



THE INSIDER'S GUIDE TO

# DISCOVERING THE UNDISCOVERED

Insights into Exploration Core Drilling



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# FORWARD

Building on a rich heritage, Boart Longyear is recognized as an industry pioneer with a proven commitment to innovation, safety, and quality.

The wealth of knowledge that exists within our walls after 130 years in Exploration would be irresponsible of us not to share — investing in the future of our industry.

“There’s no book that can teach all of life’s experiences. Every hole drilled becomes a new life experience that can’t be captured in a textbook. With the experience of surface coring, there’s a lot to be learned about the importance of quality core, difficulties encountered when retrieving core, and best practices for obtaining quality core samples. If everyone knew as much as a geologist to piece core back together, everyone would have consistent results in the field. Since this isn’t possible, however, it’s important to learn best practices and troubleshoot when necessary to recover quality core on a consistent basis.”

Robert Jex, Division Manager - Coring, U.S. & Mexico

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# THE HISTORY

One cannot talk about the core drilling industry without mentioning “Longyear” — it is undeniable the influence this organization has had on the industry since 1890 when a young mining engineer, Edmund J. Longyear, set out on a path of innovation in mining.

## INTERESTING HISTORICAL FACT: A B C D E F G H I J K L M N O P “Q”

The single most revolutionary innovation, known only as the trademarked letter Q, was the result of a tenacious engineer who discarded sixteen previous revisions before hitting the jackpot!

One of Longyear’s earliest and most recognized patented innovations was the invention of the wireline core retrieval system back in 1958. The “Q™” Wireline System provided a whole new level of productivity because the drill rods could stay in the hole while the core sample was retrieved with a wireline cable.

# THE HISTORY



SERVING THE INDUSTRY SINCE 1890

## THE INDUSTRY

Archaeological findings show three “periods” having a significant impact on the mining industry’s history: the Bronze Age, the Iron Age, and the Late Modern Period.

E.J. Longyear, a member of the first graduating class at the Michigan Mining School, sank his first diamond drill hole on North America’s Mesabi Iron Range in northern Minnesota. As the iron ore mining and steel industry continued expanding in the US, Longyear realized there was a need for Exploration drilling companies, and formed his own contracting company to serve this market.

## BRONZE AGE (2000 to 1200 BCE)

Marked by significant technological and social advances, the Bronze Age was an essential step in the evolution of European societies. The use of metallurgy to create the bronze alloy, mainly composed of copper and tin, defines this period.

## IRON AGE (1200 BCE - 400 CE)

This period is marked by Iron, which is significantly stronger and cheaper, replacing Bronze in the manufacturing of implements and weapons. Such items include the iron sword, plows with iron tips, and armor.

## LATE MODERN PERIOD (1800 CE to present day)

In Europe, this period is characterized by phenomena and events of unprecedented magnitude. Population growth and industrialization had the most significant influence on the mining industry.

Gold and Silver also held their respective places in history. The Gold Age (6000 BCE) in which gold was fashioned into jewelry and became a symbol of wealth and well-being. The Silver Age (4000 BCE) was the origin of monetary systems, with Silver becoming the currency of the Roman and Chinese empires.



Population growth and industrialization during the Late Modern Period caused the demand for various metals and minerals to grow exponentially. Increased consumption meant Exploration for these reserves were needed, often in more remote and challenging terrain, requiring faster and more efficient methods of core drilling to be developed.

## FIVE OF THE OLDEST MINES STILL IN OPERATION

- 1 Khewra Salt Mine (Pakistan, 320 BCE) is considered the oldest salt mine in the history of mining, and second largest salt deposit in the world.

## THE EARLY BEGINNINGS

### CANADA

Gold discovery by English explorer Martin Frobisher — Baffin Island, 1577. Later reports believed it to be pyrite.

### UNITED STATES

Simsbury Copper Mine discovery — Connecticut, 1709. Abandoned mid-century as unprofitable.

### MEXICO

Native populations had been extracting silver from the area for years prior to the arrival of the Spaniards — Durango, 1500s.

### SOUTH AMERICA

Chile 1850 | Peru 1890 | Brazil 1690

### ROMAN EMPIRE AND WESTERN EUROPEAN REGIONS

Mining and metallurgy's early beginnings - 6000 BCE

### AFRICA

The first mine was copper (Springbok, 1852) with commercial coal beginning 12 years. In the 1860s, two significant diamonds were unearthed in South Africa, inspiring the diamond rush.

### AUSTRALIA

The first mine (lead) opened in 1841, but it was gold that put Australia on the map. By the 1850s it was producing almost 40% of the world's gold.

The above map shows approximate time lines of mining activity spread throughout the world.

## STANDARDIZATION

The Diamond Core Drill Manufacturer's Association (DCDMA) was formed in 1929 in the United States. The voluntary group was made up of representatives from each member firm, with membership open to responsible manufacturers who met established qualifications. Currently, this group operates as a technical committee within the National Drilling Association (NDA).

The purpose of the DCDMA was to standardize the tools used in the industry; to offer a common language that would let the contractor order with confidence in compatibility and performance.

- 2 Chuquicamata Copper Mine (Chile, 1879) is the world's largest open pit copper mine by excavated volume.
- 3 The Kiruna Iron Ore Mine (Sweden, 1898) is the largest underground iron ore mine worldwide.
- 4 Bingham Canyon Mine (United States, 1906) is estimated to be one of the world's most productive copper mines, the value of metals in 2006 alone was estimated at US\$1.8 billion.
- 5 Skouriotissa Copper Mine (Cyprus, 4000 BCE) boasts a reported production of 99.99% pure copper metal cathodes, according to 2012 figures.



## STANDARDIZATION (cont'd)

DCDMA's hole sizing specifications are the basis of several national standardization bodies. The core sample sizing is specific to the tooling system employed.

There are several tooling systems available, from various manufacturers globally, which are compatible with the DCDMA hole size standards. Nonetheless, Boart Longyear's Q™ wireline tools remain the most commonly specified system globally.

### JORC CODE (JOINT ORE RESERVES COMMITTEE)

JORC was first published in 1989, with the most recent revision being released late in 2012. It is a professional code of practice that sets minimum standards according to the levels of confidence in geological knowledge and technical and economic considerations for Public Reporting. It is a mandatory system for the classification of minerals Exploration Results, Mineral Resources, and Ore Reserves.

Since 1989 and 1992 respectively, JORC was incorporated into the Listing Rules of the Australian and New Zealand Stock Exchanges, making compliance mandatory for listing public companies in Australia and New Zealand.

The driving force behind this and other public reporting standards include the unfortunate circumstances around Bre-X. A group of Canadian companies, Bre-X Minerals Ltd., were involved in a major scandal when they reported it was sitting on an enormous gold deposit at Busang, Indonesia. Bre-X bought the site in March 1993 and in October 1995 announced significant amounts of gold had been discovered, sending its stock price soaring. Originally a penny stock, its stock price reached a peak at CA\$286.50 on the TSX (Toronto Stock Exchange), with a total capitalization of over CA\$6 billion. Regrettably, after discovering that the rock chip samples had been fraudulently 'sprinkled' with gold dust, Bre-X Minerals collapsed in 1997.

As a result, and in accordance with strict JORC requirements, it is preferred to take complete rock samples (known as core) rather than just chips. The need for trustworthy samples is a driver behind the entire diamond core drilling Exploration industry.

## ORIGINS OF THE TOOLS & EQUIPMENT

A type of rotary drilling was used as early as 5000 years ago to quarry stone. A hollow wooden rod, hardened by fire, was rotated by hand or bow and string on loose, hard mineral grains such as rubies or sapphires. History shows short holes, and at least one example of a 6 m (20 ft) hole, were drilled in this manner.

A drilling method more similar to modern-day coring was invented and put to practical use in 1863 by Rodolphe Leschot, a French engineer. The method was developed for drilling blastholes for tunneling. Leschot patented the device in the United States. In 1869 the patent was reissued and Leschot shipped a diamond drill to the United States for use in a quarry in Vermont.

Leschot's diamond core drill, as well as other

### BORT | BOART | BORTZ

*Low-quality, granular aggregate or small fragment diamonds.*

In 1936, Africa's De Beers Consolidated Mines Ltd formed Boart Products in an effort to find a use for these non-gem quality diamonds.

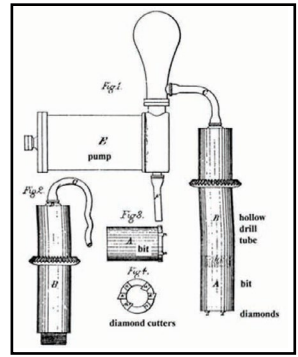


experimental drills from 1865, consisted of a hollow tube or cylinder having several stones set on the cutting end. The idea of using jewels or stones as cutting faces came from Leschot's early experience as a watchmaker and became the basis of today's diamond bit offering.

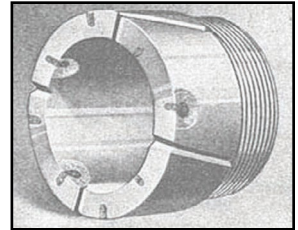
Improvements were made in the field of diamond bits in the 1930s with the introduction of mechanically set bits using non-gem quality natural diamonds (also known as boart or industrial diamonds). In this method, a mold was used to shape the crown and determine the pattern for diamond placement. The crown was brazed to a steel blank body and then added to the end of the rod string - the beginnings of the surface set bit. This process was initially developed by Boart Products in South Africa and later refined by a company in the United States.

It wasn't until the Canadian products division of Longyear experimented with diamond impregnated saw blade technology that significant improvements to bit performance were made. Small man-made diamonds (synthetic diamonds) were mixed uniformly throughout the crown matrix, allowing the bit to last longer for higher productivity. Diamond impregnated bits quickly displaced the old surface set bits.

Many changes also took place to improve the ability to capture core samples. As hole depths increased,



1869 submission for the reissue of Leschot's patent — the drill had a hydraulic system with fluid pumped down a single tube to flush the cuttings. Rotation was achieved by force applied to bevel gears. The bit or cutting piece shows six surface set diamonds. The stones most likely are carbonados (black diamonds) or South African borts, the latter being preferred.



An eight-stone diamond bit from 1926 shows four stones on the outside of the cutting surface and four on the inside. Once the stones were worn or broken off, the bit had to be reset or replaced.

## BRIEF HISTORY OF CANADIAN ASSOCIATIONS

In 1938, members of the American Diamond Core Drill Manufacturer's Association met with key operators and manufacturers in Canada to establish the Canadian Diamond Core Drill Manufacturer's Association (CDCMA). Its objective was to establish drilling equipment standards that would be interchangeable between Canada and the United States.

In 1944, as a result of amendments made to the constitution and bylaws, the CDCMA's name was officially changed to

the Canadian Diamond Drilling Association (CDDA). It was incorporated as a non-profit organization in 1958. Its name changed briefly to the Canadian Drilling Association to encompass the numerous branches of contract drilling but reverted to CDDA in 2005.

The head office was relocated from Toronto to North Bay, Ontario in 1985.

The first Driller's Training Program was established in Cobalt, Ontario in 1956 and was taken over by the Haileybury School of Mines in 1974.



the need to breakout joints every 3 m (10 ft) to retrieve a single core sample became too taxing. Like many other innovations in core drilling, inspiration was taken from the oil industry for this next advancement and provided a whole new level of productivity.

While working in the oil industry, Longyear’s drilling division witnessed a system where the sample was pulled up through the drill rod using a wire. The design wasn’t conducive for retrieving core in the mining industry, but it prompted the development of the wireline system.

The engineering of the wireline system started in 1946, but it wasn’t until 1948 when a real breakthrough happened with a unique wireline rod design. Development continued for a decade and in 1958 the patented Q™ Wireline System was launched. The system included a new double tube core barrel, a wireline overshot, and a new series of wireline drill rods.

With the original core drilling system (also known as a conventional drilling system), the entire drill string had to be pulled out of the borehole every 3 m (10 ft) to extract the core sample. With the invention of the wireline system, it became possible to retrieve the core sample with the drill rods still in the hole.



## THIS DATE IN HISTORY: LONGYEAR’S NEED TO GO DEEPER

1890	E.J. Longyear drills first hole and soon starts his own drilling service company.	1966	Q™ series rods commercially introduced.
1936	Boart Products, later to be named Boart International, was formed by DeBeers to find uses for diamonds not considered gem quality.	1969	Boart International becomes a wholly owned subsidiary of Anglo American.
1949	Longyear Company’s joint venture with Christensen Diamond Products created a platform to produce diamond bits with greater dependability and productivity.	1974	Boart International acquires 100% of Longyear — now the only company able to manufacture a complete product range and provide Drilling Services.
1950s	Wireline core drilling system developed and introduced to the market.	1980s	Advances in impregnated bit technology support deeper holes and higher productivity.
1960s	Longyear Company develops drills for the Apollo Project for moon Exploration.	1999	Improved core barrel performance with patented Link Latch system / RQ™ wireline rods released for greater performance and longevity.



## THE COMPANY – **longyear**

Initially, as a Drilling Services company, Longyear's need to improve drilling performance drove many innovations that have furthered both the productivity and safety of the industry.

Today, Boart Longyear offers Products as a supplier and Drilling Services as a contractor. The ability to innovate, develop, test, and implement new

solutions is a unique business model in the industry.

Over the last 130 years, Boart Longyear has grown to become the world's leading provider of Exploration Products and Drilling Services. Currently, Boart Longyear operates globally and employs more than 5,000 people with office locations in North and South America, Europe, Africa, Australia, and Asia.

### WHAT'S WITH THE NAME?

The DCDMA standard for the original coring systems was a three letter nomenclature representative of the HOLE SIZE, GROUP standardization, and DESIGN standardization. Today, the more commonly used system consists mainly of two letters.

Two letter naming:

- FIRST LETTER - hole size diameter.
- SECOND LETTER - representing both the GROUP standardization of key diameters for integration and DESIGN standardization of other dimensions affecting interchangeability.

### EXAMPLE:

Boart Longyear's NQ™ Wireline System

- HOLE size = 'N'
- GROUP/DESIGN = "Q™"  
(an integrated Boart Longyear proprietary system)

SYSTEM	Hole Size Ø		Core Size Ø	
	mm	inch	mm	inch
NQ™	75.7	2.980	47.6	1.88

A drilling program could use the following group of tools from Boart Longyear's NQ™ Wireline System:

- NQ™ core barrel and overshot.
- NQ™ drill rod (or modified newer versions such as NRQ™ or NXQ™).
- NQ™ impregnated bit.

2005	Advent buyout of Boart Longyear (from Anglo American).	2014	Centerbridge, Aires, and Ascribe invest in Boart Longyear.
2006	Macquarie buyout of Boart Longyear (from Advent).	2015	Boart Longyear celebrates 125 years.
2007	Boart Longyear debuts on the ASX in the second largest IPO in history. New generation bits (Stage™) and V-Wall™ rods released.	2016	TruCore™ Core Orientation tool and Freedom™ Loader (semi-autonomous rod handling) are launched.
2012	Quick Descent™, Quick Pump-in™, and Roller Latch™ head assemblies are launched.	2017	New Longyear™ Green Bit and TruLog™ digital drill report technology were launched.
2013	DCi (Drill Control Interface) introduced.	2018	TruScan™, TruShot™, XQ™ drill rod and W-Wall™ drill rod are launched. Complete series of Longyear Bits.



# THE BUSINESS OF EXPLORATION

## What can we learn from its complex history?

If the past can tell us anything, it is that predictive powers are limited when it comes to Exploration activity, and hindsight is always 20/20.

There are too many influencing factors that are beyond the industry's control to allow for an accurate prediction as to what the future investment in Exploration will be. As a result, most analysts will only offer a one year forecast, with very few going beyond three years because it becomes too speculative to be of any value.

If you wish to try your hand at the crystal ball, a lot of information on commodity futures can be found online at sites such as Yahoo Finance, Bloomberg, or S&P Capital IQ.

## INDICATORS OF AN ECONOMIC SHIFT

- Debt or equity transactions in larger mining houses.
- Currency fluctuations.
- Trade imbalances.
- Infrastructure investment in developing countries.
- Fixed asset investments.
- Unemployment.

## BULLISH AND BEARISH

Trading terms used to define whether prices of an asset will rise (Bullish) or fall (Bearish).

## RESERVES-TO-REPLACEMENT RATIO

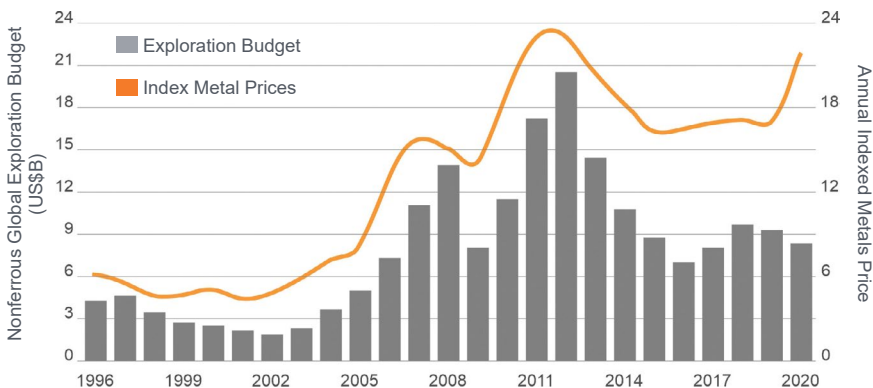
There are two fundamental metrics to judge mineral reserves. One is the Reserves-to-Production ratio which says how many years of reserves are left at the current rate of production. The other is the Reserve-Replacement ratio, which is simply the tons of known reserves added in one year relative to the production for that year. Things are stable as long

## INFLUENCING FACTORS

- Global growth in GDP.
- International trade conflicts.
- Political change.
- Global regulator restrictions including import/export.
- Changes in technology.

## MINERAL TRENDS AND EXPLORATION SPEND

The one trend that seems constant is that commodity prices drive Exploration, but underlying economic, supply, and demand factors prove complicated.



as the Reserve-Replacement ratio is 100%. This terminology originates from the Oil and Gas industry but is equally applicable to mining. The value of any mining company, in theory, is a function of all future earnings. Therefore, having substantial, stable, or growing known reserves is vital for any company and its shareholders. Whenever the Reserve-Replacement ratio falls below 100%, investors and industry analysts become worried, and if it continues year after year the company will eventually run out of mineable reserves.

**MINING HOUSE VALUATIONS ARE BASED ON THEIR RESERVES, SO IT IS NECESSARY TO KEEP THEM REPLENISHED!**

This is where the Exploration industry comes in, at least with respect to Greenfield Exploration and Brownfield Expansion projects. Its role is to discover and quantify new reserves – new mineable ore bodies – to replace those that are mined out. With global consumption gradually rising, the Reserve-Replacement ratio should be greater than 100%. Given that it sometimes takes decades to go from a discovery to an operating mine, Greenfield Exploration is a long-term activity. Also, processing or refining of

**SUPPLY AND DEMAND**

Like anything, prices for mined products are driven by supply and demand. Whether the demand is driven by actual consumption or speculation doesn't matter.

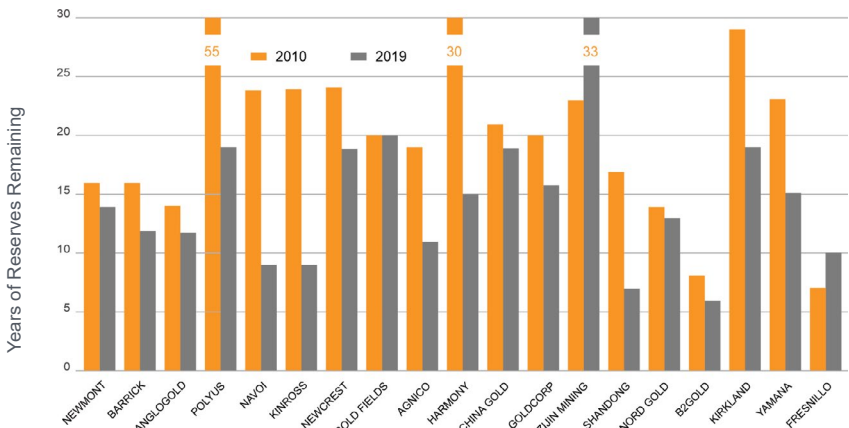
The supply side in mining is complicated. In various manufacturing industries, companies may choose across the board to get aggressive on pricing or reduce output. Mining is different since each operation has a different "cash cost" – mining is far from a level playing field!

- Lowest-cost operations can always continue at full capacity, albeit at reduced profitability.
- Higher-cost operations will gradually become uneconomical as prices fall.

The supply changes as those marginal mines are taken out of production, or vice-versa are brought on line with increasing prices.

The "cash cost" depends on many factors, but mineral grade is a key driver. From an Exploration drilling perspective, those marginal mines depend more on short-term grade-control.

**MAJOR GOLD PRODUCERS' YEARS OF RESERVES, 2010 vs 2019**



minerals requires large investments and both the industry capacity and output are relatively stable. So, considering the fundamentals one might think Exploration activities should be stable over time.

The opposite is true and Exploration spending instead correlates highly with metal spot prices. Although Exploration drives long-term solutions with little impact on supply and demand, it is short-term prices that drive Exploration. It appears the driver is mining company profitability rather than the fundamental ratios.

Any attempt to predict short-term Exploration activities are only as good as the ability to predict prices. The long-term picture is more predictable since we have no choice but to find new reserves. To take gold as an example, the trend has been to fall behind. Between 2008 and 2017, the vast majority of the major gold producers saw major drops in their Reserves-to-Production ratios. It should be said that much of the new reserves for major producers come from acquisitions of discoveries made by smaller companies. Regardless of the short-term ups and downs in commodities prices, the outlook for Exploration is fundamentally strong. Behind the numbers is also the reality that most “easy discoveries” have already been made. In general, future deposits will be deeper and of lower grade, raising demands on Exploration in terms of meters drilled, accuracy, and cost efficiency.

## MANAGEMENT’S GUIDANCE

In the first quarter of each year, most of the larger, publicly-traded mining houses will release their expected guidance for the year, including their Exploration spend; this can provide some insight into drilling demand and overall market sentiment.

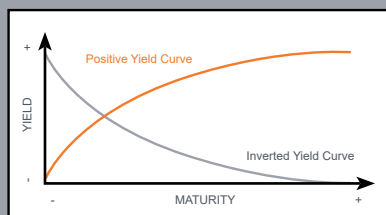
## PREDICTIONS USING ECONOMIC INDICATORS

Given the complexities of predicting Exploration activities based on commodity prices and their outlook, it might be easier to look at the macroeconomic environment. Mining is, after all, not done in a bubble and depends on whether the general market is “bullish” or “bearish.”

A simple but common tool to judge market sentiments is the so-called Yield Curve. The bond market pays a different interest rate depending on the duration of the bond - in a confident or bullish market, the short-term interest rate (the yield) is low, but for a longer-term bond the interest is higher. Hence, the different returns form a curve that trends upward.

However, if the collective wisdom of the financial markets is of an economic downturn, the Yield Curve inverts. In other words, short-term bonds pay better interest than longer-term ones. Such a Yield Curve inversion preceded the 2008 global financial crisis. Many sectors of the economy suffered, but the mining industry powered through unscathed. Its downturn instead came in 2013. Early in 2019, the Yield Curve inverted again, and many feared an impending recession that didn’t materialize.

As unreliable as any indicator appears to be, it may still be wise for any miner or contractor to observe signs of potential economic shifts before making major investment decisions. At least the Yield Curve is a simple tool.



# THE CULTURE

SAFETY FIRST

“A Safety Culture is the enduring value and priority placed on worker and public safety by everyone in every group at every level of an organization. It refers to the extent to which individuals and groups will commit to personal responsibility for safety, act to preserve, enhance and communicate safety concerns, strive to actively learn, adapt, and modify (both individual and organizational) behavior based on lessons learned from mistakes, and be rewarded in a manner consistent with these values.”

Professor Douglas Wiegmann  
Safety and Accident Investigation

# THE CULTURE

One of the more important shifts seen in the latest mining growth cycle is the desire to systematically improve. Having learned from past experiences, the industry is committed to identifying and managing risks that have the potential to affect its objectives.

Risk management is not a new concept, it has been used in the investment world for decades, but there are many types of risks in business.

## WHAT EXACTLY IS RISK MANAGEMENT?

Risk is measured in terms of the consequences of an event and the likelihood of it occurring. Risk Management is a process that identifies and addresses risks as a consideration of decision making. Then, eliminating or minimizing those risks resulting in increased business opportunities while promoting innovation and supporting the business culture.

Risk management is a continuous process and the results will need to be regularly reviewed and, when appropriate, revised and improved.

## IDENTIFYING RISKS

While it is a natural urge to find as many risks as possible, this approach often leads to so many that none of them get properly managed - it's crucial to identify just the larger risks. Another way to keep the number of risks manageable is to remember that there may be several causes and outcomes for the same risk. Also, ensure not to accidentally double up on the same risk, which can happen if several people are identifying risks from various departments.

Another issue that could hinder the process is the tendency of identifying risks that are too vague. When that happens, it will be almost impossible to assign consequences.

Recognizing a change is required is just the “tip of the iceberg,” getting everyone on board to modify behaviors, and eventually, outcomes will prove to be a much more difficult task...



...like an iceberg, much of any culture resides below the surface, comprising of “shared beliefs and assumptions” that are often shaped over generations. This can make changing the culture of a company, or an industry, very challenging.

**DON'T THINK ABOUT WHAT HAS ALREADY HAPPENED, INSTEAD, THINK ABOUT WHAT COULD “POSSIBLY” HAPPEN...**

...then, in the assessment stage, if the risk is unrealistic dismiss it.



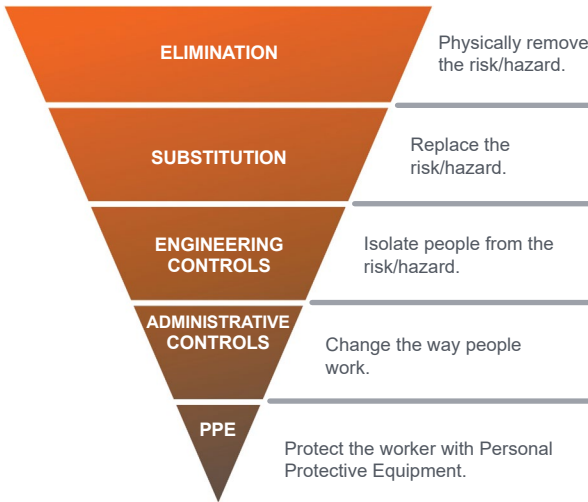
## HOW?

- 1 Ask people - use a variety of approaches such as workshops, brainstorming, questionnaires, etc. Group-based methods foster a greater risk culture.
- 2 Careful analysis of a company's operational process. This method is better suited to finding hidden critical failure points that might be missed in the first method.

## ASSESSMENT AND CONTROLS

It is essential to analyze each risk identified, and rank them according to which ones will have the greatest effect on your business and employees, and which ones you can influence. Once targeted, the next step is to apply controls. If you can control the risk, you lessen the likelihood of it occurring.

### Example of Safety Control Hierarchy



## LIFE IS FULL OF REGRETTABLE MOMENTS

WOULDN'T IT BE GREAT IF WE COULD SHARE THOSE INSTANCES SO THAT OTHERS DON'T HAVE THE SAME PITFALLS & MISHAPS?

This is not a new thought! We often hear about 'best practices' and have many laws, regulations, policies, and procedures in place that must be adhered to.

The underlying reason behind most of these "rules" include our protection, safety and security. We must abide by the law to stop at a red light not because of the threat of a ticket, but because ignoring it could bring severe consequences to ourselves, others, or property.

## CHANGING FOR THE BETTER

"As the mining industry's value proposition is increasingly called into question, mining companies are beginning to see that they cannot succeed into the future unless they change the way they operate. This is about more than enhancing efficiencies. It's about re-establishing trust with stakeholders and collaborating to devise better responses."

Glenn Ives, Americas Mining Leader Deloitte Canada



# ENVIRONMENT, HEALTH AND SAFETY

## RISK MANAGEMENT

Based on the very nature of the mining business, and the locations in which it operates, employees are exposed to risk that could affect their personal health and safety, as well as the environment in which they work. A company's reputation, operational and financial performance, can be exposed on many levels.

Every mine site has its own set of safety standards and protocols which must be followed. When considering contractors, their safety performance must play a crucial role in the selection process. Contractors with better safety records and equipment will often win work over a lowered priced provider with a poor safety record. A proven safety record reduces the probability of a recordable or lost time injury, which would affect not only the drilling contractor but also the owner of the mining property.

## HEALTH AND SAFETY

The single most impactful Risk Management objective within this industry is Safety. It's not only about following the rules, it is ensuring that employees go home to their loved ones in the same physical condition as when they reported for work.

## INTRODUCTION OF SAFETY CONTROLS

### ELIMINATION

The easiest way to deal with a safety hazard would be to remove it, but that is not always feasible. For example, a mine site can be as large as a small city, and with as much traffic. Unlike cities, roads and traffic controls are not as regulated and can pose a safety hazard, but it is not possible to operate a mine site without the movement of people, materials, and equipment.

## IN THE DRILLING INDUSTRY, SAFETY IS CRITICAL!

We would like to think we have it figured out, but the reality is that we always have something new to learn. Equipment is continually improving for productivity and safety, but human interaction is still required, and as the English poet Alexander Pope pronounced, "To err is human..."

When we go through a bad experience, we immediately adjust our behavior to prevent it from happening again. Then a short while later, we find ourselves returning to our habitual tendencies, e.g., who hasn't been sunburned more than once!



- T TAKE THE TIME**
- H HAZARD RECOGNITION**
- I IDENTIFY THE RISK**
- N NECESSARY CONTROLS APPLIED**
- K KEEP SAFETY FIRST**

## SUBSTITUTION

If a hazard cannot be reasonably removed, the next best thing would be to change the way of working to something safer. An example of that could be reducing the traffic on a mine site by replacing the large haul trucks with



conveyor systems. This would move the same amount of material or more while decreasing the amount of traffic.

## ENGINEERING CONTROLS

While removing a risk through elimination or substitution should always be considered, engineering controls are often the more practical choice for risk mitigation. A pertinent traffic example could be the introduction of smart vehicles that are equipped with proximity alerts and cameras that could alleviate the issue of human interaction and response times.

## ADMINISTRATIVE CONTROLS

Rules, policies, or procedures are examples of Administrative Controls that are used to guide behavior and protect people from risks. These controls rely on good communication, understanding, and willingness to obey them.

## COMMUNICATION

New technologies, systems, and methodologies have changed the way people communicate over the last decade. However, one factor has remained the same and has been the over arching key to success – effective communication.

Looking at the future, Exploration drilling will only be successful with efficient workplace collaboration to understand the goals and objectives of all parties involved.

## PPE (PERSONAL PROTECTIVE EQUIPMENT)

It is the lowest form of protection because it relies on so many variables to be effective. Wearing all the PPE in the world will not save you from a speeding haul truck. It may help that you are more visible, but if you are not in the operator's line of vision, you are in serious danger.

## 7 TIPS FOR EFFECTIVE COMMUNICATION

### DRILL SITE COMMUNICATION

1. Ensure all members of the drill crew understand the chain of communication. Typically the driller is responsible for all procedures and tasks on the job site, and is aware of every process. The driller also prioritizes tasks and communicates this to the entire team.
2. Ensure ALL members of the drill crew understand the drilling process.
3. Align all verbal and non-verbal communications, e.g., common job site terminology and safety language.
4. Ensure everyone on site is aware of all abnormal operating conditions, especially for EHS considerations and adherence.

### MINER-CONTRACTOR COMMUNICATION

5. Develop a strategic plan of communication that works for all parties involved.
6. Understand the goals and objectives of the project in question. Drilling can be a disruptive process, and once it starts running, the chain of communication can quickly expand to neighboring property owners, corporate officials, and regulatory government agencies. Each party requires different information to properly oversee the job to completion.
7. It's easy to assume what information involved parties would like to hear, and respond accordingly. However, listening for pertinent information prior to responding is crucial — effective communication is fully understanding what is being said before answering.



# TRACK | REPORT | PROMOTE

## FOR A CONSCIENTIOUS SAFE WORKING ENVIRONMENT

Miners and contractors alike must agree on the benefits of implementing effective procedures to keep employees and others safe. Even a daredevil has built-in safety nets to allow him to give his audience thrills for yet another day.

Where the incident reporting system goes beyond the safety net is that it also captures the before-unseen information for potential harm and flags it for an immediate thoughtful response.

One of the best methods of increasing safety is by learning from mistakes and near misses. When a company uses a Safety Management System (SMS), there are many advantages to the knowledge that is collected and disseminated. The priority is safety and warning others of potential risks always helps to place harm at a well-planned distance.

Incident Management Systems cost time and money to implement, learn, and utilize, but it is small in comparison to the value of a saved life and protecting equipment. In the long run, safety and incident management systems increase productivity and keep operations running successfully.

Recently Boart Longyear launched an easy-to-use mobile app version of its Incident Management System (IMS). The app allows employees to remotely complete tasks such as data entry, tracking, inspections, and management interactions. The information can be completed 100% in the app, with or without an internet connection, and then uploaded to the global collection database instantaneously when in reach of cellular or WIFI connections.

## ENVIRONMENTAL AND SAFETY COMPLIANCE

Recently, environmental concerns have led to an increase in the number and scope of compliance sanctions. These vary depending on the province/state and country of operation, as well as the type of drilling performed.

If there are environmental concerns, additional efforts must be made to ensure everything is done correctly or the mine site could lose its license to operate on the property.

### AIR QUALITY CONTROLS

Using specific measures identified and implemented, air quality standards can be tracked and managed for reduced air emissions and greenhouse gases.

- Fuel and power consumption.
- Mobile equipment engine hours.
- Vehicle miles.
- Volatile organic compounds.

Noise Pollution would also fall within this category.

### ENERGY AND WATER CONSERVATION

Effective conservation begins with tracking and managing the consumption of limited and crucial resources at office facilities and job sites.

- Evaluate efficiency opportunities at permanent facilities, as well as opportunities for alternative energy resources.
- Implement water conservation measures at permanent facilities and job sites.
- Limit job site impact on groundwater quality.

### WASTE AND HAZARDOUS MATERIALS MINIMIZATION

Mandatory tracking and management of all major waste streams and hazardous materials inventory are becoming mandatory. Respect surrounding and host communities by causing no harm.



- Implement waste minimization programs for manufacturing and maintenance facilities.
- Systematically reduce the use and inventory of hazardous materials in shops and job sites.
- Capture all fluid returns from the drilling program so as not to contaminate the environment.

To be able to operate, the contractor must ensure conformance to all environmental laws, standards, and any other requirements such as site permits, for each region as outlined by regional regulatory authorities. For example, in the United States all drillers need MSHA certification (Mine Safety and Health Administration), and in Ontario, Canada, anyone intending to go on site is required to go through a Common Core training program.

Compliance regulations are generally national and/or local, but many contractors work across borders. It is the contractors' responsibility to be compliant with all local regulations including examples such as importation regulations for equipment and supplies, proper documentation and immunization for any Expat workforce, as well as local employment issues including payroll.

## "NECESSITY IS THE MOTHER OF INVENTION"

A famous quote by the Greek Philosopher Plato, and nothing could be truer when it comes to the well-being and safety of individuals on a work site.

.....

During the assessment process, tools and equipment could be identified for re-engineering to mitigate potential risk. Some modifications may be very simple, while others will need to be brought to product development for redesign and implementation.

## ENGINEERING CONTROLS

Boart Longyear operates with a "safety first" approach to drilling. The product management team and engineers are focused on mitigating or eliminating risks before they happen.

The **MDR700 Underground Coring Mobile Drill Rig** is an example of this, a truly new generation drill rig where we have added technology to significantly enhance safety, increase productivity and improve ease of operation and maintenance.

- The first underground coring mobile drill rig with an on-board rod handler, which significantly reduces the risk of hand and back injuries.
- The Drill Control Interface (DCi) provides semi-automation and a fully electronic interface to safely operate both the rod handler and the drill – separating the driller from hazards.

Boart Longyear introduced the **Roller Latch™** technology on Quick Pump-In™ Head Assemblies for underground applications. This revolutionary design is a safer and improved alternative to the conventional link latch mechanism.

- Utilizes large ball bearings for reliable latching and a unique hold-back brake retains inner tube assemblies in the drill string for safer operations in up-angled holes and pressurized formations.
- Eliminates drag, to deploy and retract radially, without swinging like conventional latch mechanisms.
- Roller latch is wear-resistant and self-locking, eliminating mismatches and worn shoulders.
- Variable-lip seals allow for greater pump-in rates and reduced operator fatigue with light weight W-Wall™ rods.



## OPERATIONAL EXCELLENCE

Risk management is a continuous process that, when done properly, can effectively anticipate and mitigate risks that can impact your business.

**A CONTINUOUS IMPROVEMENT PROGRAM IS PROOF THAT SMALL CHANGES, WHEN MEASURED & CARRIED OUT CONSISTENTLY, CAN ADD UP TO A BIG IMPACT ON PRODUCTIVITY & EFFICIENCY!**

The Hard Work Cycle (HWC) is an example of a continuous improvement program. It uses a system of processes and Key Performance Indicators (KPIs) as tools to ensure productivity and efficiency while maintaining safety.

### HWC APPLIED TO DRILLING SERVICES

Comprehensive reports are used to manage individual driller and shift performances, as well as overall project progress. Sharing metric-driven results on site enhance communication, transparency, and accountability between contractors and miners.

### QUANTIFYING DRILLING EFFICIENCIES

How does one measure success?

The mining sector continues to look for ways to improve efficiencies and lower costs and drilling companies are following suit. At the end of the day, the best drilling contractors know that it's all about providing maximum value to the project. Drilling meters is only one part of the equation and other metrics provide guidance to total value.

To quantify drilling efficiencies, something must be measured. Which metrics mean the most and provides the best information on finding ways to improve performance and increase a mining company's return on investment?

## SIX OBJECTIVES OF THE HARD WORK CYCLE

- 1** **Transparent KPIs** - ensure employees are aware of their KPIs, how they are calculated, and how they performed every shift.
- 2** **Best Practice Drilling Procedures on All Drill Rigs** - best practice sharing and procedures are consistently adhered to on all drill rigs.
- 3** **Clearly Defined Roles, Incentives, and Recognition for All Employees** - all employees have clearly defined roles, and are incentivized to deliver safe, straight meters, and are recognized for their efforts.
- 4** **KPIs Reviewed as a Team and Actions Agreed and Tracked** - driller performance reviewed with management after each shift with periodic agreements for further improvements.
- 5** **Continually Generate, Prioritize, and Implement New Ideas** - Implement in order of value, manage to completion, and measure the results.
- 6** **Active and Visible Leaders that Support Drillers to Achieve Targets**



## SAFETY PERFORMANCE #1

An incident can be categorized as recordable or lost time, but the severity rating is a key factor that insurance companies consider. It's their first indication of the culture a contractor brings to the site.

### PRICE

It's tempting to assume the hourly price represents the total cost, however, this negates the value proposition of a well prepared contractor. There are always additional costs to consider, and, while some aren't in direct control of the drilling contractor, inefficient operating practices can impact them, overrunning any initially perceived savings.

### SCHEDULE

An estimate of meters (feet) per shift is used to calculate the schedule and required on site support personnel and equipment. If the drilling program takes a shorter amount of time, the mine site can leverage the savings. However, if the footage based contractor takes longer, they will still get paid roughly the same, but the program costs go up.

A lack of production and downtime also adds unbudgeted costs to the program, a clear lose-lose situation.

### QUALITY CORE RECOVERY

Core recovery is ultimately what the mine is paying the contractor for, so this metric is key to measure the drilling program's success. If there's not quality core in the box, there's no value added to the project. In the end, the data from that core is the value to the mine. If core recovery is insufficient, so is the value provided.

Drilling and retrieving quality core depends on the expertise of the driller. The driller's knowledge and understanding of the ground conditions is imperative, as is the selection of proper tools and equipment to accomplish the task at hand.

## IS LOW PRICE CONTRACTING THE SAME AS LOW COST?

It's imperative to look at the risks associated with a lack of safety and performance. When quoting or appointing a drilling contract, the difference between "cost" and "price" is a critical factor.

The lowest price may appear competitive and attractive, but may not lead to the lowest cost because of operating inefficiencies, poor safety practices, planning and logistics problems, or even poor ore recovery.

## A WIN-WIN FOR EVERYONE!

At first, employees at Boart Longyear were asked to do a few things differently, now they're brainstorming ideas daily — by changing the mindset to continually look for improvements in the way of working, we get a steady flow of ideas that deliver a lot of value.

- A driller won an award for suggesting a slight schedule change that resulted in a significant increase in productivity. This change decreased the drill start time and increased the average total meters (feet) drilled per shift.
- A supervisor had an idea for improving a part on an underground coring rig. His design was engineered, tested, and implementation globally.
- A special display board to improve communication between the drilling crews and mine operations was developed to help prioritize and ensure the maximum number of drills were turning. Results were tracked and measured, and showed a significant increase in the number of rigs turning per shift and in the total meters (feet) drilled per shift.



# GOLDEN RULES OF SAFETY

If the answer to any of these questions is NO, stop, take the necessary corrective action and continue working only when the answer is YES.

1

## Stop Any Unsafe Activity Immediately

- Are you satisfied that the process you are being asked to follow is safe?
- Are you satisfied that your co-workers are behaving in a safe manner?
- Are you performing your tasks without taking shortcuts?

2

## You Must Be Fit To Do The Job

- Have you received training and proper instruction in the task you are about to perform?
- Are you competent in your ability to perform the task?
- Are you physically able to safely complete the task?
- Are you free from the influence of drugs and alcohol?
- Are you well rested?
- Are you able to focus on the task and not preoccupied with other issues?

3

## Conduct A Risk Assessment Before Starting Any Activity

- Have you completed your pre-shift checks and corrected any potential defects?
- Have you closely examined your workplace to ensure that no adverse changes have occurred since your last shift?
- Have you identified possible hazards and associated risks?
- Have you developed controls to protect everyone from the hazards?
- Have you communicated the controls with the team?

4

## Use The Correct Tools And Safety Equipment For The Job

- Do you have the right equipment?
- Are you able to use your equipment as it was intended to be used?
- Is your PPE appropriate for the task at hand?
- Are your tools in good condition?
- Are you complying with safety signs and other instructions?

5

## Maintain A Safe Body Position

- Can you complete the task without the risk of falling?
- Can you maintain good posture?
- Can you complete the task without overreaching?
- Can you complete the task without overexerting or injuring yourself?
- Can you remain out of the line of fire from machinery, falling objects, stored energy, or vehicles during the task?

6

## Ensure NO Contact With Any Source Of Energy Or A Hazardous Substance (Rotating machinery, electricity, pressure in pipes and hoses, etc.)

