Reference book

Drilling in surface mining, quarrying and construction | 2019

Epiroc

Contents

Welcome to the insider's guide to surface drilling

The pursuit of efficiency and straighter, more accurate blastholes is a journey that unites operators, site managers and engineers worldwide. Wherever they are working, every small step toward optimization helps to raise the bar of excellence in drilling operations. As automation gathers pace, sensors and data analysis have become vital enablers. While worksites in surface mining, quarrying and construction are increasingly becoming smarter, technology also means different things to different equipment users. Will self-diagnostics be the answer to reducing maintenance costs and increasing asset utilization? How can intelligent guidance systems improve hole navigation and speed?

These are just some key considerations for drillers today. At the same time, there is always more than one way to attack problems. And there is no substitute for knowledge sharing in terms of addressing complex challenges, particularly in new mining environments.

That is why it gives me great pleasure to welcome you to this updated edition of the Epiroc reference book for surface drilling – packed with in-depth perspectives on drilling topics as well as a comprehensive new collection of case stories. I invite you to explore the valuable insights from drilling professionals and their experiences presented in these pages.

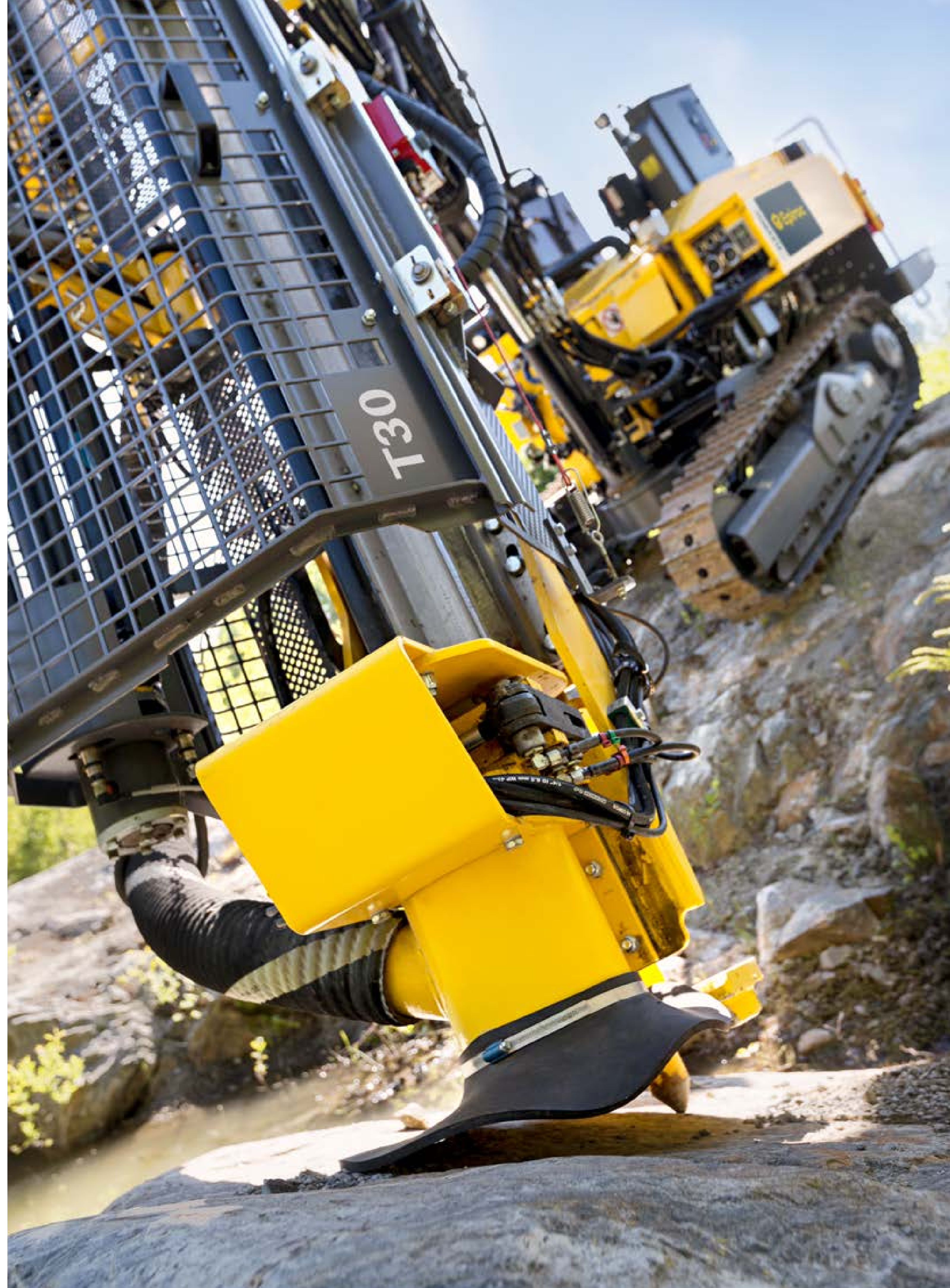
Since the book's last publishing, innovation at Epiroc has shifted to higher gears. Environmental targets are high on the agenda and Epiroc drilling equipment is now fitted with modern Tier 4 F/Stage V engines which reduce hydrocarbon and nitrogen oxide emissions by 94% compared to Tier 1/Stage I engines.

This new edition of the reference book provides a glimpse into these and many other advances in the SpeedROC, AirROC, PowerROC, FlexiROC, as well as our flagship SmartROC family of products.

Surface drilling is part of our DNA, but our world class portfolio has always matured through close collaboration with customers. As we move forward in this digitally empowered era, we will continue to steer the future of global rock excavation and surface drilling together with drillers in the field.

Yours sincerely

Brian Doffing
President, Epiroc Surface and Exploration drilling division



Talking technically

Past, present and future

Epiroc has its roots in Atlas Copco which has been acknowledged as the world leader in rock drilling technology for more than 140 years.

The modern story was forged in 1905 when the company joined the race to develop the first pneumatic rock drill. After the 2017 rebranding, Epiroc now offers the widest range of drill rigs on the market including some 50 models for quarrying and construction.

Early years

The first air-powered rock drill made by AB Atlas was a heavy, tripod mounted unit designated No 16. It was equipped with innovations such as rifle bar rotation, but was heavy and difficult to handle. Eleven were manufactured from 1905 to 1906, after which No 16 was replaced by light, hand-rotated rock drills such as the Cyclop and Rex. They were developed and produced until well into the 1930s.

The first rock drill in the RH-series, the RH-70, was introduced in 1930 for drilling in hard rock. This was followed by the smaller RH-65, with double tubes for water flushing and a new rotation chuck for a 108 mm drill shank. This resulted in better guidance of the drill steel and three times longer life for the shank.

In the late 1930s, Atlas developed the pneumatic pusher leg for use with the light rock drills, at the same time experimenting with cemented carbide tipped integral drill steel. The two were combined with the RH rock drill in 1945, when they were used on the completion of the Nämforsen power plant in Sweden. The advent of the more powerful RH-656 in 1948 resulted in the "Swedish Method" which became the world standard for underground rock drilling for the next 30 years.

For surface drilling, drill wagons on rubber wheels were introduced in 1948, and the first crawler mounted rig BVB 61 appeared in 1963. The ROC 600 equipped with the powerful BBE56 rock drill followed two years later, with a capacity of 150 m/shift drilling 76 mm holes. The introduction of button bits in the late 1960s, and their subsequent development, paralleled the improving efficiency of the rock drills, providing better hole flushing and longer life.

Figure 1: Rock drill No. 16 was first introduced in 1905. The COP 1038 arrived in 1973 and marked the beginning of the hydraulic era. Several models have since been launched, the latest of which is the COP SC19 introduced in 2019.

No. 16

RH-656

COP 1038

COP 1838

COP 2550 CR

COP SC19X

Rapid development

Atlas Copco introduced its first hydraulic rock drill, the COP 1038, in 1973 which heralded the modern era of rock drilling technology. This machine offered improved penetration rates, longer drill steel life, and lower power consumption. It was produced for 10 years, during which time it was subject to continuous development, and has inspired the design of several new, further developed models such as the COP 3038 and COP 1800 series. In the meantime, the COP 4050, the company's most powerful rock drill at the time, was launched in 1986 followed by the best-selling COP 1838 which was introduced in 1992, with an improved dampening system that allowed a 50% increase in output without destroying the drill steel.

Further development resulted in the introduction of the more powerful COP 2540 with higher frequency, and the COP 2560 for larger holes. For even larger holes, COP 3060 and COP 5060 was developed. The COP 4050 has now been discontinued for surface drilling applications and been replaced by the COP 5060CR, which is now considered to be the most powerful tophammer rock drill.

From the beginning of 2000 to the present day, all current rock drills have been modified to meet the demands of surface drilling applications. Bearing surface has increased, large robust drivers and gearings have been implemented and the new family of rock drills with the same name structure logic as its predecessors is building a solid reputation with customers. In the spring of 2019, Epiroc launched an even further development of the surface COP 1800-series of rock drills. Together with mechanical improvements that provide an increased recommended service interval of up to 800 percussion hours, both product naming and color of the rock drills has changed. The new product names indicate in which applications the rock drills are normally used, for example COP SC (Surface Construction) with variants such as COP SC16, COP SC19 and COP SC25-HF (Figure 1).

The advent of Rig Control System (RCS) in 1998 brought about a new generation of drill rigs with logging capabilities, better serviceability, drilling performance and positioning accuracy. Going from Programmable Logic Controllers (PLC) to PC-based RCS has provided a more flexible and easily maintained common platform for all Epiroc equipment. To facilitate the move from pneumatic to hydraulic rock drills and provide backup for customers, a service department was set up that to this day supports Epiroc's ongoing product development program.

DTH drilling

Epiroc (previously Atlas Copco) was a pioneer in this field with its first DTH hammer developed in 1936, which was used until the 1950s with impressive results in Swedish limestone quarries. In 1969, the company re-entered the DTH market with COP 4 and COP 6, designed for a maximum air pressure of 18 bar and with a view to dramatically increase capacity. The high-pressure design challenged compressor manufacturers to introduce compressors that corresponded to the specific hammer, air pressure and required air volumes.

From 1992, the COP 34–84 series of hammers was introduced, and immediately became the benchmark for productivity within DTH drilling. Over the years, the increase in the average drilling pressure to 30 bar has improved hammer performance, and productivity has increased proportionally to air pressure.

The introduction of the Atlas Copco ROC L8 and L6 series of high performance, high pressure DTH rigs in the late 1990s gave another boost to the market. When equipped with a COP hammer they were still the most productive 25 bar DTH drilling combination available up to 2006, when a new ROC L range fitted with both 25 and 30 bar compressors was introduced. The COP 64 Gold, introduced by Atlas Copco in 2001, offers sustainable efficiency, maintaining an average of 96% of original performance throughout its working life. The more recently developed COP 66, released in 2012, is tailor-made use on rigs with 30 bar of air pressure.

A 20 m deep blasthole that took 3.5 hours to drill using a 6.5 bar rig 50 years ago, now takes just 15 minutes using a SmartROC D60 and D65 with COP M6 hammer (Figure 2). This performance is achieved with virtually no maintenance required for the hammer over its lifetime. The Epiroc range of DTH hammers includes the COP range: 2 in–8 in hammers for hole dimensions of 70–254 mm with working pressures of 6–30 bar. The DHD Classic range of low-price hammers starts at 90 mm diameter holes, and runs up to 302 mm diameter. These have been in continuous use in the quarry, construction and mining industries for more than 30 years.

COPROD

The COPROD system, introduced in 1992, was hailed as a huge leap forward in blasthole drilling. Its concept is simple but ingenious, combining the power of the tophammer with the rigidity of the DTH drill string (Figure 4).

COPROD rods are stacked on top of each other inside the drill tubes. They move longitudinally within each tube, transmitting the rock drill percussion energy to the bit, while the tubes transfer the rotation and torque from the rock drill. Lugs on the rods prevent them from sliding out during handling and, if the bit enters a cavity during drilling operations, rotation is maintained while percussion is interrupted until the bit meets resistance again. Today, Epiroc offers two versions of rock drills for COPROD drilling; the COP 3060CR with 30 kW output power and the COP 5060CR rock drill which is a further development of the COP 4050CR rock drill, equipped with an anvil to transmit percussion, and a tube chuck for rotation. The COP 5060CR features an impact power of 50 kW and a frequency of 47 Hz. A reflection damper provides contact

Figure 2: The main advantages of DTH drilling are excellent hole straightness without guiding equipment and deep hole drilling capacity.

