100 INNOVATIONS IN THE MINING INDUSTRY

The Mining Association of Canada

Printing of this book was made possible through a generous contribution
of the Mining Association of Canada
and the Prospectors and Developers Association of Canada.

A WORD FROM THE EXECUTIVE DIRECTOR

Innovation shapes our future. Minalliance is proud to present an unprecedented study on innovations in the mineral industry. Conducted under the guidance of Michel Jébrak, this study is the fruit of extensive research and analysis. It compiles and summarizes one hundred innovations developed around the world in several domains of scientific expertise, and touches on many facets of the industry, including ongoing initiatives that improve working conditions for miners and minimize the environmental footprint of mining activities.

This book bears witness to the ingenuity and know-how of scientists, technicians, and all those involved in the mining industry. It illustrates how the industry uses innovation as a lever to stay on the cutting edge and prepare for the future, resolving major issues to remain competitive and meet worldwide needs.

The content fits perfectly within the mission of Minalliance, which is to "give all Quebecers access to clear, consistent, and coordinated information about the activities of the mineral industry, and highlight its positive contribution to Québec's social, economic, and environmental development."

This publication is sure to interest those already keeping abreast of developments in the mineral industry, in addition to people concerned with economic progress, as many of the innovations are relevant to other fields. The book's comprehensive and informative content will remain a source of reference for readers.

Michel Jébrak, professor in the Département des sciences de la Terre et de l'atmosphère at the Université du Québec à Montréal, is an expert in the field of mineral resources. Having worked in Africa, Europe, and the Middle East, he is well positioned to appreciate the innovative capacity of the mineral industry and its potential impact on the global scale. His point of view clearly demonstrates the leading role played by the industry in terms of innovation, as well as its contribution to scientific and technical knowledge. Designed for a wide readership, this book has made no compromises in either quality or substance, and we hope it will give you an appreciation of the mineral industry's energy and strong innovative character.

Claudine Renauld
Executive Director

THE MINING INDUSTRY, WHICH DATES BACK TO THE DAWN OF CIVILIZATION, IS OFTEN CONSIDERED AN ANCIENT INDUSTRY. DESPITE ITS AGE-OLD ROOTS, NATURAL RESOURCE EXPLORATION AND EXPLOITATION HAVE ALWAYS BEEN AMONG THE MOST

ACTIVE FIELDS FOR RENEWAL THROUGH INNOVATION. TODAY, MINING INNOVATIONS ADDRESS THE GROWING DEMAND FOR AN EVER-BROADENING RANGE OF MINERAL RESOURCES, WHILE RESPECTING COMMUNITIES AND THE ENVIRONMENT.

SUMMARY

This book presents one hundred innovations, mostly technological, that have marked the last ten years of mining, particularly in Québec. Although not exhaustive, the list demonstrates the ingenuity of a profession that strives for more efficient, sustainable practices by continually revisiting and renewing its methods and concepts. As such, innovations in the industry have been instrumental in the following areas:

Smarter exploration…

— Identifying minerals, chemical compositions, and physical properties directly in the field

— Detecting even deeper mineral deposits

— Modelling mineral deposits, their potential economic assets, and challenges right from the earliest stages of exploration

More efficient mining…

— Mining methods based on the latest advances in robotics

— Real-time monitoring of the flow of rock and ore through the mine and processing plant

— Simulations at the mine design stage to test different solutions before implementation

Safer working conditions…

— Improved underground communication

— Increasingly sophisticated means of ore transportation

— Emergency response measures developed for the harshest conditions

A more environmentally responsible industry…

— Solutions to deal with acid mine drainage

— Solutions to transform mine tailings into beneficial products

— Overall, innovations in the mining industry aim to improve worker safety, increase efficiency, and minimize environmental impacts

— Innovation represents an established and ongoing structural element for the mining industry that continues to draw from many areas of knowledge: chemistry, physics, biology, engineering, computer science, etc.

— By providing new techniques to deal with particularly challenging environments, mining industry innovations are often transferable to other fields and may eventually find much broader applications. For example, much of the expertise in the rapidly expanding field of environmental engineering has been fuelled by innovations from the mining sector

— Innovations create lasting value, thereby positioning Québec as one of the world leaders in this area

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INTRODUCTION

Mining lies at the foundation of civilization: from the first Copper Age smelters in Cyprus to the bronze workings of the Shang Dynasty in the twelfth century BC, to the gold rushes in the North American West and the mining complexes and steel workings of nineteenth-century Europe, mines have been prominent on the economic landscape since antiquity. Although such a long history may suggest archaic traditions, an old industry does not mean old methods!

In the eyes of the general public, the mining industry may not appear especially innovative. Its budget for research and development is on the low side compared to investments in the fields of biotechnology or communications, and even industry insiders are self-critical in this respect.

But the reality is entirely different. Mining has always been a source of innovation, consistently striving for better efficiency, safety, and environmental and social integration, often in difficult circumstances. The challenge is considerable: by definition, mines tap into non-renewable resources hidden below the Earth's surface where unknown and inhospitable conditions hinder exploration and extraction.

This publication draws attention to the innovative character of the mining industry by documenting and illustrating one hundred recent innovations originating from or relevant to the Québec mining industry, from initial exploration to final rehabilitation, which touch on many areas of science and technology.

What is innovation?
As Jacques Ménard, president of BMO Financial Group, pointed out during a presentation to the Canadian Club of Montreal on 28 February 2011, "Productivity is not working harder but working smarter, being better organized and using better tools. One word sums this up: innovation." Simply put, innovation can be defined as a new idea that works (Mulgan, 2007). Innovation is thus the result of an idea that meets a need. Technological innovation involves creating new products and improving existing ones, as well as optimizing production and adopting the latest advances. Innovation differs from discovery or invention in that it fundamentally targets the application aspect.

Innovation is not just technological, however; it can also be social, in which case the needs of society drive the technological advances. The most pertinent example today would be innovations in the field of environmental conservation, which stem mostly from the growth of the green movement over the last thirty years.

A description of our research methodology precedes a brief history of innovations in the mining industry.

RESEARCH METHODOLOGY

Our search for innovations in the mining industry drew on a vast wealth of literature from the world's principal mining regions (Canada, Australia, the United States, Europe, South Africa, Chile), as well as information gleaned from our many meetings with innovators on the Québec mining scene, particularly in the Abitibi region.

In addition to academic journals, the following sources provided information: Mining Association of Canada, Canadian Mining Innovation Council, Canadian Mining Journal, Australian Mining Association, CSST, Groupe MISA, MineCan, CANMET, CONSOREM, CIM, DIVEX, NORCAT, NSERC-Polytechnique-UQAT Industrial Chair, Gecamin (Chile), the UQAT-UQAM Chair in Mining Entrepreneurship, MRNF, and numerous mineral exploration and mining companies.

Most of the innovations presented in this publication have emerged over the last ten years. Some of the less recent — those developed during the last couple of decades — are also included because they represent groundbreaking contributions to the industry that undergo continuous improvement. Finally, a few innovations dating back more than twenty years, mainly geophysical methods, were also deemed worthy of mention, having greatly benefited from a number of technological breakthroughs over the past decade. Other selection criteria included the following:

—THE INNOVATION MUST IMPROVE PERFORMANCE;

—THE INNOVATION MUST BE USEFUL TO THE QUÉBEC INDUSTRY;

—THE INNOVATION MUST CURRENTLY BE IN USE OR SOON TO BE USED BY THE INDUSTRY.

Many of the innovations fit into broader categories, for example, signal processing, aerospace technologies, communications, new materials, etc. The world of mining innovation does not operate in a vacuum: technological advances are constantly shared with other industrial fields, the latest ideas and tools exchanged, and new solutions presented to society. Although innovations come in various forms, from concepts to applications, we have favoured the more practical ones in this book, especially those with a strong technological character that come close to true inventions and have wide public appeal.

In addition to the one hundred innovations presented here, other, more conceptual, innovations have profoundly affected the approach of the mining industry. Looking at how the types of minerals targeted by the exploration and mining industry evolve in response to societal needs, technological revolutions, and market values for raw materials is a prime example. Québec is expected to produce, in a few years, diamonds, lithium, and vanadium – all new commodities for the province.

Concepts also play a pivotal role in the development of mining methods. A recent survey of exploration geologists (Jébrak, 2010) revealed that ore deposit models, whether descriptive or genetic, were of critical importance during the past ten years. As a case in point, the realization that low-grade, high-tonnage gold deposits occur in association with granite porphyries led directly to the successful development of Osisko’s mine in Malartic in the Abitibi region. Furthermore, the concept of a "green mine" (or a "zero footprint mine"), notably advanced by Natural Resources Canada in particular, will be of significant importance in the coming years because it encourages a thorough review of all aspects of mining in terms of its environmental impact. These conceptual innovations can be conveyed to the public only through an in-depth introduction to the challenges and issues faced by the mining industry.

The mining cycle can be divided into three stages: exploration, extraction, and rehabilitation (or remediation). The aspect of ore transformation is not addressed here.

MINERAL DEVELOPMENT CYCLE. THE STAGES OF A MINING CYCLE:

—PERMITTING
—EXPLORATION
—FEASIBILITY AND IMPACT STUDIES

—CONSTRUCTION
—EXTRACTION

—CLOSURE
—REMEDIATION AND MONITORING


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EXPLORATION

In the mining industry, the first step is to discover a deposit. Exploration is a combination of all the activities leading to the discovery of an economically viable deposit before engaging in any mining activities. All of the mineral deposit discoveries in Québec over the last decade arose from the application of new concepts and technologies.

Exploration comprises many components:

— Cutting-edge research in universities and research centres

— Obtaining permits

— True exploration work, which aims to prove the existence of a mineral resource using geological, geochemical, and geophysical analyses; it typically begins as surface exploration, followed by underground exploration, mainly through drilling, which plays a crucial role in deposit definition

— Resource estimates and feasibility studies, carried out using computer modelling and geostatistical software

Innovation plays a central role in exploration. Periods of marked acceleration in deposit discovery and mining production correlate with the introduction of new methods (Lulin, 1990). A good example is the debut of airborne geophysics in the 1970s, which led to a boom in new discoveries across northern Canada.

Here, the distinction has been made between the strategic exploration phase and the deposit definition (or tactical exploration) stage.

MINING

Mining is the extraction of minerals from the ground, followed by processing and beneficiation (concentration) in facilities located on or near the mine site. Modern mines are almost completely mechanized, and the operations involve a set of techniques that are specific to the type of mine (underground mines work very differently than open-pit mines or quarries).

Underground ore is accessed by shafts, ramps, and horizontal and vertical tunnels known as drifts and stopes, whereas quarrying relies on classic techniques often used in public works. In both quarries and underground environments, ore recovery depends on ground stability, and, consequently, on the field of rock mechanics. Mining begins by blasting apart the ore, accomplished through explosives and fragmentation technologies. Several different mining methods have been developed to extract large volumes of ore at depth. Once extracted, this ore is loaded and hauled up to the surface. Mine personnel must use a variety of specialized equipment for groundwater management (dewatering), ventilation (aeration), lighting, communications, etc.

Once removed from the mine, the ore must undergo a series of transformations. In the case of metal mines, there are two main steps: mineralogical processing, which extracts the minerals of interest through crushing, grinding, sorting, and washing-drying processes followed by metallurgical processing, which extracts the metals of interest from those minerals through melting, electrometallurgy, or hydrometallurgy techniques. Innovations in this sector have played a key role in the evolution of the mining industry, rendering it economical to mine increasingly low-grade ore or rock in which the metals are particularly difficult to extract. For example, the rise of the late nineteenth-century copper industry in the American West was due to the successful technological crossover of electrolysis and Bessemer ovens. When copper prices collapsed in the 1970s, the copper industry survived by implementing the newly developed SX-EW extraction-by-solvent process.

Most of the innovations presented here pertain to the mining stage. For clarity, mining-related innovations are classified under the following themes: ore extraction (drilling and blasting), transport and communications, ore processing and safety.


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REHABILITATION

Over the last fifteen years, mine-site rehabilitation has been integrated into the early planning process, even preceding the start of mining operations. Rehabilitation management is now an ongoing consideration throughout the mine's lifecycle, from both a technical and financial perspective. When a deposit's resources are depleted or no longer economically viable, the mine ceases operations.

At this point, the final stage of site rehabilitation (remediation) begins. The aim is to remove or neutralize contaminants from the site so that it may begin a new life in a non-mining capacity. A considerable number of studies must be carried out to accomplish this, and the findings can also be used to restore orphaned (abandoned) mine sites inherited from another era.

Mine-site rehabilitation comprises several steps defined according to the landscape, the mine's geochemical and environmental impacts (on water and biological systems), and the social impacts. Rehabilitation may include activities specifically related to storage, burial, demolition, inerting, infilling, and waste management. Decontaminating waste rock and polluted soil is an important aspect of the rehabilitation process.

A BRIEF HISTORY OF MINING INNOVATIONS

Industrial innovation was born largely from the mining sector, and history is full of noteworthy examples. Environmental regulations can be traced back to Spain's Almadén mercury mine in the seventeenth century. Not long after, Thomas Newcomen designed the first steam engine in the early eighteenth century to draw water from tin mines in Cornwall. Setting out to improve the limited effectiveness of Newcomen's pump, James Watt, a technician at the University of Glasgow, invented the condensation chamber, thereby making a fortune with his friend Matthew Boulton. In 1784, the two associates patented the steam locomotive to move mined ore, and when the first locomotives hit the market twenty years later, they quickly left the underground coal mines for a breath of fresh air! Boulton and Watt's mining invention was even used to automate the manufacture of textiles and thus revolutionize the clothing industry.

The safety lamp made its debut in 1815, only slightly before the North American mining booms for copper in Michigan (1840–1843) and for gold in California (1848) and Colorado (1858). In 1867, Alfred Nobel invented dynamite, which also found an early application in the world of mining!

The expanding market for metals at the beginning of the twentieth century required new production and processing methods, paving the way for advances in the field of metallurgy. Electrolytic processes to refine aluminum and, later, copper were perfected just twenty years after the advent of Gramme's dynamo; these processes are still in use today to purify metals. Flotation, the most effective method of separating minerals from the gangue, or the barren parts of mined ore, emerged in Broken Hill, Australia, in 1903, and rapidly spread throughout the world.

Mining techniques are the Formula-One race cars of the industry: devised for a difficult and competitive world, they are at the cutting edge of new ideas and represent the testing ground for larger-scale applications.

INNOVATIONS IN EXPLORATION

INVERSION ALGORITHMS

Geophysics is traditionally used to predict the position of a mineralized body by seeking out, for example, anomalies in the magnetic field, the gravitational field, or electrical conductivity. The new inversion algorithms allow geophysical data to be used in a different way. By first establishing the geophysical properties of rocks and then measuring their geophysical signatures in the field, it is possible to generate three-dimensional models of their potential mineralization and the surrounding geological environment. Inversion algorithms have led to many discoveries of copper and gold deposits.

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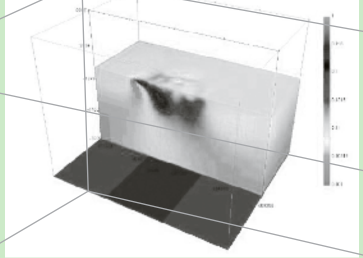

Results of an inversion of magnetotelluric geophysical data (C. Farquharson). Source: www.mun.ca

ICP-MS ANALYSES

Mineral exploration requires the accurate, reliable, and rapid analysis of rocks and minerals (expressed as percentages or as grams of metal per metric ton of rock). Advances in the 1990s in the field of spectrometric analysis led to the development of inductively coupled plasma mass spectrometry, which can simultaneously analyze dozens of elements with great accuracy. The technique is also capable of measuring certain metals down to a level of milligrams per metric ton.

ICP-MS increases efficiency through multiple analyses and lowers costs. It is used at all stages of the mining industry, from exploration to remediation.

02

ICP-MS spectrometer from Ametek. Source: www.directindustry.com

PORTABLE ANALYZER

This tool identifies the chemical elements comprising a rock's surface using X-rays. It provides on-the-spot results, which helps avoid unnecessary sampling and analytical testing at a laboratory. This time-saving device thereby reduces the environmental impact of exploration.

