ontario Research Fund – Small infrastructure grant

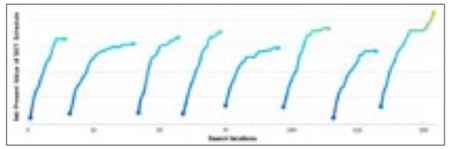
SOT+: EXTENDING THE APPLICATION OF THE SCHEDULE OPTIMIZATION TOOL

THE ISSUE: For over 4 years, MIRARCO's Schedule Optimization Tool (SOT) has provided benefit to mining companies as the only software on the market to optimize the net present value of long-term schedules for selective underground mining operations. These include both access development and production within operational resources, and precedence constraints for thousands of excavation activities. With case studies available for review, what additional optimization extensions can be added to enhance the SOT software?

THE SOLUTION: SOT 1.2 was released in the fall of 2012 with additional features including capacity analysis, capacity flexing, containment costs and pinning (fixed timing) which were features previously restricted to proprietary users. SOT is commercially available and licensed through 3 distributors - CAE Mining, MineRP and Deswik.

SOT+ aims to advance the functionality of the software for selective mining methods and to expand the software to handle bulk mining. In partnership with Vale, Newmont, CAE Mining and Deswik and project managed by CEMI, SOT+ is focused on five research themes, each of which will be anchored with a case study. Themes include: ore blending, ventilation constraints, geotechnical constraints, schedule optimization for bulk mining methods (block cave and/or surface mining), and advanced valuation. The research team includes partners from MIRARCO, Laurentian University, Curtin University and Chasm Consulting/Ventsim. Each theme will support a specialist with knowledge of mine planning and the relevant research theme. Recruitment is currently underway for additional mine planning specialists for this project. Mining companies interested in sponsoring a case study or learning more about SOT+ should contact Seppo Haapamaki at CEMI.

INNOVATION IN PROGRESS: The first case study is currently underway at Vale, with a focus on integrating and optimizing the schedule of a multi-orebody operation. The research will involve sensitivity analysis (mineral prices, costs, and mineral grades) and implementation of an advanced valuation methodology to enhance the robustness of mine plans in the presence of uncertain project parameters.



Learning curves' from a SOT run as it uses artificial intelligence techniques to optimize the net present value of a mining operation.

CONTACT:
Seppo Haapamaki,CEMI
1-705-673-6568 x 43
shaapamaki@miningexcellence.ca
www.miningexcellence.ca

SOLUTION TEAM:
Lorrie Fava, MIRARCO; Dean Millar, MIRARCO, Laurentian University; Ming Cai, MIRARCO, Laurentian University
Bryan Maybee, Curtin University; José Saavedra-Rosas, Curtin University; Craig Stewart, Chasm Consulting/Ventsim
Simon Nickson, Vale; Ralf Kintzel, Newmont; Dylan Webb, CAE Mining; Russell Vance, Deswik Mining Consultants
Richard Worsfold, Ontario Centres of Excellence (OCE); Darren Janeczek, MIRARCO; Bob Anderson, MIRARCO
Scott McGarvey, MIRARCO; Vijay Kumar Sharma (MSc), Laurentian University
Negar Saeidi (MSc), Laurentian University

RAPID DEVELOPMENT: STEP-CHANGE INNOVATION AT THE DEVELOPMENT FACE

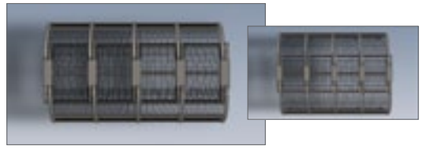
CEMI
Centre for Excellence in Mining Innovation

THE ISSUE: The ability to access ore bodies efficiently and effectively is critical to the success of the underground mining industry. The Development Cycle has not kept pace with innovations found in other key steps of the mining process, despite the introduction of powerful and efficient new equipment. Today, advance rates are at historic lows, currently at less than 4m/day vs. the 12m/day achievable 25 years ago.

THE SOLUTION: Currently, all 5 steps of the Development Cycle are separate, executed sequentially and requiring specific equipment. The process is inherently time consuming and costly, leaving the face inactive for significant periods. The Rapid Development Project consists of 3 separate research projects to be conducted within live mine sites. This research has the potential to bring about step-change innovation by integrating the machinery and process steps required to access ore bodies, with the goal to dramatically increasing time at the face. These are: (1) Development of an advanced canopy designed to withstand falls of ground that will allow for parallel activities through the integration of Support & Drill processes; (2) Configuration of equipment to utilize Jumbo for also load holes without disrupting the work of the bolter; (3) Development of a continuous mucking machine, where material removal is constant and the total mucking time is reduced.