Figure 3: The SmartROC D65 surface drill rig.

between the rods, drill bit and rock, to ensure maximum efficiency and equipment life. The COPROD system offers higher penetration rate than DTH drilling and a substantially reduced fuel consumption.

Over a decade of experience with the original COPROD system has led to the development of a new portfolio of rock drills providing greater reliability, considerably longer life and substantially lower noise. Accurate hole alignment has led COPROD users to introduce larger bit diameters, resulting in greater hole spacing and more efficient blasting. Rapid bit changing is a characteristic of the COPROD system which ensures that valuable drilling time is not lost.

Equipped with COP 4050CR heavy rock drill with double dampening system, the FlexiROC C65 was extensively used in hard rock mining and large quarry applications, drilling holes up to 180 mm in diameter. Rotation Pressure Controlled Feed (RPCF), anti-jamming and Dampening Pressure Controlled Impact (DPCI) were just a few features that helped to increase net penetration rates and rock drill bit life. Both the COP 4050CR and the FlexiROC C65 has since been discontinued.

The next big leap for the COPROD family was the introduction of SmartROC C50, equipped with COP 3060CR, and SmartROC CL, equipped with COP 5060CR. These powerful rigs would provide drillers with major benefits such as automatic functions, low fuel consumption, easier maintenance and improved drill string service life. Both units are fitted with the latest SmartROC technology and provide superior performance in the 90–216 mm hole range.

Technology impact

Epiroc's long history of rock drill development has given rise to a range of surface drill rigs. In 2002, the SmartRig ROC D7C with a new rig control system was announced. This is designed to work in the 64–115 mm hole range, and can automatically adjust its impact power and feed according to the ground conditions. The result is a much smoother drilling process, maximum penetration, improved anti-jamming, and best possible drill steel life. Because there are no hydraulics in the cabin, the operator has better visibility, more space, and is able to work in a much quieter environment. In 2011, the SmartRig D7C and D9C were replaced by the new SmartROC T35 and SmartROC T40 featuring an improved Rig Control System that can control the amount of power extracted from the engine by adjusting the air needed for drilling, as well as a new hydraulic system and new DCT control system. All of this results in significantly reduced fuel consumption, in some cases as much as 50% lower (Figure 6).

The SmartRig ROC F9C was a technically advanced rig equipped with the COP 2560 rock drill, which combines the power and terrain ability of the ROC F9 with the intelligence of the new Rig Control System. In April 2013, Epiroc (Atlas Copco at the time) launched its new tophammer surface drill rig, the FlexiROC T45 and SmartROC T45, along with its new rock drill COP 3060. As the name suggests, this new rig is flexible yet uncompromising when it comes to fuel efficiency, while the new rock drill further enhances drilling capacity. The FlexiROC T45 and SmartROC T45 are production workhorses, just like the predecessor ROC F9, but outstandingly fuel-efficient and even more productive. 2016 saw even more improvements with the introduction of SmartROC T45 Long Feed. This rig was equipped with T60 rods with a length of 6.1 m in the carousel and a start rod of 7.3 m which saves time in the handling of longer rods

SmartROC

SmartROC is a concept which facilitates all types of automation in drill rigs as well as elevates the drill rig from an efficient tool to a productivity partner. SmartROC rigs have built-in logging and monitoring functions as well as support for diagnostics and faultfinding. Computer generated electrical signals control the hydraulic valves, with control gauges and instruments replaced by a display unit. This releases space in the cabin, increasing visibility and improving operator ergonomics. One feature of the SmartROC platform is Epiroc's COP Logic system combined with an anti-jamming function, resulting in higher penetration rates and longer service life of drill string components.

The automatic rod adding system, AutoRAS, enables automatic drilling to a given depth, allowing the operator to leave the cabin to carry out other duties such as maintenance checks or grinding bits. Using Measure While Drilling (MWD), a number of parameters are logged at requested intervals while drilling which provides input for analysis of the rock properties. Other options in the SmartROC platform also support the quality of the blast. Automatic feed alignment reduces set-up-time and cancels out operator error by setting the feed to pre-defined angles at the touch of a button, improving fragmentation of the blasted rock and allowing for smoother benches. The costs for secondary breaking, crushing, loading and haulage are thereby considerably reduced.

The Hole Navigation System (HNS) has been equipped with GPS/GNSS for highest possible accuracy in drill rig navigation, within 5 cm in most situations. HNS eliminates the need for manual marking of parallel holes. Instead, the rig automatically locates the position of each hole and aligns the feed over the collar position with pinpoint accuracy. The time saved by not having to aim visually to set angles, and by being able to drill more than one hole from a single set-up, results in better rig utilization. ROC Manager, a stand-alone PC-based tool, makes drill plans, measures hole deviation, and logs, presents and reports drilling data graphically. If any deviation has occurred during drilling, adjustments can be made to correct the error before continuing.

Key performance data is gathered, analyzed and communicated by the Certiq telematics solution which provides

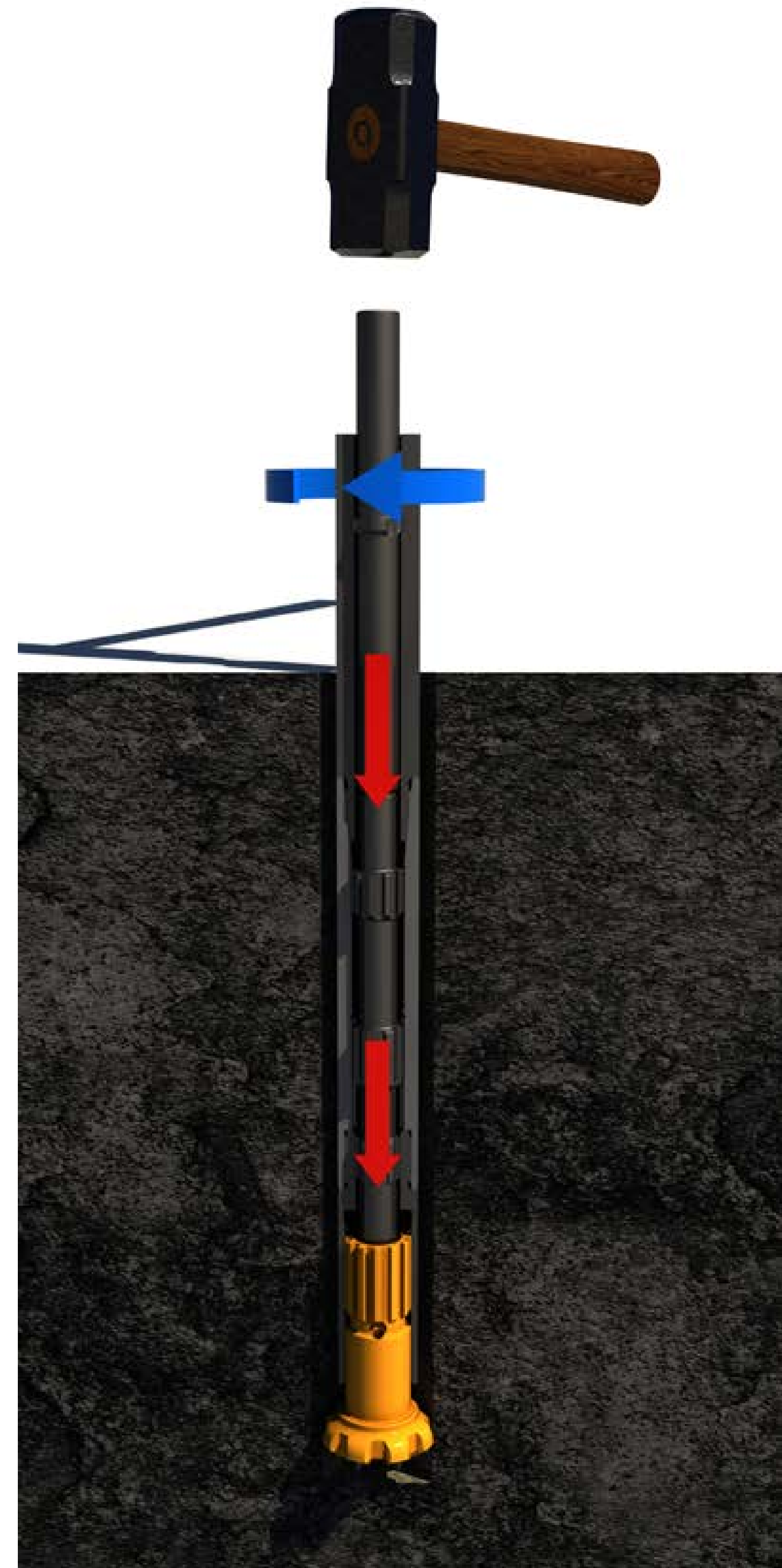


Figure 4: The unique dual string design of COPROD allows more energy to be transferred to the drill bit, keeping hole deviation to a minimum.

Figure 5: With the BenchREMOTE, up to three rigs can be remotely operated simultaneously.

a basis for real-time optimization. Drill plans, fault codes, MWD, production logs and statistics are easily transferred from Certiq to ROC Manager, which can create advanced drill plans for mining, quarrying and construction. ROC Manager is capable of handling different input formats from monitoring systems as well as direct coordinates from operators.

When the surface drill rig SmartROC D65 was launched in 2010, it was immediately recognized for its power and productivity, which is considerable, but also for its intelligence and communications capability (Figure 3). Back in 2010, drill plans prepared in the mine or quarry office were installed in the rig's control system via USB memory. Today, all SmartROC DTH drill rigs, the SmartROC T45, the SmartROC C50 and the SmartROC CL will download this data directly via the worksite's wireless network using the Rig Remote Access (RRA) function. This interface not only makes data transfer faster than ever, it is also more user-friendly as it allows planners to more easily make changes and last minute adjustments. In addition, the SmartROC D65 enabled the introduction of full drill cycle automation as a standard feature which is now available for the entire SmartROC DTH family.

The SmartROC family shares the same communication standard. The standard is based on the International Rock Excavation Data Exchange Standard (IREDES) enabling total management and operation control.

Noise reduction kit

Noise pollution from drilling is a major source of irritation, not just for drill rig operators and personnel on worksites but also for local residents. Epiroc's noise reduction kit, which is an optional feature on the SmartROC T35 and T40 drill rigs, reduces noise by 12 dB(A) at peak power, from 127 dB(A) to 115 dB(A).

Designed with a double layer of noise absorbent material, this distinctive noise reduction kit, makes the SmartROC one of the quietest surface drill rigs on the market. Coupled with the advanced energy saving features of the SmartROC platform, which reduces overall sound power, the kit helps drillers stay well within noise regulations on urban construction sites, while also improving the working environment at any location. This means that site personnel can converse with co-workers without having to shout or use a phone, and they can more easily identify other surrounding noise while keeping ear protectors in place.

Equipped with a diesel engine that delivers just the right amount of power for each drilling phase, the SmartROC platform takes fuel economy to a whole new level. Fuel consumption can be reduced by up to 50% and productivity also increases thanks to automatic rod adding and auto feed alignment. But that's not all. With the added benefit of BenchREMOTE, a unique remote control operator station, up to three rigs can be operated simultaneously, allowing personnel to work at a safe distance away from unstable benches and other hazards (Figure 5).

Figure 6: The SmartROC T40 surface drill rig has taken fuel efficiency to a whole new level.

Beneath the surface: the driller's guide to geology

Understanding the geology of worksites is essential for success in rock excavation and mineral extraction. This article explores basic concepts in earth science to help you grasp the challenges of drilling.

A good understanding of the Earth's crust and the geology of a mineral deposit are key factors in knowing how to extract valuable material in the best way. Selecting the method, choosing the equipment, designating shifts and many other key decisions that will affect the success of surface mining operations, are all directly related to the geology of the deposit.

Without a thorough knowledge of the geological conditions at the site, the wrong decisions can prove to be disastrous. Geologists have an excellent grasp of what the Earth looks like beneath its crust (Figure 1) and the properties of the various rock types that have been formed over millions of years.

What's important to the modern miner is how this knowledge impacts on ore extraction in a surface mining environment. Rock is formed with a variety of properties and usually consists of one of more minerals ranging from single chemical elements to complex compounds. There are known to be more than 3 000 different minerals in existence.

Minerals and geology

Of the 155 known elements, some of which do not occur naturally, oxygen is by far the most common, making up about 50% of the Earth's crust by weight. Silicon forms about 25% and the other common elements such as aluminum, iron, calcium, sodium, potassium, magnesium and titanium make up 99% of the Earth's crust. Silicon, aluminum and oxygen occur in the most common minerals such as quartz, feldspar and mica.