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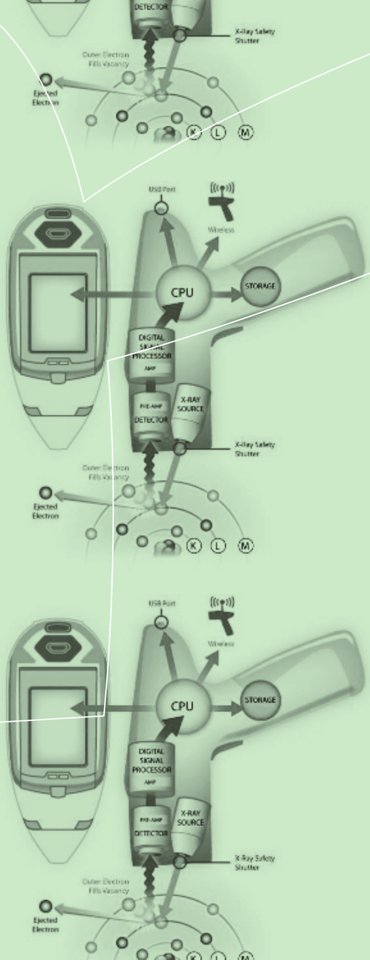
Source: www.niton.com



AVIRIS

The AVIRIS airborne sensor uses hyperspectral measurements, that is, it measures hundreds of spectral bands, whereas ordinary satellites measure only a few at a time (a spectral band refers to a part of the spectrum of electromagnetic radiation). By combining these spectral bands, it becomes possible to identify not only different types of vegetation, but also the nature of the minerals present. This process can be used to directly produce rock maps in areas lacking ground cover (cold or hot desert environments). The first such satellite was launched in 1997 (Lewis Hyperspectral Imager, HIS, NASA). AVIRIS is a spectrometer that covers the range between 0.400 and 2.500 nm, divided into 224 contiguous spectral bands.

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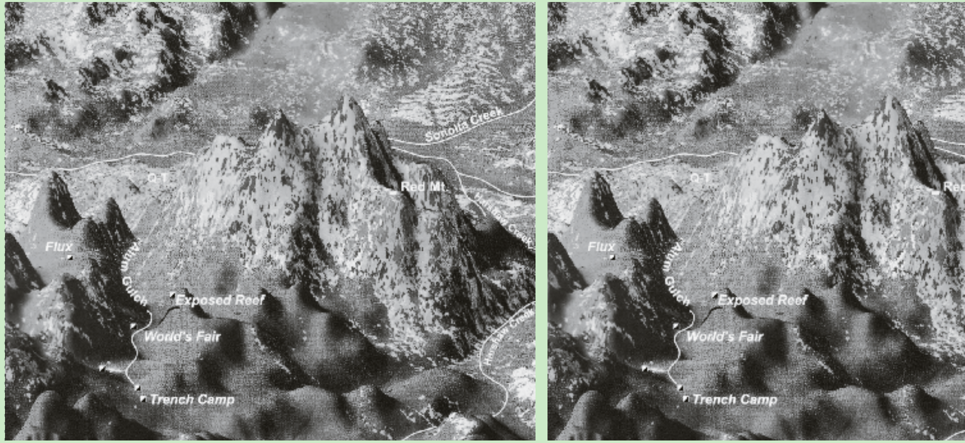
Aviris satellite, Red Mountains, Berger et al., 2003



MASS BALANCE

Deposits of copper, zinc, and gold were produced by circulating metal-laden hot water. As this water passed through rocks, it altered and transformed them, dissolving some minerals and forming others. This process may either increase or decrease the density of the rock. Since the zone containing the transformed rocks is often much larger than the deposit itself, we can explore by looking for these alteration zones.

A new quantitative method developed by CONSOREM applies sophisticated data processing to analytical results in order to calculate the quantities of chemical elements that were added to or removed from each rock sample, thereby evaluating their likely distance from the site of potential mineralization.

05

GEOGRAPHIC INFORMATION SYSTEMS (GIS)

Geographic information systems (GIS) revolutionized exploration practices by organizing and presenting spatially referenced numerical data on a computer. The offices of exploration companies were once covered in maps at different scales; today, they are filled with computer screens on which geologists compile their information using geographic information systems like MapInfo and ArcGIS.

Some GIS applications are specifically developed to represent and process particular types of geological, geochemical, and geophysical information.

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PALEOSTRESS MAPS

Finding a gold-vein ore deposit is no easy task. Research over the past few years, particularly in Australia, has revealed that a large number of these deposits represent fault zones that were active during seismic aftershocks along major geological faults, like the Cadillac Fault in the Abitibi region.

Software programs are now available to predict the location of these deposits using paleostress models of the earth's crust. Still at the research stage, the software can identify the most favourable areas, thus reducing the size of the region to cover during exploration.

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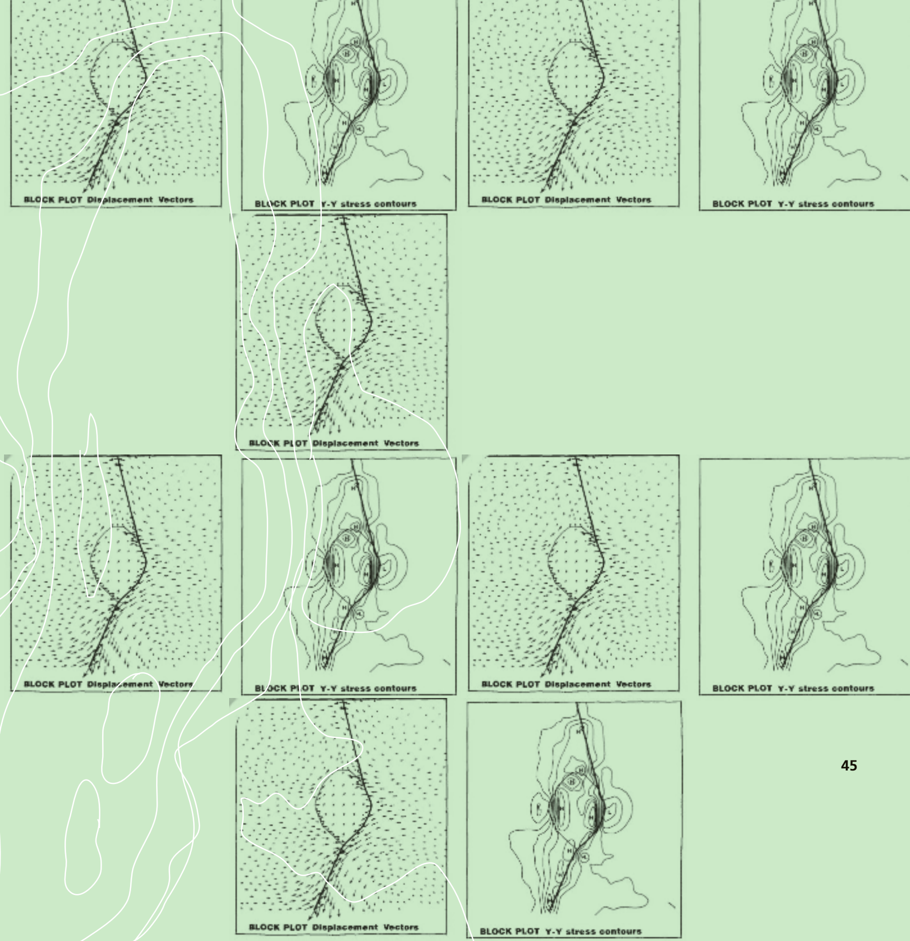

Mapping of a pressure field around a rigid body; UDEC modelling, Ridley, 1990

PREDICTIVE MAPS

The Ministère des Ressources naturelles et de la Faune du Québec (MRNF) and CONSOREM are developing new mapping products that help predict the location of potential mineralization based on the locations of known mineralization. This new kind of map relies on advances in the field of artificial intelligence, particularly neural networks and fuzzy logic. Both organizations make public the locations of identified exploration targets that share strong geological and geochemical similarities to known mineralized examples.

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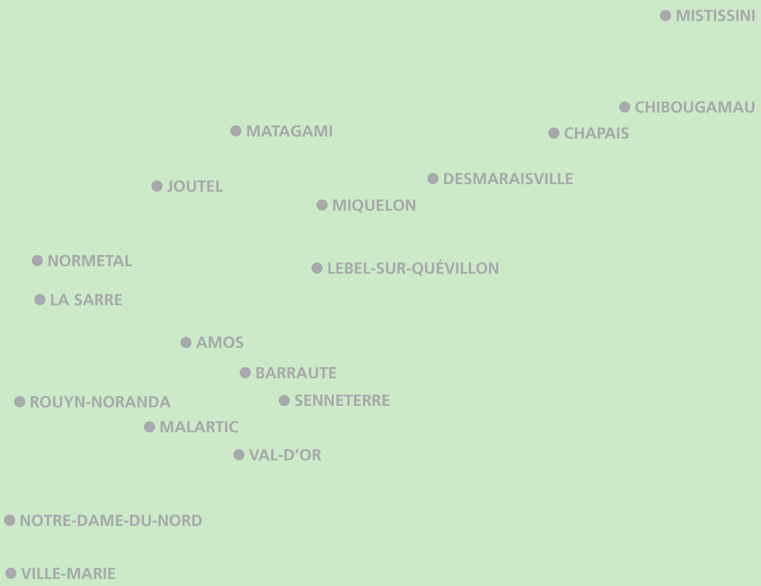
Predictive mineral map for the Abitibi region; MRNF, 2005



MAP DESIGNATION

The Ministère des Ressources naturelles et de la Faune du Québec developed a computer application that allows mining titles (mineral claims) to be acquired online via its website. Québec is one of the only places in the world to use this technology.

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Source: www.mrnf.gouv.qc.ca/mines

GAS GEOCHEMISTRY

Mineral deposits are often buried deep below the surface. Despite the great depths involved, the oxidation of a deposit's sulphide minerals will release gaseous substances that can be detected at the surface by taking gas samples from soil or down drill holes. The method can detect several different gases if present in sufficient amounts: mercury, oxygen, CO_2, and radon. The nature and concentration of these gases provide clues about which minerals occur at depth, and, as a result, whether an orebody may be present.

The method is currently the subject of methodological testing and has already been used in the field of geothermics.

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Pump at the bottom of a drill hole with a nitrogen tank to force deep gases to the surface. Diamond exploration in the Kirkland Lake region of Ontario (Leybourne, 2007). Source: gsc.nrcan.gc.ca

MMI™ GEOCHEMISTRY

Geochemistry can be used to detect metals in surface materials and consequently predict the presence of underlying orebodies. This was once difficult to impossible if the mineralization was masked by barren cover such as sand. But in the mid-1990s, it was demonstrated that some metals are released from underground mineralization and travel toward the surface in water or gases, becoming trapped on mineral grains in the unconsolidated surface sediments. The new MMI™ method takes advantage of this characteristic, making it possible to determine what lies below by analyzing surface materials. Weak acids are used to attack the outer layer of the mineral grains in the surface cover, thereby obtaining clues to potential buried mineralization.

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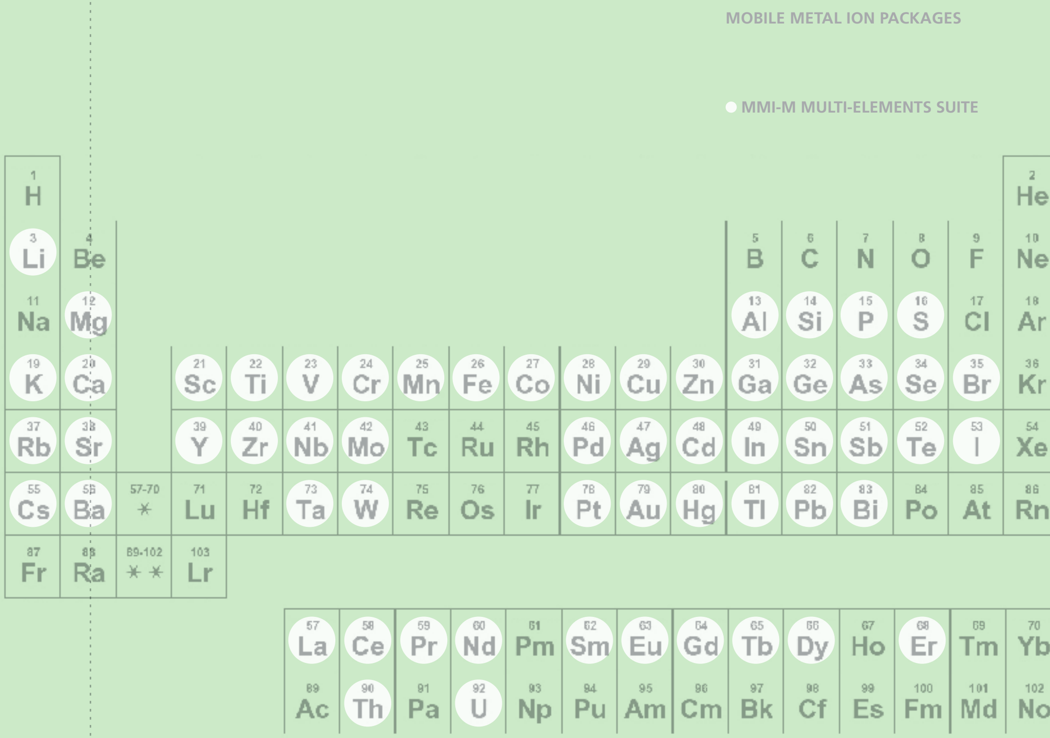
Theoretical model showing how MMI geochemical anomalies form at the surface. Source: www.geochem.sgs.com



GEOPOSITIONING

The global positioning system (GPS), which uses satellite signals to determine location, provides fast and accurate information (how fast and accurate depends on the instrument used), and dramatically facilitates field work and mapping projects. It has revolutionized exploration by allowing the user to pinpoint an observation site quickly and accurately. The use of GPS instruments avoids systematic line-cutting through the forest to create conventional location grids, thereby reducing the environmental impact of exploration work.

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www.trimble.com. Source: www.clubic.com

AIRBORNE GRAVIMETRY

Gravimetry is a technique that detects minute variations in the Earth's gravitational field. Mineralized bodies are denser than surrounding rock, causing a slight warp in the gravitational field that can be detected by a highly sensitive instrument called a gravimeter. This approach relies on having highly accurate topographic information, down to the nearest centimetre, in order to interpret the measurements successfully.

Advances in geopositioning and signal detection now allow gravimetric measurements to be made from airplanes precisely located in space. Airborne gravimetry significantly lowers acquisition costs and should revolutionize mining exploration in the years to come.

