

SPECIAL EDITION



1998 - 2018
*Years
of Success*



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OUR MISSION

Our mission is to be the partner of choice in delivering quality research and innovative solutions to the global mining industry.

OUR VISION

A global research organization that develops innovative technologies, applied solutions, and highly qualified individuals in support of a safe, productive and sustainable mining industry.

OUR VALUES

Trust, Collaboration, Quality, Innovation, New Knowledge, Responsiveness, Integrity, Efficiency, Economic Sustainability.

MESSAGE FROM THE PRESIDENT



It is my great honour to be the President and CEO of MIRARCO Mining Innovation. 2018 marks the sixth year I fulfil this role and I consider myself very fortunate to have it coincide with the organization's 20th anniversary. I was born a Mining Engineer and I'm

extremely passionate about this industry. What greater gift could you hope for than to be part of a mining organization dedicated to safe, productive, and sustainable mining?

In April 1998 MIRARCO Mining Innovation opened its doors with ambitious goals of establishing and operating an institute for advanced study, research, innovation and instruction in fields such as mining, mineral exploration, mineral processing, and environmental rehabilitation.

We have been fortunate to not only explore those fields, but we've grown our organization to conduct research on rock mechanics, software, safety, climate, and energy for a prosperous mining industry here in Canada and beyond. Having Laurentian University as our stakeholder

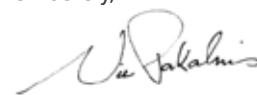
has given us access to brilliant and diverse scholars from here and around the world.

We are grateful to still have the participation of members such as Warren Holmes, a legend in Canadian mining, and our first president Dr. Kaiser, who provide us with valuable insight on where MIRARCO should be going.

Looking forward to the next 20 years we anticipate broadening the type of research MIRARCO undertakes. We will double our capacity in areas such as energy and climate adaptation and we'll emphasize research to facilitate the mining of new ore bodies at depths exceeding 5,000Km.

Our dedication to innovation and diversity will give us new mining challenges to solve and new horizons to explore. One thing is certain, we want to ensure Canada's mining brand is considered a fundamental building block of civilization, and is recognized for its safety and productivity worldwide!

Sincerely,



Vic Pakalnis
President and CEO, MIRARCO

Past Presidents and CEOs



Dr. Peter Kaiser
Founder & President and CEO
1995 - 2008



Dr. Stephen Hall
President and CEO
2008 - 2010



Douglas Morrison
Interim President, 2010 - 2011
Board Chair, 2008



Sean Maloney
Interim President/CEO
2011 - 2012

BOARD OF DIRECTORS

Andre Lauzon (Chair of the MIRARCO Board of Directors)
Vice President, HudBay Minerals Incorporated

Osman Abou-Rabia
Dean of Science, Engineering and Architecture, Laurentian University

Michelle Ash
Vice President Innovation, Barrick Gold

Samantha Espley
General Manager, Mining & Mineral Processing Technical Excellence Centre at Vale Base Metals

Dominic Fragomeni
Vice-President, XPS Consulting & Testwork

Elizabeth Gardiner
NOAMI Project and Communications Advisor, National Orphaned/Abandoned Mines Initiative (NOAMI)

Leo Gerard
International President, United Steelworkers (USW)

Michael Gribbons
President, Maestro Digital Mine

Lorella Hayes
Vice President Administration, Laurentian University

Christine Kaszycki
Assistant Deputy Minister, Northern Development and Mines

Michael O'Shaughnessy
Director, Logistics, Teck Resources

Cheryl Recollet
Director of Sustainable Development, Wahnapiatae First Nation

James Simmons
Weaver Simmons LLP

Janice Zinck
Green Mining Innovation – Processing, CanmetMINING – Natural Resources Canada

Board Chairs



Warren Holmes
Chair
1999 - 2003



George Pirie
Chair
2004 - 2005



Brian Maynard
Chair
2006



Marc Boudreau
Chair
2009 - 2016



Andre Lauzon
Chair
2017 - present

MESSAGE FROM THE FOUNDER



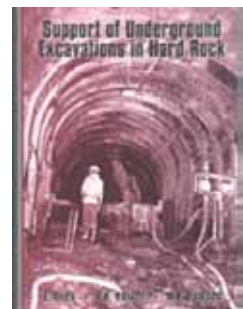
During my ‘Last Lecture’ at Laurentian University in 2016 (link attached below), I reminisced that our generation was extremely lucky and that many opportunities were open to us. One of those lucky opportunities arose when I was offered to join Laurentian University as

Chair for Rock Mechanics and Ground Control to establish the Geomechanics Research Centre (GRC) in 1987. In 1998, this opportunity then evolved into MIRARCO with three focused research centres. Thanks to an open-minded Laurentian University President, Dr. Ross Paul, and an enthusiastic industrial champion, Warren Holmes (then from Falconbridge Ltd.), who accepted to serve as the first Chair of MIRARCO’s Board of Directors, the vision for a multi-disciplinary, internationally recognized mining research centre was put in motion. Today, we look back at over 30 years of research and development by GRC and two decades by MIRARCO.

Even though a very unfortunate event; the Falconbridge mine disaster and the outcomes from the Stevenson’s Commission, formed the stimulus for the acceleration of mining research. It was the recognition that collaboration between Industry and Universities needed to strengthen to tackle a serious engineering problem; i.e., rockbursts, in order to ensure safe work places in the underground mining industry.

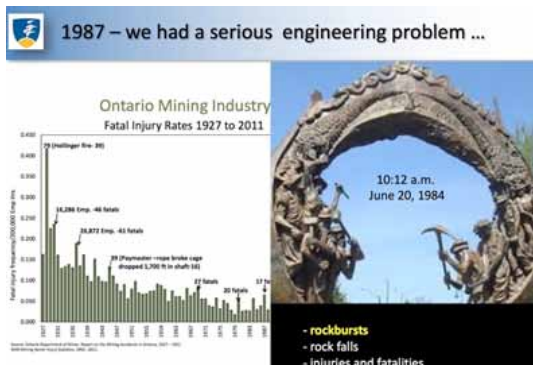
As a matter of fact, the simultaneous creation of three Research Chairs in Ontario, as a result of the ‘Stevenson’s Commission’, created an instant and most productive collaboration between Laurentian University, the University of Toronto and Queen’s University. When Dr. Walter Curlock (former CEO of INCO Ltd.) convinced other mining companies to join and fund a \$1.5M joint research project on ‘Rock Support in Mines’ we were off to the ‘races’ with dozens of graduate students at the three Universities.

This collaboration culminated in the book entitled ‘Support of Underground Excavations in Hard Rock’ by Hoek, Kaiser, Bawden (1995), which is in its fourth edition today. The number of citations steadily increased and still attracts more than 70 monthly reads according to Research-Gate.



During this phase, we were also able to attract Dr. D. McCreath to Laurentian University in collaboration with GRC and eventually MIRARCO. Dr. McCreath was able to facilitate an unprecedented growth of the Engineering department, currently known as the Bharti School of Engineering. This added tremendous and long-lasting value to Laurentian University and its Engineering program.

Lesson 1: Thanks to industrial leadership, fruitful collaboration research was accelerated to enhance underground safety and to produce lasting educational value.



With the incorporation of MIRARCO and the leadership by an Industrial Board of Directors, the foundation was laid for many successful funding applications to NSERC, CFI, the Ontario Research Fund and, of course, support by industrial leverage funding from then Inco Ltd, Falconbridge Ltd, Placer Dome Ltd, and many others.

This funding sent MIRARCO on a rapid growth

trajectory, tripling its research budget from one to three million dollars per year by 2003 and to more than five million dollars per year by 2008. With this funding, we were able to attract high-calibre scientific and engineering leadership:

Dr. Paul Dunn, who we sadly are missing today, led the initial development of the Centre for Mining Technology (CMT) and Dr. Graeme Spiers took the reins of the Centre for Environmental Monitoring (CEM). He put meaning behind the R for rehabilitation in MIRARCO. Later, we were able to attract Dr. Dean Millar to provide leadership for renewable energy solutions. In this fashion, MIRARCO did not only expand research in a most important economic sector of mining but it also facilitated the birth of a very successful spin-off company. Finally, MIRARCO was able to attract Dr. Ming Cai as Geomechanics Research Chair to provide ongoing research in the geotechnics sector. The environmental focus of MIRARCO was recently enhanced by the dedicated efforts of the Director, Al Douglas, who leads the Climate Adaptation Centre, which focuses on assisting communities and sectors to adapt to climate change through the provision of climate science and adaptation tools.