INNOVATION IN PROGRESS: Preliminary simulations indicate that there are significant efficiencies to be found in integrating processes and executing in parallel. Based on the three projects identified, CEMI has projected improvements to advance rates of 2.23 m/day, totaling 7.24 m/d over the current 5.01 m/day. This is an increase of 45%. The next step will be to configure the required equipment and conduct research within live mine sites. The benefits are clear—increased utilization of face time for machinery and human resources leads to the earlier extraction of ore, increased safety and productivity, the reduction of overall mining costs and the potential for an earlier return-on-investment.

Canopy TOP contracted and expanded.



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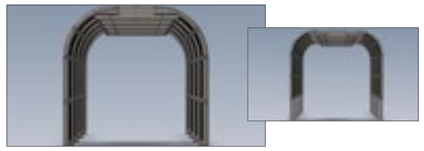

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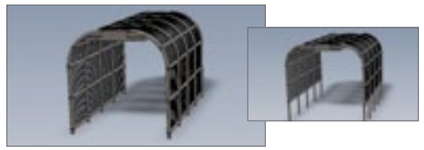


Photos courtesy of MTI

CONTACT:
Harvey Parsons, CEMI
1-705-673-6568 x 44
hparsons@miningexcellence.ca

SOLUTION TEAM:
Seppo Haapamaki, CEMI
Pierre Labrecque, Labrecque Technology Inc.
Rob Whiteford, MTI

SOLUTION TEAM NETWORK AND KNOWLEDGE CENTRE

RioTinto

With an investment of $10 million dollars, Rio Tinto established the Rio Tinto Centre for Underground Mine Construction (RTC-UMC) at CEMI. The Centre assists in creating step-change advances to support Rio Tinto's Mine of the Future™ programme with research focused on mechanized excavation in support of high-speed underground mine construction and on enhancing footprint reliability with innovative and effective support systems. The RTC-UMC at CEMI is the fifth global research centre established by Rio Tinto.

THE ISSUE: After extensive consultation and completion of its start-up phase projects, the RTC-UMC has set out a technical roadmap for the next few years with a focus on rockmass characterization, horizontal and vertical development/construction, and footprint/undercut reliability. Research projects focused on each of these technical issues have early deliverables in 2014. RTC-UMC operates with a small number of employees and a large number of networked solution team members that bring the required skills and expertise to serve the mining industry's needs. After careful assessment of needs and opportunities, and taking into the consideration the industry-wide challenge of attracting highly qualified employees, it was determined that the Centre had to expand its resource pool, expand its advisor capacity, and increase its solution team network.

THE SOLUTION: In order to rapidly increase the delivery capacity of the Centre and provide an active knowledge centre, RTC-UMC is in the process of retaining internationally recognized experts to the equivalent of three or more person years by retainer or subcontract extending over several technical projects. Researchers and consultants from Canada, the U.S.A., Switzerland, and Australia are currently being retained to increase the delivery capacity. The Centre has created a link to the Geological Engineering Department at the Federal Technical University of Zurich and is working to link other European universities to the Centre's network, allowing for the creation of a European node with identified resources to capture expertise related to rapid underground construction and ground control.

Photo courtesy of Rio Tinto

Photo courtesy of Rio Tinto

CONTACT:
Fred Delabbio, Rio Tinto
+617 3625 3750
fred.delabbio@riotinto.com
www.riotinto.com

SOLUTION TEAM:
Peter K. Kaiser, CEMI, RTC-UMC; Rob Bewick, CEMI, RTC-UMC, Golder Associates; Navid Bahrani, RTC-UMC, MIRARCO
Naeem Ahmed, RTC-UMC, MIRARCO; Florian Amann, ETH Zurich; Mark Board, Hecla Mining Company
Erik Eberhardt, University of British Columbia; Christian Frenzel, Aker Solutions; John Hadjigeorgiou, University of Toronto
Jean Hutchinson, Queen's University; Jarek Jakubec, SRK Consulting; Matt Lato, RockSense GeoSolutions
Pierre Labrecque, Labrecque Technologies; Sean Maloney, MIRARCO; Matt Pierce, Itasca

