PDAC

PROSPECTORS & DEVELOPERS ASSOCIATION OF CANADA

ASSOCIATION CANADIENNE DES PROSPECTEURS ET ENTREPRENEURS

2020 INNOVATION IN MINERAL EXPLORATION

ABOUT PDAC

The Prospectors & Developers Association of Canada (PDAC) is the leading voice of the mineral exploration and development community. With over 7,500 members around the world, PDAC's work centres on supporting a competitive, responsible mineral sector.

PDAC is known worldwide for its annual PDAC Convention—the premier international event for the industry—that has attracted over 25,000 attendees from 135 countries in recent years and will next be held March 7-10, 2021.

The work of the association is carried out by a 26-member Board of Directors, 16 committees, and a team of permanent staff. In 2018, the Board of Directors approved a five-year strategic plan for PDAC. The strategic goals and objectives in this plan centre around the themes of: competitiveness, influence, engagement and leadership.

AUTHOR

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Anne Thompson has thirty-five years' experience working in and consulting to the mineral exploration industry, including field work and applied mineralogy. She was an early adopter of field spectroscopy and helped organizations adopt the new tools for mapping alteration minerals. Thompson co-edited the Atlas of Alteration, a resource for exploration geologists.

> "The marketing drives that made us think that AI was going to take over and that it could do anything that was 'impossible' were not helpful for economic geology."
>
> Shawn Hood, GoldSpot Discoveries

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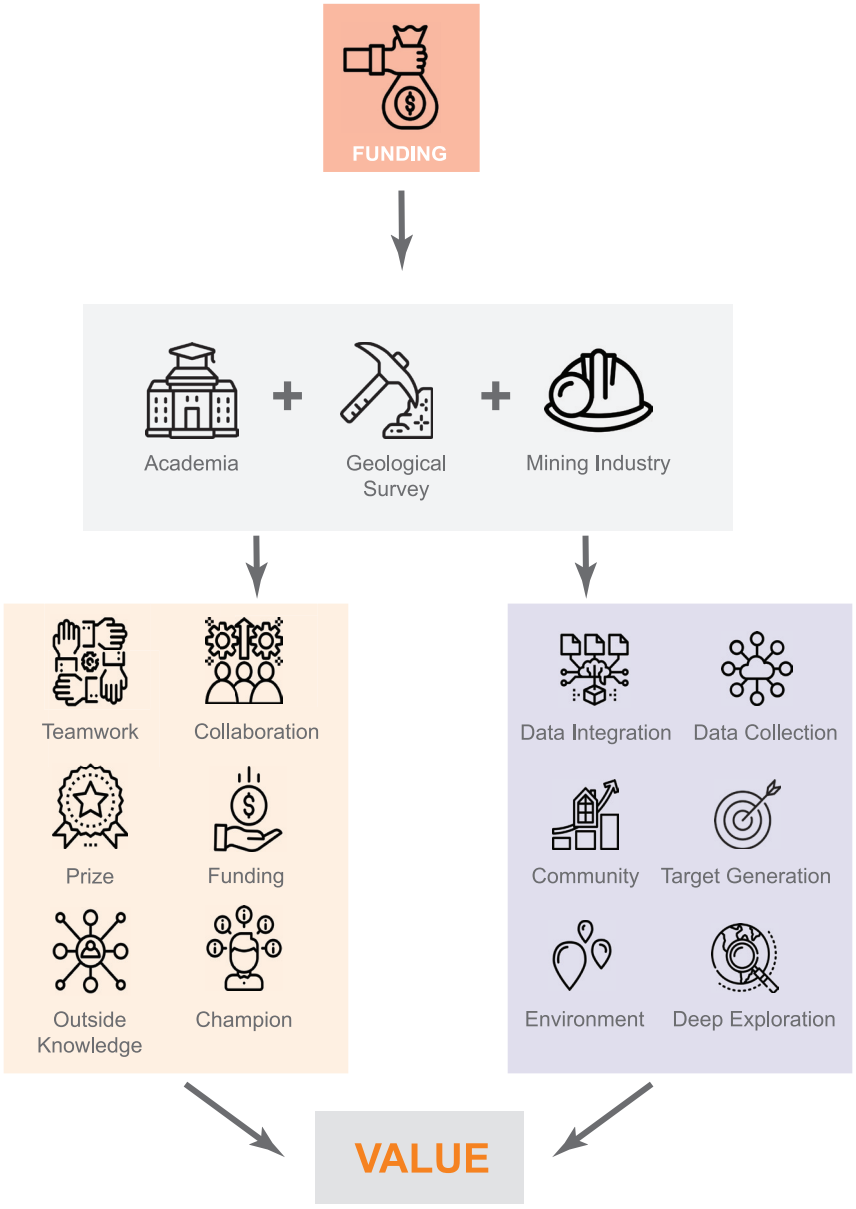
MAPPING INNOVATION IN MINERAL EXPLORATION

The modern context, and mapping innovation

- Mineral resources are fundamental to the energy transition and sustainable development to support the global population. The goal of responsible exploration and mining drives innovation and benefits constructive community engagement.
- Global discovery rates appear to be declining. In many cases, resources are hidden under cover or may be deeper than previously known mineralization.
- Conducting mineral exploration in the modern context has led to numerous innovative approaches and new techniques. Examples of innovation can be found across all aspects of exploration in Canada.
- Innovation thrives in a 'landscape' that provides access to quality university research and people, public geoscience provided by geological surveys and other organizations, research consortia-networks, and industry partners.
- Small, more agile companies and consultants operate effectively within this innovation landscape, supporting initiatives by the major companies to achieve exploration success and develop efficient operations.



INTRODUCTION

The minerals industry is fundamental to the Canadian economy, producing multiple commodities that generate jobs and sustain communities nationally and internationally - to do this requires a complex system of interrelated processes which contribute to a diverse and economically important industry. The underlying foundation for the industry is mineral exploration, however, search for metals and minerals is a risky enterprise that engages a wide variety of individuals, organizations and companies. This effort requires a significant amount of research, data collection and analysis, followed by drill testing and further analysis in order to determine the value and viability of a mineral resource.

Perceptions of the nature of mineral exploration are sometimes rooted in the past. Historically, exploration relied on boots on the ground mapping and sampling. While this has not fundamentally changed, geoscientists now have a wide variety of tools and approaches. Exploration has always relied on some level of innovation to succeed, and now there are more opportunities than ever before. Canadian companies are leaders in building the approach to modern exploration.

In order to evaluate the nature of innovation in mineral exploration across Canada, this study took a narrative approach. Interviews were conducted with 20 individuals working actively in mineral exploration, across the country and in a variety of aspects of the business. Through the course of the study, specific case histories were developed through interviews and interaction with groups engaged in exploration. Over 30 hours of interviews were conducted covering specific innovations as well as the nature of mineral exploration and innovation in general. The eleven examples range from ‘big thinking’ collaborative research, to collection of quality field data, diamond drilling and core logging, and the use of machine learning and AI in data integration and analytics.

For each case study, the major drivers as well as the key factors which supported the innovation are identified. Many innovations included in this study are proven in commercial use, however, some that are not fully implemented are also presented to demonstrate the pace of change and development. The rate of change is due in large part to digital transformation that is affecting industries globally.

Each of the case studies tells a story of an innovation. They are intentionally diverse, representing people and organizations of various size and areas of work in Canada. From these stories, however, an understanding of the importance of a variety of factors which support innovation and mineral exploration is clearly demonstrated.

MINERAL EXPLORATION

WHAT IS MINERAL EXPLORATION?

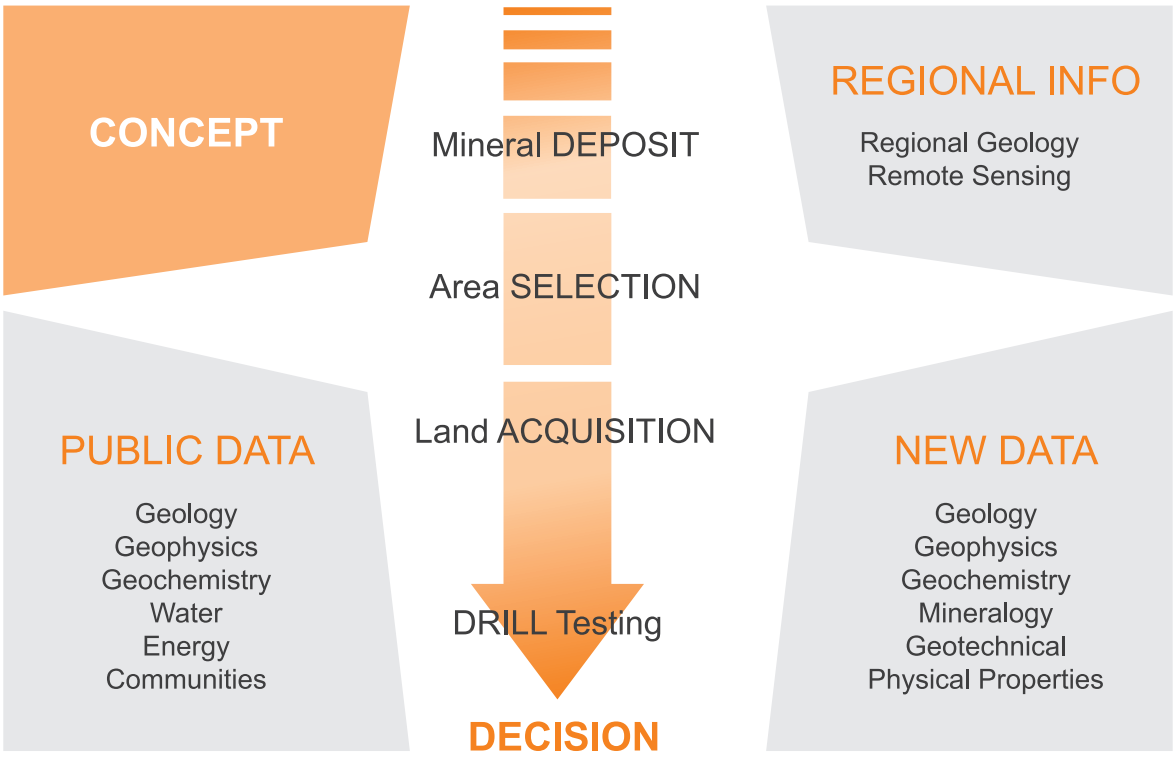
A complex process to select geographic areas, identify prospective zones, and test specific volumes of rock for metals and minerals which are of value to people.

Mineral exploration is a complex process with multiple stages and decision points. The process starts with a concept, which provides a framework to evaluate regional and country-wide constraints including politics, regulation, land access, geology and availability of data sets.

Discovery trends and data demonstrate that much of the previous exploration efforts found the 'easy' targets, i.e. those exposed at surface, or in areas of intensive exploitation.

The resources of the future are more likely to be deeper or hidden in areas of exotic cover. In order to be successful, the industry continues to innovate, creating new tools, approaches and techniques.

In addition to the drive to find resources, the imperative to explore with 'the end in mind', with less impact on the land and water and working to develop the deposits we need in a responsible manner is a vital part of the process.



INNOVATION IN MINERAL EXPLORATION

Given the complex systems required to execute exploration programs, there are many ways to innovate.

Workplace culture, community relationships, data analytics including machine learning and AI, and developing new equipment and tools may all create value for both an organization and society.

