Geology for Investors

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National Instrument 43-101: An Overview for Investors

By Christopher Rawluk in Geology Basics

Remember that a NI 43-101 compliant report is only that: A compliant report. It simply means that the rules for reporting on a property were followed.

Introduction

National Instrument (NI) 43-101 is a technical reporting standard developed by the Canadian Securities Administrators (CSA) that specifically applies to mineral projects. While it only applies to stocks traded on Canadian exchanges the standard is widely known, as more than 75% of the world’s mining companies are based in Canada.

NI 43-101 was first developed in the wake of the Bre-X Minerals scandal which rocked the mining industry in 1997. Bre-X had acquired property in Indonesia which quickly became a huge gold deposit. At its peak it was reported to contain 70 million ounces of gold and the company was valued at more than 4 billion dollars. The project was later exposed as a fraud: Billions made were lost. It had all the drama and intrigue of a Hollywood thriller, but most of all it severely eroded investor confidence in the mining industry.

A Reporting Standard is Born

Prior to the Bre-X scandal there were no standards in place for the reporting on mineral resource projects. There were no standards for the reporting of resources and reserves. There were no professional standards in place regulating the qualifications and practises of geologists. The industry and regulators realized that in order to re-establish public confidence in mineral and mining projects some changes would need to be made.

NI-43-101 is the culmination of those changes. While it is essentially a framework for the writing of reports, it incorporates standards a number of important standards:

- Definition standards on mineral resources and mineral reserves
- Estimation of mineral resources and mineral reserves best practice guidelines
- Mineral exploration best practices guidelines
- Standards and guideline for valuation of mineral properties
- Guidelines for the reporting of diamond exploration results
- Standards and requirements of a “Qualified Person”

Many of the standards which are incorporated into NI 43-101 were developed by other organizations and are maintained by those organizations. The Canadian Institute of Mining and Metallurgy (CIM) developed a number of the standards including those on the reporting of Resources and Reserves. The Canadian Council of Professional Geoscientists (CCPG) and their provincial member councils regulate the Professional Geoscientist (P.Geo) designation within Canada.
Since NI 43-101 is a reporting standard and not a report type, there are many types of reports that can be filed on a mining project which can be NI 43-101 complaint. For example, a compliant technical report may be filed for the purposes of defining a property of merit, reporting on exploration activities, or reporting on reserves and resources through prefeasibility and feasibility studies.

Qualified Persons

A report written to the NI 43-101 standard may serve a variety of purposes, but in order to qualify as *NI 43-101 Compliant* it must be written to the standard. Part of that standard is the qualification of the supervising author, or Qualified Person. Compliant reports must be written and filed with the consent of a Qualified Person who is defined as:

- An engineer or geoscientist with at least five years of experience in mineral exploration, mine development or operation or mineral project assessment, or any combination of these;
- has experience relevant to the subject matter of the mineral project and the technical report; and
- is in good standing with a professional association and, in the case of a foreign association (is of recognised stature within that Organisation)

It is important to note that the Qualified Person cannot just be a qualified engineer or geoscientist, but must have experience relevant to the subject matter. This is where lines can get blurred sometimes. A Qualified Person should technically have 5 year’s experience on the deposit type or mineralization style being reported on, but there are many specializations within geology and many different stages of project development requiring different types of expertise. It is always a good idea to check the resumes of the players involved on a project.

Be Careful!

While setting standards for reporting for mineral properties was a positive for the industry, a NI 43-101 compliant report does not translate into a good investment or even a good company. Some have argued that too many companies are focused on meeting the minimum requirements of a 43-101 report and that the standard does little to differentiate between high quality properties and marginal or poor quality prospects: For some small companies a compliant technical report is simply money in the bank.

While this is potentially true for early stage technical reports, later stage reports like feasibility studies must also follow 43-101 standards and by that point there is less room for interpretation.

Regardless, remember that a NI 43-101 compliant report is only that: A compliant report. It simply means that the rules for reporting on a property were followed. What you do with that information is entirely up to you.

Accessing Reports

Technical Reports from public Canadian companies can be accessed on SEDAR (System for Electronic Document Analysis and Retrieval) at www.sedar.com.

Further Reading

Canadian Security Administrators
Canadian Council of Professional Geoscientists

Canadian Institute of Mining and Metallurgy

NI 43-101 Standards of Disclosure (PDF)
Following Glacial Breadcrumbs: The Basics of Drift Prospecting

By Christopher Rawluk in Geology Basics

Minerals eroded from ore bodies by glaciers can be transported hundreds of miles from their source. If one knows the direction of the ice flow that transported the minerals, then theoretically the source can be located by following the mineral trail.

The earth has gone through a great many cycles of warm and cold periods throughout geologic history. Much of the world has at one time or another been covered by a sheet of ice. During the last glaciation most of Canada and much of the northern US was covered by a sheet of ice that was as much as 2 miles thick. These huge ice sheets formed the landscape in many parts of the world leaving behind lakes, eroded bedrock and sediment.

"Till" is the term applied to sediment deposited by glaciers from the bedrock that they eroded and picked up along the way. Till can be recognized as a poorly sorted sediment made of mixed rocks types and of varying shapes and sizes ranging from large boulders to fine silt. The indiscriminate erosion and transport of sediments by glaciers can be useful for prospecting and mineral exploration since ore minerals are also transported by these processes.

Drift prospecting using till has been successfully used for many economic mineral deposit types including diamonds, copper, uranium and gold.
Exploration Using Glacial Till

Geological exploration in previously glaciated areas – especially in the far north – typically includes the use of till sampling to track prospective targets.

This simplified dispersal train could be expected from a glacial ice flow in one direction. Note that the trail is many times longer than the target.

Minerals eroded from ore bodies by glaciers can be transported hundreds of miles from their source. If one knows the direction of the ice flow that transported the minerals, then theoretically the source can be located by following the mineral trail. The diagram to the right shows the simplest application of this concept.

The indicator minerals can be anything that might indicate an up-ice target: On a larger scale “boulder trains” of uranium-rich rocks have been used to locate uranium ore bodies in the Athabasca Basin. Smaller scale indicators can include minerals like pyrope garnets and chromium diopsides which are sifted and sorted from fine till to search for diamond-bearing kimberlites in the Canadian Arctic.

The basic concept is simple enough, but there are a few complicating factors.

First, the successive directions of ice flow must be established and chronologically ordered. Thick bodies of ice behave more like a viscous liquid than a solid mass. They ebb and flow and change direction, so the direction established in one area might not be the same in another. Ice flows may also be overprinted by successive ice flows from different directions which can obscure a dispersal train. The diagram below indicates the result of ice flow from two directions. The original dispersal train is “smeared” into a fan-like pattern by the second ice flow event.
This simplified dispersal train could be expected from a glacial ice flow from 2 directions. Note that the original trail has been obscured by the second ice flow event.

Till sampling programs are rarely used in isolation, but are instead part of a larger programme combining airborne geophysics, field mapping and rock chip sampling. Since indicator minerals make up a small fraction of the till, large samples are usually required across a large area. In remote regions such as the Canadian Arctic or where there is air access only, these programmes can be incredibly expensive since heavy sample bags may be required at each sample location. Hand augers or larger RC drilling equipment may be needed to access till depending on the location and the depth of the overlying sediments.

The requirements for processing and assaying of till samples varies depending on the sample and target. For boulder trains, simple geochemical assays like those used for rock chips or drill core will suffice. For fine grained till samples, a process of drying, sorting, separating and even microscopic analysis may be required before assay.

Ice Flow Indicators

In drift prospecting, knowing directions of ice flow is critical to success. Luckily for modern exploration geologists, the directions of ice flows are fairly well established in locations with important mineral resources. On a local scale, project geologists can use a variety of ice flow indicators to determine the glacial history of their project areas.

Many land forms can be attributed to ice flow and are easily recognizable to the trained eye. The satellite photo the left is a good example of how ice flow can shape the landscape. Satellite and air photos are often employed by geologists to gain a better understanding of the geologic history in an area.

On an smaller scale, the scraping, scouring and other smaller scale features can be used on the ground to determine the direction of ice flow. For example, the photo below shows two sets of striations indicating ice flow from two directions. The striations on the left (yellow arrow) appear to truncate those
on the right (red arrow), which tells us that those on the right are older. These types of features are used by field geologists to determine history of glaciation in an area.

Two sets of striations show the direction of ice flow over this rock outcrop. Photo NRC

**Proceed with Caution**

Although we’ve simplified the process in this article, a thorough understanding of glacial geology is required to successfully implement a drift prospecting program. One must be able to recognize glacial landforms, till characteristics, ice flow directions and account for the overprinting of successive glacial events.

More than one company has conducted a drift prospecting program but sampled surface sediments instead of till, miscalculated the direction of ice flow or misread the role of local glacial landforms. Expensive field programs can be rendered useless if the supervising geologist doesn’t have a true understanding of glacial geology or the field crew are improperly trained.

**Further Reading**

To learn more about this topic try some of these resources.

Glacial Processes, Ice-Flow Indicators and Remote Predictive Mapping Applications to Drift Prospecting

Glacial Erosion of Bedrock and Ice Flow History in the Kivalliq Region, Nunavut, Canada – Glacial Flow Indicators

Prospector’s Guide to Drift Prospecting for Diamonds (Northern Ontario)

New frontiers for exploration in glaciated terrain (PDF)
Folding, Faulting and Mineralization

By Christopher Rawluk in Geology Basics

On a smaller scale they can help identify planes of weakness and channels in which fluids may have deposited economic minerals. On a larger scale they can help the geologist to reconstruct the stresses that the rock has been exposed to which may lead to other important regional or local structures.

Descriptions of an ore mineral deposit or project area often refer to geologic structures or features that are important to the deposit. Indeed, we have often written about structurally controlled mineralization in our mining company press release reviews. While hydrothermal activity and ore-bearing fluids are linked to most economic mineral deposits, the paths that these fluids take are invariably the paths of least resistance: structural features like folds and faults.

So why should you care?

Mining companies will often refer to these structural features when describing their deposits. Here are some examples from real mining company news releases:

Three main fault types. Many fault systems involve a combination of movements along multiple planes.
“drill intersected significant mineralization in the hanging wall zone”
“hinge zone drilling encounters high grade gold mineralization”
“encountered high-grade gold values in the upper limb portion of the fold structure”
“the axial plane of a large scale anticline fold axis which plunges at a shallow angle to the north”
“High grade gold intersected in multiple holes along the strike of the axial plane of the anticline continues to support our geologic model”

Some of these descriptions probably don’t belong in a press release, but geologists are often hesitant to over simplify in a way that presents the data as inaccurate. Let’s review the two main structural features that may be described in a geologic report or news release.

Faults

A fault is the displacement of rock due to fracturing and movement along a plane. Large scale fault systems relating to modern earthquakes are probably most familiar, but faults are common features on large and small scales.

Tectonic activity along plate boundaries is the usual culprit for large scale structural features creating large scale fault systems, folding and mountain belts. Many mineral deposits occur in ancient terranes that are no longer tectonically active but include structural and geologic features that reveal a more violent history.

In very old terranes rock may be structurally deformed and metamorphosed by the high temperatures and pressures exerted at depth.

A normal fault showing the foot wall on the left and the hanging wall on the right.

The greenstone belts that host many mineral deposits in Canada and Europe are deformed from these types of processes. Though the deformation takes place deep within the crust, erosion and tectonic activity may eventually expose these rocks at the surface.

Examples of fault-controlled mineralization include world-class gold camps of Timmins, Ontario and Val d’Or Quebec. Large scale fault systems became channels for gold-bearing fluids through the region creating many high-grade, high tonnage deposits.

Mineral deposit description will often refer to the hanging wall or footwall zones relating to mineralizations. These terms refer to the position of the rock in relation to the fault plane and are illustrated to the left.
In structurally deformed terranes large and small scale folding and faulting will occur concurrently.

Folds

Much of the structural deformation that occurs within rock formations can be described as folding. Folds may not be as readily apparent as in the photo included with this article: In fact, it is often only through careful analysis of small scale rock textures such as mineral orientations or big-picture geophysical anomalies can a fold structure be identified.

In general terms, an anticline is a convex fold with the youngest beds on the outside of the curve. A syncline is the opposite with the youngest beds on the inside. But unless the relative ages of the folded rocks can be determined, these labels cannot be used. The various terms help geologists to describe the structure accurately and in a standardized way, but the descriptions can often be confusing. The diagram to the right may help explain some of the terminology related to structural folds.

Ultimately fold structures are important for two reasons. On a smaller scale they can help identify planes of weakness and channels in which fluids may have deposited economic minerals. On a larger scale they can help the geologist to reconstruct the stresses that the rock has been exposed to which may lead to other important regional or local structures.

Identifying a fold structure associated with mineralization can help the geologist plan new drill and exploration targets.
The mineral Sylvite is a potassium salt better known as potash.

Potash and other Evaporite Deposits

By Christopher Rawluk in Geology Basics, Mineral Deposits

Evaporites are water soluble mineral salts that form through the evaporation and concentration of salt water. Evaporite minerals can form huge sedimentary sequences, a remnant of the inland seas and marine environments that created them.

Ore Minerals

Currently, the most valuable evaporite mineral is Sylvite, also known as Potash, or potassium chloride. It is used as a fertilizer ingredient and is an important plant nutrient.

Gypsum (calcium sulfate) is also an important evaporite mineral and is primarily used to make building materials such as drywall. Technically gypsum is the name of hydrated form of the mineral anhydrite, but gypsum is a common name for both.

Halite (sodium chloride) is what one normally thinks of as “salt” and has been an important commodity for millennia. Halite is used as a food additive and for managing ice on roads.
Formation

There are a number of models that explain the formation of sedimentary evaporites. In the idealized model (pictured right) of an evaporating closed basin, it has been shown that the mineral salts are deposited in a predictable “bullseye” pattern: Certain minerals are preferentially precipitated as the basin dries starting with calcite and ending with sylvite. Large thick salt beds, like the potash deposits of western Canada and Russia, are thought to have formed in semi-closed marine systems where the influx of new sea-water allowed for a prolonged period of evaporation and salt formation.

Exploration and mining

One of the main methods of identifying evaporites in the subsurface is with the use of seismic surveys, usually as a by-product of petroleum exploration. Seismic geophysics is used heavily in oil exploration and salt deposits contrast very well in these surveys.

In addition to being a “by-product” of petroleum exploration, “Salt domes” in sedimentary basins can serve as traps for petroleum deposits and companies exploring for petroleum will often employ seismic surveys to identify these potential traps.

Depending on the depth of the deposit, evaporites may be mined from open pits or in underground mines. In-situ leaching, or “solution mining” may also be used since the soluable salts can be easily dissolved in solution and transported to the surface.
Important Deposits

The potash deposits of the Western Canadian Sedimentary Basin, specifically in Saskatchewan, are the largest in the world.

Potash Corp. is the largest producer with 5 mines in Saskatchewan and one in New Brunswick, Canada. Potash is also being extracted from the waters of the Dead Sea.

While gypsum deposits are found all over the world, the United States is the largest producer of gypsum, followed by Iran and Canada.

Salt (halite) deposits are also found worldwide, though mostly in the northern hemisphere. The largest producer is the United States. Current salt production comes not only from mining, but from the solar evaporation of salt water.
An Introduction to Uranium Deposits

By Staff @ Geology for Investors in Commodity Basics, Mineral Deposits

Although there are between 12 and 15 different types of uranium deposits, almost all economic uranium deposits come from just two types:

- unconformity-related deposits, and
- sandstone uranium deposits.

Unconformity-related deposits account for around one third of the world’s uranium production, while sandstone uranium deposits account for another third. The remaining third of production comes from a variety of the remaining 10 or so deposit types.

The **Athabasca basin** deposits grade about 2% U, with exceptionally high-grade areas such as Cigar Lake (almost 20% uranium). The Australian **Kombolgie basin** average grade is lower at 0.4%.

Ore Minerals

The most common uranium mineral is uranite or pitchblende. There are a range of other uranium minerals including camotite, branmerite and euxenite. Uranium is reactive and forms a large number of colourful secondary minerals including autunite (with calcium), saleeite (magnesium) and torbernite (copper). Uranium is only weakly radioactive, but is highly soluble, which is used to advantage with some mining methods.

Unconformity-Related Uranium Deposits

An unconformity is a boundary between two rock units that reflects a time gap. Uranium unconformity deposits are generally associated with structures in sedimentary rocks that reflect the erosion surface rocks, and then the later subsequent deposition of younger sedimentary rocks above. Uranium deposits occur in sedimentary basins deposited on top of very old basement metamorphic rocks. The source of
uranium is either from the basin or the basement rocks. Groundwater circulating in the basin results in the concentration and deposition of the mineralisation.

Uranium deposits occurring at or near an unconformity between basin sedimentary rocks and basement metamorphic rocks.

Uranium is highly reactive and will deposit and accumulate in response to the changing chemical environment – particularly when moved from an oxidising environment to a reducing one. As the fluids move through the basin and basement rocks, they convert uranium to a highly oxidised state. Eventually this fluid reaches an area which is less oxidative such as graphitic or volcanic rocks. This causes the oxidized fluid to become reduced and the uranium it’s carrying will be deposited as either uraninite or coffinite. These deposits can occur in the basin rocks, at the unconformity itself or even lower down in the basement rocks.

The most notable examples of these types of deposits include:

- in Canada’s Athabasca basin and
- Australia’s Kombolgie basin.
- Canada’s Thelon basin
The **Athabasca basin** deposits grade about 2% U, with exceptionally high-grade areas such as Cigar Lake (almost 20% uranium). The Australian **Kombolgie basin**, average grade is lower at 0.4%.

Unconformity deposits are desirable because of their high grades and because they generally occur at shallow depths, allowing for low-cost mining techniques such as open pit.

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**Sandstone Uranium Deposits**

Sandstone-hosted uranium deposits occur in sandstones that are contained above and below impermeable shale units. The permeable sandstone allows fluids to move freely between the impermeable shale units. Sometimes the sandstone units are associated with concentrations of organic matter, sulphides or hydrocarbons. These impurities create the reducing environment with the circulating uranium-rich fluids, to form the uranium ore bodies. Uranium mineralization, in the form of uraninite, coffinite and sometimes brannerite, forms along changes in the sandstone chemistry.

These deposits only occur in rocks that are around 400 million years old. These deposits are associated with the Carboniferous Period when the evolution of land plants, resulted in large amounts of organic matter (a reducing agent) to be incorporated into sediments. Exploration targets for sandstone uranium
deposits therefore focus on appropriated aged formations which rich in organics and hydro-carbons as well as shale beds. There are three main structures to sandstone-hosted uranium deposits. They are:

- roll front: deposits are arc-like and crosscut the sandstone bedding;
- Tabular: ore bodies occur parallel to the bedding of the sandstone
- tectonological: occur along fault zones that allow fluid to flow freely.