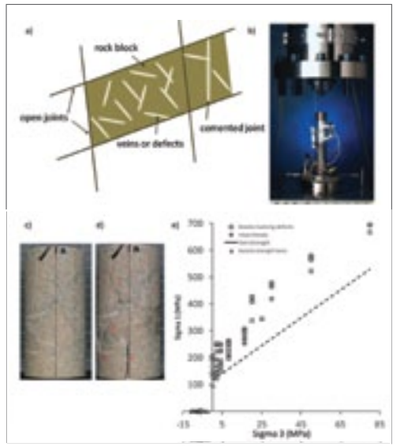
ROCKMASS CHARACTERIZATION AND BEHAVIOUR FOR GROUND CONTROL – COLLABORATIVE MONITORING PROGRAMME

With an investment of $10 million dollars, Rio Tinto established the Rio Tinto Centre for Underground Mine Construction (RTC-UMC) at CEMI. The Centre assists in creating step-change advances in support of Rio Tinto's Mine of the Future™ programme with research focused on mechanized excavation in support of high-speed underground mine construction and on enhancing footprint reliability with innovative and effective support systems. The RTC-UMC at CEMI is the fifth global research centre established by Rio Tinto

THE ISSUE: The RTC-UMC has established that strength at depth is systematically and significantly underestimated by standard rockmass characterization approaches and thus cannot be reliably determined by current characterization means. The economic impact of poor deformation and strength characteristics of brittle failing rock is reflected in ground control challenges. Hence, to improve support design procedures for cost-effective deformation management in stressed ground, develop pillar design principles with semi-empirical data for footprint design, and establish a foundation for pillar monitoring to assist cave controls requires collaborative monitoring, systematic data collection, and interpretation with dissemination.

THE SOLUTION: The RTC-UMC is engaging with various Rio Tinto operations to collect relevant data at various mine sites, including green field mines, mines under development, and operational mines. The objective is to guide the collection and interpretation of data in a systematic manner by improved data interpretation and back analysis.

The Centre has the expertise to develop procedures from the data that can be used as best practice guides for Rio Tinto consultants and testing laboratories. These best practices derived from the collaborative monitoring programme will translate into cost savings in terms of enhanced footprint reliability. With less production delay, better excavation reliability, less rehabilitation of stress fractured ground and the optimization of support to facilitate standard drill and blast or mechanical excavation damage to footprints will be minimized. Safety at operations will be enhanced through the adoption of best practices.



(a) The challenge is characterizing defected rock masses (consisting of rock blocks bound by open joints and containing a stockwork of cemented veins or defects). (b-e) The development of a best practice guide to determine the intact strength of this type of material. (b) lateral strain controlled stiff testing frame with triaxial confining stress capability up to 80MPa. (c) Defected specimen for strength testing before and (d) after testing. (d) Shows failure through intract rock (i) and along defects (ii). This is clearly not intact rock strength. (e) Making sense of lab data from defected rocks for the determination of true intact rock strength. One of the base input parameters for the Hoek-Brown failure criterion and GSI.

CONTACT:
Allan Moss, Rio Tinto
+ +44 20 7781 1955
allan.moss@riotinto.com
www.riotinto.com

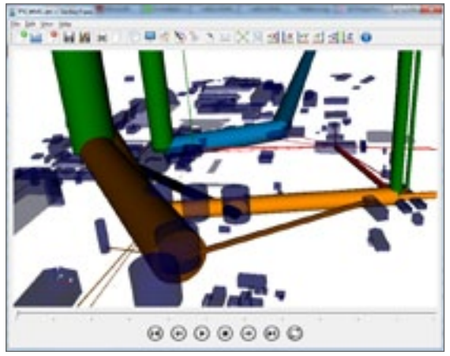
SOLUTION TEAM:
Peter K. Kaiser, CEMI, RTC-UMC
Rob Bewick, CEMI, RTC-UMC, Golder Associates
Damien Duff, CEMI
A. Naeem Syde, MIRARCO

SANKEY TREES: VISUALIZATION OF ENERGY FLOWS A SUMIT PROJECT

THE ISSUE: Reduced energy consumption for mining operations is a desirable goal, however understanding the opportunities for optimizing energy consumption is not always clear. The Sankey diagram, which has been used for over 100 years to visualize the flow of energy, materials, or cost through various processes provides an option, but there are drawbacks to this approach: i) the picture presented is static, offering no way to visualize how energy flows vary in time, ii) the picture presented ignores spatial relations between the components it describes; energy that might be wasted at a particular location, could be used at another, if the latter was in range, but if the usage location is remote from the source, the opportunity must be reprioritized.