- Are all the required safety guards, barriers, handrails, and other safety features in place?
- Are you able to meet the requirements of the Material Safety Data Sheets (MSDS) before you start work?
- Is the ventilation or extraction system working?
- Are you sure all the energy sources have been controlled, isolated, or released before you start any work?



# THE OBJECTIVE

Generating a geologic model is the purpose of Exploration drilling, and the first step in mine planning. It shows the amount of mineralization in a given deposit and is used in defining the extent of an ore body.

## MOTHER LODE:

The principal vein of mineralization, traditionally used to describe Gold or Silver ore bodies.

*Likely a literal translation of Veta Madre, an 11 km (6.8 miles) long Silver vein discovered in 1548 in Mexico.*

# THE OBJECTIVE



## WHAT ARE WE LOOKING FOR?

Simply put, the objective of mineral Exploration is to discover, define, and help assign a value to a deposit through the process of retrieving samples. Exploration projects are not to be taken lightly; it may take decades to prove the existence of an ore body, cost millions of dollars, and result in nothing.

## ORE BODY

An ore body is more or less a mass of rock that may have areas of low-grade as well as high-grade ore, depending on the placement and concentration of minerals.

Using various methods, samples of the rock are retrieved and analyzed to determine if mineralization is viable as a mine, or in the case of existing mines, indicate if additional opportunities exist in the surrounding areas.



Pictured above are samples from a core drilling program.



Pictured above are samples from a reverse circulation drilling program.



## MINERALS VERSUS ROCKS

What is the difference?

- Minerals are naturally occurring, solid, inorganic compounds that have a defined chemical structure. Minerals can be as simple as gold (Au) or Pyrite (FeS<sub>2</sub>), or as complex as Plagioclase (CaAl<sub>2</sub>Si<sub>2</sub>O<sub>8</sub>).
- Most rocks consist of many different types of minerals and waste, while some, such as quartzite, consist of only one mineral. Rock is only considered ore if it can be mined at a profit.

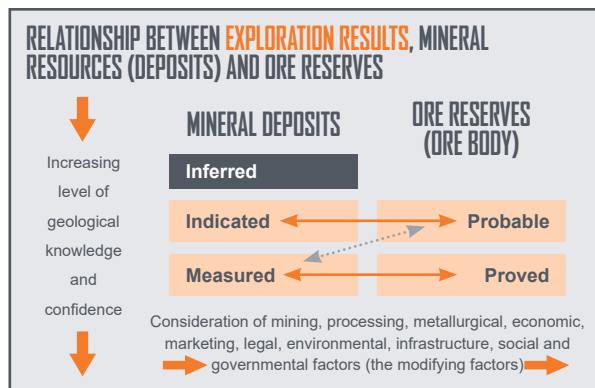
A mineral deposit is a concentration of a material of economic interest. The form, grade, quality, and quantity of the material need to be such that the deposit has reasonable prospects to be mined at a profit. For example, a layer of rock that is 2% chalcocite would have significant potential for extraction due to its high copper content.

**IF A ROCK CONTAINS DESIRABLE MINERALS, BUT CANNOT BE MINED AT A PROFIT, IT IS CONSIDERED WASTE.**

An ore body is the economically mineable part of a mineral deposit. However, before the deposit can be called an "ore body" proper studies must be performed as part of a mandatory system for the classification of a mineral deposit. Factors that could influence the results of the study include dilution, commodity pricing, mining costs, etc. For example, a rock mass

that contains 30 g/tonne (0.06 lb/ton) of gold, but is 5 km (3 mi) below the surface, and practically inaccessible, cannot be called an ore body.

**ALL ORE BODIES ARE MINERAL DEPOSITS, BUT NOT ALL MINERAL DEPOSITS ARE ORE BODIES.**



The process required to legally classify a mineral deposit as an ore body involves the collection of data through samples. The samples are analyzed and if enough information is present to make a knowledgeable decision, the classification can go from "probable" resources to "proved" ore reserves. Modifying factors must then be considered to see if the reserve can be mined at a profit. Organizations such as JORC have set minimum standards according to the levels of confidence in the geological knowledge, and technical and economic considerations for public reporting.



### GRANITE

An example of a waste rock made up of a large collection of materials of various colors and shapes.

**Feldspar:** White or pink, opaque rectangular prism shaped.

**Hornblende:** Black grains.

**Mica (biotite/muscovite):** Dark/gold sparkling grains.

**Quartz:** Usually in round glassy grains.



## HOW DID IT GET THERE?

Rocks are deposited in layers known as strata. These form in horizontal layers, but over time they can get folded and distorted by external forces acting on them. The table below explains how each type of rock is formed.



### IGNEOUS ROCKS

Formed by the cooling of molten rock which escapes from a magma chamber deep below the surface. There are two types of igneous rock:

- Volcanic Rock is formed when lava reaches the surface and is cooled quickly. When lava cools quickly there is little time for crystallization, resulting in fine-grained rocks (e.g., obsidian).
- Plutonic rock occurs below the surface, where magma is cooled slowly allowing for the minerals to grow together to form coarse-grained rock (e.g., granite).

### SEDIMENTARY ROCKS

Two types:

- Clastic rocks are formed by the collection of smaller rocks as a result of a mechanical weathering action (e.g., sandstone).
- Evaporitic rocks are formed when water containing minerals is trapped and evaporates, leaving behind the minerals (e.g., gypsum).

### METAMORPHIC ROCKS

Rocks (Igneous or Sedimentary) that have been altered by heat, pressure, mechanical stress, or a combination of these that will change the mineralogy of the pre-existing rock to form minerals that are stable at the new temperature or pressure conditions (e.g., sandstone changes to quartzite with the addition of heat and pressure).

External forces play a large role in rock formations, turning it from a solid mass into layers of fractured rocks. In addition to becoming more abrasive, fractured rock cause a variety of drilling complications:

- Decreased stability of the hole and loss of valuable drilling fluid.
- Specialized tools, such as bits and drilling muds, may be required to reduce the effects of wear and improve drilling efficiency.



The type of rock, and its mineral make-up, determine what mechanical properties it has. These properties will influence the selection of equipment and tools used in a drilling program.

### ABRASIVENESS

Mineral abrasiveness is the result of two distinct characteristics:

- 1. Cleavage** - different minerals tend to fracture into certain shapes, e.g., cubes or pyramids. This tendency is known as a mineral's cleavage. The cleavage of a mineral, in addition to its hardness, affects the abrasiveness of the rock.
- 2. Grain Size** - minerals are composed of different grain sizes. Sedimentary rocks are categorized by their grain size, e.g., sandstone consists of sand-sized particles, and siltstone is comprised of silt-sized particles. As a rule, the longer the cooling period for Igneous rock, the larger the grains. Pegmatite is categorized by very large grains, whereas diorite has

### WEATHERING vs EROSION

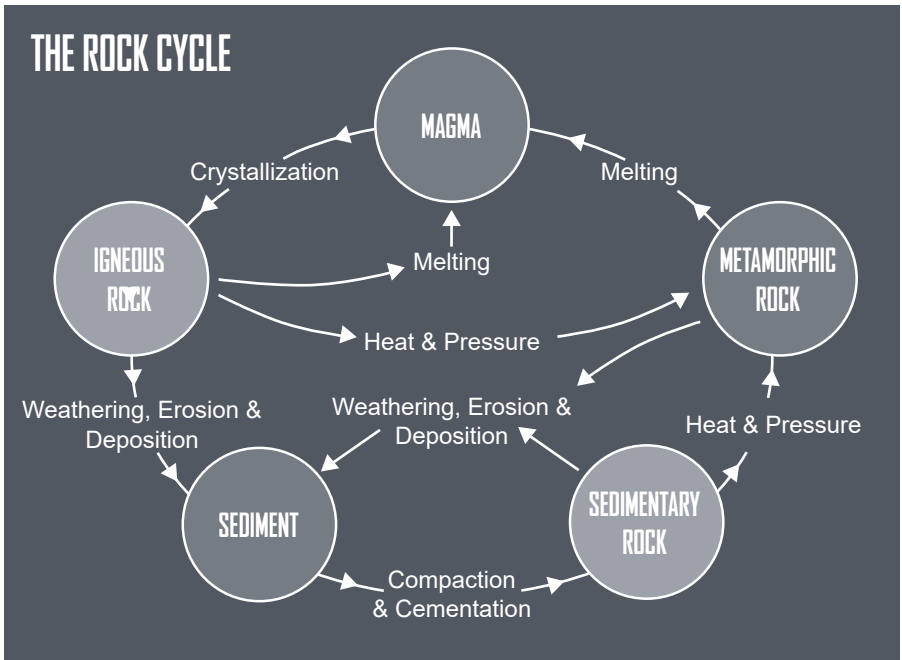
Often confused as being the same, weathering is the mechanical or chemical breakdown of rock by ice, water, and wind, while erosion is a similar process but involves transporting it elsewhere.

much finer grains. In general, coarser grained rocks are more abrasive to drill through than finer grained rocks.

### ROCK STRENGTH

Different from hardness, rock strength refers to its failure threshold when under load. A rock's strength will affect its ability to resist the following:

- 1. Deformation** - when a load is applied to any material, rocks included, it causes the material to change its volume or shape.
- 2. Fracture and Cracking** - if the load stresses the rock beyond its strength limit, it will crack and fracture.



## PLATE TECTONICS:

The Earth's crust is divided into plates that move across the mantle, in doing so they interact with each other in various ways. Plate tectonics help to explain volcanism and earthquakes when located at plate boundaries, as well as many of the other processes within the Rock Cycle that form, transform, and destroy rock.

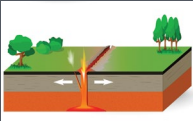
### PLATE INTERACTION:

#### Convergent Motion:



When two plates move towards one another. This could result in subduction, where one of the plates is forced under the other. Convergent motion can cause deformation and destruction of the Earth's crust, and lead to volcanism and earthquakes.

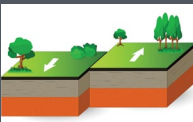
#### Divergent Motion:



Where two plates are moving away from each other. This activity

occurs mostly between oceanic plates, where molten rock rises from the mantle to the surface, solidifying to create new oceanic crust. Earthquakes are common along these boundaries.

#### Transform Motion:



Where two plates are moving alongside one another. Rocks

that line the boundary are pulverized as the plates grind along, creating a linear fault valley or undersea canyon. Earthquakes are common along these faults.

## FORCES THAT AFFECT THE MECHANICAL PROPERTIES OF ROCK

- 1. Compression** - the most common force at convergent plate boundaries and can cause rocks to fold or fracture as they are squeezed together. It can result in two plates coming together and rising to form mountains. Another possibility is one plate is forced under the other in a process called subduction, the plate that sinks is recycled back into the mantle.
- 2. Tension** - occurs as rocks are being pulled apart, as with divergent plate boundaries. The stress can cause rocks to lengthen, fracture, or even break apart. When plates on the ocean floor are pulled apart, the gaps could allow molten lava to rise, creating volcanic islands.
- 3. Shear Stress** - results when forces act parallel to each other but in opposite directions. Transform plate movement is an example and common stress found at boundaries. In contrast to convergent and divergent motions, the crust is cracked and broken, but not created or destroyed.

## ROCK HARDNESS

Scratch resistance is one way to describe the hardness of a rock and is the basis of Mohs Hardness Scale. Mohs scale is a qualitative value measured from 1 to 10. A lower value means that a mineral is easier to scratch (soft), and a higher value means that a mineral is difficult to scratch. A rock with a higher Mohs Hardness value will generally be slower to drill.

### HARDER THAN DIAMOND

Wurtzite boron nitride has a similar structure to diamond but is made up of different atoms.

wBN



## MOHS SCALE OF HARDNESS

There were ten minerals in the original Mohs Scale (shown below). However, because this scale was created back in 1812, it is no longer scientifically correct. For example, two naturally occurring, very rare minerals are now known to be harder than diamond.

Mohs Hardness is a measure of the resistance of a mineral to scratching. According to the scale:

- Talc is the softest - all other materials can scratch it.
- Gypsum is harder - it can scratch Talc but not Calcite, which is harder.
- Diamond is the hardest - it can scratch all other materials.

Rating	Mineral Example	Hardness Example
SOFTTEST (easiest to scratch)		
1	Talc	Baby Powder
2	Gypsum	Fingernail
3	Calcite	Concrete
4	Fluorite	Copper Penny
5	Apatite	Window Glass
6	Orthoclase	Steel Blade
7	Quartz	Granite
8	Topaz	Topaz
9	Corundum	Ruby
10	Diamond	Diamond
HARDEST (most difficult to scratch)		

The Mohs Hardness Scale may be a little outdated and not perfect, but many field geologists still find it very useful.

**LONSDALEITE** or hexagonal diamond is made from carbon atoms just like diamond, but they are arranged in a different shape making them harder than standard diamond.

## MOHS HARDNESS FOR COMMON MINERALS

Anhydrite	3 to 3.5	Magnesite	3.5 to 5
Apatite	5	Magnetite	5 to 6.5
Arsenopyrite	5.5 to 6	Malachite	3.5 to 4
Augite	5.5 to 6	Marcasite	6 to 7.5
Azurite	3.5 to 4	Monazite	5 to 5.5
Barite	2.5 to 3.5	Muscovite	2 to 3
Bauxite	1 to 3	Nepheline	5.5 to 6
Beryl	7.5 to 8	Nephrite	6 to 6.5
Biotite	2.5 to 3	Olivine	6.5 to 7
Bornite	3 to 3.25	Orthoclase	6 to 6.5
Calcite	3	Plagioclase	6 to 6.5
Cassiterite	6 to 7	Prehnite	6 to 6.5
Chalcocite	2.5 to 3	Pyrite	6 to 6.5
Chalcopyrite	3.5 to 4	Pyrophyllite	1 to 2
Chlorite	2 to 2.5	Pyrrhotite	3.5 to 4.5
Chromite	5.5 to 6	Quartz	7
Chrysoberyl	8.5	Rhodochrosite	3.5 to 4
Cinnabar	2 to 2.5	Rhodonite	5.5 to 6.5
Copper	2.5 to 3	Rutile	6 to 6.5
Cordierite	7 to 7.5	Serpentine	3 to 5
Corundum	9	Siderite	3.5 to 4.5
Cuprite	3.5 to 4	Sillimanite	6.5 to 7.5
Diamond	10	Silver	2.5 to 3
Diopside	5.5 to 6.5	Sodalite	5.5 to 6
Dolomite	3.5 to 4	Sphalerite	3.5 to 4
Enstatite	5 to 6	Spinel	7.5 to 8
Epidote	6 to 7	Spodumene	6.5 to 7
Euclase	7.5	Staurolite	7 to 7.5
Fluorite	4	Sulfur	1.5 to 2.5
Galena	2.5+	Sylvite	2
Garnet	6.5 to 7.5	Talc	1
Glauconite	2	Titanite	5 to 5.5
Gold	2.5 to 3	Topaz	8
Graphite	1 to 2	Tourmaline	7 to 7.5
Gypsum	1.5 to 2	Turquoise	5 to 6
Halite	2 to 2.5	Uraninite	5 to 6
Hematite	5 to 6.5	Vanadinite	3 to 4
Hornblende	5 to 6	Witherite	3 to 3.5
Ilmenite	5 to 6	Wollastonite	4.5 to 5.5
Jadeite	6.5 to 7	Zircon	7.5
Kyanite	4.5 to 7	Zoisite	6 to 7
Limonite	1 to 5		



# PERIODIC TABLE OF ELEMENTS

*Mining of elements is critical to our economy and essential in keeping our society functioning; they help us to meet our basic needs, be productive and remain safe and healthy.*

There were several earlier attempts to classify elements, but the modern Periodic Table was first proposed by Russian chemist Dmitri Mendeleev in 1869 to reflect recurring chemical properties. The elements are listed in order of increasing atomic number, its number of protons and electrons.

The importance of the structure is to group elements that behave similarly, e.g., metals are generally on the left and non-metals on the right. There are specific groups with convenient names, such as halogens and noble gases. Although Mendeleev could only arrange the 64 elements known at the time, through the brilliance of the structure he correctly predicted the existence of other elements.

H HYDROGEN 1.008																He HELIUM 4.0026																			
Li LITHIUM 6.941		Be BERYLLIUM 9.0122														B BORON 10.811		C CARBON 12.011		N NITROGEN 14.007		O OXYGEN 15.999		F FLUORINE 18.998		Ne NEON 20.180									
Na SODIUM 22.990		Mg MAGNESIUM 24.305														Al ALUMINUM 26.982		Si SILICON 28.086		P PHOSPHORUS 30.974		S SULFUR 32.06		Cl CHLORINE 35.45		Ar ARGON 39.948									
K POTASSIUM 39.098		Ca CALCIUM 40.078		Sc SCANDIUM 44.956		Ti TITANIUM 47.88		V VANADIUM 50.942		Cr CHROMIUM 51.996		Mn MANGANESE 54.938		Fe IRON 55.845		Co COBALT 58.933		Ni NICKEL 58.693		Cu COPPER 63.546		Zn ZINC 65.38		Ga GALLIUM 69.723		Ge GERMANIUM 72.63		As ARSENIC 74.922		Se SELENIUM 78.96		Br BROMINE 79.904		Kr KRYPTON 83.798	
Rb RUBIDIUM 85.468		Sr STRONTIUM 87.62		Y YTRBIUM 88.906		Zr ZIRCONIUM 91.224		Nb NIOBIUM 92.906		Mo MOLYBDENUM 95.94		Tc TECHNETIUM 98.906		Ru RUTHENIUM 101.07		Rh RHODIUM 102.906		Pd PALLADIUM 106.36		Ag SILVER 107.868		Cd CADMIUM 112.411		In INDIUM 114.818		Sn TIN 118.710		Sb ANTIMONY 121.757		Te TELLURIUM 127.6		I IODINE 126.905		Xe XENON 131.29	
Cs CESIUM 132.905		Ba BARIUM 137.327		La LANTHANIDES		Hf HAFNIUM 178.49		Ta TANTALUM 180.948		W WOLYBIUM 183.84		Re RHENIUM 186.207		Os OSMIUM 190.23		Ir IRIDIUM 192.222		Pt PLATINUM 195.084		Au GOLD 196.967		Hg MERCURY 200.592		Tl THALLIUM 204.383		Pb LEAD 207.2		Bi BISMUTH 208.980		Po POLONIUM (209)		At ASTATINE (210)		Rn RADON (222)	
Fr FRANCIUM		Ra RADIUM		Ac ACTINIDES		Rf RUTHERFORDIUM		Db DUBNIUM		Sg SEABORGIUM		Bh BOHRIUM		Hs HASSIUM		Mt MEITNERIUM		Ds DARMSTADTIUM		Rg ROENTGENIUM		Cf CALIFORNIUM		Nh NIHONIUM		Fl FLEROVIUM		Mc MOSCOWIUM		Lv LIVERMORIUM		Ts TENNESSINE		Og OGANESSON	

La LANTHANUM 138.905		Ce CERMIUM 140.12		Pr PRASEODYMIUM 140.908		Nd NEODYMIUM 144.24		Pm PROMETHIUM 144.913		Sm SAMARIUM 150.36		Eu EUROPIUM 151.964		Gd GADOLINIUM 157.25		Tb TERBIUM 158.925		Dy DYSPROSIUM 162.50		Ho HOLMIUM 164.930		Er ERBIUM 167.259		Tm THULIUM 168.934		Yb YTTERIUM 173.054		Lu LUTETIUM 174.967	
Ac ACTINIUM 227.028		Th THORIUM 232.038		Pa PROTACTINIUM 231.036		U URANIUM 238.029		Np NEPTUNIUM 237.048		Pu PLUTONIUM 244.064		Am AMERICIUM 243.061		Cm CURIUM 247.070		Bk BERKELIUM 247.070		Cf CALIFORNIUM 251.080		Es EINSTEINIUM 252		Fm FERMIUM 257.083		Md MEISENERIUM 261		No NOBELIUM 261.108		Lr LAWRENCIUM 260	

## ESSENTIAL ELEMENTS FOR HEALTH AND SAFETY:

- IRON, ZINC, and PHOSPHATE are crucial to the healthy crops we eat and help prevent nutritional deficiencies and diseases.
- NICKEL plays a vital role in food safety at every link in the food chain. It is also used in a wide variety of medical instruments and devices where the highest standards of hygiene and sterility are essential.
- COPPER is antimicrobial so hospitals integrate it into physical settings such as door handles and other exposed surfaces to help reduce the risk of infection. It is also essential to human health with its antioxidant, anti-carcinogenic, and anti-inflammatory properties.
- GOLD is used in drug therapies that treat malaria, HIV, arthritis, and cancerous tumors. It is also the world's most reliable and durable electrical conductor, essential for computer electronics and satellite communications.
- SILVER is found in virtually every electronic device. If it has an on/off button, it's likely that silver is inside. It is often added to water purification systems to help purify the water and control bacteria growth. Hospitals also leverage their antimicrobial properties to reduce bacterial contamination and prevent cross-infection.



# METALS THAT MAKE UP CLEAN ENERGY TECHNOLOGY

The transition to clean energy will be mineral intensive, requiring specific metals.

ENERGY METAL	Electric Motors	Solar Collection	Energy Storage	Carbon Capture and Storage	EVs	Nuclear Power	Solar PV	Light Emitting Diodes	Wind
Aluminum	●	●	●	●			●	●	●
Chromium				●		●		●	●
Cobalt			●	●	●	●			
Copper	●			●	●	●	●	●	●
Indium		●	●		●	●	●	●	●
Iron (Cast)								●	●
Iron (Magnet)	●								●
Lead						●	●	●	●
Lithium			●		●				
Manganese			●	●	●				●
Molybdenum				●		●	●	●	●
Neodymium					●				●
Nickel			●	●	●	●	●	●	●
Silver		●			●	●	●	●	
Steel (Engineering)									●
Zinc							●	●	
# of metals	3	3	4	7	8	8	8	10	11

Information Source: World Bank Group, The Growing Role of Minerals and Metals for a Low Carbon Future.



# THE CELLPHONE

The modern cellphone, or smartphone, exemplifies what can be done with the range of mined minerals. You may not feel emotionally attached to Bastnaesite and Sphalerite, but can you function without your device that allows for:

- Voice and text communications.
- Taking digital pictures and video.
- Reminders with a portable calendar.
- Online banking.
- Personal entertainment.



**Without mining, this and many other devices that make our existence a little easier would not exist.**

**IF IT'S NOT GROWN, IT'S MINED**

## DISPLAY

- A mobile device's glass screen is very durable because glass manufacturers combine its main ingredient, silica (silicon dioxide or quartz) sand, with ceramic materials and then potassium.
- Layers of indium-tin-oxide are used to create transparent circuits in the display. Tin is also the ingredient in the circuit board solder, and cassiterite is a primary source of tin.
- Gallium provides light-emitting diode (LED) backlighting. Bauxite is the primary source of this commodity.
- Sphalerite is the source of indium (for the screen's conductive coating) and germanium (for displays and LEDs).

## ELECTRONICS and CIRCUITRY

- The content of copper in a mobile device far exceeds the amount of any other metal. Copper conducts electricity and heat and comes from the source mineral chalcopyrite.
- Tetrahedrite is a primary source of silver. Silver-based inks on composite boards create electrical pathways through the device.
- Silicon, very abundant in the Earth's crust, is produced from the source mineral quartz and is the basis of integrated circuits.
- Arsenopyrite is a source of arsenic that is used in radio frequency and power amplifiers.
- Tantalum, from the source mineral tantalite, is added to capacitors to regulate voltage and improve the audio quality of a device.
- Wolframite is a source of tungsten, which acts as a heat sink and provides the mass for mobile vibration.

## BATTERY

- Spodumene and subsurface brines are the sources of lithium used in cathodes of lithium-ion batteries.
- Graphite is used for the anodes of lithium-ion batteries because of its electrical and thermal conductivity.

## SPEAKERS and VIBRATION

- Bastnaesite is a source of rare-earth elements used to produce magnets in speakers, microphones, and vibration motors.



# THE APPROACH

Exploration drilling is the foundation upon which a successful mine is built. It is also imperative in creating a safe mine, ensuring the slope in a surface mine is stable, and that ground support in an underground mine is sufficient.

# THE APPROACH

The Exploration geologist is responsible for identifying and assessing the location, quantity, and quality of mineral deposits. They will use a number of methods to accumulate the information necessary to determine the grade, estimated tonnage, and other extents of the deposit. The data collected can also be used to assess physical properties such as rock strength in and around the deposit, the presence of groundwater, and other information important to an engineering analysis to determine if the deposit can be mined at a profit.



## EXPLORATION METHODS

### 1. Geological Survey

A systematic investigation of the structure, composition, and relationships of rocks in a given area with special attention to the distribution, reserves, and potential recovery of mineral resources.

### 2. Geochemical Exploration

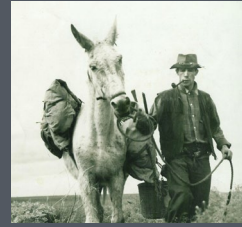
The search for economic mineral deposits through the detection of abnormal concentrations of elements in surface materials or organisms, usually accomplished by instrumental or quick techniques that may be applied in the field.

### 3. Geophysical Exploration

The examination of the physical property of rocks and interpreting the results in terms of geologic features to uncover or prove mineralization. The measurements may be taken from the surface, boreholes, or airborne or satellite platforms.

## PROSPECTING VS EXPLORATION

**Prospecting** refers to the search for mineral deposits and usually involves low-impact and non-mechanical activities, and generally without significant investment. However, prospecting is becoming more difficult and expensive as new mineral deposits become harder to find!



Despite the same objective, **Exploration Activities** tend to be more intrusive on the environment and surrounding community. It may require heavy machinery for road building, drilling and blasting, and because of this, Exploration programs normally have mandatory government regulations and concessions to comply with.



## GREENFIELD EXPLORATION SUBSTAGES

**Grassroots Exploration** is based on the conceptual ideas of a geologist about where a mineral deposit might be in previously unexplored areas or in areas where they are not already known to exist. They are considered risky and speculative, which makes it difficult to raise funding.

### CHARACTERISTICS

Lead time until mining	5-15 years of continuous activity.
Geologic risks	High, purely speculative efforts.
Land area	10,000 to 1,000,000 km <sup>2</sup>
Costs	Up to US\$10M
Economic risks/potential profit	The investment and financial risks are low, but so is the probability of success. The portfolio of projects must be managed.
Political risks, environmental and social impact	Low, this stage usually predates any significant environmental impact or involvement with surrounding communities.
Possible outcomes/studies	Target identification for next stage detailed examination or not.

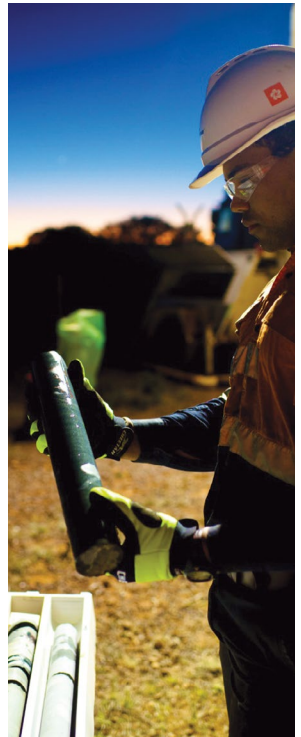
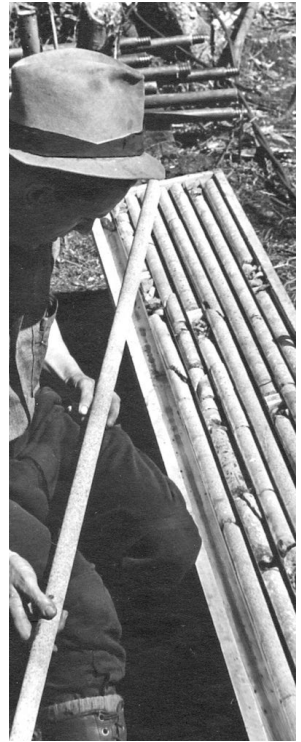
Activities: Desk studies, area selection, land acquisition, regional studies (geology, geochemistry, geophysics), preliminary community engagement.

**Advanced or Late Stage Exploration** have clearly defined mineral resources with reasonable prospects for being developed into a mine or satellite mines. These projects are generally positioned between the near pre-feasibility stage and the near bankable feasibility stage.

### CHARACTERISTICS

Lead time until mining	5 years of continuous activity.
Geologic risks	Potential mineralization exists but a more detailed evaluation is required to confirm the quantity and quality of the deposits.
Land area	1,000 to 10,000 km <sup>2</sup>
Costs	Up to US\$100M
Economic risks/potential profit	A larger investment is required although the resource is still unproven. The risk is medium and the number of projects must be restricted.
Political risks, environmental and social impact	Medium, drilling, road construction, etc, will have some environmental impact and require some community involvement.
Possible outcomes/studies	<ul style="list-style-type: none"> <li>- Scoping Study: Resource estimates, order-of-magnitude cost estimates, general idea of what a mine might look like.</li> <li>- Preliminary Feasibility Study: More detailed than scoping study and including revised resource estimates, preliminary mine design and engineering, and preliminary cost estimates.</li> </ul>

Activities: Detailed target evaluation (geology, geochemistry, geophysics), drilling, trenching, deposit delineation, preliminary metallurgy, collection of environmental and social baseline data, community engagement.

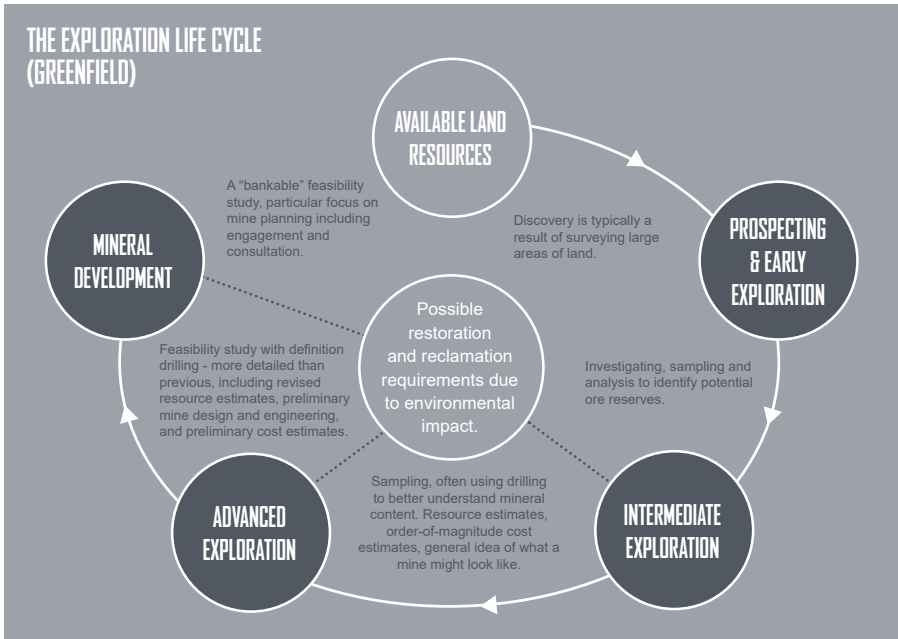


**Deposit Development** is when a full technical and economic assessment is carried out. Should a deposit continue to be attractive, a company will begin to apply for the permits and other approvals necessary to proceed with mining. A “bankable” feasibility study is a type of feasibility study that a company could take to a bank or other entity in its search for financing.

CHARACTERISTICS	
Geologic risks	Low, a clearly defined mineral deposit with reasonable prospects has been demonstrated.
Land area	100 to 1,000 km <sup>2</sup>
Costs	Varies, can be > US\$1B
Economic risks/ potential profit	A larger investment is required for this stage even prior to the “go/no go” decision to proceed to mining. If a company buys into a deposit at this stage, it will have to share the expected future profitability with the seller.
Political risks, environmental and social impact	Significant government involvement, impact on surrounding communities, and the environment. Many effects can be minimized and controlled, but some change is inevitable and permanent. Challenges include: <ul style="list-style-type: none"> <li>- Construction, mining, processing, waste disposal and tailings.</li> <li>- Potential influx of people and significant community change.</li> </ul>
Possible outcomes/studies	<ul style="list-style-type: none"> <li>- Applications for required permits and approvals.</li> <li>- Feasibility Study: Reserve estimates, mine and plant design, detailed engineering and cost estimates, full technical and economic assessment, financing.</li> <li>- “Go/no go” decision on mine development.</li> </ul>

Activities: Detailed drilling, mine planning, metallurgical testing, continued environmental assessment, continued community engagement.

**STATISTICS INDICATE THAT ONLY 1 IN 5,000 OR 10,000 GRASSROOTS EXPLORATION PROJECTS EVER REACH THE PRODUCTION STAGE.**



## BROWNFIELD EXPLORATION (EXPANSION)

### AT MINE SITE

This type of program is typically for ground evaluation prior to developing additional mine infrastructure and also for extending mine life.

### NEAR MINE SITE

Geologists look for deposits near or adjacent to an already operating mine where the risk is considerably lower than in Greenfield Exploration. Because the facilities for mining and processing the ore have already been built and paid for, the additional capital cost for processing the newfound ore is low.

A common regret is to find the next ore body below the crushing plant or waste dump - costly relocations could have been avoided with only one more Exploration hole.

.....

The Swedish mining town of Kiruna, and its 18,000 people, are moving 3 km (2 miles) east to not be swallowed up by the mine underneath. The relocation involves moving more than 20 historical buildings, including a 100 year-old church, to the new location by 2035.

Forward planning and modern drilling technology can help to avoid this in the future.



## UNDERGROUND VS SURFACE DRILLING

Underground drilling does have some advantages and some disadvantages over surface drilling, aside from the obvious view.

### 1 Logistics

There are challenges to get equipment underground. As a result, most underground drills are built modularly. Once down there, however, things get a little easier. Underground work is completed in an existing mine (Brownfield), thus things like water, air, and electrical power are typically provided right to the rig by the mine. For surface drilling, especially Grassroots, the contractor may have to bring in water which can add significant expense for remote projects.

### 2 Environment

An underground workspace can be more confining, but depending on the extent of the drilling, the heading is typically cut large enough to provide space to work efficiently. Also, working hours are often highly reduced, with no access during shift changes or blasting.

Some fundamental differences are:

- Temperatures: Underground mines are consistent year round with some being very hot. Surface mines can be different every season, and in every country.
- Noise: Usually it is only the rig noise, and the same PPE is used regardless of where the operation is.
- Air Quality: The biggest difference, especially if the drill is diesel powered. Ventilation is critical underground.
- Falling Rock: Mines make areas very safe for equipment and crew — this is not just an underground concern, rigs working close to high walls in open pit mines are also at risk.



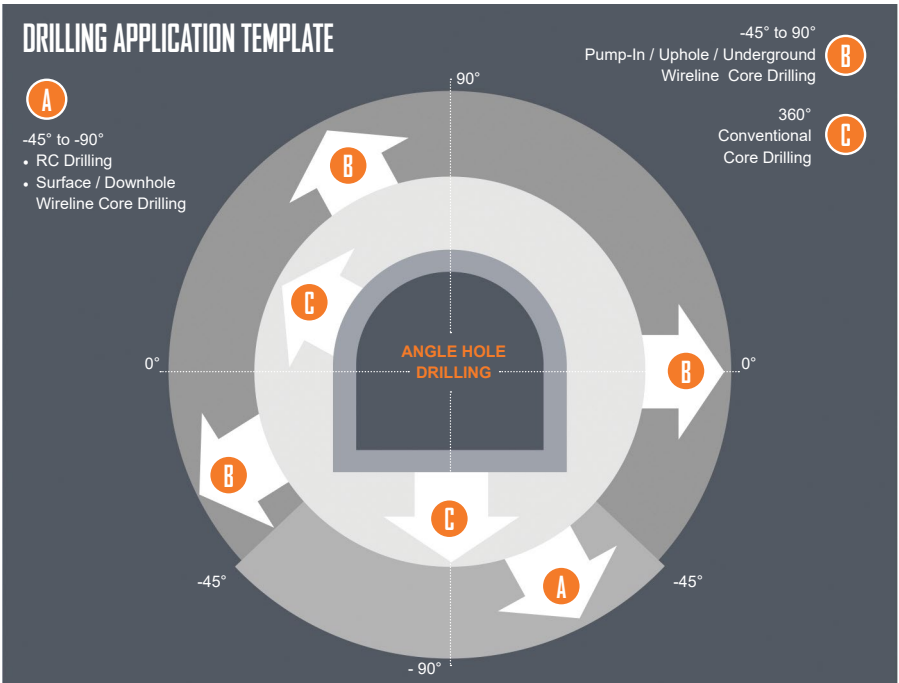
# SAMPLE RECOVERY

## WHAT IS THE BEST APPROACH TO EFFICIENT, SAFE, AND QUALITY SAMPLES?



### SELECTING THE RIGHT METHOD

Any decision to open or expand a mine hinges upon information, timely and with sufficient quality and quantity. That information largely takes on the shape of rock samples but there is no single “best method” of sampling. Each deposit has unique characteristics and, based on preliminary findings and lithology assessments, the next phase would be to set the project direction by establishing a drilling program to mechanically sample the area.



## DRILLING METHODS

Retrieving quality samples will depend strongly on the knowledge and expertise of the drilling contractor, as well as the tools and equipment selected. There are several methods available for sampling, but the two most popular methods are reverse circulation and core drilling.

### REVERSE CIRCULATION (RC)

RC drilling offers a cost effective method for getting preliminary data prior to a core drilling program. It provides a bulk sample of rock cuttings but says nothing about the rock structure. RC drilling is an excellent option for chemical analysis.

#### OPERATING GUIDELINES

Application	Normally surface but occasionally underground drilling.
Ground	Preferred, but not limited to consolidated formations.
Depth Capacity	800 m (2,600 ft) maximum
Hole Size	89 to 146 mm (3.5 to 5.75 inches)
Speed	Fast but will vary depending on ground conditions and depth of hole. - Typically 200 m (700 ft) per shift.
Accuracy	Directional control is limited even with bottom hole stabilizing assemblies.

#### ADVANTAGES

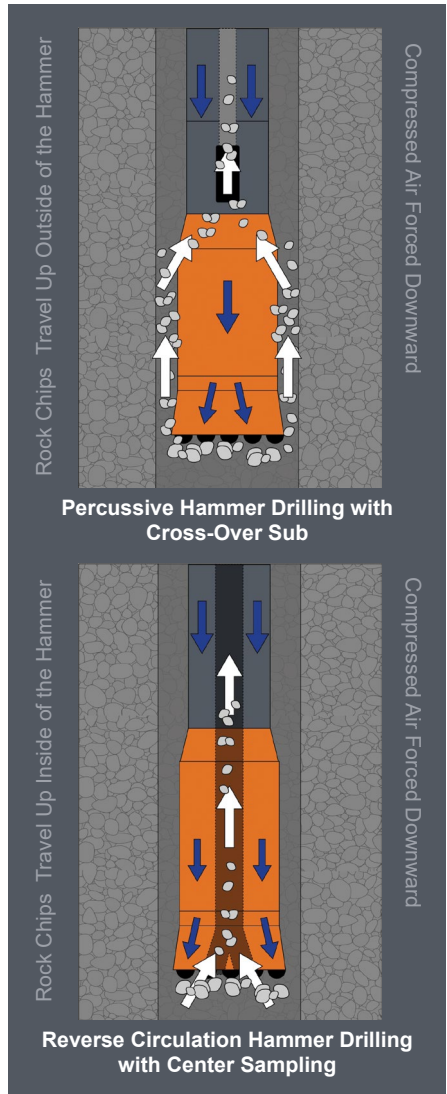
Requires less drilling fluid which makes it ideal in areas where water is scarce or expensive (Australia, West Africa, northern Canada).

Percussive action provides high rate of penetration for faster sample recovery.

The term 'reverse circulation' refers to how drill cuttings are flushed out of the hole. In most drilling, the cuttings are brought to the surface on the outside of the drill pipe; with reverse circulation the cuttings are forced into the drill pipe at the bit and transported out of the hole using air, water, or mud.

### RC HAMMER DRILLING OVERVIEW

RC Hammer Drilling is an extension of the conventional Down-the-Hole (DTH) Hammer Drilling method. Compressed air is used to power a piston that strikes



### RC ROTARY DRILLING

This method is a modification of traditional rotary drilling, where three studded rollers are used to break the rock using a heavier weight-on-bit. For RC, flushing is modified to reverse the flow of rock cuttings. RC Rotary may be preferable to RC Hammer drilling in unconsolidated ground, at high altitude, or with excessive groundwater.



## CHALLENGES OF RC DRILLING

- Drills are traditionally large, truck or track mounted machines, which make them unsuitable for remote work because of the costs associated with moving them to site.
- RC Hammer drilling suffers from deratings of both diesel engines and air compressors at high altitudes, requiring oversized engines or extra booster compressors.

Drill “pipe” or “rod” refers to similar tools; it is more of an industry preference as to which is used.

the drill bit. This percussive energy breaks the rock into cuttings that are blown to surface by the exhaust air. The difference is that with conventional DTH the cuttings exit the hole on the outside of the drill pipe.

RC is also known as “face sampling.” The key design feature is the center tube that carries cuttings from the bit face up through the hammer and drill pipe to the surface. This protects the sample from being contaminated by the surrounding rock in the hole. An extra tube inside the drill pipe is often referred to as a “double-wall pipe.” On the surface, cuttings are split with only a percentage kept to be analyzed by the geology team.



## CORE DRILLING:

Detailed information on concentration, or grade, is obviously a key criterion, but so are size and orientation of a mineral deposit. Mechanical properties of the host and surrounding rock will also play a role in the decision-making process as it helps to determine if the ore body is recoverable. To obtain all of this geological information actual rock samples (core) are required.

### OPERATING GUIDELINES

Application	Surface and underground, vertical up to vertical downholes.
Ground	All conditions, although core quality and recovery improves in consolidated formations.
Depth Capacity	4,000 m (13,000 ft)
Hole Size	Wireline: 46 to 122 mm (1.81 to 4.8 inches) Conventional: 46 to 267 mm (1.81 to 10.5 inches)
Speed	Slow steady speed, varies with ground conditions. Typical m (ft) per shift are 25 - 30 m (80 - 100 ft) for surface drilling and 60 - 70 m (200 - 230 ft) for underground.
Accuracy	With the use of wedging and other directional tools, coring holes can be quite accurate.

### ADVANTAGES

Extremely accurate representation of the rock lithology and with the assistance of positioning tools, provide accurate orientation and dip data that geologists, drillers, and engineers rely on for mineralization detail.

Drills can be compact or modular for easy transportation, including by helicopter.

No water table limitations.