Value is typically thought of as profit as a result of discovery, however more sustainable and responsible operations also create value for communities and society.

IN MINERAL EXPLORATION

Innovation refers to new technologies, tools, techniques, methods or processes that have a marked improvement on exploration costs, efficiency, rates of discovery, and/or reduce the environmental impact of activity.

KEY FACTORS

OUTSIDE KNOWLEDGE

Outside knowledge is important and is applied to a new problem, allowing innovation to occur.

TEAMWORK

Workplace culture also plays an important role. Teams of diverse individuals, operating in an environment where new ideas are welcome create innovation.

CHAMPION

Leadership is critical. Innovation needs champions and people willing to take risks.

FUNDING

Funding is needed to get the 'innovation' into the commercial space. Early adopters, providing proof of concept play a key role.

COLLABORATION

Collaboration allows teams to do more with less and achieve success.

INNOVATION TO PDAC

PDAC works to ensure the Canadian mineral exploration and development industry is at the forefront of innovation, which enhances efficiency, effectiveness and performance. Innovations across the entire mineral industry ecosystem including data acquisition and analysis, target modelling and sustainable practices are examples of progression over the last few decades.

However, innovative developments in Canada's mineral exploration industry are not always well documented. Companies may obscure innovations for competitive advantage purposes or lack the marketing resources to broadly disseminate across industry. Documenting development catalysts, sources of funding, commercialization efforts, and industry adoption processes, are central to the growth of an innovation ecosystem, and to promote Canada as the top jurisdiction for exploration and development activities.

> "Innovation occurs across our business in both technical and scientific methods and via new approaches to community engagement–addressing risks early in a project can have lasting impact."
>
> Gavin Dirom, Geoscience BC

DATA DRIVEN INNOVATION

WHAT IS DIGITAL TRANSFORMATION?

The transformation in the last five years in how digital data is hosted and handled is driving innovation across the industry. Large volumes of data can now be collected rapidly in the field and in 'real-time' ranging from information on operations to details of geology.

CLOUD-BASED SYSTEMS

Data can be hosted and stored via cloud-based systems allowing managers and researchers to view the information easily and rapidly. Software such as Leapfrog™ and other modelling packages allow datasets to be visualized in 3D.

DATA INTEGRATION

Application of machine learning (ML) and AI are rapidly gaining ground, based on gains in computing and processing power now widely available. Step changes are occurring in our ability to integrate complicated sets of data.

MACHINE LEARNING & ARTIFICIAL INTELLIGENCE

Machine Learning (ML) and Artificial Intelligence (AI) are being integrated into a variety of workflows and are used to solve a range of problems. **Success is typically dependent on strong collaboration between geoscientists and the data or computer scientists involved in the project.**

Geoscience data is typically based on interpretation and does not fall into easy categories, however, with good communication between individuals and teams, successful outcomes that are verified by geoscientists are possible.

It is easy for ML practitioners to fool themselves into thinking they have a workable mining solution. The benefit, however, in cases of high-quality collaborations is the ability of ML to process vastly more parameters and data than a human brain can.

THE POWER OF INDUSTRY DATA SETS

Prize challenges set up by industry result in public demonstrations of the value of using machine learning to generate exploration targets. The competitions provide:

1. A comprehensive data set allowing groups to trial new models and data integration techniques
2. A chance for teams to demonstrate their 'problem solving skills' – providing a platform for those willing to take on a challenge and solve for real solutions

PUBLIC DATA

Access to high quality public data sets developed by the Geological Survey of Canada, regional geologic surveys and other public science groups such as Geoscience BC are vital to mineral exploration. The public data provides a foundation for developing exploration targets and acquiring land.

BUILDING ON PAST INNOVATION

Innovation is naturally a process that builds on previous work. Digital transformation provided the step change for implementation of many techniques and innovative ideas, allowing them to become functional in the modern industry.

Ground-breaking innovative work in geophysics at the University of British Columbia developed geophysical inversion modelling with key advances made in the 1990s. Now datasets that are amenable to 3D analysis can be modelled and new inversion tools are available via open access platforms online. Models are now built in hours, not days.

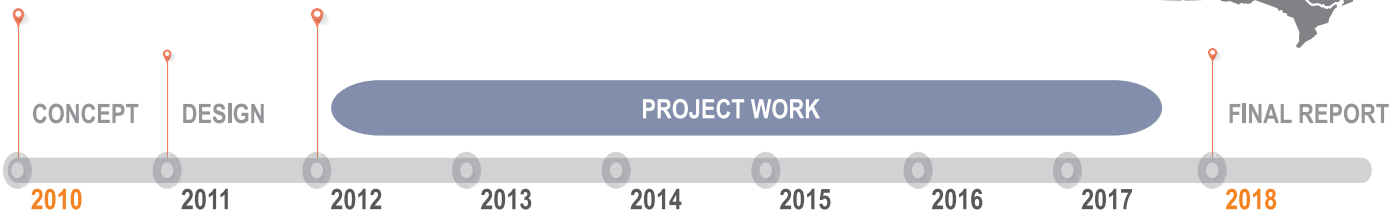
Fundamental microbiome work came out of ideas founded on research in the 1980s. Now the speed of analysis and quantity of data processed, combined with a collaborative research environment and industry expertise provided the key ingredients to develop the technique.

AI theory and algorithms were worked on as early as the 1950s and continue to develop over last 2-3 decades. These algorithms can now be executed, and the large volumes of data processed and integrated in 'real-time'.

Conducting mineral exploration in the modern context has led to numerous innovative approaches and new techniques. Examples of innovation can be found across all aspects of exploration in Canada.

CASE STUDIES

1 THINKING BIG: FOOTPRINTS



KEY PARTICIPANTS

Canada Mining and Innovation Council (CMIC)

Exploration Innovation Consortium (EIC)

DRIVERS

Deep Exploration

Target Generation

Data Collection

Data Integration

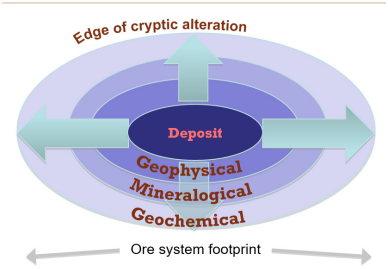
KEY FACTORS

Outside Expertise

Funding

Individual

The Problem



The big questions in mineral exploration are difficult to answer when most research work is carried out by individuals or groups on single deposits or camps. Typically, comparing different deposit types and developing comprehensive data sets of the scale and magnitude needed to test methods and models are not feasible. Defining the subtle, distal footprints of ore deposits is a challenge, as the resources of the future are most likely to be hidden under layers of cover.

The Innovation

Industry leaders recognized the key underlying issue for research and created an Exploration Innovation Consortium (EIC). The EIC would guide a broad and comprehensive research effort to study three different commodity types in Canada; porphyry copper, orogenic gold and unconformity-type uranium, using the same methodology at all three. Both the definition of the project and the consortium established to execute the work were innovative in Canada and internationally.

The Story

The concept of the EIC was formed in 2010, under the umbrella of the Canada Mining and Innovation Council (CMIC). The effort was led by a champion, Francois Robert (Barrick Gold) and supported by consultant Dick Tosdal. Francois and Dick criss-crossed the country meeting with industry groups and brainstorming – focussing on what industry needed to improve their rates of success. The idea was for industry to drive the research agenda. The final group was unusual in its diversity, with majors, juniors, and service companies from across the country and representing production of a wide range of Canada's commodities. The project was envisioned to evaluate multi-parameter footprints and 3D vectoring, working on detecting edges of deposits and directions towards ore. In addition, the effects of 'secondary dispersion' were also considered, i.e. what happens to the trace elements and indicators above an ore deposit in areas of cover?

In order to achieve those goals, the second innovation was use of a consistent methodology at deposits of three different commodities and hosted in widely different geologic environments. The undertaking was massive and on an unprecedented scale. The enterprise could easily have failed without the key people who stepped up to manage the administration and establish workflows and practices.

Three study sites were chosen, each a word-class deposit: Canadian Malartic Au, The Cree Extension-Millennium project, and Highland Valley Cu-Mo deposits. The spectrum of settings allowed a more robust development of methodologies. In order to integrate data, however, the methodologies for data collection also needed to be standardized. An additional common approach was taken that included the same team of experts at each of the sites, also facilitated by a researcher embedded at each study area.

The research involved 24 universities and a wide range of students, creating an environment that required team collaboration amongst researchers with diverse backgrounds. The work itself was heavily data focused, requiring a huge data integration effort including scanning old data and use of machine learning and algorithms as tools. The effort was based on the creation of a stable database for integrating the wide-ranging and complex data sets, and which created the opportunity to provide greater confidence in the signatures of ore deposits.

Challenges

The sheer size and nature of the program presented numerous obstacles, resulting in a slow start for some parts of the work. Industry support was challenged by the long timeline, and a three-year project duration would clearly be easier for organizations to plan for and commit to. Communication between the large and disparate group was both a challenge and a benefit to the work as it demanded consistent and frequent reporting and meetings.

Funding and Support

Major funding was provided by the *Natural Sciences and Engineering Research Council of Canada (NSERC)* through its Collaborative Research and Development (CRD) grant of $5.1M with $7M from industry. The final budget of $13M was the largest collaborative research and development project ever carried out. This funding was a direct result of the strong industry support and hard work already put in to the project before discussions started with NSERC.

Benefit

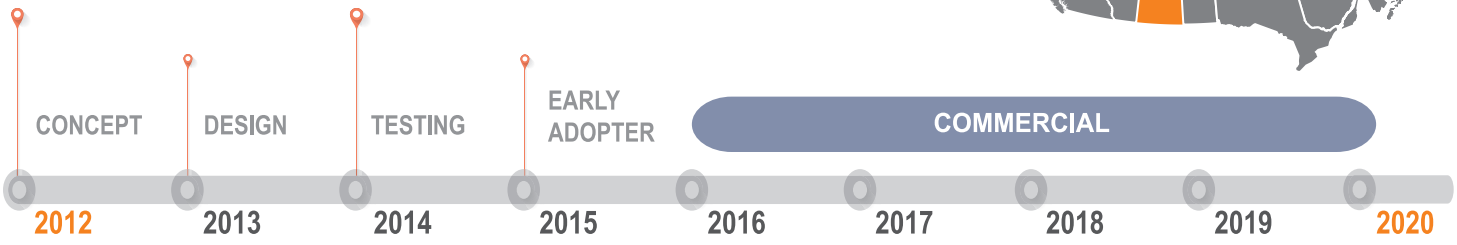
The training of young geoscientists in an industry focused environment, including extensive collaboration and diverse teams, was a significant benefit of the program. In addition, development of comprehensive data sets that can be compared between 3 different deposit types has produced an unprecedented database that will likely continue to benefit research and development in many areas of mineral exploration. Overall the large collaborative effort broke down barriers between industry, researchers and service providers.

Bottom Line

The EIC is the largest collaborative research project, focused on mineral deposits, ever carried out in Canada. The extensive databases and positive outcomes demonstrate the capability and willingness of those in Canada to work together.

CASE DETAILS	
5	Years
$13M	Budget
28	Companies
24	Universities
45	Researchers

2 IMAGING DEEP ORE BODIES



KEY PARTICIPANT

Dias Geophysical

RIVERS

Deep Exploration

Target Generation

Data Collection

KEY FACTORS

Outside Expertise

Funding

Individual

> We need to get into a full three-dimensional scanning of the earth. Much the same as you get these beautiful MRI body scans when something is wrong with your body.
>
> Dennis Wood, Discovery International

The Problem

A clear need was seen in the world of exploration to introduce three-dimensional (3D) imaging of the sub-surface, which meant developing methods of both acquiring data and visualizing it. The inversion modelling for 3D was already well advanced, but data acquisition had not caught up.