Sandstone deposits usually have low to medium grades that range from 0.01 – 0.4% uranium. Ore bodies are also only a small to medium size, but it's the fact that most of these deposits can be mined by in situ leaching that makes them highly prospective. This is because the in situ leaching technique can be carried out at low cost.

**Important Uranium Deposits**

The countries with the largest reserves of uranium are Australia (with around a third of the world’s known reserves), Kazakhstan, and Canada.

**Cigar Lake Mine, Athabasca Basin, Saskatchewan, Canada**

Not yet in production, after flooding issues, Cigar Lake has reserves of over 500,000 tonnes of 17% uranium. The mine was recently granted a mining licence and production is planned to start in 2013. Underground mining will use a high-pressure water jets to carve the ore into a slurry, allowing mining to occur with minimal exposure of personnel to radiation.
McArthur River Uranium Mine, Saskatchewan, Canada

This unconformity style deposit is the world’s largest producing uranium mine, has a regulated production of 18.7 million pounds of yellowcake/year. Current reserves are 870,000 tonnes of 17% uranium oxide. This mine is also owned and operated by Cameco.

As reserves of fossil fuels decrease and concerns over CO₂ emissions grow, it is likely that nuclear power will take on a greater role in providing our world’s ever increasing need for power. As uranium prices increase and so too does exploration and production. Familiarizing yourself with the main types, and most prospective, of uranium deposits will allow you to make the right decisions when investing in Uranium prospects.
Hydrothermal Activity and Mineral Deposits – The Importance of Hot Water

By Staff @ Geology for Investors in Geology Basics

Heat and water combined are what creates most mineral deposits. Aside from the weathering processes which will subsequently transport (placer or alluvial deposits) or concentrate the minerals in place (laterites) – mineral deposits are associated with water and heat either at shallow depths, or deep under the earth’s crust.

The Importance of Hot Water

Most of us who have stirred sugar into hot coffee, or made candy, understand that heating water will allow it to dissolve more of an additive, sugar, or metals. Heated groundwater concentrates valuable minerals particularly tin, copper, gold, and silver. Water circulation is caused by changes in temperature initiated by tectonic activity or volcanic eruptions. As the conditions change the minerals may precipitate, along faults and surrounding rocks. Those changing conditions involve:

- temperature or pressure drops
- reaction with wall-rocks particularly mafic and carbonate rocks
- degassing

The water which is critical for the process comes from a variety of sources including:

- ground water;
- sea water, for underwater hydrothermal activity;
• dewatering of metamorphic rocks;
• dewatering of buried and compressed sediments.
• water released from melting rock

The heat which drives the process comes from:

• heat from the mantle
• rising of magma into the shallower, crustal rocks;
• radioactive heat from cooling masses of intrusive rocks.

Types of Hydrothermal Deposits

Different types of hydrothermal deposits occur depending the on the geological setting.

Rising Fluid Deposits

As hydrothermal fluids rise then can result in:

• Porphyry copper 200-800°C, at moderate depths;
• Cordilleran veins, intermediate to shallow depths;
• Epithermal gold and other metal deposits 50-300°C, shallow depths.

Circulated Fluid in the Magma

Deep-seated magma has a slow circulation of fluids, which are rich in copper, gold, silver, lead, and zinc. The magma doesn't reach the surface; rather it slowly cools to form granitic rocks and circulates ore-bearing fluids. The metals originally disseminated throughout the magma are concentrated by circulating hot fluids and re-deposited to form veins.

Sulfide minerals in a quartz (white) tourmaline (black) vein are indicative of hydrothermal activity.

The concentration occurs via:

• gravitational setting
differentiation

immiscible separation of silica rich melt and a smaller volume of metal-rich liquid. This creates a wide variety of mineral deposits including:
- metal oxides hematite ilmenite iron and titanium;
- sulfides – nickel, copper, platinum-group metals;
- carbonates – rare earth elements, niobium, tantalum, copper, thorium, phosphorous

Sub-Sea Massive Sulfides

Vents along mid-ocean ridges create ideal environments for fluids rich in minerals to escape to the sea floor. Deep sea hot springs are rich in sulfides of iron, copper, zinc and nickel, and because of their black colour are known as black smokers. Troodos Massif, Cyprus, is an example of ancient oceanic crust, now uplifted and exposed on land. Troodos was such an important source of coppers to Romans, which they called copper “cyprium”. These deposits, known as volcanogenic massive sulphide deposits (VMS for short), are important sources of copper, zinc, lead, copper and silver.

Gold Deposits

One of the characteristics that makes gold valuable is it’s very resistant to reacting with other materials. It maintains its lustre because it does not react with the air to oxidize. Gold does not mix well with fluids (think oil and water), but it can get carried long with them. This is why gold is often found as “free gold” in hydrothermal quartz veins or as free-gold in placer deposits. Depending on the hydrothermal fluid composition gold can also be trapped within the “matrix” of other minerals such as iron and arsenic sulfides. These micron sized grains are difficult to extract from the sulfide ore.

Since there is such a close association with fluid movement and economic mineral deposits, geologists and prospectors will often look for signs of hydrothermal activity including fluid movement and fluid saturation in rocks.
Volcanogenic Massive Sulphide (VMS) Base Metal Deposits

By Staff @ Geology for Investors in Geology Basics, Mineral Deposits

Nearly a quarter of the world’s zinc production is from volcanogenic massive sulphide (VMS) deposits. In Canada, approximately half of country’s zinc production is from VMS deposits that also supply 40% of Canada’s silver production. VMS deposits also yield significant amounts of lead, silver, copper, and gold.

*Volcanic massive sulphide deposits are accumulations of metal sulphides that precipitate from heated hydrothermal fluid associated with volcanically active undersea environments.*
Ore Minerals

Headframe above the main shaft at HudBay’s 777 VMS Deposit

The main ore minerals in VMS deposits are, unsurprisingly, sulphides, including pyrite (iron sulphide), sphalerite (zinc sulphide), chalcopyrite (copper-iron sulphide) and galena (lead sulphide).

VMS deposits contain minor amounts of silver and gold plus a large variety of other elements including cobalt, tin, selenium, manganese, arsenic, tellurium, antimony, and mercury among others. Some of these can be extracted as a by-product, increasing a mine’s profitability.

Formation

Black Smoker in the Endeavour Hydrothermal vents offshore from British Columbia. Image CC

Volcanic massive sulphide deposits are accumulations of metal sulphides that precipitate from heated hydrothermal fluid associated with volcanically active under-sea environments.
The volcanic activity is caused by rifting in the Earth’s crust. A rift is simply an area where the Earth’s crust is being pulled apart, and the result is that magma from Earth’s mantle rises up beneath the area where the crust is being stretched.

Rifting causes magma from the mantle to rise and cool in the Earth’s crust. The magma expels volatiles that carry valuable elements toward the surface. The large temperature difference between the rising volatiles and seawater percolating down through the rock causes convection. Convection allows more metals to be incorporated into the fluids until the fluids finally escape to the surface through faults or similar structures. When the fluids are expelled into the ocean (via a “black smoker”) the dramatic decrease in temperature causes sulphide minerals to be precipitated onto the seafloor.

As the metal-rich fluids enter the overlying water at temperatures around 400°C, the drastic temperature decrease caused by mixing of these fluids with seawater causes the metals to precipitate out as sulphide minerals.

VMS Size, Geometry & Distribution

The two features make VMS deposits such desirable exploration targets are their size and geometry. These deposits often form over a long time and can be reactivated on numerous occasions. This results in individual lenses that are a hundred meters thick and extend hundred meters along strike. The reactivation also causes the deposits to be zoned around the black smoker pipe, with a predictable distribution of sulphides.

The massive accumulations of sulphides show up very well in geophysical surveys because they are both denser and more conductive than the surrounding rock, making VMS deposits a relatively easy geophysical exploration targets.

The shape of the deposits makes VMS ideal for cheap open-pit mining methods because a large amount of ore can be removed without having to remove very much waste rock. This is a much cheaper mining method than when ore is hosted in narrow veins, resulting in a much higher ratio of waste to ore removal.

VMS deposits often occur in clusters within a particularly small area (~10 km^2) all related to the same event, since the metal-rich fluids may escape to the surface through many vents. The discovery of one large VMS deposit may well mean that there are other targets nearby.

Almost any age of terrain can potentially host a VMS deposit. The oldest VMS style deposits are some 3.4 billion years old while the youngest are being deposited today in oceans including the Red Sea and the western Pacific Ocean. There are ~800 VMS deposits known worldwide with about 350 of those in Canada. Worldwide there is much exploration for VMS-style deposits, particularly in the remote Canadian arctic.

Important Deposits

Flin Flon, Manitoba, Canada.

Kidd Mine in Timmins, Ontario, Canada.

The Flin Flon Greenstone Belt are ancient Precambrian rocks which host the biggest concentration of VMS deposits in Canada. The ore bodies are predominantly zinc-copper with significant gold and silver. Ore bodies range in size from 100,000 tonnes to 60 million tonnes.
One of the largest producers is Hudbay Minerals Inc. that was founded in 1927 to mine the region. Their 777 Mine produces zinc, copper, gold and silver. They are currently developing a new project at Snow Lake some 215km north of Flin Flon. In 2012 their production figures included:

- 39,587 tonnes copper
- 80,866 tonnes zinc
- 101,059 ounces of silver and gold.

**Kidd Mine, Timmins, Ontario, Canada**

The mine is hosted in the Abitibi greenstone belt which is around 2.8 – 2.6 billion years old Kidd Mine is operated by Xstrata and is the world’s deepest base metal mines. Opened as an open pit mine in the 1960’s it’s currently mining at 2800m below ground. The main commodities are copper and zinc.
Life Cycle of a Mineral Deposit – Stock Price Implications

By Staff @ Geology for Investors in Geology Basics

A key concept for potential investors to understand is the life cycle of a mineral deposit and it’s potential relationship to stock price. Knowing the potential risk and the project value (real or perceived) at any stage can help determine entry and exit points for the investor.

Almost every project undergoes a standard exploration life-cycle. The activities can be subdivided many different ways, but here they are divided into six broad categories or stages. These are:

- exploration,
- discovery,
- feasibility,
- development,
- production and
- closure.

Life cycle of a mineral deposit and it’s potential effect on stock price.
Exploration

At this point most companies will have some indication that a property has economic potential and a general idea of where to begin. This “potential” can be a surface mineral “showing”, historical exploration data, government maps or studies, or proximity to a known deposit.

Early exploration programs are generally designed to identify drill targets. Using the aid of geochemical, geophysical and geological exploration techniques the company examines the property for signs of a potentially economic mineral targets.

Soil sampling: Early-stage exploration programs may involve a variety of methods.

At this point stock price is usually very low. Although relatively little money is required at this point, there is also little chance of success. This stage can last years and through several rounds of funding. Often the goal of a company at this point is to find a tantalizing bit of evidence that the property has greater potential. Some investors may choose to invest at this stage since it has the highest potential for profits, but there is also the highest risk of total loss. Many companies never make it beyond the exploration stage for a variety of reasons.

Discovery

Once a drill target is identified and the first few exploration drill holes return promising assay results, the company may have discovered a possible deposit. A company press release is often made, highlighting the best drill hole intercepts with the highest grades, and their stock price can be expected to rise.

The coming months will tell whether the find is significant. This is when, as an investor, you need to be asking questions.

- Is the company reporting new findings, or did they just drill hole duplicate historical findings?
- Was the drill program well designed and executed?
- What to the reported results mean? Is there missing or misleading data?
- Do the management and geologists involved have the reputation and experience to earn your confidence in their work?
Asking these questions can help you avoid a bad investment. It is at this point that a junior exploration company must make a decision; either to sell their discovery to a larger company or try to raise enough funds to proceed with mine development. This is highly dependant on what their exit strategy was going into the exploration program. This may also be a good time to sell stock.

Exploration geologists examining diamond drill core

Feasibility

During this stage the target is heavily drilled in order that the full size and grade of the resource can be reasonably defined. An Indicated Resource or Measured Resource may be reported and ultimately a feasibility study may be undertaken in order to establish a Reserve. (Read more on Reserves vs. Resources).

This stage consumes a great deal of cash and time. Stock prices may slump or slowly slide at this time unless offset by better than expected results. Beyond the technical requirement of defining an economic deposit, many other risks, or “modifying factors” must be taken into account before mine development can proceed. These factors include things like mine infrastructure, environmental assessments, public sentiment and governments. This is a risky stage because a failed feasibility study will lower stock value. However, the reward comes if the mine is deemed to be economic and development is approved.
Development

During the development stage everything needed to extract and either transport or process the ore is built. This usually involves a large investment, but it’s easier to raise the required cash since the economics and permits are in place and the risk is lower.

The stock price may increase a little with the anticipation of the start of production, but the risk of failure may keep the stock from rising too high.

Production

*Image: Bingham Copper Mine, Utah – one of the world’s largest mines Image: CC*

Stock prices may fluctuate up and down during the production phase depending on economic conditions. Companies can offset volatility and help maintain their value by efficient extraction and mine operation. The discovery of a new deposit in the vicinity of the operating mine may also increase mine life and stock value. If no new deposits are found then production winds down as reserves decrease, moving the mine toward the closure stage.
Closure

Once a mine has exhausted all of the available resources in the area it will begin the process of closing. Obviously, once all available ore has been processed production stops and with it profits cease. If a company has more than one operating mine a closure may not drastically affect their stock price, but it does not help it. Additionally, if the company has not put away adequate funds for site clean up the costs of site reclamation can bankrupt them. Either way the closure stage is not a good stage for the investor.

Knowing the right time to buy stock and the right time to sell is obviously the most important aspect of investing. While commodity prices, economic conditions, investor sentiment and other market forces play a role in the perception of a company’s value, we can predict and understand broad general trends in the life cycle of a mining company that can help increase our chances of success and understand the risks involved.
From Exploration to Opening a Mine

By Staff @ Geology for Investors in Geology Basics

A sizeable amount of time and money go into a property from the exploration process to the ideal outcome of a mine site. This summary article will serve as a good starting point to anyone interested in investing in the mineral exploration and mining industries.

Staking Your Claim

The first step for any exploration company, once an area is selected, is to stake a claim. Traditionally, this required the literal hammering in of stakes around the area of land claimed. Some jurisdictions these days operate an on-line system for registering claims, but many still require manual staking. Some areas may require contact with local or national governments in order to obtain mineral rights. In some cases landowners may hold mineral rights and direct negotiation is required. Regardless, obtaining the mineral rights to a property is essential before any exploration expenses are incurred.

An anticline structure controls the gold-bearing mineralisation in Bendigo
Finding Your Exploration Target

Once a company is allowed to conduct work on the property, their first goal is to find prospective ‘targets’ of mineralization. The preliminary work on a property can take many different forms. This often depends on the size and budget of the company involved, as well, what, if any, geology data is available.

Read more about finding an exploration target:

- Age Matters: Exploration and the Dating of Rocks
- Plate Tectonics – Mineralization and Plate Boundaries
- Location, Location, Location
- Undersea Mining

Geophysical Methods

A large range of geophysical methods is used in exploration, including seismic, gravity, magnetic, electrical and electromagnetic techniques. Geophysical surveys conducted by flying over an area (airborne geophysics) are by far the most common in the early stages of exploration. This is because
they typically cover a much larger area and therefore have a higher probability of finding prospective targets.

Airborne surveys include magnetometers that measure magnetic anomalies in Earth’s magnetic field (metal exploration) and Geiger counters that determine the amount of radioactivity (uranium exploration). In the later stages of exploration, ground-based surveys may be used to investigate smaller areas. An example of a ground-based geophysical survey is electromagnetic geophysics. This technique detects materials that are more conductive than the surround rock, e.g. metals, at much more detail than an airborne survey.

**Read more about geophysical exploration methods:**

- Ground Magnetics
- Seismic Surveys for Exploration
- Gravity Surveys
Geologic Mapping

During geologic mapping, a geologist will systematically map an area looking for rock outcrops. The geologist will analyze each outcrop recording data including rock type and structural geology as well as taking samples for geochemical analysis.

A geology mapping program may be conducted at the same time as a soil sampling program. More detailed mapping of smaller areas, i.e. individual outcrops or a few hundreds of meters square may be undertaken if an area of interest is found.

Read more about geologic mapping and field work:

- Geology Field Work
- Landowner Liaison

Scatter-plot of chromium assays against copper assays for previously analysed blanks. Most of the assays plot in a cluster which is the “Normal Population”. Two “Outliers” plot away from this cluster, which indicate possible contamination during sample preparation at the laboratory.
Geochemical Methods

Geochemical analysis is important in most exploration programs. Sampling aims to discover either anomalies the commodity of interest directly e.g. gold, or elements that are known to be associated with that commodity e.g. arsenic is often associated with gold. A program of any or all of soil, rock chip and stream sediment sampling may be undertaken. Soil and stream sediment sampling is particularly useful in areas where there are a few outcrops of the underlying rocks.

Read more about geochemical methods:

- Soil Sampling
- Quality Assurance and Control of Geochemistry
Australian coring drill rig with a rod visible on the stands to the right.
Resistivity and Induced Polarisation Surveys

By David Tilley in Exploration Methods, Geology Basics

Resistivity Method – The Basics

Without going into the physics of Ohm’s law, if you run a current through different materials you can calculate the electrical resistance by measuring the voltage and current applied. In practice this means that a resistivity survey will form an electrical circuit through the ground and take voltage and current measurements to calculate the resistivity of the sub-surface rocks.

For mineral exploration, resistivity surveys offer another indirect method to assist mapping and understanding the sub-surface geology, before we spend serious money on a drilling programme.

Alternative Geophysical Surveys:

- Telluric Currents
- Gravity
- Ground Magnetics
Why Do A Resistivity Survey?

The resistivity of the subsurface varies depending on rock type, porosity, permeability, the amount and type of salts present in the ground water and the type of clay present. When resistivity is low, conductivity is correspondingly high. Therefore, the method is useful for locating massive sulphide deposits and graphite-rich zones, both of which conduct electricity. When exploring for epithermal gold deposits the presence of quartz-rich zones and veins is important. Quartz, the most common mineral in epithermal veins and associated breccia, has a very high resistivity relative to other minerals. For this reason, quartz-rich zones that may host gold mineralisation, show up in surveys as zones of high resistivity or low conductivity.
How Is a Resistivity Survey Done in the Field?

An electrical resistivity survey involves laying out a series of electrodes, each driven into the ground about 150 millimetres. Their spacing is dependent on the depth of penetration required. The further apart the electrodes, the deeper the resistivity measurements of the subsurface that can be taken. Typically resistivity surveys range in depth from a few metres to more than 100 metres. The disadvantage of trying to obtain measurements from greater depths is a resultant loss in resolution.