THE SOLUTION: To develop an application to augment the Sankey diagram with a 4D spatio-temporal visualization capability that supports decision-making relating to energy flows and usage by mine operators.

THE RESULT: A new energy flow visualization technique called Sankey Trees has been developed. Sankey Trees is an application for creating 4D visualizations of energy flows between processes. Process locations are defined within a 3D model of the site being studied, and the magnitude of the flow between each pair of processes considered is replaced with a time series. Sustained and diminishing flows are represented through a variation of geometric properties and are animated to indicate the direction of flow and its transportation from one form of energy to multiple processes. Sankey Trees is now available for download at http://www.mirarco.org. This work was developed with the framework of research projects for Smart Underground Monitoring and Integrated Technologies for Deep Mining (SUMIT)



A screenshot of the SankeyTrees 4D energy flow visualization tool developed by Adam Turcotte as part of the SUMIT Project. It can be downloaded for free at: www.mirarco.org/ercm

CONTACT:
Dean Millar, MIRARCO, Laurentian University
1-705-675-1151 x 5071
dmillar@mirarco.org
www.mirarco.org

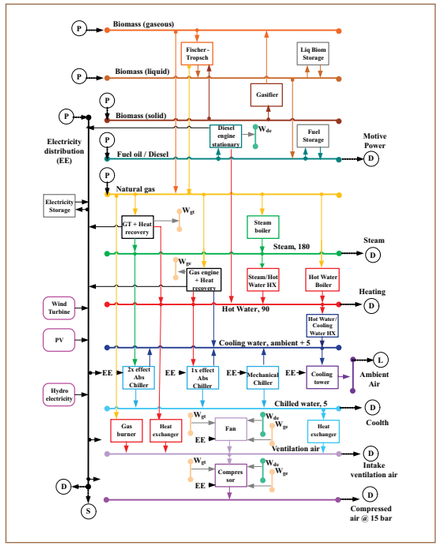
SOLUTION TEAM:
Adam Turcotte, MIRARCO

CONCEPT DEVELOPMENT OF OPTIMAL MINE SITE ENERGY SUPPLY A SUMIT PROJECT

THE ISSUE: Sustainability of deep mining is reliant on the reduction and optimization of energy consumption. With many approaches available for consideration (different equipment, different operating practices, etc.), it is essential to have a systematic, rational method available for mines to determine the best set of options. A review of precedent energy management practices in mineral operations has highlighted the energy challenges characteristic of the sector, and has informed the formulation of optimal mine site energy supply; choosing the best combination of fuels, energy supply technologies as well as identifying the best way to operate the equipment.

THE SOLUTION: This study, developed within the framework of research projects under Smart Underground Monitoring and Intergrated Technologies for Deep Mining (SUMIT) outlines the priorities of investigation, development and demonstration of new concepts and technologies to improve energy efficiency and reduce consumption of primary energy in the mining sector. Specific requirements and constraints of mineral production operations are considered against methodologies that have worked well for other sectors, such as cogeneration (the process whereby a single fuel source is used to generate two forms of useful energy) and polygeneration integrated energy supply systems that simultaneously generate two or more energy carriers (e.g. electricity and heat), in order to gain new perspective for on-site energy supply of mine sites.

INNOVATION IN PROGRESS: Scenarios with substantial economic potential in which renewables are advantageous have been identified, alone or in combination with conventional generation systems and/or utility connections. Scenario analysis based on the capability to identify optimal energy supply systems for specific load profiles helps: identify potential reductions in energy or production costs; improve the resilience of energy supply to ensure energy availability, with the added benefit of realizing a potential reduction in greenhouse gas emissions. To date, the formulation efforts are complete, and the solution team is focusing on developing a new mine-user-friendly software tool to implement the optimal mine site energy supply analysis. While the research is applied and has a Canadian focus, the work is of global scientific importance and its theoretical extensions are of generic applicability for all integration studies across disciplines.