The original team with Discovery International Geophysics also knew that a competitor was carrying out surveys and taking business, but they envisioned tackling the problem differently.

The Innovation

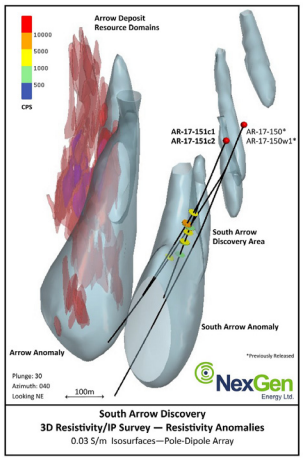
To solve the problem an entirely new array was designed – the DIAS32 cable free acquisition system – for the collection of data sets applicable to 3D modelling of IP/Resistivity geophysical data. A new company, Dias Geophysical, was also formed to provide services to the mining and exploration industry using the new technology.

The Story

Dennis Woods (Discovery International) was working on a separate project with some research funding and needed the right person for the work. Connections at the university put him in touch with a recently graduated student, with a specialty in earthquake seismology, an area of geophysics already operating in 3D.

Glenn Chubak had returned home to run his family landscaping business when Dennis phoned. A few months later the research project was on track and Dennis had given Glenn the new job of designing the 3D system. Within a few weeks the layout for the new arrays was complete and ready for implementation.

Remarkably, the early tests went smoothly, and development of the new system was rapid. The decision to start the new company, Dias Geophysical, quickly followed and Glenn Chubak now serves as VP Technology.



Grey shows resistivity zones defined in the survey – upper left is the Arrow deposit, to the right the South Arrow discovery zone.

Challenges

Although the arrays worked as planned, the sheer quantity of data presented challenges. Volumes of normal data points in an average survey are on the order of a few thousand to 100 thousand, and now they were handling 100x that, collecting millions and even 10s of millions of data points. Dias needed to develop their own quality control and processing software.

The big questions to address centred on quality control, and data processing. But perhaps even more important is how to decide what portion of these large data sets to use? In order to do all those tasks reliably, they needed to develop automated routines and employ machine learning.

With a focus on their primary business of high-quality data collection, Dias has developed strong collaborations with other groups in order to create the inversion models and interpret the data. This has allowed them to continue to rapidly build their business and refine their system.

Early Adopter

Dias Geophysical was contracted for a 2D survey by Rio Tinto, however they agreed to use the new DIAS32 array system. This gave the team an exploration example to verify data collection and processing, and an opportunity to use a comprehensive data set in the inversion modelling.

The next early success came when NextGen Energy announced that the South Arrow discovery zone flanking the Arrow uranium deposit, Saskatchewan, was discovered using a Dias Geophysical 3D survey.

Funding and Support

The initial work started with Discovery International, however the potential volume of work clearly required an independent operation. Building the new geophysical service company also gave them flexibility in terms of training people, marketing and operating.

Federal funding grants and tax rebates were vital for success and were delivered through the *Industrial Research Assistance Program (IRAP)* and *Scientific Research and Experimental Development Tax Incentive Program (SR&ED)* programs – these facilitated the rapid development of the technology.

Benefit

The need to drill deep holes under cover is aided by the higher confidence levels delivered by 3D models. These models provide a more well-defined level of target delineation, supporting decision making when drilling expensive (particularly deep) holes and allowing fewer holes to be drilled when testing targets.

There are environmental and safety benefits as well. For the same coverage required for conventional data collection, the new system requires fewer crew and less line cutting.

Bottom Line

A new company providing geophysical service globally was created with approximately two-thirds of its business in 3D data collection. The team has strong collaborative partners and business doubled every year, even during challenging market conditions.

3 MICROBIAL MINE FINDERS?

CONCEPT 2012 | DATA COLLECTION 2013 | 2014 | RESEARCH 2015 | 2016 | TEST CASE 2017 | 2018 | PRE COMM. 2019 | 2020

KEY PARTICIPANT

University of British Columbia, Mineral Deposit Research Unit

DRIVERS

- Deep Exploration
- Target Generation
- Data Collection

KEY FACTORS

- Outside Expertise
- Funding
- Individual

> A gram of fertile soil typically hosts more than 1 billion microbial cells with tens or even hundreds of thousands of bacterial species, each interacting with the environment.
>
> Peter Winterburn, NSERC/UBC

The Problem

Detecting the subtle signs of a mineral deposit buried under layers of glacial deposits or material derived from erosion, is a big challenge for exploration in Canada. With potentially very weak chemical tracers present in overburden, traditional geochemical sampling techniques may not show indications of deeply buried mineralization.

The Innovation

Recent advances in the understanding of microbial communities and their interaction with the local environment provides a new and novel approach to searching for deep or covered mineral deposits.

Centrifuge separation of DNA from sample for sequencing analysis

In order to understand these biological communities - genomics, a combination of biology, genetics and computer science - is applied to samples of soil. The samples are collected in a manner similar to standard geochemical samples. From these samples, utilizing the rapid genomic sequencing technologies available, the richness and diversity of the microbe species can be identified. Using statistical analysis, the profiles developed from the soils can be used to create indicators of mineral deposits.

The Story

Sean Crowe, a Research Chair in Geomicrobiology, worked on the idea of microbial indicators for many years, but the tools for sequencing and data analysis weren't fast enough to be practical. By 2013, the advances in lipid profiling and clone library-based community analysis provided the technical ability to pursue the idea.

A collaboration with Peter Winterburn, the NSERC/Acme Labs/Bureau Veritas Minerals Industrial Research Chair in Exploration Geochemistry, provided the perfect partnership and interdisciplinary research environment to pursue the new biogeochemical technique. Peter's industry experience and expertise was a perfect fit. The unrestricted nature of Peter's initial position also provided critical support for a novel approach to exploration geochemistry.

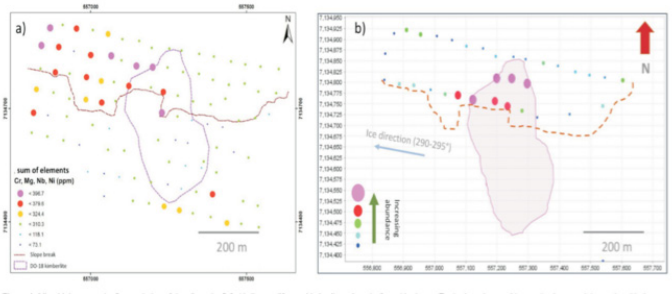
Typical B soil horizon for sampling

The first step was to proactively collect samples for future work, and to establish the sampling protocol, typically using the organic rich B horizon and keeping the samples refrigerated before archiving in a freezer 'library'. Key information such as pH and moisture content, were also recorded on sites in locations around the world. The work developed into a full research project with students, post-doctorates and professors collaborating with industry.

Test cases were needed to assess key aspects: viability of use as routine method in areas of till cover, the consistency of molecular microbial fingerprints as indicators of mineralization, and the relationship of the microbial community with its environment. A pilot study was carried out in Lac des Gras the NWT, to evaluate the viability of detecting kimberlites. The well-defined morphology of a kimberlite made them a good first test case, with positive results. Development of the technique was advanced with further proof of concept work on three porphyry Cu-Au deposits as test cases in British Columbia.

Challenges

Establishing microbial community indicators for mineralization is increasingly viable, however building reference databases is critical for the implementation of the tool and will require continued work to support determination of reliable indicators in exploration. Understanding variability in background levels, and development of statistical tools for integrating the 'fingerprint' anomalies with other geochemical, geological and geophysical data are also important.



Distribution of indicators a) elevated trace elements b) microbial indicators. Oval outlines kimberlite. Lac des Gras, NWT.

Funding and Support

Research funding was fundamental to the early stages of the project. A key factor was the NSERC/Industry funding provided through Peter Winterburn's chair at UBC. Case studies work and further research was funded through Geoscience BC, industry partners, the NWT Geological Survey and NSERC.

Benefit

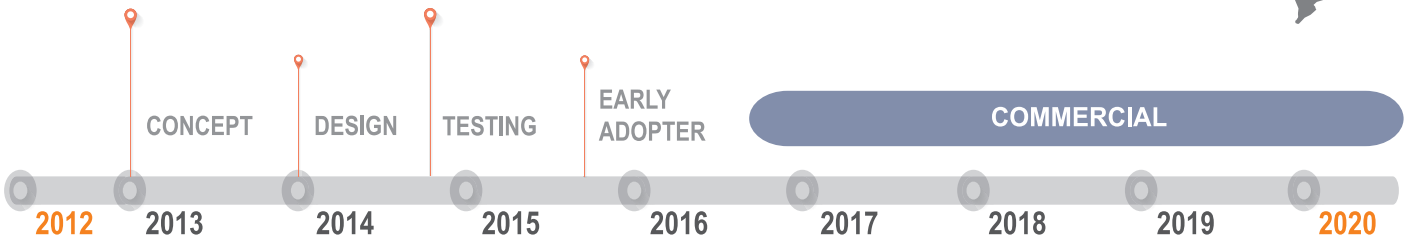
A functioning protocol for sample collection and development of known indicators for identifying kimberlites, and for further development in other geological environments is now in place.

As the technique continues to be refined, the mineral exploration industry may be on the brink of having a new reliable and cost-effective tool for making decisions regarding mineral potential that guides their programs and investment.

Bottom Line

Using microbial community indicators has significant promise as a new biogeochemical technique in exploration. Work remains however to cross over into use in active exploration programs.

4 WHY WASTE WATER?



KEY PARTICIPANT

HY-TECH Drilling Ltd

DRIVERS

Environment

Regulations

KEY FACTORS

Outside Expertise

> It is extremely beneficial to have a dedicated team in place to evaluate the endless number of ideas that come from our field crews, equipment operators and experienced personnel located in our branch facilities.
>
> Brian Butterworth, HY-TECH Drilling

The Problem

Diamond drills consume large amounts of water with on average 577,600 litres used for every 1000 m drilled. Water is pushed down the hole to cool the bit and move the cuttings back up to the surface. The process facilitates the drilling and recovers a clean core for analysis.

Standard practice is to drill using a continuous new water supply and allow the used water to percolate back into the ground. The cuttings and unconsolidated material from the drill process are typically buried in a large sump dug at the drill site. This approach is becoming unacceptable internationally. Both regulators and communities want to see better practices implemented.

The Innovation

HY-TECH Drilling Ltd. saw the need to design a method of reducing the water use in diamond drilling for mineral exploration. They envisioned a portable, easy to manage and care for system that attaches to a drill and recycles the water, creating a closed-loop. The system functions simply as a 'plug-in' to the drill. Cuttings are removed with a second very high-speed rotating assembly that pushes the solids out and the water is recirculated down the hole, resulting in 90% recovery rates.

WATER USE REDUCTION

577,600 L → 2400 L

The Story

In their workshop in Smithers, B.C., HY-TECH Drilling has its own full-time R&D unit of two people – an engineer and an experienced driller who understands the practical applications.

HY-TECH drill with plug in centrifuge system, on site in NW British Colombia.