There are number of possible layouts for electrodes; the Wenner and Schlumberger arrays are the most common. The Wenner array is the simplest, having an equal spacing between the electrodes. In the Schlumberger array, the spacing between the current electrodes is greater than the spacing between the voltage electrodes. Other configurations include the dipole-dipole and pole-dipole arrays.

A resistivity survey may consist of a single line profile across a point of interest. Alternatively, readings are taken in a grid pattern to obtain a three-dimensional image of the subsurface resistivity. A grid survey requires either advancing the electrodes along a given line or by having a number of arrays connected along a line with data simultaneously collected and recorded by the instrumentation.

The normal result of a resistivity survey is a number of profiles that show the variation in resistivity with depth. These profiles are examined and interpreted by a geologist who locates targets for follow-up exploration.
Induced Polarisation (IP) Method

When an electrical current is applied to some materials a phenomenon known as “induced polarisation (IP)” occurs, with a charge being acquired. When the current is switched off the charge dissipates over time, in a similar way that a car’s battery slowly goes flat if the car is not regularly used.

An induced polarisation survey is usually run at the same time as a resistivity survey. The resistivity method can be adapted to an induced polarisation method with the addition of switches and changes to the instrumentation. One of the main advantages of doing the two types of surveys together is to save time as well as associated costs.

The collection of induced polarisation data involves measuring the voltage at certain times after the current is switched off, usually over a period of a few seconds. There are two switches in the layout. The switch on the recorder part of the circuit, which measures the decaying voltage, is left open until the moment the current is switched off.

The layout of electrodes and instrumentation for an IP survey.

Different materials have different IP responses. Disseminated or dispersed sulphide grains within a large body of rock, for example porphyry and strataform deposits usually have a strong IP response. Small semi-massive sulphide bodies generally have a weak IP response. In gold exploration, associated minerals such as pyrite and arsenopyrite may be present in sufficient quantity in the neighbouring rock to cause an IP effect. Therefore gold mineralisation may be indirectly detected using the IP method.
Airborne Geophysical Methods

By David Tilley in Exploration Methods

There are a number of airborne geophysical methods used within the minerals exploration industry. Some of the most commonly used ones are aeromagnetics, radiometrics and VTEM. A digital elevation model or DEM is often done as an addition to most airborne geophysical surveys. Gravity surveys can also be conducted from the air as well as from the ground.

*Any unusually high or low region in the data that cannot be explained by the known geology is called an anomaly. Geophysics can create models that explain most anomalies.*

**VTEM**

In 2002, Geotech a Canadian firm developed, patented and trademarked VTEM, the versatile time-domain electromagnetic system. Time-domain simply means the recording of signal changes with time.

VTEM is useful for detecting and discriminating between moderate to excellent conductors. These types of conductors may include semi-massive to massive sulphide deposits and graphite occurrences. VTEM measurements have a high signal to noise ratio due to the low operating frequency. This enables penetration through conductive surface sediment and rock with depth penetrations of up to 300 metres.

Below is a diagram showing the general layout of VTEM. A receiver loop within a transmitter loop provides a symmetric response allowing the orientation of any conductor to be easily determined. A magnetometer is attached to the line above the transmitter-receiver loop.
Data is recorded every 0.1 second. At a flight speed of 90 kilometres per hour, with the VTEM loops only 30 metres above the ground, equates to a high spatial resolution of 2-3 metres.

Examples of the observed VTEM response in a variety of geological settings. Graphite is a strong conductor with low resistivity whereas granite is highly resistive.

A ground-based station records the daily fluctuations in the earth’s magnetic field, which are affected by solar winds interacting with the Earth’s magnetosphere. These daily or diurnal variations are subtracted from the collected data.

Radiometrics

Radiometrics is considered a passive geophysical exploration technique as it involves measuring the natural radioactivity of soil, sediment and rock that is emitted from the top 30 centimetres of the earth’s surface. The usual flying height for the survey is 80 metres above the ground.

Where does this natural radioactivity come from? To know this we have to understand the makeup of atoms and how some of them have a tendency to break apart.

An isotope is a variety of an element characterised by having a different number of neutrons within its nucleus. Some isotopes are not stable and will undergo radioactive decay. This is a process where the nucleus splits into separate nuclei with the emission of radiation. There are three types of radiation emitted during radioactive decay; alpha radiation, beta radiation and gamma rays. As they travel through air, the different forms of radiation are attenuated at different rates. Alpha radiation, which is composed of helium nuclei, can only travel a few centimetres. Beta radiation, which consists of electrons, can travel...
Gamma rays, a type of electromagnetic radiation, can travel up to several hundred metres through air before being fully attenuated.

Gamma rays are used in radiometric surveys. The energy of gamma rays is dependent on the element from which they come from. An instrument called a gamma ray spectrometer, which is fitted to an aeroplane or helicopter, counts the number of gamma rays received every second and assigns them to their respective energies. This produces a spectrum from which the abundance of uranium (U), thorium (Th) and potassium (K) can be determined. The total count (TC) is the number of gamma rays counted across the entire spectrum and includes those counts attributed to uranium, thorium and potassium.

The number of counts varies depending on factors such as the height of the spectrometer above the land surface, the amount of background radiation present and the type of spectrometer used. The results are corrected and converted to provide meaningful results. Normally, the potassium result is given as a percentage, while thorium and uranium are expressed in parts-per-million (ppm).

Radiometric data is usually displayed as maps. Normally a survey produces four separate maps; a uranium, thorium, potassium and a total count map. Another useful display used is where the uranium is assigned to the colour blue, thorium to green and potassium to red. The three different elements are then combined into the one map called a red-green-blue or RGB image. The combination of these three colours in various ways provides a multi-coloured display. For example, red and blue produces the colour magenta. When this colour is shown on the map, areas high in potassium and uranium are indicated. When the RGB image shows white areas then this is due to high levels of all three elements. Radiometric images usually correlate well with geology maps because different rock types have different abundances of radioactive elements.

The radiometric technique can help to locate areas of potassic alteration, which is commonly associated with hydrothermal deposits. And of course, when exploring for uranium and thorium deposits, it is particularly useful. It can also be used for locating rare earth element (REE) deposits. This is because such deposits may include the mineral monazite which can contain radioactive thorium.

Aeromagnetics

The principle behind an aeromagnetic survey is similar to a ground magnetic survey. However, instead of carrying a magnetometer in a backpack and walking across the landscape, a magnetometer is either carried on board an aeroplane or towed behind at a height of around 100 metres. Aeromagnetics can be done either as a separate survey or in conjunction with other techniques such as VTEM, radiometrics and/or gravity.

The main advantage of an airborne survey over a ground-based one is that a much greater land area can be covered in the same time period. The flight path of an aeromagnetic survey has a similar grid-like fashion to a ground magnetic survey, albeit with a generally greater line spacing. This explains why aeromagnetic surveys tend to be of a lower spatial resolution than ground magnetic surveys.

During the survey, the magnetometer continuously records the total magnetic field intensity immediately beneath the magnetometer. This field consists of daily fluctuations caused by changes in solar wind activity, the regional magnetic field and local variations caused by the underlying rock mineralogy.

Differences in the magnetic susceptibility of rocks are usually attributed to the common mineral magnetite. Specifically, this is used when exploring for magnetite-rich deposits during iron ore exploration. However, occasionally the variations can be caused by the iron sulphide mineral pyrrhotite,
which may directly point to a sulphide-rich body containing valuable metals such as copper, lead, zinc, silver and even gold.

Different rock types have different abundances of magnetic minerals. Therefore, with an aeromagnetic survey it is possible to produce maps which show the distribution of different rock types at or close to the earth’s surface. Even geological structures such as faults and folds can be imaged using aeromagnetics.

Anomalies and local variations in rock mineralogy are important to geologists. To see these often subtle features, diurnal variations and the regional field are subtracted from the data. After removal of any obvious artefacts caused by large man-made metal objects, any unusually high or low region in the data that cannot be explained by the known geology is called an anomaly. Geophysics can create models that explain most anomalies. This involves calculating the response that would occur from a particular shape of rock mass containing a certain amount of magnetic minerals at a certain depth.

Just like with ground magnetic surveys, geophysicists process the data in number of ways to enhance the data. Commonly used filters include:

- UC250 – upward continuing standardises data to a specific height above the ground, e.g. to 250 metres. It helps to remove or minimise shorter wavelengths in the data associated with surface magnetism and enhances longer wavelengths from deep objects and structures.
- RTP – reduced-to-pole removes any polarity in the data; and
• 1VD and 2VD – the first and second vertical derivatives are obtained to reveal subtle changes in the gradient of the magnetic data.

DEM/DTM

Another output of most airborne surveys is a digital elevation model (DEM) or digital terrain model (DTM) of the flown landscape. The height above sea level of the aircraft at a particular location is known from the GPS data collected and the height above the land surface is known from the radar altimeter recordings of the aircraft. It is a simple matter of subtracting the two to get the height of the landscape above sea level.

Geologists use DEMs to accurately locate the elevation of drill-hole collars. This is particularly important when constructing geological cross-sections from data obtained from drill-hole logs. This ensures that the cross-sections are vertically accurate.

Another use for DEMs is that other geospatial layers can be draped over a 3-dimensional digital elevation model. This can provide valuable insights into how topography is affected by certain rock types, which may help with identifying other prospective areas with similar topography.

Companies Referenced
• Geotech (www.geotech.ca)

Further Reading
• Gravity Surveys
• Ground Magnetic Surveys
• Seismic Surveys
• MT and CSAMT
• Resistivity and IP
Exploration using telluric currents – MT and CSAMT

By David Tilley in Exploration Methods

Magnetotellurics (MT)

It sounds a like something from science fiction but magnetotellurics (MT) is just a fancy name for an electromagnetic geophysical technique which is used for measuring subsurface variations in the Earth’s electrical and magnetic fields. The technique can reveal structures and differences in rock types down to a depth of 10 kilometres. Magnetotellurics is used in both petroleum and minerals exploration.

The Earth’s magnetic field is affected by solar activity and lightning resulting in the production of electrical currents below the Earth’s surface. These flows of electricity are called telluric currents. Developed by Russian and French scientists in the 1950s, magnetotellurics has now become an important geophysical technique through recent advances in instrument design and data processing techniques.

An advantage of using magnetotellurics over many other geophysical techniques is the low-impact and unobtrusive nature of the method. The equipment used is light-weight, only natural electromagnetic sources are used and personnel are not exposed to the same hazards as with other geophysical techniques. Consequently, magnetotellurics can be used in environmentally sensitive regions as well as in relatively built-up and inhabited areas.

The technique is so effective because there are large variations in the electrical conductivity of rocks and sediment with different chemistry and characteristics.
Geological structures such as faults can also be mapped using MT because of:

- the juxtaposition of different rock types along a fault, and
- chemical alteration along the fault due to ground water movement. The clays formed create changes to electrical conductivity along the fault.

**Conducting A MT Survey**

Magnetotelluric readings are recorded every 200 metres or so along a survey line. The line may be designed to cross an inferred fault or suspected change in rock type. At each station along the line electric and magnetic fields are recorded at the same time and also at right angles to each other. The readings are generally taken overnight or for a few days. To obtain information from the greatest depths data may need to be collected for several days to even weeks. This is because greater depths require lower frequencies to be recorded, with correspondingly longer recording times. Another downside to obtaining greater depth penetration is a resultant loss in vertical resolution.

Because the production of telluric currents is dependent on solar activity and lightning, particular times during the solar cycle or certain seasons are better than others. To ensure the best results, the geophysicist in charge of the survey may want to schedule the survey accordingly.

Once the readings have been collected, the geophysicist then processes the data to obtain vertical profiles of the change in resistivity versus depth. The images are then passed onto the geologist who then interprets them and plans where drill holes need to be located.

**Controlled Source Audio-frequency Magnetotellurics (CSAMT)**

You may have thought magnetotellurics is a mouthful. Well, controlled source audio-frequency magnetotellurics (CSAMT) is even worse! This is where acronyms become really handy.

CSAMT uses a controlled source rather than the natural telluric currents of the Earth. Because of the controlled frequency range of the technique, other man-made sources such as from power lines and electric fences can be filtered from the results enabling high resolution mapping of the subsurface to be achievable. The CSAMT method is a shallower technique than magnetotellurics due to the higher frequencies used. Correspondingly, the data acquisition times are shorter at each station.

The figure below shows what is possible using CSAMT. Regions of high electrical resistivity possibly associated with a quartz-rich, potentially mineralized zone are revealed using the technique. Highly conductive regions which might represent clay-rich zones, graphite-rich zones or salty ground water within porous rock can also be detected.
Conducting a CSAMT Geophysical Survey

The controlled source or transmitter for CSAMT consists of two 1-metre square aluminium foil electrodes buried in the ground, about 1.5 kilometres apart. These are placed several kilometres from the survey or receiving area. The transmitter line is parallel to the receiver array. The electrodes are connected to a portable generator which produces an electrical current through the ground. Salt water applied to where the electrodes are planted helps with completing the circuit.

At the receiving area a series of small porous porcelain pots are connected by wire to each other forming a line up to 150 metres long. These are then connected to a receiver which records the electromagnetic signals. After the data is collected, the pots, wires and receiver are advanced along the survey line to the next set of stations. The process makes it possible to record information over a 1-kilometre length.

Just like with magnetotellurics, CSAMT raw data is processed by a geophysicist and transformed into resistivity versus depth images which are then later interpreted by a geologist. If enough information is obtained from a number of survey lines, plan view plots or maps of the data can be produced for any depth. From these, three-dimensional models can be produced, which allow for accurate drill-hole design and targeting.
Gravity Surveys

By David Tilley in Exploration Methods

Gravity Surveys – the basics

Gravity surveys measure minute variations in gravity. Gravity at every point on the surface of the earth varies slightly depending on:

- distance from the equator;
- density of the underlying rocks.

*The ability for rock density to be detected using gravity variations is the basis for the use of Gravity Surveys in mineral exploration.*

A gravity survey is designed to pick up density variations below the surface.

Gravity Anomaly Map of New Jersey
If the earth was a perfect sphere and was composed of the same material throughout, gravity would be the same anywhere on the surface. However because the planet is slightly squashed, gravity at the poles is slightly higher than at the equator due to the slightly shorter distance to the centre of the earth at the poles.

The ability for rock density to be detected using gravity variations is the basis for the use of Gravity Surveys in mineral exploration. Rock below the earth’s surface is not homogeneous. It is composed of material of different densities, both horizontally and vertically. The density of rock varies with the amount of mass contained within them. Denser rocks contain more mass and therefore exert a greater force of gravitational attraction.

Rock density varies with different mineral compositions and the amount of pore space between the individual mineral grains. Metals tend to be denser than surrounding rocks, meaning that a gravity anomaly may pick up a mineral concentration that is otherwise invisible to other geological exploration methods.

Gravity Anomalies in Detail

Gravity anomalies come in all sorts of shapes and sizes. Positive gravity anomalies are produced by regions of higher than average density. Lower than average density regions produce negative anomalies. The areal extent of an anomaly defines the lateral extent of the body producing the anomaly. A sharp, short wavelength anomaly indicates a shallow, dense object. A broad long wavelength anomaly points to the presence of a deeply buried massive body.

Variations such as these provide an insight into different rock types and geological structures that are otherwise hidden. Three examples of the gravitational response above different rock types and structures are given below.

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Relative variation in observed gravity readings over different geological structures.

Gravity Anomaly #1 – Diatreme
The first example is a diatreme where granite has been broken up and redeposited within a volcanic vent. A reduction in density has occurred due to an increase in porosity. Although a sandstone layer covers the diatreme it is detectable by the gravity survey method because a mass deficit exists. A negative gravity anomaly is the result.

Gravity Anomaly #2 – Dyke

The next example shown is a dolerite dyke intruding granite. Both rocks have virtually the same porosity so this is not the cause for the different densities. The mineral composition of the dyke means it is much denser than the granite. Again, the overlying sandstone unit is no barrier to the gravity survey method. Due to the extra mass associated with the dyke, a positive gravity anomaly is recorded in the survey results.

Gravity Anomaly #3 – Hidden Fault

Faults can also be detected by the gravity surveys. Granite has been brought next to sandstone because of fault action. Later, a sandstone layer has covered the fault however the structure is still detectable by the gravity survey method because of the mass differences immediately below the sandstone layer. Granite has a higher density than sandstone and therefore contains more mass than the sandstone in a given volume. A positive response occurs over the granite while a negative response occurs over the sandstone.

How Is A Gravity Survey Done?

Gravity surveys can be can be either aerial, ship-based on land-based. On land, surveys use four wheel drive vehicles and quad bikes. The gravity meter or gravimeter is a very delicate instrument as. It is
highly sensitive and great care is required, as the unit is easily damaged by vibrations and shocks in transit. Minor vibrations may also affect the readings as they are being taken at each locality.

Once the gravity measurements have been collected data are processed by the geophysicist. The data is then plotted as a computer-generated map. The geophysical anomalies mapped are then studied by the geologist who overlays geochemical and other geophysical data. The geologist looks for coincident anomalies which can then be followed up with field work and drilling.

Iron oxide-copper-gold (IOCG) deposits can be identified quite successfully using the gravity survey method. These deposits give a strong positive gravity anomaly due to the abundance of hematite, an iron oxide mineral, which is much denser than the surrounding non-mineralised rock. Due to strong alteration of magnetite to hematite within the mineralising system a magnetic low is often produced. The combination of a gravity high and a magnetic low anomalies is good evidence for a hidden copper-rich IOCG deposit.

Exploration for Volcanic massive sulphide (VMS) and Mississippi Valley-type deposits and can also make use of gravity surveys due to the contrast between the host rock and the deposit-related sulfides.
Seismic Surveys

By David Tilley in Exploration Methods

Oil and gas exploration

Commonly, seismic surveys are used in oil and gas exploration to identify structures and rock layers deep underground. In the industry, this is called seismic stratigraphy. Large hydraulic vibrators or explosions are used to generate the powerful seismic waves needed to penetrate deep underground. Reflections from rock layers are picked up by microphones (geophones) located on the surface. Processing of the data by a geophysicist produces images of the underlying rock strata and structure. Geologists interpret these images to determine where reservoirs and traps for natural gas and petroleum are located.

Epithermal gold exploration

Gold exploration companies also use seismic surveys, although on a smaller scale, when looking for quartz veins hidden under thick layers of soil, sediment and/or volcanic ash. Hydrothermal activity, which is often responsible for gold mineralisation, results in silica-rich zones around quartz veins. This chemical alteration makes the neighbouring rocks harder and therefore more resistant to weathering and erosion. After a long period of exposure, a rugged terrain may form through differential weathering and erosion. Topographic highs revealed by seismic surveys in an ancient buried landscape may point to epithermal quartz veins and other silica-rich zones associated with gold mineralisation.