Success in research, development, and implementation does not just happen. It takes a vision, leadership, and a dedicated group of individuals with a common goal of advancing the state-of-the-art. Laurentian University and MIRARCO created a lasting environment for collaboration and thanks to the dedication of many hard-working staff and students, was able to create a self-funding research corporation, that, as you will discover in this annual report celebrating '20 years of success', has made a difference.

Lesson 2: It takes a vision, leadership, dedicated researchers, to build a team that can deliver world-class research.

Over the years, MIRARCO has disseminated the acquired knowledge through teachings, short courses, and hundreds of publications. This includes handbooks by Drs. J. Hutchinson and M.S.

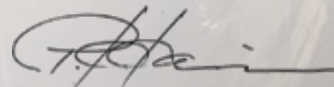
Diederichs on 'Cable Bolting', a book that is also recognized for its scientific and industrial value, as well as the Canadian Rockburst support Handbook, co-authored with D. R. McCreath and D. Tannant. But research does not stop with publications of results, the learning process continues. The findings of new research in burstprone mines is reflected in 'Rockburst Support Reference Book' coauthored with Dr. M. Cai. This work is freely distributed to registered readers at www.mirarco.org/rockburst-support-reference-book/.

Lesson 3: 'Publish or perish' is an old-fashioned model for research that has served the various funding agencies well, has made a difference, and most importantly, has built trust and respect for MIRARCO by the research sponsors.

Much more could be highlighted. I will always be grateful for having had the opportunity to work with so many industrial partners, with dedicated staff and students, and with government agencies that foster research for the development of Ontario and Canada.

It was most certainly a pleasure to lead MIRARCO and it is rewarding to celebrate 20 years of successful research at Laurentian University and MIRARCO. Maybe most importantly, I highly value the lasting friendships that have evolved from this 'journey of discovery'.

Sincerely,



Peter Kaiser - Ph.D., P.Eng., F. EIC, F.CAE
Founding President, MIRARCO
Emeritus Professor - Laurentian University

Last lecture:

<https://videostream.laurentian.ca/Mediasite/Play/bf2879ebbe874213b42762775d593bc11d>



CORPORATE PROFILE

Established in 1998, Mining Innovation Rehabilitation and Applied Research Corporation (MIRARCO) has been developing innovative solutions for the mining industry and its challenges. We are a not-for-profit corporation that operates with support from the private and public sector.

The driving force behind MIRARCO is its dedicated workforce made up of experienced professionals and students at all levels of post-secondary education. Through our unique position as a hybrid organization, combining academic and professional dynamics, we help advance innovative and applied research.

Expert knowledge, a drive to innovate, and partner support make MIRARCO a growing success.

Today, MIRARCO has established itself as a leader in 5 areas of expertise:

Rock Mechanics

The Geomechanics Research team undertakes research focused on geohazard assessment and the mitigation of unpredictable rock behavior associated with deep underground mining.

Energy

The Sustainable Energy Solutions team focuses their research on driving down energy costs for mine operations.

Software

The Decision Support Software team is developing the next generation of software for mining with an emphasis on modelling and optimization.

Safety Research

The Safety Research team addresses unique issues related to Safety and Risk Management in the mining industry.

Climate

The Climate Adaptation team at MIRARCO, is dedicated to assisting communities and sectors adapt to climate change. The centre prides itself as an adaptation leader in Canada and acts as a resource hub for decision-makers and stakeholders searching for information on climate change impacts and adaptation.

UNIQUE PLACE TO WORK: MIRARCO CULTURE

MIRARCO is one of the leading mining research and innovation groups in Canada. People from all over the world have worked on challenging and innovative applied research projects in partnership with both academia and industry. MIRARCO is committed to attracting and developing Highly Qualified Personnel (HQP) globally.



Contributions to Mining Innovation

Over 60 graduate students have worked at MIRARCO on multi-disciplinary applied research. Students conduct research with outstanding Laurentian University faculty members in a wide range of engineering disciplines and can assess their interest in pursuing studies at the Masters and PhD level.

At MIRARCO, interns are an integral part of our project teams. While working alongside engineers and researchers, they will gain valuable practical experience.

Please see the link below to a video depicting MIRARCO's diverse work force. The video was created by MiHR and can be found at <https://www.youtube.com/watch?v=ksgbQIMXcDA>

TWO DECADES OF ACHIEVEMENTS

2018 marks 20 years for MIRARCO. Two decades of hard work, struggles and success. MIRARCO's roots stem from a five-person team working in the Geomechanics research field. Since then, the company has grown and expanded its research field to include aspects of civil engineering, mechanical excavation, mining health and safety, energy, ventilation and adaptation to climate change etc. MIRARCO features an interdisciplinary blend of experts, professionals, and research students from all over the globe.

Two decades of success is something to be proud of. We've succeeded in:

- Developing strong research teams with professional staff and graduate students in geomechanics, mining technology, mining health and safety, energy and ventilation and climate change.
- Training highly qualified personnel (HQP) through unique research facilities at Laurentian University, by generating a track record of stable grant funding for research projects, and by attracting highly qualified researchers to support graduate student based research.
- Establishing state-of-the-art research facilities and equipment (ground penetrating radar, laser scanner, virtual reality laboratory, stress measurement equipment, etc.).
- Building a wide network of research collaborators in academia, government and the private sector.
- Establishing and delivering on collaborative projects with consultants, mining companies and other researchers.
- Establishing strong and wide-ranging links with industry as reflected by the composition of MIRARCO's Board of Directors.
- Commercializing research results that have created value for the mining industry including tool development and high-level/niche engineering, scientific and technical services.



1998

MIRARCO was founded in 1998 by Dr. Peter Kaiser

Mining Innovation Rehabilitation and Applied Research Corporation

1999-2000

Growing Business

Centre for Mining Technology

Centre for Environmental Monitoring

Innovation and Development Group

Centre for Integrated Monitoring Technology

2005-2008

Continuing Expansion in High Tech

Virtual Reality and Exploration Group

Enhanced Visualization and Optimization

HQP Development Spotlight



- 600+ Job Years
- 140+ Conference papers
- 60+ Journal articles
- 15+ Books and book chapters
- 175+ Other publications
- 60+ Case study and reports
- 50+ Professional development short courses and workshops

230+ Trained researchers, engineers and students
(PhD, PDF, Masters and Intern)

\$78.5 million industry & government pledges supporting R&D
\$65.5 million dollars in total revenues

2010-2015

Research Focus Areas

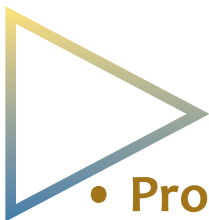
Geohazard Assessment and Risk Mitigation (GRC)
Ventilation and Production Optimization (VPO)
Environmental Monitoring and Rehabilitation (EMR)
Energy, Renewable and Carbon Management (ERCM)
Mining Safety Research (MSR)
Ontario Centre for Climate Impacts and Adaptation Resources (OCCIAR)

2018

Focus on the Future

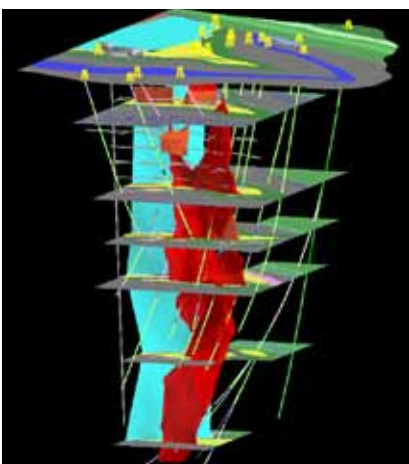
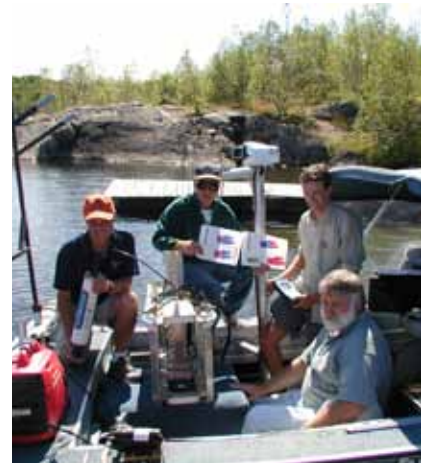
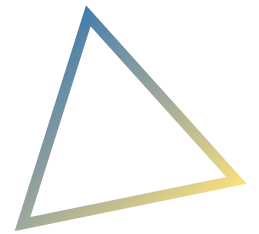
Rock Mechanics
Software
Energy
Safety Research
Climate

20 YEARS OF BEST PRACTICES IN APPLIED RESEARCH FOR MINING INDUSTRY



Leverage Knowledge

- Probing safety of the mine, the health of the environment, and adaptation to climate change
- Providing safe, productive, and sustainable innovative solutions to the mining industry



Focus: Virtual Reality (VR) Technology

In 2000 MIRARCO and Laurentian University were awarded \$1.92 million each by the Canada Foundation for Innovation and the Ontario Innovation Trust Fund, to establish a Centre for Integrated Monitoring Technology, CIMTec.