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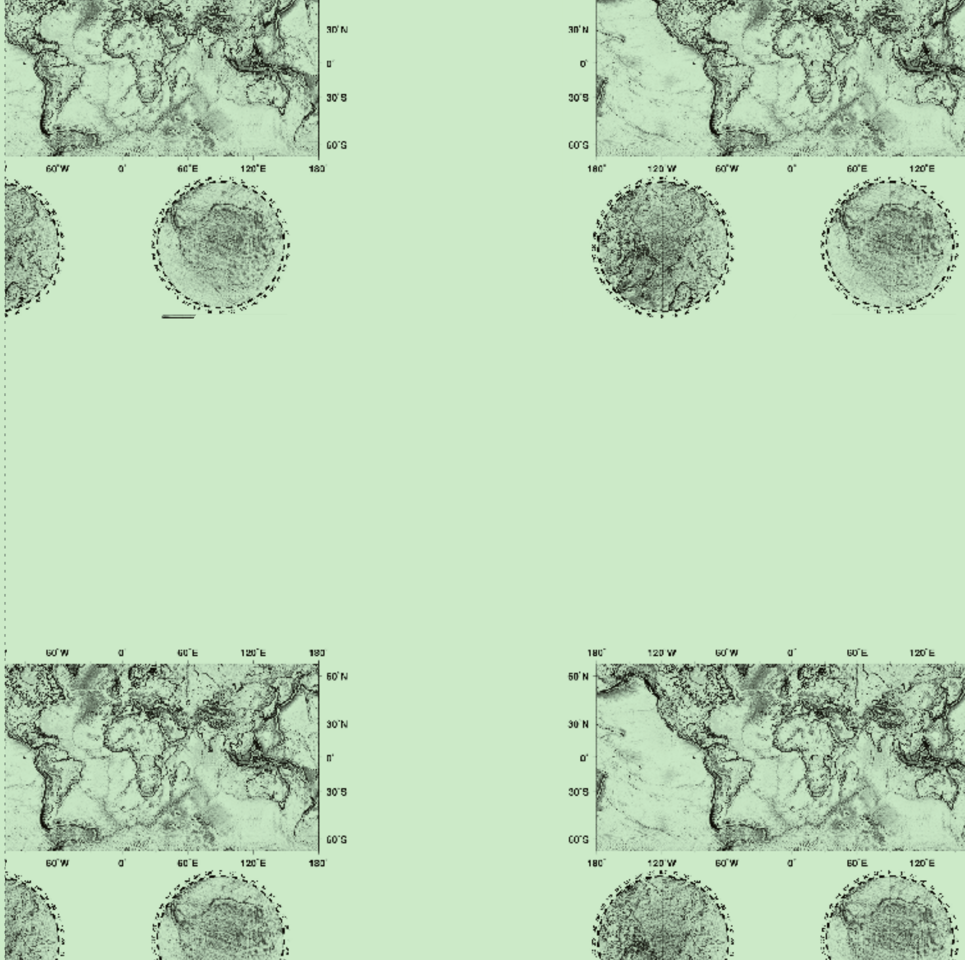

Ground and airborne gravimetric images, FUGRO. Source: www.fugroairborne.com

INFINITEM

Developed for the exploration of base metals, the InfiniTEM geophysical method measures the in-ground circulation of electromagnetic waves in the field. It can detect metallic sulphide deposits up to 1 km below the surface.

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Source: www.legroupemisa.com. www.ageophysics.com.

LIDAR

Lasers can be used to map the topography of a region accurately. Mounted on an airplane, a LIDAR (Light Detection and Ranging) or ALTM (Airborne Laser Terrain Mapper) survey can determine topography with an altimetric precision between 5 and 20 cm. Two GPS devices are used to calculate and correct the location of the instrument: one on the aircraft and the other at a fixed location on the ground. This type of mapping is both faster and more accurate than conventional means.

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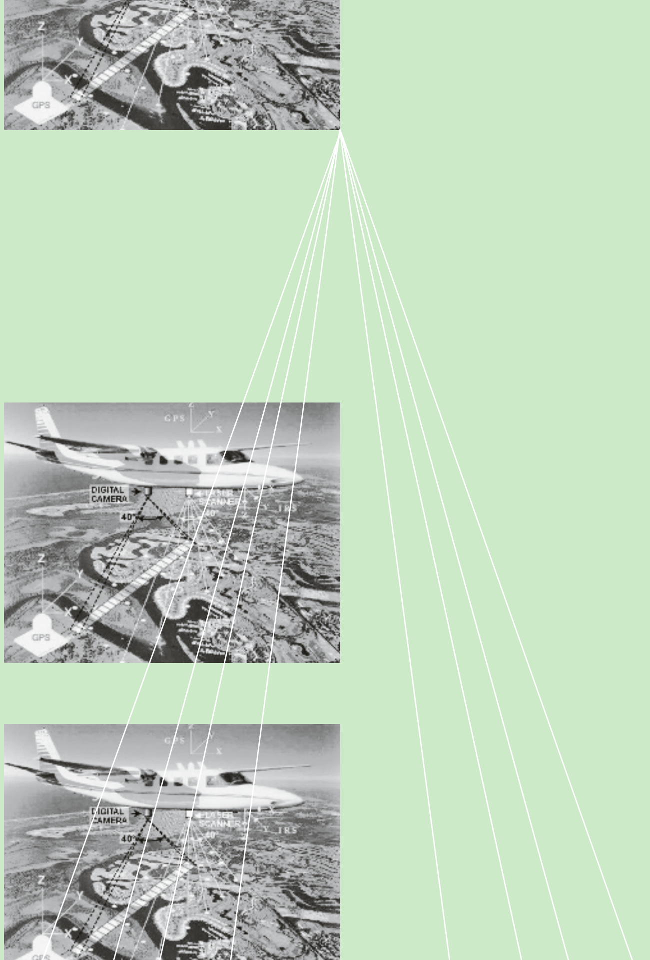

Airplane performing a LIDAR survey. Source: africansurveyors.com

MEGATEM – AIRBORNE ELECTROMAGNETIC SURVEYS

Airborne electromagnetic surveys have been used for half a century in mineral exploration. Nevertheless, technological advances in the fields of geophysics and electronic data processing have led to the development of much more sensitive instruments capable of detecting even deeper exploration targets, down to 250 m below the surface in some areas.

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Capacity for deep subsurface exploration using the MEGATEM system, data from Fugro and Virginia

INDICATOR MINERALS

Diamond exploration relies on finding so-called indicator minerals that are naturally associated with diamonds, but present in much greater quantities (typically, garnet, chromite, and ilmenite). These minerals thus act as natural “pathfinders.”
The method is based on collecting sandy samples from river or glacial deposits and then extracting the densest minerals. The approach has also been successfully used to explore for other types of mineralization, such as metamorphosed lead-zinc bodies or gold porphyry deposits.

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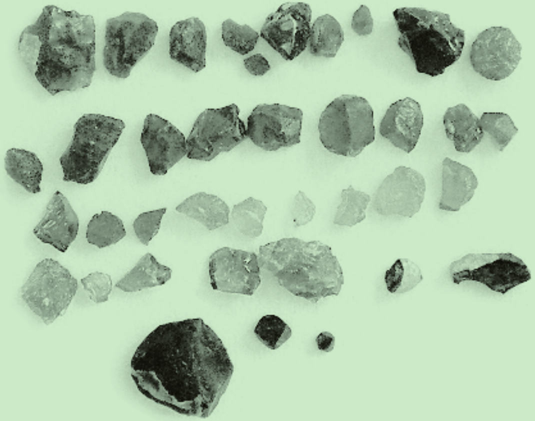

Sample of diamond indicator minerals; the size of each grain is on the order of millimetres. Source: www.odm.ca

CENTIMETRE-PRECISION SATELLITES

For more than thirty years, satellite imagery has been used to observe vast tracts of land, some of which are very difficult to access from the ground.

Recent technological advances provide optical satellites with much greater accuracy, even down to less than a metre (QuickBird). These satellites have consequently become much more powerful and can be used to better assess areas that have been targeted for exploration.

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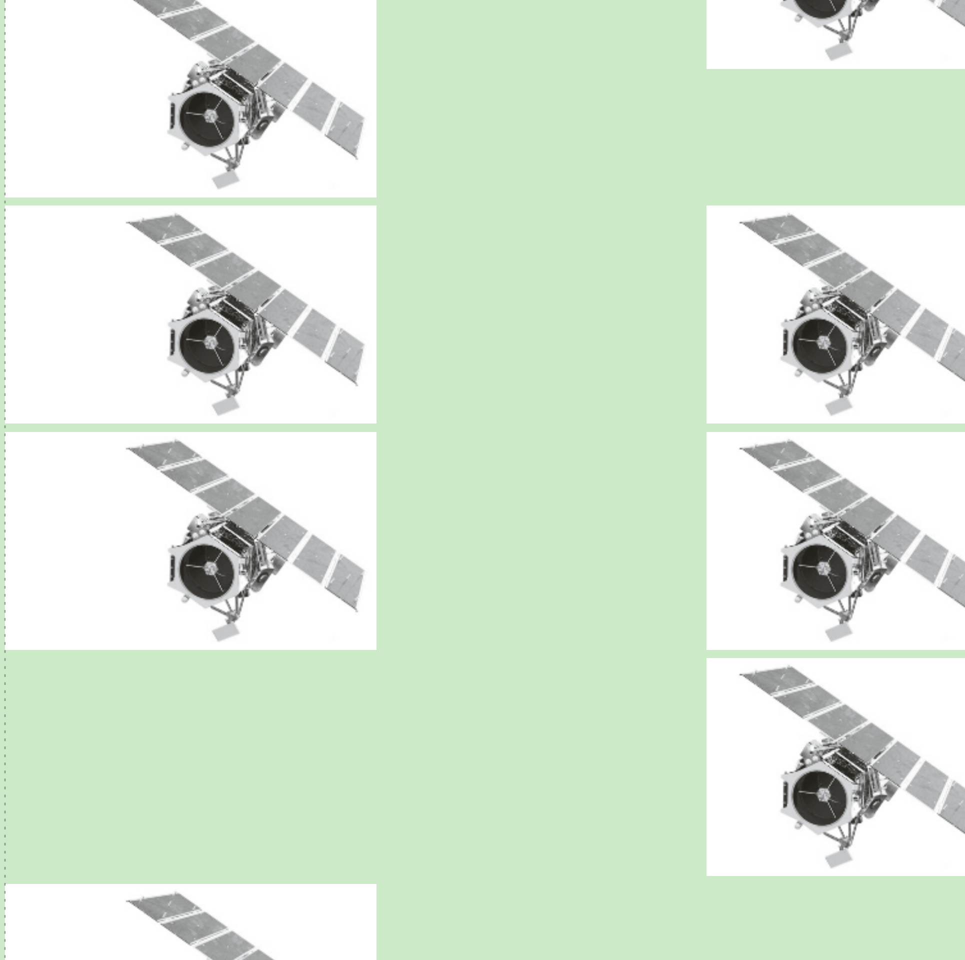
Source: news.satimagingcorp.com



LOW-IMPACT SEISMICS

The principle behind seismic geophysical methods consists of creating a shock at the earth’s surface, using a hammer or explosion, which generates a signal that is received by a wave detection system (specialized microphones or geophones). Analyzing the responses determines the nature of the rocky subsurface.

Explosions can be harmful to the environment, particularly aquatic systems. Improvements in signal capture and signal processing mean that seismic signals can now be much weaker; these more sensitive instruments need much smaller explosions, resulting in less damage to the environment. The term “low-impact seismic” describes a number of less-intrusive shock-emission methods and lighter geophones.

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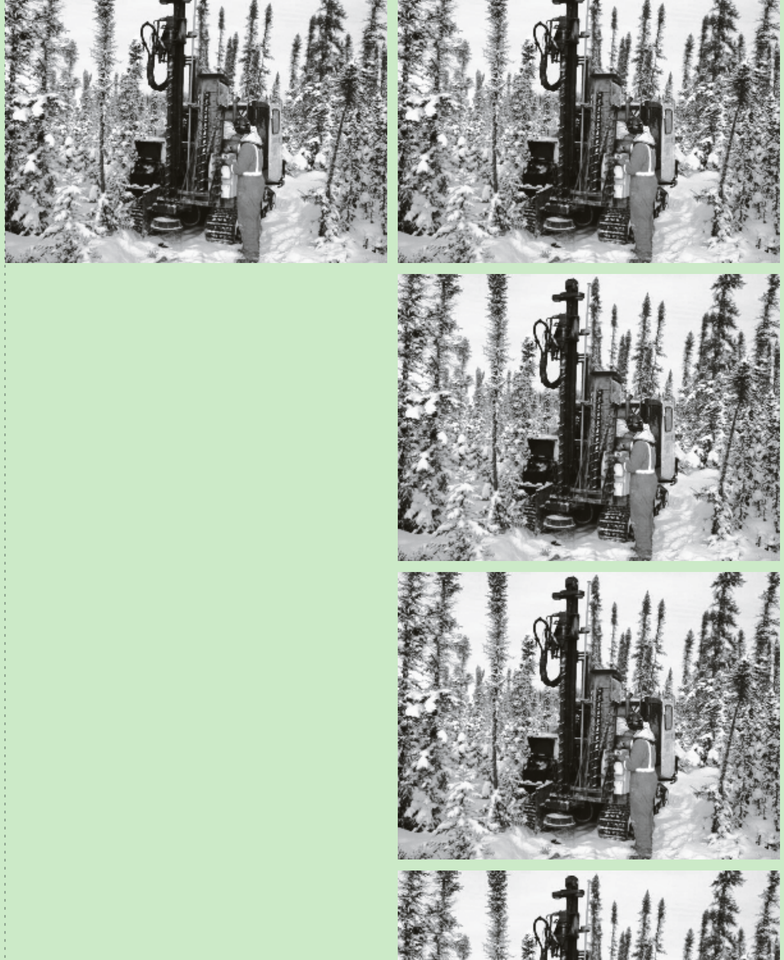

An ecodrill, or small drill rig, used to install seismic explosives. Source: www.spethdrilling.com

MULTIPARAMETER PROBE

In mineral exploration, it is important to quickly determine the geophysical properties of the rocks as well as their magnetic characteristics and their ability to transmit electrical currents (conductivity). A multiparameter probe, such as the MPP EM2S+ model, can instantly measure the properties of the sulphide minerals contained in samples of drill core or in rock samples collected at the surface. The probe measures magnetic susceptibility as well as the relative and absolute conductivity values.

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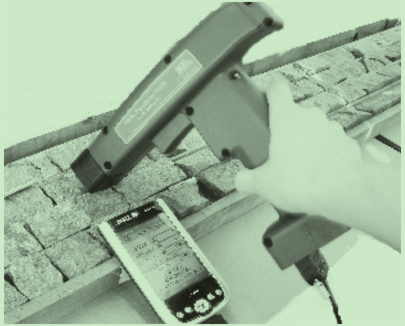
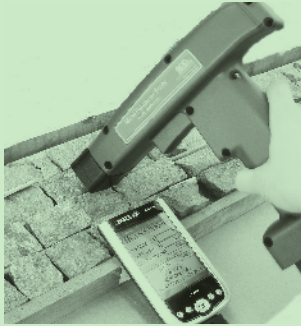
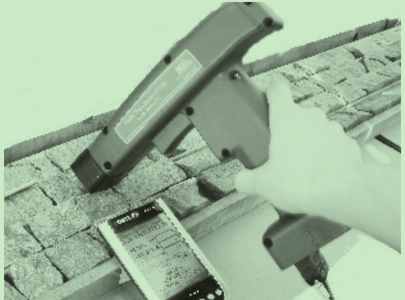
MPP EM2S+ probe from Instrumentation GDD. Source: www.gddinstrumentation.com







PORTABLE SPECTROMETRY

The term “spectrometer” covers a broad range of measuring devices that can analyze substances using different wavelengths. A new type of spectrometer uses the shortwave infrared range of the electromagnetic spectrum. The instrument can recognize different clay and mica minerals, which are widely used as indicator minerals in the search of copper, gold, and uranium. The device allows the user to identify an entire assemblage of minerals in one go and has much greater sensitivity than the human eye.

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Spectrometer. Source: www.pimausa.com

INNOVATIONS IN ORE DEPOSIT DEFINITION

STRUCTURAL LOGS

Quantifying the fractures down a borehole provides a better understanding of the geological environment and a clearer assessment of the mechanical properties of the rocks. It is now possible to measure many parameters directly from inside the borehole, without extracting the rock core, by using optical, sonic, or infrared microcameras inserted down the hole. This technology also has applications in the field of civil engineering, notably for hydroelectric dams, where the method is used to ensure proper dam design.