WHY WASTE WATER? 4

An independent drilling company, HY-TECH manufactures and operates their own drill unit that is lightweight and portable and ideal for challenging locations. Design and innovation are integral to the company and proprietary technology has been developed over many years, including various patented components. Feedback and ideas from the drillers in the field is vital to the process. The first step was to look outside the minerals business for solutions.

The team investigated existing technologies for water treatment such as clarifiers, shaker screens and centrifuges. The benefits to centrifuges became apparent. They realized that this process was already being used in the oil and gas sector, so they went looking for existing solutions. They were able to work from systems already in use and find alternative components of the right scale for diamond drilling. The system was then designed around the centrifuge to create a low interaction 'plug and play' solution.

Challenges

HY-TECH tested units used in the oil/gas drilling systems. Clearly, these were developed for holes an order of magnitude larger than typical in minerals exploration. Bringing the oil and gas equipment into Smithers required two tractor trailer loads; a daunting task. The next step was to find a small centrifuge or rotating assembly and then adapt that to plug and play into their drill equipment, working with the pumps and the rest of the drill equipment. The solution had to be helicopter portable, be intuitive and have a low interaction level from the crew.

Now with a functioning system with 13 units in operation, HY-TECH are working on version 4. The next challenge is to deal more effectively with the very fine clay fraction in the water. A particle size of 2-10 microns limits the processing capacity. Self-cleaning improvements are the next priority, again reducing the interaction level.

Early Adopter

One early adopter was Pretivm – they were working with a more advanced project and looking to reduce water consumption and needed to clean the water going to their operations plant. Other clients were working in an area with public viewing and realized that a clean and tidy operation would be positive for both them and the public view.

Typical sump used for waste water and drill cuttings on-site.

Waste from closed-loop drilling ready for transport off-site.

Funding and Support

Grants from *IRAP* were key to a positive outcome, providing critical funds to create an encompassing diamond drilling specific solution. Government regulators were also supportive, realizing the benefit of water re-cycling and recognizing the environmental value.

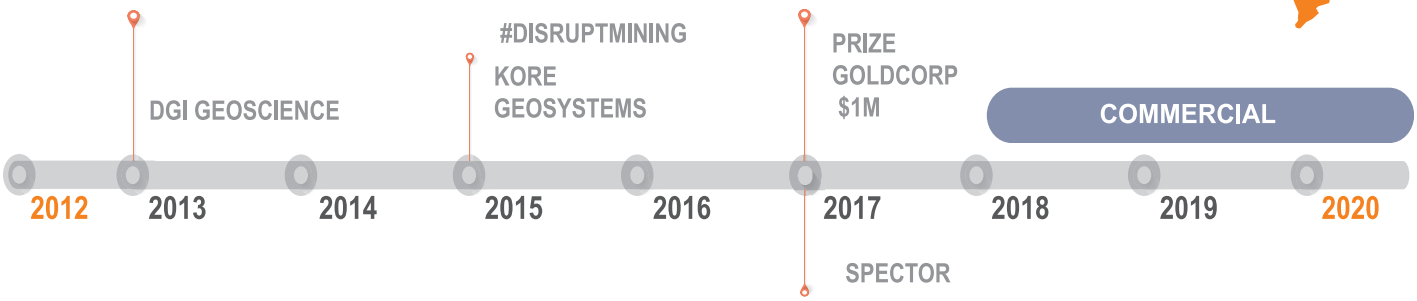
Benefit

Companies carrying out mineral exploration can substantially reduce water use. This approach is responsible and environmentally beneficial and can also be helpful in community relations and acquiring government permits. Operating in a more responsible way has big benefits for both clients and HY-TECH, creating better outcomes on the ground and with community relations.

Bottom Line

HY-TECH Drilling has developed a competitive advantage and are able to supply clients globally with an effective water management tool. Currently 13 centrifuge units are in use, creating value for them, their clients and the local areas in which they work.

5 CORE – A CLEAR PICTURE



KEY PARTICIPANT

Kore Geosystems

DRIVERS

Data Collection

Data Integration

KEY FACTORS

Outside Expertise

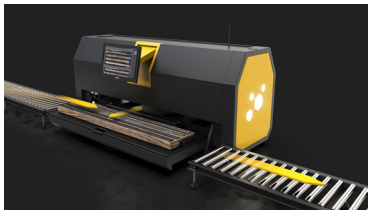
Funding

Individual

Prize

> …in fact, core logging is just data collection…geologists should be doing what they do best, which is making interpretations and decisions, not data collection.
>
> Chris Drielsma, DGI Geoscience

The Problem



Spector Optics Scanner

Core logging is a fundamental part of any exploration or mining program, with geologists visually examining thousands of meters as projects develop. This data collection can be tedious, subjective, and inconsistent depending on the team and project constraints. Geological logging is often a bottle-neck lagging behind drilling, resulting in significant delays and lack of access to timely decision-making intelligence.

The Innovation

Kore Geosystems designed a more consistent and faster platform for core logging. The solution consists of a high-resolution core imaging system and user-friendly software enhanced with machine learning, providing quick and efficient data collection.

Spector Optics can process up to 1000 m per day with the depth referenced images immediately available in the cloud. Geologists can log the core directly with touch screen or mouse gestures, avoiding time consuming manual text entries. Rock type classifications can be automatically ‘recommended’ by an AI model to assist with consistency and reduce data entry time. The AI model is trained on the unique characteristics of each site, with project specific lithology/alteration labels.

The geologist is always in control and accepts or rejects the machine learning recommendations to ensure accuracy.

The Story

The team at DGI Geoscience have thrived on new challenges right from their founding by Vince Gerrie in 1997. The company is based on the principle of providing the mining and exploration industry with more value from drill holes - from stacking sensors, to collecting digital oriented core and working in extreme environments.

CORE – A CLEAR PICTURE 5

Since DGI is well versed in data collection, they knew how much data was being acquired as well as the gaps in interpretation and clients overwhelmed with data. The issue was heightened in the downturn, with managers lacking technical staff to aid interpretation. The solution as early as 2009 was to start working with cluster analysis and machine learning applications to extract more value from data.

In 2015 DGI partnered with an Australian engineering company to work on an integrated approach to data collection and interpretation using machine learning, forming Kore Geosystems. The team built a core imaging system (SPECTOR Optics) that uploads images directly to the cloud and provides information in real time.

As SPECTOR continues to be employed, other data sets such as geochemistry and hyperspectral data can be incorporated to create a comprehensive geologic and alteration models.

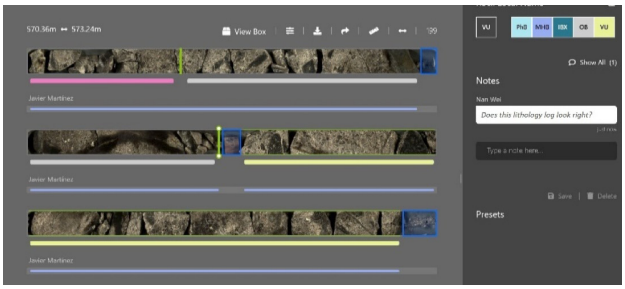
If the geology team needs to revise the geological model, the updated interpretation can simply be applied to all the data, versus having to pull out thousands of meters of core boxes one at a time. Geotechnical information can also be categorized and collected, facilitating RQD calculations.

Challenges

The largest challenge was finding funding for the development. The early stages of work were all self-funded. Once the project was advanced to the stage of proto-type testing and implementation, significant funding was needed to move to commercialization.

Early Adopter

In 2017, KORE won joint first prize in the #DisruptMining competition at the annual PDAC Convention. Based on that success, KORE negotiated a $1-million investment from Goldcorp, including implementation at a site in Chile.



SPECTOR user interface

Funding and Support

Early development was completely self-funded. Following the deal with Goldcorp however, KORE leveraged the investment and obtained both *IRAP* and *SR&ED* funding. The 'prize' was the transformative event, providing the investment needed to bring the system into practical use.

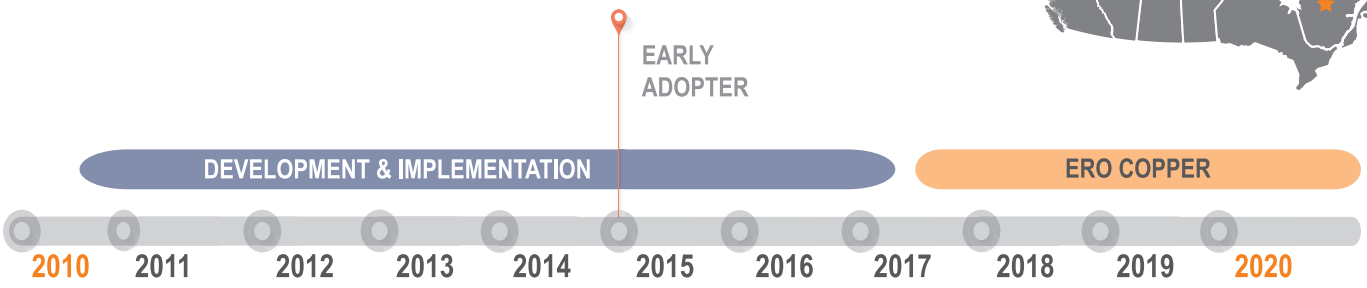
Benefit

Spector provides a flexible and efficient core logging tool, with a well curated data acquisition system and with geologist interaction. The machine learning allows the system to be trained to predict rock type and alteration and improves with additional data. A chat function also allows the team to discuss interpretations and categories. Ultimately the system becomes a 'smart companion' for the geologists, helping focus them on the most important areas.

Bottom Line

The Spector system was initially deployed at a Newmont Goldcorp site in Chile and is currently in use at other majors' sites in Canada, USA and Australia. Kore Geosystems is now working to introduce the system to other groups and demonstrate its value in multiple environments.

6 DRILLS AND DATA



KEY PARTICIPANT

Infotierra and Ero Copper

DRIVERS

Data Collection

Data Integration

KEY FACTORS

Outside Expertise

Individual

> The system works because it is customized, which makes it very functional, and you don't need training. I mean, everybody, drillers, technicians or geologists, can pick up the iPad from the desk and start working.
>
> Stephane Peloquin, Infotierra

The Problem

Data acquired from drilling activities includes everything from log descriptions, sampling, density measurements and assay results to the driller's activities during a shift. The amount of data is enormous, and the acquisition strategy has to be setup perfectly to eliminate errors and make data available as fast as possible for decision makers. Unfortunately, data acquisition methodologies generally still involve a lot of paper and re-typing in an excel spreadsheet, which affect speed and accuracy.

At the Caraiba copper Mining Complex, in Brazil, the geology team used classic data acquisition methodologies for their average annual ~20 000 meters of drilling program until 2016. Ero Copper acquired the Caraiba Mining Complex in late 2016 and initiated plans to drill +150 000 meters; therefore, data acquisition, organization and analysis needed to be much more efficient and things needed to change quickly.

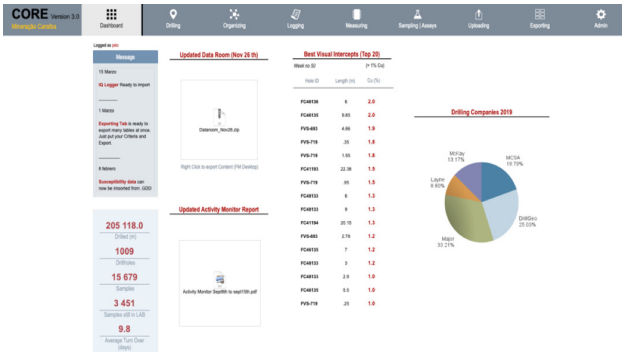
The Innovation

A robust data acquisition system that is simple to use and flexible enough to adapt to the flow of an existing operation. The basic premises of the design were that the data system needed to be simple, highly flexible and data could be acquired via iPads by geologists, technicians and drillers.