The first Virtual Reality Laboratory (VRL) for mining was officially opened on September 21st, 2001. The unique research facility was one of only a few immersive research theatres being built in Canada, which offered industry and researchers new ways to solve problems, interpret complex 3D data and collaborate.

NAVNet

Northern Advanced Visualization Network (NAVNet) project linked satellite virtual reality studios in Northern Ontario in a manner that facilitated simultaneous viewing of data in remote centres, thousands of kilometers apart.

Virtual Reality Technology has positively impacted mining at every stage:

Exploration and Feasibility - Identified potential ore bodies, planned exploration using historical and geophysical data, located exploration holes.

Mine Planning and Design - Analyzed multiple scenarios, selected best mining method, and identified inefficiencies before mining.

Mine Operation, Safety and Optimization - Optimized ore extraction for improved grade control and minimized operation costs.

VR Systems in North America:

MIRARCO brought VR technology to the Canadian mining industry.

1. MIRARCO developed ParaviewGeo a visualization platform tool for Seismic Excavation Hazard Maps. The on-site VR facility that MIRARCO designed has been implemented and commissioned at Vale's Creighton Mine in Sudbury, Ontario. MIRARCO's mining seismicity expertise was crucial in a collaborative project with Golder Associates to assist Vale in the design of future deep mining at Creighton Mine.
2. The Red Lake Virtual Reality Studio built at Red Lake Mine (2004) – MIRARCO teamed up with mining giants Goldcorp Inc. and Placer Dome Canada to establish the world's first virtual reality laboratory (VRL) in an active mining camp. The facility helped two companies with ongoing mining and exploration efforts.
3. The Timmins VR Studio at Timmins City Library (2006) – MIRARCO opened the first Virtual Reality Facility in a public library for mining application with the \$3.4 million NAVNet project. The facility enabled the library to extend beyond a typical book resource, to a high-tech, highly-integrated centre of knowledge.

VR Systems in China:

1. In 2006, MIRARCO created a splash with the first Asian VR installation, at China's Northeastern University, Department of Natural Resources and Civil Engineering. MIRARCO provided the system design, user training and shared technology.
2. In 2008, MIRARCO sold a VR system to a major Chinese mining group – Xuzhou Coal Mining Group (one of the top 500 companies in China). MIRARCO provided technical and data interpretation training, helped to create a 3D model of the mine, aimed to improve mine design, safety and communication.

Focus: Mine Safety

Improving Mine Safety

The creation of safe underground work environments depends on design and construction practices using the best available input data. The Rock Mechanics group provides such data to industry. Amongst the services offered is laboratory testing of rock materials for strength and deformation characteristics following procedures established by the American Society for Testing Materials (ASTM) or recommended by the International Society for Rock Mechanics (ISRM). Another is testing for rock drillability. Employing techniques standardized by the Norwegian Institute of Technology at the University of Trondheim or the Centre d'Études et de Recherches de Charbonnage de France (CERCHAR.)

Over the past 20 years, MIRARCO has been involved in a number of projects involving innovative new technologies aimed at improving productivity and enhancing safety.

In addition to lab-based studies, the group routinely undertakes field measurements to characterize the underground environment. Determinations of the in-situ state of stress, providing knowledge critical to the design of underground workings, are commonly acquired via overcoring using CSIRO Hollow Inclusion stress cells or the USBM borehole deformation gauge. Assessments of rock quality are obtained from downhole geophysical tools such as acoustic or optical borehole viewers and full-waveform sonic logging or, in drifts and shafts, by digital photogrammetry and physical mapping.

This data delivery role not only assists our clients in providing a safe workplace, but keeps our researchers knowledgeable of the issues facing the industry as well as keeping them grounded with respect to the applicability and feasible implementation of their research outcomes.

Geotechnical Risk

Using the borehole acoustic televiewer technology, MIRARCO developed techniques for the characterization of both the structural geology and the stress regime within a rockmass. The local mining community benefits by using such technology to improve safety.

The observation of the back-analyses of borehole logging data determined the impetus for research that has culminated in the development of a new failure criterion for brittle rock.

On-site logging of borehole with an acoustic televiewer produced data that was used in the reconstruction of 3D images showing borehole enlargement and intersecting features.

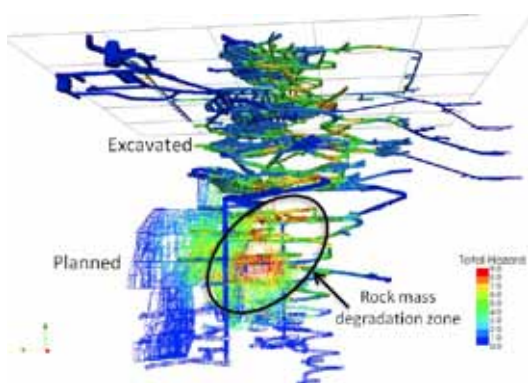
Dynamic Testing of Mesh Support

MIRARCO has a commissioned drop testing facility where the Rock Mechanics team performs dynamic testing of mesh support for industry partners. Wire meshes are regularly used in underground mines and tunnels to ensure the stability and safety of underground openings and workers, and to control the displacement and falling of the loose ground. In deep underground openings the occurrence of rock bursts and seismic activities may cause the ejection of rock, imposing a dynamic load on the wire mesh. The dynamic test system is designed to test mesh strength under impact loading.



GRC undertook a study commissioned by the Centre for Excellence in Mining Innovation (CEMI) on behalf of a consortium comprised of Rio Tinto, Xstrata Nickel and Vale to assess the applicability of digital photogrammetry as a quality control tool for shotcrete linings underground at Xstrata's Nickel Rim South Mine (Sudbury). While the imaging system employed was sensitive to camera positioning and lighting conditions, it was still possible to determine the thickness of shotcrete applied, with minimal interruption to operations.

Seismic Geohazard and Risk Assessment



Canada has become a leader in seismic monitoring. The complexity in data, interrelations and underlying principles have prevented the effective utilization of much of the now regularly collected data for mine planning, design and operational control. Over the years, MIRARCO has been able to integrate some of the research findings into support selection (Drift@Risk program), focused more research on numerical modeling and seismicity flow to fully understand and utilize the data for hazard assessment and risk management, and dealing with the related issue of slope stability assessment (Stope@Risk program).

In-Situ Stress Determination

The Geomechanics Research Centre (GRC) has a long history of in-situ stress characterization and measurement projects in both the civil and mining sectors. In the civil sector, GRC helped define the in-situ stress state at sites such as the Seymour Capilano Twin Tunnel Project in Vancouver and the Don River & Central Waterfront Wet Weather Flow System Tunnel Project in Toronto. As part of the Nuclear Waste Management Organization's (NWMO) research program into the safe disposal of hazardous waste, GRC, through borehole imaging analyses, helped establish constraints on the stress state at a proposed low to

medium waste repository site. Additionally, under NWMO sponsorship, assessments of the stress state in the Canadian Shield were conducted to aid in siting a high level waste repository.

In the mining sector, overcoring stress measurements were undertaken at numerous mine operations in northern Ontario and Quebec. At Vale's Creighton Mine, a novel approach using the recorded deformation response around a deep raise, was used to back calculate the stress field.

Hydraulic Pre-Conditioning of Highly Stressed Rock Masses



The Rock Mechanics Centre is the lead proponent of a project funded by the Ultra Deep Mining Network to demonstrate that hydraulic pre-conditioning can alter the character of the rock mass such that the maximum magnitude of mining induced seismic events can be reduced in highly stressed ground. This will be achieved through the adaptation of hydraulic fracturing technology developed in the oil & gas sector to selectively damage the rock mass on a multi-stope scale in advance of mining.