An energy supply superstructure for a mining operation. Horizontal lines show the energy utilities supplied. Blocks show the energy conversion technologies that may feature in the optimal mine site energy supply solution

CONTACT:
Dean Millar, MIRARCO, Laurentian University
1-705-675-1151 x 5071
dmillar@mirarco.org
www.mirarco.org

SOLUTION TEAM:
Alberto Romero (PhD), MIRARCO
Adam Turcotte, MIRARCO
Monica Carvalho, Universidade Federal da Paraiba (UFPB)

APPLICATION OF A POLYGENERATION OPTIMIZATION TECHNIQUE FOR A HOSPITAL IN NORTHERN ONTARIO - A SUMIT PROJECT

THE ISSUE: Polygeneration systems are integrated energy supply systems that simultaneously generate two or more energy carriers (e.g. electricity and heat); where the output or byproduct of one process can be the input for another energy supply process). Hospitals are considered good candidates for polygeneration systems due to their sustained and relatively high energy requirements (heat, steam, coolth, and electricity), and their need for high power quality and reliability. The complex energy requirements of a hospital are similar to the energy requirements in the metal mining industry, and other industries, making the stand-alone hospital an ideal test site. Using a hospital in Northern Ontario with energy pricing and tariff arrangements that are specific to Ontario, MIRARCO was able to test their optimization methodology. The work aimed to identify the lowest annual cost of meeting site demand through determination of optimum polygeneration technologies, and the optimum manner for operating that set of technologies. CO_2 emissions could be simultaneously minimized in the procedure, if required.

THE SOLUTION: In order to identify the optimal configuration, annual energy demands were estimated by the team and then validated against actual data for the hospital. A polygeneration superstructure for optimization (using MILP—Mixed Integer Linear Programming technique) of the energy supply system was created so that the energy demands of the hospital could be met and different scenarios of constraints could be investigated. Energy prices were determined and conditions arising from the regulatory framework were introduced.

THE RESULTS: Surprisingly, the optimal economic solution indicated that generating electrical power using an onsite energy supply technology from gas is more economical than connecting to the electricity grid – even when an electricity grid connection point is available close by. The methodology and findings have far-reaching implications, particularly for energy-intensive industries. This is of particular significance to mining operations relying on multiple energy utility sources. Similar to the hospital, mines too, must find ways to reduce production costs through improvements in the efficiency with which they consume energy resources.

Photo courtesy of Harvald Farrant

CONTACT:
Dean Millar, MIRARCO, Laurentian University
1-705-675-1151 x 5071
dmillar@mirarco.org
www.mirarco.org

SOLUTION TEAM:
Monica Carvalho, Universidade Federal da Paraiba (UFPB)
Alberto Romero (PhD), MIRARCO

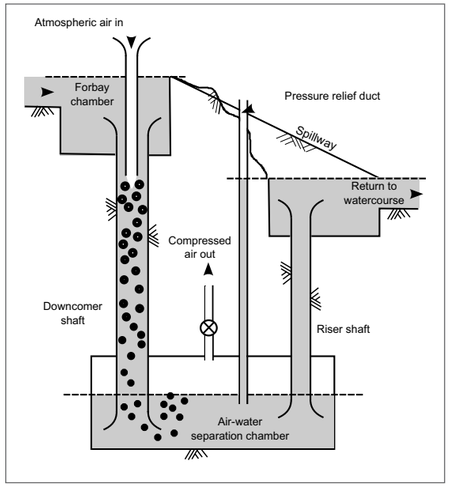
HYDRAULIC AIR COMPRESSOR FOR COOLING DEEP MINES A SUMIT PROJECT

This work was developed within the framework of research projects for Smart Underground Monitoring and Integrated Technologies for Deep Mining (SUMIT).

THE ISSUE: The Ultra-deep mining environment (below 2.5km) is of growing importance for the modern mining sector but presents key mining challenges. One of these is maintaining an acceptable working environment while the air temperatures at these depths, which can be upward of 40°C, before entering mine areas.

THE SOLUTION: Using the energy from water flow in a natural watercourse to produce compressed air is not new; 100 years ago such installations were termed hydraulic air compressors. Today, if natural hydropower resource can be harnessed, compressed air from this technology could be produced at close to zero marginal cost. Such a benefit forces reappraisal of processes and methods that were proposed for mines in the past, but eliminated due to the high cost of compressed air. One example of this is utilization of Hydraulic Air Compressors (HAC) to cool and dehumidify the bulk mine ventilation air in deep mines, the topic of investigation for this project.