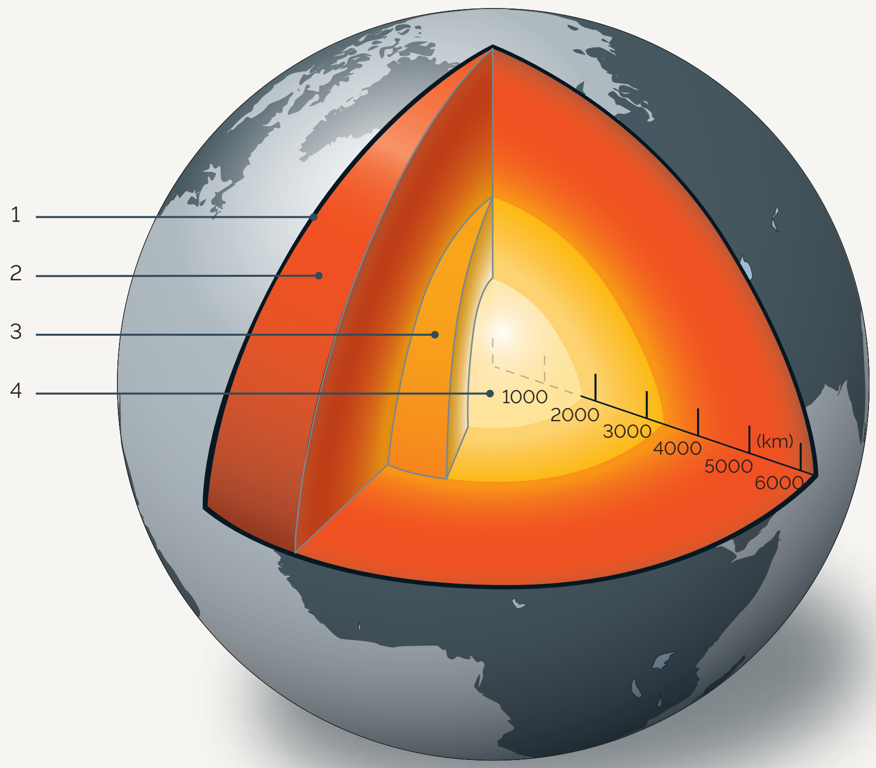


Figure 1: The Earth's interior consists of four main layers. Heavy metals such as iron and nickel are most abundant in the core.

These form part of a large group of silicates that are compounds of silicic acid and other elements. Amphiboles and pyroxenes contain aluminum, potassium and iron. Some of the planet's most common rocks, granite and gneiss, are composed of silicates. Oxygen also occurs commonly in combination with metallic elements, which are often important sources for mining purposes.

These compounds can form part of oxidic ores, such as the iron ores magnetite and hematite. Sulphur also readily combines with metallic elements to form sulphide ores, including galena, sphalerite, molybdenite and arsenopyrite. Chalcopyrite (CuFeS2) is also a very important and abundant ore forming mineral that contains copper.

Other large mineral groups important in mining, as shown in Figure 2, include halogenides such as fluorite and halite; carbonates such as calcite, dolomite and malachite; sulphates such as barite; tungstates such as scheelite; and phosphates such as apatite. Rarely, some elements can occur naturally, without combination. The important ones are the metals gold, silver and copper, plus carbon in the form of diamonds and graphite.

Properties and characteristics

It is true to say that mineralization is rarely pure. Instead, it is usually mixed, consisting of both homogenous and heterogeneous structures. Feldspar accounts for almost 50% of the mineral composition of the Earth's crust, followed by pyroxene and amphibole minerals and then quartz and mica, making up about 90% of the Earth's crust. In addition, minerals have a wide variety of properties and characteristics, and it is these that determine the best way to extract them.

Typical characteristics are:

- Hardness
- Density
- Color
- Streak
- Luster
- Fracture
- Cleavage
- Crystalline form

The particle size and the extent to which the mineral is hydrated (mixed with water) indicate the way the rock will behave when excavated. Hardness is commonly graded according to the Mohs 10-point scale. The density of light-colored minerals is usually below 3. Exceptions are barite or heavy spar (barium sulphate – BaSO4 – density 4.5 g/cm^3), scheelite (calcium tungstate – CaWO4 – density 6.0 g/cm^3) and cerussite (lead carbonate – PbCO4 – density 6.5 g/cm^3).

Dark-colored minerals with some iron and silicate have densities of between 3 and 4. Metallic ore minerals have densities over 4, and gold has a very high density of 19.3. Minerals with tungsten, osmium and iridium are normally

1. Volcanic rocks – fine-grained minerals including feldspar, quartz, olivine, hornblende, magnetite and mica
2. River valley deposits may include gold, platinum, diamonds, cassiterite or magnetite, as well as clays and sands
3. Metamorphic sandstone high proportion of quartz
4. Metamorphic limestone such as marble. etc. – calcite and dolomite.
5. Metamorphic shales such as slates, schists, etc. – with garnet, mica, feldspar
6. Weathered orebodies producing azurite, malachite, cuprite, etc.
7. Weathered sandstone, perhaps having high quartz content
8. Orebodies, e.g. containing galena, sphalerite and chalcophyrite
9. Recent alluvium, lake and sea-bed deposits
10. Weathered shale, perhaps forming bauxite
11. Typical formation and placement of mineral- and oreforming zones

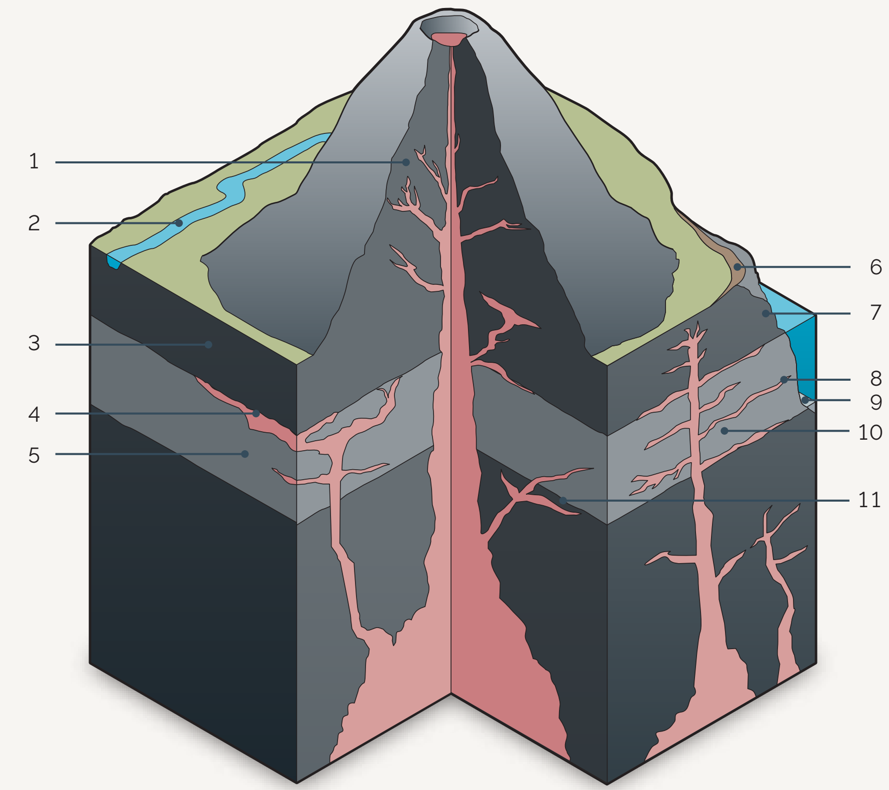


Figure 2: Typical formation and placement of mineral- and ore forming zones.

even denser. Although ore-forming mineral density may be high, the total ore density depends entirely on the host rock where these minerals exist.

Streak is the color of the mineral powder produced when a mineral is scratched or rubbed against unglazed white porcelain which may be different from the color of the mineral mass. Fracture is the surface characteristic produced by breaking a piece of the mineral and is usually uneven in one direction or another. Cleavage denotes the properties of a crystal which allows it to be split along flat surfaces. Both fracture and cleavage can be important to the structure of rocks containing substantial amounts of the minerals concerned.

Rock is normally comprised of a mixture of materials. The rock may not only combine the properties of these minerals, but also exhibit properties resulting from the way in which the rocks were formed or subsequently altered by heat, pressure and other forces in the Earth's crust (Figure 3). It is comparatively rare to find a homogeneous rock mass, and the discontinuities such as faults filled with crushed material, major jointing and bedding non-conformities are hard to predict. These discontinuities are also important, not only for the structural integrity of a mine and gaining access to mineral deposits, but also as paths for fluids that cause mineral concentrations in the Earth. In order for mining to be economically viable, the minerals have to be present in sufficient concentration to be worth extracting and within rock structures that can be excavated safely and economically. It must also be possible to enrich the minerals in an economical way. For mine development and production drilling, the rock must be correctly appraised because the results will affect projected drill penetration rates, hole quality and drill steel costs. In order to determine overall rock characteristics, it is necessary to distinguish between microscopic and macroscopic properties. As rock is composed of grains of various minerals, its microscopic properties include:

- Mineral composition
- Grain size
- The form and distribution of the grain
- If the grains are loose or cemented together

Collectively, these factors comprise the properties of the rock such as hardness, abrasiveness, compressive strength and density. In turn, these rock properties determine the penetration rate that can be achieved when drilling blastholes and the extent of wear on the drilling equipment. In some circumstances, certain mineral characteristics will directly influence the mining method. Many salts, for example, are especially elastic and can absorb the shock from blasting.

Prospects for drilling

Drillability depends on the hardness of the rock's constituent minerals and on the grain size and crystal form, if any. For example, quartz, which is one of the commonest

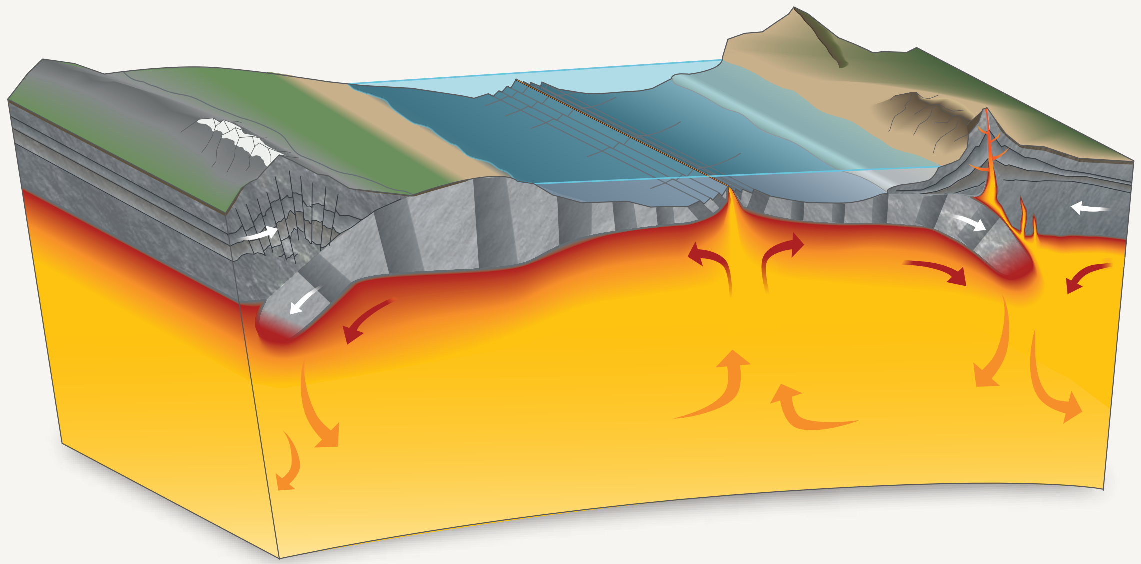


Figure 3: The Earth's eight major tectonic plates meet and create subduction zones, where relative motion carries the plates into the mantle. Spreading centers is the opposite phenomena, where tectonic plates move apart. These geologically active boundaries often result in the formation of interesting mineralizations.

minerals in rock, is a very hard material, exceedingly difficult to drill and will certainly cause heavy wear, particularly on drill bits. This is known as abrasion. Conversely, a rock with a high content of calcite can be comparatively easy to drill and cause little wear on drill bits.

With regards to crystal form, minerals with high symmetry, such as cubic galena, are easier to drill than those with low symmetry, such as amphiboles and pyroxenes. A coarse-grained structure is easier to drill and causes less wear on the drill string than a fine-grained structure. Consequently, rocks with essentially the same mineral content may be very different in terms of drillability. For example, quartzite can be fine grained (0.5–1.0 mm) or dense (grain size 0.05 mm). A granite may be coarse grained (size >5 mm), medium grained (1–5 mm) or fine grained (0.5–1.0 mm). A rock can also be classified in terms of its structure.