Partnering with MIRARCO in this initiative are Vale as the industrial sponsor, Terralog Technologies Inc. (with Trican Well Services & CW Manufacturing) bringing the

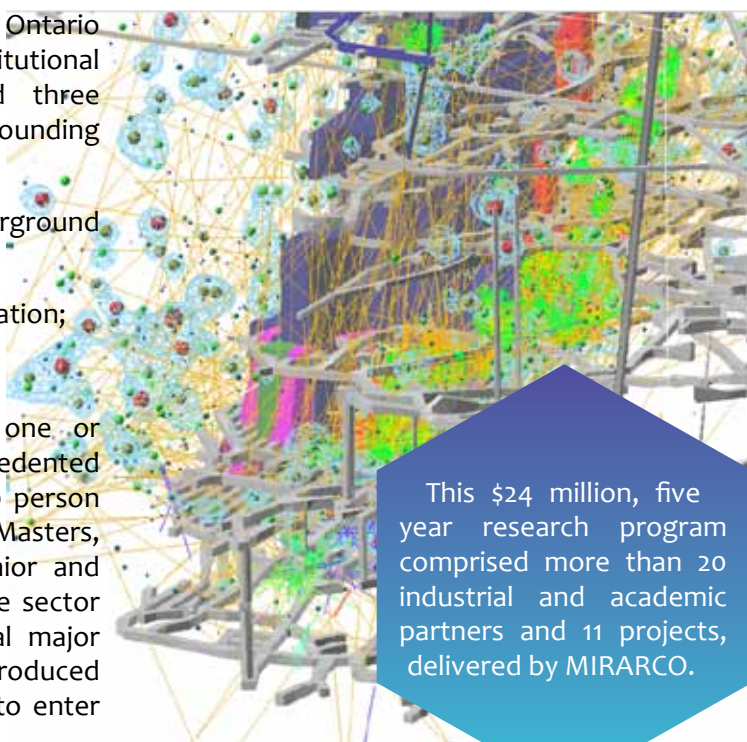
oil and gas expertise, CEMI (networking and prior knowledge), along with ESG Solutions & Yieldpoint Inc. for monitoring expertise.

► Focus: Productivity Enhancement and Risk Management in Underground Construction and Mining (PERM)

The PERM program was funded by the Ontario Research Fund as well as industry and institutional contributions. The program engaged three themes that looked to solve issues surrounding deep mining and the environment:

- Design and construction of underground excavations;
- Integrated mine design and risk mitigation;
- Environmental risk management.

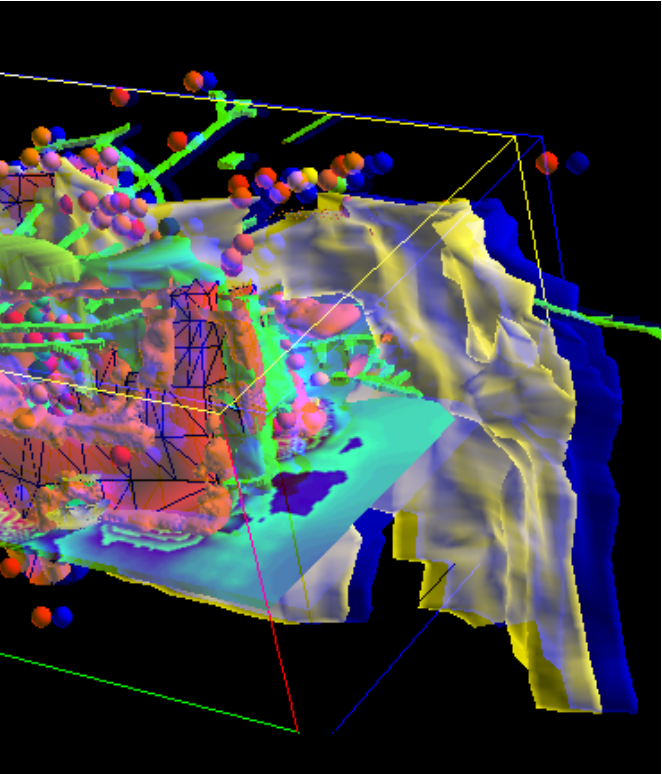
Each theme's subprojects addressed one or more knowledge gaps. This unprecedented opportunity committed to providing 150 person years of training and experience to Masters, Ph.D. and undergraduate students, junior and senior academic researchers, and private sector professionals. The PERM led to several major mining technology breakthroughs and produced a stream of Highly Qualified Personnel to enter the natural resource sector.



This \$24 million, five year research program comprised more than 20 industrial and academic partners and 11 projects, delivered by MIRARCO.

Focus: Mine Planning and Design

MIRARCO undertook research to look at the fusion of data and interpretation of mine plan audits during operations to optimally operate mines. Groups of researchers developed mine models with the time cost benefit assessment. Models of highly complex datasets provide alternative sequencing options, based on criteria such as net present value or ore grade. Dataset queries are then manipulated using algorithms to produce the most profitable stope sequences, all with higher confidence levels and less risk. Methods are devised to continuously audit and revise or improve the mine plan, incorporate chaos functions related to unexpected behavior of natural materials, integrate and process huge amounts of data and analyze the cost and revenue flow within a mine for rapid decision-making.



Ground Support Design Optimization

MIRARCO has been continuously developing a method for ground support design optimization. The project couples the Rock Mechanics Centre's 20 years of experience with cutting edge technology to develop a scientifically sound methodology for ground support design optimization according to actual conditions encountered during the mining cycle. The benefits include significantly increased drift development rates and reduced support material costs.

Ground Control with Innovative Rock Support

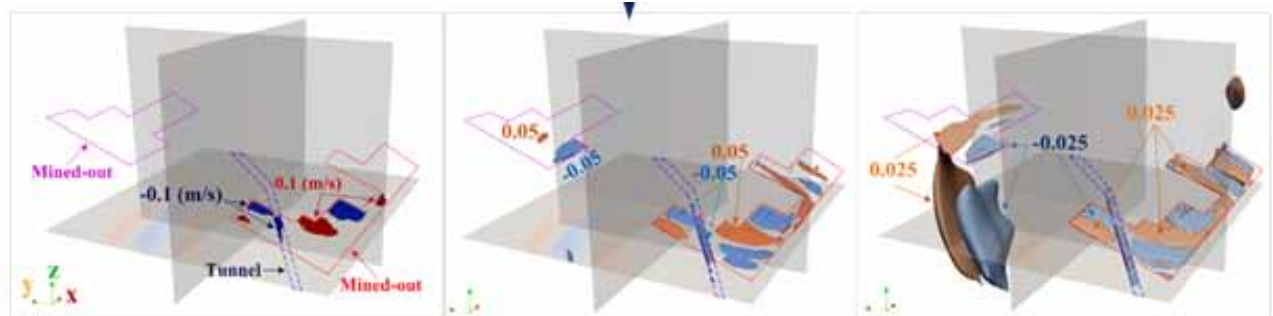
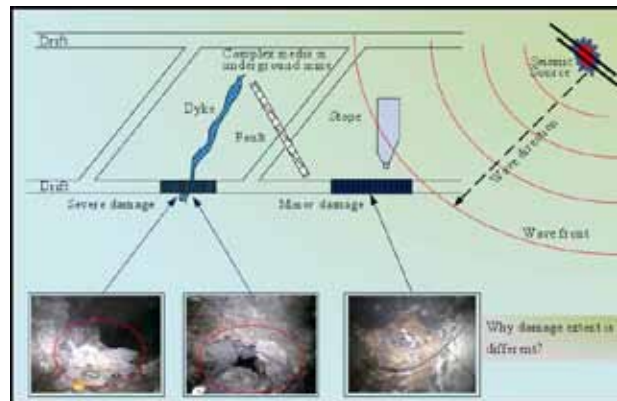
MIRARCO's geomechanics researchers engage in the development and evaluation of new support methods for rockburst-prone areas for hard rock mining including cablebolt theory practice and design, pull tests, shotcrete / spray-on liner evaluation, screen testing, rock index testing, site characterization and geomechanics mapping, risk / hazard assessment, rockburst hazard, pillar design, tailing dam stability assessment, full-face tunnel boring machine performance, drillability assessment, and rock fragmentation. The Geomechanics Research team has focused research on ground control and rock support in static and rockbursting ground with on-site and laboratory testing of innovative support components such as spray-on liners. Deep mining and new mining methods, however, demand non-conventional support systems that are able to survive large deformations without disrupting production due to rehabilitation.



Dynamic Support Research for More Effective Mine Design

This subproject* aimed at improving our understanding of seismic wave propagation in deep underground mines with a particular emphasis on ground motion near excavation boundaries due to seismic wave propagation that resulted from a remote fault-slip seismic event. Advanced numerical modeling tools were used and new modeling techniques were developed to attain this goal.

**This research project was part of SUMIT's Seismic Processing and Stress Modeling program.*



S.U.M.I.T. – Smart Underground Monitoring & Integrated Technologies for Deep Mines. A Laurentian University-led and CEMI-managed R&D project.