22

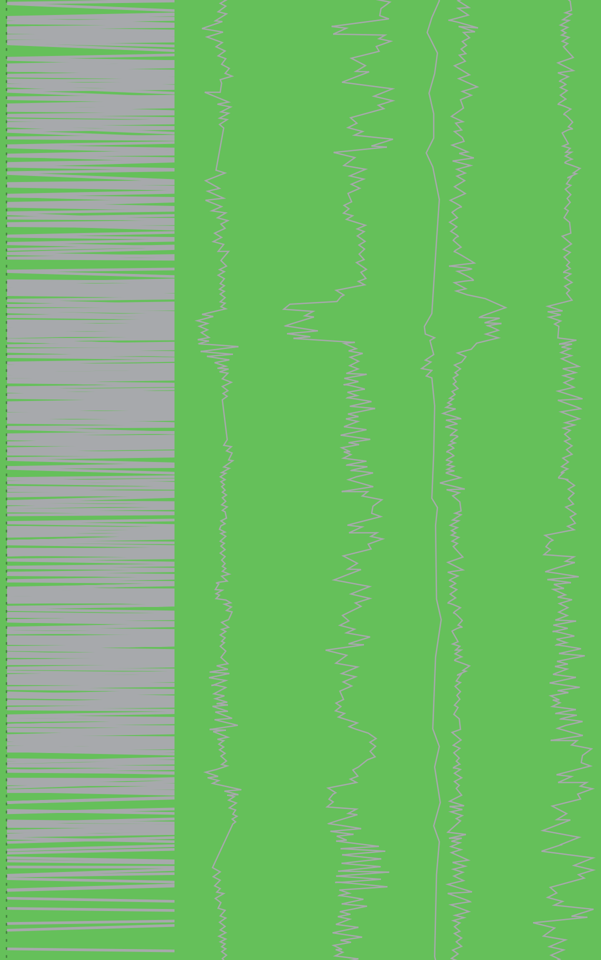


Image from a structural log in sandstone, SEMM Logging

CASING EXTRACTOR

To carry out geophysical surveys, drillers must drive metal pipes known as casing into the ground. Each pipe, either 1.20 or 1.82 m long, must be pulled out afterwards. The extractor is a hook specially designed to withdraw the metal casing from a borehole with a minimum of effort.

23

GEOMETALLURGY

It is desirable to know as quickly as possible the optimal characteristics for processing ore from a given deposit. Geometallurgy is a newly emerging field of characterization that reduces the risks related to ore processing at an early stage.

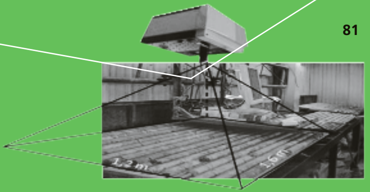
24

HYPERSPECTRAL IMAGER

Every mineral can be characterized by its spectral colour or range. The hyperspectral imager used for mineralogical mapping in mining and exploration is capable of characterizing every mineral along a borehole. The device, also known as Core Mapper, takes an image for every 2 nm of the visible and near-infrared spectral range, covering wavelengths from 400 to 1,000 nm. The 300 monochromatic images are then compiled. The result is very detailed drill core mapping.

25

Source: legroupemisa.com

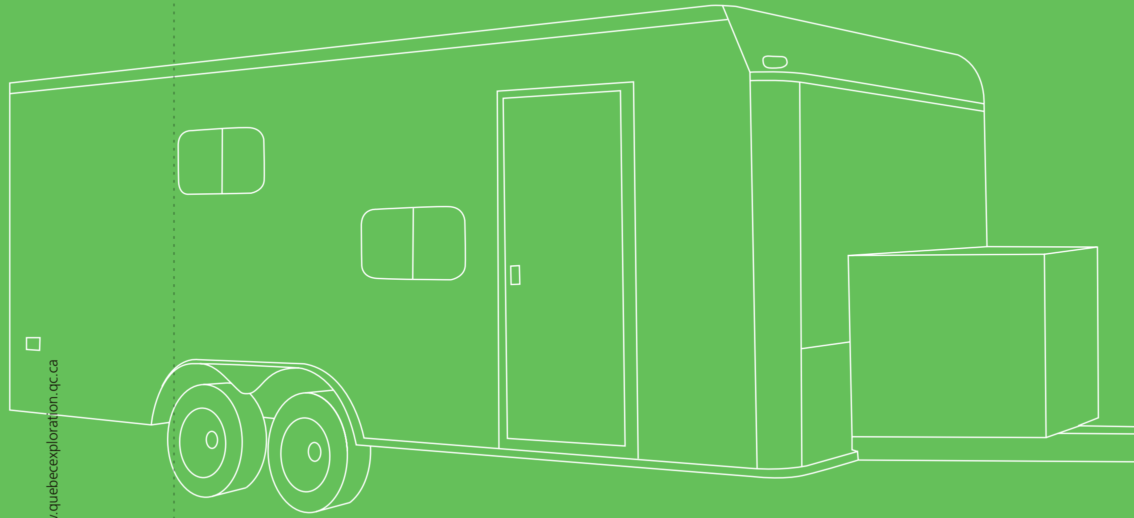


MOBILE LABORATORY

LAMROC, a mobile multiparameter drill core analysis laboratory, determines the physical, mineralogical, and chemical characteristics of rocks and minerals. It is housed in a modified trailer pulled by a 4X4 vehicle that can be driven to a core storage site. The automated system provides continuous measurements that would be impossible using the naked eye.

26

Source: www.quebecexploration.qc.ca



DENSITY MEASUREMENTS

The Bulk Density Weigh Unit (BDWU) determines the density of drill core samples. This mechanized system provides drill core density measurements with very little manual handling. It is also connected to a computer, resulting in fast and efficient data entry.

27

VERSAGUARD

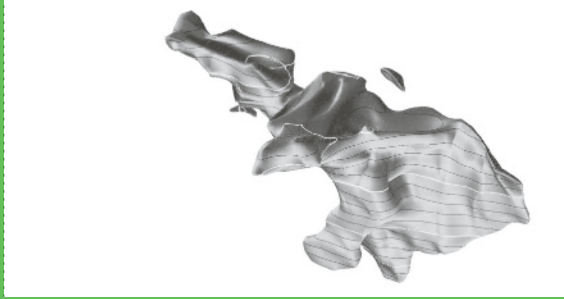
Versaguard is a barricade specially designed to block access to the rotating parts of a drill rig. These easy-to-use barricades offer excellent protection for drill rig operators.

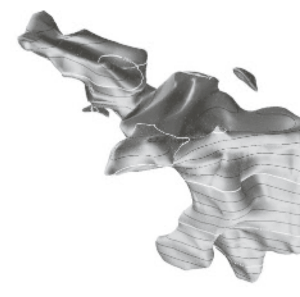
28

3-D GEOLOGICAL MODEL

Many software programs have emerged during the past decade to transform drilling or mining databases into 3-D images and data integration platforms that facilitate information management. The 3-D reconstruction of a mineral deposit reveals its shape and size, making it easier to devise an exploration and mining strategy.

29





GoCad geological model of a massive sulphide body (Bonnet and Corriveau, GSC)

CORIENTR CORE ORIENTATION SYSTEM

Drill holes must be positioned with great accuracy. Since a drill's trajectory may deviate significantly from its intended path, it is important to obtain the spatial coordinates of many points along the hole. A down-hole survey probe is a measuring device that determines the orientation of the drill core relative to the bedrock from which it was extracted, or as an absolute orientation in space, in which case a gyroscope is part of the device. This information can be added to a data-integration platform for the purposes of information management and developing three-dimensional models.

30

Source: www.fordia.ca

OWL HEAD ASSEMBLY

Drilling programs are very costly to operate, and analyzing the drill core is paramount to understanding a mineral deposit. The OWL self-lock head assembly is designed for optimal sample recovery thanks to locking and independent latches. This device eliminates the risk of losing core. A piston system keeps the latches in place while they are engaged so they cannot be accidentally retracted.

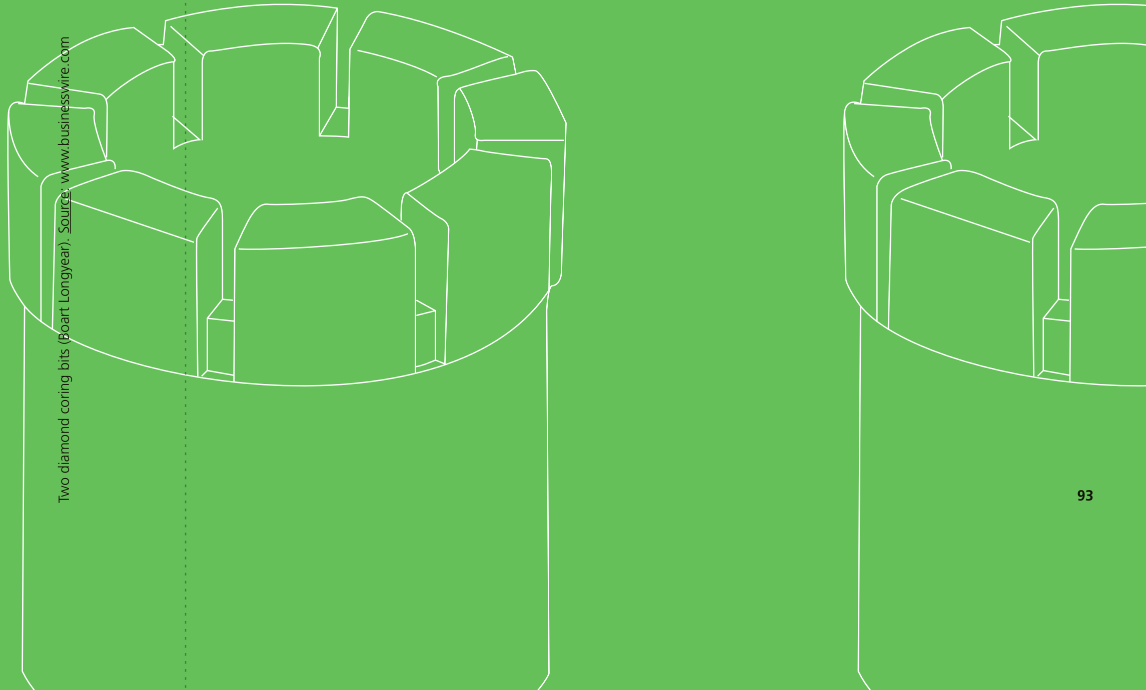
31

Source: www.fordia.ca

CORE BITS

Many different types of core bits have been developed and improved over the years, leading to today's tough, high-performance drill heads that bore more quickly and wear down more slowly. The alloys used in their construction vary greatly and depend on the type of bedrock to be drilled and on the manufacturing company.

32



Two diamond coring bits (Boart Longyear). Source: www.businesswire.com

INNOVATIONS IN ORE EXTRACTION

BLASTING BOX

The role of the blasting box, or firing box, is to ignite explosives. It may include components designed to explode the dynamite sequentially outward from the centre of a mining tunnel. And it is now possible to use an air-pressurized ignition mechanism rather than one that is spring-loaded in order to avoid unexpected explosions.

33

HYBRID BOLT

The hybrid bolt is a combination of the friction bolt and the resin bolt. In deep mines (> 1 km), bolts become deformed by foliation in the rock so that they can no longer follow the rock's movements. The bolts end up breaking and can fail to hold the screens in place. The hybrid bolt solves this problem.

34

BOULDER BUSTER

At some point, masses of rock must be broken down to facilitate their transport. The Boulder Buster simply blows them apart. A small hole is drilled into the rock and filled with water. A breech body is then inserted in the hole, a protective mat placed over the rock, and a cartridge placed in the breech body. The detonator is screwed into the breech body and an explosion is set off. No blasting licence is required to use the device.

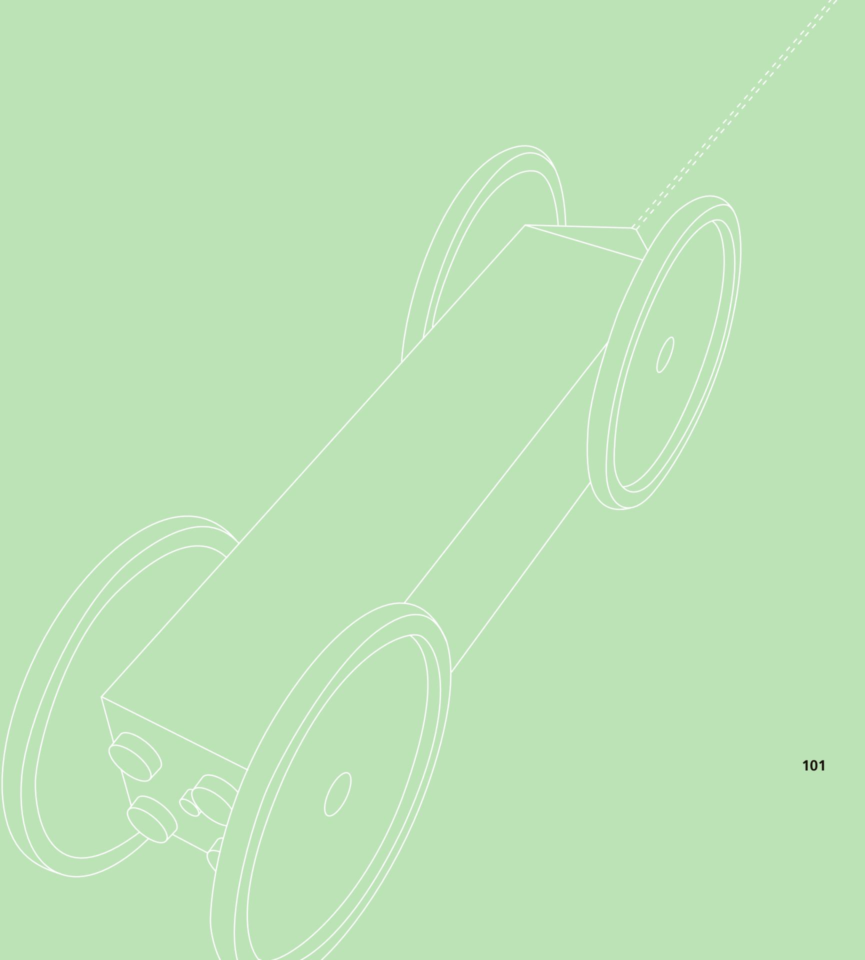
35

Source: www.boulderbuster.co.za

INSPECTION CAMERAS

A wheeled inspection camera is fixed to a rigid wheel-mounted housing and equipped with a forward-facing lighting system to carry out inspections of mine shafts and tunnels.

36



POLYMER DUCTS

For a long time, mines were ventilated through large ducts made of fabric. The use of rigid polymer ducts reduces air friction, thereby improving energy efficiency. Moreover, transport is considerably facilitated by shipping the product as sheets before assembly at the mine.

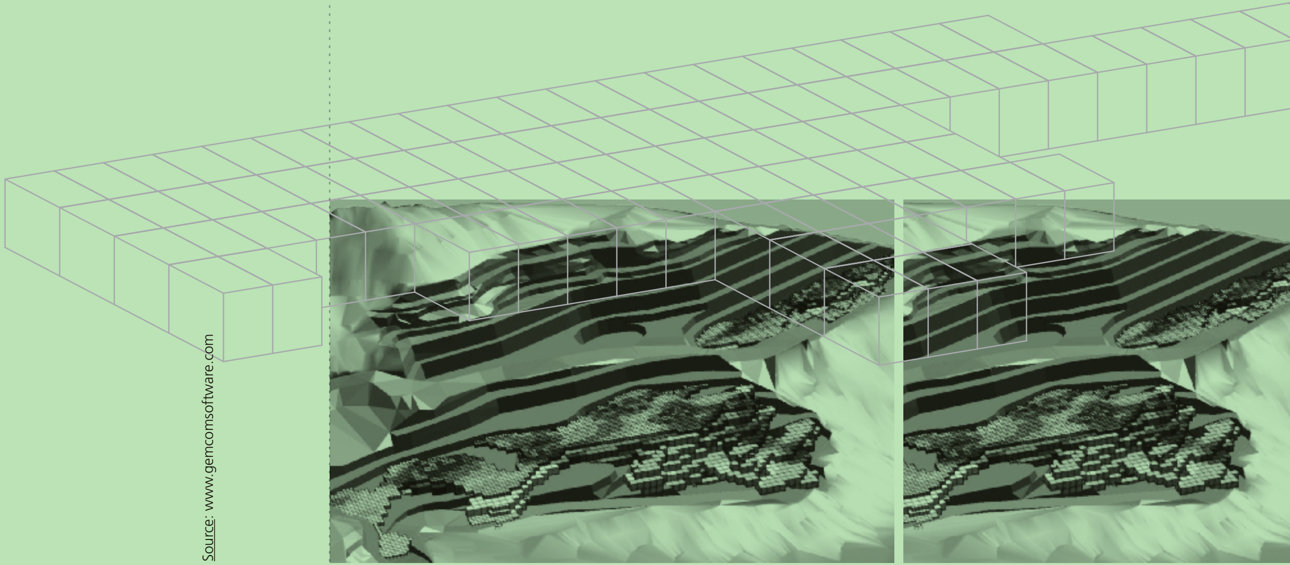
37

Source: http://mecanicad.ca

INTEGRATED DEVELOPMENT

Putting a mine into operation is a complex process during which multiple units must be designed in parallel: the geometry of the mine workings, the volume of the rocks to displace, mining rates, etc.