If the mineral grains are mixed in a homogeneous mass, the rock is termed massive (isotropic), as with most granite. In mixed rocks, the grains tend to be segregated in layers, whether due to sedimentary formation or metamorphic action from heat and/or pressure. It is therefore important to identify the rock's origins, which are divided into three classes:

- Igneous or magmatic – formed from solidified lava at or near the surface, or magma underground.
- Sedimentary – formed by the deposition of reduced material from other rocks and organic remains or by chemical precipitation from salts, or similar.
- Metamorphic – formed by the transformation of igneous or sedimentary rocks, in most cases by an increase in pressure and heat.

Igneous and sedimentary rock

Igneous rocks are formed when magma solidifies, either as plutonic rock, deep in the Earth's crust as it rises to the surface in dykes, cutting across other rock or sills following bedding planes, or as volcanic rock in the form of lava or ash on the surface. The most important mineral constituents are quartz and silicates of various types, but mainly feldspars. Plutonic rocks solidify slowly, and are therefore coarse-grained, while volcanic rocks solidify comparatively quickly and become fine-grained, sometimes even forming glass. Depending on where the magma solidifies, the rock is given different names, even if its chemical composition is the same, as shown in the table of main igneous rock types (Table 1). A further subdivision of rock types depends on the silica content. Rock with high silica content is called acidic, and those with lower amounts of silica are called basic.

Sedimentary rocks are formed by the deposition of material and its consolidation under the pressure of overburden. This generally increases the strength of the rock with age, depending on its mineral composition. Sedimentary rock is formed by mechanical action such as weathering or abrasion on a rock mass, or transportation by a medium such as flowing water or wind and subsequent deposition. The origins of the rock will, therefore, partially determine the characteristics of the sedimentary rock. Weathering or erosion may proceed at different rates, as will the transportation, and are affected by the climate at the time and the nature of the original rock. Special cases of sedimentary rock include those formed by chemical deposition such as salts and limestones, and organic material such as coral and shell limestones and coals, while others will be a combination of, for example, tar sands and oil shales.

Another set of special cases is glacial deposits, in which deposition is generally haphazard, depending on ice movements. Several distinct layers can often be observed in a sedimentary formation, although these may be uneven due to the conditions of deposition. The layers can be tilted and folded by subsequent ground movements. Sedimentary rocks make up a very heterogeneous family with widely varying characteristics, as shown in the table of sedimentary rock types (Figure 4).

Metamorphic rock

The effects of chemical action, increased pressure due to ground movement at great depths, and/or temperature of a rock formation can sometimes be sufficiently severe to cause a transformation in the internal structure and/or mineral composition of the original rock. This is called metamorphism. For example, pressure and temperature may increase under the influence of up-welling magma, or because the strata have sunk deeper into the earth's crust. This will result in the recrystallization of the minerals, or the formation of new minerals. A characteristic of metamorphic rock is that it is formed without complete remelting, or else it would be classified igneous. The metamorphic action often makes the sedimentary rocks stronger, denser and more difficult to drill. However, many metamorphic zones, particularly formed in the contact zones adjacent to igneous intrusions, are important sources of valuable minerals, such as those concentrated by deposition from hydrothermal solutions in veins.

As metamorphism is a secondary process, it may not be clear whether a sedimentary rock has become metamorphic; it depends on the degree of extra pressure and temperature to which it has been subjected. The mineral composition and structure would probably give the best clue. Due to the nature of their formation (Figure 4), metamorphic zones will probably be associated with increased faulting and structural disorder, making the planning of mine development and efficient drilling more difficult.

Macroscopic rock properties

Macroscopic rock properties include slatiness, fissuring, contact zones, layering, veining and orientation. These factors are often of great significance in drilling. For example, cracks or inclined and layered formations can cause hole deviation, particularly in long holes, and have a tendency to cause drilling tools to get stuck. However, modern drilling control methods can greatly reduce this problem.

Soft or crumbly rocks make it difficult to achieve good hole quality since the walls can cave in. In extreme cases, flushing air or fluid will disappear into cracks in the rock, without removing cuttings from the hole. In some rocks, there may be substantial cavities such as solution passages in limestones or gas bubbles in igneous rock. These may require

Figure 4: Sedimentary rock formation.

pregrouting to achieve reasonable drilling properties. On a larger scale, the rock structure may determine the mining method based on factors such as the shape of the mineral deposit and qualities such as friability, blockiness, in-situ stress, and plasticity. The shape of the mineral deposit will decide how it should be developed. The quality of the parent rock that forms the structure around the mineral deposit can be a major factor in determining the feasibility of exploitation. Depending on the amount of disturbance that the mineral-bearing strata has been subjected to, the mineral deposit can vary in shape from stratified rock at various inclinations to highly contorted and irregular vein formations requiring a very irregular development pattern. The latter may require small drifts to exploit valuable minerals, although the productivity of modern mining equipment makes larger-section drifts more economical, despite the excavation of more waste rock.

The tendency of rock to fracture, sometimes unpredictably, is also important to determine factors such as rock support requirements and the charging of peripheral holes to prevent overbreak. Although procedures for overbreak and contour are not as strict in mining as in construction or indeed tunneling, good results will yield benefits both in terms of production and safety. Minimized overbreak will prevent the excavation of too much waste rock. It is clear that rock structures, and the minerals they contain, can result in a wide variety of possible mining strategies. Obviously, the more information that is gained, the better the chances of mining success. If uncertainties occur due to unforeseen ground conditions, disappearing orebodies, or factors such as excessive water ingress, the advantage provided by modern, productive mining equipment will be lost as it will be forced to stand idle. To avoid these situations it is vital to carry out as much exploratory work as possible, not only with regards to the existence and location of worthwhile minerals, but also to establish rock qualities in and around the deposit. In underground mining, information from surface exploration drilling and geophysical methods of investigation are normally supplemented by probe or core drilling underground. Modern computer software can also assist with processing the vast amounts of data and to deduce the best strategies for mineral deposit exploitation.

The value of the minerals or metals to be mined will determine the level of the investigation work, but there will be a minimum level for every type of mine in order to give some assurance of success. For example, low value stratified deposits, which are known to be fairly uniform in thickness and have regular dips, may not require many boreholes, although there could still be surprises from sedimentary washouts or faults.

On the other hand, gold deposits in contorted rock formations will require frequent boreholes from the surface, to give assurance of the location of the deposit and to sample the minerals it contains. Having determined the value and shape of a mineral deposit, the nature and structure of the rocks that surround it, and the likely strategy for mine development, it should be possible to determine the suitability of various excavation methods for the rock that is likely to be encountered.

Rock classification

A number of rock classification systems have been developed in order to systematically determine excavation and support requirements, whether a particular method is suitable, and the amount of consumables required. The methods developed to assess drillability are aimed at predicting productivity and tool wear. Factors of drillability include the likely tool penetration rate in proportion to tool wear, the stand-up qualities of the hole, its straightness, and any tendency to tool jamming.

Rock drillability is determined by several factors led by mineral composition, grain size and brittleness. In crude terms, rock compressive strength or hardness can be related to drillability for rough calculations, but the matter is usually more complicated. The Norwegian Technical University has determined more sophisticated methods: the Drilling Rate Index (DRI) and the Bit Wear Index (BWI). The DRI describes how fast a particular drill bit can penetrate. It also includes measurements of brittleness and drilling with a small, standard rotating bit into a sample of the rock. The higher the DRI, the higher the penetration rate, and this can vary greatly from one rock type to another, as shown in the bar chart (Figure 5). It should be noted that modern drill bits greatly improve the possible penetration rates in the same rock types. Also, there are different types of bits available to suit certain types of rock. For example, Epiroc special bits for soft formations, bits with larger gauge buttons for abrasive formations, and guide bits, steering rods or retrac bits for formations where hole deviation is a problem.

The BWI, or Bit Wear Index, gives an indication of how fast the bit wears down as determined by an abrasion test. The higher the BWI, the faster the wear. In most cases, the DRI and BWI are proportional to one another. However, the presence of hard minerals may produce heavy wear on the bit despite relatively good drillability. This is particularly the case with quartz, which has been shown to increase wear rates considerably. Certain sulphides in orebodies are also comparatively hard, impairing drillability. Commonly used rock classification tools include the Q-system (Barton, et al, through the Norwegian Geotechnical Institute), Rock Mass Rating RMR (Bieniawski), and the Geological Strength Index GSI (Hoek, et al). Bieniawski's Rock Mass Rating incorporates the earlier Rock Quality Designation (RQD – Deere, et al), with some important improvements that take into account additional rock properties.

All of these give valuable guidance on the rock's ease of excavation and its self-supporting properties. In most cases, engineers will employ more than one means of rock classification to gain a better understanding of its behavior and to compare results.

Beneath the surface: the driller's guide to geology

Table of main igneous rock types

Silica (SiO_2) content	Plutonic rocks	Dykes and Sills	Volcanic (mainly lava)
Basic – <52% SiO_2	Gabbro	Diabase	Basalt
Intermediate – 52–65% SiO_2	Diorite	Porphyrite	Andesite
	Syenite	Syenite	Trachyte porphyry
Acidic – >65% SiO_2	Quartz diorite	Quartz porphyrite	Dacite
	Granodiorite	Granodiorite porphyry	Rhyodacite
	Granite	Quartz porphyry	Rhyolite

Table 1: Main igneous rock types according to chemical composition (silica content) and location where magma turned into solid rock.

Some sedimetary rock types

Rock	Original material
Conglomerate	Gravel, stones and boulders, generally with limestone or quartzitic cement
Greywacke	Variable grain size from clay to gravel, often with angular shape
Sandstone	Sand
Clay	Fine-grained argillaceous material and precipitated aluminates
Limestone	Precipitated calcium carbonate, corals, shellfish
Coals	Vegetation in swamp conditions
Rock salt, potash, gypsum, etc	Chemicals in solution precipitated out by heat
Loess	Wind-blown clay and sand

Table 2: Typical sedimentary rock types and the material from which they originate.

Typical metamorphic rocks

Rock type	Original rock	Degree of metamorphism
Amphibolite	Basalt, diabase, gabbro	High
Mica schist	Mudstone, greywacke, etc	Medium to high
Gneiss	Various igneous rocks	High
Green-schist	Basalt, diabase, gabbro	Low
Quartzite	Sandstone	Medium to high
Leptite	Dacite	Medium
Slate	Shale	Low
Veined gneiss	Silicic acid-rich silicate rocks	High
Marble	Limestone	Low

Table 3: Typical metamorphic rock types and their origin, followed by the degree of metamorphism that is needed.

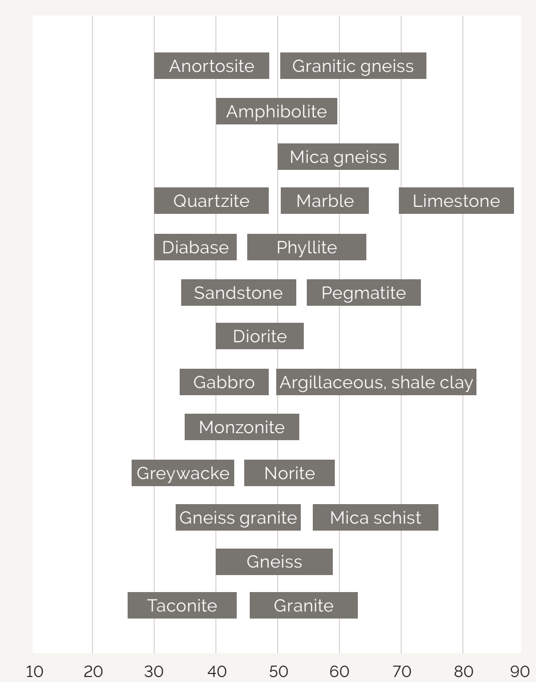
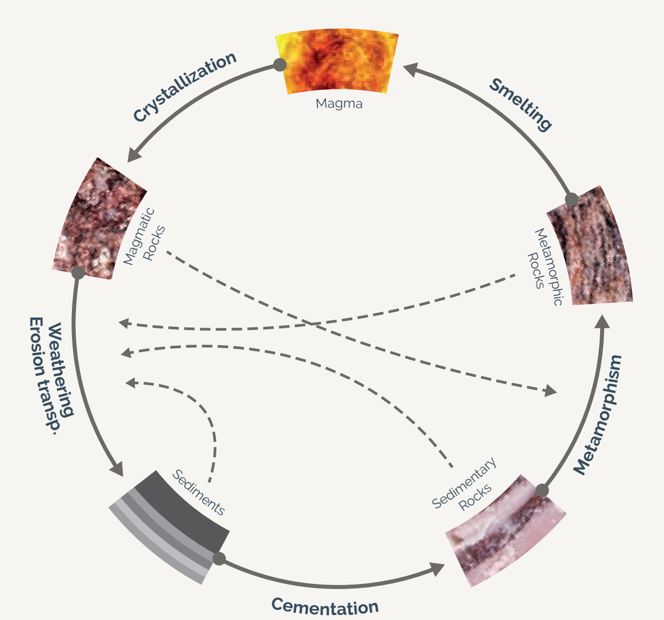


Figure 5: Relationship between Drilling Rate Index (DRI) and various rock types.