## CORE DRILLING OVERVIEW

The drill string is rotated at high speeds and as weight or pressure is added, the diamond bit end cuts into the rock. As the drill string advances the cut rock (core sample) is collected inside a hollow cylinder known as a core barrel. When the core barrel is full, typically every 1.5 or 3 m (5 or 10 ft), it is retrieved and the core sample extracted. There are two versions of core drilling, conventional and wireline, and each has a unique set of components. The main differences between the systems are highlighted in orange on the right and include the drill rod, head assembly, and the addition of the overshot to the wireline systems.

### CONVENTIONAL CORE DRILLING

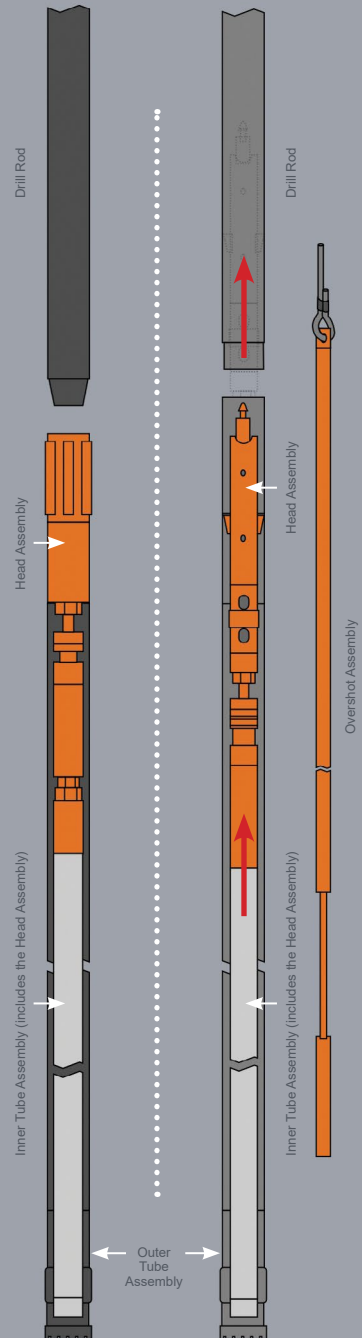
Conventional core drilling is cost-efficient for applications such as shallow hole investigation and geotechnical projects. It is typically used only for shorter holes because the entire string must be removed from the hole one rod at a time to retrieve the core sample. The process is reversed, returning the drill string to the hole to resume drilling.

### WIRELINE CORE DRILLING

Designed so that the drill rod connects to a core barrel outer assembly instead of the head assembly, as with the conventional system. This allows the driller to retrieve an inner core barrel assembly filled with core through the center of the drill string with the assistance of an overshot device. The overshot is sent down the hole and locks onto the head assembly. The other end of the overshot is connected to the surface by a wireline cable which is used to hoist the device and the inner assembly each core run. This offers significant time savings and is why this method is the dominant choice.

The only time the entire drill string needs to be pulled from the hole is to replace the diamond tools, or if there is a problem down the hole.

## CONVENTIONAL VS WIRELINE DRILL STRING



## CORE DRILLING CHALLENGES:

- Drilling is restricted by the length of the tube which receives the core. If ground conditions permit, however, multiple tubes can be assembled to extend the core run.
- A diamond bit must be cooled during the drilling process, thus drilling is dependent on a continuous supply of drilling fluid.
- Wireline drilling requires the inner tube assembly to be securely locked into position to receive the core. It also needs to be easily unlocked each time the core is retrieved.
- Highly engineered drill rod threads require proper care and handling to be able to withstand the stresses of drilling.

Core Drilling is commonly referred to as Diamond Core Drilling or Diamond Drilling because of the diamond bit at the end of the drill string.



## THIN WALL OPTION

Conventional and wireline versions are available. These systems have been optimized to allow for a larger core sample while retaining the same hole size. As a result, the components with thinner walls have limited durability and should only be used in consolidated ground conditions.

## TRIPLE-TUBE OPTION

Conventional and wireline versions are available. A second inner tube called a liner or split tube is placed inside the standard inner tube to retain the core in its received state. This allows for easier loading of the sample into trays. Ideal for core recovery when drilling coal, clay bearing, or highly fractured formations.

## DECODING CORE SAMPLE SIZES

Given a desired target zone, typically the ground or 'formation' dictates a minimum size of core sample for productive operations, which must be balanced against limitations in available drill power, schedule, and cost that limit the maximum size of hole.

## INFLUENCING FACTORS FOR SYSTEM SELECTION:

**Surface vs Underground Operations:** All sizes are found in both surface and underground drilling programs, but there is a bias towards the larger 'H' size on surface, while 'N' is the most common underground. The driver is practicality, not geological, since rods and core are manually handled underground. As automation increases, 'H' could potentially become the preferred choice underground as well.

**Drill Site Location:** Heli-portable drills may be necessary for remote locations, but even the smallest drills of today can utilize 'N' and 'H' systems for shallow holes. Deeper holes may dictate the use of smaller systems due to the drill's pullback capability.

**Ground Conditions:** If the key objective is to get the largest core sample from the smallest hole possible, thin kerf would be the preferable system over standard. The competence of the rock, however, plays a significant role in choosing which of the systems are used. Broken or unconsolidated ground can cause issues with thin kerf components. Therefore, it is recommended to use the standard kerf systems.

As a general rule, the more difficult the ground conditions, the larger and more costly a system is required to drill efficiently and recover core successfully. It's common to upsize from 'N' to 'H' size

if ground conditions dictate, but 'P' only when 'H' is proven not to work.

**Borehole Depth:** Machine capability may dictate a hole size to full depth, with pullback becoming a limitation before rotation torque. It may be necessary to telescope drill, starting the hole with a larger size system and then switch to a smaller system as the hole gets deeper.

**Mineral Type:** Base metals are biased towards 'H' with precious metals and gold towards 'N'. Coal exploration slants towards 'H' and 'P' to collect more bulk for evaluation.

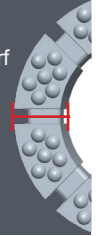
**Mineral Grade:** For very low mineral concentrations, larger samples such as 'H' are typically used. This is common when concentrations of the mineral in question may be low per tonne of ore. A 'P' sized system may sometimes be

used to bulk sample an area for process evaluation.

**Budget:** Smaller coring systems slightly reduce drilling cost, thanks to higher penetration rates and lower costs for consumables.

**Established Practice:** Whatever standards are established on a site to manage core samples is usually maintained for consistency. This can make it impractical to switch to another coring system size.

**KERF:** Refers to the surface area of the bit that cuts the rock. Thin kerf and smaller diameter systems cut less rock, therefore have a higher penetration rate. A thicker kerf bit is more robust and improves hole straightness.



## CORING SYSTEMS

System	Hole Size Ø		Core Size Ø		Where Used (Applications and Ground Conditions)
	mm	inch	mm	inch	
A Thin Wall	48	1.875	35.5	1.375	Smallest drills and shallow holes, typically underground.
B	60	2.375	36.4	1.167	Used primarily underground.
B Thin Wall	60	2.375	40.7	1.625	Mixed use, but more common underground in consolidated ground conditions.
N Triple-Tube	75.7	2.980	45	1.375	Used in very unconsolidated, broken ground conditions where obtaining a core sample in its original state is difficult.
N Conventional Triple-Tube	75.7	2.980	45.0	1.375	Shallow holes in unconsolidated, and broken ground conditions. Typically underground.
N	75.7	2.980	47.6	1.875	Very common in Greenfield Exploration or Brownfield Expansion. Usually the default choice underground.
N Conventional	75.7	2.980	47.6	1.875	Shallow holes, typically underground.
N Thin Wall	75.7	2.980	50.6	2.00	Preferred in highly competent rock.
N Conventional Thin Wall	75.7	2.980	50.6	2.00	Shallow holes in consolidated ground conditions. Typically underground.
H Triple-Tube	96	3.375	61.1	2.375	Used in very unconsolidated, broken ground conditions where obtaining a core sample in its original state is difficult.
H Conventional Triple-Tube	96	3.375	61.1	2.375	Shallow holes in unconsolidated, and broken ground conditions. Typically underground.
H	96	3.375	63.5	2.50	Very common in both Greenfield Exploration or Brownfield Expansion. The default choice on surface or in broken ground.
H Conventional	96	3.375	63.5	2.50	Shallow holes, typically underground.
P Triple-Tube	122.6	4.875	83	3.25	Used in very unconsolidated, broken ground conditions where obtaining a core sample in its original state is difficult.
P	122.6	4.875	85	3.375	Used only when necessary in deep holes where size is reduced at depth, or where bulk samples are needed.



## DRILLING FLUIDS

As the challenge increased to overcome difficult and deeper boreholes, improvements in technology have been made, including more efficient and effective drilling fluids. Drilling fluids (or muds) are essential to the drilling process and success by maximizing recovery and minimizing the amount of time.

While the technology and chemistry of drilling fluids have become much more complex, the concept remains the same. Drilling fluids are added to the borehole to facilitate the drilling process including:

**Suspending Cuttings:** During the drilling process cuttings are created and carried up to the surface as waste by way of drilling fluids. The fluids are pumped into the borehole and through the drilling system.

Drilling fluids can also prevent the cuttings from settling back down to the bottom of the hole if drilling is stopped. In this instance, the viscosity of the drilling fluid changes when the activity changes, i.e., while drilling the fluid is a liquid consistency, but then turns into a more solid substance when drilling has stopped. Cuttings are suspended in the hole until drill starts up again and the “gel-like” substance transforms back into a liquid.

**Controlling Pressure:** Drilling fluids help to control pressure by offsetting the pressure of the rock formations. Weighing agents are added to the drilling fluids to increase its density and, therefore, its pressure on the walls of the borehole.

**Stabilizing Exposed Rock:** Special additives can be added to the drilling fluid to ensure it is not absorbed into rock formation, and that it stays within the borehole for drilling purposes.



Adding Sodium Bentonite to drilling fluids will create a mud slurry.

## ORIGINS OF DRILLING FLUIDS

The Chinese were using drilling fluids as early as the third century BCE, in the form of water, to help permeate the ground when drilling for hydrocarbons.

The term “mud” was coined in the US. Drillers would run a herd of cattle through a watered-down field and then use the resulting mud to lubricate the drill string.

## ENVIRONMENTAL IMPACT OF DRILLING FLUIDS

Environmental implications are minimal as long as they are used responsibly. Read the Safety Data Sheets carefully to make well informed decisions on drilling fluid usage, safe handling (PPE), and disposal.

Settling tanks or a centrifuge can be used to help remove cuttings (solids) from the drilling fluid. The cuttings are then hauled offsite and disposed of at different facilities depending on the rock typed drilled. This practice allows the drilling fluid to be recycled and reused which can be very cost effective, especially in remote conditions.

**Providing Buoyancy:** The addition of drilling fluids add buoyancy which assists with waste cuttings to be carried out of the hole. As the borehole becomes deeper, buoyancy can also aid in the reduction of significant stress on the drilling equipment, as well as the drill rod joints.

**Cooling and Lubricating:** Drilling fluids help to reduce friction with the rock formation, reducing heat. This lubrication and cooling are essential in prolonging the life of the drill bit.

## TYPES OF DRILLING FLUIDS

Drilling fluids are composed of water, oil, or synthetic based materials and each composition provides different solutions in the borehole.

Some drilling programs employ a drilling fluid engineer who is responsible for the drilling fluid composition. In addition to considering the chemical composition of the drilling fluid and properties of the borehole, this individual must also take into account the environmental impact, e.g., oil-based drilling fluids may work better with a saltier rock however, water-based drilling fluids are generally

considered to affect the environment less.

- **Soda Ash:** Used to increase pH of water from 7 to 9 allowing Gel (Bentonite) to mix easier.
- **Gel:** Used to help keep the hole from caving in and increases mud weight keeping water out from formation. Suspends cuttings and increases cutting carrying capacity.
- **Pac R:** Increases viscosity and helps control fluid loss. Also firms up wall cake created by gel, decreasing differential sticking.
- **Liquid Poly:** Increases viscosity with minimal quantities, reduces torque on the drill string, and decreases clay swelling. Also used in slobber tank to prevent rod vibration in dry holes.
- **Lost Circulation Material (LCM):** Includes materials that help seal off small fractures in the borehole wall, preventing the loss of costly drilling fluids into the surrounding rock formation. Cedar fibers, crushed walnut shells, and cotton seed are sometimes used to seal up larger fractures.

## DRILLING FLUID CIRCULATION

The positive displacement pumps typically used on Exploration drills pump fluids in proportion to how fast they are spinning; the faster they spin the more they pump. The amount of fluid pumped will be nearly the same over a very large pressure range. For this reason, the fluid pressure does not tell the driller anything about how much fluid is flowing.

Two methods of calculating fluid flow include:

**1** Measure the fluid pump shaft rpm with a tachometer, and compare the measured shaft speed with the maximum speed listed on the information plate on the

drill. If the shaft speed is half of the maximum speed, then the fluid pumped will be half of the listed flow at maximum speed.

**2** Disconnect the outlet hose and run it into a 20 ℓ or 5 gallon bucket and time how long it takes to fill. The flow rate is equal to the time in seconds divided by 60 and multiplied by either 20 ℓ or 5 gallons.

.....

High penetration rates require additional flow to keep cuttings off the bit face, as do higher rotation rates. There is no maximum fluid flow rate, though at high pressure and flow rates, a bit can be lifted off the rock face, causing it to polish due to insufficient weight on bit (WOB).



## DIRECTIONAL DRILLING

Directional drilling has a long history in the oil and gas industry and is increasingly being used in mining thanks to technological advances that have made steering tools more feasible for mining equipment.

This technique helps the driller overcome environmental challenges, including reaching a target zone under a bench or other geological feature that would be inaccessible with vertical drilling practices, or drilling into a deep mineral zone covered by rock that would make drilling multiple surface holes difficult and dangerous.

Compared with traditional coring, directional drilling can provide greater mineral production from one hole and save significant time and costs by controlling the trajectory of the borehole. Safety and environmental benefits can be realized as well by not moving drill rigs to new sites and drilling multiple surface holes.

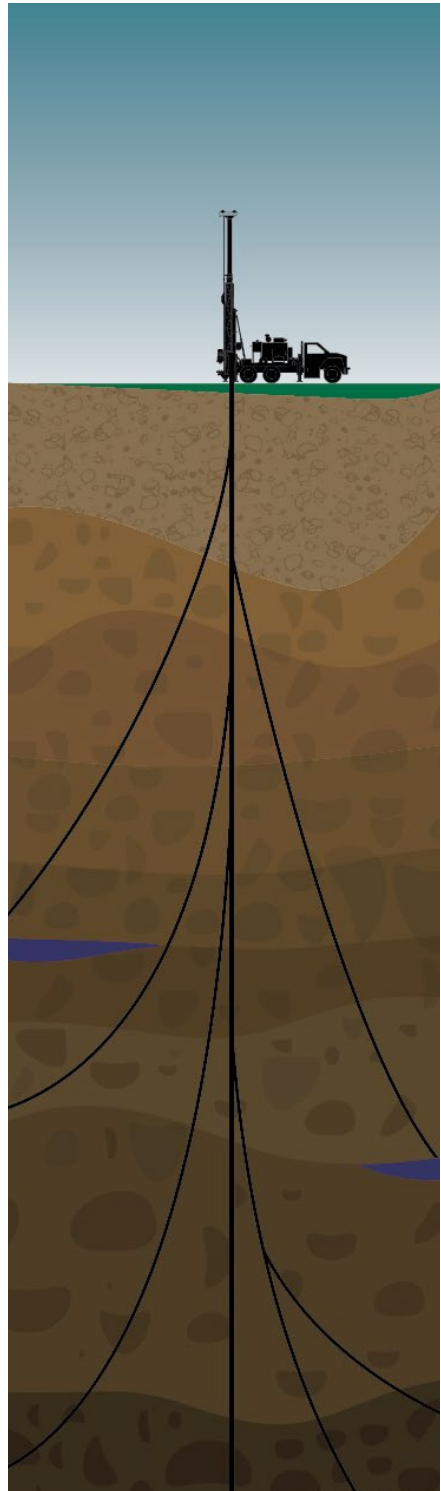
### COMMON TERMS

**Vertical Borehole:** A “straight” hole close to vertical - 1.5 to 3 degrees from the vertical line is usually accepted as “vertical.”

**Main (Parent) Borehole:** The borehole drilled first in a formation or target. Often, the term “mother” or “mother borehole” is used.

**Directional Borehole:** A borehole whose trajectory has been designed and consciously directed to reach a zone of interest. The smaller the diameter, the greater the deviation capability. It is not recommended for ‘H’ or ‘P’ sized coring systems or with casings.

**Borehole Branch:** Describes that portion of a borehole initiated from a point along the main or mother borehole path. Often referred to as a “daughter borehole.”



**Multi-lateral Borehole:** Describes a borehole with a single collar at the surface and several branches drilled from the main borehole. Multi-lateral drilling is a highly efficient technology in deep drilling projects to explore ore body targets and surrounding rock conditions.

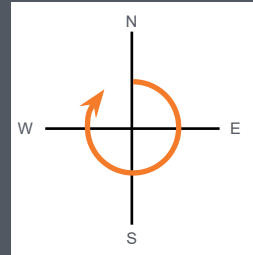
**Azimuth:** The angle, in the horizontal plane, between North and the projection of the tangent to the borehole axis at the point of measurement. In the drilling industry, it sometimes means direction or heading, while drift is occasionally used. Borehole azimuth is usually specified in degrees with respect to the geographic or magnetic North pole. By industry convention azimuth is typically measured clockwise from North, 0° azimuth coincides with North, 90° azimuth with East, 180° azimuth with South, and 270° azimuth with West.

**Inclination/Dip:** In diamond core and oil and gas drilling, these terms are often interchangeable. Inclination is the angle of the borehole defined by a tangent line and a vertical line. Dip is the magnitude of the inclination of a plane from horizontal. This means that the sum of inclination and dip angles is always equal to 90°.

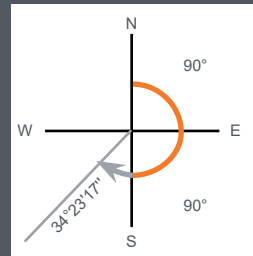
**Depth:** The measured depth is the borehole length measured along the borehole axis. This measurement differs from the true vertical depth of the borehole.

## AZIMUTH

Azimuth will always start at North and turn clockwise with angles between 0° and 360°.



### Calculating Azimuth:



Azimuth = 218°23'17"  
(90°+90°+34°23'17")

## IMPORTANCE OF DIRECTIONAL CONTROL

When planning drill holes, there are two typical patterns, either Arbitrary Hole Location or Systematic Grid.

Arbitrary Hole is typical of the Exploration stage. The use of representative structure and lithological environments greatly increases the probability of discovery with a minimum amount of drilling. In this scenario, deviating holes can have drastic consequences - averaging just 0.5° of deviation over 1,000 m (3,300 ft) would place the hole 9 m (30 ft) off at target depth. In a narrow vein deposit, this could mean missing everything of interest.

In development/grid drilling better sample distribution over a given area can be achieved for a more accurate model of

an ore body. Inaccuracy, however, can result in a distorted interpretation of the actual ore configuration and grade distribution. Deviation in this instance will reduce the value of the drill hole even if the consequences are not as severe as in geotechnical drilling.

Deviation Guidelines - max. degrees per rod length\*

ARQ™TK	2.0
BXQ™/ BRQ™/ BRQ™TK	1.5
BQ™	1.2
NXQ™ W-Wall™/ NRQ™/ NRQ™ W-Wall™	1.0
NQ™	0.8
HXQ™ W-Wall™/ HRQ™/ HRQ™ W-Wall™	0.8

HQ™/PHD & PHD W-Wall™ - not recommended

\* Reduce deviation for excessive pullback applications, e.g., deep holes



## CORE INFORMATION PROCESSING

The importance of knowing exactly where the sample is collected is self-evident, but geologists can also infer more information about the potential ore body if they know the structural orientation of faults and ore bearing zones.

HIGH ACCURACY INCREASES THE VALUE OF THE CORE SAMPLES AND SHOULD THEREFORE BE ONE OF THE MAIN CRITERIA ALONG WITH SAFETY AND EFFICIENCY, BEFORE DRILLING EVEN COMMENCES.

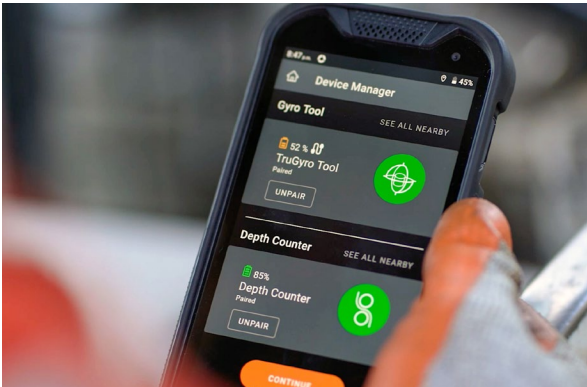
## LOCATION ACCURACY

Two aspects:

- 1 Three-Dimensional Hole Path Data Tracking  
Azimuth and Dip
- 2 Core Orientation

## Instrumentation

- Instrumentation using magnetometers and gyroscopes are used to track both the hole and the core barrel.
- Establishing True North requires careful calibration to eliminate magnetic disturbances, such as the drill rig itself.
- Gyroscopic tools must be practical to use, providing frequent measurements, long battery life, good ergonomics for reading core orientation, and reliable data transfer.
- To reduce the risk of mistakes, core orientation marks are best read without having to disassemble the core barrel.



Boart Longyear's TruGyro™ can help you achieve your drilling project objectives by delivering accurate, industry-leading surveys that inform drilling decisions and provide context to valuable geological data.

## TOTAL CORE RECOVERY

Resource estimation and JORC compliance depend heavily on the quality of core samples collected. Advanced software models and application of sophisticated statistical techniques cannot correct for poor deposit data. As a result, it is imperative that both the quality and quantity of core samples be maintained during drilling. Core loss is relatively common, so it is recommended that total core recovery (TCR) is a minimum of 85% and preferably above 90%.

Losing core or having it badly disturbed during sampling can create significant issues for geologists:

- Depth estimation.
- Accurately calculating the overall grade of ore, and volume of ore to weight of ore.



## SPEED AND DECISION MAKING

### *Assaying of core samples onsite informs real-time decision making.*

The delay between drilling and receiving assay results through off-site testing can take up to 6-8 weeks. This typically involves a lengthy process whereby core samples are labeled, boxed and shipped for off-site destructive testing. Advances in technology have enabled same-day assay results based on concentration data obtained through X-Ray Fluorescence (XRF) scanning, a non-destructive method to map the chemical composition of core samples or chips at the drill site. At the same time, integrated professional photography systems consistently capture high resolution images for retention and further processing of structural information.

When geologists have access to immediate results, real-time decisions on drilling, borehole direction, or starting a new hole are possible. Immediate results also enable targeted sorting of the best samples to submit for further analysis vs. samples that must simply be stored. Since the cost for geochemical testing is similar to the total cost of drilling, having quality information for optimal sample selection is time-critical and an opportunity for major cost savings.

Onsite assaying allows geologists to build accurate conceptual geological models based on the output concentration of target elements and structural information all while the drill is still on the borehole

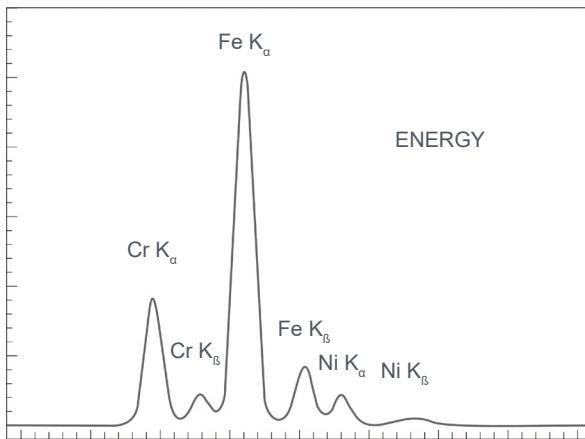


## WHAT IS XRF

X-Ray Fluorescence is effectively the opposite of medical X-ray images. While medical X-rays show what is transmitted through an object, XRF identifies what is absorbed and subsequently radiated back.

When energy is absorbed from X-rays, electrons are ejected or elevated to a higher orbit. Fluorescence is when the electrons return to their natural state, and in doing so emit their own rays. Since every atomic element has a unique number of electrons in different orbits, each element has its own emission signature. By analyzing the fluorescent spectrum, it is possible to tell gold, copper, nickel, and other elements apart.

The outcome from XRF analysis is not an image, but rather a chart with different peaks showing the presence and relative amount of each element.



This shows the XRF spectrum of a steel sample, showing the relative amounts of Iron, Chromium, and Nickel.

XRF is a fast, accurate, and proven technology and hence suitable for use in the mining industry. However, it only measures the surface of the sample, so it is not a substitution for bulk chemical analysis. Nor does it detail in what forms or compounds the elements exist. For example, detecting copper in mineable concentrations is only the initial step; to design the downstream processing you must know more.

In one case, XRF may report 2% copper, but it doesn't automatically say if it's in the form of an oxidized mineral such as Zurite ( $\text{Cu}_3(\text{CO}_3)_2(\text{OH})_2$ ) or a sulfide mineral such as Chalcopyrite ( $\text{CuFeS}_2$ ). The answer fundamentally changes how you later extract the copper.

## DISCOVERY OF X-RAYS

Light comes in a very broad spectrum, of which only a narrow band is visible to the human eye.

During an experiment in 1895, German physicist Wilhelm Röntgen accidentally discovered some invisible rays that could penetrate solid materials to expose a photographic plate. Lacking any explanation of what this light was, he called them X-rays.

Within weeks, his wife "volunteered" as the first human subject in an image dubbed "Hand with Rings."

While the medical use of this may be more recognized, a miner's eye goes to the gold!



# THE TOOLS

Successful Exploration, including the optimization of wireline drilling, requires a purposeful selection of the right tools. Specifically, this includes coring rods, diamond products, and wireline systems.

Per drilled meter, core drilling is about one order of magnitude more expensive than blasthole drilling, highlighting the operational challenges, technical demands, and opportunities for good decisions in tools selection.

# THE TOOLS

## CORING RODS



In terms of investment, the coring rod is the biggest tooling decision. Rods may appear simple, but they are highly engineered products.

Wireline drill rods serve multiple purposes: support drilling forces, conduct flushing/cooling media, and allow for core retrieval. They are also exposed to several forces - compressive near the drill bit, tensile near the top of the drill string (for downholes), twisting along the full length, and bending in any curves. Wear, fatigue, corrosion, and handling add to the accumulated damage exposure.

Holes with an excess of 1,000 connected rods illustrate how a chain is only as strong as its weakest link. Regardless, rods are wear-items and it's beneficial to understand how all the parameters affect failure modes and total rod life.

## VARIABLE WALL ROD

Most coring rods have a straight wall, i.e., are made from a tube with the same thickness along the full length. In deep holes, the load bearing capacity is limited by the combined weight of the rods.

Having full wall thickness at the joint is required as the thread determines the joint strength, but reduced thickness in the midbody can significantly reduce the full string weight and improved wireline tripping speeds.

Modern rods exist with a variable wall, and the benefits are fivefold:

- 1 More internal space for faster wireline speeds.
- 2 Less weight increases total depth capacity of the rods.
- 3 Less weight also increases the depth capacity of the drill rig.
- 4 Increased flexibility when drilling curved holes reduces stresses on the rod threads.
- 5 Easier manual handling for improved safety.



# NOMINAL TUBE WEIGHTS AND MEASURES

Systems	Midbody Outer Diameter		Midbody Inner Diameter		Rod Weight per Unit Length		Rod Content Weight per Unit Length (water)	
	mm	inch	mm	inch	kg/m	lb/ft	l/m	gal/ft
ATK Drill Rod	44.7	1.76	37.5	1.47	3.60	2.40	1.10	0.09
AW Casing	57.1	2.25	48.4	1.91	5.67	3.80	1.84	0.15
B Drill Rod	55.9	2.19	46.1	1.81	6.26	4.20	1.67	0.13
BTK Drill Rod	55.8	2.20	45.4	1.91	4.80	3.20	1.84	0.15
BW Casing	73.0	2.88	60.3	2.38	10.43	7.0	2.86	0.23
N Drill Rod	69.9	2.75	60.3	2.38	7.80	5.20	2.86	0.23
NW/NWT Casing	88.9	3.50	76.2	3.00	12.80	8.6	4.56	0.37
H Drill Rod	88.9	3.50	77.8	3.06	11.50	7.7	4.75	0.38
HW/HWT Casing	114.3	4.50	101.6	4.00	17.40	11.70	8.11	0.65
P Drill Rod	114.3	4.50	101.6	4.00	17.40	11.70	8.11	0.65
PW/PWT Casing	139.7	5.50	127.0	5.00	21.43	14.40	12.67	1.02

Standard METRIC straight wall rod and casing lengths include 1.5 m and 3.0 m.

Standard IMPERIAL straight wall rod and casing lengths include 2 ft (starter rod), 5 ft, and 10 ft.

## PERFORMANCE PARAMETERS

Rods are designed with three sections - threaded box end, mid-section, and threaded pin end. A number of parameters decide the performance of a core drilling rod, in particular:

- Raw Material
- Heat Treatment
- Thread Geometry
- Manufacturing Accuracy or Quality Control driving consistency

### RAW MATERIAL

Unlike blasthole drill rods, where the box and pin ends are welded to the mid-section, coring rods are manufactured

from a single piece of tubing so that the inside bore is smooth, allowing for the wireline system to pass unimpeded. The tube used is produced in two different ways:

- 1 Welded**  
Starts with flat sheets of steel that are rolled and welded to form a tube. Generally have a more consistent wall thickness.
- 2 Seamless**  
Extruded by pushing heated steel over a mandrel to form a tube without a welded joint. Have a more uniform chemical composition.

Heat treatment can be used on welded rods to minimize differences in material structure due to welding but there is no correction for wall thickness variation and concentricity in seamless tubing.

### CONCENTRICITY

A uniform wall thickness contributes to better concentricity. Variations can misalign the threads during manufacturing and cause severe vibration during high rotational drilling speeds.

- A welded tube can maintain <2.5% variation in wall thickness while a seamless tube can have 3x that variation.

### STRAIGHTNESS

Rods are straightened to a maximum deviation of 1 mm per 3 m (1/32" per 10 ft) length after manufacturing using specialized machinery.



The exact composition of the low alloy steel used in the manufacture of the tubes varies between suppliers. The content of carbon and other more expensive elements will determine what properties can be delivered in the final product. Chemical composition of the raw material drives the possible combinations of strength, hardness, wear resistance, and fatigue life of the commercial rod.

## HEAT TREATMENT

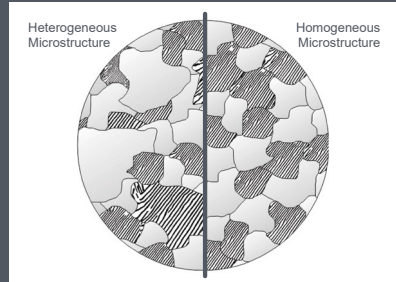
Steel goes through various heating and cooling cycles to give it the desired properties for superior performance. To simplify, higher hardness increases wear resistance and wear life. But lower hardness increases toughness and resistance to cracks. The properties given to coring rods is a deliberate compromise based on experience, metallurgical expertise, and statistical tracking of performance in the field.



Besides hardness and toughness, another goal of heat treatment is stress relief. In manufacturing, residual stresses are built into the material which, unless relieved, will reduce the maximum operational load. The highest quality rods go through multiple heat treatments, resetting material properties after making the tubes, eliminating residual stresses, and fine tuning the wear resistance and toughness properties after final manufacturing.

## TERMS USED IN HEAT TREATMENT

**NORMALIZING:** The process of heating steel prior to cold drawing, and letting it cool down to room temperature in air. This causes recrystallization of all grains in the steel. This “resets” the steel; all residual stresses disappear.



**ANNEALING:** The heat treatment that normally follows any cold working, such as cold drawing or straightening. Annealing restores the elasticity or the full yield strength of the material.

**QUENCHING:** The rapid cooling, in water or oil, after heating above the recrystallization temperature. This causes a fine-grained structure that is excessively hard and brittle.

**TEMPERING:** Quenching is almost universally followed by tempering. This involves heating to a temperature below recrystallization and in a controlled way to reduce the brittleness and get a specific balance between strength, hardness, and toughness. Tempering dials in the exact properties of coring rods.

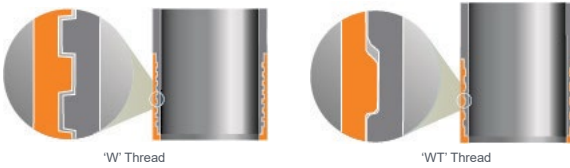
**CASE HARDENING:** To address the issue of galling, some manufacturers have adopted this process to harden the pin thread of core drilling rods. The process involves the rapid heating and quenching of the finished product so that only the surface of the steel is affected, producing a wear resistant surface above a tough core.



## CASING

Wireline drill rods are designed to nest inside casing; e.g., N wireline rod will nest into NW or NWT casing. The casing provides support for both the nested rod and the borehole (borehole collar). Unlike drill rod, casing is not subjected to significant stress, therefore the material, manufacturing processes, and threads are much less complicated.

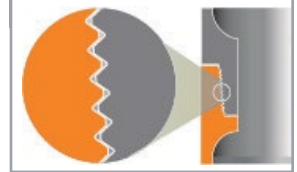
- 'W' thread is a simple double-butt joint thread used in easier drilling applications where casing is to be left in the ground.
- 'WT' thread is an engineered tapered thread for increased strength in more challenging applications, and where the casing is pulled out and used multiple times.



## CONVENTIONAL RODS

Unlike their successor, the wireline drill rod, conventional drill rods have a pin and box end welded to a mid-section making the inner diameter incompatible with wireline coring.

Their v-style thread known as WJ is simple and easy to thread together. Typical rod sizes include AWJ, BWJ, and NWJ.



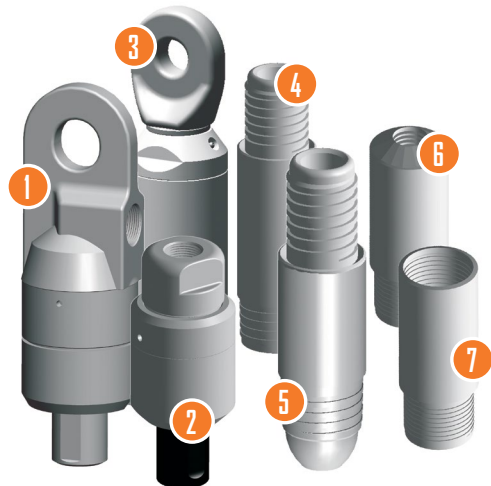
## ROD STRING ACCESSORIES

No rod string is practically usable without various connectors. Common categories are water swivels, hoist plugs, and adapter subs, but there is a wide range of specialty connectors with associated tools and components. Some have specialty functions and are used rarely. Others are always used and serve as “sacrificial” wear components. Which ones are needed depends on the application and the type of drill rig, in particular whether it has top or chuck drive.

Every thread type and size of rod or casing requires its own set. One adapter sub particularly useful to have available is the “blank”, it has the defined thread in one end while the other can quickly be machined to whatever is needed.

### Examples of Accessories

- 1 Surface Water Swivel
- 2 UG Water Swivel
- 3 Hoist Plug
- 4 Pin to Pin Adaptor Sub
- 5 Bull Nose Adaptor Sub
- 6 Water Swivel Adapter Sub
- 7 Box to Pin Adapter Sub



New accessories should always be used with new rods to preserve the rod thread.

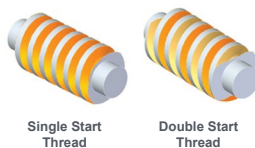


# THREAD GEOMETRY

The physical design of the box and pin thread is often what ultimately determines the performance of the drilling rod. There are essentially three aspects:

## EASE-OF-USE

The ease with which threads screw together or apart impacts productivity. A harder-to-use thread can misalign or jam, causing delays and damage to the first thread. Any single-lead thread has a tendency to tilt when pushed together. Only the newest generation of threads have dual-leads, which self-align.



## WEAR LIFE

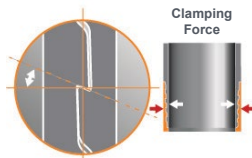
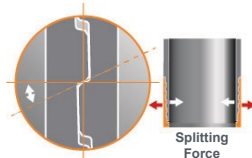
Even with the use of recommended thread compound/high-grade grease, every threading and unthreading causes wear. The material properties are critical, but so is having a design that distributes the loads across the largest possible surface. Thread wear life often becomes the limiting factor when the joints are broken frequently, like when drilling many shallow holes or abrasive grounds that requires frequent bit changes.

## LOAD EFFICIENCY

Since about half of the wall thickness is machined off, the threaded joint must be a weak area. The load efficiency simply measures the strength of the joint as compared to that of the mid-body. A key factor for efficiency is the flank angle.

Thread	Flank Angle	Load Efficiency
Q™	+10°	30%
RQ™	-10°	50%
XQ™	-20°	up to 60%

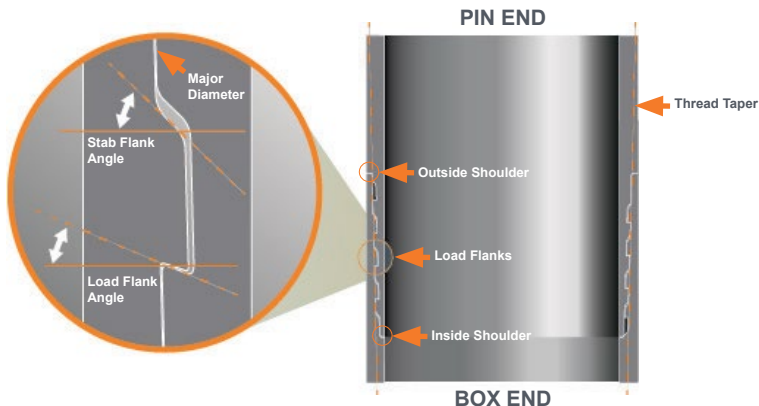
### Positive Flank Angle



### Negative Flank Angle

The most obvious difference is the ability to drill deep holes, in excess of 3,000 m (10,000 feet). For normal applications, though, the practical difference lies in how the pin and box lock together. With a positive flank angle, the box and pin are pushed apart, eventually causing a worn box to split. By contrast, a negative angle clamps the box and pin together, allowing for a full wear life of the joint.

## ANATOMY OF A ROD THREAD



- **Thread Taper:** All threaded joints suffer from uneven load distribution, tapered joints, however, can improve the distribution because the thinner portions stretch or compress more under a given load.
- **Stab Flank Angle:** When adding a rod, the angle of the flank will make it easier for the pin and box to slide together properly.
- **Load Flank Angle:** Where the tensile or stretching load is transferred between rods. The angle largely determines the strength of the entire drill string. A negative angle is stronger and has a higher load efficiency than a traditional positive angle.
- **Interference Fit:** Certain dimensions are designed so that the threads must stretch or compress to join together. Therefore, the required torque to join them exceeds what can be applied by hand. The major diameter of the pin is slightly oversized, ensuring a snug and stable joint. And the distance between the pin threads is slightly undersized to keep the connection tight and ensure proper load transfer.
- **Shoulder Interfaces:** Wireline rod joints have external and internal shoulder interfaces which provide a large portion of the drilling load transfer between mated rods. However, while the external shoulder is normally closed and transferring drilling loads, there is a small engineered gap at the inside shoulder to allow for length changes under normal loading without hanging up the wireline tooling passing internally. This gap should be closed in maximum load conditions to provide the highest load transfer capability.

*Interference fit illustrates the importance of manufacturing tolerances and why different suppliers' threads should not be mixed within the same drill string.*

**GALLING:** When friction and adhesion tend to pull steel from one surface to another if they are of similar hardness. It can be a serious problem between box and pin threads on drill rods but, can be avoided if heat treatment is used to make one surface harder than the other.

## FATIGUE STRENGTH

All steels have a limit to the number of applications of load, commonly referred to as 'fatigue strength'. The generally accepted definition of the maximum fatigue strength is the load that can be applied, or cycled, three million times without failure.

Drill rod fatigue failures can be caused by a load that fluctuates or reverses due to rotation, such as a bend caused by borehole curvature. Also, fatigue damage is cumulative; a rod may complete one demanding application and then fail in a future, less demanding application when the limit is finally exceeded.

## YIELD STRENGTH

At low loads steel is elastic; it compresses or stretches but returns to its original shape when the load is removed.

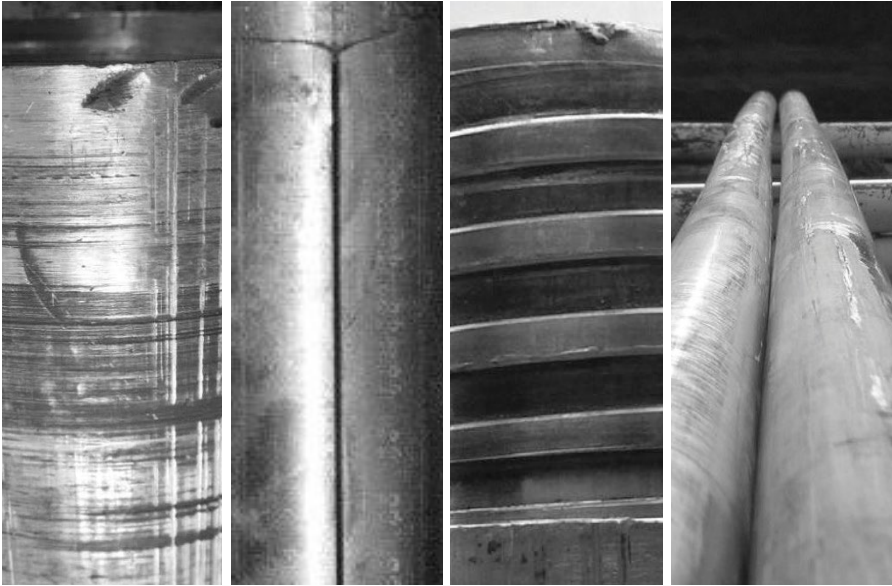
Permanent or "plastic" deformation occurs when stresses due to applied loads exceed the yield strength. The ultimate strength is higher, but beyond the yield strength the rods are not practically usable. This can be witnessed in bent or twisted rods, deformed threads or shoulders, or in dents and grip marks.

The required straightness requirements on coring rod are the reason why the yield strength is critical.



## FAILURES

In general, rods are manufactured in a controlled environment, while drilling in the field is highly variable and unpredictable. Proper selection and care dramatically increases rod life, but all rods eventually fail. Keep track of drill rod condition and retire worn or damaged rods before failures happen down the hole. Good practices can lead to significantly reduced downtime and operating costs.