A number of software programs have been developed to plan and manage all the operational aspects of any type of mine. It is now possible to design a virtual mine before building it using a 3-D model of the mine workings, and to plan the development schedule in advance.



Source: www.gemcomsoftware.com

38

VENTILATION DRILLING

Significant progress has been made in drilling accuracy. It is now possible to drill down to a precise point up to 800 m deep. The effectiveness of the process was demonstrated during the rescue of Chilean miners in 2010. An additional advantage is that the drilled material can be brought up to the surface.

39

LUNAR MODULE

Manning the system control centre for a muck bucket in an underground mine was once a difficult and dangerous job because of its hefty weight (about 175 kg). The lunar module is a prefabricated piece of equipment that can be towed and set up in a new tunnel each time the muck bucket needs to be used. This saves time and improves safety.

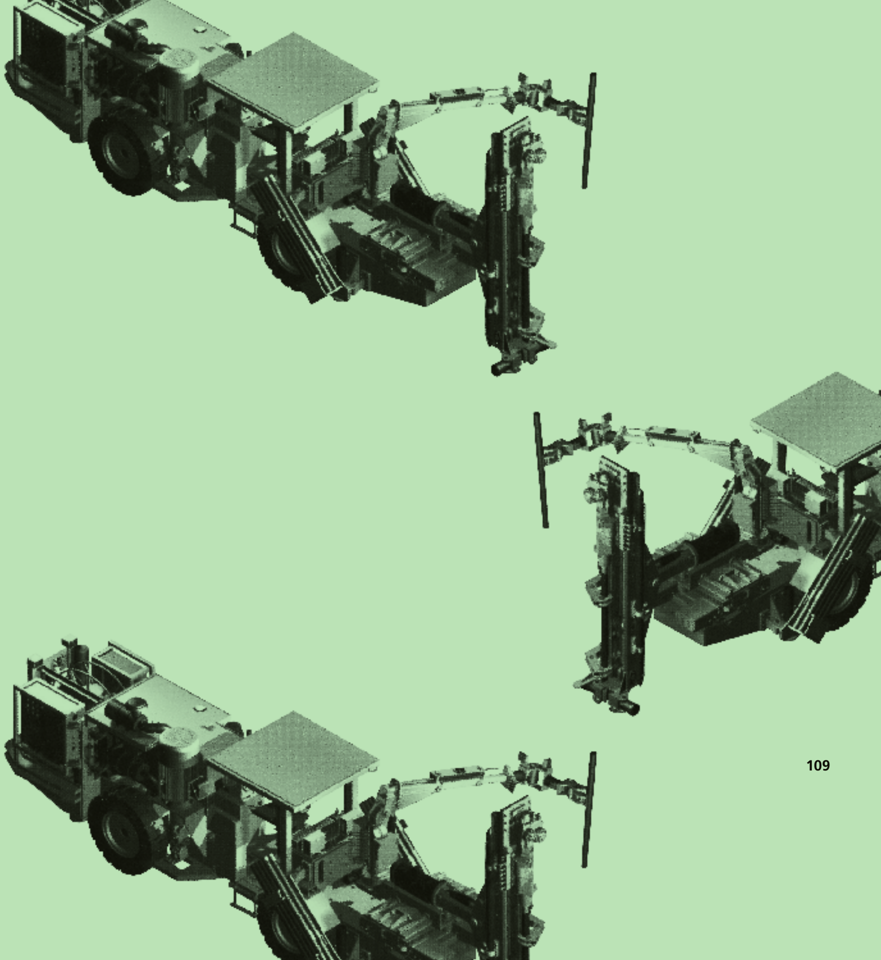
40

MOBILE DRILL

The CMAC SPLH drill is used for production holes and ground support in underground mining, being employed as much for diamond drilling as it is for regular boreholes. The small conveyor makes it easier to access narrow excavations. The positioning table (patented by CMAC-Thyssen) makes for quick manoeuvring.

41

Mobile long-hole drill (CMAC/MTI SPLH). Source: www.cmac-thyssen.com

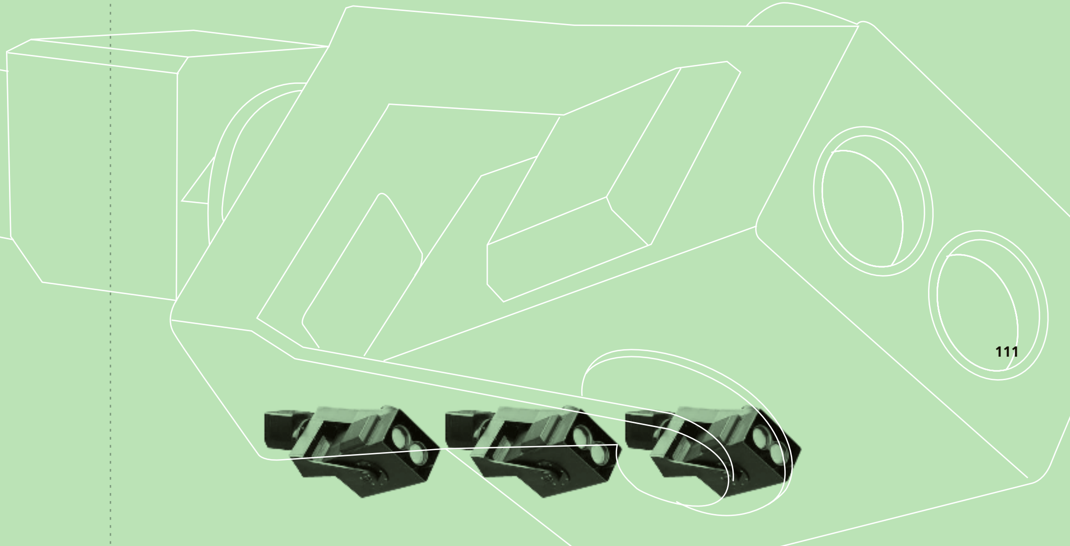


CAVITY MEASURING

Measuring mine cavities is an essential step in underground operations since it supplies information about the shape and volume of the rock mass that was extracted. Optech's Cavity Monitoring System (CMS) provides the 3-D geometry of a mine tunnel using an optical telemetry device that is rugged enough to work in a mine.

42

Source: www.geomon.it

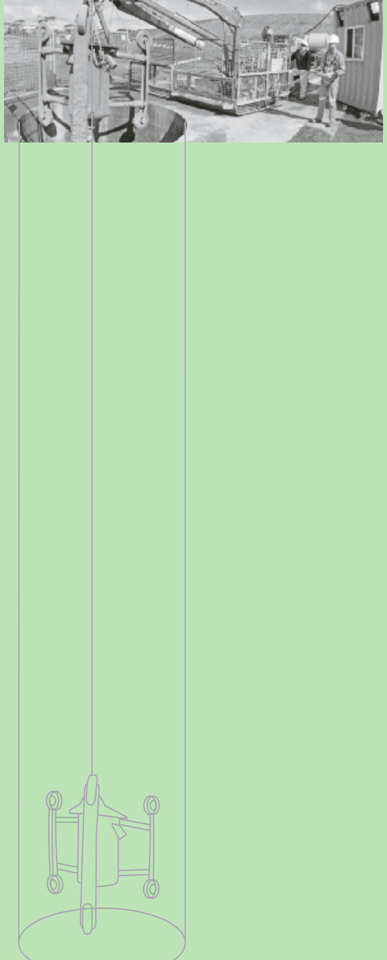


MINE SHAFT LINER

Mine shafts need to be smooth to avoid friction between the walls and the hoisting cage that transports miners and ore. A new robotic system can apply a liner to the shaft walls (Robotic Shotcrete Shaft Liner), which reduces the risk to workers while they are moving up and down the mine, and gives better results than conventional methods of shaft lining.

43

Source: www.macmahon.com.au



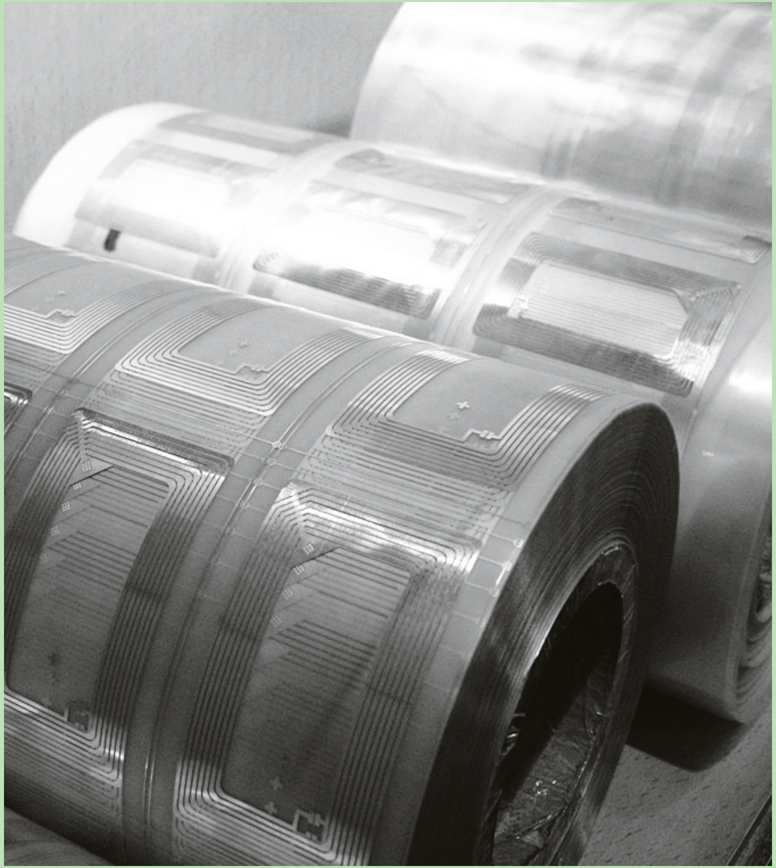
ORE RFID

RFID tags are the successors to barcodes. They are used to identify a product without any need for an optical scanner by communicating the information using radio waves, which can even pass through thin layers of materials like paint or snow.

The tags are now being used to track ore after it has been extracted: RFID tags are affixed to each shipment of ore trucked from the mine, allowing it to be tracked from its source to its point of processing. This monitoring provides the mining company with real-time information about daily production rates.

44

RFID tag. Source: www.k-roll.fr



ROBOMAP

The invention of mining robots provided an opportunity to design autonomous tools for mapping underground tunnels in mines, particularly for mapping the texture (roughness) of their walls. The robots are able to gain access to areas that would be difficult for humans. Robomap is an autonomous or remote-controlled machine equipped with a motion sensor (accelerometer) for positioning — much like video game joysticks — and a set of telemetry lasers. See www.headupflight.net.

45

Robomap in action. Source: www.penguinasi.com

ROCK MESHA™

ROCK MESHA™ installs protective meshes on mine walls. The machine improves safety by mechanizing the application of the mesh, thereby avoiding manual handling by workers. An operator can send all commands from inside the vehicle. In addition, mesh can be installed up to 30% faster than the standard practice.

46

Source: www.rockaustralia.com.au

MINING SIMULATOR

Immersive and virtual training systems for all types of mining operations provide training for personnel in a safe environment. By placing workers in situations they are likely to encounter over the course of their careers, these amazingly realistic systems teach workers to react appropriately without exposing them to any real danger.

47

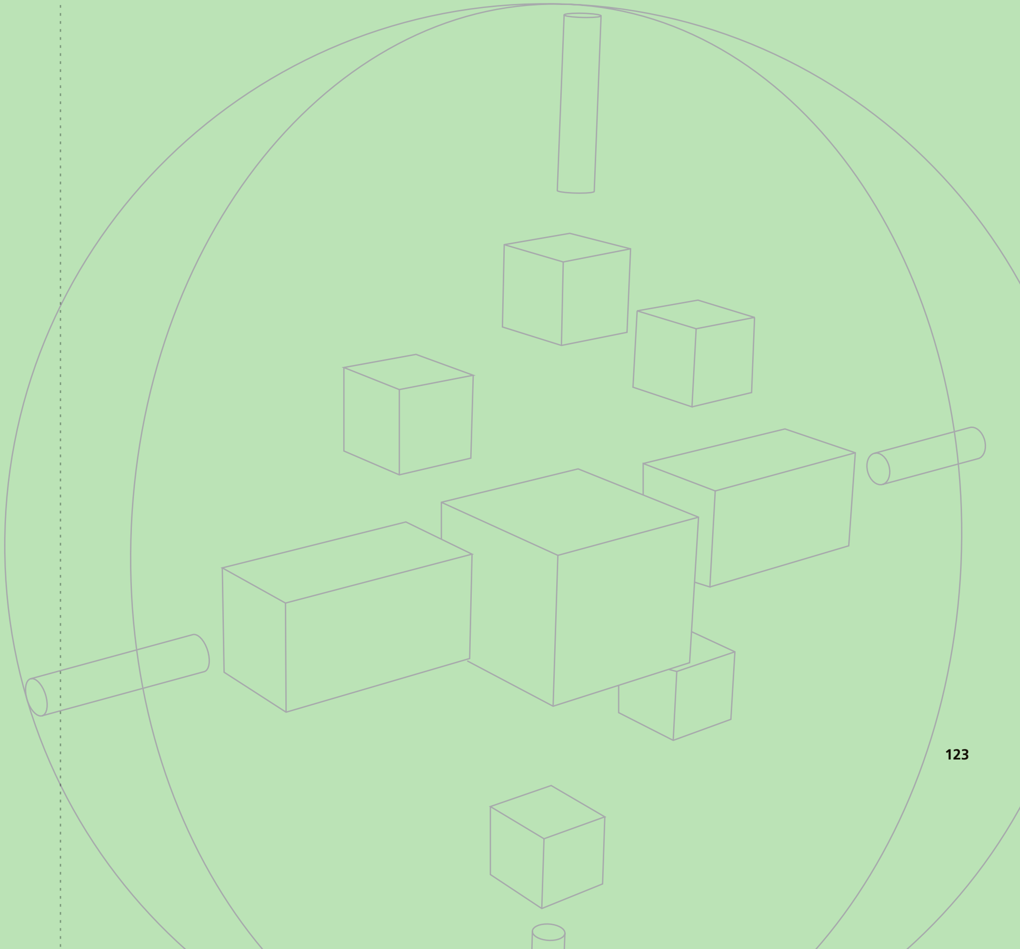
Source: virtualrealitytrainingsystem.com

SMART ROCK

It is often difficult to track the movement of rocks in an underground mine when the broken ore is stored in vast underground spaces during a mining process known as block caving. To help solve this issue is Smart Rock — an electronic gadget that resembles a rock. It is equipped with an electronic device containing a positioning system that functions on the same principle as a GPS, as well as a computer and an emitter. Smart Rock is inserted into the ore through a drill hole and can signal its position up to a distance of 2 km inside a rock mass. This makes it possible to track the movement of ore in real time using a geographic information system.

48

Source: www.penguinasi.com



WARNING PROBE

When a drill operator bores holes into the floor of a mining tunnel, the roof of the tunnel below could collapse. A warning probe attached to a rope is lowered into one of the boreholes in the tunnel floor until it rests on the roof of the lower tunnel. If the roof collapses, tension on the rope will illuminate a signal light that warns the drill operator.

49

SUPER WATER CANON

Water cannons are used to clean mine walls and in some cases to mine clay deposits. They can also be used as cutting instruments to slice into or through harder materials. The super water cannon has an even stronger jet than other types of cannons, but uses less water.