S.U.M.I.T Program Journal:

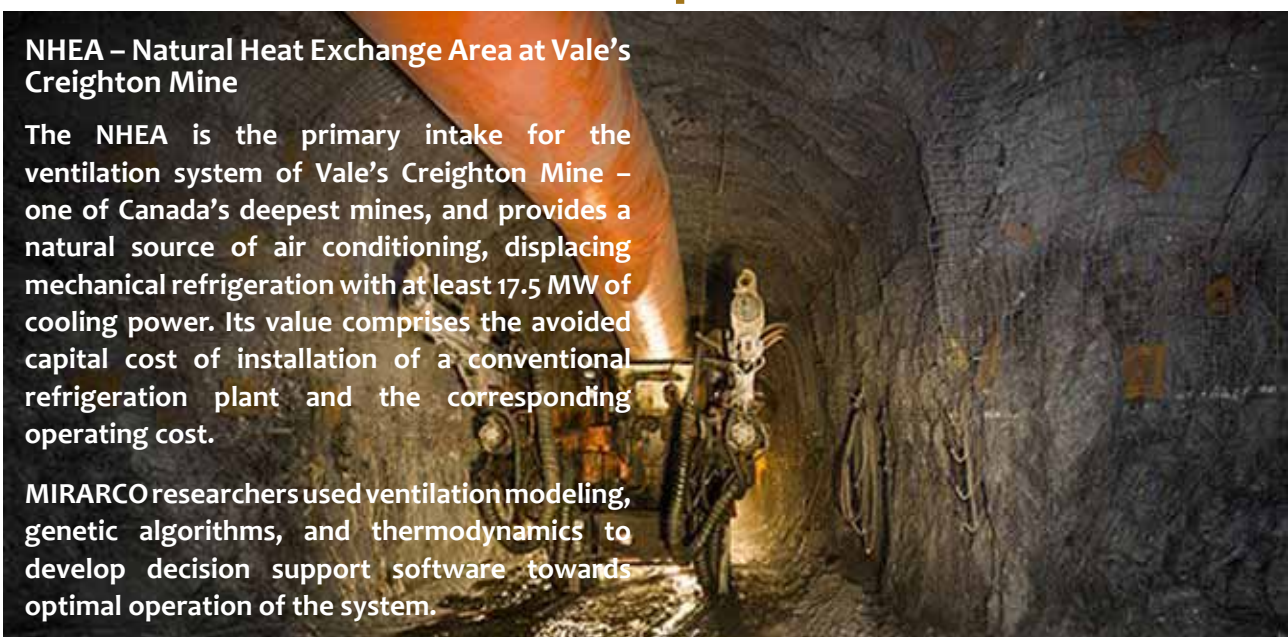
<https://www.cim.org/en/Publications-and-Technical-Resources/Technical-Resources/Reports>

Focus: Energy Management and Ventilation Improvements

NHEA – Natural Heat Exchange Area at Vale's Creighton Mine

The NHEA is the primary intake for the ventilation system of Vale's Creighton Mine – one of Canada's deepest mines, and provides a natural source of air conditioning, displacing mechanical refrigeration with at least 17.5 MW of cooling power. Its value comprises the avoided capital cost of installation of a conventional refrigeration plant and the corresponding operating cost.

MIRARCO researchers used ventilation modeling, genetic algorithms, and thermodynamics to develop decision support software towards optimal operation of the system.



The NHEA is a pit containing a mass of broken rock connected to underground mine workings including a set of tramways and slusher trenches. Doors located in the trenches are operated manually to regulate the airflow that comes from surface, passes through the rock mass and enters the fresh air system of the mine.

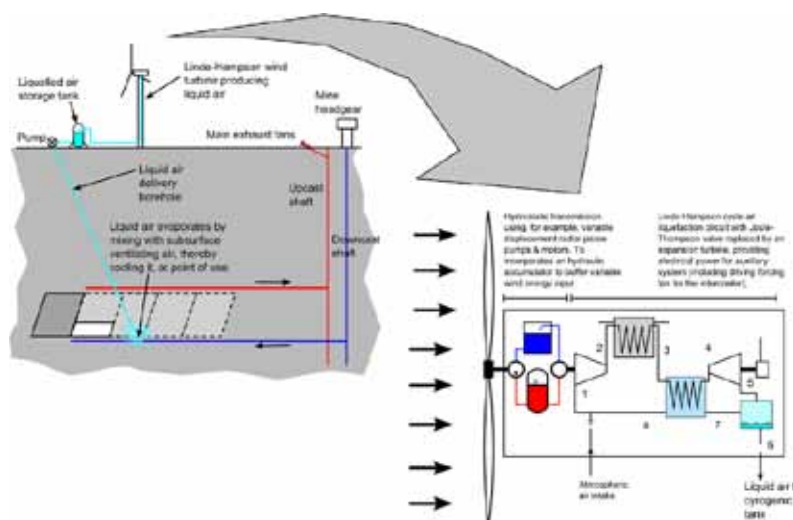
The work that MIRARCO completed on the NHEA has provided Creighton Mine opportunities to plan improved strategies for management of the system which will potentially allow mining to greater depth without mechanical refrigeration.

CRYOVENT: Wind Turbine Produced Cryogenics

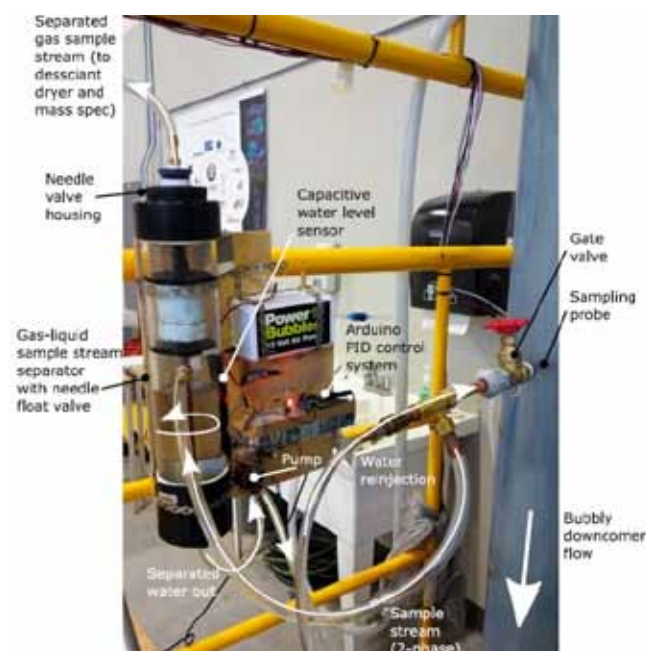
The CRYOVENT project was concerned with low-carbon production of cryogenics to be used for ventilation in deep mines where heat is increasingly becoming a limiting factor on production.

Technologies such as CRYOVENT are required to decrease the overall carbon footprint and operating costs of underground mining operations. Specifically, this project attempted to outline the feasibility of using wind powered liquefaction plants to produce liquid air, used to cool underground workings and supplement auxiliary ventilation systems.

This research project focused on the potential yield of such a plant as well as the performance of liquefaction cycles in the face of the transient work input provided by wind turbines. CRYOVENT allows the potential to incorporate low cost and renewable technology into the mining industry, resulting in lower overall operating costs as well as a cleaner, more sustainable operation and better overall public appearance.



Funding was secured from CEMI to fund a junior researcher for this project for 4 years and also from the Canadian Foundation for Innovation to fund the building of the experimental rig.

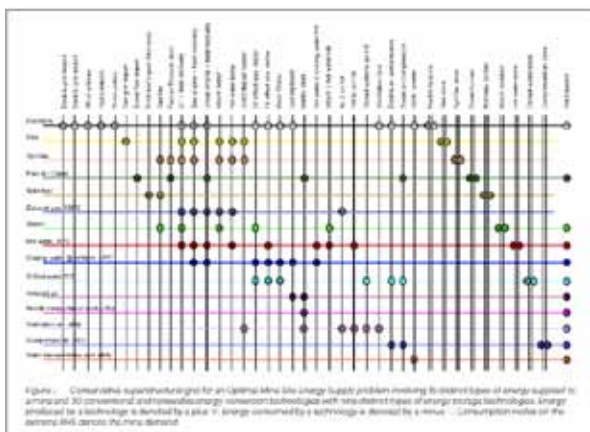


Hydraulic Air Compressor (HAC)

The Hydraulic Air Compressor (HAC) project involves the installation of a demonstration scale HAC within a mine shaft in Sudbury. The project aimed to install and operate the HAC and assess its effectiveness for: i) the production of compressed air, ii) the provision of cooling for deep mines, iii) the separation of CO₂ from exhaust gas streams, and iv) the compression of refrigerant gases on a large scale. A HAC offers a practical, minimum work gas compression; that is, as the gas is compressed by the water, the water simultaneously acts as a heat sink so that the overall process is isothermal.