Seismic surveys are used in the Coromandel region of New Zealand, where epithermal gold mineralisation is hidden under thick volcanic ash layers.

How is it done?

A seismic survey requires the planting of a series of geophones into the ground that are connected via a cable to a computer. Another cable runs from a metal base plate several metres from the end of the line of geophones. When the plate is struck with a sledgehammer, shock waves propagate outwards. These waves then interact with the underlying rock layers. The computer records the delay between when the hammer strikes the plate to when the waves are picked up by the geophones. The longer the delay the deeper is the feature that caused the reflection.

Usually a couple of strikes of the plate are recorded and the results are either averaged or the best shot used during data processing. Different geophones are used for recording different frequencies, each of which corresponds to different depth penetrations. Progressively, the plate and the geophones are moved, in unison, across the landscape. Successive shots and recordings build up a picture of what lies beneath the surface.
Layout of a seismic survey. An old rugged landscape overlain by recently deposited volcanic ash layers is detected by this method. A topographic high is the result of differential weathering and erosion of the ancient land surface.

A team of people is required to run a seismic survey. Two or three field assistants are on the geophone line, moving cables and planting the geophones. The biggest and strongest assistant usually operates the metal plate and hammer, as the more energy that can put into the ground the deeper the seismic waves can penetrate. When carrying out seismic work, quiet during recording is important, as is avoiding windy days. Wind can generate seismic waves at the base of trees which can interfere with the recordings and generate “noise”. The work usually progresses slowly with much standing around waiting for the geophysicist to give the go ahead to move the base plate and geophones. This is not so much of a problem when working in a beautiful country such as New Zealand with its spectacular scenery. It’s certainly not as good for your fitness as a ground magnetic survey!

*Before starting a survey, consultation with the local council is needed to ensure that no noise control regulations are being breached.*

Good landholder liaison is required, the repeated bashing of a metal plate, may annoy neighbours. Before starting a survey, the local council needs to be consulted to ensure that no noise control regulations are being breached. This may include restricting the survey to certain times of the day.
Data interpretation and drillhole planning

Later, after processing by the geophysicist, the seismic images are interpreted by the geologist who infers the rock type and any geological structures at depth. The geologist then plans the best locations for drillholes to intercept any possibly mineralised zones.

To aid the geologist in drillhole planning other techniques such as rock and soil sampling may be used to confirm the prospect. Geochemistry assay may be used to detect what is known as coincident anomalies; where a seismic anomaly coincides with a geochemical anomaly. When this happens, the evidence for a buried mineralised zone is significantly stronger as is the argument for drilling it.
Ground Magnetic Surveys – Seeing Beneath The Rocks

By David Tilley in Exploration Methods

Although ground magnetic surveys measure rock magnetism, they can help find minerals that aren’t magnetic, including gold. In fact, the areas that aren’t magnetic can be as significant as those that are. This is why ground magnetic surveys are important for far more than finding iron ore.

Why Is A Ground Magnetic Survey Useful?

Ground magnetic surveys map the magnetism of underlying rocks. The most common magnetic minerals found are pyrrhotite, (iron sulphide), and magnetite. Magnetite when found with sufficient purity and quantity may become an iron ore deposit.

Pyrrhotite is important because of the minerals it’s often associated with including pyrite, another iron sulphide mineral, which may contain gold. Other valuable minerals often associated with pyrrhotite include; chalcopyrite (copper sulphide), sphalerite (zinc sulphide), and pentlandite (nickel sulphide).

*Pyrrhotite is key to the ability of ground magnetics to reveal hidden zones of potentially valuable non-magnetic minerals.*

Ground magnetic surveys are also used to understand the general structure of underlying rock, identifying faults and folds otherwise hidden beneath cover rocks and for identifying demagnetised zones associated with hydrothermal activity.

The heat of, hydrothermal activity demagnetises rocks. These demagnetised zones may be identified using ground magnetics on a local scale, or by aeromagnetics at a regional level. This technique can identify epithermal gold deposits. In the goldfields around Charters Towers, Queensland, Australia, aerial and ground magnetic surveys helped identify demagnetised associated with swarms of hydrothermal quartz veins, under younger sedimentary cover.

Conducting A Ground Magnetic Survey

A survey is usually done by two operators. While walking across the landscape an operator can encounter numerous obstacles, but the idea is to walk as straight as possible. In heavily vegetated areas, walking can be quite slow and concentration has to remain high to avoid hazards such as snakes, rabbit holes or even obscured mine shafts. On good ground, operators can walk up to 15 km a day, so a high level of fitness is required. If you are not fit at the start of the survey, you will be by the end!

Each operator walks across the survey area with a magnetometer and GPS in a backpack. Changes in the earth’s magnetic field are recorded along the length of each line. GPS coordinates for the readings are also recorded. A plot of these coordinates reveals that the actual paths walked are normally not perfectly
straight but wriggle across the landscape. Luckily, these minor deviations do not significantly affect the result.

Planned ground magnetics with a line spacing of 25m (red). Walked lines by Operator 1 (white) and Operator 2 (black) are shown. Base image: Google Earth.

Along with the magnetic field changes, the elevation of the land surface is also recorded by the GPS. This data will later be used by software to generate 3D model of the topography of the survey area.

The spacing between successive survey lines can vary between 100m to 20m depending on the resolution required. The narrower the line spacing, the higher is the resolution of the resultant magnetic image. The highest resolution images can reveal subtle structures including subtle features in faults and shears, which may point to high grade ore shoots.

A base station is needed for every survey. The station records daily variations in the earth’s magnetic field caused by electric currents in the upper atmosphere, by solar activity. These daily fluctuations are later corrected for, otherwise incorrect magnetic images can result.
Interpreting A Ground Magnetic Survey

Back in the office, a geophysicist processes the data removing artefacts produced from surface items such as steel drums and wire fences. Filters and corrections are used to enhance the data to reveal subtle features and structures within the underlying rock.

Reduced-to-pole (RTP) is a very important correction made to the data, particularly for locations far from the earth’s magnetic poles. The RTP filter corrects for the artificial effect of being of the distance to the earth’s magnetic poles, allowing for accurate drill-hole location and targeting.

Geophysical interpretation is as much an art as a science. An experienced scientist will use a variety of filters that highlight different aspects of the magnetic gradients in the data, and reveal subtle changes which may point to concealed structures and associated mineral occurrences.

Other high level filters used by geophysicists include tilt derivative and horizontal derivative, each providing a slightly different way of viewing the data.

A correction may be applied to standardise the data to a specific height above the ground. Upward continuing helps to remove or minimise erratic surface magnetism, while enhancing longer wavelengths associated with deep objects and features.

The geologist in close consultation with the geophysicist interprets the magnetic images. The use of specialised GIS mapping software allows for other data such as stream sediment, soil and rock chip geochemistry to be combined with the magnetic images. Any coincident anomalies become potential drill targets.
Geological Field Work – When Is It Justified?

By David Tilley in Exploration Methods

Most geologists are happiest when they are furthest away from the office, the phone, and management. Fieldwork, although essential for any exploration program, is also expensive, and potentially dangerous. So what are the questions that should be asked before an expedition is mounted, particularly into a remote area?

Once a number of prospects have been identified by the desktop review it’s time to plan follow-up field work.
Planning and Logistics

What is the reason for going into the field? This is a question that every geologist should ask themselves before venturing out into the wilderness. Sure, going into the field is full of fun and adventure however a great deal of time and money can be wasted too. The first step of geological reconnaissance happens back in the office, studying old company reports and online databases. Data may include old drill-hole, rock chip, stream sediment and soil geochemistry results as well as geophysical information. There is no point in “reinventing the wheel”, as they say. Though it’s worth remembering, that until GPS’s started to be used in the field in the 1990’s, locations can not always be relied on.

The purpose of the desktop study is to gather as much information about an area as possible. One of the best ways to do this is using a geographic information system (GIS) software package. This is because the different types of data including geological, geochemical and geophysical can be viewed on a single digital map. A GIS displays makes trends and gaps in the data more apparent. Often the gaps are significant, as this is where data is lacking and exploration should be focussed.

Once a number of prospects have been identified by the desktop review it’s time to plan follow-up field work.

Equipment

Even for geologists, the tools of trade have gone high tech. Probably the most important piece of technology for the modern field geologist is the hand-held GPS. No longer is there a real risk that samples and observations will be mis-recorded on a map or aerial photo.

A tough portable computer, either a note book or a tablet is used to transfer data and is backed up regularly onto an external hard-drive. If there is an Internet connection available, an off-site backup should be made too.

Some items of field equipment haven’t changed though. The geologist’s pick is still essential for breaking rocks apart for inspecting freshly exposed surfaces. The outside surface of rocks is usually
covered in dirt and a layer of oxidation that can make it difficult to identify the rock type and any ore minerals present within the rock.

A compass and inclinometer should be carried as well. These are used for measuring the rock strata’s orientation, including the strike and dip.

A number of sample bags, normally calico, for collecting samples are required. A ticket book with a set of unique numbers for labelling rock, sediment and soil samples is essential. Getting samples mixed up can waste days of fieldwork.

Safety

The safety of field personnel should always come first.

A communication schedule that is agreed in advance is an important document. It includes the schedule by which the leader of the field party, usually the geologist, must make contact with base. It might only be a brief conversation to say that everything is okay or it might be a much longer conversation about an exciting discovery made during the day.

The communication schedule also outlines the reason for going into the field and includes travel notes including the route to be taken and the times of departure and arrival to and from the field site. Contacts and emergency procedures are included in the document in case the field party is overdue for a scheduled communication time or if a serious incident occurs. Additional items such as the registration number of the vehicles, names and phone numbers of personnel, landholders and management should be included as well.

Field workers should come equipped with the appropriate clothing and footwear; depending on the conditions, this can range from thermal underwear to sun hats. In North American backcountry, it’s not unusual to work with a dog, to scare off the curious bears, and to be equipped with high-powered rifles in polar bear territory. During hunting season, other humans can be a risk as well, and a whistle is a light and useful survival item.

These days a GPS tracker is a great way for people back in the office to see where you are at all times on Google Earth. Essential communication devices include a satellite phone, a UHF radio. In many remote areas as a mobile phone alone cannot be relied on.
Geological Mapping in the Field

Should give a nice assay – but is it typical?

Geological mapping has come a long way since the days of hand drawing on a base map. These days, geological observations are entered directly into a GPS at each site. More detailed descriptions can go into a field note book. Back at camp the GPS tracks and waypoints are transferred from the GPS onto a portable computer. Mapping software is then used to interpret the extent of rock types in the area and key structural elements such as faults.

Alternatively, mapping can be done directly in the field with a tablet computer attached to a GPS. Using technology means that not only are more accurate maps produced, in a shorter time, but that changes to the field program can be made on the fly, as the field geologist’s understanding of the area’s geology improves. ..

Rock Chip Sampling

The collection of representative rock chips for geochemical analysis is a key task in any exploration program. Each sample should be around a kilogram in weight. Geologists are very good at identifying the most mineralised rocks. So investors should be wary. What might look like great numbers in an assay may not be representative of the mineral deposit as a whole.

Stream Sediment Sampling

Sampling of stream sediment is a great way to cover large areas of land. The catchment areas of streams and their tributaries can be large. Over time, material from these catchment areas is washed into adjoining drainage channels where sediments accumulate. By sampling sediments at junctions and at regular intervals along streams, an overview of the geochemistry of drainage channels and adjacent catchment areas can be developed. About 4 kilograms of sediment is required at each site, which makes for a heavy backpack at the end of the day.
A well-executed field trip should result in the answers to the questions asked at the start. Fieldwork alone will not confirm the existence of an economic mineral deposit, but it may be the first step on the long road from prospect to operating mine.
Age Matters! Exploration and the Dating of Rocks

By Christopher Rawluk in Exploration Methods, Mineral Deposits

There is not a geologist alive who doesn't relish the idea of finding something that someone else missed. And many do. Why? Sometimes it has to do with time and money. There may not be enough of either. Abandoned land positions are often picked up during good times and dropped during market slumps. From a geologist’s perspective that can’t be helped. Sometimes, however, a misinterpretation of property geology from lack of information can result in a lost opportunity. Gaining a full understanding of property geology is not only an academic pursuit; it is the key to a good exploration program.

One of the tools used in understanding the geologic history of the property and its economic potential is radiometric dating. Why would be important to know the age of the rocks on a property? There are certain times in geologic history when the earth was more tectonically active than at other times. Consider the relationship between these activities and the occurrence of gold deposits.

Few gold deposits are found in rock between 1.7 billion and 600 million years old.

The Good Times

There are two major episodes of geologic activity that are thought to have occurred around 2.7 billion years ago and again around 1.9 billion years ago (yes, billion). These were episode of crust and continent formation which resulted in the formation and preservation of gold deposits. Many gold deposits fall within these peak age ranges.

Orogenic Gold Deposits

Orogenic gold deposits are associated with major mountain building events. There are two major peaks in these gold deposits between 2.75 and 2.55 billion years ago and again between 2.1 and 2.75 billion years ago.

Though the mountains have long since been eroded away and the gold concentrated through other geologic processes, the gold mines of Red Lake Ontario (Gold Corp) are good examples of orogenic gold deposits of that age.

Gold-Bearing VMS Deposits
Gold-bearing sulphides are found along a quartz-tourmaline vein.

These deposits are associated with sea floor volcanism. There are two major peaks in deposits aged between at 2.7 billion years ago and 1.85 billion years ago. The La Ronde mine in Canada (Agnico Eagle) is a good example of a gold-bearing VMS deposit.

Paleoplacer Deposits

Paleoplacers are essentially ancient placer deposits which have been metamorphosed back into solid rock over time. Good examples of paleoplacers of this age are Witwatersrand, South Africa and the Tarkwa deposit in Ghana.

The Barren Years

Few gold deposits are found in rock between 1.7 billion and 600 million years old.

A relatively “quiet period” of geologic activity and the erosion of crust formed during that time are a few reasons proposed for the lack of deposits. Regardless, there’s not much to be found in rocks of this age.

More Good Times

In rocks younger than 600 million years old several deposit types can be found and are most often associated with mountain building and collision events during this time.

Gold-bearing Porphyry Copper and Epithermal Deposits

Since these deposits form at shallow crustal levels (<1-3 km), few old deposits are found due to erosion. Many epithermal and porphyry deposits are less than 65 million years old. Chuquicamata, Chile (Codelco)
is an excellent example of a gold-bearing porphyry copper mine while the Waihi mine (Newmont) in New Zealand is an epithermal deposit.

Placer Deposits

Significant placer gold deposits are deposited next to older mountain belts and are the result of the erosion of rock from older orogenic gold deposits. Most are less than 65 million years old. Placer deposits drew miners to the Yukon and Alaska during the Klondike gold rush.

Intrusion Related Gold Deposits

These are deposits associated with granitic magma bodies, but farther from collision zones than orogenic deposits. These types of deposits are generally younger than 500 million years. The Fort Knox deposit in Alaska (Kinross) is an example of this deposit type.

Conclusion

There are a lot of ingredients to a good exploration program and determining the age of the rocks and events associated with a property is just one of those ingredients. Smart companies will try to understand the nature of their property or deposit as best then can. In less-developed regions, using dating studies to develop broad geologic histories can be a good starting point for a larger reconnaissance project.
Rock & Soil Sampling – The Key To Most Exploration Projects

By David Tilley in Exploration Methods

Soil sampling is a basic technique of mineral exploration. Cheaper than drilling, sampling can be used to quickly establish the existence and extent of hoped for mineralisation.

Initial geophysical and other remote sensing methods are used to target a geological structure which may contain mineralisation. Soil sampling can either stop a project dead in its tracks, or give the green line for further expenditure including drilling.

Why Is Soil Sampling Important?

Soil sampling is undertaken to define the location and shape of an obscured mineralised structure and to identify any higher grade sections within the structure. A successful soil sampling program will result in accurate drill-hole targeting. Many structures are not mineralised to the same degree along their length. A great deal of money can be wasted drilling along a geophysical anomaly only to realise later that the highest grade zones are confined to narrow steeply plunging zones in the plane of the structure.

*All too often, drilling doesn’t intersect any of these zones and the prospect is subsequently abandoned or relinquished. Opportunities are missed because a thorough chip and soil sampling programme was not undertaken.*

Rock Chip Sampling

Rock chip sampling is sampling of exposed potentially mineral-bearing rocks. Chips are taken during initial mapping, and if promising results are returned, a subsequent soil sampling survey undertaken. Alternatively, in many cases, outcrops maybe either minor or non-existent, and soil sampling is a key next step for an exploration programme.

Designing A Soil Sampling Programme

A soil sampling programme must be designed to ensure that it tests the structure which is causing the geophysical anomaly. In the example below, the plan consists of seven lines each separated by 120m. These lines cross, at right angles, the structure that was identified using a ground magnetic survey. Each sampling site along the lines is spaced 20m apart, a total of 147 samples. Surface rock chips may provide evidence as to where the high grade zones lie along the structure. The geologist take these into account when planning the soil sampling programme. When the geologist is happy with the plan, the sample points are entered into a GPS in readiness for the survey.
Taking Soil Samples

Soil sampling is a lot easier now that a GPS is standard equipment, so the uncertainty of where the actual sample comes from is minimised. The team uses the coordinates that were entered into the GPS to locate each site. Normally, this can be done to an accuracy of ± 5m, which is the typical accuracy of a hand-held GPS.

Soil Sample with Friends

Soil sampling is normally done with a minimum of two people; a geologist and a field assistant. This is not only for getting the work done more quickly, but for safety reasons too. As with any work in remote areas emergencies can happen when least expected, which can lead to life threatening situations. Once while soil sampling, my assistant had an asthma attack triggered by fungal spores in a particular soil sample. The fungus had apparently grown on sheep dung. Fortunately, her medication wasn't too far away in the truck and she recovered quickly. The moral of the story here is to be prepared at all times.

No Jewellery Please, We’re Soil Sampling!

All jewellery such as rings, bracelets and necklaces must be removed by those directly involved in collecting and handling the samples. This eliminates any chance of jewellery coming into contact with a
sample and contaminating it. Gold and silver are obviously a risk, but I once knew a company that got excited by a “palladium anomaly” which was later found out to be caused by the sampler wearing a platinum ring. Both platinum and palladium commonly exist together as they both belong to a group known as the platinum group metals (PGM).

Another source of contamination can come for the sampling equipment itself, such as lead-silver solder used to attach the mesh to the outer ring in some sieves and chromium from stainless steel picks and shovels. Even the type of sunscreen used by the samplers must be considered, as zinc based creams can contaminate samples from sweat off the skin.