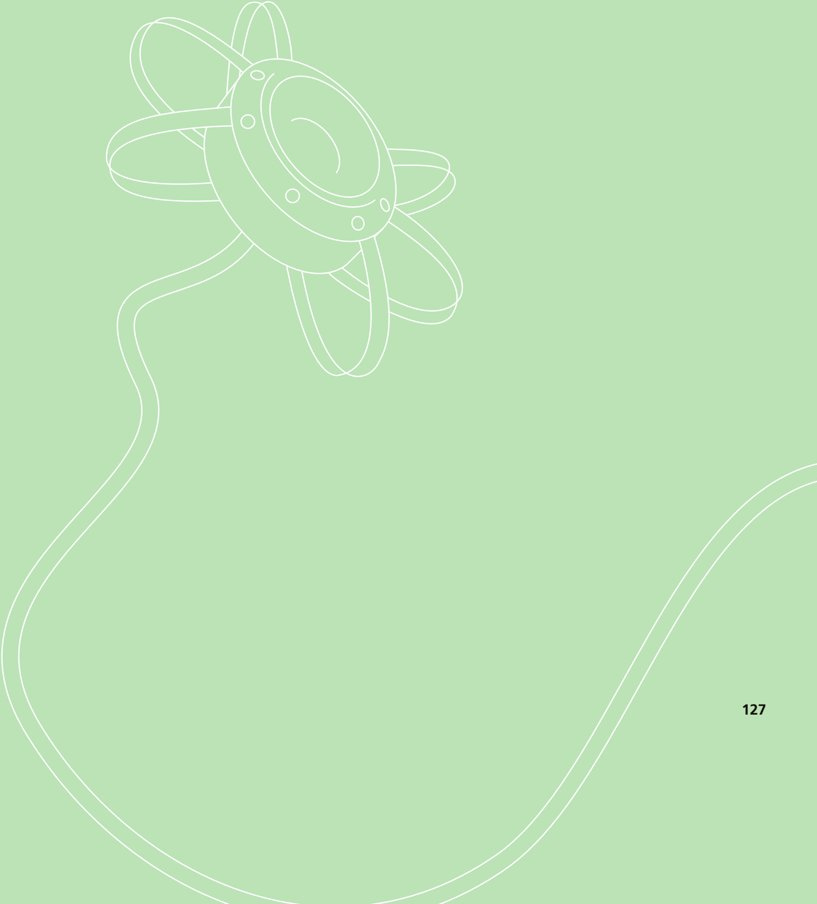
50

SPOUTNIK

Vertical tunnels excavated in ore (known as raises) are used to drop the broken ore into a collecting tunnel below. The descending ore sometimes gets stuck and blocks the raise. Spoutnik is an air-filled balloon that carries an explosive charge to the base of the obstruction in the raise. It is released from the lower tunnel and the ensuing explosion clears the blockage.

51

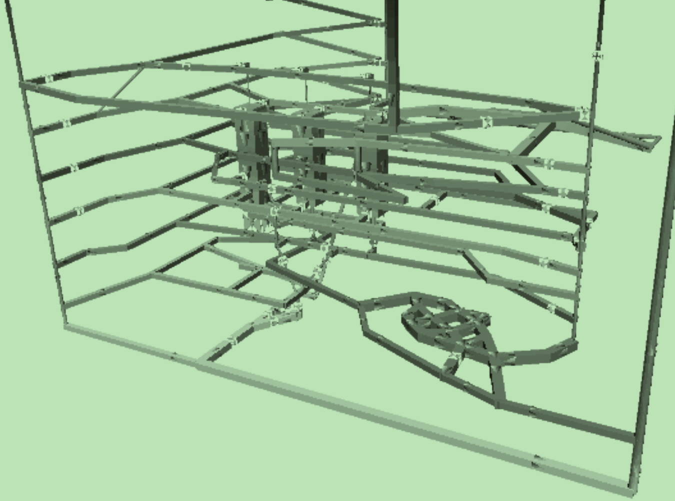
Source: www.plastiquesgplus.com



VENTILATION ON DEMAND

Ventilation in underground mines is a top priority for any operation looking to provide a satisfactory work environment. A ventilation system is complex because it must maintain adequate quality, temperature, and pressure for the air in every part of a mine. It is possible to improve energy efficiency through better management of the ventilation system by supplying air only where it is required and adapting the flow to the specific needs of those areas. Modelling is done using the animated 3-D graphics interface in Ventsim System. Ventsim System uses thermodynamic modelling to simulate airflows, the movement of particles emitted from diesel engines, and pressure and temperature conditions. This innovation can also be used to improve the ventilation of other types of underground workings.

52



Ventilation model used for the underground mine workings below an open-pit mine.
Source: www.mining-technology.com

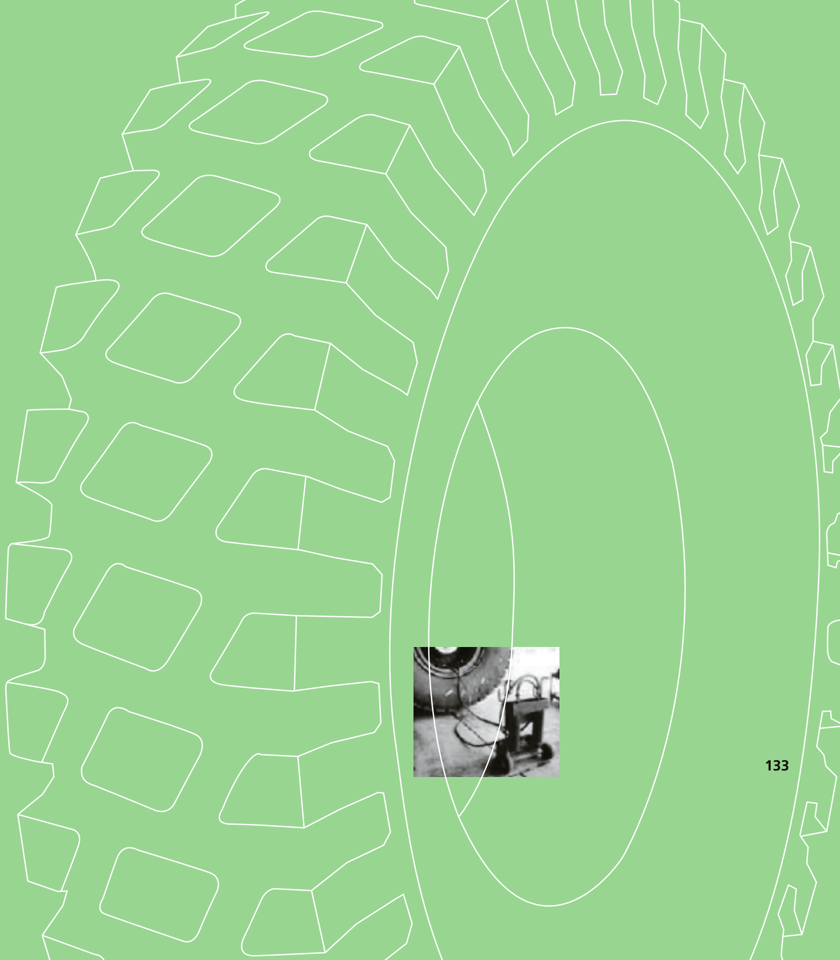
INNOVATIONS IN TRANSPORT AND COMMUNICATIONS

DEFLATION STATION

Tires need to be regularly deflated as part of vehicle maintenance in a mine. In addition to being noisy, the process carries with it the risk of injury caused by flying impurities and pieces of rubber ejected at high pressure. Specialized equipment is now available, consisting of a mobile trolley fitted with two mufflers and a deflector. This tool, which is easy to move around, is attached to the tire that requires deflating; the air released from the tire passes into the tubes connecting the tire to the muffler and ends up at the deflector, which traps any ejected impurities.

53

Source: www.qrc.org.au

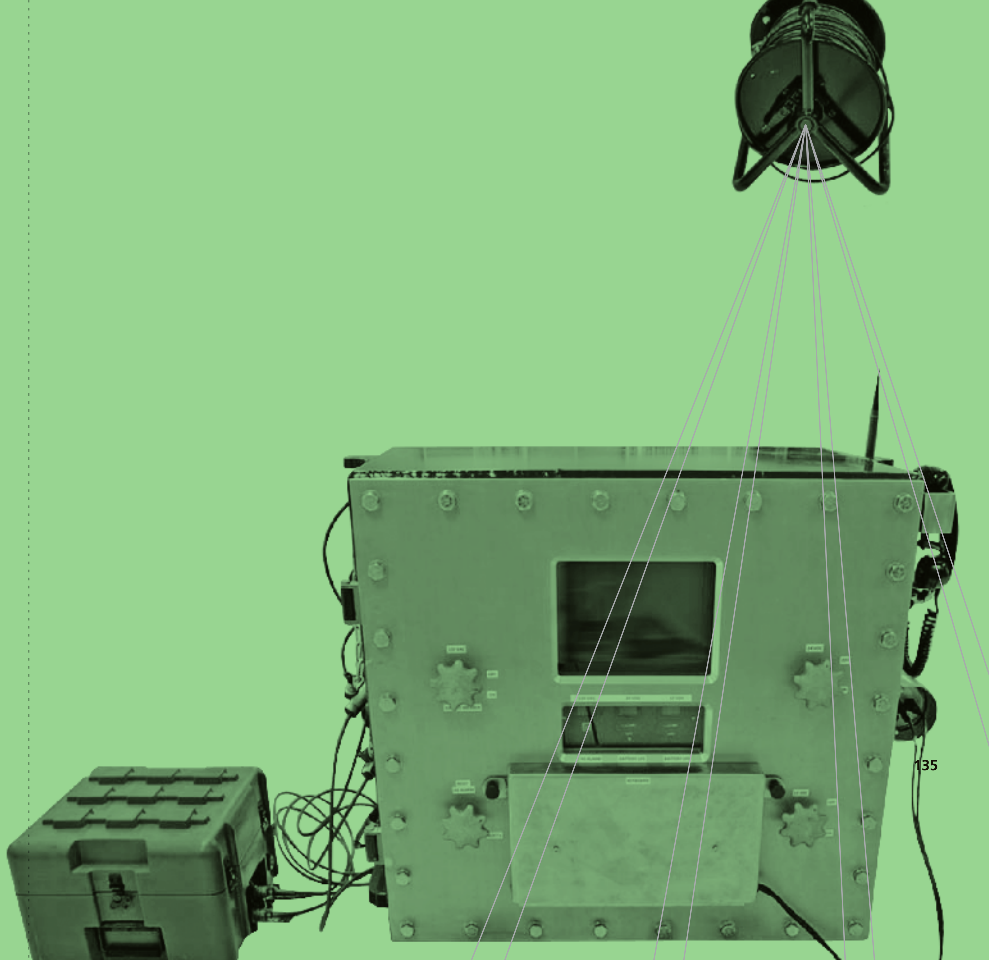


MAGNELINK

Underground mines are potentially hazardous environments, and it is sometimes imperative to relay messages right through the rock. The MagneLink Magnetic Communication System (MCS) is an emergency communication system for underground mines that transmits magnetic waves through the ground. It allows two-way communication via voice or text messages.

54

Source: www.lockheedmartin.com



NEW TRUCKS

A German company has developed a new design for mine trucks with a hauling capacity ranging from 88 to 240 metric tons. The trucks are modular and have up to five axles with a total of up to twenty tires. The axles can tilt 10 degrees to either side and adapt to the ground, with very flexible suspension. When a truck is empty, eight tires are not used. The trucks can practically turn on a dime compared to conventional trucks, and tire pressure is continually adjusted. Each truck has four engines that work independently or are synchronized electronically, which translates into lower fuel and oil consumption.

55

Example of one of the newly designed mine trucks. Source: Source: www.etftrucks.eu

ROLLER REPLACEMENT

Replacing the rollers of a conveyor system was once a difficult task owing to the considerable weight of the pieces and the uncomfortable position required to change them. A specially designed tool has greatly facilitated this job.

56

TRUCK SEALANT

Dust and rock fragments tend to fly out of a truck while it transports ore. To avoid this problem, the trucks pass through a station where a liquid sealant is applied over the surface of the load to keep it in place. This innovation reduces the environmental impact of ore transport.

57

RADAR SENSORS

Mining vehicles are getting bigger all the time, considerably reducing visibility for the operator. The machines are now equipped with radars (radar sensors for vehicle detection) that alert the operator if there are any vehicles or people nearby, whether moving or stationary. These radars use high-frequency waves and are more effective than optical devices, which could be obstructed by mud and dust, or magnetic devices, which are affected by electrical fields generated by steel machinery in the vicinity of the vehicle.

58

Source: www.osisko.com

TRUCK TRACKING

Large mine trucks are subjected to enormous forces owing to their heavy loads (which can be more than 150 metric tons) and the often harsh road conditions in mines. The Road Analysis Control (RAC) is a system of sensors linked to computer software. The system monitors the road conditions for heavy loads and improves truck performance and safety while reducing maintenance requirements. It measures road conditions ten times per second using truck-mounted sensors and informs the driver when to slow down. Coupled with a GPS and telemetry system, it can also be used to map out problem areas and alert managers about necessary road repairs. The data are recorded and can be used to compile a chronicle of each truck's physical condition.

59

UNDERGROUND TELECOMMUNICATIONS

Communicating underground is difficult. For a long time, whistles were the only means of exchanging messages. The arrival of wireless telephones and Wi-Fi antennas revolutionized communication in mines. Installing relays made it possible to communicate using wireless VOIP-type telephones in the tunnels. This made it easier for workers to communicate with each other inside the mine; they can also be used to call up to the mine surface and even to contact people much farther away.

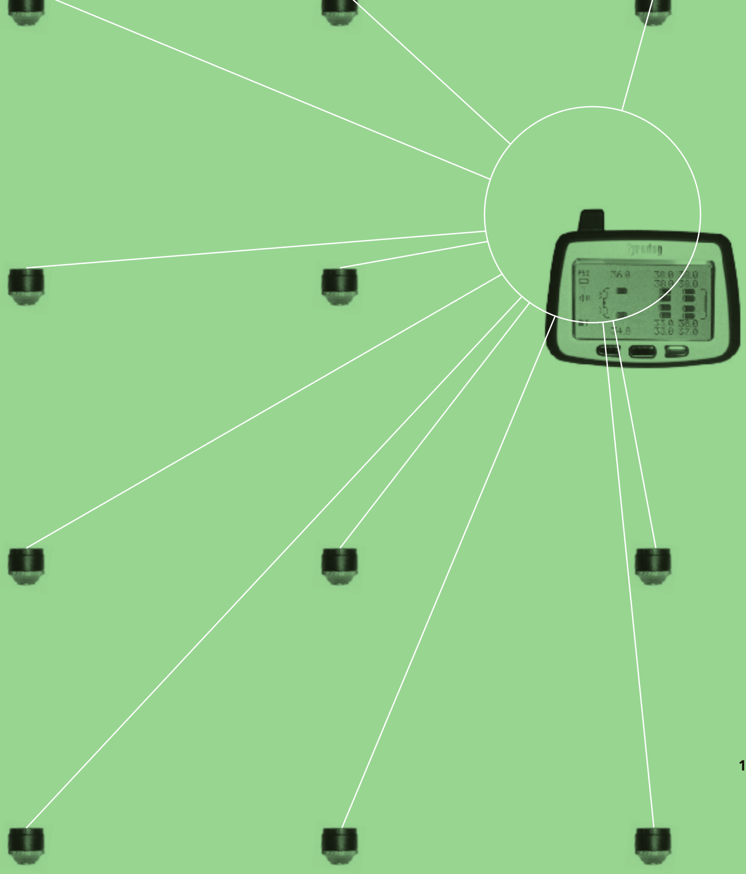
60

TIRE PRESSURE MONITORING SYSTEM

Tires constitute a vital component of mining operations. Tires for an underground ore loader or a large-haul truck can cost more than $100,000, so tire maintenance is extremely important. The tire monitoring system can provide a driver with information on the state of the tires: pressure, temperature, air leaks, change in tire pressure over time, etc. For example, inadequate tire pressure raises fuel consumption. This information also helps prevent blowouts at high speed.