INNOVATION IN PROGRESS: Based on research findings to date, a patent application has been made for novel uses of a Hydraulic Air Compressor. Ongoing studies will assess this method of cooling and dehumidifying deep mines. The technology also shows promise as a method of carbon capture from fossil fuel burning plants and as a method for domestic air conditioning.



The hydraulic air compressor (HAC) is driven only by water, held up by a dam, to create relatively low head (typically 10-20 metres), such that the developed hydropower is used to cause flow in openings deeper underground. Air is entrained in the water at the inlet to the sub-surface openings and is compressed as it is carried along by the deepening water flow. At depth air bubbles separate out of the water flow and are collected in a receiver space above the flowing water creating a reservoir of compressed air that is much drier than that would be produced from a contemporary mechanical compressor. Water, free of air, then passes back up a return shaft (up-pipe) and rejoins the river or stream flow. The HAC installed at Ragged Chutes, near Cobalt, Ontario operated near continuously for 70 years, supplying free air delivery of 40,000 cfm (68,000 Sm3/h) at a pressure of ~130 psi (8.9 bar) for around 70 years, only being stopped twice for repairs to its intake head.

CONTACT:
Dean Millar, MIRARCO, Laurentian University
1-705-675-1151 x 5071
dmillar@mirarco.org
www.mirarco.org

PEATLAND RESTORATION TRIALS

Bay Lowland. It adds to a body of knowledge, protocols and socially responsible practices that are attuned to community needs and expectations. The Peatland trials support ecologically-sound rehabilitation of mine sites in high boreal and subarctic regions of central Canada, especially around the Ring of Fire.

THE ISSUE: Mining activity is increasing in northern boreal and subarctic regions of Canada. Peatlands, also known as muskeg, dominate the landscape in the Hudson Bay lowland covering 98% of the landscape in the vicinity of the Victor Mine and 95% of the entire lowland. About 5000 hectares of peatland will be disturbed due to mining and construction activities. There is a need to develop peatland rehabilitation protocols that ensure a small mine footprint and the return to representative muskeg ecosystems after mine closures.

THE SOLUTION: Test whether fragments of Sphagnum mosses and protective covers are required to restore a vegetative cover of peat–forming plants over bare peat. To do this, Sphagnum fragments were spread over severely disturbed peatland and then peat blocks, local sedge mulch, coconut mulch, straw mulch and two densities of cottongrass *(Eriophorum)* tussocks were added and compared to putting no cover at all. Multiple parameters were examined to test the recovery of Sphagnum and the need for a mulch to reclaim disturbed subarctic peatlands in the region.

RESULTS: Over the course of a 3 year study, control plots without Sphagnum fragments did poorly but all those that received fragments had a >70% bryophyte cover and 30-60% Sphagnum cover, even without a mulch or companion plants. The spreading of fragments is therefore needed but no mulch or companion plants are required to restore these peatlands. The study shows progress towards the sustainable reclamation and revegetation of mine sites in the Hudson

Winter road from the air. Photos courtesy of Katherine Garrah.

Moss fragments coming back underneath a mulch in year 1 Photos courtesy of Angie Corson.

Angie Corson in her peatland mulch experiment plots. Photos courtesy of Daniel Campbell.

CONTACT:
Daniel Campbell, MIRARCO
1-705-675-1151 x 2385
dcampbell@mirarco.org
www.mirarco.org

SOLUTION TEAM:
Angie Corson (MSc), Laurentian University
Brian Steinback, Debeers Canada
Terry Ternes, Debeers Canada
Douglas Morrison, CEMI

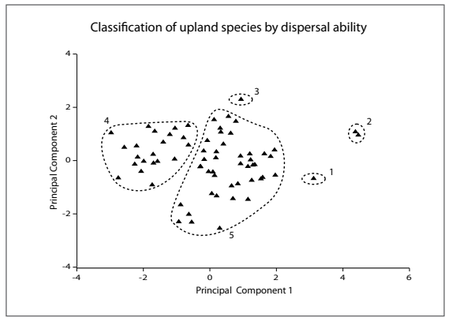
NATIVE PLANTS SPECIES FOR THE RECLAMATION OF UPLANDS

THE ISSUE: A major challenge in the reclamation of the Victor Mine and other mine sites in the Hudson Bay Lowland (HBL) is the selection of suitable plant species for the reclamation of these new uplands. How do we choose the best candidate species for the rehabilitation of mine sites, given the condition that they must be native and local?