Local Site Contamination

Sometimes, the actual location of the sample site can cause problems too. Some wood preservatives used in fence posts can contaminate the soil and hence nearby samples with chromium and arsenic. Corrugated galvanised iron in close proximity to sample sites can result in elevated zinc levels. The possibilities for contamination are numerous, so one must always be on the lookout for potential sources.

Start At The Most Interesting Line

The first line that is sampled is usually the one with the highest probability of encountering a soil anomaly. The reason for doing the “best” lines first is so that if the sampling cannot be completed for any reason, e.g. bad weather or a twisted ankle, then it is not so much of a great loss.

XRF Spectrometry

Another way of saving time and money on a sampling programme is to use a hand-held X-ray fluorescence (XRF) spectrometer on each sample as they are being collected. This quickly gives the geologist an idea as to whether or not a geochemical anomaly is being detected during the programme. By using the instrument in the field, the sampling programme can be modified as it proceeds. Soil lines can be dropped while others can be added to infill the survey. If a geochemical anomaly is suspected the spacing between sites can be done reduced, say from 20m to 10m.

How To Take A Soil Sample

In country where the soil cover is quite thin, a sample is obtained by digging a small hole with a long handled pick, usually down to weathered rock. The sample is then placed into the top sieve with a small garden spade. This coarsest sieve removes organic matter such as leaf litter and charcoal as well as coarse sand and gravel.
A soil sample ready to be sieved.

The sample is sieved on-site using a 80 mesh sieve, 178 micrometres, using a stack of sieves with progressively finer mesh sizes. This ensures that the finer clay and silt size particles are concentrated as this is the particle size range which contains the highest concentration of common indicator elements such as copper, lead, zinc and arsenic.

Sieving also removes coarse quartz grains which may have coarse or nuggetty gold attached. At first, this may seem like an odd thing to do removing the coarse gold from the sample. The reason why it is done is so that the resultant geochemical data has a smooth gradient and doesn't contain spikes in the data or unusually high values which can be difficult to map and contour.

In contrast in areas where deep moist soils exist, a hand soil auger is usually used to obtain soil samples. Hand augering down to a depth of a metre or more is sometimes necessary to obtain a sample from the top of the weathered rock. Soil samples by this method are almost always moist or wet, so sieving is not possible. Mud tends to stick to the sampling equipment so a nylon brush is used to clean most of the dirt and mud off before the next sample is collected. Otherwise, cross-contamination can occur. Wet samples are placed in plastic bags and submitted to the laboratory as is. The laboratory then does the drying and sieving required prior to analysis.

Which Sample Was That?

Sample numbering using a foolproof method is extremely important. Due to the large number of samples taken during a soil survey, great confusion can occur if numbering is not systematic. One of the best methods is to use a pre-numbered ticket book. At each site the coordinates are entered into the ticket book, the number is written on the outside of the sample bag with a permanent marker and the duplicate ticket is torn out of the book and placed in the bag with the soil.
Analysis of samples

Before samples are submitted to the laboratory the geologist determines the suite of elements to be analysed and what the detection limit should be. As labs charge more for lower detection limits, budgets come into play with both the suite of elements analysed and the methods used.
Landholder Liaison – Geologists and Landowners

By David Tilley in Exploration Methods

The First Contact

The initial contact with a landowner can be nerve-racking not only for the geologist but also for the landowner. Much is at stake for both parties.

Even though a company holds an exploration permit or license over a piece of land they don’t have the automatic right to enter the land without the owner’s consent. It is common courtesy to always ask first.

*Rural property owners treat their land as you do your own backyard.*

Landowners can be very protective of their properties, many having been handed down from generation to generation. Just because a property is thousands of hectares in area doesn’t mean that the landowner cares any less about a square metre of it. Walking onto a property a couple of kilometres away from the owner’s homestead is just the same as someone walking across your front lawn in suburbia. Some landowners will resort to force or even firearms to evict a trespasser.
When working in large organisations other people such as a tenement manager or landholder liaison officer may seek permission on behalf of a geologist to enter a property. Even though permission has supposedly been granted, it is essential that the geologist also makes contact with the landholder. Sometimes, a geologist may think that permission has been granted only to find out later that the person responsible for gaining the permission did not follow through. Alternatively, a notice of entry letter may get held up in an administrative process and the landowner is not actually informed. I have been in this situation a couple of times in my career and I must say it was not a pleasant experience.

The best way to approach a landholder for the first time is via a telephone call. First introduce yourself, the company you work for and the reasons why you would like to explore on their land. Always listen to their fears and be truthful with your answers. Suggest a time and date you would like to visit to sit down with them for a friendly discussion. Make sure it is a convenient time for the landholder and ensure they never feel pressured or coerced. The relationship should develop slowly and steadily, to ensure cooperation is forged from the very start.

Try not to refuse an offer of a cup of coffee, tea or even cake. Forget about your waistline! Being standoffish can be quite offensive. Most landowners like to talk about their business, just like any other business proprietor. It's a good time to become familiar with each other and sometimes even really close friendships can develop. The landowner is often the only person for hundreds of kilometres around. So your safety and that of your team depends on a good relationship from the very start. A landowner may need to be called upon in an emergency; fortunately, many are only too happy to help.

An Access Agreement

An agreement or contract is commonly required for access to land for an exploration program. Some landholders shy away from such formal arrangements and would rather be compensated on a more casual basis. A carton of beer or wine or even just a box of chocolates is all that some landowners want while others may not want anything at all in return for granting access.

Many, however, would rather have an access agreement in place to compensate for the use of farm tracks, loss of quiet enjoyment and any other number of things that may impact on the landholder’s family and business life.

At the other end of the scale, access may not be granted. This could be as simple as a clash of personalities which can be solved by choosing another person to negotiate with the landholder. If this fails and an exploration company is still adamant about gaining access, then this becomes the realm of lawyers. Unfortunately, such avenues are invariably costly and time consuming, so are best avoided where possible.

An access agreement is normally for a fixed term and must be renewed at the end of the period should the explorer wish to continue work on the land.

When it comes down to compensation, a fixed amount is normally negotiated and agreed to with the landowner. This agreed figure typically covers access by personnel for low-impact exploration such as reconnaissance, mapping, geophysical surveys and geochemical sampling with hand tools. For any techniques which are more invasive, such as trenching, drilling and bulk sampling, additional payments are usually required. This is normally agreed to per item or by area of land disturbance.
Many landholders own their own earth-moving equipment. They would rather help build access tracks as well as pads and sumps for drilling than have external contractors coming onto their land to do the work. This arrangement and any other miscellaneous ones may need to be put into an access agreement.

Code of Conduct

While on a property, the exploration team should always be careful not to damage anything. It is better to minimise the chance of accidents happening by following safety procedures and to use common sense at all times. For example, unsealed roads should not be driven on when wet as wheel ruts can cut deeply into them. Care should always be taken while driving to avoid injuring or killing livestock. The livestock is the landholder’s livelihood and must always be treated with care and respect.

Driving on sown fields should be avoided as irreparable damage to that season’s crop can result. Fire safety is extremely important in hot dry countries such as Australia. One spark from electrical equipment or an ember from a cigarette butt can result in catastrophic destruction of land, property and lives. Despite all the best intentions, accidents can and do still happen.

Drilling The Target

Once a prospective target has been identified, the next step is to try to better define the size of the mineralization found.

The first stage of drilling is to assist in the further definition of an exploration target. Drilling not only confirms and extends the understanding of the geology of the deposit, it also allows a sampling program which established the grade of the resource. The ultimate goal of a drilling program is for resource evaluation, i.e. quantify the grade and tonnage of the mineral occurrence. A successful drilling program is the first step towards the confirmation of an economic ore reserve.

Read more about exploration drilling:

- Drillhole Planning
- Diamond Drilling
- Drillhole Targets: Apparent vs. Real
- Reverse Circulation Drilling
Evacuating a mine site after torrential rains have turned the main access road into a waterway.

Feasibility Studies

Determining the economics of a potential ore reserve definition involves far more than the size and grade of the resource. A feasibility study must also consider many other aspects including:

- mining techniques,
- logistics of getting the resource to markets, and getting staff to site,
- metallurgical requirements to process the ore,
- likely future demand for the commodity which may affect its price,
- staff availability and housing issues,
- legal issues,
- environmental issues and cost,
- governmental factors including legislative risk and governmental stability in some countries.

The economics, or otherwise, of a given deposit is a complex decision with many variable factors involved.
Read more about reserve definition:

- Why Drilling in Mines is Essential
- Classification of Resources
- Drilling Methods in Coal Mines

Opening A Mine

Ultimately, the process of opening a new mine can take years and sometimes even a deposit that may seem economical at first can prove to be uneconomical due to any number of the factors mentioned. To evaluate this one of three formal mining feasibility studies (order of magnitude, prefeasibility and detailed feasibility) is carried out. These studies determine whether the commodity can be mined economically or not. If the site is still economically viable after the detailed feasibility study, the company will begin the process of generating a mine site.

Read more about the difficulties of developing and operating a mine:

- Mining hazards – Often Mundane, Often Preventable
- Mining Production Delays
- Mining At Altitude in South America
- Mining Volcanoes
Lies, Damn Lies and Drill Highlights: A Critical Look at Interpreting Drill Results

By Christopher Rawluk in Drilling and Drill Results

That’s the problem. Not every drill result is good. As investors we must evaluate public results with a critical eye and approach every mining company news release as questionable. Our investment depends on it.

For junior miners, especially those with early-stage projects, drilling represents a significant exploration expense. The results of a drill program can make or break a project and where management is concerned, those results should always be good.

That’s the problem. Not every drill result is good. As investors we must evaluate public results with a critical eye and approach every public release as questionable. Our investment depends on it. In this article we review a few items to watch out for when reviewing company drill results.

We’ve talked about reporting interval thickness and proper QA/QC programs before so those won’t be reviewed in this article, but you should familiarize yourself with those concepts as well.

Drill Highlights

This is a big one. Nearly every release will have highlights, but how significant are they? Do they add value to the project? Are they anomalous or continuous?
Consider this drill result:

<table>
<thead>
<tr>
<th>Drill Hole</th>
<th>From (m)</th>
<th>To (m)</th>
<th>Gold (g/t)</th>
<th>Thickness (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A</td>
<td>61.50</td>
<td>69.00</td>
<td>20.50</td>
<td>7.50</td>
</tr>
<tr>
<td>including</td>
<td>66.50</td>
<td>68.00</td>
<td>96.90</td>
<td>1.50</td>
</tr>
</tbody>
</table>

This drill result includes a fantastic 96.90 g/t gold across a 1.5 meters interval with 20.50 g/t over 7.5 m.

**Is this good? It depends.**

One of the problems is that the highlight skews our average grade up significantly for the full interval. We can remove the highlight and calculate the grade of the remaining 6.0 meters as follows:

First we multiply our intervals by our grades:

- 7.50 m x 20.50 g/t = 153.75 (larger interval)
- 1.50 m x 96.90 g/t = 145.35 (highlight)

Then we take the difference between the two:

- 153.75 - 145.35 = 8.40

Calculate the remaining interval length:

- 7.50 - 1.50 = 6.00 m

And divide our meter-grade difference by the remaining drill interval:

- 8.40 / 6.00 m = 1.40 g/t

**So what we really have is 1.5 meters of 96.90 g/t gold and 6 meters of 1.4 g/t!** By all accounts the published result appears misleading, but it may not be. Consider the following scenarios:

- This is an narrow vein hosted gold deposit (like an epithermal gold deposit) and the high grade zone is continuous through several drilled intervals. The low grade zone may be an alteration halo that could be used track deposit continuity and target higher grade zones. It may also be above the cut-off grade especially in an open pit mining scenario. In this case it is a perfectly legitimate and positive result.
- This could be an isolated “nugget effect” anomaly. Not within a continuous zone and not found elsewhere. In a very early stage exploration project this could be a target worth following up on. In a more advanced project the result may be meaningless.

There are a number of other scenarios which may apply, but all of them involves understanding the nature of the deposit and, at least to some degree, the project geology. Of course, it’s also quite possible
that the results were **intended to be misleading**. This is sometimes referred to as “grade smearing” and happens more often than we’d like to think.

Aside from taking a look at the highlights, the reader should ask themselves a few other important questions:

### Cut-Off Grades

Is the result within the cut-off grade for the deposit? Or if the cut off grade is unknown, is it above a cut off grade for comparable deposits? In large homogeneous open pit copper-gold porphyry deposits or Carlin-trend style gold deposits, very low grades are typical. In underground mines, much higher grades are generally required. Companies will sometimes choose overly optimistic cut-off grades based on market-high commodity prices and highly favourable recovery rates. When times get even moderately tough for commodities these cut off grades can become obsolete.

### Grade Equivalents

Speaking of recovery rates, it is common especially in multi-commodity deposits to report assay results as a grade equivalent, or “Eq”. This is most common in copper porphyry deposits and can allow the reader to compare the combined value of the various commodities. Consider the following example:

<table>
<thead>
<tr>
<th>Drill Hole</th>
<th>From (m)</th>
<th>To (m)</th>
<th>Width (m)</th>
<th>Cu %</th>
<th>Mo %</th>
<th>Au g/t</th>
<th>Ag g/t</th>
<th>Cu Eq. %</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1-100</td>
<td>6.5</td>
<td>37.0</td>
<td>30.5</td>
<td>0.37</td>
<td>0.037</td>
<td>0.55</td>
<td>1.43</td>
<td><strong>0.92</strong></td>
</tr>
</tbody>
</table>

In this example the company is telling us the total grade of the sample is 0.92% copper if all the accessory metals were converted to copper. The problem with these calculations is that they generally assume a 100% recovery rate for all of the accessory metals and use current market prices for the conversion. The market prices that are used can significantly impact the Eq calculations. In this example the company has used $2.50/lb copper, $1200/oz gold, $15 silver, and $10/lb molybdenum. These are reasonably conservative calculations, but the issue here is they have undervalued the value contribution of the copper which gives the gold a greater weight in the calculations.

If we change the copper price to $3.50/lb and keep all other values the same our **CuEq goes down to 0.76%**. Which is significantly less interesting and we’re still assuming a 100% metal recovery rate.

Suppose the economics were a little more robust. Let’s use 2012 metal prices $3.50/lb copper, $1700/oz gold, $30 silver, and $12/lb molybdenum. We end up with a CuEq of 0.76% again. Why so low when all the commodity prices are higher? This calculation uses the relative price equivalents so the higher prices of everything removes the overweighting of any individual contributor. Eq calculations can be a useful apples-to-apples comparison, but be mindful of the variables. The point is that these numbers can be easily manipulated.

While it’s true that published data is often massaged by over-eager public relation teams and can at worst be the intentionally misleading efforts of a desperate company, news releases can also be an excellent source of information on up-and-coming projects. With a critical eye and a bit of research smart investors can find the gems and identify the dead-ends.
Why Drilling Is Essential in Mines

By Jess Peláez in Drilling and Drill Results, Mining Stories

The phrase “exploration geology” calls to mind a lonely geologist and a drill rig in the middle of a windswept, rocky expanse miles away from civilization. While that is the case in some instances, exploration geology activities are not restricted only to pre-production mine sites. Rather, drilling is a crucial part of the mine production process. Mines that have been active and producing for years still have exploration drilling programs.

Drilling programs are essential, due to the constraints of our current methods of discovering what is beneath the earth’s surface. Seismic studies, magnetometry, and geological modelling all have their limitations, and the best way of determining what is under all of that soil and vegetation is still to actually take a look. This is especially important for underground mines, as the safety and integrity of the underground environment depends on knowing exactly where faults and other weaknesses in the surrounding, or “country” rock are.

Logging Drill Chips in Queensland

While supervising drilling activities at a large underground metallurgical coal mine in rural Queensland, Australia, I was performing routine sampling of rock chips produced by my drill rig and drill crew. Our target depth was roughly 250 meters, and we expected to encounter two well-known coal seams and a few minor ones. The coal measures in this part of the Bowen Basin have been extensively mapped, and are well understood. This part of the drilling program was supposed to be simple. We were on a section of the mining lease that would soon be part of the larger underground mine. In fact, we were less than a kilometer away from the advancing longwall, which is the part of the mine that is being actively worked. On this particular day we were drilling for coal quality, which means that I was simply supposed to confirm the data in our computer models about the depth and quality of the coal seams. The major faults in the area had been identified, and the senior mine management team was confident in the data we had collected to that point.

Typical 1m interval chip piles set in 6m groups. Coal is visible at the top of the image, with carbonaceous mudstone, siltstone, and sandstone towards the bottom.
As our drill depth closed in on 200 meters the offsiders, or driller’s assistants, set down basket after basket of rock chips in neat rows on the ground for me to examine, describe, and record. With one basket load per meter of drilling, we had been keeping a good pace through the morning.

I was logging about ten meters behind the drill crew when one of the offsiders approached me with news that the drill was failing to produce any chips. I told him to let the driller know to keep going, and stopped logging to watch. Basket after basket was empty, so I marked the ground where each meter of chips should have been with pink spray paint. With that placeholder, I would not forget and log incorrectly. After eight meters of no returns, the drill finally produced chips. The offsider set down a meager pile, and I hurried over to take a look.

I was incredulous as I scooped up a loose pile of smooth, rounded rocks ranging from blueberry to cherry size. The sample contained many different types of rocks, including good-sized pieces of what looked to be pure quartz. Some schists were also present, and I was surprised at this since nothing similar to these metamorphic rocks was represented anywhere else on the mining lease. I set my handful of rocks back on the pile and waited. A few moments later, the offsider was back with another set of chips. Again, the sample was a collection of well-rounded rocks of various sizes from small to large pebbles.

There was no matrix connecting any of these rocks. When you hand a geologist a sample like this, it is a safe bet that you will be told that they are from a river. Poor sorting of rocks means that they have multiple sources, and the high degree of rounding means that they have travelled a great distance and had their sharp edges eroded away.

The next load of chips was the same, but the one after that was simple sandstone again. Prior to the section of no returns followed by what I was now calling the fluvial (river) section, we had drilled through sandstone and siltstone partings consistently for at least 30 meters. In the Bowen Basin, sandstone and siltstone are often found between coal seams. River deposits, however, are not.

I stopped the drill crew after another few meters of simple sandstone chips and called the senior mine geologist. I explained the situation, and it’s fair to say he was skeptical. No one working on this lease had ever found evidence of an underground river. The senior mine geologist came out to inspect the chips firsthand and brought along printouts of the 3D model of that part of the mining lease. We studied the model but found nothing; no indication of an underground river.