61

Source: www.tyredog.com.au



ROAD-TRAIN

Transporting ore from a satellite deposit to the processing site is a very costly operation. To reduce this cost, companies use a dual-engine road-train (Smith MK4 Hydrapede Dolly), which increases haulage capacity to more than 300 metric tons compared to 55 metric tons for conventional vehicles. In contrast to other vehicles used in the mining industry, the Smith MK4 Hydrapede Dolly can drive on existing road infrastructure because of its small size.

62

Source: www.smithson.au

WHEELPRO

Mining vehicles are enormous — their tires alone can weigh more than 2,000 kg! The Wheelpro is a hydraulic clamp attached to a forklift to remove tires from vehicles.

63

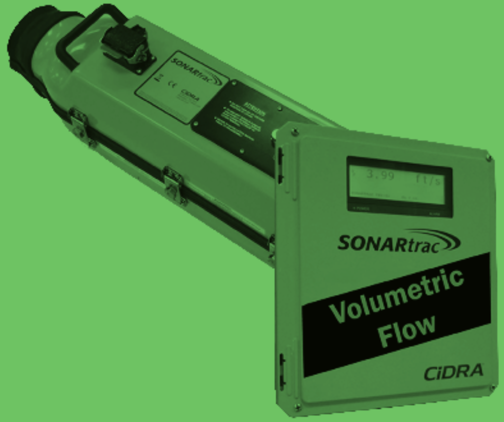
INNOVATIONS IN ORE PROCESSING

SONAR FLOWMETER

In a mining complex, the ore follows a predetermined path from extraction to concentration, mainly via trucks and conveyor belts. Tools such as SONARTRAC from CIDRA have been developed to measure the flow of material en route, particularly in iron mines. Without coming into physical contact, these tools measure the amount of material passing along conveyor belts using a sonar capable of measuring solids just as well as liquids.

64

A sonar device for measuring flow rates in a magnetite mine in Australia. Source: www.im-mining.com



UNDERGROUND PRECONCENTRATION

The first step in separating ore minerals from gangue (the non-economic part of mined rock) typically involves crushing and grinding the ore. This preconcentration step is very noisy and often emits a lot of dust, resulting in considerable environmental impact.

Attempts are now being made to carry out preconcentration operations directly underground. This would also reduce transport costs since less material would have to be moved out of the mine.

65

ORE GRINDING MONITORING

Milling is the first step in ore processing. The ore must be broken down into increasingly smaller pieces in order to separate out the minerals of interest. This reduction can be done at the time of mining by blasting, and during processing by crushers and grinders. It is important to know the size of the fragments throughout the process. Sieves can be used to take measurements, but this is often a difficult process owing to mud build-up.

It is now possible to instantaneously measure the size of fragments using continuous image analysis. The Split-Online System is an automated digital imaging system that monitors ore during milling. The images are captured by photographic devices installed in the crusher and on the conveyors. These images are then processed by specialized software that measures the size of the milled fragments as well as their shape, colour, and texture. This information is sent to the control centre in real time for an assessment of milling quality.

66

MODULAR PLANT

The UMCO modular treatment plant is a low-cost solution for mining small-scale ore deposits. Although designed for gold processing, it could be used to concentrate other types of ore. Its small size allows it to be moved from one mine to another.

67

INNOVATIONS IN HEALTH AND SAFETY

JACK ADAPTER

Heavy machinery requires regular maintenance and occasional repairs. To do either, the equipment must be lifted up and held there, safely and securely. To prevent the jack from slipping, Rio Tinto Alcan designed an adapter that is placed between the jack and the raised machine.

68

PERSONNEL TRACKING

Knowing the whereabouts of employees is a constant preoccupation at an underground mine. The traditional method was to place a token on a board each time a worker went underground, and to remove the token once he came back up. This method was not very reliable because of mistakes or oversights, and operations were sometimes stopped just to see whether a worker was underground or not.

RFID tags easily solve this problem. Presented earlier as innovation 44 for ore transport, these radar tags, which emit radio frequencies, can be sown into miners' clothes to track exactly who is down the mine and who is out. The risk of human error is thus eliminated and emergency rescue teams are better prepared, in the case of an accident, by knowing the location of each miner.

69

GAS-DETECTION DEVICES

Underground mining operations produce gases, often toxic, from machinery running on diesel engines and from explosives. Sensors that measure gas concentrations in real time have been designed to assist with ventilation management. These systems can be adapted to work in other confined areas such as underground parking lots.

70

Source: www.austdynatech.au

FENIX CAPSULE

NASA designed the Fenix capsule to rescue thirty-three Chilean miners in 2010. It can transport one person through a hole with a diameter of about 60 cm.

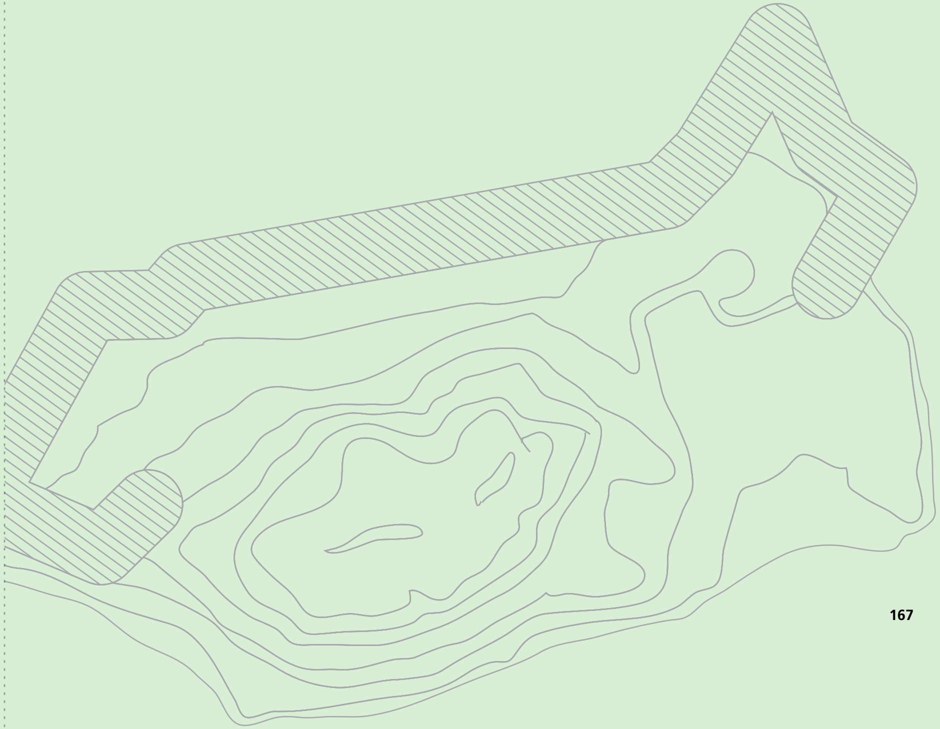
71

RISK-AREA MAPS

Open-pit mines are dangerous places to work because of the many cliffs and steep embankments that may collapse. To protect personnel and machinery from these geotechnical hazards, the company BHP Billiton Mitsubishi Alliance-Poitrel Mine designed a risk-area map using acoustic and optical telemetry. The map, which is updated once a week, provides a simple colour code to identify dangerous and safe areas at the mine site. Easy to understand, it encourages discussion and communication between workers.

Similar maps could be made for underground operations using rock mechanics data and 3-D modelling.

72



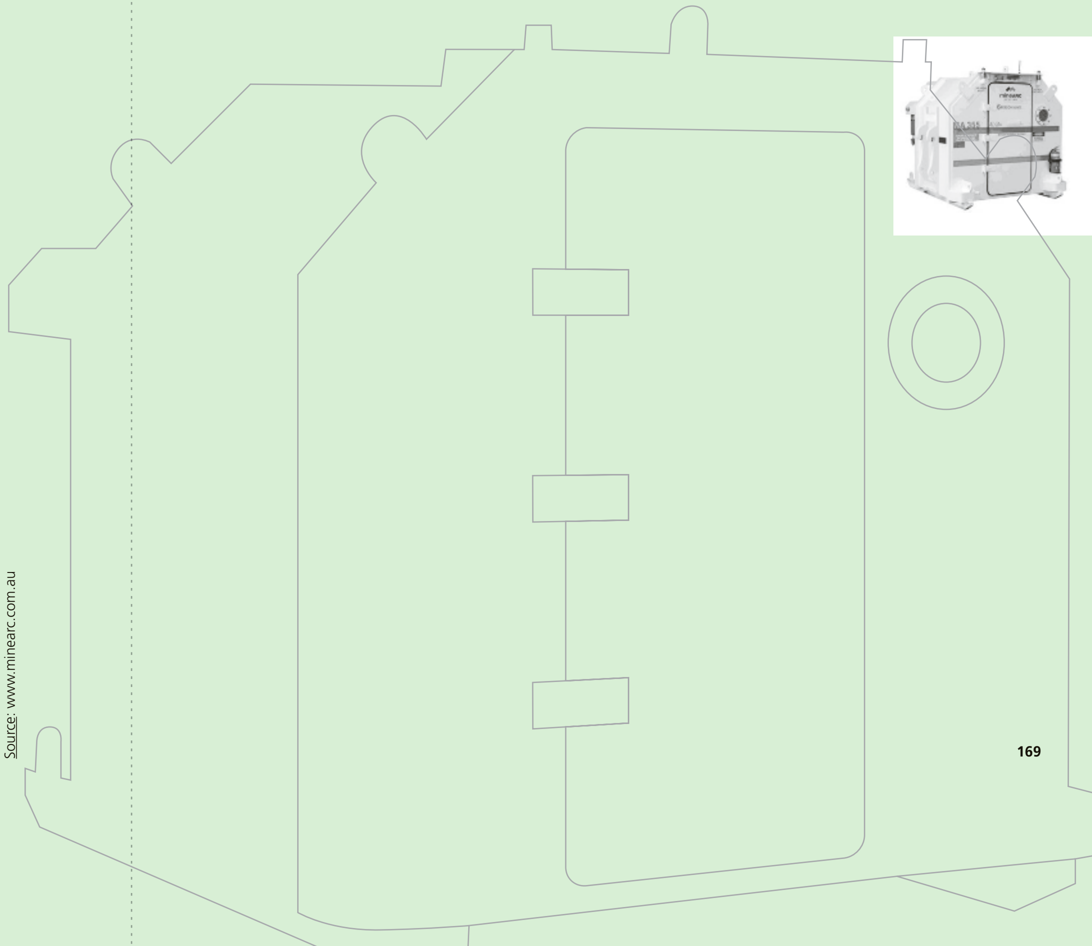
Risk area map. Source: www.mirarco.org

SURVIVAL CHAMBER

In case of an accident, survival chambers offer protection for trapped workers. Easily moved from one place to another, these chambers provide thirty-six hours of protection, including a supply of oxygen and electricity, for four to six workers.

73

Source: www.minearc.com.au



COOLING APPAREL

The clothing used in the mining industry is becoming increasingly sophisticated, allowing greater comfort and safety for the wearer. Among recent improvements is a series of microclimate conditioning garments that use a membrane technology; a liquid coolant gradually evaporates, thereby cooling the person wearing the clothing, vest, or head/neck shade. The garments combat the heat found in deep mines where it can get very hot, sometimes reaching more than 60°C. Other advances in mining apparel include the use of new highly reflective fabrics (3M).

74

Evaporative cooling head/neck shade for hard hat. Source: www.workwearindustries.com

LED MINING HEADLAMPS

The technology for the lamps that attach to miners' helmets has progressed significantly. Before the advent of LED bulbs, mine lamps were heavy (more than a kilogram hanging from the miner's belt) and their lighting power paled in comparison to the technology available today.

LED lamps offer better illumination and have much longer continuous operating times. They also have a longer lifespan because they use lithium batteries, which are also much smaller and lighter (only 0.45 kg). Some models have a battery integrated into the lamp.

75

Source: www.mining-technology.com

FATIGUE-MEASURING WATCH

The ReadiBand Fatigue Risk Management System (FRMS) is an electronic strap that measures the fatigue level of a worker, particularly heavy equipment operators, to determine whether they are fit for work.

The design of this wrist-worn device combines knowledge acquired from fifty years of sleep research with the latest in data-processing technologies.

The strap quantifies and processes a multitude of data relating to fatigue accumulation: amount of sleep, quality of sleep, ratio between the time spent sleeping and the time spent awake, etc.

76

Source: www.qrc.org.au

ROAD SIGNS SNOW REMOVAL

During snowstorms and blizzards, snow accumulates on road signs and signal flags. Workers knock the snow off by tapping them with a metal pole.

This tedious task is circumvented by mounting a movable metal bar, controlled by a spring, onto the back of a truck. The driver rolls along at 22 km/h while the bar strikes sign panels and flags, clearing them of snow. This innovation saves time and avoids possible injury.

77

SOUNDPROOF TENT

Some parts of the mechanical winch used to lower the cage elevator down a mine are very noisy. The gearbox casing for the winch is covered by a soundproof tent, which serves the dual purpose of improving communication between the winch operator and the miners in the cage, and reducing the risk of hearing problems for the winch operator.

78

SAFETY PICKETS

In open-pit mines, roadsides are marked with reflective pickets to improve nighttime safety for heavy vehicle operators. Dust, vibrations, and bad weather damage the pickets. Replacing them is a long and tedious task that is also hazardous because the pickets are planted on top of rock mounds.

The new generation of pickets has wider reflective bands, which offer better visibility. In addition, the attachment system makes them safer to position because it is no longer necessary to climb up onto the rock mounds. The pickets can be adjusted to the shape of the road.

79

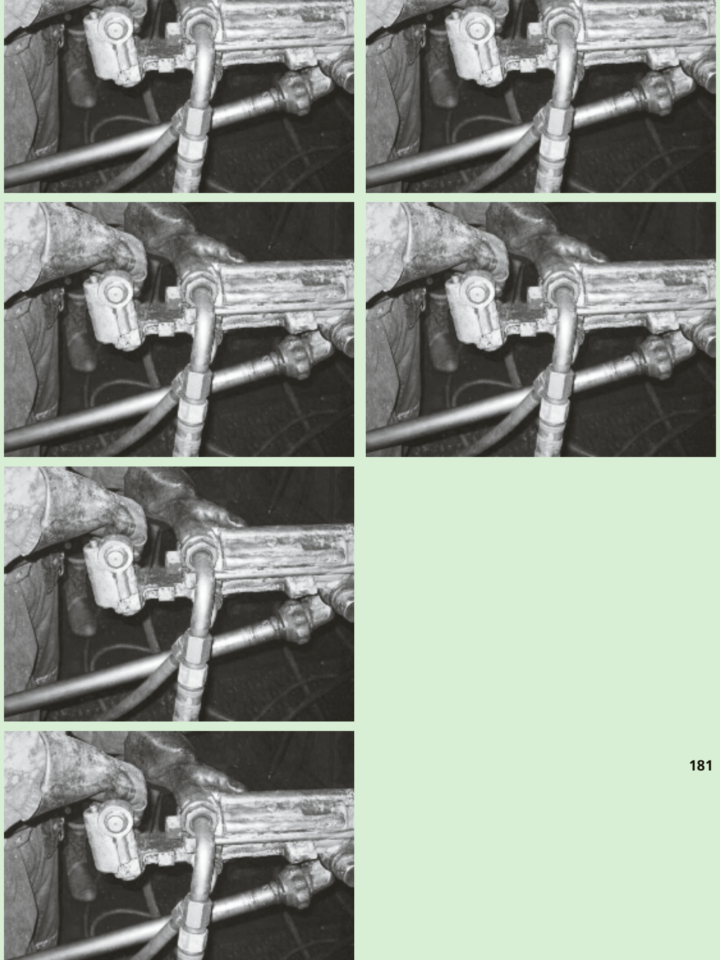
Source: www.qrc.org.au

ANTI-VIBRATION HANDLE

Vibrations caused by hand-held tools, like the hydraulic drill, are a major cause of injuries in mine workers (white-finger and carpal tunnel syndromes). The anti-vibration handle is a separate device that attaches to a tool and reduces damaging vibrations by up to 60%.