The rock forming cycle shows the creation of various rock types and how they deteriorate.

Market outlook: minerals and metals

Rock excavation is essential for global development, whether for supplying materials for bridges and skyscrapers or sourcing precious minerals for medical devices. Here is an overview of key market forces and trends.

For skyscrapers, high speed trains, medical equipment, computers, smartphones and an infinite variety of other elements of modern society, the world depends on a steady supply of valuable minerals and geological materials. Over the past decade, market demand has entered a transformational phase in tandem with the new industrial era.

Rock excavation, and materials sourcing, is essential for supporting emerging sectors and the ever-increasing pace of innovation. Take for example the electrification of transport – one of today's megatrends which is still in its infancy. A booming battery industry worldwide now depends on uninterrupted supply of commodities such as cobalt and lithium (Figure 3–4) to keep pace with changing markets and customer expectations.

Global demand for minerals and metals has diversified during the 2010s. New markets and technology trends are competing with traditional industries and extracted material needed to support the construction boom of now largely mature markets such as China, Brazil and India.

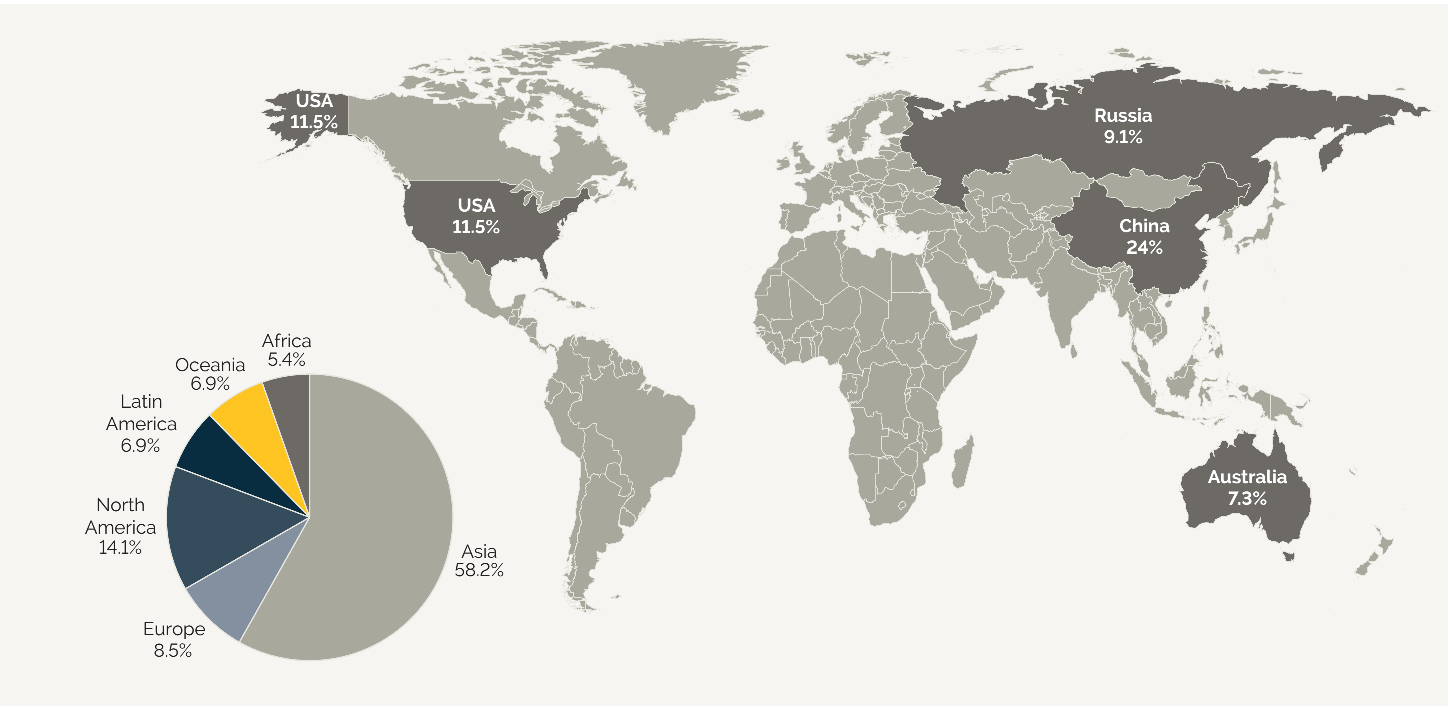


Figure 1: Global mining production based on total output. The world mined 16.9 billion metric tons in 2016. China, USA, Russia and Australia are the world's largest mining nations. (Source: World Mining Data, 2018, World Mining Congress).

Market recovery

To recap, following the financial crisis of 2008 when metal prices plunged and lost nearly half their value, prices began to recover at a promising rate. By 2011, the outlook was positive and the International Monetary Fund's (IMF) metals and minerals price index had exceeded its pre-bust price levels. In 2012, the influential economies of Brazil, India, Russia and China (BRIC) accounted for 20% of the global economic output[i]. The Chinese, Indian and Brazilian economies, like many other countries in a state of rapid development, passed through a resource-intensive stage of economic growth, consuming larger amounts of minerals and metals per percentage increase in economic growth relative to the traditional industrialized economies. The factors driving this demand for minerals and metals range from increased urbanization, investments in infrastructure, and increased manufacturing of both consumer and capital goods.

However, prices for base metals such as iron ore, copper, aluminum and nickel began to decline once again as more opportunities for mining opened up in Africa and Latin America. At the same time, cobalt and lithium mines have in the latter half of the 2010s struggled to keep up with the battery boom, which will underpin the shift to electric vehicles. In this context, global demand for materials is likely to remain high while, to a degree, being driven by entirely new market forces.

Urbanization accelerates

For the first time in human history, roughly the same number of people live in urban areas as in rural areas, and by 2030, 60% of the global population will be residing in urban centers. The largest increase in this rural-to-urban migration will be seen in cities in rapidly emerging world regions.

China alone intends to urbanize 350 million more people by 2025, resulting in 221 cities with over one million inhabitants. China's five-year plans continue to be ambitious including a range of infrastructure expansion goals. Other countries such as Brazil have positive growth expectations in the construction sector, all of which implies that urbanization, infrastructure development, consumer goods and energy will contribute to increased demand for minerals and metals.

Furthermore, as stated in a 2017 report released by the World Bank[ii], the continued construction boom for urban development will drive demand for low-carbon technologies, which in turn depends on a high availability of minerals and metals. Against the background of increasing focus on renewable energy, energy storage and the rapid rise of battery manufacturing, the report highlighted the following minerals and metals as key enablers for green development: aluminum, copper, lead, lithium, manganese, nickel, silver, steel, zinc as well as rare earth minerals such as indium, molybdenum and neodymium.

To support the pace of development in battery production, the World Bank report specifically highlights seven minerals and metals that are expected to see an exponential 1 000% increase in demand, if global warming levels are to be kept under 2°C: aluminum, cobalt, iron, lead, lithium, manganese and nickel. The report concludes that the shift

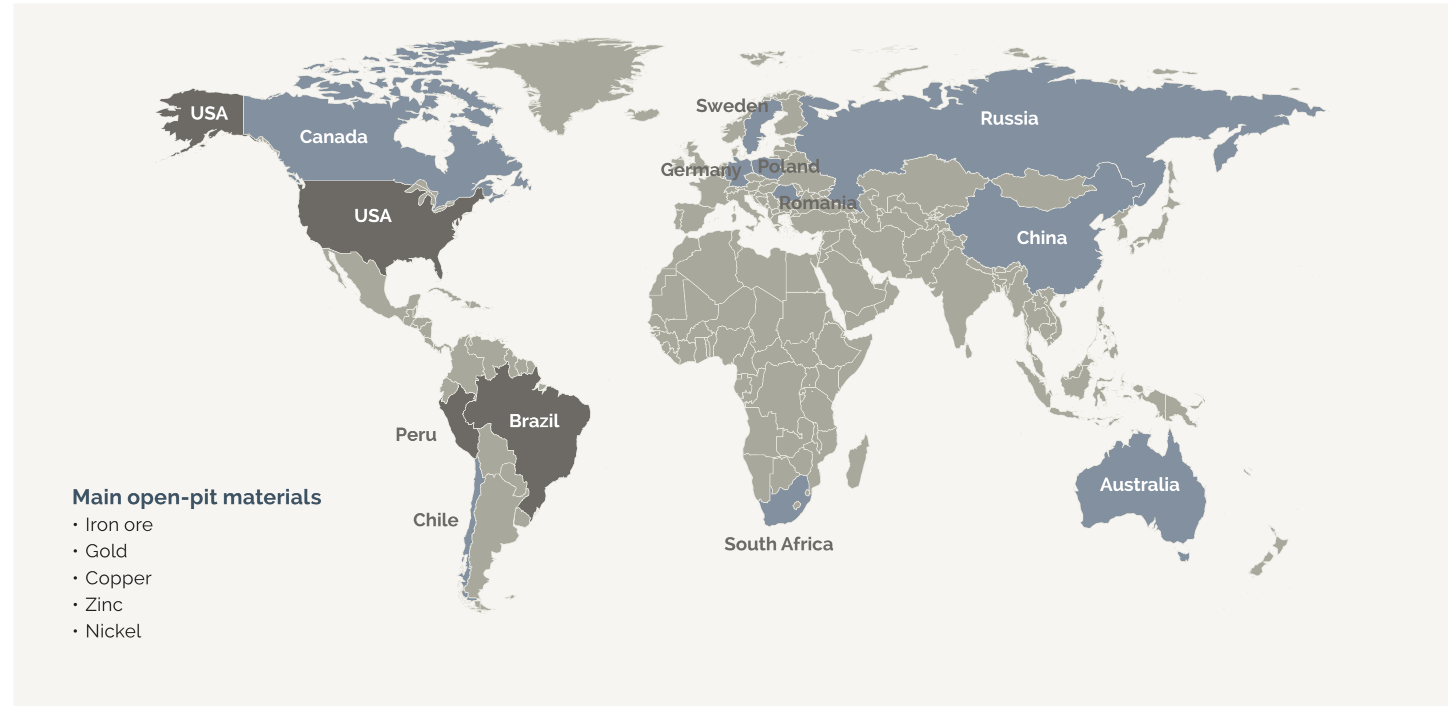


Figure 2: Open-pit mining accounts for more than half of global minerals production. In the USA, Peru and Brazil, more than 50% of materials are extracted from surface mines. (Source: Luleå University of Technology, Statista).

to a low-carbon future "could result in opportunities for mineral rich countries," while pointing to the need for countries to put "long-term strategies in place that enable them to make smart investment decisions and to safeguard local communities and the environment."

As such, global demand for minerals and metals is not just expected to be defined by urbanization but, in equal measure, by the shift to clean industrial technologies, renewable energy, smarter product development, recycling and not least the development of zero or low-carbon transport alternatives.

Electric vehicle revolution

When it comes to the rapid growth of electric vehicles, and indeed the continued development of alternative technologies such as hybrid and hydrogen, metal demand will differ in each case and reflect "the component mix of low-carbon technologies", as the World Bank report points out. For example, electric vehicles will drive demand for lithium while hybrid vehicles will do the same for lead. Hydrogen powered vehicles are expected to create a spike in demand for platinum.

Based on these trends, the World Bank estimates that countries such as Chile, Peru and potentially Bolivia will play a key role in supplying copper and lithium. Brazil has ample opportunities to provide bauxite and iron while southern Africa and Guinea "will be vital" in meeting the growing demand for platinum, manganese, bauxite and chromium. Many of the large car manufacturers have made substantial investments to accelerate the push toward electric vehicles. In 2019, Volkswagen committed to developing 70 new EV (electric vehicle) models by 2028, and other manufacturers are not far behind in their ambitions. At the national level too, the trend is unmistakable. According to the International Energy Agency, the expansion of the EV market continues at an annual rate of around 50%[iii]. More than half of the world's sales take place in China, while Norway remains the world's most advanced market for electric vehicles which accounted for over 39% of new car sales in 2017.