This project was part of SUMIT's Sustainable Operations – Energy Management and Ventilation Program.

Optimal Mine Site Energy Supply (OMSES)



OMSES finds the best way to meet mine energy demands in all energy forms (electrical, heat, cooling, diesel generated) taking time-varying energy tariffs and environmental uncertainties into account. The system simultaneously finds the optimum set of technologies to achieve the job, and the optimal operating state of each item of equipment in this set, on an hourly basis, throughout a complete year. We worked to consider energy storage technologies in the formulation as well as variable and intermittent renewable energy technologies. In the latest work, OMSES has been coupled with Model Predictive Control algorithms so that the optimality of the design solutions found can be assessed for their robustness in the face of uncertain climatic and price variables.

This project was part of the SUMIT 6 (Sustainable Operations – Energy Management and Ventilation) work focused specifically on optimizing the integration of conventional and novel energy technology, motivated by the imperative of minimizing energy costs for mine operators.

Focus: Innovative Solutions



Solar Photovoltaic Technology

The Floating Solar Photovoltaics project is a new application area with solar photovoltaic (PV) technology that MIRARCO's researchers deployed offshore of Malta near the Mediterranean Sea. PV panels convert sunlight directly into electricity and are therefore potential power generators for mining operations located far from electricity transmission and distribution infrastructures.

MoFrac

MoFrac is a newly released software package that generates 3D fracture network models for rock mass characterization. Driven by the need for safer geotechnical design, MoFrac implements methods developed by R. Mohan Srivastava to create discrete fracture networks (DFNs) well-suited to both civil and mining applications.

The project:

1. Developed improved algorithms, to allow geotechnical engineers to generate visually realistic and geologically plausible fracture networks;

MIRARCO has put mining innovations to work; demonstrated & implemented workable beyond the theoretical, and has also shown commercial viability.

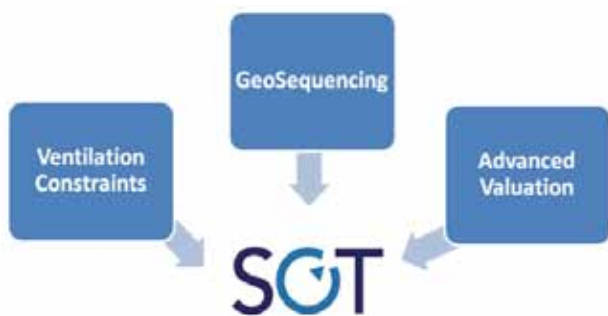
2. Investigated how rock engineering in fractured rock masses can be enhanced with the aid of better-characterized DFNs;
3. Transfers knowledge to the industry by means of embedding algorithmic and methodological improvements in the MoFrac software tool; and
4. Trains highly qualified professionals.



The approach to be adopted is a combined application of experimental observation, field monitoring, and numerical modeling. This research is intended to advance DFN generation and materially improve the safety, productivity and profitability of underground engineering projects.

SOT – Schedule Optimization Tool

SOT was developed at MIRARCO, and was enhanced through the PRIMO (Planning and Rapid Integrated Mine Optimization) project. PRIMO aimed to adapt and integrate existing software into a single planning and scheduling framework, assisting mining engineers in optimizing mine design and scheduling. The end result was a semi-automated, integrated set of tools to provide engineers with multiple scenarios for better decision making.

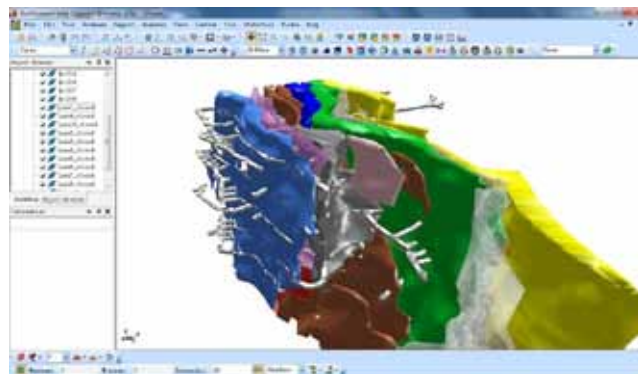


SOT uses a custom genetic algorithm and heuristic rules to optimize the net present value of a life-of-mine schedule for an underground mine. It produces feasible, optimized schedules in a fraction of the time needed by conventional methods, allowing mine planners time to review and assess alternative options.

The SOT+ research project has developed three new modules that integrate with SOT. The research themes for SOT+ focused on advanced valuation, ventilation constraints, and geotechnical constraints.

BurstSupport

BurstSupport is a stand-alone Windows software tool designed and developed by MIRARCO for the mining industry to conduct preliminary rock support design in drifts in deep underground mines or civil tunnels. This tool enables the user to assess load, displacement and energy demands at multiple drift locations by considering anticipated event magnitude and location, in-situ stress conditions, drift orientation, and rock mass quality simultaneously. Using BurstSupport, the user is able to quickly evaluate the impact of potential mining-induced seismicity on drift stability.



BurstSupport can assist ground control engineers to quickly and systematically evaluate different rockburst support options in a user-friendly manner, and rockburst risk management can be significantly improved.

Green Mines Green Energy (GMGE)

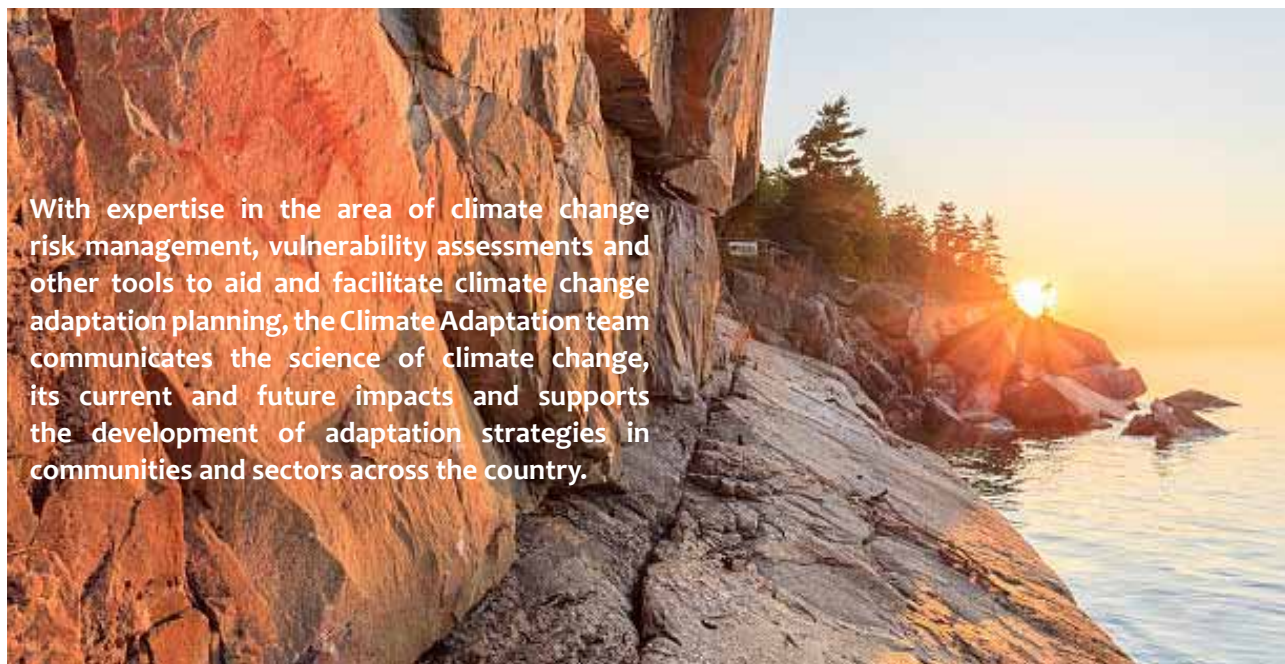
MIRARCO, in partnership with industry in the NRCan-led Green Mines Green Energy project, conducted a feasibility study of rehabilitating mines in a novel way. The “Eco-friendly Farming of Energy Crops on Tailings” researched collaborative, conducted a study to determine if tailings can be made into biofuel croplands. In the project mine tailings were rehabilitated to the extent that they can support the growth of biomass and “energy crops” such as canola and corn, which can be harvested to provide feedstock for biofuel processing plants. The objectives of this study demonstrated promise as a solution to fuelling an increasingly resource-strained 21st Century – from mining wasteland to biofuel crop production.