The Story

Stephane Peloquin (Infotierra) and Mike Richard (Ero Copper) are geologists that have been working-on innovative exploration ideas for decades, Mike as a manager and Stephane as a developer and programmer. Since the beginning, they have focused on looking for simple, creative ideas and new ways of doing things.

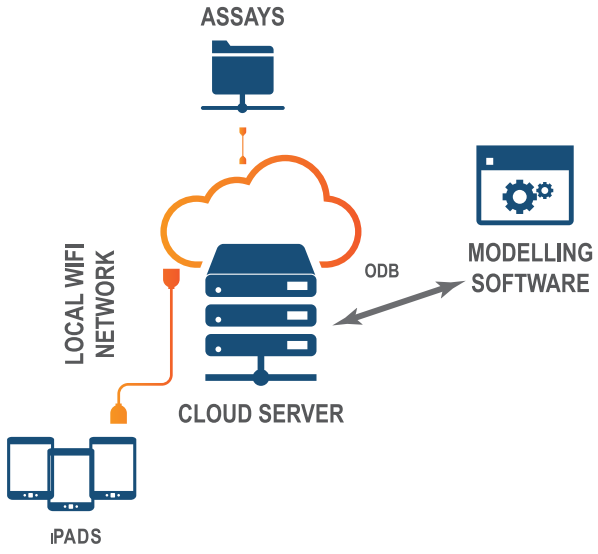
Given the size of the planned drill program (+20 drill rigs), the lack of time for implementation and the local geological team's limited experience with large



digital data systems; Ero Copper took the risk of designing their own Data Acquisition System and Central Database. In part, the idea was that an in-house design of the system would be accepted more easily by staff.

Experience suggested that a large complex commercial data acquisition and database management system was not the way to go in Brazil. Simple pull-down menus, mobile devices, easy cloud access and fresh ideas would form the base of the Optimal System. Initial foundations of what now is CORE were developed in 2013 starting with major mining companies in Chile, Peru and Turkey and Ecuador. Other versions were developed by Stephane for companies working in Spain, the Dominican Republic and the United States.

Ero contracted Infotierra to create a suite of applications to be used on tablets with the objective of a rapid implementation. Infotierra worked with the local staff to design each module therefore making sure that the new system would be accepted without resistance. It was assumed that things would not be perfect at the beginning, so even during production, coding was done on the fly and modifications to the system were conducted almost daily using a transparent way of updating each module.



Another important innovation is that the locally collected (iPad) data is synchronized to a cloud server (AWS, Amazon) where all the information is made available via a web browser. No need for local servers, no need to take care of maintenance or updates by the IT group.

Ero Copper's project in Brazil is different and at another scale to what was done previously but the foundation was there. Less than two years after creating the first "Caraiba version" for Ero Copper, more than 70 iPads are at work.

Challenges

The biggest challenge was transforming the culture of a 40-year-old mining company while drilling eight times more meters per year than previously.

The interface of the programs was also a hurdle, with it important to be able to migrate professionals of different backgrounds to a new system without any training.

Funding and Support

The entire system is self-funded by Ero Copper, with Infotierra contracted to design and manage implementation of the system.

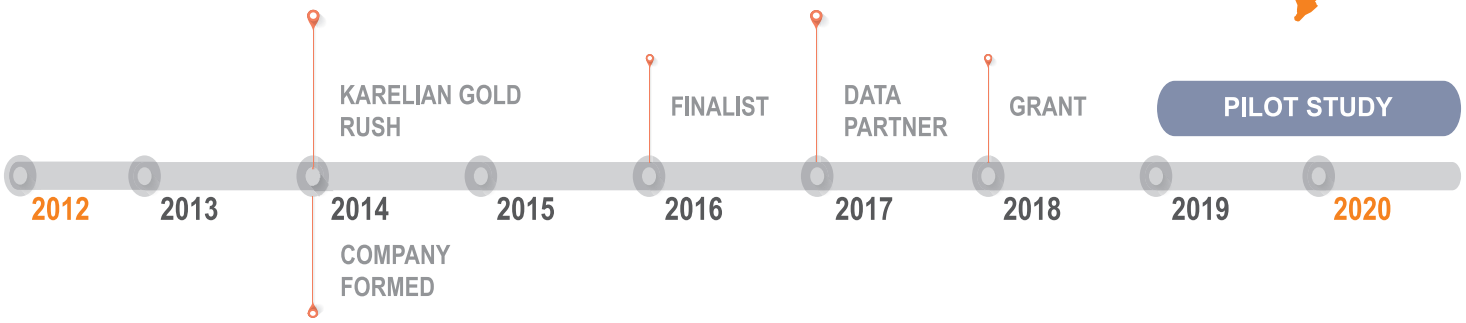
Benefit

Ero Copper is now working with an ultra dynamic customized system that allows the company to "see" what is happening at every moment. Decisions are taken daily to adjust the drilling and shorten the time to discovery and value creation. Constant news flow is critical to new companies. Ero believes that without CORE it would have been practically impossible to gather, organize and analyze so much information so quickly.

Bottom Line

During peak drilling production in 2019, 36 drills were operating, more than 80 professionals were entering information via iPads and thousands of records were uploaded per day. The daily automatic reports assure that senior staff and managers can make effective and real-time decisions.

7 WHAT ARE THE ODDS?



KEY PARTICIPANT

Ronacher McKenzie Geoscience

DRIVERS

Target Generation

Data Integration

KEY FACTORS

Outside Expertise

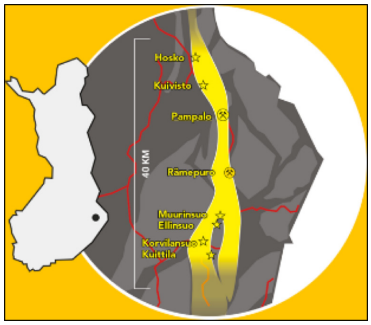
Funding

Individual

> It's really difficult to keep 33 elements in your mind over 40 kilometres and relate that to geophysics, alteration and geology with a human brain.
>
> Elisabeth Ronacher, Ronacher McKenzie Geoscience

The Problem

Target generation is an increasingly difficult task, with resources hidden under cover and success rates diminishing. Part of the issue is effectively integrating data, a core business for Ronacher McKenzie Geoscience (RMG), but a challenging one with ever growing data sets.



Karelian gold belt, Finland

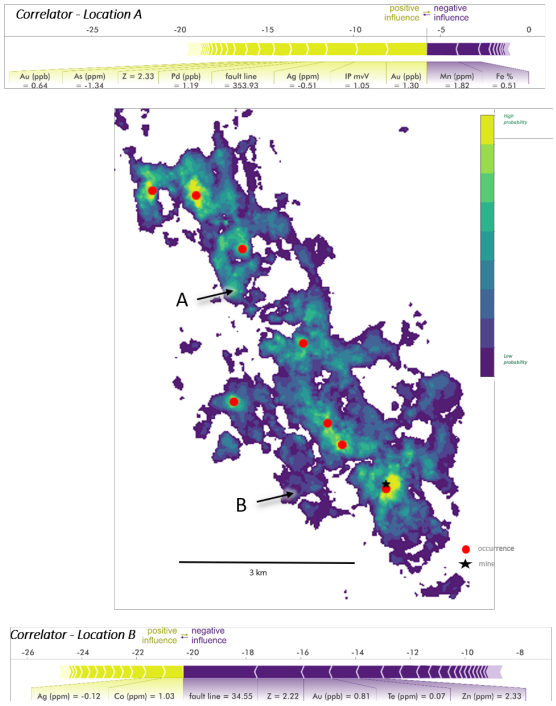
The Innovation

The manual process by its very nature means having to reject data as inconsequential to the ultimate targeting process, whereas a machine learning approach would allow use of all the data. The team partnered with a data analytics company to develop a machine learning tool for target selection on a regional scale, creating probability maps.

The Story

Elisabeth Ronacher and Jenna McKenzie formed their consulting company in 2014 as a service group providing customized data integration and analysis to its clients. An important aspect of their service is to give geological context to geophysical data, enhancing area and target selection. In five years, they have grown to a group of 10 senior geoscientists with diverse expertise.

A challenge in 2015 by Endomines in Finland intrigued Elisabeth and Jenna, largely due to the scale of the data set. The database included geology, structure and alteration, as well as till and bedrock samples (~100,000 multi-element samples). In addition, extensive geophysics was available: magnetics, chargeability, resistivity and conductivity. The goal was to find new targets in a belt that appeared prospective but where traditional exploration had not delivered results efficiently and quickly. Searching for new ideas, Endomines created an open contest, setting up the 'The Karelian Gold Rush'.



Probability map showing the likelihood of an area to host mineralization. Location A is a point with high probability to host mineralization. The correlator on this area is displayed at the top of the figure. Location B has lower probability. The key parameters with positive influence are gold, chargeability, silver and distance to fault.

The team worked for 2 months, manipulating, analysing and integrating the data sets in 3D. From an original 150 teams downloading the dataset, they finished as a finalist. The big takeaway for them was the need to move on from human methods for targeting and develop a ML approach.

The team initiated an in-house project, sourcing knowledge and expertise in AI and data analytics in another small data and software company. A partnership was created to obtain ML insights from a well-integrated and comprehensive data set through probability maps. Initially the data for training the system was largely in 2D. The first pass was promising, but the team realized they needed more information to train it well.

After a two-year hiatus, RMG went back to Endomines and explained their new work on the dataset. The timing was good, post the challenge, the company had not advanced the work in the Karelian, while they focused on a more advanced project in Idaho, USA. Intrigued by the initial output provided by RMG, they shared additional data, providing shapes of known ore zones to add to the modelling. The result was improved and a new probability map was completed. They also created a tool, called “The Correlator”, to determine the relative influences of each parameter on the probability.

Throughout the process, data handling protocols were put in place, with standards for cleaning data and creating systematic files in ASCII format that can be read and stored in a cloud-based server system.

Challenges

Early on there were issues creating strong communication with the data analytics group, establishing common language and explaining what the critical needs of mineral exploration. Learning how to communicate with each other took patience.

Early Adopter

Endomines’ willingness to engage with RMG following the challenge results, allowed them to develop the new ML approach and to re-evaluate their data integration with a methodology that is more efficient.

Funding and Support

Ronacher McKenzie Geoscience received a grant from the Federal Governments *Women Entrepreneurship Fund*, enabling them to dedicate time to the project and accelerating the completion.

Benefit

Promising advances in the ability of exploration groups use large data sets effectively and define target zones with greater confidence levels and potentially less risk. Created a ML assistant to the geoscientist that predicts targets and determines the correlations to and relevance of individual parameters for exploration.

Bottom Line

The company has a newly developed ML tool now available as part of their business, and ready for implementation by clients.