Below are some common reasons, often appearing in combination, that lead to the replacement of rods:

- **Insufficient Make-up**

Hydraulic tools are required to tighten the rod threads. If insufficient torque is used, this may cause the pin thread to snap when drilling.

- **Box Wear**

Even wear around the outside circumference of the box thread is normal. Uneven wear on one side leads to premature replacement and possibly cracking on the box. Wear should be monitored.

- **Thread Wear**

Each make-up causes some wear, starting in the first thread and progressing down. Proper grease, case hardening of the pin, and dual-start threads maximize service life.

- **Thread Damage**

Various factors may cause threads to fail before they are worn out. It's important to always use approved thread grease. "Stabbing" damage is common and some threads are susceptible to galling if they lack special pin heat treatment.

- **Fatigue Cracks**

Repeated moderate level stresses can eventually lead to cracking. There are many different sources and circumstances that can lead to fatigue.

- **Clamp Damage**

Rod handlers must be set to the right hydraulic pressure or clamping will result in "bite marks" and cracking.

- **Corrosion**

Improper storage leads to surface corrosion and pitting. When drilling, rods can corrode due to the chemistry of the fluids. Stress combined with corrosion leads to cracks and eventually to failure.

- **Heat Check Cracking**

Severe combinations of frictional heating and cooling by the flushing media can destroy the material properties and lead to premature cracking outside the box threads.

- **Bad Adapter Subs**

A worn, damaged, or incompatible sub can destroy an entire drill string. Subs should be inspected and replaced frequently, and never mixed between suppliers.

- **Twisted Rods**

At certain combinations of rotational speed and in-hole friction, the drill string can start to oscillate and cause it to twist into a helical shape, leading to wear and cracking problems.

Rods are less susceptible if they have tight tolerances in straightness and concentricity and low residual stresses, but no rod is immune to twisting.

For information on troubleshooting rod failures, refer to THE METALLURGY section.

## FAILURE FROM FATIGUE

*A concept in materials science, fatigue cracking is a failure that occurs at a lower stress than a metal's theoretical strength.*

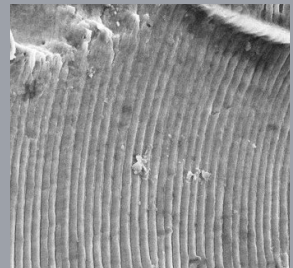
Stress is often not uniform in a structure but concentrated around corners, notches, holes, etc. The geometries create a stress concentration factor that leads to the formation of microscopic cracks. Every time you remove and reapply stress, the crack grows, first imperceptibly, but after many thousand cycles, will suddenly cause a catastrophic failure.

The most famous failure is of the de Havilland Comet, the world's first commercial jetliner. The squared windows created the stress concentration factor and pressurization of the cabin provided the stress, causing two planes to break up mid-flight. As passengers were flying in windows with rounded corners,



Drill rod failures may be less dramatic but work the same way.

Stress concentration can be caused by grippers, foot clamps, hammering, stabbing, and other handling tools. The applied stress can come from the weight of the drill string or bending in the hole. A general recommendation is to immediately retire any rod with a flaw greater than 10% of the wall thickness.





### OVERVIEW

Diamond products are drilling tools that utilize diamonds in their wear surfaces, usually man-made industrial diamonds. They typically represent a lower spend than coring rods, but exhibit the largest variability in performance and therefore require the most field testing. Difference in ground conditions and operator technique drives the variability.

Main categories include:

- **Coring Bits:** The bits are literally the front end of the entire drilling process, doing the actual work of cutting the core samples out of the ground. They are connected to reaming shells.
- **Reaming Shells:** Bits wear not only on the front face but also on the circumference, gradually decreasing in diameter. The reaming shell has two jobs, first stabilizing the drill string and second to ensure that the hole maintains a full diameter.
- **Casing Shoes:** The shoe is the cutter that aids the casing through any boulders and into solid rock. Unlike a bit, the inside diameter is flush, allowing the coring drill string to later pass through. The shoe is reused only if the casing is retracted after completing the hole.

### TYPES OF BITS

#### PCD BIT (POLYCRYSTALLINE COMPACT DIAMOND)

Made for cutting softer formations at high penetration rates. They typically have round PCD cutters that can be replaced, extending the life of the bit.



#### SURFACE SET BIT

Typically used for higher penetration rates than the impregnated bits in softer formations. They utilize a single layer of natural diamonds set in a hard matrix.



#### IMPREGNATED DIAMOND BIT

Used for cutting holes in medium to ultra-hard formations. They are the most widely used bits, with a variety of types available to maximize drill life and penetration.



## BIT CROWN

There are good technical reasons why bit crowns come in so many combinations.

- A tall crown has longer wear life than a short one, but costs more and has less strength depending on the waterway geometry.
- A crown with many openings is more effective for allowing water to flush away the rock cuttings but leaves less wear material. The open area is the percentage of the face designated to flushing, usually between 15 and 30%.
- The composition of the crown material is also critical. A material that exposes the diamonds more quickly, known as “free cutting,” may increase drilling penetration rates at the expense of bit life.

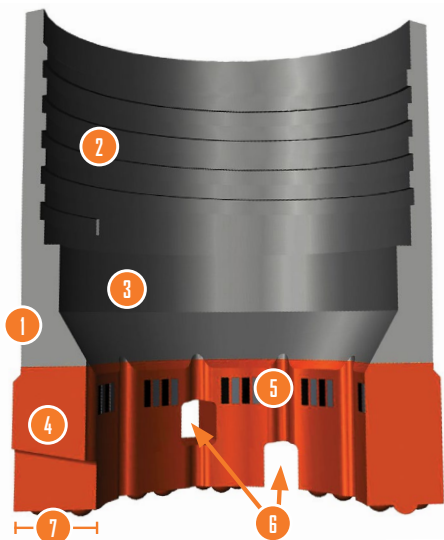
Adding to the complexity, various design combinations are easier or more difficult to run for the driller, or not even possible depending on the power of the drill rig.



## IMPREGNATED DIAMOND BITS

There are various types of coring bits, but the impregnated diamond bit is the dominant type used in modern mineral Exploration. A typical impregnated diamond bit features the following:

- 1 Bit Shank is the steel body upon which the bit is built.
- 2 Threads used to attach the bit to the reaming shell.
- 3 The inside is machined with a core lifter case seat to help secure the core sample.
- 4 The crown is the cutting portion that is customized and tailored in virtually endless combinations.
- 5 Regardless of design, the crown typically has extra wear elements on the inside diameter such as Thermally Stable Diamond (TSD) pins. An advantage of using TSD pins is that they can be shaped into any form. The TSD acronym refers to their manufacturing process.
- 6 All bits have some combination of waterways to direct the fluid for cooling and flushing of rock cuttings. The waterways are what give each bit a distinct look.
- 7 Bit kerf refers to the surface area of the bit that cuts the rock. Thin kerf bits cut less rock, therefore have a higher penetration rate. Thicker kerf bits may be slower, but improve hole straightness.



## IMPREGNATED BIT CROWN MATERIAL

The crown material, or matrix, is a mixture of synthetic diamonds and powdered metals, including tungsten and tungsten carbide. Initially, the matrix is a powder that is pressed to the desired shape, with an infiltrant added. The infiltrant is a glue based on copper alloys and often includes silver. In a high-temperature furnace, the infiltrant melts and bonds all the components together.

When drilling, the diamonds cut the rock, while the binder materials hold the diamonds in place and conduct heat away from the cutting face. There are three parameters involved:

### 1. Diamond Size and Concentration

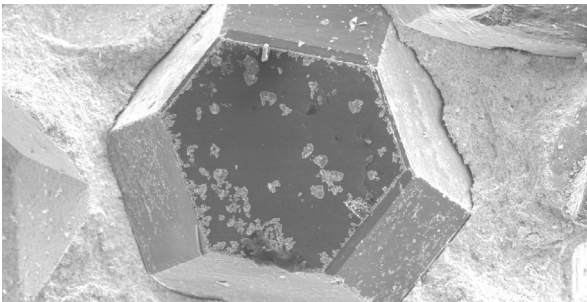
Larger diamonds cut rock faster, but also require more torque and may be more difficult to drill with. The largest bits and normal formulas, using 0.5 mm (0.02") diamonds, can have over a million individual diamonds. In contrast, the smallest bits and 1.25 mm (0.5") diamond formulas could have as few as 3,500 diamonds in a bit.

### 2. Matrix Hardness

There is a delicate balance between a matrix that is too soft and too hard. Too soft and the diamonds are quickly exposed, and subsequently lost for rapid bit wear. Too hard and the bit surface polishes without exposing fresh diamonds, causing a loss in penetration rate. Counter-intuitively, in hard rock, the matrix needs to be softer to ensure that new diamonds are exposed for cutting.

### 3. Bonding

The bond between the diamond and the binder determines to what extent a diamond can protrude before falling out. The balance between productivity and bit life depends on the strength of this bond, whether it is a chemical bond or only mechanical.



A single diamond protruding from the matrix of an impregnated coring bit.

## NO ONE SIZE FITS ALL

There is no one-size-fits-all in the crown design of coring bits. There is logic in pairing design features with operating conditions, but it typically requires iterative field evaluation to select the ideal configuration. Operating conditions influencing bit design and selection include:

- Rock hardness
- Ground consolidation
- Rock abrasiveness and grain size
- Drill power

Even so, what is the right choice at the top of the hole may not be right at the bottom of the hole. Personal preferences among individual drillers also play a big factor, but this should not be a limiting factor in trying new designs to optimize drilling.



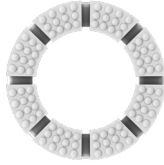
*Nomenclature between suppliers is inconsistent, but there are cross-references to help identify similar bits.*

## IMPREGNATED BIT CROWN GEOMETRY

Waterways, or openings for flushing, present the widest array of choices.

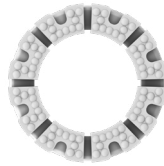
### STANDARD

Maximizes the amount of wear material, with less emphasis on penetration rate.



### EXPRESS

Opens up the cutting surface with the opposite emphasis.



### TAPERED

A compromise that has proven effective at removing rock cuttings while maintaining bit life.



### STAGE™

Balances life and flushing with taller crowns. Using windows rather than grooves, STAGE™ bits are the most contemporary design concept.



The importance of flushing to cool the bit cannot be overstated. Water volume, pressure, and open waterways are critical to prevent overheating. A few seconds without flushing and the bit will “burn-in.” The frictional heat melts the rock, effectively welding the bit to the rock. The bit will be destroyed and stuck in the hole which can result in significant downtime.

Each style of waterway has been designed to meet the demands of various drilling conditions, flushing the cuttings from the bit face while minimizing the effect flushing has on the core sample.

With traditional waterways, a 20 mm (0.78") crown height is generally the strength limit, however, 16 mm (0.63") is the most common. Crowns as tall as 75 mm (2.95") have been built using Boart Longyear's Stage™ waterway design.



## OPERATIONAL WEAR

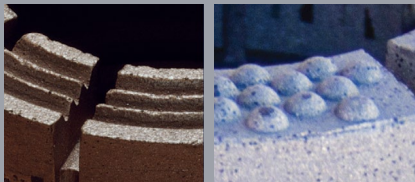
The performance of the bit is linked to the wear of the diamonds and depends on the control and skill of the driller. One key operating parameter is weight-on-bit (WOB). If WOB is too low, the diamond wear accelerates because they rub against the rock rather than cut. But the matrix wear will not accelerate, resulting in a smooth, polished surface, causing a loss in penetration rate. The gauges on the drill will also show a lower torque to rotate the bit. This problem is simply rectified by increasing the WOB.

When the diamonds are buried into the rock the matrix also makes contact and wears away rapidly to better expose the diamonds. This is known as “sharpening the bit.” Once the bit is sharpened, the driller needs to reduce the WOB or the bit will continue to wear excessively. Between operating parameters like WOB, torque, rotation speed and flushing, it becomes a balancing act to maximize bit life while maintaining an acceptable penetration rate - a bit is only as good as the driller.

Cont'd ▶



New bits do not have diamonds protruding from the binder material. Instead, the bit face will have ridges, grooves, or the Boart Longyear Razorcut™ bumps that will wear quickly to expose diamonds. These design features allow the new bit to cut rock without first being sharpened.



Ideal bit wear with exposed diamonds.

## REAMING SHELLS

Reaming shells are optimized for wear life and, in most applications, independent of rock type or drilling conditions. They are slightly larger in diameter than the coring bit, which helps to stabilize the drill string to reduce vibrations and ensures the full diameter of the hole is maintained and typically resides between the bit and the core barrel's outer tube.

The outer diameter features one, or more, wear pads which are made of a diamond matrix that may be further enhanced with block or pin inserts of thermally stable diamonds to improve wear resistance. Besides the choice of wear resistant elements, there are other design features to improve performance, including waterways. These grooves in the wear pads allow the drilling fluid and cuttings to be flushed to the surface to minimize regrinding which can reduce the life of both the bit and the reaming shell.



The grooves were traditionally straight, but a spiral shape as shown above is currently more common. The drilling fluid and cuttings swirl, so the concept of the spiral shape is to minimize the wear from the cuttings.

A general rule-of-thumb is that reaming shell life is four times the bit life, but anywhere in the range of three to five can be normal. It is important to inspect the reaming shell each time the drill string is pulled to change the bit, and replace if necessary.



In terms of purchasing price, reaming shells are cheaper than coring bits. Opportunities for cost savings should be explored even though they are not a key driver for overall productivity or cost of operations.



## GOING FOR GOLD COMMITMENT TO CHANGE PAID OFF!

A year-long testing program in western Australia demonstrated the potential of bit optimization. To find the gold in dykes of quartz porphyry, drilling must go through greenstone, shale, basalt, and banded iron formations. A tall order!

The optimum drill bit design had to be highly versatile and could only be established through testing and statistical tracking. Four generations were evaluated in 3-month periods, exhibiting stunning differences.



Generation	Penetration Rate	Bit Life	
Design #1	22 cm/min (8.7 in/min)	180 m (54.9 ft)	<i>While Design #2 had the lowest bit cost per meter, it came up short in productivity. The final decision fell on a two-bit strategy, optimizing penetration rate with Design #4 near the surface while reducing bit changes with Design #3 at depth.</i>
Design #2	26 cm/min (10.2 in/min)	356 m (108.5 ft)	
Design #3	35 cm/min (13.8 in/min)	300 m (91.5 ft)	
Design #4	60 cm/min (23.6 in/min)	120 m (36.6 ft)	

## CASING SHOES

When drilling through unconsolidated ground like overburden, or if groundwater contamination is an issue in quality core collection, a string of casing can be drilled before the drill string to act as a protective sleeve. Casing however requires a special bit, known as a shoe, that allows the rod string to pass through the inside without getting hung up on the shoe.

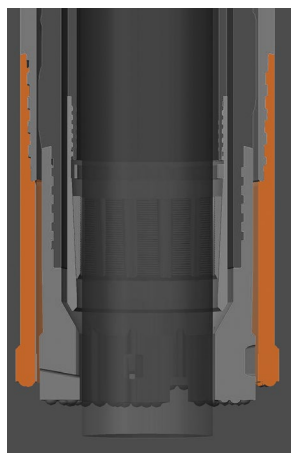
Casing depth varies, but the number of drill meters is generally limited due to its steel grade and manufacturing processes. Hence, only a small amount of wear material is needed on the shoe, typical crown height is 3 or 6 mm (0.12 or 0.24 inches). This means that the flushing geometries are simple and without the variations seen in coring bits.



The life and quality of the casing shoe matter most when the casing is retracted and reused for multiple holes.

The use of casing shoes is not limited to mineral Exploration. Casing and casing shoes are used in various applications such as geotechnical drilling.

RIGHT: Casing shoe (in orange) installed on casing, with a regular core drilling system inside.





*In 1958, Longyear developed the first wireline core retrieval system which allowed for the retrieval of an inner tube filled with core, without the need to pull the rod string out of the hole.*

*This new wireline system increased productivity on the worksite and made tripping core from the bottom of the hole safer.*

### CONVENTIONAL VS WIRELINING CORE

The depth of holes in today's mineral Exploration projects has made wireline core drilling significantly more popular than conventional.

### OVERVIEW

Wireline core retrieval is accomplished using a completely independent inner tube assembly that is not attached to the rod string, allowing for it, and the core, to be retrieved without removing the drill rods from the borehole. The inner tube system rests at the bottom of the rod string, behind the drill bit, and is held in place inside the drill string by the head assembly which is mounted at the top of the inner tube assembly.

The head assembly also includes the hardware necessary for retrieval. When the inner tube is full, a device called an overshot is lowered down the hole via a wireline cable and winch. The overshot attaches to the top of the head assembly, unlocks the inner tube assembly from its position, and allows for the complete inner tube assembly filled with core to be retrieved out of the hole.

Once the inner tube assembly is out of the hole, an empty assembly is sent back into the hole so drilling can quickly resume. The core from the recently pulled inner tube is then carefully removed and placed into a core tray and labeled for the onsite geologist to review.

## WIRELINE CORE RETRIEVAL SYSTEMS

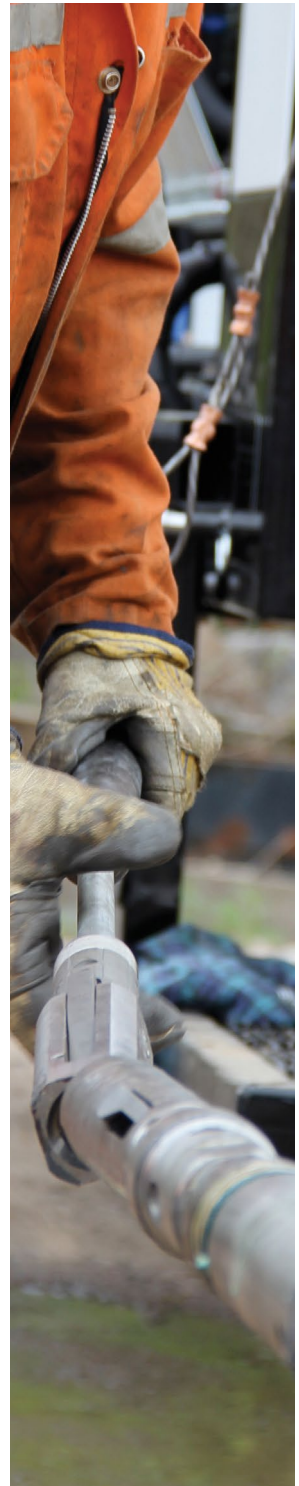
Like the other components of the drill string, core retrieval systems are selected according to drilling conditions and the demands of the geologist.

- Double-tube core barrels include an independent inner tube assembly that collects the core sample and protects it from exposure to drilling fluid. Modern systems typically include a swivel or bearing to allow the inner tube to be fixed while the drill string rotates, for a truer representation of the ground in question.
- TK (thin kerf) systems feature double-tube core barrels that allow for a larger core sample while retaining the same hole size. By minimizing the bit kerf, one can effectively increase core size in a 'B' size hole to the point where nearly 'N' size core is retrieved, however sacrifices to the durability of the system are required to achieve this. The lower bit weight necessary to run a thin kerf bit reduces wear and tear on the drill rig, and can improve core recovery in highly fractured ground. An example of this system would be BQ™TK.
- A triple-tube core barrel is similar to the double-tube but includes an additional liner to better protect the sample. This system should be considered in any formation known to have highly fractured ground as they provide the best core protection. Triple-tube core barrels are typically called Q™3, with the liner being called a split tube or just splits. The liner sits inside the inner tube and maintains the core sample in its drilled state. HQ™3 is the most common size system utilized, as geologists opt for a larger sample size to improve core quantity and quality. Triple-tube core barrels require a pump-out group to pump the liner out of the inner tube.

If core washing is of significant concern, a specialized core lifter case and bit could be incorporated to create a seal that channels water flow away from the inner tube to further improve core recovery.

- There is also a specialized system for uphole drilling, referred to as underground or pump-in. The core barrels feature a unique head assembly with seals that allow the inner tube assembly to be pumped into position, overcoming the effects of gravity and/or friction.

All of these systems use a device known as an overshot to pull the inner tube assembly from inside the drill string to recover the core. It can also be used to lower the inner tube assembly in certain ground conditions.



## CORE BARREL COMPONENTS

### OUTER TUBE ASSEMBLY

Sits between the rods and the diamond products and is only removed from the hole when replacing the diamond products or completing the hole. It houses the inner tube assembly during the drilling process.

#### 1 Locking Coupling

Typically supplied with a rod thread on the box end, it connects the drill rod to the adapter coupling. The locking coupling gets its name because when the latching (locking) mechanism opens inside the adapter coupling, the latches press against the pin shoulder to hold (lock) the inner tube assembly in position for coring. As a result, the shoulder of the pin end needs to be heat treated to improve wear resistance. Two main types:

- Stabilized Locking Couplings feature wear pads on the outer diameter. Similar to the reaming shell, these pads help to stabilize the drill string to reduce vibrations. They are also known as Conventional Locking Couplings.
- Full Hole Locking Couplings produce the straightest hole, but increase torque requirements, particularly in broken ground or if a smaller rig is used. As a result, it is less suitable for underground.
- An optional tang or drive key can help ensure rotation of the head assembly reducing wear of mating components such as the latching system and landing shoulder. For use in surface applications.

Problems may arise down the hole that prevents the latch mechanism from unlocking due to a lack of space. Roller latching deploys and retracts radially, preventing instances of stuck tubes.

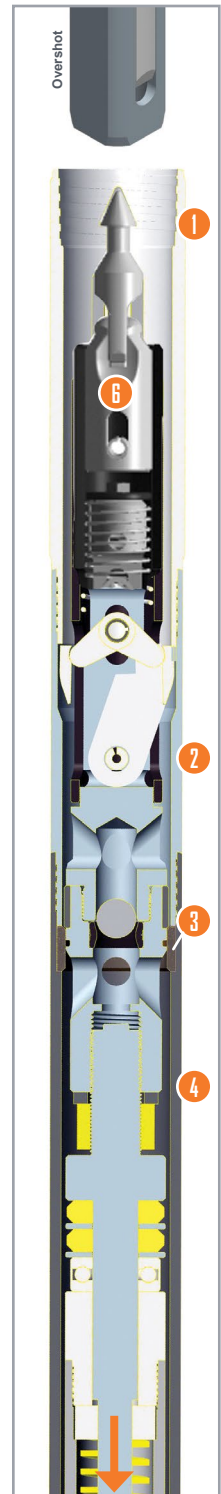
Using rollers for latches, as with Boart Longyear's Roller Latch Systems, allows a self-locking feature wherein the latches are driven rotationally by the rod string. This ensures the head assembly rotates with the rod string minimizing wear of rollers, landing shoulders, and outer tube landing rings. Eliminating the need for mechanical elements such as keys or tangs.

#### 2 Adapter Coupling

Connects the locking coupling and the outer tube. It is counterbored to allow space for the latching (locking) system in the head assembly to open fully in order to lock the system in position for coring.

#### 3 Landing Ring

Made of high quality alloy steel that is heat treated to increase durability. It sits in the end of the outer tube and



is held in place by the adapter coupling. As the inner tube assembly is lowered into the drill string, the landing shoulder on the head assembly impacts the upper edge of the landing ring, setting the inner tube assembly into drilling position. It is reversible when worn on one side.

#### 4 Outer Tube

Slightly thicker and larger in diameter than the drill rod, the outer tube provides stiffness and directional control in ever changing formations. It houses the inner tube assembly and connects the upper drill string to the reaming shell and bit. The outer tube length is typically 1.5 or 3 m (3 or 10 ft), but can be assembled together to extend the length of the core sample. Chrome plating, an optional outer tube treatment, reduces friction and increases life in broken conditions.

Where straightness and accuracy are a top priority, full hole systems (outer tubes and locking couplings) should be used. The four-flat oversized design keeps the core barrel system tight to the hole increasing core barrel stiffness and stabilization, while still allowing flow of drilling fluid and cuttings out of the hole. While hole straightness is maximized with this system, higher drilling torque will be experienced, especially in broken ground. Not suitable for use in directional drilling applications.

#### 5 Inner Tube Stabilizer

Made of quality bronze alloy for durability and is seated in the reaming shell (except for P sized systems). It provides centralizing for the inner tube assembly and acts as a bearing between the stationary inner tube and the rotating outer tube.

Coring bits and reaming shells are technically part of the outer tube assembly. However, being specialized, diamond products are often referred to separately.

## INNER TUBE ASSEMBLY

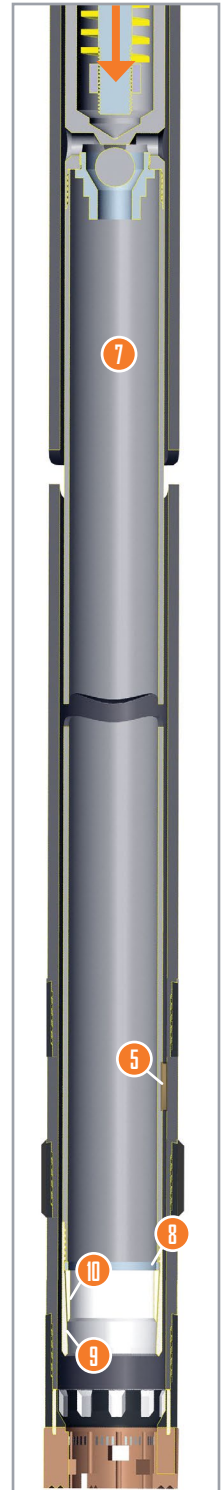
Responsible for the collection of the core sample and is removed each time the inner tube is filled with core, or if a blockage occurs down the hole.

#### 6 Head Assembly

It's the uppermost part of the inner tube assembly and the most complex part of the core barrel assembly. It features all of the components for latching or locking the inner tube assembly into drilling position and retrieval of the core sample.

#### 7 Inner Tube

Attaches the head assembly and the core lifter case. Its purpose is to capture and protect the core sample as drilling



progresses. The inner and outer tubes define the length of the core sample, typically 1.5 or 3 m (3 or 10 ft), but the lengths can be joined together with couplers to extend the core length to 4.5 m (13 ft); it is more economical to collect longer core samples.

Extensions are also available to make up for the use of an extended length reaming shell, or double shells, in the outer tube assembly. Chrome plating is optional and aids in the reduction of friction, decreasing core blockages, and increasing wear life in broken conditions.

### 8 Stop Ring

A steel snap ring that sits in a groove at the top of the core lifter case. It ensures the core lifter is held in position during the drilling process. Quality stop rings are made of alloy steel tubing that is specially heat treated to increase strength, toughness, and wear life.

### 9 Core Lifter Case

The final component of the inner tube assembly which sits on the inside taper of the bit and houses the core lifter and stop ring. It works in conjunction with the core lifter to create a check valve that allows the core to enter into the inner tube but prevents it from falling out during core retrieval. The inside of the core lifter case is tapered and as the core lifter is drawn into the taper, it tightens its grip on the core. Core lifter cases should be made of alloy steel that is specially heat treated to increase strength, toughness, and wear life.

### 10 Core Lifter

Designed to allow its grip to tighten on the core sample preventing core loss in the hole. The core lifter works in conjunction with the core lifter case to create a check valve; the core enters into the inner tube but is prevented from falling out during core retrieval. Core lifters require the toughness of

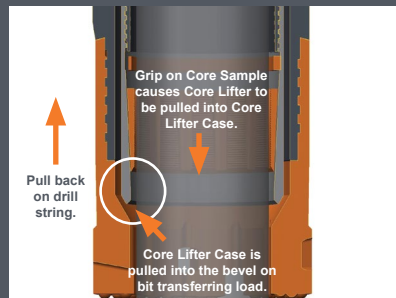
heat treated steel to withstand the pressures required to break the core off the bottom of the hole. The grip pattern or teeth machined onto the inner diameter is subject to significant wear during normal operations, requiring frequent replacement to avoid core slippage or drops.

Common types include:

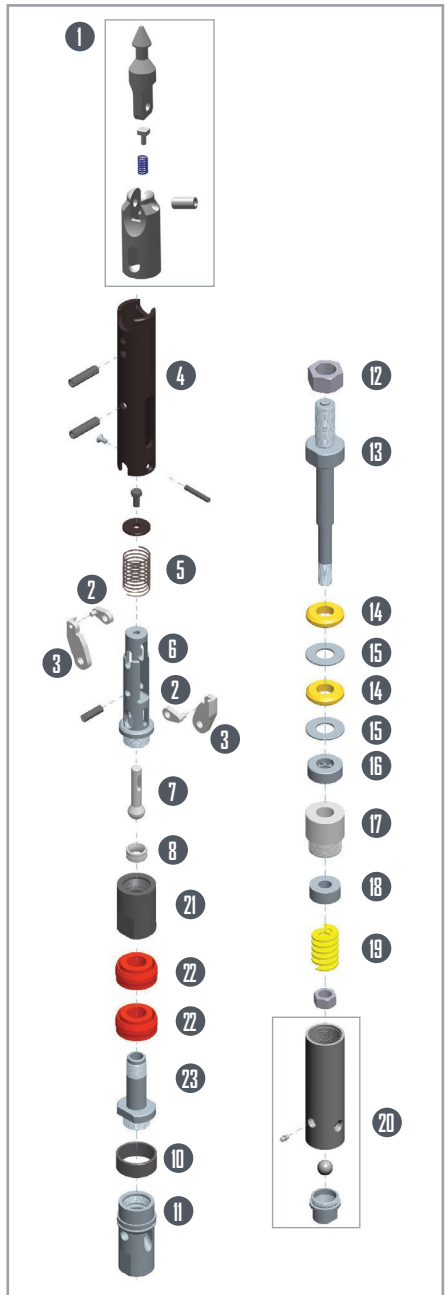
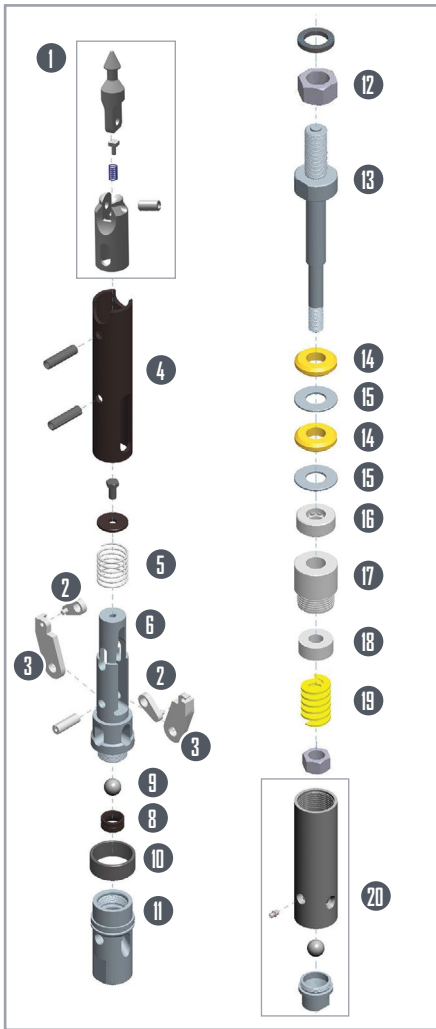
- Fluted Core Lifters are the most popular globally and have better mixed-condition performance.
- Broached Core Lifters are the same as fluted, but have a slightly different machining process.
- Slotted Core Lifters are stiffer and better suited to competent ground, hence their popularity in some regions.
- An optional micro-diamond coating is available for superior wear life and gripping. It adds significant expense, however, it virtually eliminates slippage and drops.

## CORE BREAKING FOR RETRIEVAL

- As the rod string is pulled back, the core lifter grip tightens on the core.
- The compression spring inside the head assembly allows it to move with the outer tube until the bit contacts the stationary core lifter case.
- As a result, the breaking load is transferred through the bit and outer tube, protecting the inner tube assembly from the forces.
- The core breaks below the core lifter.



# HEAD ASSEMBLY BREAKDOWN



## KEY FUNCTIONS

- Insertion and retrieval of the inner tube assembly from the drill string.
- Locking the inner tube assembly in position before drilling can start.
- Fluid pressure signals to alert the operator when the inner tube assembly has landed at the bottom of the hole, as well as a full or blocked inner tube.
- Fluid circulation control to the bit to ensure the bit is cooled and the cuttings are flushed to the surface.

- Break the core for retrieval when used in conjunction with the core lifter/core lifter case.
- Surface and Pump-In versions.



## COMPONENTS

### 1 Spearhead Assembly

Connected to the latch retracting case and features the spearpoint which the overshot assembly connects to on retrieval. Includes a pivot, or knuckle, making the inner tube assembly handling safer and easier once retracted from the hole.

#### SAFETY: SPEARPOINT

Old style spearhead designs represent a weak point and source of failure in handling operations. Recent redesign by some suppliers reduces the chances of failure and injury during handling. Completely redesigned head assemblies are being introduced which eliminates the spearpoint requirement altogether.

### 2 Links

Two required. Connects the latches to the latch retracting case, ensuring equal deployment of both latches; locks the latches into place once the connection point goes over center.

### 3 Latches

Two required. Attached to the upper latch body and links. They open into a locked position upon passing through the locking coupling to prevent the inner tube assembly from moving out of position.

Latches create friction and could slow the descent of the inner tube assemblies due to their spring loading. Some head assemblies hold the latches in a retracted position using a detent until the head assembly lands, which eliminates all latch drag.

Other head assemblies use rollers, as with Boart Longyear's Roller Latch Systems, which eliminate this sliding friction and speeds up descent times and reduce wear.

#### SAFETY: LATCH RELIABILITY

Latches should reliably lock the inner tube assembly into position. Latching mechanisms using the old style spring-latch design may easily be overcome due to drilling vibration, releasing the latches. In a downhole, this would prevent the core from feeding into the inner tube, but in an uphole, this creates a hazardous situation.



### 4 Latch Retracting Case

Connected to the upper latch body and spearhead assembly. On retrieval, it is pulled upward drawing the latches inward to release the inner tube assembly. It also connects to the valve piston, if one is present, pulling the piston back through the bushing during retrieval releasing any fluid pressure build-up.

### 5 Latch Compression Spring

Applies load to the latches to ensure they deploy once they pass through the locking coupling.

### 6 Upper Latch Body

Houses the latch mechanisms and the latch/landing indication features.

### 7 Valve Piston

Attached to the latch retracting case and works with the landing indicator bushing to seal fluid flow until latches are deployed and lock. This sealing creates a pressure spike observable by the driller, known as latch indication or landing of the inner tube assembly. It requires the landing shoulder to be resting on

the landing ring to seal the space between outer and inner assemblies.

### 8 Indicator Bushing

Seals against the valve piston for latch indication or the indicator ball for landing indication.

### 9 Indicator Ball

Seals against the indicator bushing to stop fluid flow until the inner tube assembly lands. The sealing creates a pressure signal for the driller, known as landing indication. The driller needs to manually reset the ball once the head has been retrieved. It requires the landing shoulder to be resting on the landing ring to seal the space between outer and inner assemblies.

### 10 Landing Shoulder

Contained by the lower latch body. When the inner tube assembly is in drilling position, the landing shoulder rests on the landing ring to create a seal, preventing the flow of fluids between the inner and outer core barrel assemblies. Allows for the latch and landing indication to function.

### 11 Lower Latch Body

Contains the landing shoulder which creates a seal when seated against the landing ring. As a result, the fluid is redirected through the lower latch

body and back out to the annulus between the inner and outer core barrel assemblies.

### 12 Adjusting Nut

Locks the spindle in position creating what is referred to as the bit gap.

### 13 Spindle

Threads into the lower latch body and houses the shut-off valves, bearings, and heavy-duty compression spring. Adjusting the spindle length will increase or decrease the space between the core lifter case and the inner bevel of the bit, commonly referred to as bit gap.

Most head assemblies use outer diameter porting to route fluid around the spindle, adding significant fluid drag. Newer head assemblies use a hollow spindle to eliminate this porting, thereby increasing descent speeds.

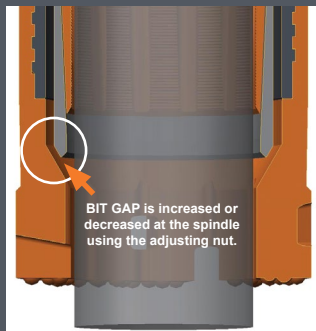
### 14 Shut-off Valves

Installed on the spindle and contained by the thrust bearing and spindle bushing. They expand under load to restrict the flow of drilling fluids to indicate either a core block or a full inner tube. The flow restriction increases the water pump pressure warning the driller.

## BIT GAP

Controls the flow of fluid at the bit. It is set by loosening the adjusting nut and either increase or decrease the length of the spindle. This in turn changes the space (gap) between the core lifter case and the inner bevel of the coring bit. This gap should be checked and adjusted, if necessary, with every bit change.

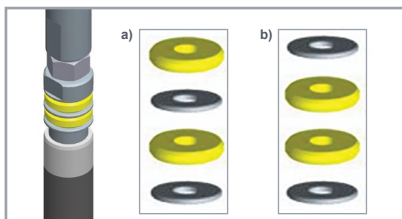
- Too small a gap can cause bit wear and potential mislatching.
- Too large a gap can cause poor core recovery or short runs.



## 15 Valve Adjusting Washers

The positioning of the shut-off valves in relation to the valve adjusting washers will determine the force required to shut off the fluid supply. For example, on an N system:

- Separating the valves, which is the standard configuration for harder ground, will require a force of 1,150 kg (3,300 lb).
- Sandwiching the valves, which is appropriate for soft or friable ground conditions, will require a force of 800 kg (1,764 lb).



## 16 Thrust Bearing

Located on spindle below the shut-off valves and valve adjusting washers. Allows the spindle bushing, inner tube cap assembly, and inner tube components to remain stationary while the upper head assembly spins with the drill string during drilling. This force pushing on the inner tube as core enters is carried or supported by the thrust bearing. When the core jams or blocks in the inner tube, this force becomes much greater as the drill string continues to advance.

## 17 Spindle Bushing

Connects the inner tube cap assembly to the upper head assembly. It is supported by a series of bearings allowing it, and the inner tube, to remain stationary while the upper head spins during drilling.

## 18 Hanger Bearing

The lower thrust bearing or hanger bearing is positioned on the spindle above the heavy duty compression spring. It carries the weight of the

core sample during retrieval and the force on the compression spring during core breaking.

## 19 Heavy Duty Compression Spring

Sits on the end of the spindle just below the hanger bearing. It transfers the load from the inner tube assembly to the bit, protecting the hanger bearing and the inner tube assembly from damage during core breaking.

## 20 Inner Tube Cap Assembly

Connects the spindle bushing to the inner tube and contains:

- A grease port for lubricating the bearings.
- A check valve that allows fluid to pass through the inner tube during descent, increasing speed.
- Bypass porting for the drilling fluid.

During drilling, the check valve shuts off fluid flow through the bypass ports to prevent the core from being washed away.

## PUMP-IN APPLICATIONS

### SAFETY: LATCH INDICATION

Only head assemblies with latching indication should be considered. Without it, heads can be either partially latched or not latched at all, creating a hazardous situation, where gravity could cause an uncontrolled descent.

Changes to head assembly are necessary when going from downhole to pump-in drilling, most suppliers offer a conversion kit that includes the following pump-in version of standard components:

- Latch Retracting Case
- Compression Spring
- Coiled Pins
- Indicator Bushing

The addition of the following components is necessary to allow for pumping in of the inner tube assembly:



## 21 Adapter

Houses the valve bushing and connects the upper latch body and the seal seat.

## 22 Pump-In Lip Seals

Blocks fluid flow so that sufficient pressure builds up within the drill string allowing the inner tube assembly to be pumped into the drilling position in  $-15^\circ$  to uphole applications where gravity will not carry them.

## 23 Seal Seat

Located between the upper and lower latch bodies and retains the pump-in lip seals and adapter.

### SAFETY: LIP SEAL POSITION

Some head designs have lip seals above the latches which may cause pressurized fluid to unlatch the head assembly and accelerate it out of the hole. This type of design poses an unacceptable safety risk and should not be used.

Some assemblies allow simple removal of the lip seals from a pump-in head assembly and installation of a spacer for use in  $-45^\circ$  to  $-90^\circ$  holes, eliminating the need for an additional surface head assembly in underground operations.

## 24 Loading Chamber

An accessory used in pump-in drilling applications. It connects to the end of the rod string and allows the inner tube assembly and overshot to be pumped into position without fluid loss.

### SAFETY: BRAKE

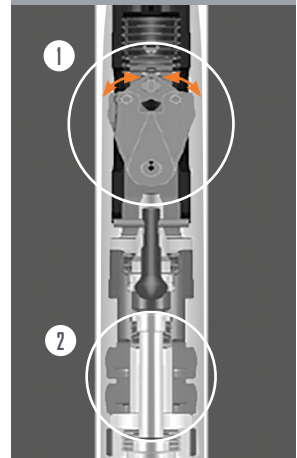
The loss of water in uphole drilling applications poses a significant risk to driller safety and may cause significant injuries. To reduce this risk, Boart Longyear has introduced a head assembly featuring a hold-back braking system. Only when the wireline is taut during retrieval operations will the brake rollers retract, allowing for a controlled descent. During an event such as blow-back or free-fall, the rollers automatically engage and immediately stop the inner tube assembly. As a safety feature, the hold-back brake is always engaged by default.

## VARIABLE WALL RODS COMPATIBILITY

Variable wall drill rods were not utilized underground until Boart Longyear launched its innovative Roller Latch™ head assembly to address the following issues:

1 Previous core barrel link latch mechanisms would open prematurely in the larger inner diameter of the rod, and move into a locking 'over-center' position which could fully prevent pump-in of the assembly. Similarly, other latch mechanisms suffer significant drag during pump-in, due to the large spring-loads required to avoid unlatching and falling tubes.

2 Lip seals were insufficient in diameter to allow for proper pumping in of the inner tube assembly.



## OVERSHOT ASSEMBLY

The overshot is an integral part of the wireline system and, as with the core barrel systems, a downhole and pump-in version are offered to compensate for the effects of gravity. There are a number of features that should be considered to ensure the safe and reliable retrieval or lowering of the inner tube assembly.

- Heavy duty lifting dogs for gripping onto the spearhead point on the head assembly.
- Locking sleeve to prevent premature release.
- Quick-release safety pin.
- Dry hole lowering kit.

The overshot has two functions:

- 1 Retrieve the inner tube assembly filled with core.
- 2 Lowering the inner tube assembly into position in dry hole applications.

### INNER TUBE ASSEMBLY RETRIEVAL

To retrieve the core filled inner tube, the overshot is lowered (or pumped-in) to the bottom of the hole. Once there, the overshot lifting dogs grab hold of the core barrel head assembly and, as it is pulled out of the hole, triggers the release of the latching mechanism holding the inner tube assembly in place.