Green Mines Green Energy had supported environmental training of numerous students from high school to post-graduate level and post-doctorate fellow.



Focus: Climate Change Impacts & Adaptation

With expertise in the area of climate change risk management, vulnerability assessments and other tools to aid and facilitate climate change adaptation planning, the Climate Adaptation team communicates the science of climate change, its current and future impacts and supports the development of adaptation strategies in communities and sectors across the country.



Partnering with First Nations to Address Climate Change

In 2016, MIRARCO was awarded a \$5M grant from the Ontario’s Green Investment Fund to help build capacity in First Nations to address climate change. In partnership with Laurentian University and the Ontario First Nations Technical Services Corporation, the Climate Adaptation team worked with First Nations across the province to build capacity to understand climate change, respond to the impacts through adaptation, as well as take steps to assess energy needs and manage greenhouse gas emissions. Energy planning, conservation, efficiency and First Nations participation in the Ontario Cap-and-Trade program were important components of the project. The work also included a climate change impact study for the north.

Climate Change Adaptation Community of Practice (CCACoP)



The Climate Adaptation team has developed an interactive, online community of practice where researchers, experts, policy-makers and practitioners from across Canada can come together to ask questions, share knowledge and communicate with others who are also working in the field of climate change adaptation. The CCACoP is a unique resource in Canada, as it is the only web-based community that supports knowledge transfer between decision-makers and climate change experts in order to promote the incorporation of adaptation into policies, planning and other decision frameworks.

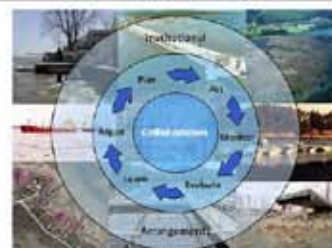
<http://www.ccadaptation.ca>

International Upper Great Lakes Study

The Climate Adaptation team was a member of the adaptive management technical working group of the International Upper Great Lakes study (2007- 2012), led by the International Joint Commission. The study explored the challenge of fluctuating water levels in the upper lakes in the face of uncertain future water supplies and how that will affect a variety of sectors / interests on the lake system.



Adaptive Management: Strategy and Legacy



Ontario Regional Adaptation Collaborative

Since 2013, the Climate Adaptation team has hosted the Ontario Regional Adaptation Collaborative (RAC) which continues to provide resources and tools to communities and sectors in Ontario to address the impacts of climate change through adaptation. Funded by Natural Resources Canada, the RAC program includes hubs in 5 regions across Canada.



Focus: Knowledge Transfer

Global Minerals & Industry Risk Management Course (G-MIRM)

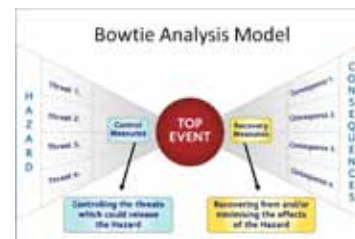
Since 2011, MIRARCO has successfully implemented the delivery of the G-MIRM course in North America in partnership with JKTech Pty Limited and University of Queensland, Australia. The course was developed by Anglo American and is making their highly-acclaimed and award-winning education program available to the whole industry to contribute to a systemic change in safety and risk management.

Water Quality and Lake Evolution

One of MIRARCO's cornerstone projects was "Probing the Health of Ramsey Lake". The project looked at water quality issues in the North and the impacts that they have on human health. The chemical and physical data that collected from towed sensors and continuous monitoring equipment supported the development of dynamic predictive models crucial for planning, effective resource management, and for the creation of a watershed protection plan for Ramsey Lake. This research focuses on ensuring quality drinking and operational water in mining camps and develops a flexible technology platform to support research for a multitude of water quality analyses and deployment scenarios.

Bow-tie Analysis

Significant work in facilitating safety risk analysis, using the Bow-Tie tool has been undertaken by MIRARCO. This tool allows for a systematic analysis of the effectiveness of the controls in place that would prevent an unwanted event from occurring. Sessions have been held in Sudbury, and Goose Bay Province with additional sessions scheduled in Sudbury and Long Harbour Province.



Risk Assessment and Environmental Management – Case Study Text Book



MIRARCO released the “Risk Assessment and Environmental Management” book in January, 2012. This case study text book was edited by Dr. Chris Wren and is based on the ground-breaking Sudbury Soils Study. The book covers all aspects of the study including human health risk assessment, ecological risk assessment, risk management, and risk communication and consultation. The book is available through MIRARCO and Maralthe Publishing, Netherlands.

Sudbury 2007 Mining and Environment International Conference



The conference was co-hosted by MIRARCO’s Centre for Environmental Monitoring and the Cooperative Freshwater Ecology Unit (CFEU) in Oct, 2007.

The theme for the conference was ‘sustainability’ (inclusive of the workforce and the communities in which they work). This conference brought more than 400 delegates together including technical experts, policy makers and regulators from more than 19 countries to address mine, land and waterways rehabilitation and related environmental protection issues.

36th International Conference of Safety in Mines Research Institutes



MIRARCO Mining Innovation and the Canadian Institute for Mining, Metallurgy and Petroleum (CIM) hosted the 36th International Conference of Safety in Mines Research Institutes in Sudbury, Canada from October 25 to 27, 2015. The conference attracted approximately 160 delegates and speakers from Europe, Australia, South Africa, and across North America. This is the first time the conference was held in Canada.

The theme was mining safety research and was invaluable to academics, researchers, safety experts, and industry professionals for discussion and assessment of challenges and achievements in the field of mines safety and disaster management.

Mine Ventilation Symposium



June 13-16, 2010 MIRARCO, Laurentian University in partnership with CANMET successfully hosted the 13th U.S./N. American Mine Ventilation Symposium in Sudbury, ON. The theme of the symposium was “Green Mining” with numerous papers, courses and exhibits focusing on ventilation efficiency through ventilation on demand, energy management, reduced environmental impact from diesel equipment and methane abatement. The symposium attracted 272 delegates from 16 countries. The globally recognized symposium provided a forum for the exchange of mine ventilation knowledge and R&D experience amongst experts from industry, government, academia and the supply sector.



Peter Kaiser

Director, Geomechanics Research Centre (GRC), 1998-2008



Vic Pakalnis

Director, Mining Safety Research, 2011-2012



Sean Maloney

Director, Geomechanics Research Centre (GRC), 2008-2017



Andrew Dasys

Director, Innovation and Development Group (IDG), 2000
Director, Centre for Integrated Monitoring Technology (IMT), 2000-2005
Director, Enhanced Visualization & Optimization (EVO), 2005-2008
VP, Commercialization, 2008-2010



Dougal McCreath

Director, Elliot Lake Research Field Station (affiliated MIRARCO centre), 2000-2001



Mark Andersen

Director, Centre for Mining Technology (CMT), 1999-2000



Paul Dunn

Director, Centre for Mining Technology (CMT), 2001-2005



Dale McKinnon

Director, Ventilation and Production Optimization (VPO), 2010-2011



Dean Millar

Director, Energy, Renewables & Carbon Management (ERCM), 2011-2017
Chair, Energy in Mining, 2011-2017

**Leaders
MIRARCO**



Al Douglas
 Project Coordinator,
 Centre for Environmental Monitoring,
 2007-2008
 Operations Manager,
 Elliot Lake Research Field Station,
 2006-2009
 Director, Climate Centre,
 2007-present
 Chief Administrative Officer,
 MIRARCO, 2015-2017



Ming Cai
 Chair, Geomechanics Research,
 2009-present



Graeme Spiers
 Director, Centre for Environmental
 Monitoring (CEM), 1999–2010
 Director, Environmental
 Monitoring & Rehabilitation (EMR),
 2010–2011
 Director, Elliot Lake Research Field
 Station, 2002-present
 Chair, Environmental Monitoring,
 1999 - present

of
 Business



Lorrie Fava
 Director, Ventilation & Production
 Optimization (VPO), 2013-2017
 Director, Software Centre,
 2018-present



Jacqueline Richard
 Coordinator,
 Climate Centre,
 2007-present



Sherry Greasley
 Director, Operations,
 2009-2013



Glenn Lyle
 Director, Safety Centre,
 2012-present



John Henning
 Director, Rock Mechanics
 Research Centre, 2017-2018

“

“Looking back at my formative years as a young engineer, I recognise how rare an opportunity I was given as a student, and then later as a staff member of the GRC and MIRARCO. I value the experience I gained by working on many unique R&D projects while being surrounded by many high calibre people working in our field. It is difficult to imagine where I would be in my career today without having had that experience/opportunity.”

Luigi Cotesta
General Manager & Principal Engineer,
Itasca Consulting Canada Inc.