8 DATASETS: SMART INTEGRATION

INTEGRA GOLD RUSH

1ST PRIZE XPLOREIQ

EARLY ADOPTER NAP

COMMERCIALIZATION

2012 2013 2014 2015 2016 2017 2018 2019 2020

KEY PARTICIPANT

SGS Geological Services

DRIVERS

Target Generation

Data Integration

KEY FACTORS

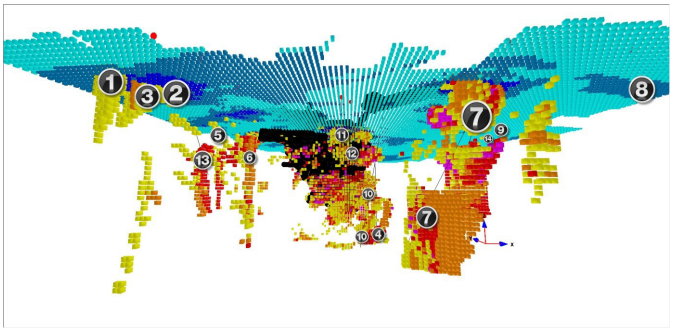
Outside Expertise

Funding

Prize

The Problem

During a downturn in commodity cycles, Integra Gold Corp. – a junior mining company – needed to find a way to evaluate a comprehensive data set in an established mine camp in Quebec. The active mine was closing after 85 years and resources were limited, so they opted to create an open source data challenge, banking on the ability of competitive teams to find new zones.



Original model for the Integra Challenge

> We feel that there's a real interest in the mining industry to use advanced mathematics and technology to analyse data; integrating historical, public and current exploration data sets.
>
> Marc-Antoine Laportez,
> SGS Geological Services

The Innovation

SGS is a group normally busy with mine and development analysis and resource calculations, but in 2015 the same downturn in business meant they had time to spare. Management agreed to give the team time to enter the challenge, realizing that even if they failed, the process would likely yield valuable benefits for the business. The SGS team went on to develop a machine learning data integration tool, XploreIQ, that correctly identified zones of mineralization.

The Story

A group of nine SGS Geological Services professionals, with diverse experience of geology, geochemistry, geophysics and mining engineering took on the Integra Challenge and spent four months developing an approach. The team began to play with the datasets using conventional tools, but quickly realized other approaches might be more productive.

New zone of mineralization identified at Lac des Iles Deposit, North American Palladium

With no pressure on them to succeed, they decided to try machine learning. The first pass with an organized block model went well, so additional information was added for quality control.

The diversity of the team was critical to success. In particular, an important part of the process is to create vectors and train algorithms, requiring geologists to provide real information and verified examples. A system trained on false principles will of course yield false targets.

By the time of the challenge presentation, SGS had a solid product, and a slick virtual reality-based presentation. They won the competition where only a few other teams used some form of AI or machine learning. Initially there was no plan to commercialize, however client enquiries continued to come in asking for SGS to review data sets and apply their data analysis in a variety of settings.To begin with there was just one or two contracts per year, but demand increased substantially, prompting further development and refinement.

SGS invested in the data management side of the business, carrying out its own R&D, as well as developing a proprietary software package. Research continues on the next generation of algorithms using neural networks and deep learning, testing improvements.

Individual companies may lack the internal resources to execute this type of work. In particular, a tremendous amount of effort is required to digitize historical data and create datasets ready for integration and analysis.

Data storage is also a challenge, currently solved by using ‘the cloud’. SGS is going through the process of eliminating physical servers, moving to a completely cloud-based system.

The density and quality of datasets in brownfields settings (mining districts) means that these target areas are ideal for machine-learning and AI, and they remain the core part of the business for SGS Geological Services.

Challenges

Competition in the AI and machine learning space is building quickly with many groups building expertise rapidly. However, there are also multiple approaches possible and numerous projects that require this type of data-driven analysis, providing extensive opportunities. It is unlikely that one company will provide the solution for all the data integration projects and problems.

Early Adopter

North American Palladium brought in the SGS Geological Services team to work with them on the Lac des Iles Deposit, Thunder Bay, Ontario, one year after the Integra Challenge. Processing and analysis of the data using XploreIQ defined a new mineralized target zone that was verified by drilling.

Funding and Support

A combination of the support of management at SGS, who realized the potential benefits of the competition process to the company as well as the prize money offered by Integra ($1M total) created the perfect conditions for success.

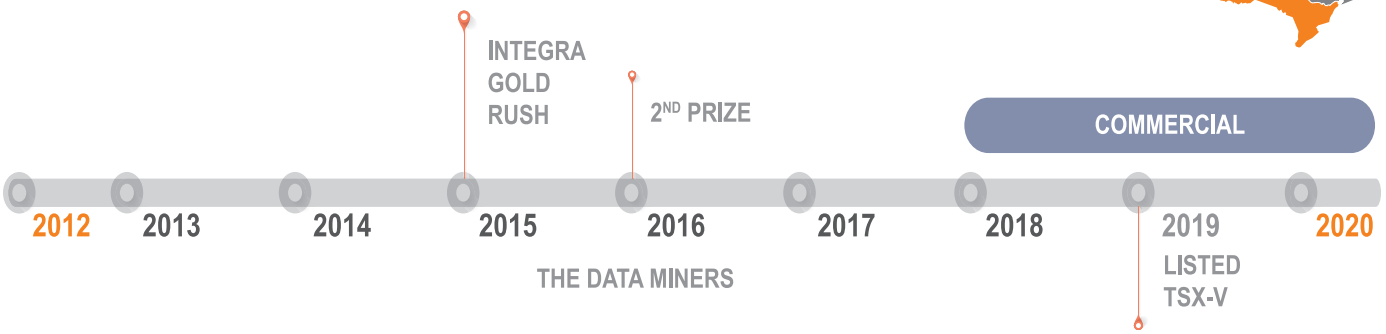
Benefit

With an effective machine learning system and model, the geologist can improve the outcomes by creating probabilities and continually update models. With real-time models, a big benefit is increased certainty leading to better targeting and potentially reduced drilling, creating cost savings.

Bottom Line

By 2018, SGS Geological Services was using XploreIQ extensively and projects were being coordinated globally by SGS. Currently it is close to 35% of the business. The scale of the projects has also increased, both with respect to size of areas and amount of data.

9 FROM DATA MINERS TO TSX-V



KEY PARTICIPANT

GoldSpot Discoveries Corp.

DRIVERS

Target Generation

Data Integration

KEY FACTORS

Outside Expertise

Funding

Prize

> At GoldSpot, 27 people are all working hard every day, but there's no reason for them to. There's no whip, right? And the carrot is that we all have a job. And we like it. And to me, that's super cool.
>
> Shawn Hood,
> GoldSpot Discoveries Corp.

The Problem

The 'Data Miners' were big news in 2016, coming in second to SGS in the Integra Gold Challenge. The team, however, were a group of students based in Quebec and British Columbia, with no formal industry connections. Was it possible to capitalize on the talent and abilities of the young team, while also helping to solve the problem of finding mineral resources?

The Innovation

The demonstrated abilities of a student team were combined with the expertise of experienced junior mining business professionals, creating a company with a broad approach to creating value. The publicly-listed junior exploration company applies advanced data analytics and machine learning to process geoscience data, identify mineral targets and solve exploration problems.

The Story

The original team formed as an alliance spanning the country, a collaboration between students at the Institut National de la Recherche Scientifique (INRS) and the University of British Columbia (UBC). They built a group with the diverse backgrounds in order to develop a machine learning solution for the Integra Challenge in 2016.

FROM DATA MINERS TO TSX-V

9

Initially the team worked as individuals on facets of the data which matched their expertise. Key to success was Vincent Dubé Bourgeois, now COO of GoldSpot, who melded the work and ultimately packaged it for presentation. The independent and youthful nature of a group, with a quality product, attracted the attention of Denis Laviolette and Cejay Kim. The pair of mining business professionals initiated discussions which led to the formation of GoldSpot Discoveries. A corporate structure and initial private investment were followed by a handful of early jobs that produced clients who not only liked the results, but also invested in the company.

Right from the start, a very flat organizational structure was created, aiming to create a culture where everyone wants to be involved and to contribute. Hiring is done based on finding the right people for the culture of the company, but not inserting them directly into an organizational chart. New staff can grow into the positions that fit them best and allows them to add the most value to the group.

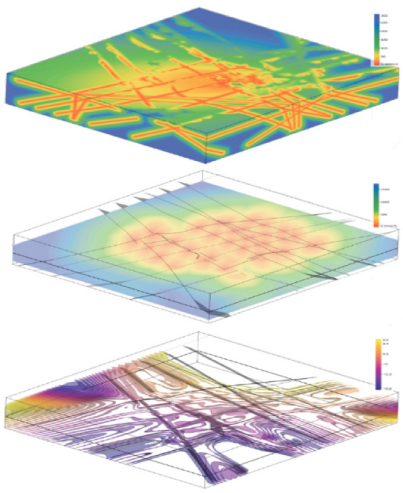
Projects include a variety of commodities and range from 2D regional greenfields targeting and mine camp exploration, to brownfields mine extension, to collaboration with multi-stakeholder research efforts such as Metal Earth at Laurentian University in Sudbury. In addition, internal R&D is continuous and includes close to 40 initiatives. The CEO plays a critical role in keeping the teams' focus and work on track.

The company operates on a flexible basis, from cash for services to investing directly in companies, up to a cap of 9.9% and building their own stock and royalty portfolio. GoldSpot strives to develop collaborative, ongoing relationships and to provide individual and modular solutions to problems.

Data sets are hugely variable, as is the quality of the storage, ranging from mouse eaten and water damaged paper to perfectly formatted and cleaned Excel spreadsheets. Projects may require natural language processing, deep learning photo processors or adaptations of machine learning algorithms. GoldSpot uses its geoscience expertise to do exploratory data analysis, to identify which patterns are useful and which can be cast aside, allowing the group to chisel away to the nugget of the problem. This part of the work can be as much as 75% of the project.

Challenges

Building relationships with clients is important as is developing the right framework for each deal. Some partners or clients may be disinclined to work with a company that also funds its own projects and takes and equity stake in others. By nature, being listed as a junior mining company also requires promotion, which is difficult to balance with demonstrating strong technical capabilities.



Schematic workflow

Early Adopter

While still private, the first consulting assignment was for Sprott Mining Inc., where GoldSpot was deployed on the prolific Jerritt Canyon camp in Nevada.

Funding and Support

The Integra Challenge was the kick-starter for the eventual formation of GoldSpot Discoveries. Early private investment by Eric Sprott and Hothschild Mining led to Triple Flag, taking the lead order in GoldSpot's $7.5 million go-public financing. U.S. Global Investors bought in and Frank Holmes serves as GoldSpot's Chairman.