Regional initiatives such as the European Battery Alliance (EBA250), which was launched by the European Commission in 2017, further demonstrate the determination of advanced economies to accelerate the EV transition. In this joint forum, Epiroc has taken a frontline role in helping to develop the new value chain for electrification.

The automotive sector is a useful indicator of changing demand for minerals and metals where prices are increasingly reflecting a situation of limited supply and growing demand. The price of cobalt is a good example. According to the World Economic Outlook report published by IMF, cobalt prices rose by no less than 150% between 2016 and 2018[iv].

Mining sector continues to expand

Although the mining industry is cyclical by nature, demand tends to remain stable as long as the global economic outlook is favorable. Today, attention tends to be focused on megatrends such as electrification of transport. There is currently no end in sight to the rise in demand for commodities such as nickel, lithium, cobalt and graphite. These minerals and metals will be crucial for developing new battery solutions to power electric vehicles.

According to Statista, global demand for lithium will increase from 252 653 tonnes in 2018 to 422 614 tonnes by 2025, which corresponds to 67% growth (Figure 3)[v]. In addition to this exponential development, the short term forecast for mainstream commodity markets is predominantly stable as demand continues to outweigh supply.

In order to meet this demand, mining companies worldwide continue to invest in the sector and S&P reports renewed confidence in exploration mining. However, decisions are carefully taken, and the top priority among business leaders today is to find new ways of optimizing the efficiency of existing mining operations using digital tools.

Open-pit vs underground

Asia continues to be the largest producer of minerals and metals (excluding coal) and accounts for 24% of the global value of the industry, followed by Latin America (22%) and Oceania (15%). Africa and the Commonwealth of Independent States (CIS) account for a further 10% each of the global value, with North America (8%) and Europe (2%) accounting for the rest.

China, USA, Russia and Australia are the world's four largest mining nations (Figure 1). When it comes to the share of commodities sourced from surface mining operations, the majority of mined materials in the USA, Peru and Brazil comes from open-pit mines (Figure 2). Among the economically most important metals, zinc and lead are primarily extracted using underground mining methods. Open-pit mining also accounts for the majority of the production of iron ore, gold, copper, zinc and nickel.

Overall, the ratio of open-pit to underground mining will remain stable or increase towards open-pit for the major metallic ores. Globally, the increase in volume of ore extracted through underground mines, has not been higher than volumes extracted through surface and open-pit mining. The higher costs associated with underground mining have instead encouraged companies to take advantage of scale and operate deeper open-pits instead. Furthermore, the fast growth in lithium demand has further motivated an expansion of existing open-pit mines.

Improving sustainability

More sustainable use of metals and minerals has encouraged recycling of a number of these products. For example, 67% of scrap steel, more than 60% of aluminum and 40–45% (in the EU) was already routinely recycled in 2012[vii], and the volume has been steadily climbing through the 2010s.

However, the share of recycled metals is outweighed by "new" production and metals such as lithium are currently not achieving their potential for recycling. The environmental impact of these materials needs to be weighed against the vast benefits they provide in terms of enabling clean technologies such as batteries for electric cars. This further strengthens the conclusion that the mining sector will continue to grow, but predominantly in non-traditional areas of extraction.

While the importance of recycling metals increases, metals being used for the construction sectors in emerging economies have only just begun their lifecycles, and it will take decades before the recycling phase begins. Meanwhile, new technologies and modern practices in rock excavation will ensure that the extraction projects that do take place are managed as responsibly as possible, with minimized resource waste.

Future outlook

Global growth has remained robust as economies gradually emerged from the shadow of the financial crisis. This means that drilling and exploration activity has followed suit. A mining project has a long gestation period. It can take more than 10 years from the start of exploration through project development and construction to eventual output. Therefore, by fully utilizing current capacity, the response to an increase in metal and mineral prices can be met with a small increase in supply in the short term.

New mines are typically located in remote areas and away from traditional metal markets. They are often in developing economies with fewer well-developed road and port facilities. In addition, the orebodies are low grade and are located much deeper which, in turn, increases energy consumption. All these factors contribute toward new sources of mineral supply being more costly as well as time consuming to become operational.

The mining sector will continue to face such serious challenges as the search for new orebodies takes them further into non-traditional mining regions. However, smarter methods and automation technology for rock excavation will advance the capabilities of mining companies (see case story on autonomous drilling in Canada, page 158) Even for projects that have been mothballed, an increase in metals prices will solicit their return to operations quickly.

Once again, global exploration budgets for non-ferrous metals are on a positive trajectory. In terms of fast-growing markets such as lithium mining, one of the largest risks to price levels is posed by the stampede effect in terms of investments, which creates oversupply. As the new industrial era evolves toward low carbon growth economies, mining activity and investments will continue to expand overall with a mining sector expected to remain in good health.

Figure 3: Cobalt prices continue to surge on electric car demand

In metric tons, three-year period as of February 19 (Source: Bloomberg, U.S. Global Investors)

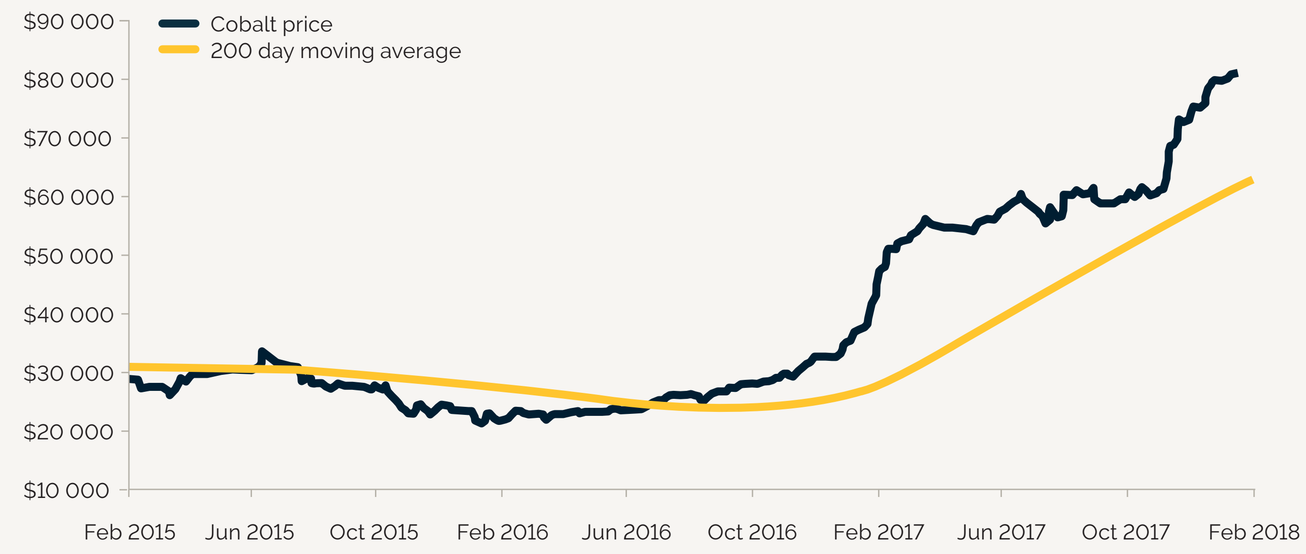
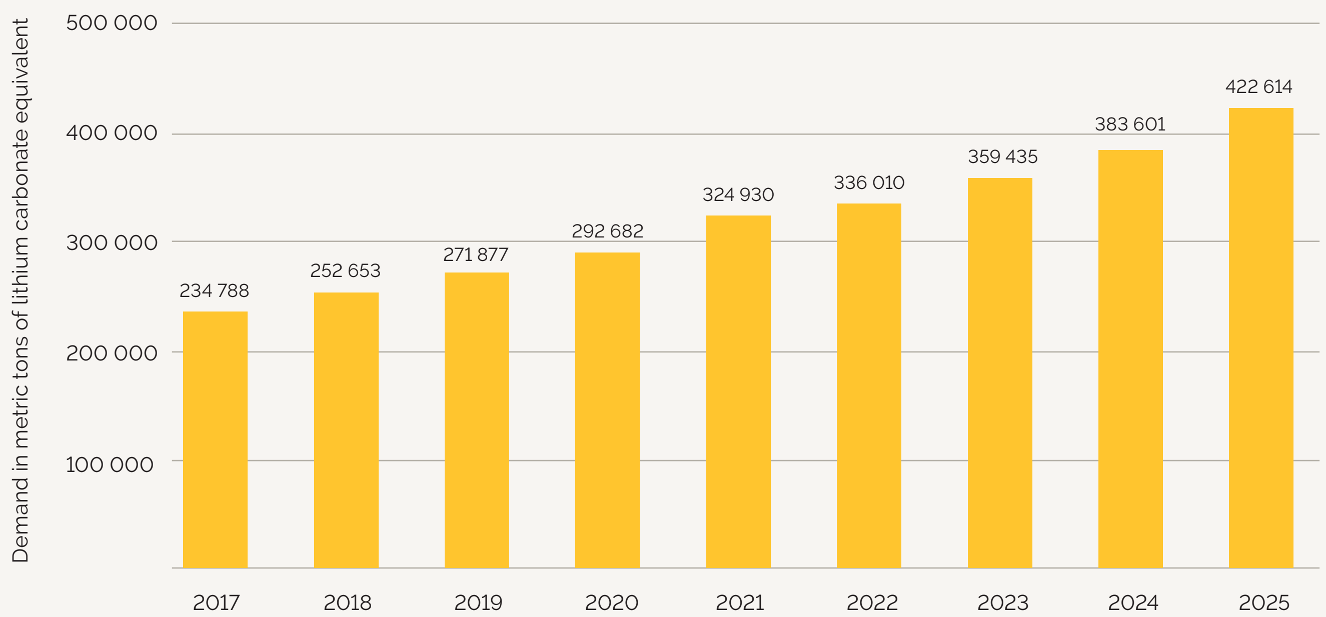


Figure 4: Battery production drives fast-growing demand for lithium

Projection of total worldwide lithium demand from 2017 to 2025, in metric tons of lithium carbonate equivalent (source: Lithium Outlook 2028, 16th edition, Roskill)



[i] International Monetary Fund, IMF
[ii] The Growing Role of Minerals and Metals for a Low Carbon Future, World Bank, 2017
[iii] Global Electric Vehicle Outlook 2018, International Energy Agency, IEA
[iv] World Economic Outlook 2018, International Monetary Fund, IMF
[v] Projection of total worldwide lithium demand 2017–2025, Lithium Outlook 2028, 16th edition, Roskill
[vi] Industry Top Trends 2019, S&P Global Ratings
[vii] Mapping Resource Prices: The Past and the Future, Ecorys 2012, European Commission

Keep it straight

For the best overall blasting result, the drill hole needs to follow its designed path along its entire length. Straight holes are paramount, so deviation should be avoided as far as possible, with each hole collared in the exact spot and drilled in the correct direction and to the planned depth.

Precision drilling

Precision in collaring and hole alignment can be achieved with proper surveying and mark-ups of the drill pattern grid, coupled with a drill angle indicator mounted on the feed and a hole depth instrument. It is also essential to have a good view of the collaring procedure from the operator's cabin. A well-prepared setup and selection of drilling method and equipment will help minimize deviation and improve the potential for a successful rock breaking operation.

Consequences of deviation

Tophammer drilling is the conventional choice for civil engineering applications. However, more options are available for quarries where 51–165 mm holes are commonly drilled from benches ranging to a depth of 30 m. Figure 1 illustrates various causes of hole deviation. The consequences of hole deviation are primarily: uncontrolled fragmentation of blasted material; possible misfires due to intersecting holes firing at undesirable intervals; excessive burden and spacing between adjacent blastholes; secondary breaking, leading to higher costs for loading, haulage and crushing; and uneven bench floors, resulting in higher equipment maintenance costs.

Deviation can result from faulty set-up, alignment and collaring, all of which can be remedied but preferably altogether. The Akselberg limestone quarry in Norway, owned by Brønnøy Kalk AS, is good example. By using Epiroc's SmartROC T45 drill rig equipped with Hole Navigation System (HNS) and the AutoPos function, operators can achieve perfectly straight and parallel holes drilled on 15 m high benches. This means that blast rounds produce a fragmentation exactly according to plan, at a maximum of 1.2 m x 1.6 m.