### DRY HOLE LOWERING

In applications where groundwater is non-existent (dry holes), the overshot can be used to safely lower or pump in the inner tube assembly. Once the inner tube assembly has landed, the head assembly in combination with an overshot locking sleeve releases the overshot allowing it to be retrieved out of the hole before drilling starts.



The overshot is connected to the winch by a wireline cable.

- Surface applications recommend a Swaged Wire Rope. It has a 50% higher breaking strength than other cables, and resists "bird nesting".
- Underground applications require a cable with a minimum radius of less than 127 mm (5 in).



### LOADING CHAMBER

Must be attached to the end of the drill string to pump an overshot into position.



# THE EQUIPMENT

Drill rigs are complex machines, requiring a solid understanding to make the right decision. Key factors include application, level of technology, power needs, size and weight, mobility, design style, and options.

Understand your options to keep your next project on time, on budget, and safe, with flexibility and reliability for future work.

# THE EQUIPMENT

## CHOOSING THE RIGHT RIG

No matter the application, finding a rig with the desired specifications and options is critical to having a successful Exploration program. It comes down to what kind of drilling is being done, the geology, key technical design features, economic viability, and of course, safety requirements. Matching the equipment with the scope of work is key.

### INFLUENCING FACTORS

Whether it is a first drill, a replacement of an old drill that's eating into productivity and profits with downtime and maintenance, or expansion of a fleet to meet growing demands, there are a number of things to consider before making the purchase.

- Lithology being investigated and selected method of drilling.
- Budget, capital constraints, and project duration.
- New technology and safety features.
- Depth requirements, hole size, and drilling tools selection.
- Transportation requirements and options.
- Maintenance and availability of spare parts.
- Delivery schedule.
- Fleet standardization and supplier reputation.

## SELECTING THE DRILLING METHOD AND DRILL

### 1 DIAMOND CORE DRILLING

Rigs come in a wide size and performance range, and are capable of drilling most ground conditions. Underground drills are generally smaller than surface drills due to the size constraints of a mine drift and hoist cage. Smaller underground drills are occasionally used on selective surface projects.

### 2 REVERSE CIRCULATION (RC) DRILLING

Although considered less time consuming with faster penetration rates, depths are commonly limited to 500 m (1,700 ft) due to back pressures and ground water. RC drilling requires far less water than core drilling, making it ideal in places where water may be scarce or costly, or pre-collaring holes on a larger project.

## ARE TWO DRILLS BETTER THAN ONE?

### Same Drilling Method vs Multiple Drills

A drill should have adequate depth capacity in all planned holes.

However, if only a small fraction of the holes are deep (+2,500 m / 8,000 ft), having two different sizes of drill might be more feasible for overall operating costs such as fuel, drilling fluids, etc.

### Multiple Drilling Methods vs Single Drill

Because conditions can vary within a drilling program, contractors may gravitate towards a multi-purpose rig that offers an "all-in-one" solution.

This flexibility might be attractive, but it comes with a price tag that may be out of reach, and often sacrifices performance. If depth capacities are of concern, having an independent RC and coring drills may offer the desired outcome.



# CORING RIGS

Coring rigs are available with two different drive systems (drill heads) to provide the necessary pull-down/hold-back, rotational torque and speed. They offer similar performances but allow for different drill configurations.

## 1 TOP DRIVE:

The drill rod is threaded directly onto the drill head with a drive sub and the integrated water swivel provides the porting for drilling fluid. Top drive drills have a longer stroke making them very efficient for tripping in and out of the borehole. They are easier to integrate with rod handling and can be highly automated for increased safety.



### DRAWBACK:

Size requirement makes top drive drills impractical to enclose or use in underground drilling.

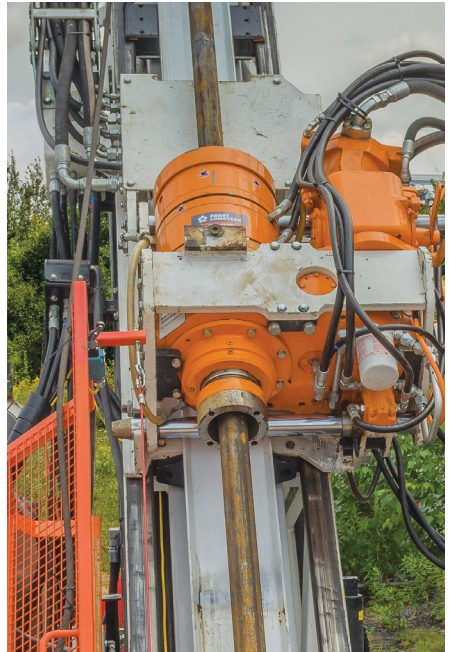
## 2 CHUCK DRIVE:

The drill rod is fed through the center of the head, where chuck jaws grip the outside of the drill rod to drive the system. An independent water swivel must be attached to the top drill rod to provide porting for the drilling fluid. Chuck drive drills typically have a shorter stroke, making them less efficient for tripping out of the borehole. A mainline hoist may be added to increase stroke capability and improve efficiency.

The smaller size allow the drills to be enclosed inside a shack or tent to protect the operator and drill from extreme climates. Underground versions are modular and compact for the limited space inside a drift.

### DRAWBACK:

Rod handling is complicated to automate. Shorter stroke without optional mainline hoist.



## DEPTH CAPACITY

Once the type of rig is selected, the diameter and depth of the borehole will determine its size. Borehole diameter is typically specified by the mine site and reflected in tool selection, while depth capacity is primarily a function of a drill's ability to provide:

### TORQUE

The drill head must provide enough rotational force to overcome all friction in the borehole. The required torque increases with hole diameter, depth, and wedges or other deviations.

### PULL BACK

The drill must be able to lift the full weight of the drill string and still provide enough additional force to break the core and overcome all friction. Larger diameter drill strings will limit the depth capacity of the drill, primarily because of the increased weight of the rods.

## HOLE SIZE (SYSTEM) VS DEPTH CAPACITY OF DRILL

REPRESENTATIVE RATINGS OF A MID-RANGE TOP DRIVE DRILL		
Hole/System Size	Depth Rating	
	meters	feet
B	2,000	6,700
N	1,600	5,300
H	1,000	3,300
P	500	1,600

### AIR VOLUME (RC)

Unlike core drilling, depth capacity for RC is limited by the available air pressure and volume. Deeper holes require more powerful compressors; the longer the pipe, the more pressure is lost before reaching the hammer. Additional rod joints also mean more potential volume leaks. Most significantly, the inflow of groundwater creates back pressure and makes the cuttings wet and heavier to flush out.

## MULTI-PURPOSE DRILL DISADVANTAGES

The advantage of having one rig on site performing multiple tasks is obvious, however, the downsides include:

- **FUEL ECONOMY:**  
With additional gears, larger hydraulic systems, and more powerful pumps, efficiency when core drilling is typically reduced by 30%.
- **MAINTENANCE COST:**  
In general, these costs are proportional to the capital cost of the machine, or commonly 30% higher for a multi-purpose drill than an equivalent dedicated coring drill.
- **CONVERSION DOWNTIME:**  
Switching from RC to core drilling saves time when the drill stays on the hole. But the conversion of the rig itself takes between 2 and 4 hours.

## AUTOMATION VS MECHANIZATION

Innovation in surface Exploration drill design has taken significant steps in recent years as engineers adapt new technologies to tackle the need for more agile equipment, but don't be fooled by the terminology.

Mechanization is normally defined as the replacement of a human task with a machine. True automation encompasses more than mechanization, it involves the entire process and may require re-evaluating and changing current processes rather than simply mechanizing them.

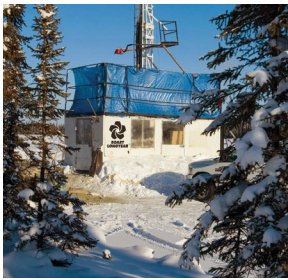
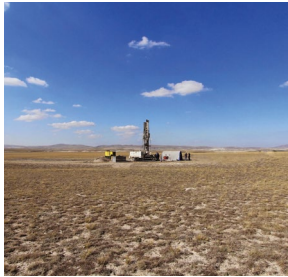
A good example of automation is Boart Longyear's Drill Control Interface (DCi). It is a fully electronic interface that incorporates CANbus (Controller Area Network) technology to enable communication between the drill rig, rod handler and the DCi to self-monitor and semi-automate most drilling operations.



## LOCAL DRILLING CONDITIONS AND EQUIPMENT SELECTION

Exploration drilling programs can be very challenging, and equipment choices will often be limited by the conditions and location of the drill site:

- **Terrain:** Drill sites could be on the side of a mountain, in the middle of a forest, lake, ice field, or desert. Greenfield Exploration programs are often very remote with limited to no conventional access. As a result, rig size, weight, and modularity can be important.
- **Climate (extreme heat/cold):** Work environment is a priority, and the need to provide a controlled environment for the drill crew will influence the type and size of the drill. A drill shack or tent will limit the footprint of the equipment.
- **Available Space:** A surface Exploration site will typically have enough space for a standard setup. Underground operations within an existing mine will be limited by drift size and transportation options to the site.



## DRILL MOBILITY / MOUNTING OPTIONS

### TRUCK:

- Preferred for a quick turnaround between job sites.
- Used with larger drill configurations.
- Requires easy site access and level ground conditions.
- Integrated jacks for levelling the unit during drilling, and to raise the drill for removal of the transport truck if necessary.

### TRACK/CRAWLER:

- Preferred on smaller sites due to flexibility.
- Useful on sloping ground conditions.
- Adaptable for various drills sizes.
- Integrated jacks for levelling the unit during drilling.

### SKID MOUNTED:

- Great for difficult terrain where access is limited.
- Towed into position by heavy equipment like a bulldozers.

### SKID STEER:

- Compact and mobile.
- Quick setup and ease of moving from site to site.

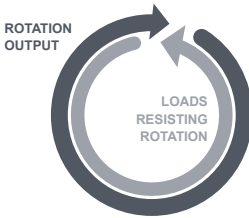


# ESSENTIAL DRILL OPERATIONS

The drill should be able to perform these key functions.

## ROTATION:

A rotary motor provides the desired rotational output speed (rpm) while overcoming the various loads resisting that rotational output, known as torque (Nm / ft-lb). Speed and torque are the two primary performance factors of a rotary motor. The output power, measured in watts (W) or horsepower (hp), sets the speed and torque performance boundaries.



Torque can provide valuable information regarding conditions in the borehole, because when the ground changes, the torque can change as well. It is important for the operator to monitor the rotation pressure to determine if changes in torque are taking place.

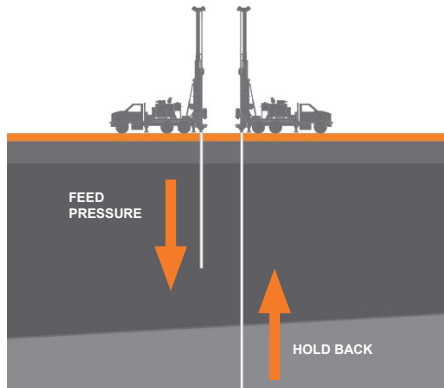
Most applications are dynamic with both the torque and speed changing throughout. Calculating the speed and torque requirements at various

operational points will help determine the appropriate sized motor to be used.

## HOLD BACK / FEED PRESSURE:

In upholes or at the beginning of a downhole, the operator will need to apply feed pressure to ensure optimal contact between the bit face and rock. However, with the addition of each rod in a vertical downhole, the drill string will become heavier and the operator will need to watch for increasing torque levels on the bit. If they begin to climb beyond the narrow, allowable bit weight range, the operator will need to reduce the feed rate or even hold back the weight on the bit (WOB) to optimize bit performance and life.

Hold back operations will vary according to the drill's control and feed system type, but the overall objective is to manage the balance between enough and too much weight on the bit.



## UNIQUE FOR CORE DRILLING

- Operators closely monitor borehole circulation fluid pressure and return volume. Changes can alert them to a number of conditions down the hole, including a completed core run.
- The drill's pull back force is used in combination with the core barrel system and bit to break the core off the bottom of the hole.

## WIRELINE RETRIEVAL:

A winch and cable are used to retrieve the inner tube assembly from the hole.

**CABLE:** Typical sizes are 3/16", 1/4", and 6 mm. The cable should have a high breaking strength and resist unravelling.

**WINCH:** Size will vary according to cable capacity (hole depth), and the speed is controlled with hydraulic system valves.



## PULL BACK / HOISTING:

Pull back is the force the drill head exerts on the drill string when pulling rods from the hole. It is much greater than the force required for hold back, and can be calculated based on the hydraulic system pressure and feed actuator size.

### Drill Head Capacity:

Representative Chuck Drive Drill Head rated to 167.7 kN / 17,100 kg (37,700 lb) (less core breaking)  
(Dry Hole - no buoyancy factored into rod weight)

Rod Size	Recommended Maximum Depth for Drill Head		Drill Rod Weight per Unit Length		Rod Weight at Maximum Depth for Head	
	m	ft	kg/m	lb/ft	kg	lb
B	2,762	9,061	6.0	4.0	16,572	36,244
N	2,076	6,811	7.8	5.2	16,193	35,417
H	1,347	4,418	11.5	7.7	15,491	34,019
P	817	2,679	17.4	11.7	14,216	31,344

Hoisting refers to the force the mainline hoist can exert on the drill string. Used with surface chuck drive drills only, the mainline hoist can provide a longer rod pull (multiple rods) in a single pass versus multiple passes when using only the drill head which is limited by stroke or travel. The length of the pull will be determined by the mast height with additional mast extension pieces.

### Mainline Hoist Capacity:

Representative mainline hoist rated to 71.2 kN / 7,257.6 kg (16,000 lb), single line pull.  
(Dry Hole - no buoyancy factored into rod weight)

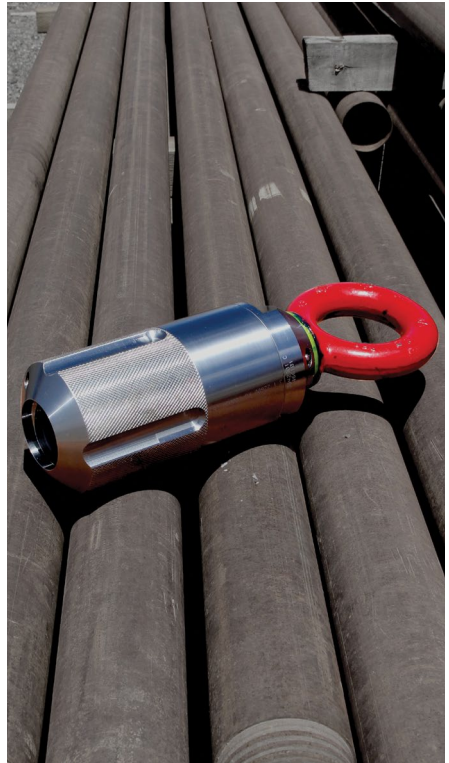
Rod Size	Recommended Maximum Depth for Hoist		Drill Rod Weight per Unit Length		Rod Weight at Maximum Depth for Hoist	
	m	ft	kg/m	lb/ft	kg	lb
B	1,210	3,968	6.0	4.0	7,260	15,872
N	930	3,053	7.8	5.2	7,254	15,876
H	631	2,071	11.5	7.7	7,257	15,947
P	417	1,368	17.4	11.7	7,256	16,006

The mainline hoist has an extended pull capacity, but weight restrictions limit its use to the top of the borehole. The depth capacity / number of drill rods is reduced by half due to weight limitations.

3 m (10 ft) rods	Drill Head Capacity	Mainline Hoist Capacity
Number of B sized rod	921	403
Number of P sized rod	272	139



The mainline hoist (above) uses a hoisting plug (below) to pull multiple rods from the borehole at once. The hoisting plug is mounted to the free end of the top rod, replacing the water swivel.



Various hoisting plugs are available for use with safety rated lifting capacities. Hoisting with a water swivel is never recommended.



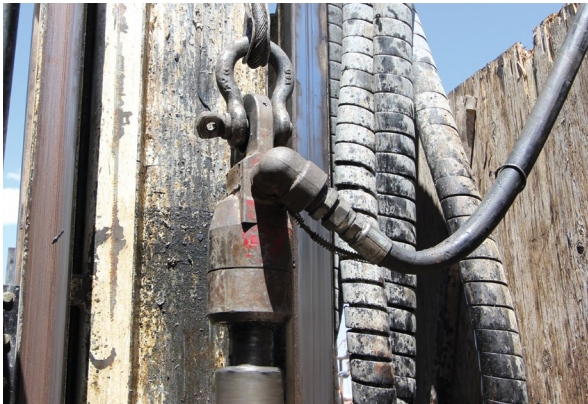
## CIRCULATION OF DRILLING FLUID

The circulation of drilling fluids is a major component of core drilling operations, and helps to improve:

- 1 **Tool longevity by flushing cuttings out of the hole and maintaining inhole temperatures.**
- 2 **Tool performance by providing lubrication to reduce inhole friction.**
- 3 **Formation stability with the addition of drilling fluid additives.**

The fluid circulation system is also used to power downhole equipment and instrumentation such as mud motors and data logging tools.

The drilling fluid handling system includes fluid pumps, holding tanks, mud chemical mixing systems, and in some instances solid separation or cleaning equipment. A device known as the water swivel is used to connect the system to the drill string; it is a watertight/airtight rotating joint that connects the pump to the drill string with a high-pressure hose.



The main fluid circulation pump sets the desired flow and the pressure is continually monitored for any changes which could indicate issues down the hole.

- Loss of pressure and return could indicate fluid leaking into the formation and could result in

## UNIQUE FOR UNDERGROUND DRILLING

- **Space Limitations** (transport / setup): A modular drill with a chuck drive rotation unit is better suited and typically selected to better fit into captive areas.
- **Air Quality:** Improperly maintained mechanically controlled engines can be

a significant source of contaminants in the underground environment. Modern engines provide optimum performance and cleanliness, but the available fuel grade is critical to which Tier engine is selected. The vast majority of underground drill rigs have hydraulic - electric motors.

## THE COST OF CLEAN WATER

If clean water is not easily accessible, it can add significant cost to a drilling program:

- Cost to ship to site if a natural source is not available can take a significant bite out of a budget.
- Cost of repair or replacement of equipment if the drilling fluid has not been properly treated for reuse.
- Cost to remove contaminated drilling fluids from a drill site for less environmental impact.

As a result, special equipment such as centrifuges, have been making their way onto the drill site for the reclamation of clean water.



excessive torque. Introducing additives to the drilling fluid may be required to resolve the issue.

- Increased pressure could indicate the core tube is full, or a core blockage which may require the drill string being pulled from the hole.

### ROD HANDLING:

The single most labor-intensive task on a core drill is rod handling, considering hundreds of drill rods are used in a single hole and the finite life of a drill bit. Prior to mechanization efforts, this was the responsibility of the driller's assistant which exposed them to a number of safety concerns. Today's drill configurations include improvements such as rod-loading systems for top drive drills.

### Rod-Loading System for Top Drive Drills:

The hands-free rod handling and remote controls allow the assistant to work outside the area of moving equipment, with no intervention required to trip or align the rods.



The safety benefits and effectiveness of rod handling is driving a trend towards more top drive drills such as Boart Longyear's LF™160 Core Drill.

An important component of successful rod make-up is alignment; having a rod that self-aligns to minimize cross-threading and damage has been effectively solved with the Boart Longyear dual-lead XQ™ thread.

## UNIQUE FOR RC DRILLING

### DRILL ROD

A dual wall pipe allows pressurized air to pass through the annulus of the inner and outer tubes to drive the piston. The uncontaminated cuttings are then flushed up to the surface through the center of the inner tube. These rods are significantly heavier than coring rods.

### SAMPLE COLLECTION

The rock chips are directed through a series of cyclones and splitters to dry and separate them according to size. The samples are then bagged for the geologist.



## DRILL RIG COMPONENTS

Each drill is equipped with the components necessary to achieve the critical functions. Some components may provide options to better suit drilling needs.

### 1 ENGINE/PRIME MOVER (SURFACE)

Supplies the power required to operate systems such as the hydraulics and fluid circulation pumps.

- Engine power is generally proportional to the rig's depth capacity. However, a higher power rating may be required for higher elevations.
- Global Environmental Regulations are in a constant state of change, and may vary according to region:
  - Diesel engines must conform to the emission standards for the country of end use.
  - Engine replacements must also comply with those regulations.
  - Tier 4 engines run extremely clean but require the highest quality diesel. Hence, Tier 3 engines are still necessary in markets where ultra low sulfur fuel is not available.

### 2 BASE FRAME

The base frame is constructed of structural steel and holds most of the drills components. Underground drills are typically modular with the powerpack and control console separate from the positioner/feed frame unit.

## TIERED ENGINES

The first Emissions Standards were adopted in the early 1990s and are used to classify non-road diesel engines over 37 kW (50 hp). Several tiers based on particulate matter (PM) emission rates have been set up and phased in over the years — Tier 1, 2, 3, 4, with a Tier 5 in development. Regulations are based on approved emission standards set by the US Environmental Protection Agency (EPA) and European Commission (EC), but acceptance varies by region and availability to source clean fuel.



### 3 HYDRAULIC PUMP(S) AND TANK

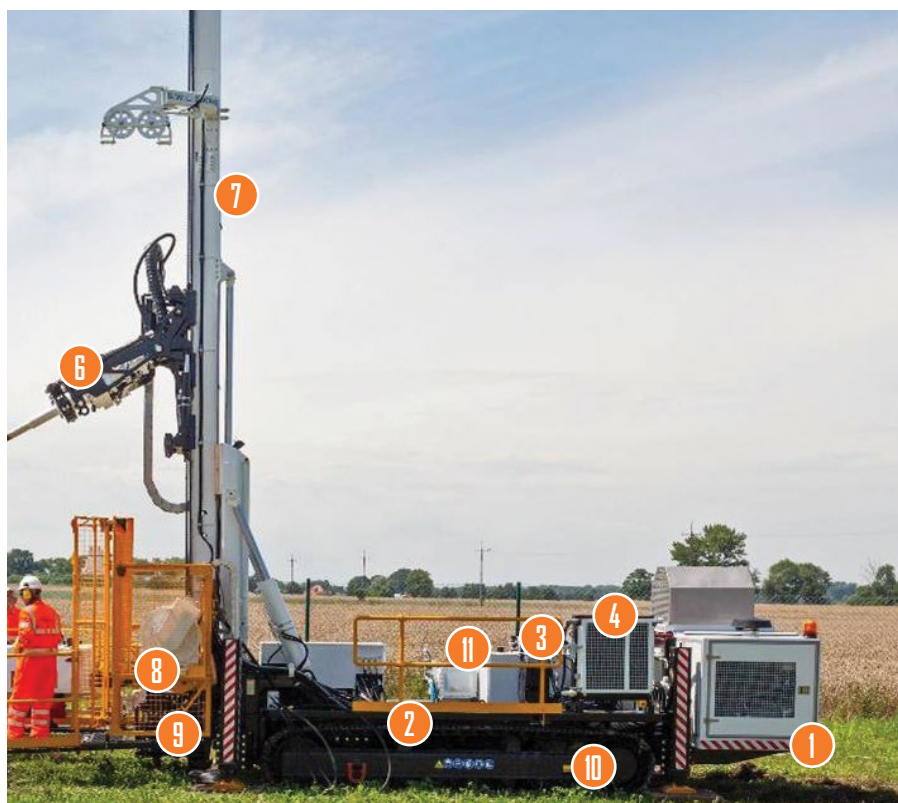
The majority of drill functions are hydraulically powered (e.g., drill head, rod handling, etc.), making the design and capacity of the hydraulic system vital for its operation.

### 4 HYDRAULIC COOLING AND FILTRATION

Maintaining hydraulic oil temperature and cleanliness within the proper range is critical to optimizing hydraulic component life. A hydraulic oil cooler maintains the hydraulic oil temperature, and hydraulic oil filters are installed to remove particles of dirt from the system.

### 5 CONTROL PANEL

All critical functions are controlled and monitored through a central control system. The operator's control panel is the interface between the driller and machine.



It consists of the hydraulic valves, gauges and switches required for the operation of drilling functions. Interlocks are often integrated into the system to prevent the operator from accidentally giving certain harmful commands.

All drills should have an Emergency Stop button located within reach of the operator/helper that switches off the engine instantly.

## 6 DRILL HEAD (ROTATION UNIT)

Provides the rotational torque, feed pressure, holdback, and pullback for the drill string. Alternative designs include top drive or hydraulic operated chuck drive.

Top drive units have a permanent water swivel fixed to the top of the drill head. The drilling fluid passes through the center of the head and into the drill string. However, if a chuck drive unit is selected, an independent water swivel must be attached to the free end of the top drill rod to allow for drilling fluid to be pumped into the drill string for drilling.

## 7 MAST / FEED FRAME / FEED FRAME POSITIONER (SURFACE)

Mast construction may vary according to manufacturers' design and the drilling requirements (length of pull).

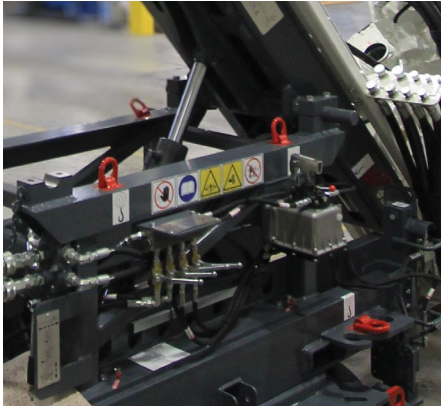
**Feed Frame:** The portion of the mast where the drill head travels up or down on a rail system by way of a cylinder that is directly coupled to the drill head, or indirectly by a chain or cable system that is powered by a cylinder or motor. It provides the guidance system, thrust, and pullback for the drill head. Surface drill feed frames can typically provide 3 - 7 m (10 - 23 ft) of travel.

- Top Drive Rigs - the mast must be the full length of one, or commonly two rods. It may require an extension to pull the inner tube assembly out of the

hole as the drill rods are unthreaded from the bottom of the head.

- Chuck Drive Rigs - the feed frame can be shorter, but the overall mast length must accommodate a mainline and wireline hoist, with enough of an extension to allow for removal of the inner tube and core sample.

**Feed Frame Positioner:** A system to ensure the correct angle of the mast and distance to the ground. Consists of hydraulic cylinders for raising and sliding (dumping) the mast into position.



**DUMP MAST:** The mast can slide along its axis to compensate for different drilling angles and mounting options. Allows the mast to be lowered to an appropriate working height for handling the inner tube without fall protection, and helps to stabilize the rig.

### Alternative Mast Designs:

- Telescopic masts are ideal for speed of set up with minimal labor required. When retracted they are compact for easy transport.
- Multiple section masts consist of two or three pieces which may be unfolded or assembled on site. The middle mast section could be omitted if only pulling 3 m (10 ft) of the string at a time. Solid masts can be more restrictive on larger drills due to transport restrictions.



## 8 WIRELINE WINCH

A mechanism consisting of a drum, gearbox, motor, and wireline cable. The cable is attached to an overshot assembly which is sent or pumped into the borehole to retrieve the inner core barrel assembly after each core run.

In dry hole conditions, the wireline winch and overshot may be used to control the descent of the inner core barrel assembly into the borehole to prevent damaging the system.

## 9 BREAK OUT DEVICE / FOOT CLAMP

The break out device is a hydraulic rod clamp located near the base of the mast. It is used in conjunction with the drill head to make and break drill rod joints. Proper rod alignment is essential to this process to prevent thread damage. As a result, some rigs also include a rod alignment device and centralizer.

The foot clamp is used to prevent the drill string from falling down the borehole during rod handling.



## 10 MOBILITY / MOUNTING

Various options exist for ease of drill mobilization such as truck, track, skid

and helicopter configurations. Base frame configuration may vary according to mobility option.

## 11 FLUID CIRCULATION PUMP

Used to circulate the drilling fluid through the coring system to flush the cuttings and to cool the bit.

## 12 ROD HANDLING

The current wave of innovation for surface and underground drilling involves moving the industry forward in safety. Electronic controls and other technology developments which enable the driller to operate equipment while physically removed from potential sources of danger. Although the catalyst for this is the need to increase safety, it can also provide greater productivity for mining operations.

An example would be the mechanization of the rod handling processes which is a key development to reduce the potential for hand and back injuries. Even though it is not equally suited for every drill, various degrees of mechanization is a positive step towards an improved work environment.

The Boart Longyear Freedom™ Loader and LF™350e rig combination is optimized for deep hole Exploration.

Together they maximize performance and provide total hands-free rod handling. No intervention from the driller's assistant is required to align and cycle the drill rods.



## UNDERGROUND DRILL RIG COMPONENTS

Footprint constraints require equipment components to be more compact, and in most cases modular to allow for easier transport. Designed with the ability to drill at all angles from vertically up to vertically down.

### 13 FEED FRAME

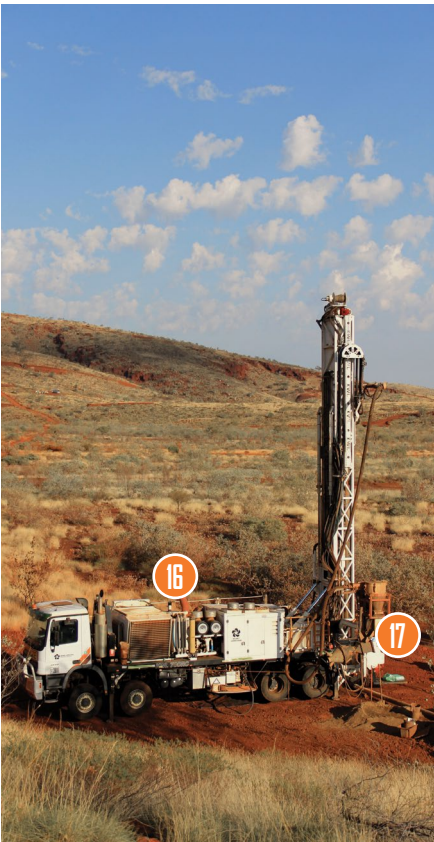
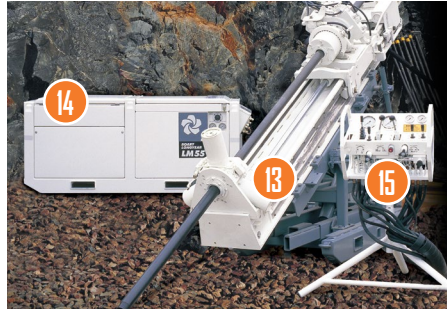
The rail system on which the drill head travels to provide the thrust and pullback requirements. Underground drill feed frames are much shorter than surface, and use a direct coupled cylinder to run the chuck drive drill head.

### 14 ENGINE / POWER PACK

Consists of the electric motor, hydraulic pumps and controls necessary to power the drill head and feed system.

### 15 CONTROL STATION

All critical functions are controlled through a central control system. Space constraints may require a modular drill be used for easier transport to the site and drill setup. In this instance, the controls are a separate module.



## RC DRILL COMPONENTS

### 16 ONBOARD AIR COMPRESSOR/ AUXILIARY AIR SUPPLY

The industry standard is 2.4 MPa (350 psi), but the demand for higher pressures in the primary feed compressors is growing. If you consider the RC hammer typically needs around 1.7 MPa (250 psi) to operate efficiently, there is only 0.7 MPa (100 psi) left for lifting the cuttings and any water that might get in the hole. If water is encountered, which happens in most cases, you will need additional air pressure to lift the weight of the water that comes in from the formation. A higher pressure compressor or an air booster may be required.

### 17 CYCLONE AND SPLITTERS

Air pressure moves the rock chips through a series of chambers that dry and sort them according to size for collection. As a result, the inner diameters of these components need to be very resistant to the spiraling, abrasive rock chips. They are usually ceramic lined.

## CONTROL SYSTEMS

Exploration follows other mining equipment towards increased automation, albeit cautiously since remote maintenance access can be challenging and completely manless operation would be a stretch. The primary driver is safety, but increased productivity and limited availability of personnel also drive the development. Fundamental to automation is the type of control system.

### LEVEL 1: Manual Hydraulic Control

- Simple to operate, troubleshoot and repair.
- Manually operated components including valves for actuators, motors and pressure controls.
- Typically one handle for each function.

### LEVEL 2: Electro-Hydraulic / Pilot Hydraulics

- Simple to operate with the ease of adding more complex controls and timers like rotation and rotation barrier interlocks, speed and pressure controls.
- Offers control over all basic functions, rotation, feed, hoisting, with no limit other than cost.

### LEVEL 3: Electro-Hydraulic + PLC

- PLC (Programmable Logic Controller) for timers and interlocks, eliminating stand-alone relays and reducing the complexity of wiring and associated downtime.
- Offers control over all basic functions with multi-function controls combined into the push of a single button.
- On board monitoring of pressure and control position.

### LEVEL 4: Electro-Hydraulic CANbus + PLC

- Very easy to manage/coordinate controls and sensors anywhere on the rig. CANbus further simplifies interconnecting wiring and improves troubleshooting.
- Allows the PLC to communicate directly with the engine or any other CANbus components on the network.

### LEVEL 5: Electro-Hydraulic CANbus + PLC Automation

- The PLC can monitor inputs such as component positions, hydraulic pressures and flows, switch outputs, valve spool positions, motor speed, and engine control data.
- Provides the operator with real-time drilling data such as penetration rate, feed force, head speed and torque, E-Stop, and barrier condition.
- Works well for more complex tasks including unattended drilling / monitoring and mechanized rod handling.

## SUPPORT EQUIPMENT AND TOOLS

- Projects are often remote requiring live-in facilities for the crew including a full camp, office, workshop, and light plant.
- Drilling fluid or mud systems can include holding tanks, mud mixers, and settling ponds to reclaim the water.
- A drill shack or tent protect the crew while working on the drill. Elevated platforms or decking can also make the site more workable.
- Hand and power tools. Specialty tools such as inner / outer tube wrenches and rod wrenches prevent damage.
- Proper storage for tools and equipment extend their life.
- Separate storage facility for hazardous materials.
- Core trays to store and organize the core samples.
- Lifting equipment and material movers assist with installation and onsite organization.
- Hauling vehicles used to bring the drill and equipment to site, or bringing in water.



# ESSENTIAL MAINTENANCE

## RELIABILITY CENTERED MAINTENANCE (RCM) REDUCES UNPLANNED DOWNTIME, AND WILL INCREASE THE DRILL'S PRODUCTIVITY AND LIFESPAN.

Some drilling contractors will run drill rig parts to failure, while other maintenance programs call for the replacement of parts at fixed intervals regardless of wear or condition. Neither of these philosophies, however, is the most cost-effective.

- Running parts to failure can cause minor or even major breakdowns, which costs money – lost productivity, jeopardizing up-time contractual obligations, and lost drilling time waiting for replacement parts.
- Even though planning is critical, component wear life is dependent on the type of drilling, size of the bore hole and the environmental conditions. As a result, a strictly preventive maintenance program can cost more by replacing parts, regardless of condition, and leaving some life (\$\$) on the table.

A drill rig maintenance program of regular inspections, planned preventive maintenance, and scheduled major maintenance/overhauls is a better way to lower and manage the cost of ownership, and will keep the rig running and drilling reliably.



# TECHNOLOGY DRIVERS

**HOLE DEPTH:** With most easily accessible ore bodies already exploited, new bodies have to be explored at increasing hole depth. This in turn drives directional drilling and increasing use of mother-daughter holes. New drill rigs are consequently increasingly powerful and capable.

**COST EFFICIENCY:** Economic viability demands increasing productivity. Speed of setup, ease of training, uptime, and reliability drive cost efficiency. Drill rig technology should be leveraged to increase productivity per man-hour.

**AUTOMATION:** Developments in digital technology support automation of various functions. This has multiple advantages, least not reducing manpower requirements and attracting a new generation of drillers to the profession.

**SAFETY:** The safety focus and culture of the mining industry places new demand on mechanization, service accessibility, interlocks and other safety features. Today, a risk assessment is central to the engineering process, leading to very tangible differences in how mechanical, hydraulic, and electric systems are designed.

**ENVIRONMENTAL IMPACT:** Upgraded clean engines, efficient hydraulics, and compact layouts all contribute to reduce the environmental footprint. Exploration drilling technology contributes its share to more sustainable mining.

**INFORMATION:** Management, tracking, and invoicing is increasingly data driven, creating an expectation of and reporting from the drill site. Connectivity is a challenge in Exploration, but technologies and processes are improving to extract meaningful and timely information.

VALUE DRIVER	INFLUENCING FACTORS	FUNCTIONALITY	CONSIDERATIONS
SAFETY	MECHANIZATION	<ul style="list-style-type: none"> <li>Less risk of injury with operator not being in proximity of or handling of drill rods.</li> </ul>	<ul style="list-style-type: none"> <li>Not all mine site safety protocols will require rod handling.</li> <li>May not be practical in all instances, e.g., fly jobs or when access is limited.</li> <li>Increased rig cost.</li> </ul>
	GUARDING	<ul style="list-style-type: none"> <li>All rigs have some form of guarding to keep the operator safe from potential hazards.</li> <li>More advanced rigs may use radar systems or laser curtains to restrict access to areas.</li> </ul>	<ul style="list-style-type: none"> <li>Interlock barriers will limit or stop certain functions.</li> <li>The amount and technology used may vary. More basic drills may have physical barriers with no interlocks, but such low-cost designs may be sufficient.</li> </ul>
	RIG CONTROLS	<ul style="list-style-type: none"> <li>Type of control will dictate how comprehensive the safety system of a rig can be.</li> <li>Moves the operator farther away from potential danger.</li> </ul>	<ul style="list-style-type: none"> <li>Increased initial cost.</li> <li>Maintenance personnel may need additional skills (electrical).</li> </ul>
	AUTOMATION	<ul style="list-style-type: none"> <li>Reduce the need for multiple operators/helpers.</li> </ul>	<ul style="list-style-type: none"> <li>Increased cost and may not be suited to every drill.</li> <li>Remote maintenance challenges.</li> </ul>
	NOISE LEVEL	<ul style="list-style-type: none"> <li>Better work environment, and less impact on surrounding communities and wildlife.</li> </ul>	<ul style="list-style-type: none"> <li>Engine design has taken significant strides in emission and noise reduction but regional limitations may exclude use due to fuel availability.</li> </ul>

VALUE DRIVER	INFLUENCING FACTORS	FUNCTIONALITY	CONSIDERATIONS
FIT FOR PURPOSE	SUITABILITY	<ul style="list-style-type: none"> <li>A number of rig types are offered to meet demands, but selecting a rig which meets the application and power requirements will help to ensure successful completion of the project.</li> </ul>	<ul style="list-style-type: none"> <li>Sorting through the many rig offerings on the market to find what is right for the application.</li> <li>Geographic location may limit rig options.</li> </ul>
	OBJECTIVES	<ul style="list-style-type: none"> <li>Knowing what the majority of work will be prior to rig selection will help narrow the selection process.</li> </ul>	<ul style="list-style-type: none"> <li>Larger drill - a greater capital investment and generally higher operating costs.</li> <li>Smaller drill - may not be capable or as efficient when drilling deeper or larger diameter holes.</li> </ul>
	LIFE CYCLE	<ul style="list-style-type: none"> <li>Price vs Cost - lower priced drills offering similar characteristics may not meet the project demands.</li> </ul>	<ul style="list-style-type: none"> <li>Continued operation at maximum capacity may result in excessive downtime. A more heavy-duty rig may perform more consistently.</li> <li>The cost of maintenance and downtime may add up to more than a higher priced drill.</li> </ul>



VALUE DRIVER	INFLUENCING FACTORS	FUNCTIONALITY	CONSIDERATIONS
PRODUCTIVITY	POWER	<ul style="list-style-type: none"> <li>Better depth capacity and larger core samples.</li> </ul>	<ul style="list-style-type: none"> <li>Increased fuel cost, potentially larger rig footprint.</li> </ul>
	SIZE	<ul style="list-style-type: none"> <li>Increased feed stroke and longer inner tube pulling capacity drive higher productivity.</li> </ul>	<ul style="list-style-type: none"> <li>Less mobile for harder to access areas and potentially larger pad size.</li> </ul>
	TECHNOLOGY	<ul style="list-style-type: none"> <li>Semi-autonomous drilling over breaks and shift changes can increase productivity and meters/feet drilled dramatically.</li> </ul>	<ul style="list-style-type: none"> <li>Additional cost to provide the additional productivity may be hard to utilize.</li> <li>Potential need for more skillful maintenance personnel.</li> </ul>
	MOBILITY AND SETUP TIMES	<ul style="list-style-type: none"> <li>Time savings between holes - critical for short holes, less important for deep holes.</li> <li>Mobilization to site.</li> </ul>	<ul style="list-style-type: none"> <li>Mounting options and hydraulic features like a telescopic mast will increase initial rig cost.</li> <li>Consider the initial cost of equipment vs. the time savings.</li> </ul>

VALUE DRIVER	INFLUENCING FACTORS	FUNCTIONALITY	CONSIDERATIONS
RELIABILITY	PROVEN COMPONENTS	<ul style="list-style-type: none"> <li>Reduced maintenance cost, and less downtime.</li> </ul>	<ul style="list-style-type: none"> <li>Difficulty in sourcing the components, limited availability.</li> <li>Time to market.</li> </ul>
	AFTERMARKET SUPPORT	<ul style="list-style-type: none"> <li>Manufacturers providing highly skilled maintenance teams with access to spare parts, ensuring little to no downtime.</li> <li>Concise manuals and work instructions are key support items.</li> <li>Individual spare parts or kits are critical to keeping the rig operating.</li> </ul>	<ul style="list-style-type: none"> <li>Open line of communications with the supplier for planning and stocking of replacement parts.</li> <li>Less common rigs may require the user to stock additional spares themselves.</li> </ul>
	ADVANCED DIAGNOSTICS (Troubleshooting)	<ul style="list-style-type: none"> <li>Embedded diagnostics to indicate when preventative maintenance may be required.</li> <li>Access to or removal of rig components for easier maintenance or repair.</li> </ul>	<ul style="list-style-type: none"> <li>Requires a more complex operating system and an understanding of how to navigate the diagnostics.</li> <li>More accessibility generally means the size and cost of equipment increases.</li> </ul>

## YEARS OF USEFUL LIFE

*Downtime has become a bigger issue as Exploration programs move to more remote locations around the world. If a contractor is down for more than a day it can cost thousands of dollars.*

A number of factors can influence equipment life:

- Drilling conditions and the operating environment.
- Water quality (brackish).
- Maintenance - a daily walk around by the driller and a preventive maintenance schedule is advised.



# THE RESULTS

The alignment of clear objectives, miner-contractor relationships, equipment, and tools, drive cost-effective and safe results.