THE SOLUTION: A functional assessment of upland native plants in the Hudson Bay Lowland was conducted to determine their potential to disperse, establish, grow, allocate resources and contribute to the ecosystem development. Sixteen simple traits (plant height, leaf thickness, stem density, ability to fix nitrogen, etc) were measured on three populations of 67 species near the Victor Mine. This produced a very large data base which was simplified using multivariate analysis.

RESULTS: Species can be easily separate and classified on the basis of key ecological criteria which will be important for ecological practitioners. A list has been complied of species and simplified classification of traits and their importance or use, abilities to perform which will help in the selection of suitable species at early, mid and later successional stages of mine reclamation. Candidate species will be investigated further in field trials.

Here is a shot of early successional plants along the river. Note the rocks, the lack of soil but the high diversity of plants.



An energy supply superstructure for a mining operation. Horizontal lines show the energy utilities supplied. Blocks show the energy conversion technologies that may feature in the optimal mine site energy supply solution

CONTACT:
Daniel Campbell, MIRARCO
1-705-675-1151 x 2385
dcampbell@mirarco.org
www.mirarco.org

SOLUTION TEAM:
Cory Laurin (MSc), Laurentian University
Brian Steinback, Debeers Canada
Terry Ternes, Debeers Canada
Douglas Morrison, CEMI

UPLAND REFERENCE CONDITIONS

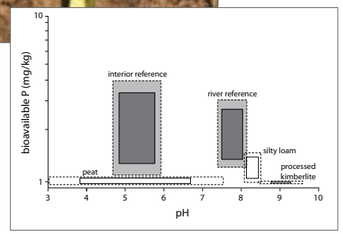
THE ISSUE: Uplands without water-logged soils are rare in the vicinity of the Victor Mine. The question arises as to what the reference conditions or targets for restoration should be when reclaiming new upland deposits of mining wastes, roads and gravel pads. This is of particular importance when aiming to rehabilitate new upland features to sustainable ecosystems dominated by native subarctic vegetation.

THE SOLUTION: 35 interior upland islands and 37 river uplands along the Attawapaskat River were sampled. At each site, multiple soil parameters were measured and samples were taken. In 10x10 plots, tree growth, plant cover, composition of plant species and soils were measured.

RESULTS: It is now possible to characterize the best reference conditions as targets for reclamation of new uplands at the Victor Mine through examination of soil and vegetation parameters on a univariate or multivariate basis. The upland reference conditions determined for the Victor Mine are taken from a broad landscape, and so should be applicable to other mine sites in the region within the limestone plain of the Hudson Bay Lowland (HBL).

Picture of Katie digging away. (Photo courtesy of Marisa Talarico)

Typical soil pit in interior upland. (Photo courtesy of Katherine Garrah)



Example of application of reference information using two soil = criteria, pH and bioavailable phosphorus. The idea is to make soil from = the mine waste materials to get within the river or interior reference = sites.

CONTACT:
Daniel Campbell, MIRARCO
1-705-675-1151 x 2385
dcampbell@mirarco.org
www.mirarco.org

SOLUTION TEAM:
Katherine Garrah (MSc), Laurentian University
Brian Steinback, Debeers Canada
Terry Ternes, Debeers Canada
Douglas Morrison, CEMI

PROOF OF PRINCIPLE OF COMFREY PLANT PROPERTIES TO BIO-REMEDIATE HEAVY METAL-CONTAMINATED MINING SITES

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Courtesy of Gerardo Ulibarri

Courtesy of Gerardo Ulibarri

THE ISSUE: To determine if naturalized comfrey (*Symphytum officinale*), which is easily grown in tropical climates where farmers can produce multiple crops per year, will absorb metals from contaminated soils. Comfrey is a perennial plant with large foliage, a deep root system, is very resilient to diverse conditions and is easy to cultivate, growing rapidly and covering large areas at a time, which would make it an ideal crop for developing countries.

THE SOLUTION: In order to determine if some of the most toxic or abundant metals were absorbed, commercial black soil was spiked with several concentrations of water soluble salts of metals such as Nickel (Ni), Chromium (Cr) Iron (Fe) and Zinc (Zn). Plants were grown in artificial conditions at Vale's Greenhouse in Copper Cliff and at the end of the growing period, samples from roots, stem and leaves were tested for metal concentration levels.