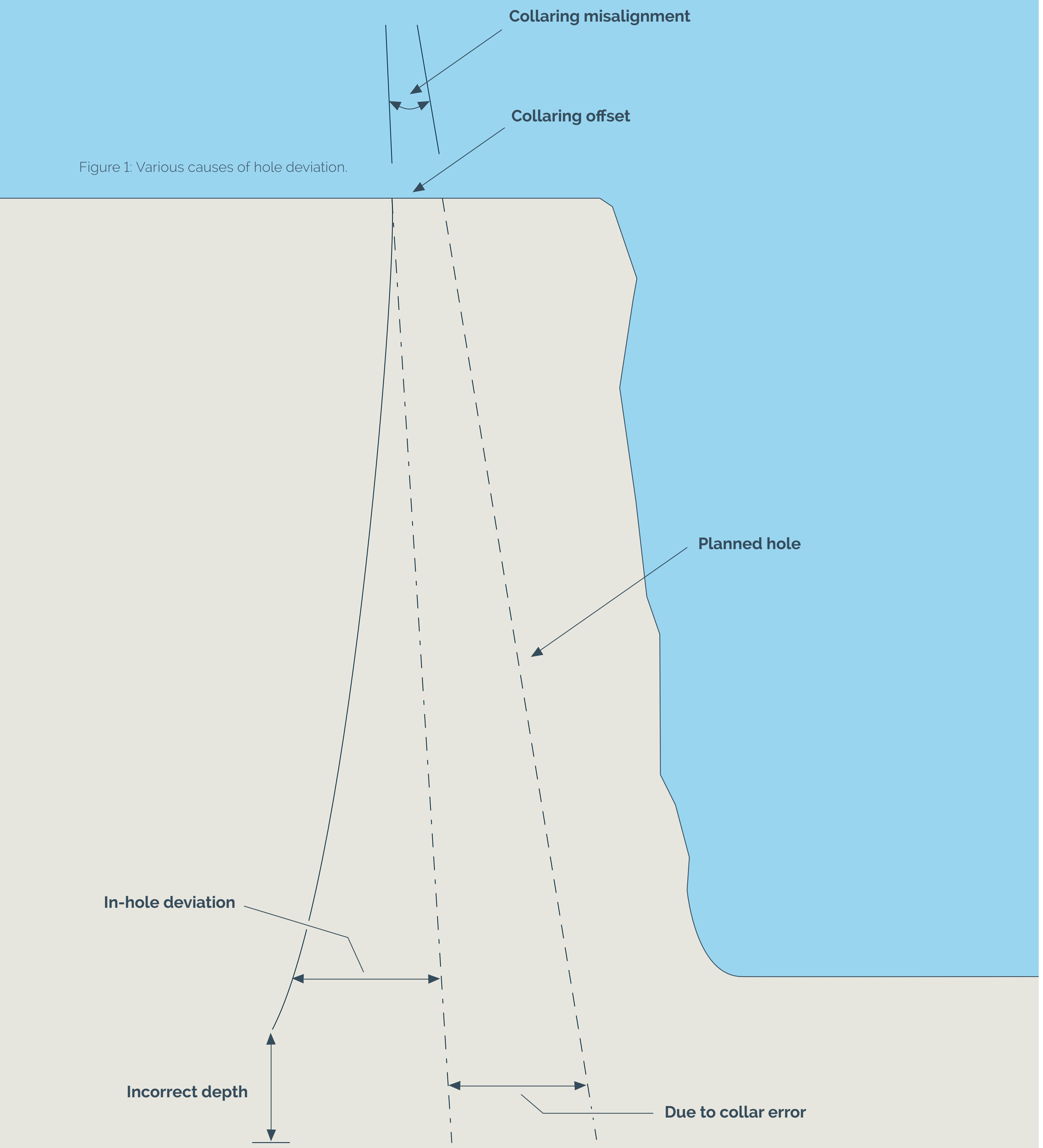


Figure 1: Various causes of hole deviation.

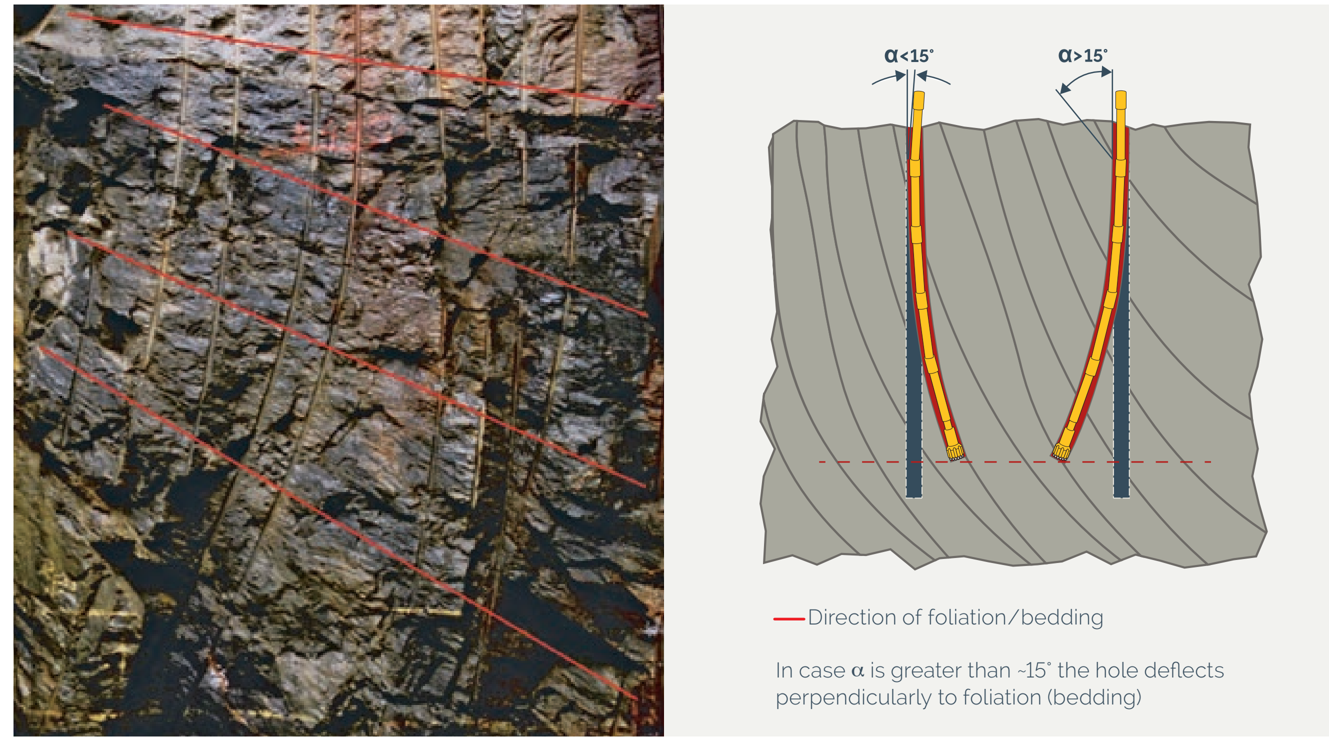


Figure 2: How deviation results from rock bedding at different angles.

Raymond Langfjord, Production Manager at the site, explains: "Everything here starts with the drilling. If we get that wrong, it has consequences for every other phase of our operation – from blasting and loading through to crushing and, ultimately, the quality of our products."

Located some 400 km north of Trondheim, this 2.5 km long and 1.5 km wide pit produces about 1.8 million tonnes of limestone carbonate per annum – a product widely used in the European paper industry. Langfjord continues: "We have to make sure that all of the holes are positioned in exactly the right spot, drilled to the right depth and with the right inclination and absolutely parallel. Any deviation, however small, will undermine the success of the blasted round. As these rounds are spread out over such a large area, small errors can become big problems."

First, to secure a correct hole inclination before drilling, it is crucial that the rock drill and drill string are lined up parallel with the feed beam. Sliding components on the feed beam, such as the rock drill cradle, intermediate drill support, and drill steel guide bushings, must be frequently checked, and any free play adjusted to a minimum. Worn drill rod guide bushings should be replaced at regular intervals.

Second, double drill steel support ensures a stiff drill string alignment close to the collaring surface. Epiroc equips its modern ROC range of surface drill rigs with double drill steel support for improved visibility and rod guidance. The FlexiROC tophammer drill rigs are furnished with an interme-diate drill steel support on the feed. With the lower support raised, the rock surface can be checked before the collaring sequence, and an inspection of the drill string after initial rock penetration can be easily carried out.

Third, instruments for inclined hole and hole-length measurements can also be combined with a laser sensor coupled with a laser plane, enabling drill holes to be drilled exactly to the pre-determined depth. This ensures an even bench floor, independent of rock irregularities where the holes are being drilled. Fourth, restricted percussion, feed and flushing during collaring can ensure that the most critical part of the hole does not deviate. Finally, hole straightness is also a function of the stiffness of the drill string, especially when using tophammer drilling.

In-hole deviation

The extent of in-hole deviation is relative to the hole depth, and is often claimed to be proportional to the depth at a factor of two. Geological conditions are a major cause of in-hole deviation during drilling. Figure 2 illustrates the influence of bedding and foliation. The drill hole tends to deviate in a direction perpendicular to the jointing, and the more structured, foliated and faulted the rock, the greater the deviation. Conversely, drilling through homogeneous rock, such as isotropic granite with sparse jointing, does not produce in-hole deviation. Experience shows that the approach angle of the drill bit towards the bedding is crucial. There seems to be a tendency for the bit to follow parallel to the bedding where the angle of approach is smaller than 15 degrees. Figure 2 also shows how the drill string is affected by the direction of the rock bedding, resulting in substantial hole deviation. There are various ways and means to reduce this problem.

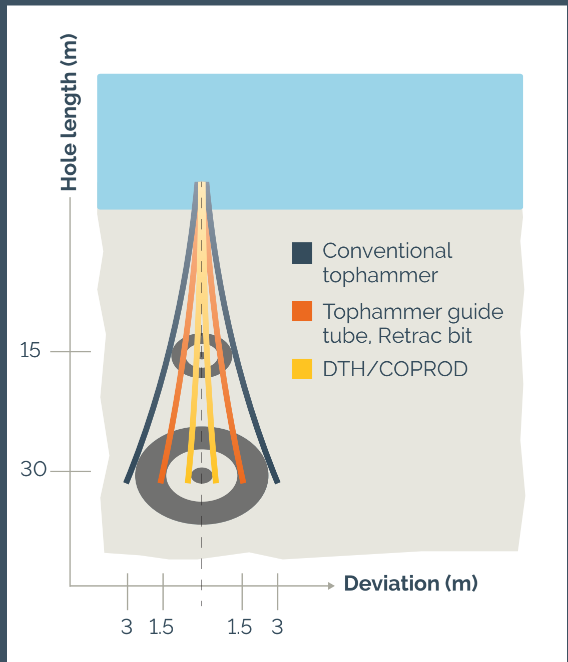


Figure 3: How different types of drilling equipment influence hole straightness.

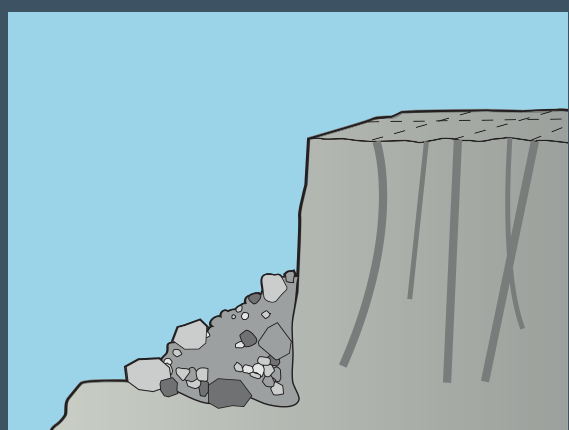


Figure 4: Poor blasting typically results in increased handling and crushing costs.

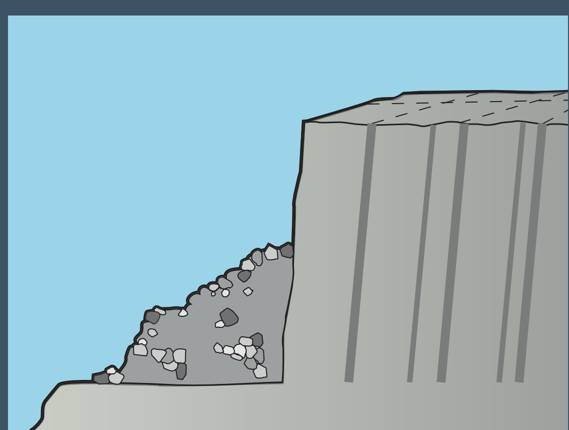


Figure 5: Drilling straight holes improves rock fragmentation and reduces overall costs.