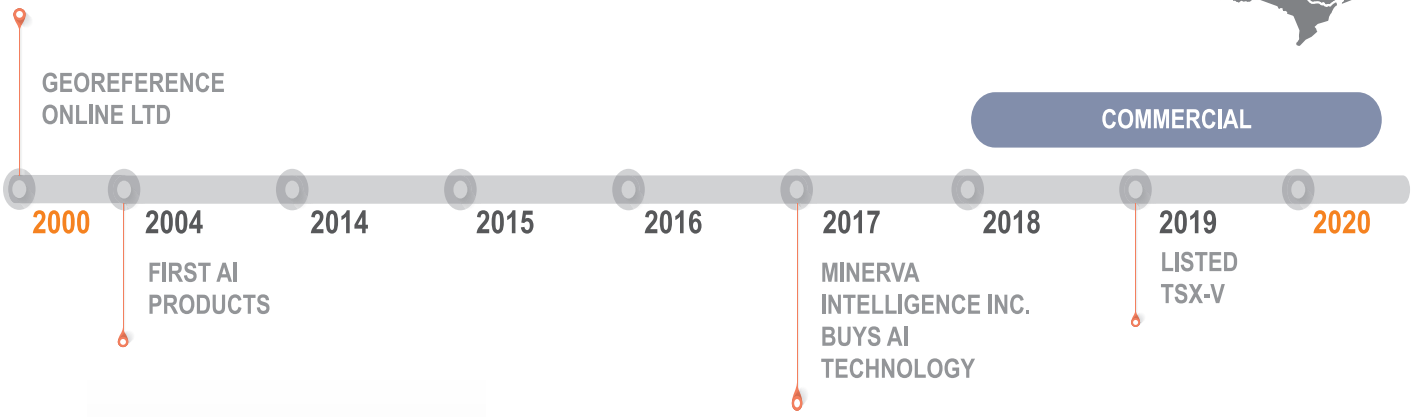
Benefit

GoldSpot Discoveries is adapting data analytics, machine learning and AI to create value and target mineralization. The company provides flexible solutions for data-oriented problems, taking advantage of large datasets.

Bottom Line

GoldSpot Discoveries is one of the new exploration companies that is using data analytics, machine learning and AI to create value and target mineralization.

10 THE VALUE IN WORDS



KEY PARTICIPANT

Minerva Intelligence Inc.

DRIVERS

Target Generation

Data Integration

KEY FACTORS

Outside Expertise

Individual

Funding

> Our bottom-line business model is software as a service, including geological knowledge within the software. To do that we have to make sure that geological knowledge and data use the same semantics.
>
> Clinton Smyth, Minerva Intelligence Inc.

The Problem

Datasets and geological knowledge have increased exponentially in the last 30 years and now encompass a broad range of resources from hand-written reports to millions of digital geochemical analyses. Finding useful information and integrating old and new data in order to effectively identify targets for exploration, creates corporate headaches and requires hundreds of hours of labour-intensive work.

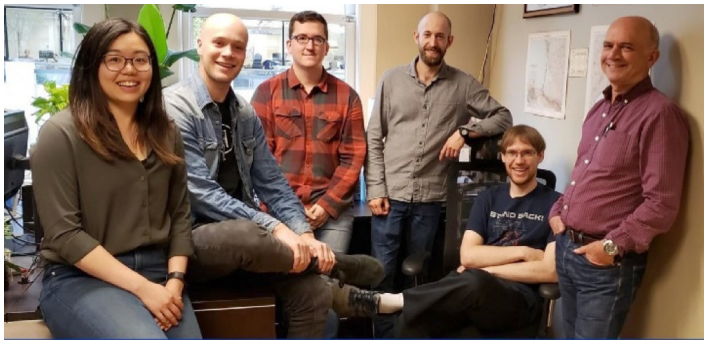
The Innovation

Embedding geological knowledge into computers and enabling them to carry out first-pass interpretations of data should lead to more effective mineral deposit exploration. The solution was to apply AI's knowledge engineering technology to the problem, combining both geoscience and computer science expertise.

The Story

Minerva Intelligence Inc. dates back to work carried out by the Anglo American Corporation of South Africa in the 1980s and 1990s, where there was a culture of institutional support for research. Clinton Smyth was put to work on artificial intelligence initiatives into expert systems, pattern recognition and logic programming.

The Anglo team also explored the use of neural networks. After moving to Canada in 2000, Clinton partnered with Professor David Poole at the University of British Columbia (UBC) to pursue an AI approach to minerals exploration incorporating knowledge engineering, logic programming and Bayesian technologies.



The driver for the new partnership was the desire to combine their scientific curiosity with business relevance. The partnership paired domain expertise from the mining industry with the specialist computer science expertise available from the university. Georeference Online Ltd., a private company, was the early vehicle for delivering their solutions to governments and the industry. Early trials included comprehensive British Columbia and Yukon exploration target maps, the latter recently updated and now freely available online.

Over the years the company was stable as a small consulting group. In 2017 their AI technology was purchased by a venture capital (VC) group and a new company, Minerva Intelligence Inc., was created. The team grew rapidly and began refinement and expansion of their products and services. The current staff is at 19 and the company has established a subsidiary in Germany. Key to their work is achieving interoperability between data and geological knowledge as expressed on a computer. They use semantic networks to represent and process knowledge about mineral deposits and deposit models and to represent information extracted from exploration data.

Products now include cloud software for managing earth science terminologies and large document collections as well as an application for interpretation of multi-element drill core assays. A consulting service assists companies with terminology standardisation and workflows preparing exploration and mining data for a range of AI applications. Continual development is critical, and Minerva maintains strong relationships with MDRU-UBC and Mitacs, supporting three MSc students at UBC.

Challenges

Finding and using semantics that are “interoperable” between geologists, the knowledge they use, and their data, is a fundamental challenge for Minerva and the entire AI community. Minerva addresses this challenge is by being a strong supporter of standards organisations working internationally.

Early Adopter

Work with governments including the Yukon and British Columbia Geological Surveys and the Geological Survey of Canada provided early demonstrations of viability.

Funding and Support

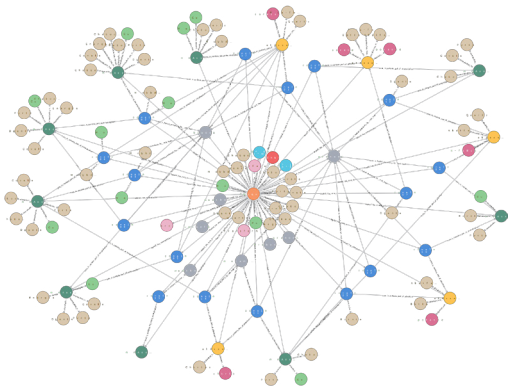
Georeference Online Ltd. from 2000-2017 was privately funded and supplemented with limited SR&ED support for five years. Minerva purchased the AI intellectual property from Georeference in 2017, and injected US$5 million into the resulting company, going public in May 2019.

Benefit

Minerva’s work highlights the importance of semantic standards, and helps drive the industry towards the adoption of the consistent language that will increase the interoperability and ultimately the rewards that semantic standards provide. Most importantly, effective use of the knowledge-based tools can reduce exploration costs and improve success rates.

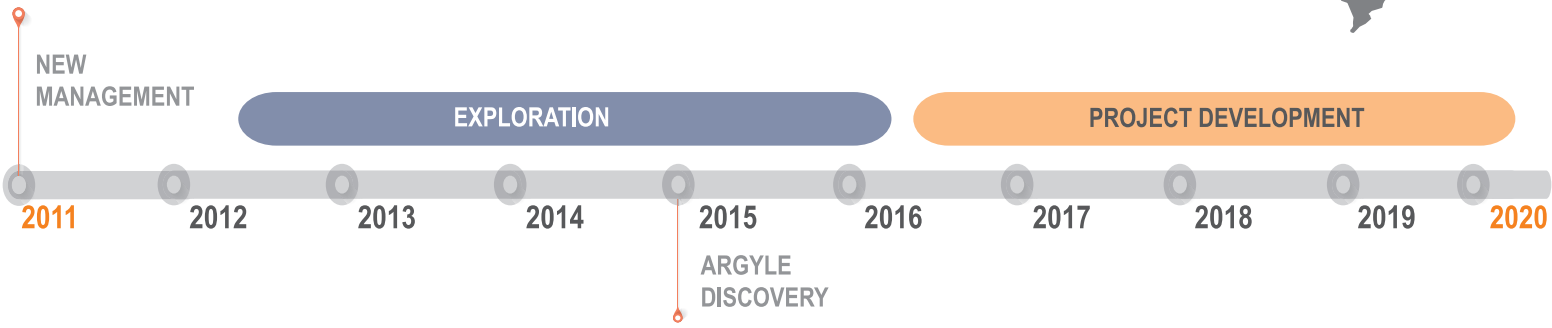
Bottom Line

Minerva Intelligence is a rapidly expanding knowledge-based company with the ability to solve complex technical problems using AI.



Schematic of semantic network for Chuquicamata, Chile

11 DOING MORE WITH LESS



KEY PARTICIPANT

Anaconda Mining

DRIVERS

Value - Community

KEY FACTORS

Funding

Individual

Team Culture

> We have to do more with less and we believe that innovation allows us to do this and is a key tool that will lead to continued business success… From a junior exploration perspective, we believe that encouraging this culture internally and collaborating closely with others will spark multiple levels of innovation that will become standard exploration practice leading to future discovery.
>
> Paul McNeill, Anaconda Mining

The Problem

Anaconda Mining has an operating gold mine and processing plant in the Baie Verte Peninsula, Newfoundland, an area that had been prospected and explored for over 100 years. The challenge was to find new resources to supply an already operating mill, with the aim of building value for the company, while also creating employment and benefit to the local community.

The Innovation

Following the development of the Pine Cove deposit, the company needed to address the challenge of finding new resources and recognized that building an innovative culture and collaboration would be key factors. A talented team was assembled, including exploration management, staff and consultants. A complete change in workplace culture was introduced creating a collaborative environment and a focused geologic and technical program was initiated.

The Story

Anaconda Mining was a company with an operating mine, but limited capacity to deliver new resources.

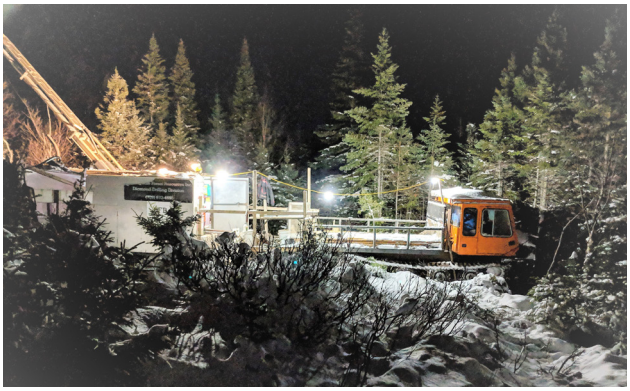
Exploration on the Baie Verte Peninsula, Newfoundland

Early in 2011 the change in management brought in a variety of innovations, including education of the employees and strong relationships with research staff at Memorial University of Newfoundland (MUN) and the College of the North Atlantic in St. John's (CNA).

The focus was on building the capability of staff and applying the best technical approaches possible to create success in the well-explored region.

In 2014-2015, the group at Anaconda noticed an area with minimal soil coverage and prospective geology and undertook a soil survey. Results showed anomalous samples and prompted a comprehensive exploration program. The trench work revealed prospective gabbros (intrusions), with magnetite destruction halos that could be correlated in the ground magnetics, and that were also borne out in drilling. Right from the first discovery hole, the team embarked on a R&D program using hyperspectral analysis, lithogeochemistry, mineral chemistry and geology. Active engagement with researchers at MUN had positive impact on the understanding of the mineralization. The goal was to inform and update the company's exploration model to better enable future discovery.

Despite the small size of the deposit (e.g., <200 k oz), production is likely due to its location a few kilometres from the Pine Cove mill. The discovery was the direct result of a team of technically sound people, utilizing various geological, geochemical, and geophysical methods, and integrating these methods to target and develop mineralization.