Still, the physical evidence does not lie, and we were in an area of known heavy faulting. We now had evidence that an underground river exists in the middle of this heavily studied major mining operation. The longwall excavation was postponed until additional geotechnical studies could be carried out. This is just one example of how geologists are frequently reminded that there is always more to know about the environments in which we mine.
Drilling Methods Used in Coal Mines

By Jess Peláez in Drilling and Drill Results

For coal deposits, like most other minerals, drilling is a key to identifying in detail the grade and size of the resource, both prior to mine development, and during operations.

Mining operations employ a variety of drilling methods based on the requirements of the project. In the majority of cases, a drilling program will begin with the exploration phase. The aim is to confirm survey data about the location and extent of the coal deposits or seams. Additionally, exploration drilling is used to identify or confirm the location of faults, folds, dikes, sills, and other geologic features that may influence how the coal is ultimately mined.

As mining progresses from the initial exploration phase to the latter stages of exploration and into production, a higher level of detail about the site’s subsurface is required.

Initial Exploration Drilling

The initial phase of many exploration drilling programs involves a method known as chipping. True to its name, chipping involves a drill that cuts into the subsurface rock and produces small chips of the material it encounters. These chips range from very small sand particles (<4mm) to larger pebbles (2-3cm). From a geological perspective, chipping is useful for understanding the boundaries of a deposit or seam, but is not so helpful for providing information about the quality or grade of the target coal. Chipping paints a broad picture for mine geologists, and provides crucial information for refining the geologic model of a mine site.
Geologists will sometimes collect samples for geochemical analysis during drilling, but typically, the most important part of chip drilling for a geologist is logging the chips. As the drill advances meter by meter, the chips produced are blasted up the sides of the borehole. When they emerge at the surface, they are caught in a bucket and set out in rows.

One pile of chips is roughly equivalent to one meter of drilling, and this way the geologist are able to log the entire depth of the borehole. Some of the data recorded includes rock type, minerals present, color, grain size, and any unusual traits. Since chips are coarsely pulverized rock fragments at best, when true detail about a deposit or seam is needed mines turn to a different method of data collection.

Detailed Mine Resource Drilling

As mining progresses from the initial exploration phase to the latter stages of exploration and into production, a higher level of detail about the site's subsurface is required. Coring (diamond drilling) is another way of collecting information about a potential coal resource. The drill rig is equipped with a hollow tube, and as the drill pushes the rods into the ground, a cylindrical piece of the rock is pushed into the hollow tube. These samples are usually the length of a drill rod, which is 6 meters. Shorter and longer samples are also possible. The “core sample” is then pulled back to the surface, where the geologist has a few minutes to log the core in detail before the drill rig produces another sample. Time is important during this process, as drill crews are often paid by the number of meters drilled in a day. It is in everyone’s interests to produce good core samples quickly and accurately.

Logging diamond core is slower and more labor-intensive than logging chips, but it produces much more detailed information than chip logging. The information a geologist records may be used to make a rough determination of the quality or grade of a resource at a specific location within the mining lease. Core samples can be used to identify potentially combustible minerals, faults, and other weaknesses in the
rock surrounding a deposit. Geotechnical samples of the "roof" and "floor" material bordering a deposit are taken from core samples, and this information is critical to understanding the potential integrity of a mine’s construction.

 Unexpected deposits of intrusive volcanic rocks or extremely lithified (hardened) sedimentary rocks can often be seen in core samples, and identifying these is essential when creating a cost-effective mine design. Encountering an unexpected section of very hard rock can derail mine production by hours or even days, which is a delay that mines cannot afford. Core sampling has the ability to pick up finer variations in the country rock than seismic surveys can, and this is why such a labor-intensive process is still used at even the most cost-conscious mining operations.
Reverse Circulation (RC) Drilling

By David Tilley in Drilling and Drill Results

Reverse circulation or RC drilling is a fast and inexpensive method of drilling, particularly compared to diamond drilling. A hundred metres or more of drilling is possible a day. RC is a commonly used drilling method in the mineral exploration industry.

*The speed of RC drilling means the drill programme needs to be planned well ahead of drill schedule. The supervising geologist should also have sufficient experience to change the programme at short notice, if necessary.*

RC drilling works by blasting air down an outer drill pipe using a high performance air compressor at the surface. An air-driven hammer at the end of the drill stem pounds a tungsten-iron drill bit against the rock, pulverising and breaking fragments away. The drill bit, stem and pipe continuously rotate as the rock is being hammered. Jets of air are forced up the drill hole on the side of the drill bit.

Rock dust and fragments known as cuttings or chips are carried by the strong airflow up through the middle of the bit into an inner drill pipe. The air current is so strong that rock material can be brought to the surface from hundreds of metres down. When it reaches the surface, the dust and chips are fed into a cyclone splitter that slows the air flow down and divides the sample into small and large samples.

A sketch of an RC drill stem showing the drill bit and hammer. The direction of air flow is shown with white arrows. The blue arrow represents the rotation of the drill string.
RC Drillhole Planning

The speed of RC drilling means the drill programme needs to be planned well ahead of drill schedule. The supervising geologist should also have sufficient experience to change the programme at short notice, if necessary.

A site inspection by the drilling contractor prior to drilling can iron out issues that may not be apparent to the geologist. Only the driller knows his equipment and its capabilities.

RC Drilling Safety

Combined Diamond and RC Drill Rig

Reverse circulation drilling has a number of inherent hazards associated with it.

In the past, hearing loss was common among drillers and offsiders as well as geologists and field assistants from being around an operating RC drill rig. The constant hammering of the drill bit through the rock and the loud air compressors combine to make an extremely noisy work place. Occupational health and safety laws now require that workers are protected from this noise. The wearing of hearing protection in the form of earmuffs and earplugs is now mandatory.

Dust is also a hazard. Freshly ground up rock is extremely dangerous when breathed in. When the mineral grains are broken, their fresh surfaces are highly reactive. They can interact adversely with lung linings and other soft tissues. Silicosis, once common among miners, is a chronic lung disease that can result from exposure to crystalline quartz dust. It is essential that workers around a drill rig wear dust masks to prevent silica particles entering their lungs. An even greater risk to health in certain areas is asbestos. Asbestos can be associated with some types of iron ore and nickel sulphide deposits. So, when drilling these types of deposits extra care needs to be taken to protect workers.
The machinery itself can be extremely dangerous. I have heard of reports of tubing coming detached from compressors and cyclones and violently snaking around, seriously injuring workers. To protect eyes, safety glasses must be worn at all times. A hard hat, high visibility clothing, steel capped boots and gloves are also extremely important.

Sample bags are normally very heavy so care needs to be exercised when carrying these, otherwise back injuries can result.

Sampling of RC Drilling

Most RC drill rigs have a splitter attached to or incorporated within the cyclone. The job of the offsider is to attach bags to the two outlets of the cyclone to collect samples. A small bag collects a sub-sample whilst a large bag collects the rest of the sample. When the samples are collected the smaller one is taken to where the geologist is set up. The larger sample is normally stored on-site together with others in neatly arranged rows. These are kept until all the necessary laboratory analyses have been done. The smaller bag is the one that goes to the laboratory. Both bags are labelled with the same unique number. This is obtained from a ticket book or by another foolproof method. Due to the fast pace, it is best to pre-number bags otherwise mix-ups may occur.
A common practice to reduce laboratory analysis costs is to group three consecutive samples together into what is known as a 3-metre composite. Although cheaper, this method does reduce the accuracy of the sample assay. When the laboratory has issued the results, the geologist then decides whether to submit any of the individual metre intervals for analysis. This normally happens if mineralisation is detected in the composite samples and improved resolution is required.

Reverse Circulation Sample Logging

Samples from RC drilling are composed of broken up pieces of rock called chips. These individual pieces of rock are around 10 millimetres in size. As well as chips, there is much fine grained material as well.

The field assistant normally puts some of the sample from the large bag into a plastic sieve for the geologist. A wash and sieve may be done by the field assistant or by the geologist. The geologist inspects the contents of the washed rock chips using a hand lens and quickly describes the rock and records the information on a logging form or directly onto a computer. Most of the time, the geologist can only spend a couple of minutes on each sample. Therefore, usually a quick look and short description is all that can be done. After logging each sample a representative portion is placed into a pre-numbered plastic RC chip tray for future reference.
The diamond drill-core drilling is used to obtain oriented and intact rock from hundreds of metres below the ground’s surface. An experienced geologist then describes core in detail, a process known as logging. Diamond drilling provides the most detailed geological and geotechnical information available prior to mining.

Diamond drilling is the result of months, or years of field work and is a significant investment in a prospect.

*Drill site selection is often an iterative process comprising office work together with site visits to ensure that drilling is physically possible at each site.*
Drill Planning and Logistics

Prior to undertaking any drilling, a drill-hole plan is designed and a proposal written. This document outlines the reasons for drilling, the expected costs and details of contracts. Diamond drilling is expensive, so the proposal is likely to require board of director’s budgetary approval.

Drill site selection is often an iterative process comprising office work together with site visits to ensure that drilling is physically possible at each site. What might look like a good site on the computer could, on the ground, be a site fraught with difficulties.

Site inspections by the drilling contractor are also conducted to ensure that all logistics of the proposed drilling exercise are considered. This may include the inspection of access tracks and selection of camp sites for personnel.

Combined Diamond and RC Drill Rig
In most jurisdictions environmental authorities need to be consulted prior to and after drilling to ensure that drilling activities are approved in a particular area and to ensure that sites are properly rehabilitated. Often a bond is required by the jurisdiction to encourage explorers to satisfactorily complete land restoration.

Continued landholder liaison from the initial design to drill-site rehabilitation at the completion of drilling is important. Many landholders like to be involved throughout the process and may provide support with earthworks and camp facilities. They have a vested interest in seeing their land returned back to the pre-drilled state.

Traditional landowners may also need to be consulted and approvals given to ensure that any impact to cultural heritage in the area is kept to a minimum.

With approvals in place, sites can be cleared and earthworks begin. This usually involves the building of access tracks, construction of drill pads and the digging of sumps.

Drill Programme Supervision and Safety

Exploration companies are responsible for the health and safety of their staff and drilling contractors during a drilling programme. The supervising geologist is usually the nominated staff member for performing safety checks on a drill rig. These safety checks are done at the start of the programme and after every rig move as well as at random times during drilling. The safety inspection is done in the presence of the head driller and involves carefully going through a checklist of items. Any problems or hazards need to be corrected before drilling can start.

Diamond Drill Hole Monitoring

Diamond drilling holes can extend hundreds, even thousands of meters below ground. However, as any child who has pushed a garden hose into the ground only to find the end of it coming up several metres away, knows drill holes can go badly off-course. The same happens to a length of drill pipe. Although made of metal, over hundreds of metres it can bend significantly. I have heard of drilling done without surveying with the same outcome as the garden hose. On this occasion, the drill bit was seen exiting the ground hundreds of metres away from the rig!

A survey instrument is lowered down the drill hole to record the direction and angle of the hole at that depth. The geologist plots drill-hole depths and surveys using 3D modelling software. Given the information about how the drill-hole is tracking relative to the target the driller, can make corrections. The driller can adjust the torque to change the direction of the drilling to ensure that the target is reached.

The type of rock that is being drilled through has a great effect on the behaviour of the drill bit, stem and pipe. If the rock has a strong fabric such as schist, the drilling direction tends to migrate towards the plane of the foliation. Sometimes adjustments are extremely difficult or impossible to make to the direction of the drilling. If the hole is way off target and cannot be corrected even with navigational drilling techniques, the hole may need to be abandoned before its completion.
Diamond Drill Core Logging

A qualified and skilled geologist normally carries out core logging. This is done to extract as much information out of the core as possible.

Drill-core comes in various sizes including; PQ which is 85.0 mm in diameter, HQ is 63.5 mm and NQ is 47.6 mm. Typically as the holes gets deeper the drill core size is reduced.

After collecting the core trays from the drill rig they are laid out in an area where logging, sampling and storage takes place, normally a purpose built core shed. First, the core trays are laid out in order on trestle tables. Core is washed down with water and a brush is used to remove any mud and other residue from the core’s surface.

The core is then marked up; with the start and end of each metre interval is marked on the core with a brightly coloured wax pencil. During marking up any gaps in the drilling are noted and a wooden block is placed at the location of the missing core. Core can be lost down the hole when drilling encounters faults and fault zones. Rock within these zones is often broken up and may fall out of the drill pipe when it is being removed from the hole. Gaps in the core can be significant.
Diamond Core Sampling

Core sampling involves identifying the mineralised zones that require assaying. The procedure is similar to that used for rock and soil sampling. The core several metres either side of the identified zone is also sampled to establish if the adjacent wall rock are mineralised too. The technician then uses a rock saw, to cut each metre of core in half along its length. One half is put into a plastic sample bag and the other half is retained and kept in the core tray for later reference. A duplicate sample is obtained by cutting the halved core again resulting in a quartered piece of core. One of the quartered pieces is submitted as the sample and the other is submitted as the duplicate.

Each sample bag is labelled with a unique identification number from a ticket book and the duplicate ticket is torn out of the book and placed in the bag with the sample. When the core has been cut it is submitted to the laboratory for assay along with the required number of blanks, standards and duplicates for proper quality control purposes.

Interpretation

When the results of the assays become available, they are plotted along with observations from the logging onto cross-sections. This enables the results to be easily visualised and interpreted by the geologist.

Intervals of significant mineralisation are identified and reported as the average grade over an interval of drill-core with corrections applied to account for the angle of the hole. This is how the true thickness of mineralisation is obtained.

Investors should always be on the lookout for drill hole data that has been reported without corrections. Some companies have reported results of drilling that are at an oblique angle to the mineralisation without any corrections, giving apparently very wide zones of mineralisation. In extreme cases some companies may even drill parallel to the mineralisation with seemingly hundreds of metres of mineralisation. Therefore, company exploration reports should always be read with care to avoid any misinterpretation of the data.
A successful soil sampling programme will result in a map of geochemical anomalies. The next step in exploration is for the geologist to design a drilling programme.

The exploration geologist uses several lines of evidence, both geophysical and geochemical, when developing a drilling proposal.

Rationale

The purpose of drilling is to confirm if anomalies in data are real and provide further evidence of a concealed ore deposit. Anomalies can be geochemical and/or geophysical. Anomalies are often ranked according to their strategic and geological rating. Those ranked highest are normally drilled first.

A geochemical anomaly is an unusually high level for a particular element. To be anomalous the concentration of the element needs to be at least a magnitude or higher than the element’s background level. When the anomaly involves several sample points and has a consistent geometric shape, it’s more likely to exist, and a greater confidence is placed on the existence of mineralisation.
Geophysical anomalies are unusually high or low points in the data which define a region of peculiarity. Geophysical techniques are indirect methods of mineral exploration. A mineral deposit may affect a certain geophysical parameter, which results in an anomaly. Not every geophysical anomaly indicates an ore body so geophysics is usually used together with geochemistry, not as a stand-alone technique.

The exploration geologist uses several lines of evidence, both geophysical and geochemical, when developing a drilling proposal. The proposal needs to have robust evidence, preferably from several different sources, before seeking a budget from directors and shareholders.

Designing A Drill Programme

The design of a drilling programme depends on whether it is designed to discover a new deposit or for delineating an existing resource.

Resource definition requires drilling at close spacing to provide a high level of certainty and confidence in the results. If an ore deposit is variable in grade then a large number of drill-holes will be required to define the resource. For deposits with a consistent grade, much less drilling is needed. Gold deposits are usually variable in grade over short distances, so a large number of drill-holes are needed to define this type of resource. Resource geologists and modellers “cut” the data to remove the highest gold values. This provides a closer approximation of the total resource and its average grade.

Planning a Drilling Programme

In the example shown in the image below a number of angled holes at 60° are designed to intersect at depth with the mineralisation that is causing the surface geochemical anomaly. The mineralisation is assumed to plunge almost vertically due to a known steeply dipping rock structure in the area. Hydrothermal alteration along this structure has resulted in a strong magnetic low, which is coincident with the soil geochemical anomaly.

Dispersion of elements from the ore body into the neighbouring country rock has resulted in the formation of an alteration halo. Dispersion of elements at the surface has also occurred causing a soil geochemical anomaly. The coincident geochemical and geophysical anomalies provide very good evidence for the drilling proposal.

Scattered highly mineralised rock chips found at the surface in the area indicate the potential underground ore grades. The spacing between drill-holes is designed to maximise the chance of intersecting the ore body while also gaining some understanding of its extent along the line of strike.
Drilling Methods

There are various drilling methods used in exploration. Cost is often the biggest decider of what technique is chosen.

Diamond Drilling

The best sample achievable through drilling is the **diamond drilling** method which produces core. A great deal of geological, mineralogical and structural information can be obtained from diamond drill core. Cross-contamination from one adjacent interval to the next is virtually absent. Diamond drilling is used for deep holes of approximately 300m or deeper. Diamond drilling is also the most expensive and slowest form of drilling.

Reverse Circulation

**Reverse circulation** or RC for short, is the most commonly used drilling method in the minerals exploration industry, mainly because it is cost effective and fast. A drawback to RC drilling is that less information can be obtained when using this method. This is because the samples produced consist of a mixture of small rock chips over each metre interval, so structural information is lost. Some
contamination between adjacent intervals can occur and this should be kept in mind when interpreting the results. RC is useful for drilling holes to a depth of 300m. With the addition of extra high powered compressors and boosters, depths of up to 500m are possible.

Percussion Rotary Air-Blast

**Percussion rotary air blast** or RAB is one of the cheapest forms of drilling. It is also the fastest. It is a very good technique for quickly drilling a large number of shallow (0-30m) holes across a deposit. Unfortunately, the technique produces samples of fine dust and chips that are often cross contaminated with material from other intervals. Drilling has to stop when groundwater is encountered as the hole quickly becomes clogged with mud.

Surveying A Drill Hole

The deeper the drilling the greater is the need for down-hole surveys. These are important drill holes can be very off course. A survey will confirm the actual angle and direction of the holes at a specific depth. Typically, surveys are conducted every 30 metres. However, sometimes there is a need to obtain surveys every 15 metres, especially when the hole is being deliberately redirected using navigational drilling techniques. When the surveys are plotted using 3D-modelling software the trajectory of the drill-hole relative to the target is revealed. Monitoring of the orientation of the hole during drilling allows the driller to make minor adjustments which can result in some degree of control over the drilling direction.
QA/QC of Geochemical Data

By David Tilley in Drilling and Drill Results

Quality assurance (QA) is a proactive approach to ensuring that chemical analyses of rock and soil samples are correct and accurate. QA systems and procedures occur before a batch of samples is sent to the laboratory for analysis. Typically, QA involves the addition of “check” samples including:

- blanks,
- duplicates, and
- standard samples.

Quality control (QC), in contrast, is a reactive process of analysing the data returned from the lab. This is crucial for determining the quality of data and for revealing any deviations from the norm.