# THE RESULTS



## THE RFQ PROCESS

Drilling can be a highly uncertain business and the RFQ (Request for Quotation) is a critical part of that process. It needs to be clearly defined by the miner and understood by the drilling contractor in order for both parties to be satisfied with the outcome.

Changes to the scope of a project after it has been awarded can affect the budget of anybody who invests in finding and evaluating potential ore bodies. It may require a portion of the contract to be renegotiated.

### MINER RESPONSIBILITY:

- Define exactly what is expected. All work and preparations costs money, so everything must be clear before the drilling contractor can bid.
- Outline expected delivery targets.
- Understand what qualified contractors provide, and what is needed to assist

with the success of the project, e.g., utilities, accommodations, support vehicles, qualified personnel, or logistics services.

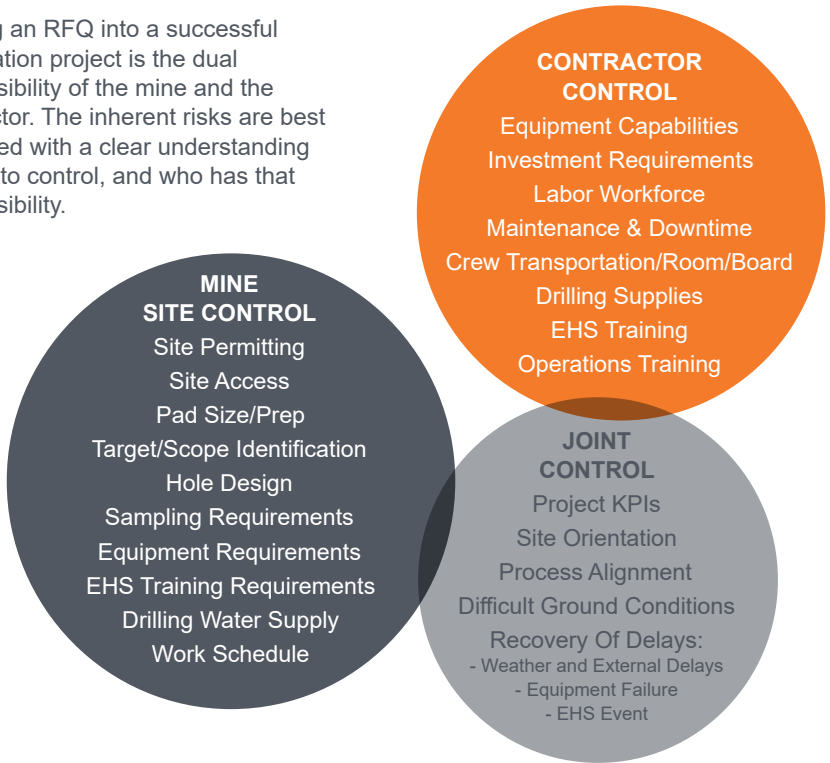
### DRILLING CONTRACTOR RESPONSIBILITY:

- Understand the scope of work. Gather as much information as possible.
- Failure to do a site visit prior to bidding could result in over or under pricing the job.
- Clearly state what the price is based on. Ask questions if any points in the RFQ are unclear.
- Complete a credit check and ask for a deposit where necessary.
- Competitive landscape – who are the players, this could indicate what the market price should be.
- Consider the competitive landscape. Understand the quality requirements and price expectations for a successful bid. Be aware of how any previous contractors have fared.



## PROJECT CONTROL

Turning an RFQ into a successful Exploration project is the dual responsibility of the mine and the contractor. The inherent risks are best managed with a clear understanding of how to control, and who has that responsibility.



## MUTUAL DEPENDENCY

The relationship between the mine and contractor is mutual; both depend on the other to succeed, and both need to understand the other's position, strategy, and way of working. Ultimately, it is a question of outcomes, be it technical geological information or long-term financial viability.

While the RFQ process typically focuses on the next project at hand, a broader and longer term perspective is justified.

The first step is to evaluate what relationship is desired or possible. This can be mapped as a matrix with four quadrants.

The value of the relationship matrix is to illustrate that the dependency between miners and contractors go beyond the next job or open RFQ.

Commercial Potential	HIGH	<p><b>Technical Specialist</b></p> <p>Cooperate in niche applications where the contractor is focused.</p>	<p><b>Strategic Partnership</b></p> <p>Leverage innovation and best practices to create the most value in one discovery.</p>
	LOW	<p><b>Transactional Agreements</b></p> <p>Establish agreements in areas where the contractor provides the best value.</p>	<p><b>Preferred Supplier</b></p> <p>Develop stable agreements where the contractor can be most cost effective.</p>
		LOW	HIGH

**Technical Potential**

For a major mining house or a global contractor, all four quadrants are possible, although the transactional may not be desirable. But for a minor mining house or local contractor, the opposite may hold true.



The next step is to evaluate the actual behaviors. The illustration includes some of the factors worth considering to reach alignment. These factors are largely non-financial, but should nevertheless be part of the bidding and tender review process.



## THE DRILL PAD



Designing and planning a drilling project is a complex exercise in which many risk factors need to be considered in order to mitigate issues that could impact productivity and/or cost.

Attention must be given to the size of the equipment needed, and all of the necessary ancillary equipment, including sumps and access. The depth of the

hole can also affect the setup area, also known as the drill pad, including organization of the equipment for mud and cuttings management, drill rod staging, and the storing of consumables. Typically the geologists will work with the contractor to establish the ideal dimensions, ensuring both safety and productivity.

It is also key to consider the location of the borehole prior to setting up the area, ensure at least 3 m (10 ft) of clearance around the drilling equipment.

The drill pad layout will need to address site access as well so that visitors remain safe and are not exposed to any site hazards prior to a comprehensive and robust site induction.

If surface disturbance permits or environmental permits are required, a

## COMMON MISCONCEPTION

The smaller the drill pad, the less it will cost — cutting corners on this important aspect of a drilling program can cost a lot more in the end. For example, if there's not enough room to position the rig and the rod handling equipment, manually handling rods can impede productivity and reduce safety on the site.



consultation with the contractor on drill pad size prior to applying for the permits might save time and avoid any misunderstanding. Communication is critical, a simple oversight could possibly delay site mobilization or start-up if permits are not what's needed for the appropriate size and location. Ideally, these conversations should start happening early in the planning stages of the drilling program.

## **A MISCALCULATION IN THE REQUIRED DISTURBANCE AREA CAN LEAD TO HOLES BEING REMOVED FROM THE SCOPE TO REMAIN IN COMPLIANCE WITH REGULATIONS.**

Other considerations when planning:

### **Access Road**

- Width
- Berms
- Grades
- Overhead clearances (power lines).

### **Location of Water and Fuel**

- Road conditions and grades
- Size and location - distance from pad and access around other equipment.

### **Communications**

- Radio
- Cell phone
- Satellite phone

### **Sumps**

- Size requirement and proximity to rig, hole, and mud tank.
- Accessibility to remove muds when full or at the end of project.

### **Drainage**

- Environmental controls/potential runoff.

### **Ground Condition Controls**

- Sloped banks
- Rock face
- Subgrade utilities

### **Surveyed Hole Layout**

- Hole location
- Direction
- Front/back site

It is critical to working closely with all involved parties and to listen to concerns and suggestions to optimize the drilling program outcome.



## THE BOTTOM LINE

Anybody looking for a simple formula to calculate productivity and cost for Exploration drilling will be disappointed. There are simply too many variables for generic figures or rules-of-thumb.

Specific numbers can be discussed in examples, but it's better to understand the underlying factors that drive productivity and cost in order to pull the levers that deliver the results and optimize the bottom line.

To simplify, costs are either:

- 1 VARIABLE**  
e.g., bit cost per meter (foot).
- 2 FIXED**  
e.g., rig depreciation cost per hour.

To optimize the total cost, fixed costs must be minimized through productivity. In reality, most costs fall in-between, but the road to minimize costs like labor or maintenance still goes through increased productivity.

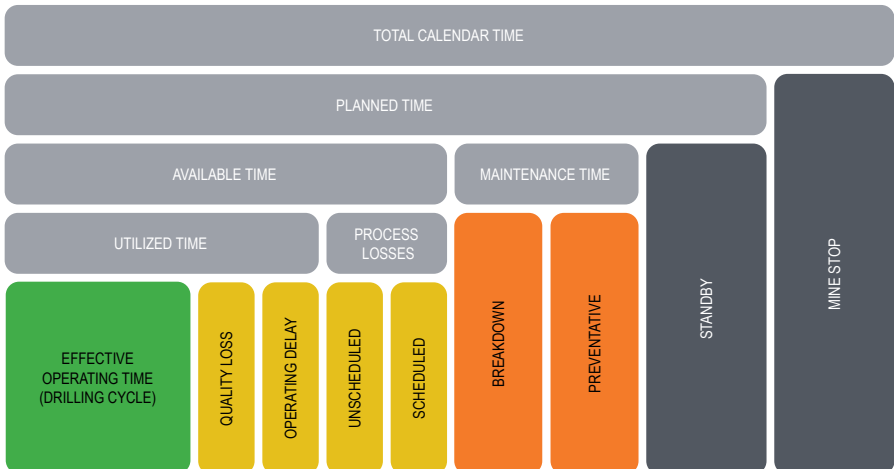
## TIME UTILIZATION

In Exploration drilling, effective operating time is the time spent in the drilling cycle. Everything else is non-productive time,

albeit often necessary and value-added, such as set-up time, safety briefings, or preventive maintenance. Understanding and minimizing the losses are often very effective. A Time Usage Model is a tool to increase operating time. Consider that it's common to only actively drill for 5 hours in a 10 hour shift in an underground operation, or 8 hours in a surface operation, but 3 hours of productive time is not unheard of. Some of the main issues are:

- **Process Loss** - travel to and from the drill, lunch breaks, or blasting time all significantly reduce effective shift time. Different solutions could include hot changes or modifications in the shift roster.
- **Operating Delays** - these could include restricted site access, meetings, waiting for decisions, inputs, or materials, and other hold-ups, such as surveying or waiting for the hoist to get underground. These can often be addressed through communications and planning.
- **Breakdowns** - unplanned maintenance should be minimized through inspection procedures and preventative maintenance. New or recently rebuilt rigs are also more reliable. Nevertheless, mechanical,

## Time Usage Model



Identifies all non-productive time that reduces the active drilling cycle time.



hydraulic, and electrical failures do occur and there must be protocols in place for quick response of spare parts and maintenance expertise.

- **Quality Loss** - some operations/drillers are inherently more efficient than others. Spacious enough drill pads, proper setups, training, and incentives reduce the efficiency losses. Poor ergonomics and physical work, like manual rod handling, are tiring and impact performance during long shifts.

### Time Usage Model

The full model is generic and applies to all mining activities. As such, it is useful to manage Exploration with the same KPIs. However, a simpler and more pragmatic approach is to only use three categories, along with a color-coded dashboard, e.g. as shown in the model. The percentage of drilling is a straightforward measure of Operational Equipment Efficiency (OEE).

- **Drilling Cycle** - maximize this area!
- **Utilization** - non-drilling activities outside the drilling cycle should be minimized (e.g., operational delays).
- **Downtime** - preventive or breakdown maintenance of the drill. Minimize or eliminate the red!

## DRILLING EFFICIENCY

The next step in the efficiency modeling is to break down the drilling cycle into recurring activities. There are additional steps that consume time, such as setting casing, cementing the top section, or adding wedges for direction control, but those need to be analyzed case-by-case and tracked as utilization losses. Including some common figures, the recurring on-hole cycle time consists of:

### 1 Bit on Bottom

This is the actual drilling and is determined by the penetration rate. In a typical hard rock application, penetration rate is 0.30 m/min (1 ft/min), but can vary from 0.1 to 1 m/min depending on rock type and drill bit. Often the strata changes with depth. Variations in lithologies, mineralogy, and rock quality all significantly impact penetration rate.

### 2 Rod Handling

To change worn drill bits or reaming shells, time is spent “tripping,” removing and returning the entire drill string to the hole.

## GOOD PLANNING CAN HELP A CONTRACTOR TO AVOID UNWANTED CONSEQUENCES...

...that could affect compliance, cost of reputation, and profits.

1. Supply Logistics: Delayed equipment/supplies due to incorrect documentation can delay the project start date.
2. Forecasting: Not ordering the correct consumables could cause rig shutdown.
3. Assumed Productivity: Not understanding variations in conditions could impact both progress and cash flow.
4. Training: Not ensuring the crew is properly trained could result in injury, equipment damage, and loss of reputation.
5. Spill Containment: Improper handling of environmental spills could result in heavy fines.
6. Equipment Condition and Maintenance: Any unplanned downtime affects the schedule and increases costs.
7. Change Orders: It is important to ask questions at the bidding stage. Changes made after startup are not always welcome by either side (mine site or contractor).



This breaks into four components and times will vary with the speed of the drill hydraulics, thread profile of the drill rod, and section length:

1. Break-out rod joint (30-40 s/ea).
2. Retract one rod section out of the hole (20-30 s/ea).
3. Make-up a new rod joint (30-40 s/ea).
4. Feed one rod section back into the hole (20-30 s/ea).

Most rod handling in surface drilling is done two rods at a time, in 6 m (20 ft) sections. Handling of rods outside the drill is done in parallel, so it normally does not affect the cycle time. The number of “trips” is driven by the bit life; 250 m (820 ft) is a normal life, but it can vary from 10 to 2,000 m (30 to 6,600 ft) in extreme cases! The reaming shell is typically changed out on the third bit change.

### 3 Core Recovery

This is the “wireline” time to extract the core sample, including three trips up and down the hole:

1. Send the overshot to the bottom to lock onto the core barrel.
2. Pull the overshot and core barrel inner tube assembly to the surface.
3. Return an empty inner tube assembly back down the borehole.

Down-speed ranges from 0.8 to 1.3 m/s (2.62 to 4.27 ft/s) and up-speed

from 0.6 to 1.0 m/s (1.97 to 3.28 ft/s), assuming the overshot and the locking mechanisms work properly. The tripping speeds are largely determined by the hydraulic drag inside the drill pipe, especially with gravity driving the down-speed descent.

These figures are common in surface operations but will change for uphole drilling in underground applications. For example, there is also a step to extract the core barrel at the rig.

Those so inclined can calculate the cycle times using the formulas shown. These are simplified and ignore the less important components. In practice, average drill meters per shift are estimated, and normally fall in the range 30 - 150 m (100 - 500 ft) per shift for surface drilling and 25 - 80 m (80 - 260 ft) for underground drilling.

### IMPACT OF HOLE DEPTH

Consider a sample calculation of ‘N’ size core drilling with various inputs, including a bit life of 250 m (820 ft) and a drilling penetration rate of 0.30 m/minute (1 ft/min). Such a shallow hole is very efficient, with 65% of the cycle time spent with bit on the bottom.

But even with the same penetration rate, drilling a 2,000 m (6,600 ft) hole is much less efficient, with only 21% efficient drilling time and a 3.4 times higher drilling cost. Still, these averages mask how cost escalates with depth.

## CALCULATING WIRELINE AND TRIPPING TIME

### (As Part of The Drilling Cycle)

The main implication of the summation ( $\Sigma$ ) is that time losses for wireline and tripping increase rapidly as holes get deeper. Actual drilling time falls off sharply with depth.

$$\text{Wireline Pulls} \sum_{(n=1)} n \times \text{Core length (m)} \times \left( \frac{1}{\text{Wireline down (m/s)}} + \frac{1}{\text{Wireline up (m/s)}} + \frac{1}{\text{Overshot down (m/s)}} \right) \times \frac{1 \text{ hour}}{3,600 \text{ seconds}}$$

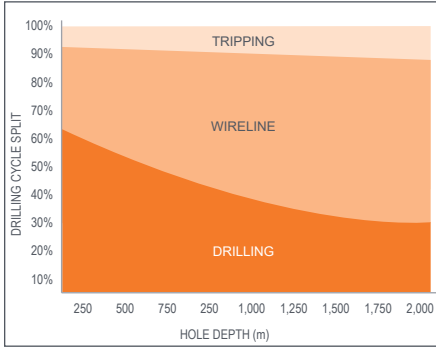
$$\text{Rod Trips} \sum_{(n=1)} n \times \frac{\text{Bit Life(m)}}{\text{Rod Pull (m)}} \times (\text{Rod break (min/rod)} + \text{Rod make (min/rod)}) \times \frac{1 \text{ hour}}{60 \text{ minutes}}$$



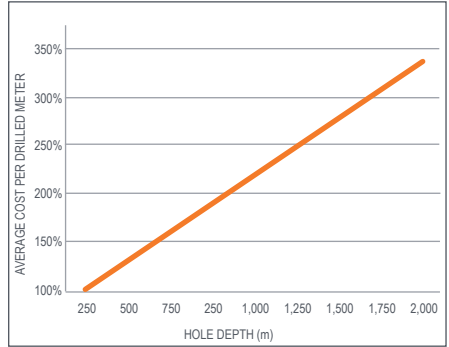
In this example the last 100 m (330 ft) cost as much as the first 425 m (1,400 ft)! The example does not include additional factors that affect the total drilling cost.

The non-drilling time is spent recovering core or tripping rod to replace the bit. The modest increase in tripping is somewhat of

an illusion; instead, compare the relative time of tripping versus drilling. Near the surface, tripping time is marginal and the focus should be on the bit's penetration rate. But at the bottom of a deep hole, tripping time starts to approach the drilling time, especially if the bit life becomes shorter.



Example: Average time split of the drilling cycle depending on hole depth.



Example: Cost escalation as a function of total hole depth.

## ADDITIONAL COSTS AND OVERRUNS

Besides direct drilling costs, there are indirect costs, such as safety personnel, geologists, managers, and other support personnel. Any delays or inefficiencies in the drilling program will extend these costs. There are also upfront costs for constructing the drill pad and ongoing costs for hauling water, surveying, and maintaining access roads.

The larger cost to consider is the complete cost of handling and assaying the core. These costs will often exceed the total cost of drilling activities. Timely and accurate evaluation on site can reduce these downstream costs.

Delays can happen for a number of reasons. In operating mines, site access can be restricted for operational or safety reasons. And on the hole, failures can occur that interrupt drilling. A broken or dropped drill string can take days to fish out, and equipment failures can shut operations down for weeks.

In the worst case, a deep hole may have to be abandoned and redrilled, causing months of delay. While these delays are unfortunate for everyone, they can be financially detrimental for smaller companies.

Nobody plans or budgets for accidents, but everybody must be aware that they do occur. Even a small job can come with a high penalty! Direct costs include workers' compensation, medical, and legal expenses. Indirect costs include replacement employees, accident investigation, corrective measures, and productivity losses.

The Occupational Safety and Health Administration (OSHA) in the United States provides cost estimates by type of injury. For example, direct and indirect costs are estimated at US\$69K for a strain, US\$112K for a fracture, and US\$186K for an amputation. Everybody is better off with enough money in Exploration projects to invest in safety before and during the work.



## DIRECT COST FACTORS

These cost factors apply somewhat differently to surface and underground Exploration. Effective productivity and labor costs are actually similar; the low utilization underground is offset by shallower holes. But the smaller underground drills have significantly lower depreciation and maintenance costs. Mobilization/demobilization and living expenses tend to be lower at established mine sites

- **COMPETENCE**

Experience and professionalism by the drill crew have a major impact on productivity and therefore on cost. When planning a job, many things can go wrong and you really must “sweat the small stuff.” Competence goes beyond the drill crew; the support network has a major impact on planning, parts supply, and technical support.

- **CONSUMABLES**

This includes drill rods and casing, wireline components, drilling muds, cement, etc., and is normally around 15% of the total direct cost. Diamond product costs are usually itemized since they are highly dependent on the rock type, but fall in the 2-10% range. The costs for energy, diesel

fuel or electricity, is only 1-2%, and not necessarily tracked per drill rig.

- **LABOR**

This is the single highest direct cost in drilling. Depending on the local labor costs, it is typically in the 35-50% range of the total Exploration cost.

- **MAINTENANCE**

This includes both parts and labor for preventive and corrective maintenance, including oils, lubes, filters, and replacement parts. It is typically 10-15%.

- **DEPRECIATION**

One way to treat the cost of capital equipment is to simply depreciate the value over a fixed number of years. Another is to take the cost of capital (the interest rate), to calculate the annual cost. A third, but more complicated approach, is to calculate the opportunity cost (what other investment could be done with the same money). When done, all costs should be covered, including rigs, rebuilds, and support/rental equipment. The cost is usually 5-10% of the total.

- **LIVING EXPENSES**

The costs for travel, housing, and per diem vary, but 5% is a good average.

## PRACTICAL OPTIMIZATION

*3-5% of direct cost, but 10% impact on productivity and total drilling cost. That is the influence of wireline systems, drill bits, and rods – EACH!*

So, how do you optimize productivity and minimize total drilling cost? Every situation is different, but the following could be addressed, in order of importance:

- Maximize operating time - apply a Time Usage Model to minimize all non-productive time.

- Fill the core barrels - utilize skilled drillers to consistently fill the core barrels. It is common to specify a 95% recovery. If conditions dictate shorter core runs, it could dramatically increase the wireline time.
- Increase wireline down-speed - wireline time is the single most important factor in the drilling cycle. Utilize a combination of drill rods and wireline tools that allow the tools to move the fastest to the bottom of the hole. It can impact productivity and total cost up to 10%.



- **MOBILIZATION/DEMOBILIZATION**

These costs vary widely but are normally 3-5%.

- **AUTOMATION**

Mechanization and automation of individual functions are typically driven by safety and have little or no impact on productivity and cost. It would have to be taken to the level of manpower reduction on site to actually impact costs. But if at some point in the future, remote or manless operation of Exploration drills becomes a reality, that will drive a huge improvement in time utilization.

## COST BUDGETING

It is common to include 'N', 'H', and 'P' sized boreholes in the same contract. This may seem challenging, but the difference in direct drilling cost is not as significant as one might think.

Usually, the drilling equipment is the same and so are the labor requirements. The impact of consumables changes the total costs only 1-2%; the bigger driver is that productivity decreases with larger sized drilling systems. Practical experience says that drilling with 'H' is about 4% slower than 'N', and 'P' approximately 6-7% slower than 'H'.

Drilling contracts are done following one of three models:

### 1 METER PRICE

The contractor is paid at a fixed price/ meter drilled, with no additions for standby time, such as weather delays, water delays, site access, or blasting delays. This drives productivity and cost efficiency, but not necessarily quality, safety, and collaboration between miners and contractors.

### 2 HOURLY RATE

There is no link to productivity and the contractor rate is strictly based on hours. The pros and cons are the opposite of the "meter price" model. Although not commonly used, this model works when the relationship is strong and the contractor is highly motivated to retain the contract long term.

### 3 SPLIT CHARGE

This model simply splits between a price/ meter when drilling and an hourly rate when not drilling. By sharing the risks between difficult drilling conditions and time delays, it protects both parties. It is

## PRACTICAL OPTIMIZATION (cont'd)

- Deliberate drill bit choices - the criteria are penetration rate and life. For shallow holes, high penetration rate dictates the choice, but for deep holes the balance shifts to long life and reduced tripping time. At least two different bit styles should be kept on hand, to account for depth and changes in rock conditions. Optimization is more difficult than with wireline speed, but it too can impact productivity and cost by 10%.
- Drill rods - rods are often chosen based on history of reliability or depth capacity, to minimize the risk of broken drill

strings and, worst case, of lost holes.

Many operations track wear life and cost per meter for the rods alone. But rods also have an impact on productivity through make- and break-time of joints and wireline speeds by reducing the drag. The combined effects can impact productivity and cost also by 10%.

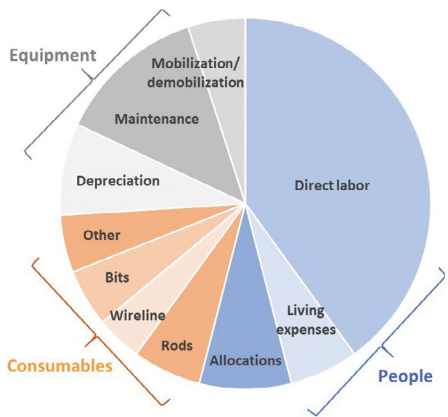
- Hydraulic speeds - faster rod retract and feed reduce tripping time to change bits, although speeding up the hydraulics only has a net impact on productivity up to approximately 2%.



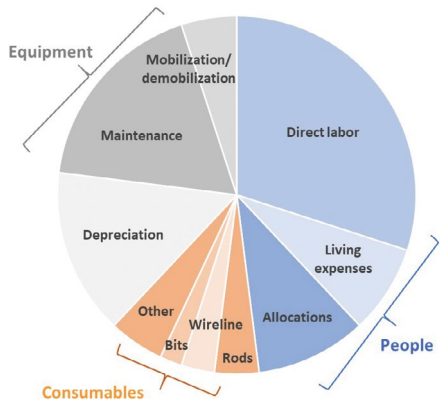
the most common model and works well if the definitions are clear and the administrative procedures to track time are strong.

For illustrative purposes, three examples are shown with indicative breakdowns by type of cost. These examples show the general proportions between equipment, consumables, and people costs. Various allocated costs are included, such as general overhead, recruiting, training, and insurance.

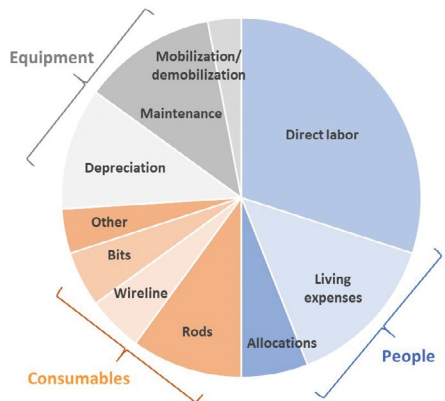
Even small changes in rock conditions, hole depth, or accessibility can significantly change the total cost per drill meter. Any attempt to estimate effective total cost must also include the standby time. Excluding extreme cases, effective total cost per drill meter commonly ranges between \$50 and \$250.



Example: Costs for underground gold exploration in Canada, 'N' sized drilling, 250 m hole depth.



Example: Costs for surface copper exploration in Chile, 'H' sized drilling, 600 m hole depth.



Example: Costs for surface coal exploration in Indonesia, 'P' sized drilling, 250 m hole depth.

# THE OFFERING

BOART LONGYEAR TOOLS & EQUIPMENT

For over 130 years, Boart Longyear has advanced Exploration core drilling to its current state-of-the-art.

Our offering has evolved through innovation, materials science, engineering expertise, and advanced manufacturing. Every product we bring to market is already proven to deliver results.

- Safety and reliability.
- Functionality, precision and ease-of-use.
- Longevity and serviceability.
- Penetration rates and cycle time.
- Information collection and sharing.

# BOART LONGYEAR TOOLS

## NEVER STAND STILL

A philosophy that has kept Boart Longyear a global leader in Exploration tools for over 130 years.



## FASTER DRILLING WITH DECREASED CYCLE TIMES

Manufacturing accuracy, quality controls, materials development, and innovative engineering, has enabled Boart Longyear to offer superior products to the Exploration market that save time, and time is money in the drilling business.

**Tool design and quality tie directly to operational requirements:**

As the need grows to explore at greater depths, choosing the right tools for the job has never been so important. If your tools are not made to the highest standards, your investment can be lost down the hole.

- 1 Drill rods need to withstand the stress placed upon them as the number of rods and rod joints increase. Directional drilling or wedging programs will add significantly more stress.
- 2 Variable ground conditions, shallow and deep holes all dictate different performance requirements from a bit. Selecting a bit that strikes the right balance between life and penetration rate is critical to maximizing profits.
- 3 The core barrel inner assembly travels a great distance to land at the bottom of the hole. If it is not equipped with quick descent features, you could be wasting a lot of time before you can resume drilling.
- 4 Latching and unlatching of the inner tube assembly is critical to core recovery. If your assembly does not perform as expected, drilling efforts and your core sample can be lost.
- 5 Added depth also means added cost for the mine site. If you need to provide accurate geological data to help the mine make a more confident decision, you will need the best tools to do so.



# WIRELINE DRILL ROD

Since Boart Longyear's introduction of the Q™ wireline drill rod in 1966, we have continued to evolve our offering through design, material specifications, and processes that set the benchmark in the industry.

## MATERIAL SELECTION AND HEAT TREAT:

Boart Longyear continues to work with expert metallurgists and select steel mills to optimize material properties ensuring the end product has both the fatigue and yield strength necessary to stand up to the rigorous demands of core drilling. We start with the highest quality tubing that has been "reset"; releasing all residual stress and restoring the elasticity or the full yield strength of the material.

*Imagine the amount of torque needed to turn a 4,000 m (13,000 ft) string of drill rods while cutting through various rock formations. That is over 1,300 pieces of drill rods rubbing against the side wall while the bit advances.*

Boart Longyear has spent years perfecting the heat treatment process. We use two methods to produce an end product that is perfectly balanced for superior life and reliability.

175% INCREASE  
MATERIAL STRENGTH

Through-wall induction heat treat transforms the material to a specified hardness, finding the perfect balance between wear resistance and toughness. It is applied to Boart Longyear's drill rod and locking couplings.

VIRTUALLY ELIMINATES  
GALLING

High-frequency induction case hardening is applied to the pin threads to make them significantly harder than the box, reducing galling. It is a challenging process, and Boart Longyear was the first to successfully apply it.

Boart Longyear uses the same high quality drill rod steel in the manufacturing of our locking and adapter couplings, and outer tubes. We stand out by never compromising system integrity to save on nominal costs.

## DESIGN:

When challenged to redesign the drill rod to better suit deep hole drilling, Boart Longyear engineers pioneered a concept to overhaul the traditional straight wall rod tubing. This led to the launch of our W-Wall™ rod tubing.

### W-Wall™ Rod Tubing

A patented, internal-upset rod tubing that offers the following benefits and is available with our HD, RQ™, or XQ™ threads:

- 1 Quicker descent times thanks to the increased annulus between rod string and inner tube assembly.
- 2 Increased mid-body flexibility for reduced stress at joints, improving thread life in wedging or steering applications.
- 3 Reduced weight:
  - Less operator fatigue and risk of hand/wrist/back injury when handling manually.
  - Improved depth capacity using the same drill.

### EXAMPLE:

Depth capacity using the same LF™90D rig.

Drill Rod	m	ft
PHD	417	1,368
PHD W-WALL™	542	1,778

**125 additional meters equals a 30% increase in depth!**

- A smaller drill could achieve similar depth capacity with reduced operational requirements and cost.

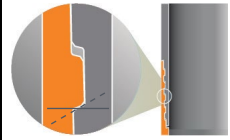


## THREAD PROFILES

### Genuine Q™

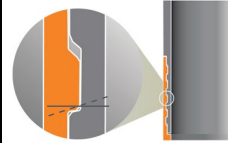
A tapered, coarse thread providing easy make and break. Load efficiency of 30% provides sufficient strength for the average drilling application. Attempts have been made around the world to copy Boart Longyear's proven thread design, but only the Genuine Q™ offers consistent quality, strength, and increased wear life.

*Although highly functional, the positive flank angle on the thread limits wear life and load capacity.*



### HD (Heavy Duty)

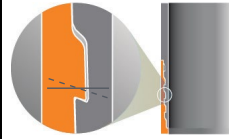
For P sized rods, the Q™ thread is modified to be coarser and deeper, taking advantage of the additional material to increase the joint strength. Load efficiency increases to 40%.”



### RQ™

A coarse thread with an increased taper and a 10° reversed angle load flank. The result is an interlocking joint with increased strength and anti-jamming for easier make-up. Load efficiency of 50% provides high strength for demanding applications.

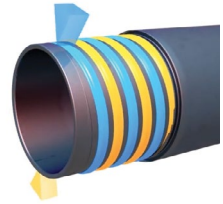
*A negative flank angle clamps the box and pin together, allowing for a full wear life of the joint.*



### XQ™

A patented double-start, tapered, coarse thread with 20° reversed angle load flanks. It provides balanced load stresses across the joint, offering the ultimate in strength and wear life. The self-aligning thread start geometry eliminates wedging and jamming for faster make-up and easier break-out (less torque). Load efficiency up to 60% provides the ultimate in strength for demanding applications, and maximum reliability and productivity in all applications.

*Double-start eliminates the mis-alignment during make-up inherent to all single-start threads. XQ™ is at 2 rather than 3 threads per inch, as a result make and break using the rig will need to be adjusted.*



**STRONGER | LASTS LONGER |  
EASIER MAKE AND BREAK**

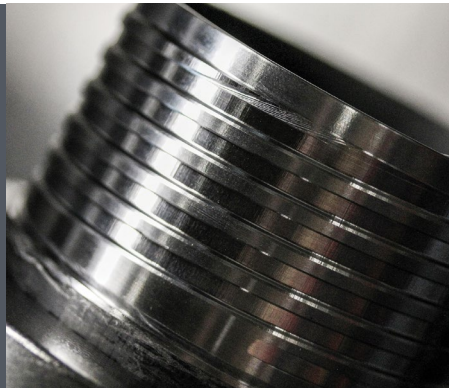
**XQ™ THREAD LIFE:**

**2X** Boart Longyear's RQ™

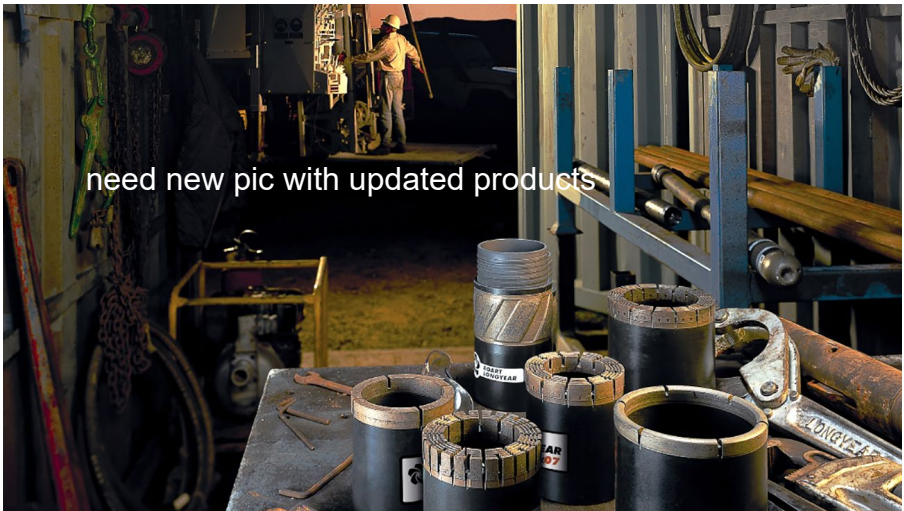
**3X** Boart Longyear's Q™

**8X** Best competitor rod\*

\*Internally controlled testing with non-case-hardened drill rod.







need new pic with updated products

## WITH MORE CORE IN THE BOX!

Advanced metallurgy and years of research have resulted in Boart Longyear's "ground-breaking" matrix where the chemical bond between diamond and matrix is stronger than the diamond itself.

Boart Longyear diamond products:

- Drill faster
- Last longer, and
- Perform in a wider range of conditions and formations.

## LONGYEAR™ DIAMOND BITS

A bit may encounter multiple rock formations in a single borehole, and what optimizes penetration rate at the top of the hole may not offer the extended life required at the bottom. It only stands to reason that having a series of bits capable of handling various needs would significantly benefit the efficiency of the driller.

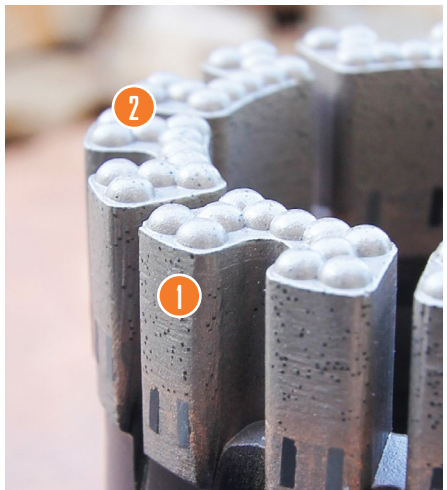
This challenge led to the development of the Longyear™ Diamond Bit. A line of color coded, impregnated bits engineered to simplify the science of bit selection while prioritizing productivity during the entire operation — high penetration rates throughout and long life at depth.

They perform similar to bits with larger diamonds, but with the easy, smooth drilling characteristics drillers prefer. The advanced formulas are combined with a variety of features to make them the bit of choice for the diamond core driller.

### FEATURES:

#### 1 Longyear™ Matrix

Using novel metallurgy, Boart Longyear has successfully created a patented chemical bond between diamond and matrix allowing for increased diamond



projection. The unique formulas are broken into color groups that represent a suggested range of operation on Mohs Hardness Scale (see the selection chart on the following page).

## 2 Razorcut™

The unique Razorcut™ protrusions on the face of the bit contain diamonds that enable the bit to begin cutting right out of the box – even in the softest ground. The arrangement of these protrusions also improves the tracking and balance in the hole when drilling begins.

## 3 Tapered Swirl Geometry

To support higher penetration rates, we have combined the new Longyear™ formulas with a new, more open geometry. Designed for fast cutting in competent ground, the new swirl geometry has an open area that matches Express configurations but with even more cutting edges. This is combined with tapered waterways to enhance flushing. They are available in our 16 mm (0.63") crown heights to maintain bit life at higher cutting speeds.

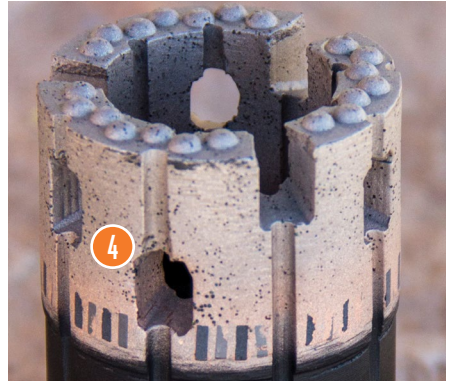


## SYNTHETIC DIAMONDS

Guaranteed conflict-free, Boart Longyear uses 100% synthetic diamonds in our products. They have the most edges in any given volume and a very consistent shape, which translates to a predictable performance. They also have less flaws than natural diamond making them stronger.

## 4 Stage™ Design

Our Stage™ bits are some of the tallest crown heights in the industry. The window distribution and shape provide optimum performance in any ground condition, enabling time savings and increased productivity. Many competitors have tried to match it, but to date none have succeeded.



## BLACK AND GRAY LARGE DIAMOND LONGYEAR™ BITS

To meet the demands of the seasoned driller for extreme performance, Boart Longyear has extended the Longyear™ line to include a series of bits with larger synthetic diamonds.

### BLACK LONGYEAR™ BITS

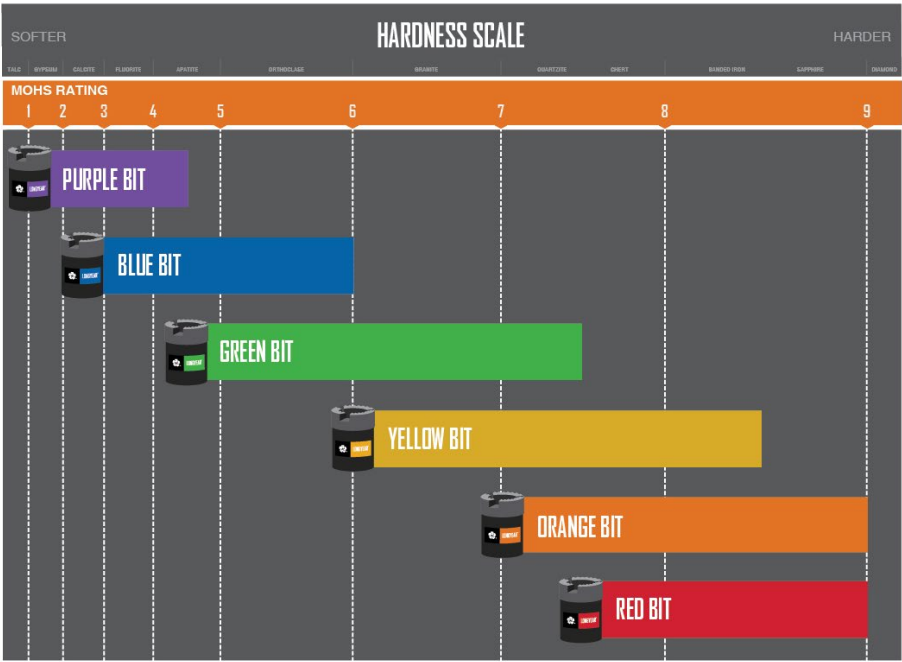
Our fastest penetrating, diamond bit featuring advanced technology for a free-cutting matrix good for use in medium to hard formations. This bit maximizes productivity!

### GRAY LONGYEAR™ BITS

The large synthetic diamond increases penetration and bit life over the original larger diamond bit. Drillers report a minimum of 200% life over traditional surface set bits. Many surface set drillers never had a reason to leave their traditional technology behind for impregnated diamond bits — until now!



# LONGYEAR™ DIAMOND BIT MOHS HARDNESS RATING



HIGH POWERED DRILLS  
MORE DURABLE matrix  
ABRASIVE or BROKEN GROUND

LOW POWERED DRILLS  
FREER CUTTING to expose more diamonds for easier cutting in hard ground.



\*Drill adaptation is required for High Torque LongYear™ Bits, ask your regional Boart Longyear representative for more information.

Color	Hardness	Boart Longyear Bit Comparison	Competitor Bit Comparison
<b>PURPLE BIT</b>	1–4.5	ALPHA/02 SERIES: 2.5–4.5	EPIROC 3AC   FORDIA HERO 3   HAYDEN 2
<b>BLUE BIT</b>	2.5–6	ALPHA/06 ABR, 06, 06COM: 4–6	EPIROC 7AC   FORDIA HERO 7 & 9   HAYDEN 4
<b>GREEN BIT</b>	4.5–7.5	ALPHA/07ABR, 07, 07COM: 5–7 ALPHA/08ABR, 08, 08COM: 6–7.5	EPIROC 11AC   FORDIA HERO 11 & 9-11   HAYDEN K55 & 9AA
<b>YELLOW BIT</b>	6–8.5	ALPHA/08ABR, 08, 08COM: 6–7.5 ALPHA/09ABR, 09, 09COM: 7–8	EPIROC 13AC & 15AC   FORDIA 11-14   HAYDEN 12-14
<b>ORANGE BIT</b>	7–9	ALPHA/09ABR, 09, 09COM: 7–8 ALPHA/10ABR, 10, 10COM: 8–9	EPIROC 13AC & 15AC   FORDIA 11-14   HAYDEN K55, 12-14
<b>RED BIT</b>	7.5–9	ALPHA/10ABR, 10, 10COM: 8–9	EPIROC 15AC   FORDIA 11-14   HAYDEN 12-14
<b>GRAY BIT</b>	1-7	SSUMX, 7UMX	—
<b>BLACK BIT</b>	4-8	7UMX, 9UMX	—

If a tougher bit is required for very abrasive conditions, select the next bit in the series, e.g., go from **GREEN** to **BLUE**.