Drilling on the Argyle Deposit

The workplace culture at Anaconda Mining is also producing other innovative approaches from evaluation of selling waste rock for road aggregate, to research into use of tailings for plant soils and an innovative new method of mining veins.

Challenges

The challenge as a junior miner is to internally study and fund long-term research projects that lead to innovation and discovery. With limited resources, collaboration with colleges and universities is necessary to create new approaches to exploration and development and generate success.

Funding and Support

The company leverages its own funding for research with industry grants from NSERC and IRAP as well as the Government of Newfoundland and Labrador. Boots on the ground exploration is helped by flow-through share tax benefits, facilitating innovation.

Benefit

Anaconda Mining developed a competent and engaged workforce. The group engages with students, providing employment and additional training, introducing them to skills that can't be learned at university. The Earth Science department at MUN has also benefited by active participation and interaction with a talented industry partner. Longer term the local community also benefits from an extended life for the plant and the mine operations

Bottom Line

Innovation within Anaconda Mining is directly driven by the need to succeed as a business. As a junior mining company, they compete for market interest with much larger companies and they have worked hard to create a culture of innovation across all aspects of the business from production to early stage exploration. Building collaborative relationships with a broad group of researchers, consultants, government organizations and business partners is an important part of the effort.

WHAT HAVE WE LEARNED?

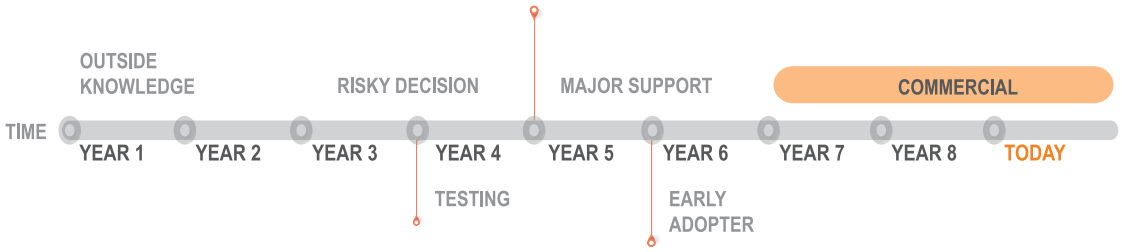
Innovation is occurring throughout the mineral exploration business in Canada. The case studies demonstrate that a wide variety of organizations are innovating and whether they are driven by academics, consultants, service providers or exploration and mining companies, they are all contributing to more successful and efficient mineral exploration both in Canada and globally. The stories demonstrate that the foundations of a strong mineral industry, excellent universities and quality geological surveys are important parts of the innovation landscape in Canada.

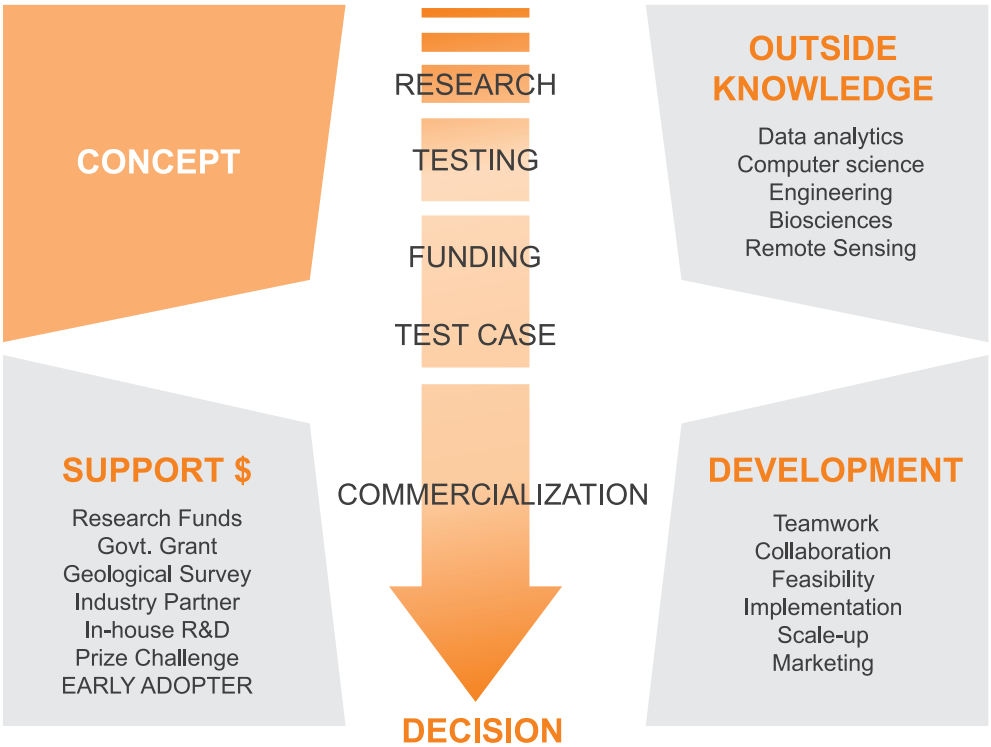
The people involved in exploring for resources are problem solvers, used to working on the puzzles and challenges presented by the search for mineralization. Success in their efforts to innovate are directly related to their willingness to seek outside help and to collaborate. Many are experts in their own fields but recognize the value in combining their knowledge with that from other industries or scientific disciplines. These partnerships provide the fertile environment for new ideas to develop.

While many innovations build on decades of past work, the current pace of change and development is driven directly by changes in the collection, storage and integration of data.

Within the work environment itself, the ideas needed to innovate come out of an open and inclusive culture that values input from the entire team. Once a concept is fully developed, typically a champion (leader) will take the lead to make the decisions on moving ahead. The early stages may well be self-funded and developing a new idea requires perseverance and commitment.

In order to reach a level of commercialization, innovations in mineral exploration succeed based on three key areas: **Support and Funding, Outside Knowledge, and a strong team committed to Development**. Support and funding, as well as outside knowledge often comes through the addition of an early adopter. Early Adopters fill the gap with respect to funding and testing for concepts to reach commercialization. As the work develops, increased levels of funding and support creates the time and space needed for teams to develop the innovation.





BARRIERS TO INNOVATION

Established routines and practices are challenging to change because many times the status quo is easier than changing a style of work or approach to solving problems. Large organizations are renowned as being similar to large ships – great at staying the course but challenging to change directions. In addition, tradition within the mining industry dictates a culture of secrecy that may work against long term success. Methods and approaches are kept as proprietary information, limiting opportunities to build off other successes and curtailing innovation.

Industry may also approach university research with the same style of control as in their company operations. Examples include limiting publications, and restrictions on outputs which creates a further barrier, restricting the number of researchers willing to engage in the work.

CHALLENGES

Recognizing an opportunity is much easier than executing a research and development program to develop a new service, technology or technique. Many challenges occur throughout the process.

- Finding the right people for the job
- Supporting early stage concepts – and verifying ideas
- Gaining outside knowledge and establishing new partnerships
- Accessing data sets for testing, particularly new integration analysis techniques
- Finding the right contacts within the major companies that are willing to consider new tools and be the ‘early adopter’
- Accessing the funds needed for full commercialization

TAKEAWAYS

Innovation is occurring throughout the mineral exploration business, driven by external and internal factors. Measuring the scale of the impact may take years to demonstrate, given that discoveries typically can take 5 -15 years, to achieve full recognition and subsequent development.

The key takeaways are that the small, agile groups are innovating and thrive with support from both major companies and government. Groups that collaborate with universities have places to test new ideas and more importantly, sources of high-quality people to hire.

What else could be done? Funding and collaborative environments for work can be directly influenced by governments and other organizations. Funding research, early stage concepts, and development of technology are vital. With the current federal focus on the big-scale, high profile government clusters, there is a lack of smaller scale, regional centers. 'Incubators' could provide support for small to medium size enterprises to gain access to skills, funding or other support.

Supporting a thriving system that fosters innovation requires both geographic and virtual clusters as well as an environment open to the exchange of ideas and collaboration.

- Universities play a role by establishing strong relationships with industry
- Professional organizations foster exchange of ideas via conferences and new programs
- Industry both innovates and provides the testing ground for new techniques.

> One barrier to implementation is identifying who will adopt new processes in the companies that are carrying out exploration programs. Whose role is it to decide to adopt new practice?

DRIVERS

- Optimizing target generation in an era of big data sets.
- Refining techniques for finding deep ore bodies, creating higher degree of confidence in testing them.
- Developing more sustainable and lower impact methods of exploration.
- Building small businesses that can survive the cyclical nature of commodities.
- Creating value and sustainable economic development for communities.
- Prizes – opportunity to win financial support and demonstrate talent.

APPENDIX: FUNDING AND LINKS IN CANADA

GEOSCIENCE BC

Geoscience BC generates independent, public geoscience research and data about British Columbia's minerals, energy and water resources. This advances knowledge, informs responsible development, encourages investment and stimulates innovation. They operate collaboratively with industry, academia, communities, Indigenous groups and government, providing a responsive for public earth science that complements other government organizations.

www.geosciencebc.com

NATIONAL SCIENCE AND ENGINEERING RESEARCH COUNCIL (NSERC)

NSERC aims to make Canada a country of discoverers and innovators for the benefit of all Canadians. The agency supports students in their advanced studies, promotes and supports discovery research, and fosters innovation by encouraging Canadian organizations to participate and invest in postsecondary research projects. NSERC researchers are on the vanguard of science, building on Canada's long tradition of scientific excellence.

www.nserc-crsng.gc.ca/index_eng.asp

THE NATIONAL RESEARCH COUNCIL (NRC) INDUSTRIAL RESEARCH ASSISTANCE PROGRAM (IRAP) RESEARCH GRANTS FOR CANADIAN BUSINESSES

The Industrial Research Assistance Program (IRAP) is a Canadian government funding program designed to accelerate research and development projects of Canadian innovators. The National Research Council (NRC) administers and manages the program. Projects funded are typically focused on the development of new products that fill a market gap. Activities include process or product development, commercialization, or customization for particular customers.

nrc.canada.ca/en/support-technology-innovation/about-nrc-industrial-research-assistance-program

THE NORTHWEST TERRITORIES GEOLOGICAL SURVEY

The Northwest Territories Geological Survey is a Division of the Department of Industry, Tourism and Investment, Government of the Northwest Territories. They advance geoscience knowledge of the Northwest Territories (NWT) by conducting geoscience research, analysing mineral and petroleum resources, and offering excellent digital data.

SR&ED

The Scientific Research and Experimental Development (SR&ED) Program uses tax incentives to encourage Canadian businesses of all sizes and in all sectors to conduct research and development in Canada. These tax incentives come in three forms: an income tax deduction, an investment tax credit, and, in certain circumstances, a refund. The SR&ED Program provides more than $3 billion in tax incentives to over 20,000 claimants annually, making it the single largest federal program that supports business R&D in Canada. The program is administered by the Canada Revenue Agency (CRA).

www.canada.ca/en/revenue-agency/services/scientific-research-experimental-development-tax-incentive-program.html

WOMEN ENTREPRENEURSHIP FUND

The Women Entrepreneurship Fund is committed to advancing gender equality, women's economic empowerment and supporting women entrepreneurs. The Women Entrepreneurship Fund helps women-owned and women-led businesses invest in activities that focus on supporting pursuit of market opportunities abroad, supporting scale-up, expansion and growth improvements and additional activities that support the objectives of the Women Entrepreneurship Fund.

www.ic.gc.ca/eic/site/128.nsf/eng/home