80

Source: www.legroupemisa.com



WIRE-MESH APPLICATION

Wire-mesh screens are attached to the roofs of tunnels in underground mines to help retain the rock and increase safety.

Supports are needed to hold the screens in place. The old-style supports were not completely safe for workers, who could be injured by the equipment or required to use extreme force to install the wire screens.

Today, a new T-shaped, spring-loaded support is available, designed by IAMGOLD. The spring ensures stability when the support is vertical by applying pressure on both the roof and floor of the tunnel.

81

Source: www.sante-abitibi-temiscamingue.gouv.qc.ca

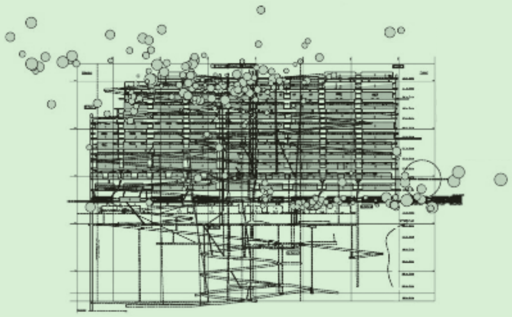
MICROSEISMIC MONITORING

Rock masses react to mining excavation by tiny readjustments that produce microquakes. Recording these microquakes and locating them in three-dimensional space provides a means to monitor rock mass stability in real time, as much in underground mines as in surface operations.

This approach records the changes in stresses and their redistribution, the locations and growth of fractures, and the effects of the mining operations. It also makes it possible to predict the appearance of instabilities that could lead to collapse.

82

Source: www.asse-archiv.de



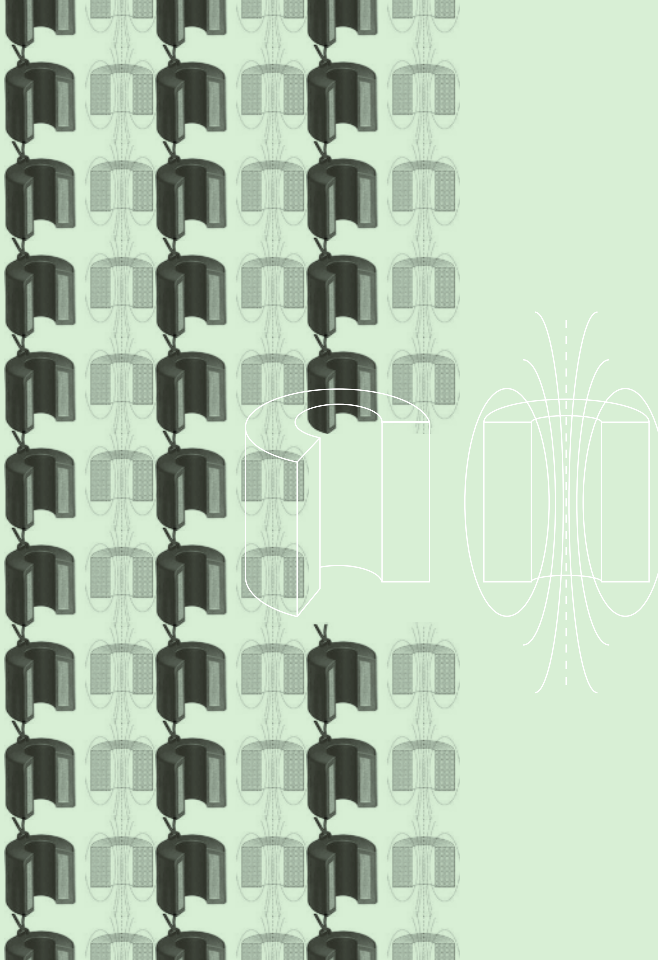
CABLE CHECKUPS

The cable of a mine cage is a critical element in miner safety. Maximum allowable loads and cable lifespans are governed by strict standards laid out by Québec's health and safety commission. Although cable breaks are extremely rare, it is nonetheless necessary to conduct periodic checks.

A continuous monitoring system for winch cables in underground mines has been developed by the research consortium SOREDEM. The system establishes the amount of wear in real time and determines the precise moment the cables should be replaced, thanks to an electromagnetic coil that induces a field in the cable.

83

Source: www.legroupemisa.com



TELE-MINING

Some ores are not easily accessible, such as the uranium-rich ores of the Athabasca Basin, which are too naturally radioactive to be handled directly by miners. Many technological solutions were developed to allow these types of ore to be mined using robots. The mining machines are remote-controlled, operated from a safe zone inside the mine or even from the surface. In fact, thanks to the Internet, these robotic devices could be controlled from anywhere in the world. The operator uses cameras and joysticks to work the equipment.

84

Tele-mining. Source: www.penguinasi.com

INNOVATIONS IN REMEDIATION

MULTI-LAYER BARRIER

When sulphide minerals are exposed to air and natural elements, they produce acids that penetrate the ground and contaminate groundwater.
A capillary barrier covering, commonly known as a multi-layer covering, controls the acid mine drainage emanating from a tailings pond by shielding the problem minerals from the elements.

85

Source: www.mrnf.gouv.qc.ca

CYANIDE DESTRUCTION

When gold is very fine-grained, one of the only feasible extraction methods is to mix it with cyanide, a toxic chemical responsible for major incidences of pollution. Cyanide management necessarily constitutes an important factor in all processing operations of this kind. A new cyanide destruction procedure was devised by Maelgwyn Mineral Services (MMS CN-D process), which also allows any remaining gold in the residue to be recovered.

86

BIODEGRADABLE EXPLOSIVES

The residue from explosives contributes to mine site pollution. To combat this problem, strains of the *Bacillus subtilis GN* bacterium were selected for their ability to decompose explosives in only a few days. Bacterial spores may be added to wood flour, an ingredient in explosives, without substantially affecting its properties (Dario et al., 2010).

87

CONSTRUCTED WETLANDS

Wetlands have the ability to remove metals from mine site effluents and neutralize their acidity. Since these ecosystems are self-regulating, they may represent a long-term solution to acid mine drainage.

Constructed wetlands comprise vegetation (reeds and cattails) and bacteria that uptake contaminants. The construction of these artificial wetlands is a complex process, however, and the bacteria require nutrients to perform their function as decontaminators.

New methods elaborated by the Savannah River National Laboratory (SRNL) research group consist of pouring biodegradable oils and waxes on top of contaminated waters. These waxes and oils provide food for selected bacterial populations, which induce precipitation of minerals at the bottom of the basin.

88

Source: http://technology.infomine.com

REUSING MINE TAILINGS

Some companies use the tailings from active mines to treat contaminated soil. Tailings act as an oxygen barrier and stem the flow of contaminated drainage water by sequestering polluted sediments.

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NEUTRALIZATION OF TAILINGS

To reuse mine tailings, they must first be stabilized. Tailings can be mixed with lime, ashes, wood shavings, cement, or other types of material to make a paste that can serve as a waterproof barrier or as backfill.

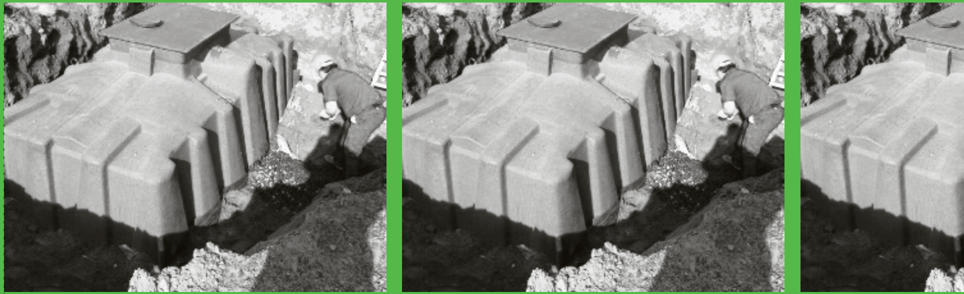
90

PEAT AND SAND FILTERS

Wastewater can be filtered through peat to reduce acidity and eliminate up to 90% of biodegradable organic matter and 99% of pathogenic organisms (coliforms). The filtration systems use sphagnum moss and coconut shavings, effectively replacing septic fields. These systems are remarkably effective (Kennedy and Van Geel, 2001). They are capable of working in very cold conditions and meet the strictest environmental requirements. Sand filters can be added, consisting of a membrane and beds of sand. Industrial units are prefabricated in Québec, notably at Rivière-du-Loup (Premier Tech Aqua).

91

A passive FDI disinfection filter, installed in a rocky landscape, in conjunction with an Ecoflo filter. Source: www.infodimanche.com



REUSING BAUXITE WASTE

Bauxite residues can be processed and transformed into three marketable products: Red Sand™ (used in backfill, road construction, etc.), Red Lime™ (for neutralizing acidity, controlling pH), and Alkaloam® (for enriching agricultural soils, quickly lowering soil pH, and reducing the migration of soil nutrients into ground and surface waters).

92

ROBYS™ SYSTEM

Used oils can be recycled by thermal cracking, a process that uses heat to break the long molecules in oil into the shorter molecules of diesel fuel. There is a problem with the process: the fuel it produces is unstable and has an unpleasant odour because it is contaminated by acid compounds.

The solution is ROBYS™, a solvent that stabilizes the fuels derived from thermally cracked used oils and purifies them, providing a marketable product.

93

GEOTEXTILE SEPARATORS

Geotextiles are films composed of a screen, woven or not, made of synthetic material. Their main role is to create a physical barrier between the ground and the materials stored in or used to construct a facility or structure. At a mine site, they are particularly useful for ore storage areas. The barrier allows water to flow through, but stops fine particles in the underlying natural environment from entering the storage area. Another application is to prevent clogging in drains and drainage systems. Geotextiles thus act as separators or anticontaminants and can also be used to protect mine tunnels.

Geotextiles can be reinforced by new structural elements that form a semi-rigid lattice.

94

Source: www.tensar.co.uk

UNDERGROUND BACKFILL

Sending waste material underground (either waste rock or cement paste) has several advantages: it reduces the amount of surface waste by about 50% and stores the waste in a stable environment (little water circulation, no temperature fluctuation, and no rainfall or meltwater).

Hydrological and geomechanical models have been developed to assess the changing properties of these waste materials and their effect on the underground environment (Aubertin and Bussière, 2010).

95

SOLAR PANELS FOR TAILINGS SITES

Mine tailings can cover considerable amounts of land. They are difficult to rehabilitate and may quickly become abandoned environmentally. Reforestation is the most commonly attempted remediation measure.

Chevron has been recently developing their innovative idea of using old tailings sites as solar farms. The acid-generating waste at the Questa mine in New Mexico is now fitted with 173 solar cell panels that should produce about 1 MW of energy.

Source: www.energydigital.com

96

JAROFIX

Processing zinc ores produces a residue known as jarosite. In 1998, CEZinc of Valleyfield developed a process that physically and chemically stabilizes this residue. The Jarofix process involves adding lime, cement, and water to the residue. Once dried, the resulting mixture has a consistency similar to clay. Since Jarofix is compact, easy to dig into, and chemically stable, it constitutes an excellent filler material (Seyer et al., 2001).

97

Jarofix process, installed in Spain. Source: www.iturmo.com

GEORADAR

Georadar is a technology that emits radar waves into the subsurface. Like an aboveground radar, a georadar unit emits short, high-powered waves in the direction of the intended target. It receives signal echoes that are analyzed to determine the characteristics of the object. The depth range is up to several metres below the surface.

This method can be used to determine soil structure, particularly that of permafrost in arctic environments, or to monitor changes over time in underground contamination by using the device to conduct periodic surveys over the ground surface.

Georadar is used in many other fields, particularly for recognizing subsurface stratigraphy (Geophysics GPR, Chile).

98

Georadar profiles of the esker at the BHP landing site, Lac de Gras, NWT. (Geological Survey of Canada). Source: http://gsc.nrcan.gc.ca

GEOTUBE

A geotube is a tubular polypropylene bag used for dewatering and sludge drying at water-treatment facilities. Geotubes come in various sizes (from 5 to 100 m long) and are filled via cyclic or continuous pumping, with or without the addition of a polymer flocculant. Dewatering is accomplished by filtration, thereby capturing the solids (heavy metals and nutrients) in the bag. Clear water flows out through the pores of the geotubes, and the solids are consolidated through desiccation (drying).

Geotubes reduce the volume of waste to be treated by up to 90%.

A geotube setup. Source: http://greenlinkpartners.com

HYDROSEEDING

A mine site must be landscaped both during production and after it closes. A planting process known as hydroseeding sprays a slurry of fertilizer, seeds, and water onto the ground to make grass grow.

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ACKNOWLEDGEMENTS

We would like to thank all those who helped us in our research in Montréal, the city of Québec, and the Abitibi region, in particular:

Andrea Amortigui (MRNF)
Robert Lacroix (MRNF)
James Moorhead (MRNF)
Jean Carrier (MRNF)
Gaétan Lavallière (Groupe MISA)
Denis Bois (UQAT)
Michel Aubertin (École Polytechnique)
Pierre Bérubé (Abitibi Geophysics)
Alain Carrier (InnovExplo)
Carl Pelletier (InnovExplo)
Sylvie Poirier (InnovExplo)

REFERENCES

1/ Aubertin, M., and B. Bussière. 2010. Industrial NSERC Polytechnique-UQAT Chair in Environment and Mine Wastes Management. http://www.enviro-geremi.polymtl.ca/

2/ Dario, A. et al. 2010. Development of a biodegradable ethylene glycol dinitrate-based explosive. *Journal of Hazardous Materials* 176: 125–130.

3/ Global Economics Limited. 2001. Mining Innovation: An overview of Canada's dynamic, technologically advanced mining industry. Prepared for the Mining Association of Canada. http://www.mining.ca/www/media_lib/MAC_Documents/Publications/English/innovation.pdf

4/ Hale, M. 2010. Gas geochemistry and deeply buried mineral deposits: The contribution of the Applied Geochemistry Research Group, Imperial College of Science and Technology, London. *Geochemistry: Exploration, Environment, Analysis* 10: 261–267.

5/ Jébrak, M. 2010. L'innovation en exploration minière: enjeux et défis. Paper presented at Québec Exploration, November 2010.

6/ Kennedy, P., and P. J. Van Geel. 2001. Impact of density on the hydraulics of peat filters. *Can Geotech J.* 38: 1213–1219.

7/ Leybourne, M. I. 2007. Aqueous geochemistry in mineral exploration. In *Mineral deposits of Canada: A synthesis of major deposit-types, district metallogeny, the evolution of geological provinces, and exploration methods,* ed. W. D. Goodfellow, pp. 1007–1033. Geological Association of Canada, Mineral Deposits Division. Special Publication 5.

8/ Lulin, J-M. 1990. Une analyse du développement minier du Nord-Ouest québécois. In Rive et al. , pp. 17–34.

9/ Mulgan, G. 2007. The process of social innovation. http://www.scribd.com/doc/8177770/Geoff-Mulgan-The-Process-of-Social-Innovation-2007

10/ Rive, M., P. Verpaelst, Y. Gagnon, J-M Lulin, G. Riverin, and A. Simard. 1990. The Northwestern Quebec polymetallic belt. CIM Special Volume 43: 17–34.

11/ Seyer, S., T. T. Chen, and J. E. Dutrizac. 2001. Jarofix: Addressing iron disposal in the zinc industry. *JOM* 53: 32–35.

12/ Sobolewski, A. 1996. Wetlands for treatment of mine drainage. http://technology.infomine.com/enviromine/wetlands/Welcome.htm

13/ Wright, G., and J. Czelusta. 2002. Exorcizing the resource curse: Minerals as a knowledge industry, past and present. Working Papers, Stanford University, Department of Economics. http://www-siepr.stanford.edu/workp/swp02008.pdf

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ISBN 978-2-9812840-3-7
(French edition: ISBN 978-2-9812840-1-3, Minalliance, Montréal)

Legal deposit - Bibliothèque et Archives nationales du Québec, 2012
Legal deposit - Library and Archives Canada, 2012