“

“It was a great pleasure to join MIRARCO/GRC as a young engineer in 2008. For nearly seven years, I was given the opportunity to interact and work with world class researchers and be a part of exciting projects. MIRARCO/GRC gave me everything I needed to grow and become an independent researcher.”

Navid Bahrani, Ph.D.
Assistant Professor, Mineral Resource
Engineering Department of Civil & Resource
Engineering, Dalhousie University

“

“I came to Laurentian University in 1989 to join Peter Kaiser in teaching and researching rockburst phenomena in deep mining. Little did I know what impressive results Peter would deliver, creating first the Geomechanics Research Centre (GRC) and then the Mining Innovation Rehabilitation and Applied Research Corporation (MIRARCO). Led by Peter, the staff and graduate students of MIRARCO have made seminal contributions to the understanding of many challenging issues in deep hardrock mining, and have had a lot of fun doing it! It really was a privilege to have worked with this group, and to have been part of the birth and early days of MIRARCO. I’m looking forward to your future achievements.”

Dougal R. McCreath PhD, PEng, FEIC, FCAE
Professor Emeritus, Bharti School of Engineering,
Laurentian University

“

“The technical hometown in Canada which taught me that ‘Your beginnings will seem humble, so prosperous will your future be’.”

Bo Kim
Lead Mining Engineer,
National Institute for Occupational
Safety and Health (NIOSH)





“MIRARCO provided me the much needed technical and professional platform to stand tall as new immigrant to Canada. An absolutely robust, unparalleled and unchallenged leadership of Dr. Peter Kaiser is still my strongest career pillar. I am still using, on day-to-day basis, the Seismic Hazard Mapping tools developed under Dr. Kaiser’s leadership in the year 2004.”

Atulya Verma
Senior Ground Control Engineer,
Vale Canada Ltd



“The early days of Virtual Reality for mining, MIRARCO was a pioneer in the development and promotion of using large scale visualization systems to help exploration and mining professionals. These systems used stereoscopic projection to create a 3 dimensional image in the middle of a room.

The goal was to encourage collaboration between teams of professionals and to use the stereo projection to display complex mine design information - such as changing stress fields.

Systems were installed at a number of mine sites and in the Timmins library where VR was used by the local mining companies and by library patrons.

Interestingly, mining investor relations people saw large scale VR as a means to gain investor interest by helping them better express the value of their properties.”

Andrew Dasys
President, Objectivity

MIRARCO



“The MIRARCO glory years with Kaiser and Hall between 2000 and 2012 were amazingly successful for the fledgling Centre for Environmental Monitoring led by Research Chair Graeme Spiers. With a large group of Post Doctoral Fellows, Scientists and multi-disciplinary Graduate Students completing applied research projects, the CEM group led the world in environmental applications of 3-D Modeling within the MIRARCO Virtual Reality Facility, a first in any Canadian University in 2001, with VR project outcomes enhancing our understanding of both Landscape and Lake Anatomy. The CEM Research Team completed the regional soil metal-level mapping in the Sudbury Basin which formed the basis for the acclaimed Sudbury Area Risk Assessment Study, subsequently highlighted in ‘Risk Assessment and Environmental Management: A Case Study in Sudbury, Ontario, Canada’ by Chris Wren (published by Maralte B.V., Leiden). The CEM brought the National Climate Change Adaptation Network (C-CIARN) to Sudbury to guide and develop the Risk Based Climate Planning approach for many Ontario Agencies and Communities. The greatest achievement and legacy of CEM was the provision of training opportunities for over 100 undergraduate and graduate students in the Environmental Sciences.”

Graeme Spiers
Chair Environmental Monitoring
Departments of Chemistry, Earth Science and Biology
Director, Elliot Lake Research Field Station, Laurentian University

LOOKING AHEAD





As MIRARCO celebrates its 20th year, the business centres will continue their most significant legacy projects while stepping forward into new endeavours.

China-Canada Centre of Deep Mining Innovation

Since 1996, Northeastern University (NEU) in China and Laurentian University (LU), have been in various forms of collaborations in the areas of virtual reality, rock failure process simulation, rock property testing, and rockburst damage mitigation. On December 7, 2017, NEU and LU (under the auspice of MIRARCO) entered into an agreement to establish a “China-Canada Centre of Deep Mining Innovation” (CCCDMI). The goals of the Centre are:

- to establish a global leading research hub and collaboration platform in deep mining, and;
- to stimulate innovation and cooperation of universities, institutes, and corporations between China and Canada in deep mining.

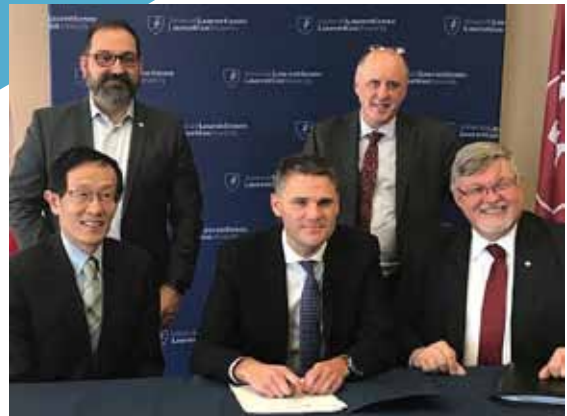
The Centre is composed of five departments:

1. mine and exploration geology,
2. rock mechanics and rock engineering for deep mining,
3. advanced extraction techniques in deep-ground,
4. mine safety and health,
5. green and sustainable mining

and a scientific committee comprised of leading experts and academics from China and Canada as well as some other countries. The Centre is managed by an executive committee and an administration committee.

The centre does not only establish academic collaborations but also seeks to establish strong collaboration with industry partners and provide solutions to engineering problems for the industry partners. Within five years, both the Chinese and the Canadian bodies will identify at least 4 industry partners and solve at least 5 major industrial problems in mining and provide technical support to the industry partners. In addition, the Centre will provide a communication channel to build a win-win relationship for the Chinese and the Canadian governments as well as the industry companies from both nations, and serves as the bridge between enterprises of the two nations.





Sustainable Energy Research

The use of small modular reactors (SMRs) for remote communities and mines in northern Ontario will be studied following the signing of a memorandum of understanding (MoU) between Bruce Power, Laurentian University and MIRARCO Mining Innovation. The five-year, million dollar research agreement will create an Industrial Chair position at MIRARCO.

“The Chair position will allow MIRARCO to further explore the use of SMR applications to remote mining operations. By welcoming Bruce Power into the fold, it will support increased research mining safety and align further research with Laurentian Mining Innovations and Technology, allowing for dedicated time to foster research excellence. Northern Ontario will benefit from this strategic investment by the capacity to recruit a Chair of

high calibre, who is internationally renowned in the field of sustainable energy solutions.” - Vic Pakalnis, MIRARCO President and CEO.

Mike Rencheck, Bruce Power President and CEO, said SMRs could play a role in safely powering the most remote northern communities that do not have adequate electrical grid infrastructure.

“Ontario has been and continues to be a leader when it comes to clean and sustainable energy,” said former minister Glenn Thibeault. “Investing in research for sustainable and low-carbon energy sources, right here in Sudbury, is a key part of our commitment to securing a clean energy future in remote Northern Ontario communities.”

Rockburst Support Reference Book

MIRARCO is releasing the manuscript of a Rockburst Support Reference Book consisting of three volumes:


1. Rockburst Phenomenon and Support Characteristics
2. Rock Support to Mitigate Rockburst Damage Caused by Dynamic Excavation Failures
3. Rock Support to Mitigate Rockburst Damage Caused or Dominated by Dynamic Disturbances from Remote Seismicity (to be released in 2018)



This book evolved from the Canadian Rockburst Support Handbook (Kaiser et al. 1996) and includes findings from subsequent research by the authors and others around the world. This book specifically addresses support design aspects for strainbursts and for conditions where it is difficult, if not impossible, to establish a priori kinetic energy demand. A new design aspect – the concept of seismically triggered and dynamically loaded strainbursts – is introduced. Deformation-based support design principles are introduced to assist in selecting robust support systems to mitigate rockburst damage. This book provides comprehensive guidance to create safe working conditions in burst-prone mines.

This project aimed at consolidating research findings from various SUMIT sub-projects and of relevant research funded by other means including NSERC, CEMI and industrial sponsors (Sudbury Integrated Nickel Operations, a Glencore Company, LKAB, Newcrest, Rio Tinto and Vale).

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WMC Resources Ltd.
Workplace Safety and Insurance Board
WSP Canada Inc.
XPS Consulting & Testwork Services
Xuzhou Coal Group Corporation
Young Davidson Mine

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