Western Australia is an extremely competitive diamond drilling market and drillers are constantly searching for higher productivity to reduce costs and improve returns. In an underground gold project, competitor bits maxed out at 180 m (590 ft) of bit life with 22 cm/min (9 in/min) per bit of penetration over a 3-month trial period — a solid performance, but productivity needed to improve.

### **SOLUTION: INTRODUCING LONGYEAR™ GREEN BITS**

When compared over the same trial period, penetration rates increased to 26 cm/min (10 in/min) per bit and bit life nearly doubled, increasing to 356 m (1,167 ft).



**23%** INCREASE IN METERS DRILLED PER HOUR

*"The other night I witnessed a bit cutting 24" a minute — by far the fastest cutting bit Boart Longyear has made."*

**BOART LONGYEAR SUPERVISOR,  
WESTERN TERRITORY**

## REAMING SHELLS

By combining patented technologies with customer collaboration, Boart Longyear has created the high performing RSUMX™ reaming shells. The Ultramatrix™ technology and new pad design makes these reaming shells the longest lasting available.

- Large, spiral, diamond ground pads increase stability and reduce drill string vibration at the face of the bit.
- Diamond grinding pre-exposes the diamonds and allows tighter size control putting more diamond in contact with the rock, stabilizing the bit. The pre-exposure and reduced size variation maximizes available life.
- RSUMX are also available with optional heavy duty steel blanks and dual pads, making it your first choice in all Exploration coring applications.



## CASING SHOES

With a color-coded application much like the Longyear™ bit line, the casing shoes feature a patented matrix formula and large synthetic diamonds to maximize performance.

Single-use shoes offer maximum penetration rates while multiple-use shoes have increased life in various applications.



## WIRELINE CORE RETRIEVAL SYSTEMS

Good decisions on tools selection means faster and more efficient cycle times, happy customers, and increased profitability for the contractor - every step counts from descent speed, dependable latching and unlatching, and reliable core recovery. For the miner, staying on or ahead of schedule means making the right decisions as to continuing or adjusting the Exploration project.

Boart Longyear has led the innovation of wireline technologies for over 60 years, including the following to name a few:

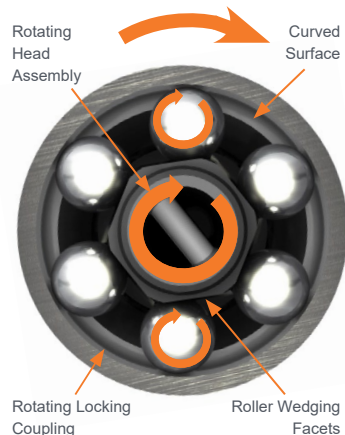
1958	Original Q™ Wireline Core Barrel and Overshot
1960s	Pump-In System
	Triple Tube System
1970's	Brown Style (Slotted) Core Lifter
	Knuckle-Joint Spearhead
1980s	Hydro-Latch System
	Fast Descent Check-Valve
1990s	Landing Indication
	Pump-In Lip Seal
	Link Latch Mechanism
	Fluid Retention Valve
2000s	Ezy-Lock Overshot
	Quick Pump-In™ Pump-In Valve
	Quick Descent™ System (Hollow Spindle)
2010s	V-Lip Pump-In Seal
	Quick Pump-In™ Roller Latch™ System
	MKII™ Spearhead
	Split-Tube Loading Tool
	Quick Descent™ Roller Latch™ System
	Pump-In Holdback Plug
	TruCore™ Orientation Device
	Mag-Grip Hands-Off Tool
2020s	Roller Latch™ Overshot

While Boart Longyear's Link Latch Quick Descent™ and Quick Pump-In™ core barrel assemblies continue to offer productive drilling, our most recent innovation featuring the patented Roller Latch™ technology offers significant improvements for safety.

## ROLLER LATCH™ TECHNOLOGY



Boart Longyear's Roller Latch™ head assemblies continue to build on our legacy of innovative technology and offer precise compatibility with all Genuine Q™ wireline systems. The patented, ultra-reliable Roller Latch™ deploys and retracts radially, reducing the play and jamming associated with traditional 'swing-out' latches. The new system also eliminates the need for any adapter coupling, drive key, or tang feature.



## QUICK PUMP-IN™ ROLLER LATCH™ HEAD ASSEMBLY

Downhole and uphole applications, featuring:

- 1 Roller Latch™ Technology
- 2 Hold-back Brake
- 3 MKII™ Spearhead
- 4 Free Flow Design
- 5 Variable Lip Pump-In Seals
- 6 W-Wall™ Compatible

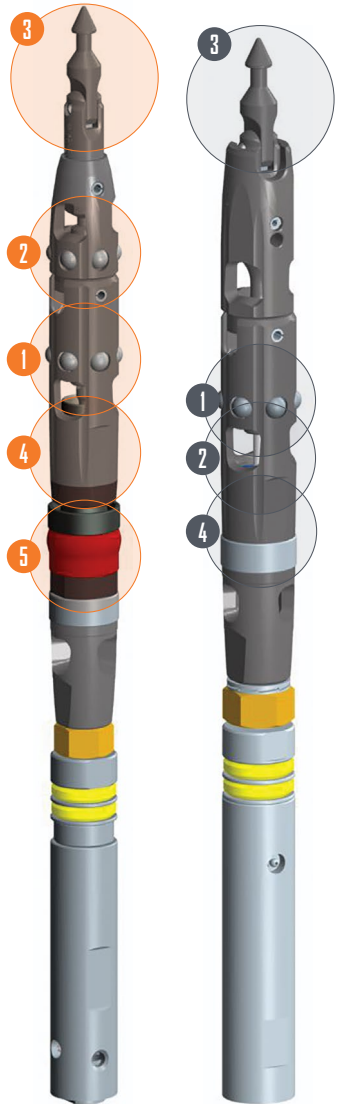
### ROLLER LATCH™ HOLD-BACK BRAKE

As a safety feature, the hold-back brake is engaged by default. Unlike other systems that could be accidentally driven out of the hole by gravity or adverse in-hole pressures, the Pump-In™ Roller Latch™ head features a spring-driven retracting case that deploys the braking rollers. This permits tripping into the hole, but tripping out of the hole is not unless the brake is unloaded by either gravity (downholes) or fluid pump-pressure (upholes) during wireline retraction.

## QUICK DESCENT™ ROLLER LATCH™ HEAD ASSEMBLY

Downhole applications only, featuring:

- 1 Roller Latch™ Technology
- 2 Latch Indication
- 3 MKII™ Spearhead
- 4 Free Flow Design with Hollow Spindle
- 5 W-Wall™ Compatible



### Available Assemblies:

Quick Pump-In™ Head	AQ™TKU	BQ™U	BQ™TKU	NQ™U	NQ™TKU	HQ™U	—
Quick Descent™ Head	—	BQ™	—	NQ™	NQ™TK	HQ™	PQ™



### LANDING INDICATION

All Boart Longyear systems offer landing/latching indication. Without it, the head assemblies may be either partially latched or not latched at all, resulting in damage to tools and possibly creating a hazardous situation where gravity could cause an uncontrolled descent in uphole drilling applications.



Wireline components are manufactured using materials with selected metallurgical properties. Consistent heat treatments and additional case hardening for key components drive strength, wear resistance, and toughness. A wireline system is only as strong as its weakest link.

**Core Barrel Assembly:**

- Latch bodies and landing shoulders are machined from heat treated alloy steel bar and case hardened.
- Core lifters, core lifter cases, and stop rings are manufactured from steel, then quench and tempered.
- Linkage style latches are investment cast from alloy steel and case hardened.
- Roller Latch™ retracting cases are machined from heat treated alloy steel bar and case hardened; roller latches are bearing-quality heat treated stainless steel.

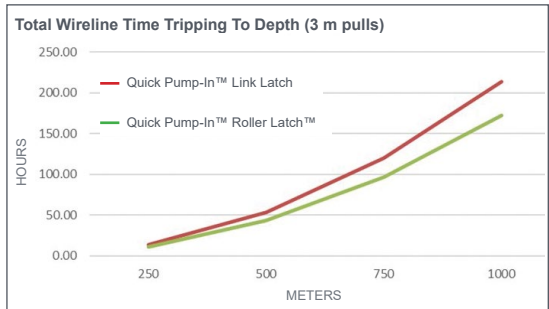
**Overshot Assembly:**

- Lifting dogs are investment cast from alloy steel, then quench and tempered.
- Roller Latch™ Quick Pump-In™ use bearing-quality heat treated stainless steel rollers.

## OVERSHOT SYSTEMS

Boart Longyear overshot systems provide highly reliable retrieval of the inner tube assembly for surface and pump-in applications.

- **EZY-LOCK™**  
The safety and productivity features make this overshot a favorite of drillers for surface applications with spearhead core barrel systems.
- **QUICK PUMP-IN™**  
For uphole applications with underground spearhead core barrel systems. Dual pump-in lip seals provide a significant improvement in pump-in rates.
- **ROLLER LATCH™ QUICK PUMP-IN™**
  - **Safer:** Eliminates spearheads and lifting dogs entirely; for use with the Roller Latch™ Quick Pump-In™ head assemblies, and the socket adapter replaces the spearhead making it compatible with all head assemblies.
  - **34% More Productive**



- Auto-reset landing indication valve eliminates partial trips and false indications.
- Threaded connections for easier maintenance - no assembly pins.
- V-Lip seal for use with variable wall W-Wall™ rods.



Optional hold-back brake release for more reliable retraction in flat and downholes when running with Quick Descent™ Roller Latch™ head assemblies only.



*"This is a smart and innovative system, I can't believe no one thought of it before."*

**DRILLER -  
CANDALARIA MINE  
SITE, ATACAMA  
DESERT REGION  
OF NORTHERN CHILE**



High water and gas pressure underground significantly increased the risk of blow-back of the inner tube. This, combined with the possible loss of control of a head assembly during core retrieval in upholes, could lead to severe injury and even death to the underground operators. Older generation head assemblies lack design features to stop an uncontrolled descent from an uphole. Also, worn latches of those systems would occasionally jam and cause the wire to break, creating a different safety hazard.

### **SOLUTION: QUICK PUMP-IN™ ROLLER LATCH™ SYSTEM WITH BRAKE!**

*"The Roller Latch™ is much safer for my drillers," says the area superintendent. "There are fewer parts and fewer things that can go wrong. It is also very efficient. The new V-lip seals pump is much faster than the traditional head assemblies in upholes of all angles. We have saved nearly 1 minute for every 200 m (700 ft) we have to pump in with the new head assembly. This is a big time saving in a 1,500 m (4,900 ft) hole."*



# BOART LONGYEAR GDS TOOLS



## REDEFINING THE FUTURE OF DRILLING

Boart Longyear's Geological Data Services (GDS) provide industry-leading products and services that redefine the future of resource definition and mineral exploration.

### CORE ORIENTATION

#### TRUCORE™ UPIX CORE ORIENTATION TOOL

TruCore™ UPIX is an easy-to-use, highly accurate core orientation system featuring step-by-step workflow guidance, wireless communication, and a field-replaceable battery. The patented TruCore™ UPIX orientation system fits hole sizes ranging from N to P with interchangeable adapters and barrel systems that are easily swapped whenever a change in hole size is required.



# DOWN-HOLE SURVEY

## TRUSHOT™ MAGNETIC SURVEY TOOL

TruShot™ is an accurate magnetic survey tool optimized for driller deployment. Made for durability, precision, and simplicity, drillers can capture high-quality 3D hole path data with confidence.



## TRUGYRO™ GYRO SURVEY TOOL

TruGyro™ is a hassle-free survey system and the most compact and integrated north-seeking gyro tool in exploration drilling. Provided in a compact kit for easy transport and deployment, TruGyro™ integrates seamlessly with Boart Longyear tooling by using secure data management solutions that fit your operation. The gyro and depth counter tools pair seamlessly with an intuitive app that walks users through the process. With high-speed continuous in-rod surveys and no warm up time, TruGyro™ is best-in-class, providing borehole depth, azimuth and dip results that form the basis of good ore body knowledge.



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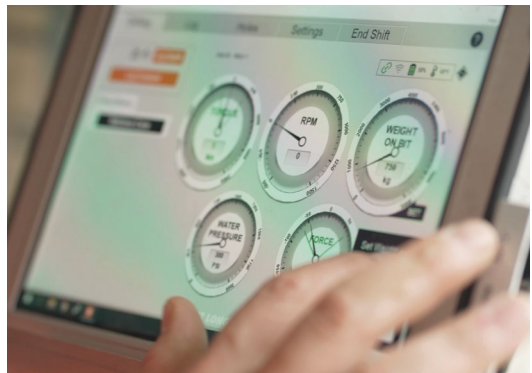
# ENHANCED DRILLING DATA

## TRUSUB™ CONTEXTUAL DRILL DATA, MEASUREMENT AND MONITORING

An in-field installation option for select top drive coring rigs, TruSub™ captures accurate drilling data from a wireless sub.

Depth-based drilling logs add context to core samples and geological data. Contributing to and enhancing your ore body knowledge.

Improve performance using accurate and consistent digital gauges to fine-tune settings on-the-fly. Driving productivity insights, optimal drilling and valuable performance data for geology.



# BOART LONGYEAR EQUIPMENT



## WHERE PRODUCTIVITY AND SAFETY COME TOGETHER!

**Boart Longyear offers a range of equipment that provides reliable, high-performance drilling for all Exploration needs.**

From field-proven workhorses to today's innovative rig designs and technologies, Boart Longyear is geared up for the successful completion of any project.

### **Options include:**

- Chuck drive series for underground or surface applications.
- Top drive series for surface applications.
- Multi-Purpose for surface applications.

Each series offers drill rigs of various sizes, depth capacities, mounting configurations, and cutting-edge technical capabilities. Boart Longyear's commitment to safety and the environment drives our development, ensuring we stay ahead of the competition.

### **FIELD-DEVELOPED RELIABILITY**

As the only global integrated drilling services and equipment provider, Boart Longyear is able to combine engineering excellence, global manufacturing and the most experienced drilling services group in the business. The result is products that are state-the-art, yet proven when introduced to the market. This makes Boart Longyear the most trusted and reliable supplier in the industry, providing maximum productivity and safety.

***Proven performance for more uptime and more meters.***



# BOART LONGYEAR DRILL RIG OFFERING

DRILL RIG FEATURE	LM™75	LM™90	LM™110	LM™30 SS	MDR700	LF™90D	LF™230	LF™160	LF™350e	LX6
	UNDERGROUND			MOBILE / SELF PROPELLED / UNDERGROUND		SURFACE				
Chuck Drive	●	●	●	●	●	●	●			
Top Drive								●	●	●
Multi-Purpose										●
Compact	●	●	●	●		●				
Deep Hole			●				●		●	
Modular	●	●	●			●				
Rod Handling	●	●	●	●	●			●	●	
Automated Controls (DC)	●	●	●		●					
Truck Mount						●	●	●	●	
Crawler/Track Mount				●	●	●		●		●
Skid Mount	●	●	●			●	●			
Telescopic Mast						●	●			
Dump Mast	●	●	●		●	●	●	●		
Tier 4 Diesel Engine				●	●	●	●	●	●	
Tier 3 Diesel Engine				●	●	●	●	●	●	●
Power Pack (Electric)	●	●	●		●					





# DEPTH RANGE - SURFACE

Vertical Down - W-WALL™ / NQ™ / NRQ™ / NXQ™



100 m (328 ft)					
200 m (656 ft)					
300 m (984 ft)					
400 m (1,312 ft)					
500 m (1,640 ft)					
600 m (1,969 ft)					
700 m (2,297 ft)					550 m (1,804 ft)
800 m (2,625 ft)					
900 m (2,953 ft)					
1,000 m (3,281 ft)					
1,100 m (3,609 ft)					
1,200 m (3,937 ft)	1,193 m (3,915 ft)				
1,300 m (4,265 ft)					
1,400 m (4,593 ft)					
1,500 m (4,921 ft)					
1,600 m (5,249 ft)					
1,700 m (5,577 ft)					
1,800 m (5,906 ft)					
1,900 m (6,234 ft)		1,800 m (5,906 ft)			
2,000 m (6,562 ft)					
2,100 m (6,890 ft)					
2,200 m (7,218 ft)					
2,300 m (7,546 ft)					
2,400 m (7,874 ft)					
2,500 m (8,202 ft)					
2,600 m (8,530 ft)					
2,700 m (8,858 ft)					
2,800 m (9,186 ft)					
2,900 m (9,514 ft)					
3,000 m (9,843 ft)					
3,100 m (10,171 ft)					
3,200 m (10,499 ft)					
3,300 m (10,827 ft)					
3,400 m (11,155 ft)					
3,500 m (11,483 ft)					
3,600 m (11,811 ft)					
3,700 m (12,139 ft)					
				3,360 m (11,024 ft)	

Calculated using the pullback capacity of the drill and on an effective rock tensile strengths of 5 MPa, actual results may vary.



# UNDERGROUND CORE DRILLS

## LM™ SERIES



Modular with a number of options, the LM™ series of underground rigs are easily tailored to the specific needs of the application and can be upgraded when drilling requirements or conditions change.

### FEATURES:

#### PROPORTIONAL CONTROLS

Proportional controls and lock levers provide optimum control of rpm and feed.

#### DIRECT COUPLED FEED FRAME

Direct coupled feed frame results in lower maintenance and smoother feed transmission. Various sized feed frames are available to suit different applications.

#### REVERSIBLE FEED CYLINDER

The feed cylinder on the LM™90 and LM™110 rigs can be unbolted and inverted to increase uphole drilling capacity.

#### HIGH TORQUE BREAKOUT

Breakout device loosens most rod joints automatically.

#### FAIL SAFE ROD CLAMP

Hydraulic open and spring close rod clamp results in fail safe operation.

#### LOAD SENSING HYDRAULICS

Load sensing hydraulics for consistent flow, maximizing efficiency and heat reduction.



### SEMI-AUTOMATED ROD HANDLER (OPTIONAL)

Sets the standard for ease-of-use, versatility, and most importantly, safety. The LM rod handler supports consistent productivity while significantly reduces an operator's exposure to hand injuries caused during manual rod handling.

### 33% MORE TORQUE



### LM™110

Designed for deeper holes and increased productivity, the LM™110 delivers more torque to the head than the similarly equipped LM™90.



## TECHNICAL SPECIFICATIONS (WIRELINE):

	LM™75		LM™90		LM™110	
Depth Rating: NQ™/NRQ™/NXQ™						
Upholes	280 m	920 ft	620 m	2,050 ft	620 m	2,050 ft
Horizontal Holes	1,020 m	3,360 ft	1,190 m	3,900 ft	1,260 m	4,140 ft
Downholes	850 m	2,800 ft	990 m	3,260 ft	990 m	3,260 ft
Chuck Jaw Opening	A to H sized rod/casing					
Maximum Pull Back Force	81 kN	18,250 lbf	128 kN	28,708 lbf	128 kN	28,708 lbf
Maximum Rod Pull Length	1.83 m	6 ft	1.83 m	6 ft	1.83 m	6 ft
Head Torque - 1,250 RPM	325 Nm	240 ft-lb	371 Nm	274 ft-lb	430 Nm	317 ft-lb
Head Torque - 500 RPM	900 Nm	664 ft-lb	845 Nm	623 ft-lb	1,088 Nm	802 ft-lb
Electric Motor	75 kW	101 hp	90 kW	120 hp	110 kW	147 hp

## DIMENSIONS AND WEIGHTS:

700 Series Feedframe: L x W x H	4276 x 698 x 801 mm	168.25 x 27.50 x 31.50 in
Weight	960 kg	2112 lb
1300 Series Feedframe: L x W x H	4894 x 698 x 851 mm	193 x 27.50 33.50 in
Weight	1520 kg	3344 lb
Control Panel: L x W x H	575 x 480 x 521 mm	23 x 19 x 20.50 in
Weight	46 kg	101 lb
LM™75/90 Power Pack: L x W x H	3893 x 1318 x 1526 mm	153.25 x 52 x 60 in
Weight	1400 kg	3080 lb
LM™110 Power Pack: L x W x H	3940 x 1410 x 1540 mm	155 x 55.5 x 60.6 in
Weight	1712 kg	3774 lb

For detailed information, see the Technical Overview sheets.

## DCi™

DCi™ (Drill Control Interface) is an electronic interface that enables a single operator to control both the drill rig and rod handler while providing real-time feedback on the drilling conditions. It incorporates CANbus technology to enable communications between the drill rig, the rod handler and the DCi to self-monitor and semi-automate most drilling operations.

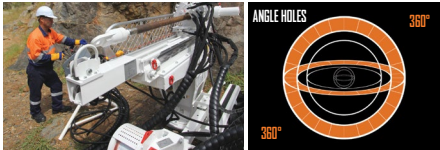
- System integration and sensors provide real-time information.
- Unattended drilling at shift change, breaks, or catch up on other tasks.
- Monitors drill rod position, rotation speed and feed, and continues drilling with a push of a button.
- Safety innovation by isolating the driller from moving components of the drill.

**SEMI-AUTONOMOUS  
DRILLING OVER BREAKS AND  
SHIFT CHANGES INCREASE  
PRODUCTIVITY BY ALMOST  
14% — OVER SIX MONTHS,  
THAT CAN ADD UP TO AN  
ADDITIONAL 1,000 M  
(3,200 FT) OF CORE.**



# UNDERGROUND MOBILE CORE DRILLS

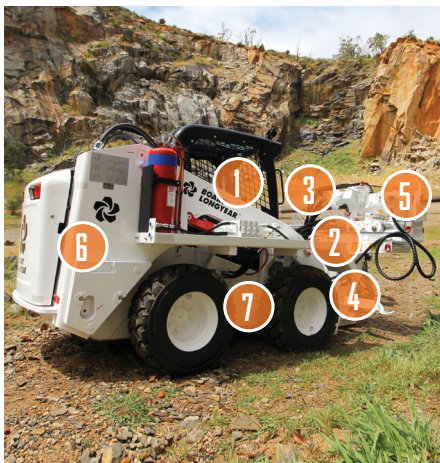
## LM™30SS



The LM™30SS is a mobile rig powered by a 246D Skid Steer with a diesel engine. Designed for quick setup time and ease of moving from site to site.

A lightweight rig suited for drilling small holes with either conventional or wireline systems.

### FEATURES:



- 1 VARIABLE CONTROLS**  
Variable controls ensure smooth operation throughout.
- 2 DIRECT COUPLED FEED FRAME**  
Direct coupled feed frame reduces maintenance requirements.
- 3 HIGH-PRESSURE BREAKOUT**  
Breakout system features a high-pressure circuit to effortlessly break rod joints.
- 4 INTEGRATED POSITIONER AND TURNTABLE**  
Integrated positioner and turntable allows for drilling at all angles from vertically-up to vertically-down.
- 5 FAIL-SAFE ROD CLAMP**  
Spring-close and hydraulic-open rod clamp ensures fail safe operation in case of a burst hose.
- 6 SMART HYDRAULICS**  
Smart hydraulics with synchronized control between rotation unit and foot clamp allow for faster and safer rod handling.
- 7 SKID STEER MOBILITY**  
The skid steer is used as the carrier to transport the feed frame and water pump, and to power the hydraulics for drilling operations. No electricity supply is required.

### TECHNICAL SPECIFICATIONS (WIRELINE):

Depth Rating: NQ™/NRQ™/NXQ™		
Upholes	180 m	590 ft
Horizontal Holes	400 m	1,312 ft
Downholes	250 m	820 ft
Chuck Jaw Opening	A to H sized rod/casing	
Maximum Pull Back Force	40.3 kN	9,060 lbf
Maximum Rod Pull Length	1.1 m	3.6 ft
Head Torque - 1,200 RPM	104 Nm	77 ft-lb
Head Torque - 500 RPM	375 Nm	276 ft-lb
Diesel Engine	54 kW	73 hp

### DIMENSIONS:

L x W x H	3.94 x 2.01 x 2.30 m (9.60 x 6.59 x 7.55 ft)
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For detailed information, see the Technical Overview sheets.



# UNDERGROUND MOBILE CORE DRILLS

## MDR700



The MDR700 utilizes proven Boart Longyear underground technology and offers wide drilling angles, quick and easy setup, and advanced mobility.



TWO-WHEEL STEERING FOR ON-ROAD TRAVEL



FOUR-WHEEL STEERING FOR SHORT TURNING RADIUS



CRAB-LIKE MOVEMENT FOR LATERAL APPROACHES AND DELICATE EXITS



## FEATURES:

- 1 QUICK AND EASY SETUP**  
Rig moves are up to 80% faster with unique maneuvering features and speeds up to 7.5 km/hr (4.7 mph).
- 2 OPERATOR SAFETY AND COMFORT**  
Attenuation insulation reduces noise levels to 88 dB while drilling, and 74 dB when equipment is idling.
- 3 EFFORTLESSLY BREAK ROD JOINTS**  
The breakout system on the drill head uses a high-pressure oil and gear rack assistance to effortlessly break rod joints.
- 4 ENGINEERED SAFETY WITH ROD HANDLING**  
Semi-automated rod handling includes smart hydraulics with synchronized control between the rotation unit and foot clamp for faster and safer rod handling.
- 5 SEMI-AUTOMATED DRILLING**  
The Drill Control Interface (DCi™) semi-automates drilling and provides a fully electronic interface to efficiently operate both the drill rig and the rod handler.

## TECHNICAL SPECIFICATIONS (WIRELINE):

Depth Rating: NQ™/NRQ™/NXQ™		
Upholes	250 m	820 ft
Horizontal Holes	650 m	2,133 ft
Downholes	700 m	2,297 ft
Chuck Jaw Opening	A to H sized rod/casing	
Maximum Pull Back Force	81 kN	18,299 lbf
Maximum Rod Pull Length	1.8 m	5.9 ft
Head Torque - 1,250 RPM	371 Nm	274 ft-lb
Head Torque - 500 RPM	1030 Nm	760 ft-lb
Electric Motor	90 kW	120 hp

## DIMENSIONS:

Overall L x W x H	9.93 x 2.3 x 2.3 m (32.6 x 7.4 x 7.5 ft)	
Weight	14,500 kg	31,967 lb

For detailed information, see the Technical Overview sheets.



# POPULAR SURFACE CORE DRILLS

## LF™90D



The LF™90D has proven to be an industry work horse for decades for both remote and environmentally sensitive locations, and within an open pit mine against the highwall.

### FEATURES:

#### 1 SELF-CONTAINED OPERATOR PANEL

The straightforward hydraulic system is easy to operate and maintain, and neutral lock levers provide additional operator safety.

#### 2 HYDRAULIC DESIGN

Direct-coupled hydraulic pumps with a PTO driven auxiliary pump allow for easy maintenance.

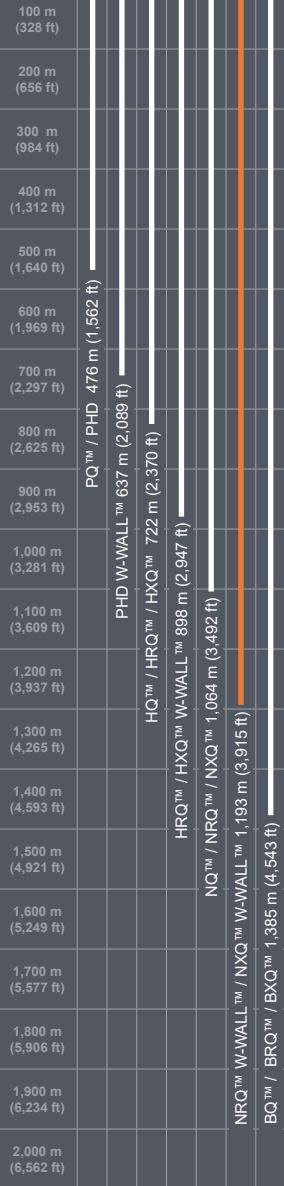
#### 3 NITRO-CHUCK™

Nitrogen gas spring jaws with hydraulic open/spring close function ensures fail-safe operation.

*Its compact design allows for transport and navigation in densely wooded, rugged arctic, or any other areas where access is a concern, and the modular layout makes this rig highly configurable and easy to replace worn components.*



Depth Rating: Vertical Downhole (Fluid Filled)



Calculated using pullback capacity of the drill and effective rock breaking strengths of 5 MPa, actual results may vary.



#### 4 ROTATION BARRIER

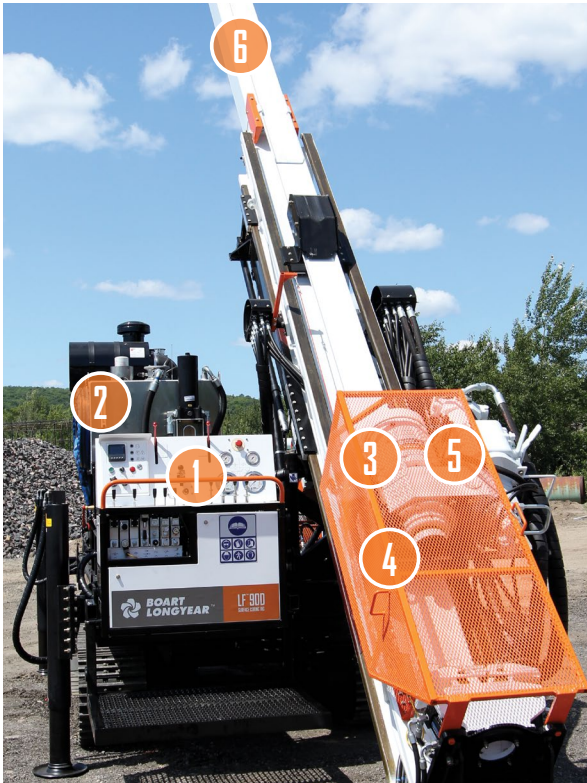
Prevents accidental contact with rotation unit while in operation.

#### 5 HYDRAULIC SIDE SHIFTING HEAD

Lowers working height when handling inner tube.

#### 6 DUMP / TELESCOPING MAST

Dump feature enables the drill to be mounted on different platforms while telescoping mast makes drill compact for transportation.



### TECHNICAL SPECIFICATIONS (WIRELINE):

Depth Rating: NQ™ / NRQ™ / NXQ™

Downholes	1,193 m	3,915 ft
Chuck Jaw Opening	B to P sized rod/casing	
Maximum Pull Back Force (Head)	111.8 kN	25,133 lbf
Maximum Pull Back Force (Mainline Hoist)	72 kN	16,000 lbf
Maximum Rod Pull Length	6 m	20 ft
Engine Option - Tier 4 and Tier 3 (High altitude option available)	QSB 6.7 l Diesel	

For detailed information, see the Technical Overview sheets.

### NITRO-CHUCK™

Field tested and designed to offer performance and reliability to conquer even the hardest projects. The patented nitrogen gas spring jaws with hydraulic open / spring close function ensures fail safe operation, providing a constant gripping force throughout jaw travel.

- More uniform gripping of drill rods (P has 7 jaws / H has 5 jaws).
- Greater diametrical jaw travel of 13 mm (1/2 in) for effective gripping on worn rods.
- Balanced “floating” design permits rotation speeds only limited by the drill head.
- Bearing does not rotate when the chuck is in closed position, ensuring a low operating temperature for longer life.
- PQ™ Chuck accepts B to HWT rods/P reaming shell.
- HQ™ Chuck accepts B to H rods/H reaming shell.
- Design allows for reverse rotation for making and breaking rods.
- Adaptable to most drill heads - ask a Boart Longyear representative about retrofitting your drill.



# POPULAR SURFACE CORE DRILLS

## LF™160



Boart Longyear's flagship rig combines state-of-the-art technology with practical experience, to set the new standard for safety, operational control, efficiency, and reliability. Ideal for even the most sophisticated drilling projects.

The top drive, tilting head combined with the automated Freedom™ Loader provide superior hands-free rod handling. With up to 1,800 m (6,000 ft) of NRQ™/NXQ™ capability, the LF™160 rig can cover the majority of surface coring drilling needs.

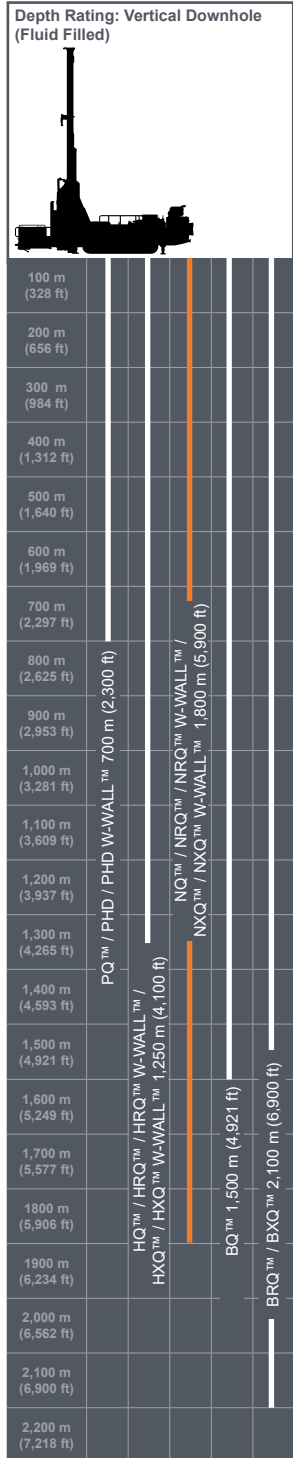
### FEATURES:

#### 1 100% HANDS-FREE ROD HANDLING

The driller's assistant is not required to physically intervene while tripping and aligning rods, or connecting to the head when operating the FREEDOM™ Loader. All operations happen at the control panel and radio remote with the touch of a finger.

#### 2 TILTING TOP DRIVE HEAD

The forward tilting head design simplifies the rod handling process and reduces the need for intervention by the helper and maintenance.



Calculated using pullback capacity of the drill and effective rock breaking strength of 5 MPa, actual results may vary.



### 3 CLAMPING & BREAKING DEVICE

Multiple tools in one:

- Provides a constant clamping pressure to reduce the risk of dropped rods down the hole. Commonly referred to as a foot clamp.
- A hydraulic breaking device loosens the rod joint, which means no unrestrained wrench under power.
- Rod alignment and centralizer devices are critical to facilitate hands-free rod handling.

### 4 CE CERTIFIED

The LF™ 160 is CE certified, including the latest EN standards to maximize the safety of those who work on and around the rig.



### TECHNICAL SPECIFICATIONS (WIRELINE):

Depth Rating: NQ™ / NRQ™ / NXQ™		
Downholes	1,800 m	5,900 ft
Maximum Pull Back Force	170 kN	38,200 lbf
Maximum Rod Pull Length	6 m	20 ft
Engine Option - Tier 4 and Tier 3 (High altitude option available)	QSB 6.7 t Diesel	

For detailed information, see the Technical Overview sheets.



## FL262 FREEDOM™ LOADER

Boart Longyear's FL262 FREEDOM™ loader is engineered with drillers' safety and productivity top-of-mind.

It is a radio remote operated system that utilizes a patented magnet system to move rods from the integrated rod bin into the loading tray. The loading tray then extends out to present the rod to the drill head, without any need for an operator to handle the rods. The magnetic system safely picks up the rods without risk of damage, prolonging drill rod life.

### FREEDOM TO MOVE

Remote control enables operator to find an ideal place to work safely, efficiently, and with good visibility.

### FREEDOM TO DRILL

Attention is focused on driving the drilling cycle, not back-breaking rod handling.

### FREEDOM TO BID

The system meets the most rigorous CE and Australian Health and Safety standards. It provides peace-of-mind and freedom to work everywhere.





#### 4 HYDRAULIC SWING-OUT HEAD

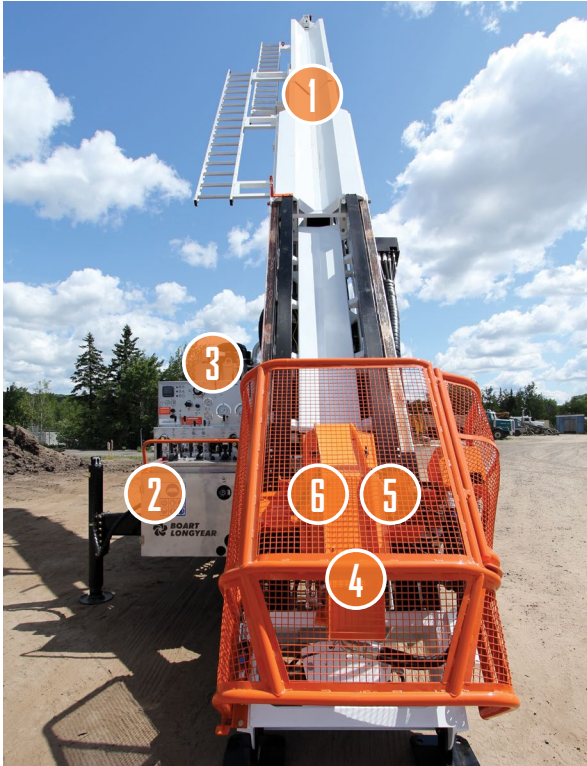
Lowers working height when handling inner tube.

#### 5 NITRO-CHUCK™

Patented nitrogen gas spring jaws with hydraulic open/spring close function ensuring fail safe operation.

#### 6 ROTATION BARRIER

Interlocked rotation barrier slows rotation when barrier is open, providing additional operator safety.



### TECHNICAL SPECIFICATIONS (WIRELINE):

Depth Rating: NQ™ / NRQ™ / NXQ™

Downholes	2,661 m	8,730 ft
Chuck Jaw Opening	B to P sized rod/casing	
Maximum Pull Back Force (Head)	223 kN	50,200 lbf
Maximum Pull Back Force (Mainline Hoist)	178 kN	40,000 lbf
Maximum Rod Pull Length	9 m	30 ft
Engine Option - Tier 4 and Tier 3 (High altitude option available)	QSB 8.3 l Diesel	

For detailed information, see the Technical Overview sheets.

## EXTENDED ROD PULL

**OVER 30%  
INCREASE IN  
PRODUCTIVITY  
WITH 9 M (30 FT)  
MAST!**

When compared to the standard 6 m (20 ft) rod pull capacity, the 9 m (30 ft) telescopic mast on Boart Longyear's LF™ 230 allows for extended rod pulls and increased productivity.

When tripping rod in and out of the hole, the longer rod pull reduces the time to make and break joints by 1/3. This is especially advantageous for deep holes.

An additional benefit of the longer mast is the ability to retrieve a 6 m (20 ft) inner tube filled with core. Compared to a 3 m (10 ft) inner tube pull, the extended inner tube can deliver efficiencies of up to 50% for deeper holes, conditions permitting.





### 3 ROD BREAKING CLAMP

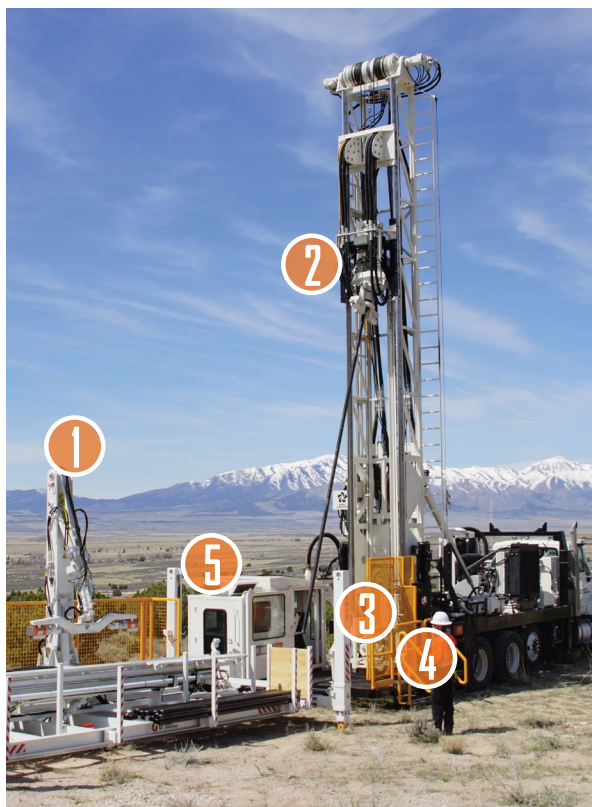
A hydraulic breaking device eliminates the need to apply "wrench under power" resulting in a significant reduction of hand injuries. Includes a rod alignment device and centralizer included.

### 4 ROTATING FOOT CLAMP

The foot clamp rotates to break rod joints located between the foot clamp and Rod Breaking Clamp.

### 5 CLIMATE CONTROLLED CAB

The heated and air conditioned driller's cab protects workers from the elements.



## TECHNICAL SPECIFICATIONS (WIRELINE):

Depth Rating: NQ™ / NRQ™ / NXQ™

Downholes	3,000 m	9,800 ft
Maximum Pull Back Force	289 kN	65,000 lbf
Maximum Rod Pull Length	6 m	20 ft
Engine Option - Tier 4 and Tier 3 (High altitude option available)	QSL 8.9 l Diesel	

For detailed information, see the Technical Overview sheets.

## THE "e" IN LF™350e REFERS TO THE FULLY ELECTRONIC CONTROL SYSTEM

Utilizing CANbus Communication and PLC Programming, all functions are controlled electronically.

These controls are the platform for future software development. Electronic controls enable the implementation of engineering safety controls through the use of programming rather than through complex relays or hydraulic circuits. This is highly desirable to keep the machine physically simple yet sophisticated in functionality.

The control's software can be updated from time to time to add functionality without necessarily changing any components on the drill.



# POPULAR SURFACE MULTI-PURPOSE DRILLS

## LX™6



Configurable to various drilling techniques, the LX™6 is a high-powered machine in a small package. It is an essential rig on today's job site and has proven itself time and time again in the most demanding conditions.

Boart Longyear's LX™6 is capable of wireline and conventional coring, undisturbed sampling and testing, geological work, ground consolidation drilling, water well drilling, auger drilling, jet grouting, micropiling, soil nailing, and reverse circulation drilling.

### FEATURES:

#### 1 SAFETY

The LX™6 comes loaded with standard safety features. The safety cage ensures drillers remain a safe distance from the drill string, while low speed and low torque rotation ensures safe rod management. The steel crawlers coupled with the LX™6's upright stability make this machine extremely sure-footed on uneven formations.

#### 2 DUMP MAST

Improved positioning on rough terrain with a 1,000 mm (40 in) mast dump.