Very proud of his landscaping efforts he showed the geologist who promptly “blew his top”. The gravel had been carefully stockpiled to act as a readily available source of blank material for use during the drilling campaign.

Appropriate QA and QC of samples from both drilling and soil sampling is critical if results are to be trusted by investors and management.

Blanks

A blank sample is added to the beginning of a sample batch. Blanks are used to determine whether a laboratory is clean or not. Busy laboratories are under constant time pressures and when there is a high throughput, mistakes and omissions become a real possibility, even with the best systems in place. It all comes down to human nature and the economics of running a laboratory. All too often, a technician may be under so much pressure that don’t clean a crusher or ring mill properly before the next sample or batch of samples.

Crushing and grinding equipment is normally cleaned with what is known as a “quartz rinse” i.e. very clean quartz sand

Blanks are made of local non-mineralised rock. I once knew a contractor who was caught out due to the material's ordinary appearance. One day while helping with tidying up around a core shed he helpfully filled in all the ditches and hollows with what he thought was a pile of gravel. Very proud of his landscaping efforts he showed the geologist who promptly “blew his top”. The gravel had been carefully stockpiled to act as a readily available source of blank material for use during the drilling campaign.

Washed river sand, is also commonly used as a blank for QA purposes. Again, it can end up as a component of concrete, unless carefully labelled!

The geologist quickly picks up any contamination issues by plotting two different elements against each other. In the example provided below, two “outliers” plot away from the “normal population”. These deviations were caused by equipment not being cleaned properly prior to starting a new batch of samples.
Scatter-plot of chromium assays against copper assays for previously analysed blanks. Most of the assays plot in a cluster which is the “Normal Population”. Two “Outliers” plot away from this cluster, which indicate possible contamination during sample preparation at the laboratory.

Duplicates

Duplicates are two identical samples submitted to the laboratory for analysis to detect sample switches and/or cross-contamination issues. They can be submitted proactively with the batch. Alternatively, the same sample can re-submitted later to check if an unusually high result is valid or not.

The reactive approach is not the best approach, because unusually low results may be missed, potentially missing an important result.

Sample switching can sometimes occur at any stage during sample handling. Laboratories normally have in place systems which minimise the potential for this happening.

Typically, several evenly distributed duplicate samples are submitted for analysis within a batch. Later analysis of the data through graphing can easily reveal deviations from the trend-line. These sample “outliers” can be repeatedly re-assayed until the geologist is satisfied with the result.
Scatter-plot of duplicate gold assays within a sample batch. Most of the assays correlate well with each other. An "Outlier" plots away from the trend-line, which indicates possible contamination or a sample switch.

Standards

Standards or certified reference materials are added throughout batches to detect cross-contamination and sample switches. Standards are normally purchased from reputable suppliers however their pre-packaged appearance is a dead giveaway to laboratories. In addition, because they are usually come pre-prepared they do not test the sample preparation stage for cleanliness. Laboratories can become familiar with which result is expected from a standard, even without any identification on the packet.

A n alternative, is to prepare in-house standards which look similar to regular samples. That way the laboratory has no idea that it is a standard and will therefore treat it like a normal sample. Unfortunately, there is a higher cost associated with doing this as in-house standards need to be assayed several times prior to their routine use, preferably at different laboratories, to obtain an average composition for the material.

A line-plot of assayed standards will instantly show any deviations, which can then be investigated to identify the cause of the discrepancy.
Other Considerations for Sample QA/QC

Field Contamination of Samples

While collecting rock and soil samples in the field, geologist must always be on the lookout for potential sources of contamination. It goes without saying that all jewellery must be removed during any handling of samples because even the slightest contact with the sample, be it rock, soil or stream sediment, can result in an elevated assay for that particular metal.

Field Security of Samples

Sample security is also important. The geologist should be aware of where and how samples are being stored. Samples should be kept under lock and key to avoid any malicious attempts at deliberate contamination or switching by competing companies or individuals wanting to do harm. Samples should not be left unattended in the back of truck at the hotel. Instead samples should be secured in the truck’s cabin or storage container, or even in the hotel room or. A great deal of money is spent collecting samples, so they should be treated like extremely valuable possessions.

Samples Should Be Representative

In other words, assays of samples should represent the material being sampled. When selecting rock chips the geologist should ensure that average looking ones are also selected otherwise bias towards
high results will occur. Most geologists are very good at identifying and collecting highly mineralised rock, so investors should always be on the lookout for this practice. In areas of “coarse gold” mineralisation such as Bendigo, Australia – getting a representative sample is a difficult and important issue.

Splitting a subsample from a sample has to be done with care to ensure that the subsample is representative of the sample. Geologists use various techniques for doing this such as “quarter coning” and the use of equipment such as riffle splitters and sampling spears.

**Summing up**

All data released into the public arena should have undergone QA/QC to ensure that any decisions made by potential investors are based on accurate and truthful data.
Drill Results: Apparent Versus True Thickness

By Staff @ Geology for Investors in Drilling and Drill Results, Geology Basics

It seems the farther we get in life the more we realize that we can’t escape those lessons we learned in elementary school. Sometimes a refresher is required and this is most often the case when it comes to math. This simple bit of geometry may help you determine whether a company has actually found something of value or is simply trying to hide poor results in technical jargon. At the very least it will help you determine the current level of confidence in project drill results.

When it comes to drill results, difference between apparent and true thickness can be the difference between a serious prospect and a lot of arm waving. It should be noted that thickness is also often reported as “width”. These are the same thing.

Let’s begin with a brief explanation and then follow that up with some real life examples. The ultimate goal of a drill program is to intersect mineral resources below the Earth’s surface. Drill holes are not always drilled vertically. In actuality they are often drilled at angles to best intersect their target. Combine this with that fact that mineral deposits come in all shapes, sizes and orientations and you have a recipe for skewed drill results.

![Diagram showing apparent versus true thickness]

Figure 1: Two drills intersecting the same feature. Drill 1 will intersect a larger “apparent thickness”, while drill 2 will intersect the true thickness of the feature. When reporting the results from drill 1 the true thickness should be calculated.

In the diagram to the right there are two diamond drill holes that intersect the same feature below the Earth’s surface. The feature can be anything, a coal seam, a gold vein or any number of things, because for our purposes it doesn’t matter. Drill 1 is drilling vertically (straight down) while drill 2 is drilling at an angle relative to the Earth’s surface. They both intersect the same feature, however drill 1 will intersect a larger interval of this feature than drill 2 will. In geology, the thickness of the feature observed by drill 1 is called an apparent thickness, because it varies from the true thickness of the feature. An apparent
thickness will give the illusion that a larger amount of the resource has been found than is actually present. That is why for resource estimates only true thickness is used.

For example, let’s say the feature in figure 1 is a gold vein. Drill 1 may have an intersection of 5 g/t of gold over 25 metres, while drill 2 has an intersection of 5 g/t over 17 metres. The grade, which is often reported as grams of gold per tonne of rock (g/t), doesn’t change – only the length of the interval changes. Obviously drill 1 has better-looking results, but the key is that drill 1 is reporting an apparent thickness and drill 2 is reporting the true thickness.

The true thickness of the intersection in drill 1 must be calculated using a bit of algebra (Remember SOHCAHTOA?) and it will inevitably be the same as the results from drill 2. The geologist uses the apparent thickness of the drill intercept and the angle between the drill and the target zone in order to make this calculation. The is angle can be determined a few different ways. In many cases it can be measured right from the drill core. This is possible where there is a sharp transition between the target zone and the surrounding rock. In other cases, the distance between a surface outcrop of the target rock and the drill might can be used to calculate the angle of the drill intercept.

It is important to know exactly what a company is reporting when they release drill results. Generally companies will either report “true width” or add a note below the results disclosing that the information provided is not a true thickness (or width). You can bet that if a report does not label an interval as a true thickness then it is NOT a true thickness. A quick search of drill results for mining companies reveals that different companies have different ways of reporting their findings. Here are three examples:

**Actual Published Drill Results**

<table>
<thead>
<tr>
<th>Grade</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.18 g/t</td>
<td>over 22 metres true width</td>
</tr>
<tr>
<td>7.35 g/t</td>
<td>over 24 metres</td>
</tr>
<tr>
<td>7.05 g/t*</td>
<td>over 25 metres</td>
</tr>
</tbody>
</table>

The company with the asterisk added a note that stated “Drill intercept lengths only are reported in the tabulations; it is estimated that true width will be approximately 80% of the reported drill intercept length.” This means that the last intercept is actually 25 m x 0.80 (80%), which is equal to 20 metres. It also means that the the 80% is the geologist’s best guess based on available data and not a bankable number. This potentially makes it the least impressive of the three findings, but more importantly, it helps the reader gauge the company’s level of confidence in the published result.

The second company didn’t report whether the number was an apparent or true width. While it’s possible that this information was left out in order to make the results seem more impressive, it may also be that the true thickness is unknown. Either way, the reported result by itself is poor evidence of the true resource.

For even the casual resource and mining company investor, a basic understanding of drilling intercepts and reported results is a necessity. In this case, differentiating apparent and true results can help one quickly assess the value of a published drill result.
Starting A Mine: Pre-Feasibility and Feasibility Studies

By Jess Peláez in Mining and Mine Design

While the basic concept of mining may be familiar to most people, the total process from exploration target to profitable mine is complex and involved. There are a wide range of natural resource types that we extract from the earth and an even wider variety of mining methods.

The key question to be asked is always; is the mine going to make a profit, will revenues exceed the cost of production.

The techniques required to develop a diamond mine are very different from those needed to exploit a Mississippi Valley Deposit. However, there are a number of standard steps in the overall process of development of an exploration project to an operating mine.

Kittila open cut mine in Finland.

The key question to be asked is always; is the mine going to make a profit, will revenues exceed the cost of production? Once a potential resource is located, there are many steps required before a mine can be opened. Knowing what stage of the process a company is currently involved in can assist in making sound investment decisions. This information can help a potential investor with timing the investment, or in assessing whether the project is likely to even proceed to actual production within a reasonable time-frame (or in some cases, ever).

There are a few terms to become acquainted with in the world of mining feasibility studies: order of magnitude, pre-feasibility, and feasibility. They range from the lowest level of certainty (order of magnitude) to the highest level of certainty (feasibility), and have increasing levels of detail and expense associated with their completion. We’ll look at each type of study in a bit more detail.
Order of Magnitude (Scoping) Studies

Order of magnitude studies are also known as scoping studies, which is a more descriptive name for what they cover. These studies are designed to delineate the scope of a potential project, including rough estimates of potential production values and costs. When a resource is classified as “indicated”, an order of magnitude or scoping study will provide a financial assessment of the resource.

A key part of a scoping study is the creation of a preliminary mine plan, using software which models the options. There also needs to be decisions made to continue with further engineering work and an exploration drilling program. The basis for these studies are the geology plans from the exploration phase. This allows the individual or team responsible for conducting the study to make reasonable estimates using known costs and likely outcomes. The level of accuracy associated with a scoping or order of magnitude study is between 40-50%.

Preliminary (Pre-Feasibility) Study

The next step on the road to establishing a working mine is the preliminary, or pre-feasibility study. Aspects of this type of study include further exploration drilling program to gain more concrete knowledge about the target ore body, and the adoption of a detailed mine plan and accompanying mining methods that will be best suited for removing the material in a cost effective, timely manner.

Pre-feasibility studies also cover the processing of the material, which can include washing, milling, and numerous other techniques designed to prepare the material for sale and distribution to customers. An effective waste management program will also be designed as part of a pre-feasibility study, which will include ground and waste-water controls, and management of waste, tailings, leach ponds, etc.

The ability to hire, manage, and house staff adequately for the potential mine will also be assessed during this study. Environmental protection, permits (legal and social), and the eventual closure of the mine must all be considered during this phase. Mine access and associated transportation for employees, materials, and equipment typically round out a pre-feasibility study, and these tend to achieve accuracy between 20-30%.
Where to house a workforce for a mine, or how to transport them to a temporary camp are key decisions. Dawson City, Yukon, Canada Image CC

Full Feasibility Study

The full feasibility study is the final step required to determine if a mine is truly viable, and these are more detailed and costly than the previous two study types. This cost comes largely from the associated engineering work that must be done during the study, as it is complex and time-consuming. Feasibility studies are the basis for raising capital, and the most figures that will be used for budgeting and forecasting come from these studies. Full feasibility studies are significantly more expensive than the other types of studies, and can account for between 0.5-1.5% of a project’s total budget. The level of accuracy increase with this type of study to between 10-15%, which is why the costs rise accordingly.
Inside a coal handling and preparation plant (CHPP).

Typically, projects become hung up during the pre-feasibility stage due to requests for additional information. This is to be expected, as any mine is a large investment with an inherent degree of risk.

Some risks fluctuate based on the type of material that is being mined, as market prices for certain commodities can be volatile. Environmental factors can change, and some may be mitigated while others may not be. Regulations and taxes may also vary depending on the government in charge of the area to be mined, and this can cause a mining climate to go from friendly to inhospitable very quickly. It is important that mining project employ consultants and teams who will fairly and accurately assess the project’s potential without regard for their own continued employment. It is easy to see how this could create a conflict of interest, so consulting teams must be carefully chosen and include experienced project managers and technical staff.

If a project advances successfully through the three typical studies, then the next phase to be completed before construction on the site begins is the detailed design phase. This will not occur unless a mine is going to be built, so barring sudden major funding problems, natural disasters, or political upheaval, your mine is moving forward! An understanding of the full spectrum of information that goes into opening a mine will help investors make informed decisions.
Exit Strategies – Knowing when to Hold ‘em (and when to fold ‘em)

By Staff @ Geology for Investors in Mineral Deposits, Mining and Mine Design

An exit strategy can be defined as: a means of leaving one’s current situation, either after a predetermined objective has been achieved, or as a strategy to mitigate failure.

Everyone knows the importance of a good exit strategy. Whether you’re leasing a new car, opening a small business or deciding to invest in a company, a good exit strategy enables you to optimize gains and minimize the chance of losses.

To Mine, Or Not To Mine?

Identifying the exit strategies is also important for exploration companies. There are many different exit strategies and the right one usually comes down to the size of the company and its available resources. Most junior exploration companies do not have a goal of opening a mine, that’s not their game. The skills required to identify a successful exploration prospect, are quite different to those required to design and operate a mine.

Alternatively, walking away too soon can also be a mistake. As geologists, one of the most frustrating parts of the job is a partially executed exploration plan, overseen by a jittery management team.

In contrast, a large company may have an exit strategy of not just finding, but developing and producing from a mine. The new mine may be the source of more ore for existing processing plants and be sold to existing customers.

An exit strategy should be included in the design of any new project. This is now standard practice in the industry. It works on the premise that, “You cannot know how to start a project if you do not know how to end it.” Often exit strategies change and evolve as a project progresses. If a company operating a small mine that ships the ore out for processing discovers extensive new reserves, they may decide to build their own processing facility on site.

A junior that is conducting exploration with the goal of finding an economic deposit may have a number of alternative exit strategies that don’t include developing a mine. They may aim to sell their prospect to a mining company. Or they may aim to simply option their property to other juniors with the goal of eventually proving up a saleable deposit. Smart companies will have several contingency plans.

A common problem among the junior exploration companies in knowing when to throw in the towel. While during challenging economic times it may be wise to wait out the market, waiting can cost a lot of money. A project that is only marginally economic during high times may not be worth hanging on to for the years it might take to once again become economic.
Alternatively, walking away too soon can also be a mistake. As geologists, one of the most frustrating parts of the job is a partially executed exploration plan, overseen by a jittery management team. There is a constant pressure to produce market-shaking results, and any results that aren’t stellar are met with panic. Patient and thoughtful companies can often benefit from picking up projects that have been abandoned by fair weather friends.

Exit Strategies that Mitigate Failure

All of the above assumes success but an exit strategy can also used to “mitigate failure”. In mining, this usually involves knowing when a deposit either ceases to be economically viable or is not economic to begin with.

As the price of gold drops, more and more mines will be put onto a “care and maintenance” regime, not abandoned, but not producing. This is an example of a mitigation exit strategy. When the commodity price increases again, the mine will resume production. If the price stays low the mine may be sold if cash is required.

Finding an ore deposit is only a small portion of the battle, a number of other factors can sink a potential mine. So after a prefeasibility study fails does the company have an exit strategy that will reduce potential losses? After drilling numerous exploration holes into a potential deposit, but realizing that the mineral occurrence just isn’t large enough to be economically viable, does the company have the resolve to know when to move on? Or will they keep pouring money into a losing battle. These all have to do with having a comprehensive exit strategy that makes economic sense.

Exit Strategies and the Investor

As an investor, it’s critical to consider the company’s exit strategies and whether they fit with your investment goals. It’s best if the company has multiple exit strategies so that even if everything doesn’t go exactly as planned the endeavor can be successfully and profitably brought to a close.

It’s also important to have your own exit strategy for an investment. Ideally you won’t have to worry about this if the company has a good exit strategy and executes it diligently. However, far too often mines are kept operating at a loss because it’s too expensive to shut them down. It is key to recognize dwindling reserves and poor exploration results as vital signs that a mine is on its last legs, so that you can get out while you’re still ahead.
Underground Mining Techniques and Risks

By Lis Sowerbutts in Mining and Mine Design

Undergrounds mining is still, even after hundreds of years of safety improvements, a dangerous and expensive business. It’s wise for an investor to understand both the basic workings for an underground mine and the risks associated with underground mining. A bad mine disaster may not only kill miners; it can also bankrupt companies and close mines permanently.

The two main types of underground mine are named for the type of rock the minerals are hosted in:

- hard rock; and
- soft rock

According to the US mine Rescue Association, of the 17 disasters in US mines since 1976, all but one has occurred in coal mines.

Hard Rock Mines

Hard rock mines include most metal and diamond mines. They tend to be deep, and the orebody is often steeply inclined (or dipping). Shafts can be as deep as several kilometres. Access from the surface is via a shaft or a decline. There is a variety of mining methods used, often in the same mine, depending on the geometry of the orebody and the stability of the rock.
Ore is broken up by blasting and drilling. Ore is then removed or "mucked out" by a LHD (load haul dump) machine, which resembles a low-profile articulated front-end loader. The ore may be dumped into a truck which then drives out via a decline, or ore may be dumped down a chute or ore pass to an underground crusher and then moved to a shaft using conveyer-belts, underground trucks or train either to a shaft, a horizontal adit or via decline direct to the surface.

How an ore-body is mined is complex and the main factors include:

- geometry – is the orebody flat or dipping, solid or lenticular;
- grade of the orebody – will all the ore be taken, or is mining selective, only chasing the higher-grade sections;
- strength of the ore and the surrounding host rocks – how much support is required once ore is removed;
- how easily will the ore break.