THE RESULTS: Comfrey *(Symphytum officinale)* successfully absorbed chromium, iron and zinc onto the root system and nickel onto the leaves and root system confirming proof of principle. Use of Comfrey in developing countries where tailings waste have left a footprint, may offer local farmers an economic and environmental benefit. Farmers can not only remove and process metals for economic gain but the residue biomass can also be converted into energy to produce electricity. Furthermore, research unveiled which cyclic peptides were used to capture metals. This led to a further study into the possibility of artificially creating cyclic peptides for use in remediation.

CONTACT:
Gerardo Ulibarri, Laurentian University
1-705-675-1151 x 2107
gulibarri@laurentian.ca
www.laurentian.ca

SOLUTION TEAM:
Douglas Morrison, CEMI
Nohaiah Aldarini (MSc), Laurentian University
Josee Bertrand (MSc), Laurentian University

CYCLIC PEPTIDES SEQUESTER RESIDUAL HEAVY METALS FROM MINING TAILINGS

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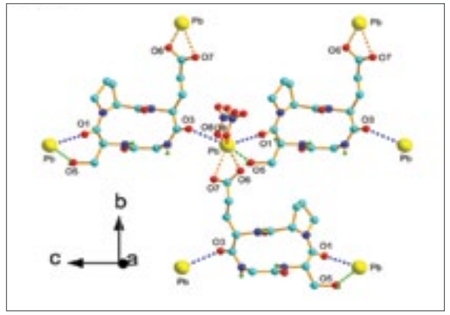
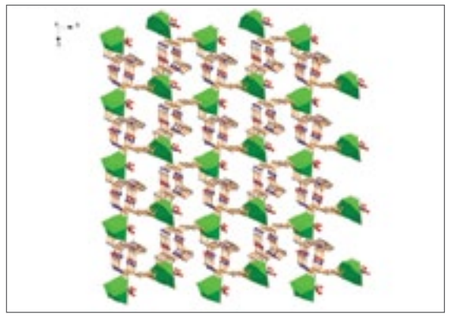
THE ISSUE: Heavy metals continue to constitute a global environmental hazard, with no affordable solutions for their removal to an acceptable concentration. There are multiple benefits that can be gained from the development of cyclic peptides in the laboratory that mimic plants that bio-remediate heavy metal-contaminated mining sites.

THE SOLUTION: Establish a methodology to create cyclic peptides in the laboratory that can be complexed with diverse metals present in tailings in order to establish applicability in the field of recovering metals from contaminated soils in a self sustainable manner.

INNOVATION IN PROGRESS: In-silico molecular simulations (assisted by Dr Gustavo Arteca) determined the optimal theoretical length and circular size of the cyclic peptide, complexed to a given metal. With successful proof of principle, the synthetic reproduction of cyclic peptides for diverse metals has the potential to become a secondary process for extracting or remediating metals from tailings. This provides an opportunity to extract more value from tailings waste and end up with a smaller environmental footprint (ie. reduce the potential of metal leaking into local aquifiers; reduction of metal contamination in mining areas and beyond) than we currently have.



Crystal structure of 2. Perspective view showing binding mode of cyclo(Gly-L-Ser-L-Pro-L-Glu) 1 to Pb(II) ion. Only hydroxyl O-H and amide N-H group hydrogen atoms are shown.



Polyhedral view in three-dimensional structure of 2. Color code: green, Pb: gray, C; blue, N; red, O.

CONTACT:
Gerardo Ulibarri, Laurentian University
1-705-675-1151 x 2107
gulibarri@laurentian.ca
www.laurentian.ca

SOLUTION TEAM:
Douglas Morrison, CEMI
Gustavo Arteca, Laurentian University
Caterina Noula-Millar, (PhD), Laurentian University
Wafa Aldarini (MSc), Laurentian University
Azizah Al-Radhwan (MSc), Laurentian University

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CEMI
Centre for Excellence in Mining Innovation

Centre for Excellence in Mining Innovation (CEMI)
935 Ramsey Lake Road | Willet Green Miller Centre | Sudbury, Ontario, Canada P3E 2C6
T. 705.673.6568 | F. 705.671.3878 | info@miningexcellence.ca | www.miningexcellence.ca