Depth Rating: Core Drilling Vertical Downhole (Fluid Filled)



100 m (328 ft)			
200 m (656 ft)			
300 m (984 ft)			
400 m (1,312 ft)	PQ™ / PHD W-WALL™ 145 m (475 ft)		
500 m (1,640 ft)		HQ™ / HRQ™ / HRQ™ W-WALL™ / HXQ™ / HXQ™ W-WALL™ 275 m (900 ft)	
600 m (1,969 ft)			NQ™ / NRO™ / NRO™ W-WALL™ / NQX™ / NXQ™ W-WALL™ 550 m (1,800 ft)
700 m (2,297 ft)			
800 m (2,625 ft)			BQ™ / BRQ™ / BXQ™ 800 m (2,625 ft)
900 m (2,953 ft)			
1,000 m (3,281 ft)			

Calculated using pullback capacity of the drill and effective rock breaking strengths of 5 MPa, actual results may vary.

#### ROTARY DRILLING (TRICONE)

Hole Diameter	216 mm	8.5 in
Hole Depth	175 m	570 ft

#### AUGER DRILLING

Hole Diameter	150 mm	5.9 in
Hole Depth	15-20 m	49-65 ft

#### DTH DRILLING

Maximum hammer size: 98 mm (3-7/8 in) @ max 17.2 m<sup>3</sup> / min @ max 24 bar

Rec. Hole Size	115 mm	4.5 in
Maximum Hole Size	127 mm	5 in
Hole Depth	290 m	950 ft
Rec. Rod Size	76.1 mm	3 in



### 3 HYDRAULIC HEAD SIDE SHIFT

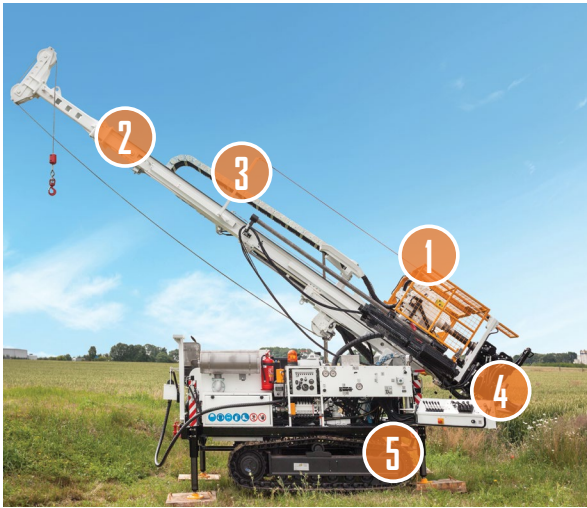
Hydraulic side shift for easy rod-pulling and clear access to the center line.

### 4 ROD CLAMP AND BREAKER

220 mm (8.7") double clamp for making and breaking rod joints quickly and safely.

### 5 INCREASED ACCESSIBILITY

Powerful steel crawlers ensure mobility on difficult terrain.



## TECHNICAL SPECIFICATIONS:

#### WIRESLINE: NQ™ / NRQ™ / NXQ™

Depth Rating Downholes	550 m	1,800 ft
Maximum Pull Back Force	55 kN	12,364 lbf
Maximum Rod Pull Length	3 m	10 ft
Engine Option - Tier 3	D914 L04 Diesel	
Engine Option - Tier 2 High altitude option	BF4L914 Diesel	

#### ROTARY DRILLING (Tricone):

Hole Diameter	216 mm	8.5 in
Depth Rating Downholes	175 m	570 ft

#### AUGER DRILLING:

Hole Diameter	150 mm	5.9 in
Depth Rating Downholes	15-20 m	49-65 ft

#### DTH DRILLING:

Hammer Size	98 mm	3-7/8 in
Hole Diameter	127 mm	5 in
Depth Rating Downholes	290 m	950 ft

For detailed information, see the Technical Overview sheets

## EXTREME VERSATILITY

The Boart Longyear LX™6 is a compact, lightweight, and versatile multi-purpose drill rig designed for geotechnical investigation, construction, and exploration drilling.

Engineered for fast set-up on site, superior mobility and powerful performance, the LX™6 delivers the versatility and productivity for most geotechnical project requirements with fast and easy tooling conversions, operation reliability and customizable options.

It weighs only 6,500 kg (14,330 lb) and is less than 2 m (6.6 ft) wide, providing excellent site accessibility. The heavy-duty mast and two-speed drill head provide a powerful solution in a small and lightweight footprint.

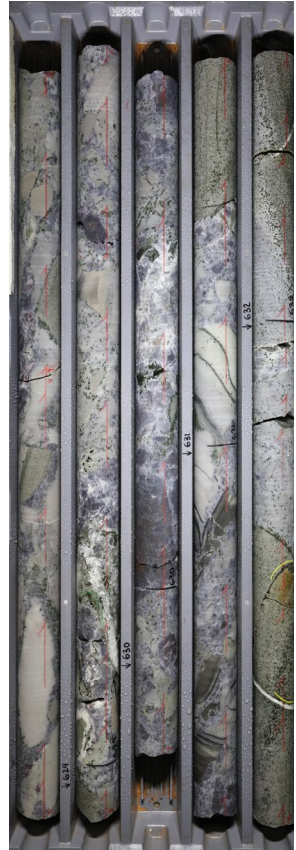
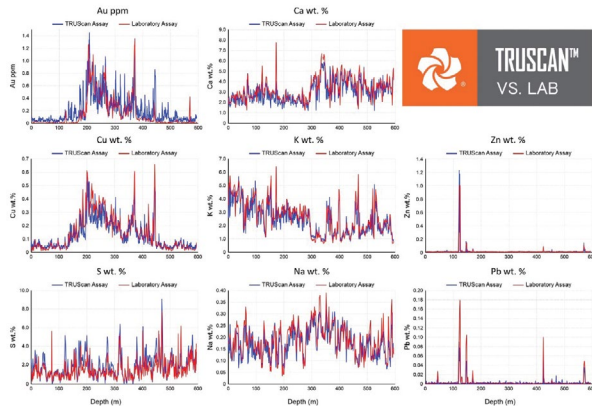


# BOART LONGYEAR TRUSCAN™



## ONSITE SCANNING TECHNOLOGY

TruScan™ is a core/chip imaging and X-ray fluorescence (XRF) system that provides near real time high-definition images and matrix-matched geochemical results.



Boart Longyear's TruScan™ is an innovative scanning technology, utilizing advanced XRF technology and high-definition cameras to provide superior imagery and continuous, non-destructive, matrix-matched elemental results, all in near real time. It is a fully integrated, rugged and mobile technology housed in a mine-specification trailer that can operate in the most challenging greenfield environments. With its ability to scan 60 to 100 m (200 to 330 ft) of core per 12-hour shift (depending on required data density) and many more meters (feet) per shift on RC chips, a single unit can potentially scan the core from multiple drill rigs, legacy core, or a combination of both, providing geoscientists access to near real time geological data from anywhere in the world. Boart Longyear offers TruScan™ as an independent service to mining clients or the technology can be bundled as a part of a drilling services agreement.

**ACCURACY:**

Boart Longyear's proprietary matrix-matched calibration method, in combination with its unique hardware, software, and continuous scan of the core or chip sample, delivers the most accurate non-destructive XRF-geochemical results as compared to peer technology and p-XRF. Each data point is quantified and processed through a systematic QA/QC procedure, ensuring data integrity.

**SPEED:**

TruScan™ is an onsite analysis system designed to fit within the normal workflow of drilling crews. Data is captured directly from the exploration or mine site and is continuously transferred to secure cloud storage, providing geoscientists access to near real time geological data from anywhere in the world. While typical lab assays may take weeks or months to return geochemical results, near real time results from TruScan™ can enable rapid decision making while the rig is still on the hole, all while significantly reducing assay costs.

**ACCESSIBILITY:**

Access to data allows the leveraging of global expertise from anywhere in the world. In addition, Boart Longyear offers a suite of applications that allow TruScan™ data to be conveniently viewed and, with the assistance of powerful analytics and machine learning, interpreted to deliver geological insights including lithological and structural information.

**SAFETY:**

As opposed to traditional lab assays which require core to be cut, bagged and shipped off site, TruScan™ analyzes material while it's still in the core tray, removing manual core handling and therefore reducing the likelihood of repetitive strain injuries. Furthermore, reducing the amount of core assayed and providing data to consumers remotely can significantly reduce the number of staff required on site.



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purpose



# THE METALLURGY

In a perfect world, all Exploration rods could be used until predictably and evenly worn out. But, in real world applications, other types of damages occur. Know the tell-tale signs of applications damage, learn to preempt them, or retire rods ahead of catastrophic failures.

# THE METALLURGY

## FUNDAMENTALS

***Coring drill rods represent a big investment, so big that many contractors capitalize the expenditure over more than one year. Yet, they are consumables with limited life and must eventually be retired, individual rods or the entire string.***

Getting the maximum life obviously reduces replacement costs; avoiding unexpected failures in the hole is a must. Recognizing the common types of failures is critical to drive change and implement best practices. Understanding the root causes requires metallurgy, but you don't have to be a metallurgist to turn failures into learning experiences.

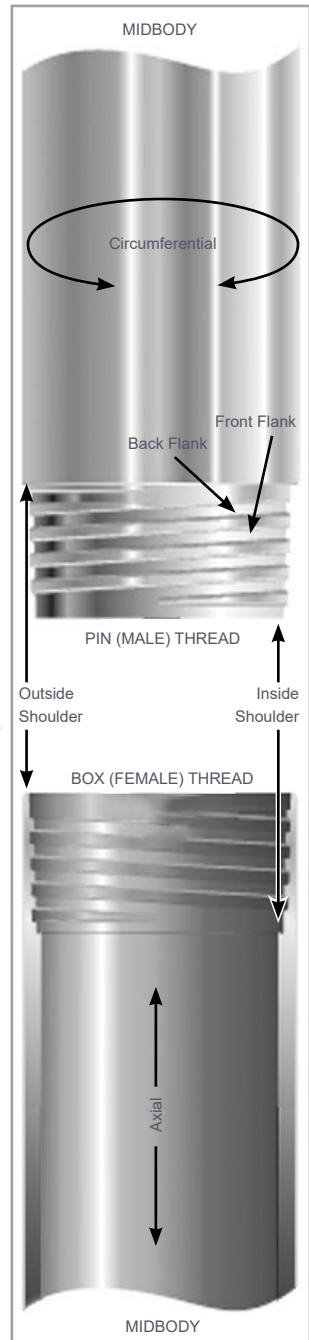
Rod failures in the field often come with mixed symptoms, sometimes making it hard to decipher the true root cause or causes. The most fundamental problem is a misfit of the thread, usually from mixing rods and subs or adapters from different manufacturers. These threads may appear to fit but without the required interference. A misfit may lead to circumferential thread cracks, thread galling, or box flaring/pin rolling.

***Never mix threads from different manufacturers! Threads may appear to fit, but manufacturing practices differ between suppliers.***



If the joints are leaking, one simple reason could be that the outside shoulders are not smooth and firmly sealing against one another. Increasing the make-up torque may solve it, but only if the outside shoulder of the box thread has not been damaged. If rushing when trying to thread rods, damage from stabbing means that the shoulder will not seal. Treat threads with care and respect.

***Quality rods are worth taking care of!***



## PROPER THREADING

Careful joining or making of the rod joint is crucial and the correct amount of torque must be applied. The specific torque will depend on rod size, thread type, as well as the amount of load. In deeper holes, more torque is required to keep the outside shoulder of the box and pin ends closed.

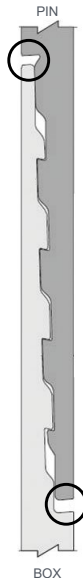
Proper threading is done in steps:

- 1 Alignment**  
Ensure true vertical alignment of the pin into the box. Misalignment can damage the first turn of the thread, or even cause stabbing damage.



- 2 Threading**  
Slowly rotate the pin while advancing the rod. Threading by hand will advance the pin automatically, but if using the drill's rotation unit the feed rate must be set for the thread type. If the feed rate is too slow, it will damage the back flank of the thread (the load flank). If the feed rate is too high, it will damage the front flank. **Never "snap" threads together to "save time."**

- 3 Stand-off Gap**  
At least periodically, threading should be done with hand tightening to evaluate the stand-off gap. The gap should normally be in the range of 0.4 mm to 2.4 mm (1/8 to 3/4 inches) for all rod sizes. If this gap is greater, it could indicate debris in the thread. This will cause damage or wear. If the gap is lesser, the threads may be worn or have been overloaded. Mixing of different manufacturers' rods may show either too little or too much gap. Using a torque wrench and



applying no more than 70 Nm (50 ft-lb), the gap should close. If not, one of the issues above is present.

- 4 Minimum Make-up**  
Proper make-up requires pre-loading the joint. Just closing the stand-off gap does not constitute proper make-up. Even the smallest ATK rod requires a minimum torque of 340 Nm (250 ft-lb), so make-up is done with the rotation unit and not by hand.

- 5 Depth Compensation**  
When drilling downholes, holding back the weight of the rods will put the threads in tension. To prevent a stand-off gap from opening, extra torque is required beyond the minimum make-up torque. Note that excessive torque will cause additional thread wear and reduce the total load capacity of the string. In theory, the torque should be increased with each extra rod. In practice, additional make-up torque is added at 1,000 m and 2,000 m (3,000 ft and 6,500 ft) depth. Only in exceptional circumstances is this done to the point of making up the inside shoulder.

The loads and vibrations during drilling sometimes tighten the threads further. Loosening or breaking of the thread may become difficult depending on the maximum break-out torque on the drill. A rubber mallet can be used to loosen the threads. But a metal hammer or wrench will damage the steel and form crack initiation sites.



# BOX AND PIN END THREAD FAILURES/CRACKS

## CIRCUMFERENTIAL CRACKS

Appear along the root of the thread, where the remaining wall is the thinnest. It occurs in both pin and box ends, shown as a broken pin or a through-crack in a box.



### ROOT CAUSES:

- 1 Insufficient make-up. Outside shoulder did not make-up during operation, giving excessive flex.
- 2 Excessive make-up. Applied torque damaged the thread or reduced the load bearing capacity.
- 3 Hole curvature. Planned curves or caves caused high bending and fatigue loading.
- 4 Helical twisting. Oscillations of the drill string at certain RPMs led to bending and joint damage.
- 5 High pullback load. The depth capacity of the rod was exceeded.
- 6 Box wear. Outside steel was worn too thin, limiting the load bearing capacity of the thread.
- 7 Mechanical damage. Dents or dings created crack initiation sites in the box.
- 8 Thread wear. Total number of makes and breaks was exceeded, accelerated by foreign debris or a poor choice of thread compound.
- 9 Bad top sub. A worn top sub or misfit (top drive rigs) damaged the rod threads.
- 10 Stress corrosion. In-hole chemistry, e.g., pH, salt, chlorine, fluorine, sulfides, or hydrogen weakened the steel.
- 11 Surface corrosion. Improper storage led to corrosion pits in the thread.

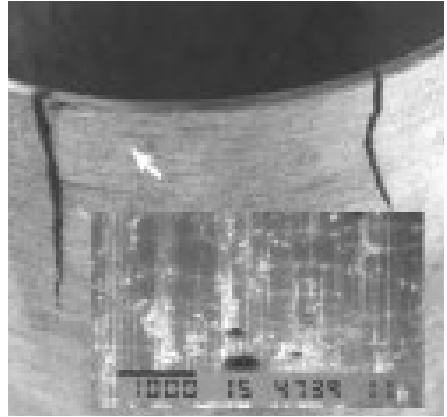
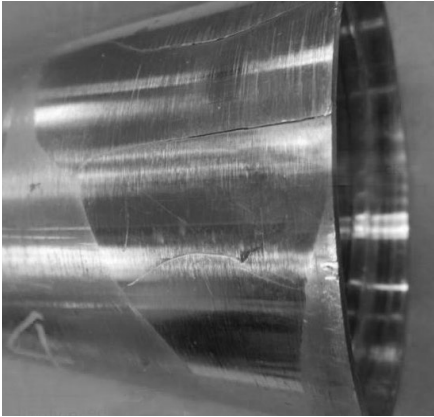
### POSSIBLE SOLUTIONS

Some solutions simply come back to good standard processes and consistent enforcement, including training, inspections, and record keeping. Other solutions require even more engagement, such as proper hole design, progressive changes in make-up torque, frequent adjustments to rotation speed, and sampling of drilling fluids.



## AXIAL CRACKS (Box Threads)

Cracks along the axis of the box thread due to damage to the steel in what is known as Heat Check Cracking. Axial cracks in a polished spot are telltale signs. These can appear seemingly at random and be a source of much frustration, even in new rods and easy drilling conditions.



### ROOT CAUSE:

Drill rods rubbing against the hole wall with sufficient friction to cause excessive heating, followed by rapid cooling from the flushing media. This is equivalent to the normalizing and quenching done during manufacturing but without the benefit of tempering. The result is a structural change to the surface layer of the steel called martensite. It is excessively hard and brittle, and susceptible to cracking.

Metallurgists are well familiar with this steel structure known as martensite. Under the microscope, the changes in the metallurgical structure are evident.

### Heat Check Cracking

Can occur in any hole, but may be easier to avoid in straight holes than in curved. During drilling, careful monitoring of the RPM, torque, and oscillations is critical to avoid excessive friction. Ensure good fluid circulation for effective cooling.

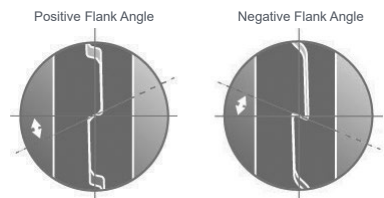
How quickly the damaged steel develops a crack or catastrophic failure may be exacerbated by:

- Localized wall thinning
- Rod twisting
- In-hole chemistry
- Excessive loads

**WHEN NOT IN USE, ROD BOX ENDS SHOULD BE INSPECTED FOR POLISHING AND THINNING!**

### Note:

- Threads with a positive flank angle will have higher circumferential stresses and be less forgiving if the steel has been damaged.
- A thread with a negative flank angle will provide a better opportunity to identify the polished area before a failure occurs.
- Bulging will also accelerate wear at the box.



## EXCESSIVE WEAR

Some thread wear is expected depending on the number of makes and breaks. However, accelerated wear or visible damage is not normal - monitor wear and discard before a failure happens in the hole.

It is normal for the first turn of the thread to wear most rapidly. Use a designated gauge to evaluate the condition of the box thread. As wear progresses, the pin and box must be further tightened. Eventually, the ability to pre-load is reduced, compromising the load bearing capacity.

similar style pic  
of someone  
using a thread  
gauge



## THREAD GALLING

A phenomenon where metals glide against each other in compression, with metal-to-metal contact on an atomic level. This causes layers from one surface to adhere to the opposing surface. The result is not smooth like in wear, but rather rough and with lumpy protrusions. Galled threads do not make or break as intended and may eventually seize.

The most obvious corrective actions include the consistent use of proper procedures and designated thread compound, each time and in sufficient quantity and using a wide paint brush. Use a recommended compound – not common grease – and ensure the threads are clean using a brass brush.

Proactively, galling can be avoided if the material hardness is dissimilar on the two mating surfaces. It's preferable to have a pin thread with a higher surface hardness than the box thread. Also, a dual lead thread will align better than single lead and spread the loads across a larger surface area. This will particularly slow the wear rate on the first turn of the thread.



# BOX FLARING/PIN ROLLING

The inside shoulder of the pin is sometimes observed to be rolled. This is often combined with flaring of the outside shoulder, which can be evident on the pin but is more common on the box.

## ROOT CAUSE & CORRECTIVE ACTION:

### 1 Excessive Make-Up Torque

The thread may otherwise be good, but the pre-loading is so high it causes the outside shoulder to flair. High interference on the inside shoulder also causes inward rolling of the pin. Verify and reduce the make-up torque.

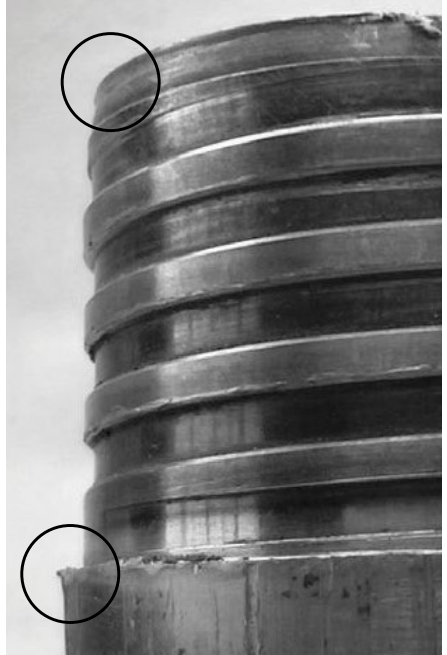
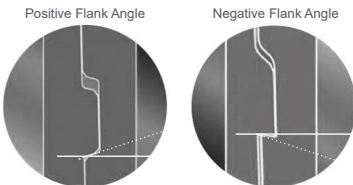
### 2 Worn Out Thread

The proper torque may have been used, but the thread is simply worn out. With pins and boxes of dissimilar hardness, the pin may appear to have substantial remaining wear life. Use a gauge to evaluate wear on the box thread. Ensure proper thread compound is used to reduce the wear rate.

A longer term solution is to use a dual-start thread.

### 3 Overloading

Make-up of thread with a positive flank angle always pushes the box out, referred to as bulging. This accelerates the wear and the bulging gets progressively worse. Threads with a negative flank angle will clamp the joint together instead of pushing the box out. Weight on bit becomes more critical as the box wears, as it too contributes to bulging.



# EXCESSIVE MIDBODY WEAR

Refers to any significant loss of metal anywhere along the length of the rod, other than the box- or pin-end. Some degree of wear is perfectly normal. However, if the wear rate is accelerated it is worth evaluating.

## ROOT CAUSE & CORRECTIVE ACTION:

### 1 Lost circulation

Reduced or lost circulation of drilling fluid will cause an increase in friction, accelerating the wear. Improve the lubrication by increasing the flow rate or upgrading the drilling fluid.

### 2 Broken Ground

Some formations are inherently unstable and collapse against the rods. Upgrade the drilling fluid to attempt to stabilize the hole walls.

### 3 Caved Sections

In any oversized or caved sections, there is no lateral support to stabilize the rod. In compression, the rod string will elastically bend, buckle, or twist, increasing the contact pressure and friction where the rod is supported by the hole. As a first step, reduce the weight on bit as well as rotation speed. Or, for a more sustainable solution, grout the caved section.

### 4 High Hole Curvatures

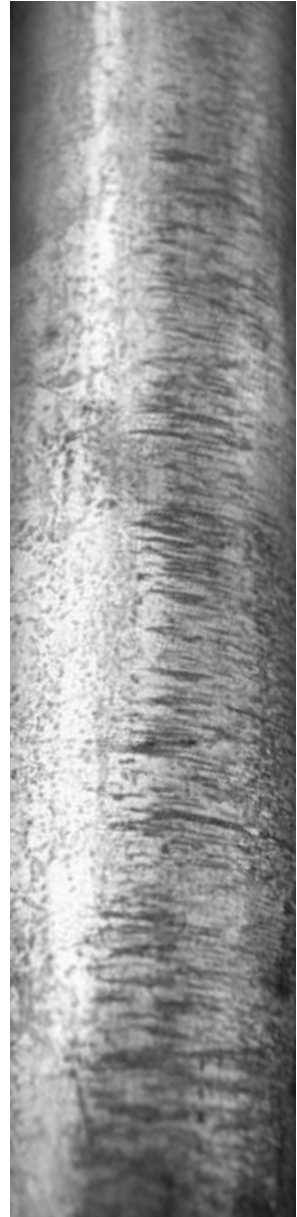
Curves come at a cost of midbody wear. The rod is constrained by the hole, increasing the friction near the curve. There are good reasons for curves, but it impacts wear and rod cost. At minimum, stay within recommended maximum curvatures and ensure good circulation of drilling fluid. A rod with variable wall thickness will be more flexible, but will experience a similar loss in wear.

### 5 Rod Twisting

Whether a rod is temporarily or permanently deformed, a twisted rod will exhibit a spiral shaped pattern of polishing or heavy wear. This problem is often driven by caved hole sections or high curvatures. Manage the bit load and RPM to avoid or minimize vibrations in the drill string.

### 6 High Bit Load

A high bit load increases the side load and the frictional rubbing against the hole wall. It may increase rate-of-penetration, but at a cost of accelerated tool wear.

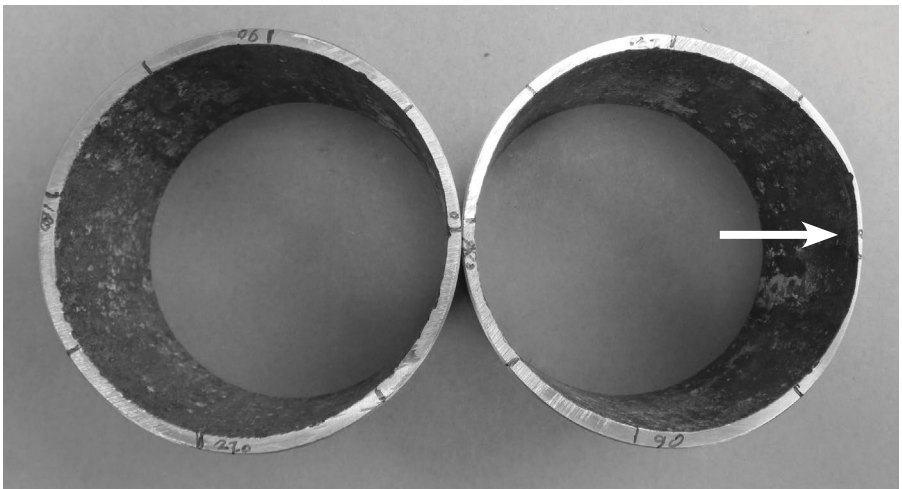


# BOX WEAR

Wireline drill rod wall thickness is the thinnest at the box end. Alternative, and as a result, external box wear often limits the useful life of the rod.

Bulging causes localized wear on the box, although the bulge may not be obvious. But the wear rate accelerates since a thin remaining wall will expand more than the original full wall thickness. Flaring will further accelerate the wear by the outside shoulder due to additional contact with the hole wall. In extreme cases, the box and pin thread will "jump". A rod with a negative flank angle will slow the wear and delay the ultimate replacement of the rod.

The steel has limited strength and elasticity, eventually leading to a crack. This could simply be from overload or in combination with heat check cracking. The thinner the wall, the less forgiving it will be against any failure mode. Note that bulging depends on the compressive load so it will vary along the length of the hole.



A simple "go/no-go" gauge can be used to quickly verify whether sufficient remaining wall thickness remains. The "go" end should slip on to the box, but the "no-go" should not fit. The "no-go" width is about 60% of the original wall thickness of the outside shoulder. Be careful to measure at multiple angles if the wear is uneven, for which the root cause would be bent or twisted rods.

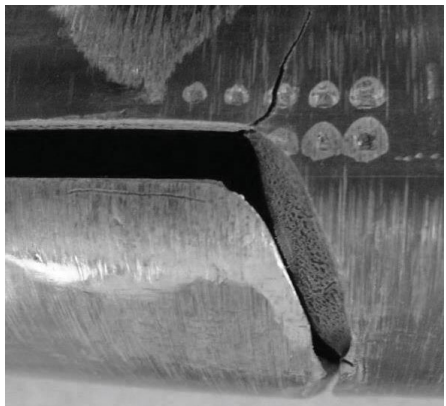
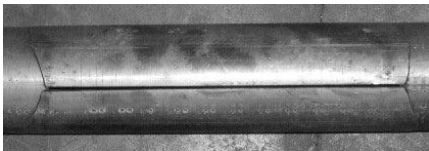
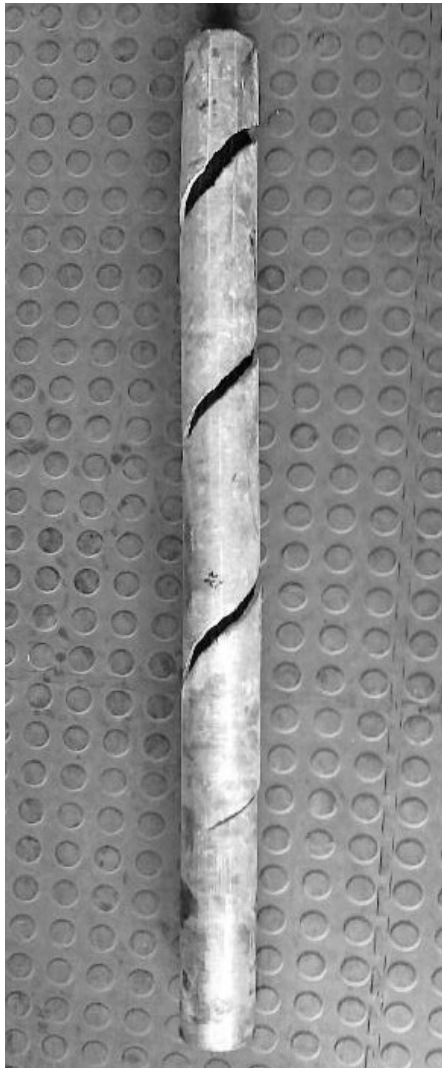


## MIDBODY CRACKS

Physical handling of the rods may cause dents, dings, and scratches. A common type of surface damage is grip marks from the rod handler when the clamping pressure is excessive. Only set the pressure high enough to safely lift and move the rods.

The indentations will not cause immediate failure, but in combination with tension and torque they become crack initiation sites. A general recommendation is to retire any rods with surface damage deeper than 0.8 mm (1/32").

The appearance of the cracks will vary depending on the damage itself, operational loads, number of initiation sites and other failure mechanisms. It can show up as a vertical crack, a spiral crack, or a T-shaped crack. Sometimes repeated clamping marks are evident, while other times the surface has been polished. The spiral is an example of a single initiation site, followed by crack propagation due to the torque.



## TWISTED RODS

Rod twisting is a complex form of damage. Excess weight on bit is not the cause since the rod is constrained by the hole wall. What actually happens is that the rod has twisted. In-hole, the rod “catches” on the hole wall to accelerate and decelerate violently. The dynamic torque exceeds the yield strength of any steel. The rods are twisted into a long spiral shape, commonly with a full revolution over four rods. Polishing or heavy wear is a telltale sign.

Twisted rods must be removed or the oscillations will only worsen. Continued drilling will lead to other damage such as rapid wear or heat check cracking. The concentricity built into the new rod is lost and they will be seriously unbalanced. You can straighten bent rods, but it must be done properly using dial gauges and a press. Proper straightening does take time and drilling cannot continue unless a second string is available. Avoiding the problem to start with is the best solution.

### 1. Reduce Maximum RPM

Resist the temptation to maximize short-term productivity, especially in surface drilling. There is simply more friction at high RPM, increasing the likelihood of oscillations in the hole.

### 2. Tweak Operational RPM

Oscillations occur at certain natural frequencies, determined by the friction and weight of the rod section. An experienced and attentive driller will immediately adjust the rotation speed. A change by as little as 50 RPM may be sufficient.

### 3. Improve Fluid Flow

Fluids dampen vibrations and reduce friction. Ensure good circulation.

### 4. Restrict the Annulus

Oscillations, vibrations, and deformation depend on the available space. Use tighter casing or great caution if switching to a smaller size in-hole. Grout any caved sections.

### 5. Restrict Doglegs In Hole Design

Respect the bending ratings of the rod. Curves always add friction and will contribute to twisting problems. It's safer to place curves towards the bottom of the hole.

### 6. Select Proper Rods

Use rods with the best type of stress relief during manufacturing. Lower residual stresses will make the rods less susceptible to twisting.



## CURVATURE

Design and survey the holes to keep curves within the guidelines. The maximum curvature must be determined on 3 m (10 ft) intervals, i.e., the length of a drill rod. Longer intervals may disguise sharper turns. A software tool is needed to calculate curvature in three dimensions. Be prepared to re-cut or ream out any section with excessive curvature. Reference allowable curves for each rod. Narrower rods are more flexible, as are variable wall rods.

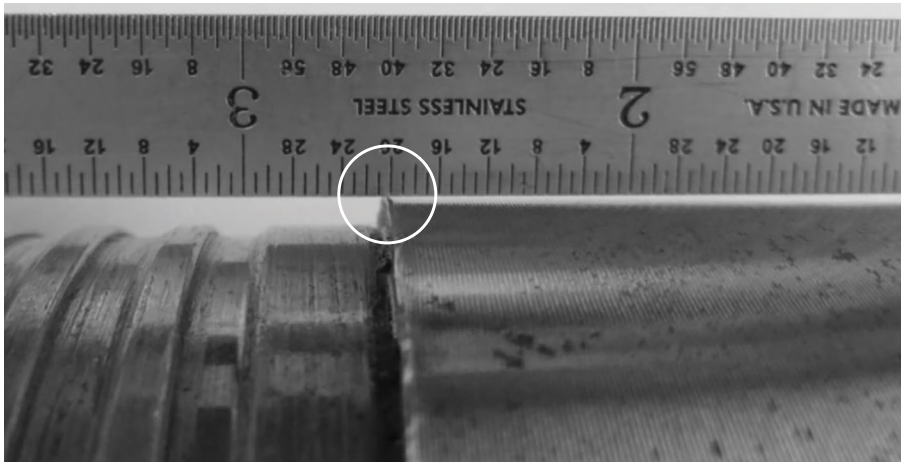
## SUBS ON TOP DRIVE RIGS

Use correct subs and check the fit by following the steps of proper threading. While each rod only sees one make or break, for the sub that is multiplied by the number of rods. Treat these subs as wear items with multiple spares on hand. In deep holes, you may need to discard a sub after a single trip. It's a good idea to use separate subs for tripping (more wear) and for drilling (more load). Subs with extended "bullnose" guides will align better and reduce damage to the first rod thread. The pins should be case hardened to avoid galling and extend the sub wear life. Pay special attention to the outside shoulder of the sub. If the threads and the shoulder are worn,

it could damage the entire rod string. The shoulder should be wider on the sub than on the rod, extending the wear life and making it easier to spot a worn shoulder.

## STORAGE AND TRANSPORT

During transit, stack rods on at least three cross members. When stored, ensure the supports keep the rods at least 30 cm (1 ft) off the ground. Always clean and lubricate the threads. For longer storage, a corrosion inhibitor on the mid-body is recommended. While initial surface corrosion may only be cosmetic, even small corrosion pits could be future crack initiation sites.



## IMPREGNATED BIT WEAR TROUBLESHOOTING

Much can be learned from examining impregnated bits when they are pulled from the hole. This section can help identify and remedy many common field problems. Normal retirement or discarding of an impregnated bit should take place only after it has been totally consumed. Most Boart Longyear impregnated bits have full-depth waterways to allow the bit to be fully consumed. The first indicator that a bit is nearing normal retirement is a rise or kick in pump pressure due to the diminishing depth of waterways. In Stage™ bits, this rise is observed at the transition of each stage. Ideally, an impregnated bit drills steadily with the matrix and diamond wearing away at the same rate.

### NORMAL WEAR PATTERNS



#### Ideal Wear Pattern

Should be relatively flat with slightly chamfered sides. Bit feels sharp, comet tails have formed to support diamonds. Diamonds are released as they are worn. Gauge stays within tolerance.



#### Normal Retirement

Full depth of impregnation evenly consumed. Gauge stays within tolerance.

### IRREGULAR WEAR PATTERNS

The causes and solutions described in this section are not exclusive lists, but represent common causes and generally effective solutions.



#### Concave Face Wear (Rounded to Inner Diameter)

**Cause:** Often caused by excessive penetration rate for the RPM used. This can also be caused by core grinding, overdrilling.

**Solution:** Reduce penetration rate or increase RPM.

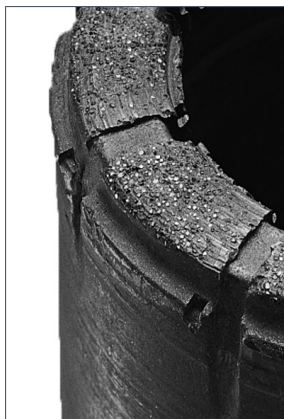


#### Concave Face Wear (Rounded to Outer Diameter)

**Cause:** Insufficient water flow.

**Solution:** Check pump and rod string for leaks; increase pump output.





### **Gauge Loss: Inner Diameter**

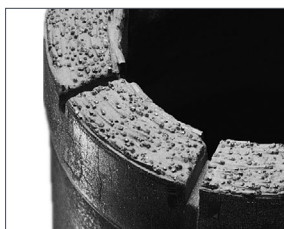
**Cause:** (A) Overfeeding; (B) Broken formations; (C) Drilling over lost core; (D) Insufficient drilling fluid.

**Solution:** (A) Reduce penetration rate; (B) Cement or change to a lower series bit; (C) Check core barrel/core lifter/core lifter case; (D) Check inner tube length adjustment; check pump and rod string for leaks – increase pump output.

### **Gauge Loss: Outer Diameter**

**Cause:** (A) Lack of circulation; (B) Bit being reamed down under-size hole; (C) Vibration.

**Solution:** (A) Increase coolant flow rate; (B) Check reamer shell gauge and replace if under-sized; (C) Alter RPM.



### **Excessive Diamond Exposure**

Matrix abrades away before diamonds have worn sufficiently, resulting in high diamond exposure and low bit life.

**Cause:** Caused by overfeeding/over drilling.

**Solution:** Increase RPM, change to a lower series bit, or reduce bit weight.



### **Face Glazed (Diamond Polished and Metal Bound)**

Bit does not feel sharp; diamonds are flush with matrix; no significant “comet tails” behind each diamond.

**Solution:** Sand blast face or use other recommended methods to re-expose diamond. If the face glazes repeatedly, change to a higher bit.



### **Cracked Waterways (Diamonds Polished)**

**Cause:** (A) Excessive bit load; dropped rods; free fall of (wireline) inner tube in dry hole; (B) Bit crushed by rod holder, foot clamp or pipe wrench; (C) Pushed down an undersized hole (i.e., reaming shell worn out).

**Solution:** Review proper operating procedures.



### **Burnt**

**Cause:** (A) Lack of fluid. (B) Too high of weight on bit being used.

**Solution:** Check pump and rod string for leaks; check inner tube adjustment; maintain coolant flow rates.

# RESOURCES

## WEBSITE:

[mining-technology.com/features/history-of-mining-oldest-mines/](https://mining-technology.com/features/history-of-mining-oldest-mines/) (September 2019)  
[miningafrika.net/mining-countries-africa/south-africa/](https://miningafrika.net/mining-countries-africa/south-africa/) (September 2019)  
[australianminesatlas.gov.au/history/index.html](https://australianminesatlas.gov.au/history/index.html) (September 2019)  
[blog.midwestind.com/history-of-mining/](https://blog.midwestind.com/history-of-mining/) (September 2019)  
[thecanadianencyclopedia.ca/en/article/mining](https://thecanadianencyclopedia.ca/en/article/mining) (September 2019)  
[firstmajestic.com/social-responsibility/mining-history-of-mexico/](https://firstmajestic.com/social-responsibility/mining-history-of-mexico/) (September 2019)  
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[thisischile.cl/economy/mining/?lang=en](https://thisischile.cl/economy/mining/?lang=en) (September 2019)  
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[wikipedia.org/wiki/Bre-X](https://wikipedia.org/wiki/Bre-X) "Long-awaited Bre-X court decision due Tuesday". National Post and Calgary Herald.[permanent dead link] (September 2019)  
[Grundhauser, Eric](https://Grundhauser, Eric) (August 21, 2015). "The \$6 Billion Gold Mine That Wasn't There". Slate. Retrieved September 21, 2015. (September 2019)  
[petroleumhistory.org/OilHistory/pages/Diamond/inventor.html](https://petroleumhistory.org/OilHistory/pages/Diamond/inventor.html) (September 2019)  
[silverbulletrisk.com/blog-how-to-identify-risks](https://silverbulletrisk.com/blog-how-to-identify-risks) (October 2019)  
[pubs.spe.org/en/ogf/ogf-main-page/](https://pubs.spe.org/en/ogf/ogf-main-page/) (September 2019)  
[drillingcontractor.org/facilitating-a-change-in-hse-culture-must-begin-by-identifying-understanding-existing-culture-1392](https://drillingcontractor.org/facilitating-a-change-in-hse-culture-must-begin-by-identifying-understanding-existing-culture-1392) (September 2019)  
[deloitte.com/us/en/pages/finance/articles/cfo-insights-culture-shift-beliefs-behaviors-outcomes.html](https://deloitte.com/us/en/pages/finance/articles/cfo-insights-culture-shift-beliefs-behaviors-outcomes.html) (September 2019)  
[cliffsnotes.com/study-guides/geology/metamorphic-rocks/hydrothermal-rocks](https://cliffsnotes.com/study-guides/geology/metamorphic-rocks/hydrothermal-rocks) and <https://www.cliffsnotes.com/study-guides/geology/the-earths-components/the-rock-cycle> (October 2019)  
[newscientist.com/article/dn16610-diamond-no-longer-natures-hardest-material/#ixzz63jmcch2N](https://newscientist.com/article/dn16610-diamond-no-longer-natures-hardest-material/#ixzz63jmcch2N) (October 2019)  
[britannica.com/topic/yield-curve](https://britannica.com/topic/yield-curve) (November 2019)  
[sc.org/periodic-table/](https://sc.org/periodic-table/) (November 2019)  
[geology.com/minerals/mohs-hardness-scale.shtml](https://geology.com/minerals/mohs-hardness-scale.shtml) (November 2019)  
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[mining-technology.com/features/history-of-mining-in-south-africa/](https://mining-technology.com/features/history-of-mining-in-south-africa/)  
[australianminesatlas.gov.au/history/index.html](https://australianminesatlas.gov.au/history/index.html)  
[Investopedia.com](https://Investopedia.com)

## PRINT:

National Drilling Association / Diamond Core Drill Manufacturers Association Inc.1980 Bulletin  
Collared & Cased, Barry Avery  
A book commissioned by ADIA and released at the DRILL2019 conference  
Longyear: The Mesabi and Beyond, Edmund J. Longyear / Walter R. Eastman  
Tracks and Trends © 2018. Deloitte Touche Tohmatsu Limited. Designed and produced by the Deloitte Design Studio, Canada. 17–5250V  
CDDA Bulletin, 65th Anniversary Issue  
S&P Global Market Intellegency, World Exploration Trends 2018, March 2019  
The Mining Association of Canada (MAC), Facts and Figures 2018  
CIM Mineral Exploration Best Practice Guidelines 2018



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Fax: +61 8 8375 8497

## **Canada**

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## **Latin America**

Av. Los Libertadores 16.500 - Sitio 1- A-2  
Complejo Industrial Los Libertadores  
Colina, Santiago-Chile  
Tel: +56 2 2595 3300

## **South Africa**

1067 Katrol Ave  
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