Standard mining techniques include:

- cut and fill or drift and fill; ore is mined and the stope filled with tailings, raising the level of the mining
- shrinkage stoping – similar to cut and fill except the ore is blasted and left in place and used as a mining platform. Most of the ore stays in the mined area (the "stope") until mining of the particular area is complete. The advantage is that mining can be highly selective, the disadvantage is the delay in actual production;
- room and pillar mining – pillars are left at regular positions in a flat or gently dipping orebody. The pillars are removed at the end of the operation starting from the furthest point, with the stope allowed to cave in behind the retreating miners.

Cut and Fill Mining. Image: CC
Soft Rock Mines

Soft rock mines are predominantly coal and shale mines. Here, the rock and the minerals are softer and easier to break up, but the roof requires more support.

The most common mining method is longwall mining which is largely automated using a self-advancing coal shearer including hydraulic roof supports 150-250m wide 1.5 -3m high extract panels roof collapses as machine withdrawals. This is the safest way to mine coal and shale as it requires no blasting in a potentially explosive environment.

Mining Risks

A serious disaster can close a mine permanently. In the 2010 New Zealand’s Pike River Coal Mine disaster, not only killed 29 of the 31 miners underground, but also saw charges of manslaughter against mine management. It also bankrupted the mining company and the mine is unlikely to re-open.

In the same year, an explosion at Upper Big Branch Mine in West Virginia Massey Energy’s coal mine also had a death toll of 29 out of 31 miners. This incident saw an multi-million dollar compensation settlement. The mine will not re-open.

That both of these mines were coal mines is not coincidental, according to the US mine Rescue Association, of the 17 disasters in US mines since 1976, all but one has occurred in coal mines. Of those 16 accidents, 13 involved explosions, one was fire, one was oxygen-deficient air, and one was a stockpile collapse. Or in other words, mine ventilation is critical, particularly for coal mines.

Ventilation

Ensuring adequate ventilation is crucial in any mine, even more so in coal mines where the build-up of methane and other explosive and toxic gases is an on-going issue. Fortunately modern technology means that canaries used in Victorian coal mines as early warnings are now replaced by carbon monoxide gas detectors.

Interesting fact – the last canaries were made redundant from British coal mines in the mid-1980’s (no that’s not a typo).
In hard rock mines, the ore itself doesn't give off lethal, explosive gases, but the exhaust fumes from vehicles do. In addition, the great depths that some mines reach, means that the geothermal gradient can see wall rocks as warm as 45°C, making ventilation and air-conditioning necessary.

In mines with shafts, the shaft doubles as a downcast airway i.e. a source of fresh air being forced into the mine. Additional shafts are required for upcast ventilation for the removal of stale air; these can also be secondary or emergency escape routes.

Other Underground Mining Risks

Old historic mines are often more dangerous than newer ones. When I worked underground in Australia in the 1980’s (a mine still in production), there were upper levels, which were either not mapped, or for which the maps had been lost.

Although the famous silver mines of Potosi, Bolivia, closed down officially some 150 years ago, to this day locals looking for some extra cash work the mine, and tourists are routinely taken down them, as well. The entire mountain is riddled with uncontrolled mining tunnels, all of which is unmapped and some of which is over 300 years old.

An unmapped, un-monitored level of a mine is dangerous because the dirt on the floor can be concealing a wooden or other cover to a deep winze (minor shaft from a level). Old mine workings are always propped by wood, and wood rots, so minor local collapses are to be expected.

In modern mines, most accidents occur, because of the juxtaposition of men and machinery in small, confined spaces. Tracked levels are safer as an approaching train is obvious, however, in untracked areas where electric vehicles are used, accidents do occur. Electric loaders and similar machinery are normally tethered by a thick power cable, which can break limbs or worse if the unwary visitor is caught out in the process of stepping over it; if you visit a mine always step ON such cables not over, the worst that can happen is that you get thrown clear.
Mining Techniques

By Staff @ Geology for Investors in Geology Basics, Mining and Mine Design

Once a potentially economic mineral deposit has been found many different challenges face the company preparing to open a mine. One of the most important factors in determining whether a deposit can be economically extracted is the type of mine that will be required.

Figure 1: Examples of the two main categories of mining. The surface technique on the right is an example of an open-pit mine, while the subsurface technique on the left is an example of a vertical mine shaft with horizontal “drifts”.

Mining techniques can be divided into two broad categories: surface mining and subsurface mining (See Figure 1). Surface mining consists of stripping soil and vegetation away and possibly a limited amount of rock and then removing ore in large quantities. Conversely, subsurface mining involves sinking a mine shaft and digging tunnels to reach a deposit at depth. These two broad categories encompass almost all mining techniques and will be discussed in detail. As a general rule surface mining is more cost effective than subsurface mining.

The most common surface mining technique is open-pit mining (Figure 1), where a commodity is extracted via an open pit in the ground. This is an extremely cost effective way of removing a resource because large quantities can be removed with minimal effort. Other surface techniques include quarrying and strip mining.

Subsurface mining can be done in many ways with a vast number of terms to describe each type. However all types involve digging tunnels or shafts to access a resource that is too far below the surface or too spread out to use a surface technique and remain economical. The tunnels that are offshoots of the main shaft are termed “drifts”. The commodity is extracted in the subsurface and then brought to the surface for processing and waste rock disposal. Subsurface extraction requires vast amounts of planning because of the increased safety concerns of working underground. A collapse can be costly in more ways than one. Digging tunnels designed to intersect ore bodies isn’t easy either. Complex geometry is used to determine the orientation of the ore body and drifts are constructed to maximize the amount of ore removed, a miss can lead to loss of revenue because large amounts of host rock are removed that do not contain any ore. The smaller volumes extracted only prove to increase extraction costs, which is why higher grades are needed to open a subsurface mine.
Cheap and easy techniques can make a small or low-grade deposit economical, while costly and complex techniques can make a prospective deposit nothing more than a noisy press release.

The first, and sometimes only, question to ask is how close is the deposit to the surface? Proximity to the surface plays a major role in determining which mining technique will be used. A small deposit near the surface may very well be economical if open-pit mining can be utilized. However, the same deposit a few hundreds of meters below the surface may prove to be uneconomical due to costs associated with subsurface extraction.

Another factor is the geometry of the deposit(s). For instance there may be multiple small deposits in an area where the construction of a single mineshaft allows for the extraction of more than one small deposit. The deposits may not be horizontally spaced but vertically spaced making the open-pit technique economical for only the upper deposit. Alternatively, the deposit might have a very complex shape, where open-pit mining would involve the removal off a tremendous amount of waste rock. This waste rock can dilute the grade of the deposit and render the deposit uneconomical. In this case subsurface mining could be used because of the precision of the technique – but at a much higher cost.

Host rock can play a key role in mine economics. Subsurface mining techniques may not be possible in a very weak and unconsolidated host rock. Cost associated with stabilizing drifts and risk of collapse may over shadow any potential revenue. On the other hand, unconsolidated and soft host rock is ideal for open-pit style mining because it favors the bottom line (i.e. The less money it takes to extract the resource, the more profitable the operation.)

A high water table and a highly permeable host rock can also create problems when it comes to the de-watering of a mine. In order to combat this, some companies have employed the use of frozen barriers, or ground freezing to literally freeze the groundwater around the mine using refrigeration units and underground piping. Again, this is only appropriate where the deposit is rich enough to warrant the expense.

Figure 2: In-situ leaching can be carried out without removing any rock. A solution is pumped through the rock that dissolves the commodity (potash, uranium, copper etc.) and then is pumped back up to the surface for processing.
In-Situ Leaching

Another more specialized mining technique is in-situ leaching (Figure 2), also referred to as in-situ recovery, or solution mining. This is perhaps the most economical of all techniques, but is only appropriate under certain conditions. In-situ leaching can be conducted without removing any rock at all, but the commodity of interest must be soluble. This technique is used to extract resources such as potash, uranium and copper by pumping leaching solution down holes drilled into the deposit and pumping the solution back to the subsurface. The solution travels through fractures that are either naturally occurring in the rock or produced artificially by hydraulic fracturing. The chemistry of the solution varies depending on what is being extracted. For instance, water is used for potash, acids or carbonates for uranium and acids for copper.

This is not to be confused with heap leaching which is not a mining technique but a method of extracting commodities from mined ore.

Heap leaching works on the same principle as in-situ leaching except that the rock is mined, crushed then piled before the solution is pumped through the rock. It is perhaps most famously used for extracting gold from mines along the Carlin Trend in Nevada. With recent advances in technology heap leaching practices have even been applied to waste rock and tailings sites to extract any remaining ore. A company planning to perform leaching (whether in-situ or heap) does not require very high grade ores and faces fewer logistical problems than a company planning on using any other technique.

Leaching is not without risk and controversy though. The use of acids to extract uranium and copper, and cyanide to extract gold in heap operations has environmental implications. Groundwater contamination and surface run-off are potential problems that need consideration during the mine design process.

Conclusion

Consider this short list of general rules when it comes to evaluating a potential mining operation.

- Surface mining techniques are generally cheaper than subsurface mining techniques.
- The closer a deposit is to the surface the cheaper it will be to extract. The ideal situation is a deposit close enough to the surface to that it can be removed by the open-pit method.
- Consider the geometry of the deposit. Impressive near-surface drill results do not mean that surface mining is possible.
- An unstable host rock makes for a costly and possibly uneconomical subsurface mine.
- In-situ leaching is a very quick and easy method of extraction.

In short, cheap and easy techniques can make a small or low-grade deposit economical, while costly and complex techniques can make a prospective deposit nothing more than a noisy press release.
Mining Production Delays

By Jess Peláez in Mining and Mine Design

Mining operations exist solely to produce valuable commodities while making profits for investors and key stakeholders. All mining executives are extremely aware of production costs and the need to ensure optimum production levels. If a mine can’t produce, it can’t make a profit.

Mine management is always attempting to increase efficiencies and cut costs in any way possible. However, in spite of the best efforts of management, circumstances can sometimes conspire against smooth, on-schedule production.

*Mine production targets need to be carefully developed, with assessment of all factors which could affect production and the mine’s profitability.*

Evacuating a mine site after torrential rains have turned the main access road into a waterway.
Weather Delays

One of the principal culprits behind production delays in both large and small mining operations is completely outside of the control of even the best managed operations. Weather accounts for hundreds of lost production days each year, and this trend shows no sign of decreasing.

Flooding can make open pit and exploration sites unsafe at the very least, and in the worst-case scenario, they may become inaccessible. Flooding can also affect underground mine sites as well, with disastrous consequences. Rain can also wreak havoc on uncovered mine stockpiles, as excess moisture can damage certain types of ore, and reduce the value of the product.

Extreme heat and cold can also bring production to a halt. Much mining work is still manual which that extremes in temperature can cause unsafe working conditions. It’s also not good for machinery as any oils and lubricants lose effectiveness and at very high or low temperatures and may need to be shut down to prevent damage.

Dangerous winds can make drilling impossible, and electrical storms cause crews working near metal structures to shut down work until the storm has completely passed.

Intentional vandalism of crew equipment at a remote site.
People Issues

Political issues can also directly influence mining operations. Many countries with significant mining industries suffer from serious industrial unrest from time-to-time. These situations cannot only shut down mine production either temporarily or permanently, but can also result in injury and loss of life if confrontations between striking workers and authorities turn violent.

Political pressure from communities in close proximity to mines can also force both short and long-term work stoppages. In more developed countries, these pressures are often related to environmental concerns. In countries that are less developed, political pressure often takes the form of wage, working conditions, or benefits lobbying. In regions where the local indigenous population has a strong voice, cultural heritage and land rights matters can also delay or even halt production.

Occasionally, remote sites may be the targets of vandalism for a number of reasons, which can damage equipment or product.

Equipment Failure

Smaller-scale production delays happen on a daily basis at operating mines, and most can be tied to mechanical failure of equipment due to wear and tear. Mines attempt to prepare for true equipment failure by instituting regular maintenance and replacement schedules, but many times these mechanical issues are unforeseen. Air hoses snap, conveyors break, trucks break down, generators die, and crushers jam. Larger operations have extensive crews of diesel fitters, electricians, and other professionals to handle these problems in a timely manner. Smaller outfits, and especially those located in remote areas, often have to wait hours, days, or even weeks for qualified repair personnel or specialized parts to arrive.

Worker Issues

With the growing focus on safety in mines, many operations will halt production temporarily if a safety issue occurs. Many of these issues are caused by mine workers themselves, who may show up for work with a blood alcohol content above 0.0% or without having slept an adequate amount. Random Breathalyzer tests are given at many mine sites, and supervisors are trained to observe staff members carefully for any erratic or inattentive behavior. Mine site workers have varying levels of professionalism, and some will engage in horseplay or otherwise irresponsible behavior. This can result in broken equipment, injury, or loss of production.

Supply Line Issues

Transportation issues further down the production chain can also cause production delays or stoppages. Driver strikes, damage to rail lines and roads, high costs of transportation, and inadequate transportation opportunities can all adversely influence a mine’s ability to deliver finished product. As with issues of weather and some political factors, transportation can often fall outside of a mining management’s control.
Management of Production Delays

Mine production targets need to be carefully developed, with assessment of all factors which could affect production and the mine’s profitability. All realistic contingencies must be weighed against a mine’s maximum potential production in order to provide key stakeholders and investors with an accurate picture of the mine’s likely production.
A Brief Look at Geological and Technical Risk Analysis in Mine Planning

Having a basic understanding of the orebody modeling and the mine optimization methods used can help investors determine how much effort a company places into the quantification of risk to manage their assets.

This article briefly describes some aspects of geological and technical risk analysis in mine planning projects. A full account is beyond the scope of this article, as the full breadth of this intricately complex topic is the combined effort of many research papers and books.

What makes a mining project profitable?

Notwithstanding global macro-economic drivers for particular minerals at a given point in time, the key concept in mining is the extraction of material from the earth that leads to a profit. It follows that whatever material extracted and processed for this purpose is generally called the ore. Starting with simple terms, the principal profit equation in any mining venture is:

\[
\text{Profits} = \text{Revenues} - \text{Costs}
\]

\[
\text{Profits} = \text{Units of Material sold} \times \text{Price/unit} - \text{Units of Material sold} \times \text{Cost/unit}
\]

The price is typically set by others through the effect of global supply and demand. What differs from project-to-project is the mining engineering team’s ability to effect price per unit costs. This is done through a better understanding of the deposit as well as the use of site-specific innovation to improve the extraction process. Innovation, in this context, serves to describe the different strategies used to define and extract ore. Technology is only important in a site-specific context; otherwise, it can be assumed that it does not take very long for everyone to have the same ‘new’ technology.

Cost reduction through safe and environmentally responsible practices is taken extremely seriously today. If it is not done from an ethical standpoint, it is in large part respected given the negative effect that a poor social media image can have on shareholder investments and the company’s future. From a socio-economic point of view, these terms are tied together:

An orebody model represents a quantified understanding of a mineral deposit in three-dimensional space. In a mining venture, the orebody will be discretized into a group of blocks, which are used to define an
optimal mining sequence of extraction by way of an optimization process. Note that the decision to mine a deposit is based on relatively limited drilling information (compared to the entire deposit) provided by the exploration and planning phases – i.e. the conclusion of a feasibility study.

**Orebody Modeling: Understanding the Origin of the Risk**

The orebody model and the blocks that represent it are the starting input for the optimization process. Typically, drilling information used to construct an orebody model will comprise less than 5% of the total volume of the deposit. For this reason, geostatistical *estimation* methods, combined with geological modeling/interpretation, have commonly been used to model the spatial distribution of mineral grades between drilling locations and within the mining blocks representing a deposit. However, despite their current use, it should be known that these estimation techniques are not capable of using the drillhole data to reproduce the in situ variability of the deposit grades.

**What does this mean?** Using a simplified block model below, it means that any *estimation* process, such as kriging or inverse distance weighting, will have a smoothing effect on the modeled data such that an *estimate* for the ‘?’ block will result in a value between 1 and 5 but never 1 or 5. If we consider these numbers as representing mineral grades, we are left with a model that consistently under-represents important information about high-grade blocks. In other words, the effect of this smoothing, starting at the orebody model, has considerable implications through the mining production optimization process and the subsequent financial return expectations of the project. Furthermore, *estimated* models do not provide any quantification of uncertainty in the mineralized ore, leading to an uncertain input supply variable for mine production scheduling. This is an important factor in any investment decision.
A simplified block model of the type used to estimate mineral reserves and resources. These estimation processes have a smoothing effect on the modeled orebody data. The effect of this smoothing is that it consistently under-represents important information about high-grade blocks.

**Optimization: Innovation in the extraction process**

Optimization in mine planning refers to the forecasting, maximization, and management of cash flows from a mining venture resulting from the extraction of the orebody. The objective of the optimization is to maximize the total NPV of the mine plan. Optimization is a necessary tool of any financially efficient mining operation.

Traditional optimization techniques will assume that the orebody model provided represents a perfect reconstruction of the subsurface deposit. As the block model example showed, estimation techniques effectively smooth out the block model values destroying high value blocks. For this reason, so-called traditional optimization techniques cannot generate optimal extraction schedules, since they are not considering the high value blocks.

Within the last 15 years, a new modeling and optimization framework has been developed to address the smoothing effect of estimation techniques and to improve the quantification of risk in the mining industry. Within this framework, a number of equally probable orebody models are simulated to fit the available data by representing the actual and unknown spatial distribution of grades. Through multiple equally probable orebody models, mine planning teams can gauge the sensitivity of their mine designs, on short- and long-term scales, to geological uncertainty. By extension, it becomes possible to choose mining scenarios that lead to higher financial rewards.
Risk-based mine planning and optimization refers to an operational framework capable of integrating uncertainty through multiple, equally likely scenarios within an optimization method to simultaneously evaluate high value outcomes. A risk-based (or stochastic) optimizer is able to evaluate a group of blocks by simultaneously using all combinations of economic values of the blocks in the group (note that more than one orebody model is being used, thus a given block has a distribution of possible values).

While detailed information about mining projects is confidential, a lot of useful information is often included in a company’s publicly available Technical Reports. As an investor, a basic understanding of the type of orebody modeling and the mine production optimization methods used is enough to see how much effort a company places into the quantification of risk to manage their assets. In the long term, this has a direct influence on value return to shareholders.

An example where a risk-based optimization approach leads to a considerable NPV increase over the life of the mine compared to a case relying on the optimization of a single estimated model. Note that the risk-based curves have a range of possible values that are upper and lower bounded. By contrast, the conventional curve has no measure of associated uncertainty. (adapted from a research paper by Godoy and Dimitrakopoulos, 2004).

Further Reading