A stiff drill string, and small clearance between the hole and the drill string components, gives straighter holes. For tophammer drilling, Epiroc provides TAC tubes to be added behind the bit. The use of TAC tubes improves flushing and reduces the risk of jamming. A combination of reduced feed force and bit load with increased rotation speed gives less deviation. Down-The-Hole (DTH) drilling, COPROD drilling, and rotary drilling all result in less deviation than tophammer drilling. Less hole depth, and consequently low benches, gives better control of deviation. As in-hole deviation is a three-dimensional problem, the burden as well as the toe spacing of adjacent holes can become excessively off-line.

Bits and rods

Although the influence of geology can never be completely eliminated, certain measures can be taken to ensure acceptable blasting results. One such measure is to employ a stiff bottom pack behind and including the drill bit, where the play between hole diameter and the following part of the drill string is as small as practicable. Drill bit and rod selection play a key role. Crossbits, for example, generally result in straighter holes compared to button bits. However, they have lower penetration coupled with more frequent grinding intervals, leading to higher costs.

Ballistic button bits that are reground on a regular basis will, in most cases, result in straighter holes than spherical button bits. Dull, worn out buttons result in lower penetration and increased hole deviation. A concave bit front also results in straighter holes than a flat front, which, when subjected to abrasive rock and several regrinds, gradually gets more convex. A drop center type of bit is therefore commonly used. Retrac bits are another alternative. These self-guiding bits act as a short guide rod directly behind the bit front to reduce deviation. By installing a guide rod or tube behind a retrac bit, more than half of the in-hole deviation can be eliminated, compared to a conventional tophammer drill string.

Total costs

DTH drilling with large diameter drill tubes, and COPROD with a combination of drill rods and large diameter drill tubes, will produce straighter holes than any type of tophammer drill string due to stiffer string and better hole guidance through the rock (Figure 3). At comparable hole dimensions, however, tophammer with a conventional drill string drills faster than DTH, but not as fast as tophammer drilling with COPROD system.

Many contractors and site owners focus on minimizing drilling costs without taking into account the overall effects on blasting results. However, when fragmentation and total handling and crushing costs are considered, it is clear that purchasing drilling equipment which produces the least deviation is far more advisable, especially when hole depths exceed 10 m (Figures 4 and 5). The latest drill rigs from Epiroc, incorporating SmartROC technology, provide an exceptional platform from which to drill straight holes.

Tophammer drilling

The classic tophammer method is renowned for high penetration rates in favorable drilling conditions. Exhaustive research into how impact energy can be transmitted into the drill bit in the most efficient way, with least possible stress, has resulted in a new generation of rock drills. Development has been focused on the key component in the rock drill – the piston. The piston length, mass, and geometry have resulted in even faster penetration. The effect is that more rock is crushed with each blow from the piston.

Moreover, a double dampening system reduces the load on components which extends their service life, at the same time as drill steel wear is reduced. In other words, the positive results of faster drilling are not counteracted by higher drill steel costs. An extractor unit is available as a useful accessory for poor rock conditions.

Down-The-Hole drilling

Drills using the Down-The-Hole method (DTH) are easy to operate and maintain. The method offers a reliable way to drill hard to soft, solid to fissured or fracture rock, and features a hammer piston, which strikes the drill bit with virtually no power loss. Shallow, deep or long holes are drilled with barely any change in capacity. Hammer casing and stiff drill tubes offer good guidance for the hammer and drill bit, minimizing the hole deviation. This means that blasting patterns and use of explosives can be optimized, increasing the yield of rock at a reduced cost per meter or footage drilled. The tubes are smooth and flush along the entire length of the drill string, minimizing the risk for jamming while ensuring efficient hole cleaning in almost all rock conditions. Apart from blasthole drilling, the DTH method is widely used for water well drilling, shallow gas and oil wells, and for geothermal wells. It is also developed for sampling using the Reverse Circulation (RC) technique.

COPROD drilling

The COPROD system combines the speed of tophammer drilling with the precision and long service life of the Down-The-Hole method. Inside each rigid, threaded tube section is an impact rod. It is furnished with stop lugs to hold it in place inside the tube. The COPROD sections are joined together via the outer tubes. Since the other tubes transmit rotation torque and feed force only, the stress to the threads is minimal which increases service life. All negative effects of transmitting the impact energy through the threads are eliminated entirely. The result is high impact power with minimal wear. The outer tubes are smooth and flush along the entire length of the drill string, minimizing the risk of jamming while ensuring efficient hole cleaning in almost all rock conditions. The method gives good overall economy, particularly in large scale production drilling and drilling in broken rock or other demanding rock conditions.

See the importance of parallel holes to correct depth

Principles of rock drilling

This article deals with surface rock drilling used for the purpose of excavating rock in quarries and construction projects by means of blasting. Other types of drilling, such as for oil and water, mineral exploration and exploitation, and grouting are not covered.

Also included is a brief explanation of prevailing drilling methods, together with an introduction to blasting techniques and the interrelation of drilling and blasting. Also discussed are the main parameters involved when planning and executing blasthole drilling at quarries and civil engineering projects.

Drill and blast excavation

Epiroc's extensive product range for the drill and blast technique will be discussed by comparing suitability and expected productivity in relation to selected applications. Case studies from worksites around the world provide insight into the planning and selection process in terms of methods and equipment for blasthole drilling applications. Blastholes have unique characteristics that are critical for achieving success, such as hole diameter, depth, direction and straightness. Drilling produces a circular hole in the rock, the strength of which must be overcome by the drilling tool. Depending on rock properties, there are several ways to accomplish this, as will be discussed.

Percussive drilling

Percussive drilling breaks the rock by transferring hammering impacts transferred from the rock drill to the drill bit at the hole bottom. The energy required to break the rock is generated by a pneumatic or hydraulic rock drill. A pressure is built up, which, when released, drives the piston forwards. Figure 1 illustrates the principle of tophammer percussive drilling. The piston strikes on the shank adapter, and the kinetic energy of the piston is converted into a stress wave traveling through the drill string to the hole bottom. In order to obtain the best drilling economy, the entire system – rock drill to drill steel to rock – must be harmonized.

Stress wave

Theoretically, the stress wave has a rectangular shape, the length of which is twice that of the piston, while the height depends on the speed of the piston at the moment of impact, and on the relationship between the cross-sectional area of the piston and that of the drill steel.

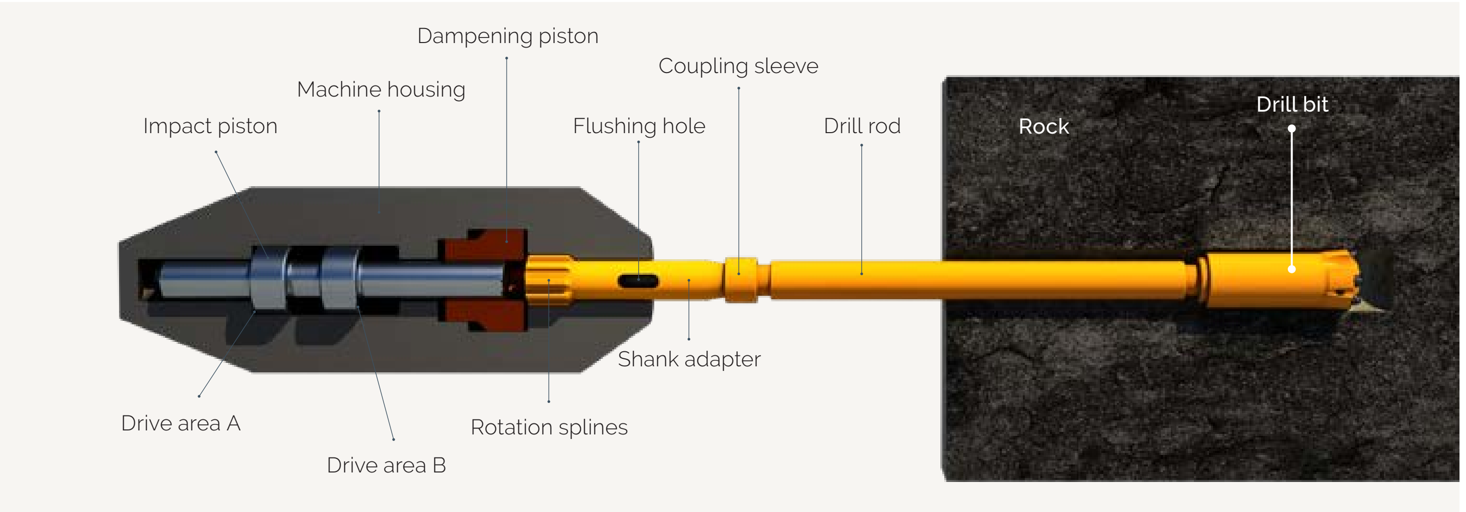


Figure 1: Principle of tophammer drilling.

The total energy that the wave contains is indicated diagrammatically in Figure 2. To calculate the output power obtained from a rock drill, the wave energy is multiplied by the impact frequency of the piston, and is usually stated in kW. Rock drill designers seek to find the best combinations of various parameters, such as the piston geometry, the impact rate and the frequency. Two rock drills having the same nominal power rating might therefore have quite different properties. The shock waves that are generated by hydraulic (Figure 3) and pneumatic (Figure 4) rock drills are significantly different in shape. Drill rods used with hydraulic rock drills will normally show substantially longer service life, compared with pneumatic rock drills, because of the higher stress level obtained with the pneumatically driven piston.

The reason is the larger cross-section needed when operating at substantially lower pressure, which is 6–8 bar, compared to the 150–250 bars used with hydraulic systems. The slimmer the piston shape, the lower the stress level. (Figure 5) compares the stress level generated by three different pistons having the same weight, but with different shapes and working at different pressures. The lowest stress, or shock wave amplitude, is obtained with the long slender piston working at high pressure.

Efficiency and losses

The shock wave loses some 6–10% of its energy for every additional coupling, as it travels along the drill string. This loss is partly due to the difference in cross-sectional area between the rod and the sleeve, and partly due to imperfect contact between the rod faces. The poorer the contact, the greater the energy loss. When the shock wave reaches the bit, it is forced against the rock, thereby crushing it. The efficiency at the bit never reaches 100%, because some of the energy is reflected as a tensile pulse. The poorer the contact between the bit and the rock, the poorer the efficiency (Figure 6). To optimize drilling economy, the drilling parameters for percussion pressure, feed force, and rotation must harmonize.

Percussion pressure

The higher the percussion pressure, the higher will be the speed of the piston, and consequently, the energy. Where the bit is in good contact with hard and competent rock, the shock wave energy can be utilized to its maximum. Conversely, when the bit has poor contact, the energy cannot leave the drill string, and reverses up the drill string as a tensile wave. It is only when drilling in sufficiently hard rock that the maximum energy per blow can be utilized. In soft rock, to reduce the reflected energy, the percussion pressure, and thus the energy, will have to be lowered (Figure 7). For any given percussion pressure, the amplitude, and hence the stress in the drill steel, will be higher with reduced cross-section of the drill rods. To get the longest possible service life from shank adapters and rods, it is important to ensure that the working pressure is matched to the drill string at all times.

Feed force

The purpose of the feed is to maintain the drill bit in close contact against the rock. However, the bit must still be able to rotate. The feed force must always be matched to the percussion pressure. Figure 8 illustrates this relationship. Lack of feed force can cause premature wear on the rock tools and the rock drill and excessive feed force can cause deviation problems and jerky rotation.

Rotation

The purpose of rotation is to turn the drill bit to a suitable new position for the next blow. Using button bits, the periphery is turned about 10 mm between blows. Consequently, the rotation rate is increased using higher impact frequency and reduced bit diameter. Using insert bits, the recommended rotation rate is 25% higher.

Setting parameters

In practice, the driller sets the percussion pressure that the rock can cope with, and then sets the rpm with regard to the percussive frequency and the bit diameter. When drilling

Figure 2
Stress wave energy.

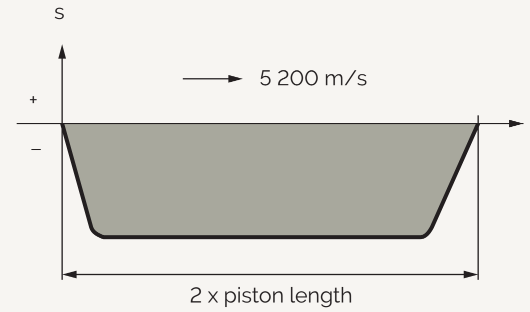


Figure 3
Shock wave generated by hydraulic rock drill.

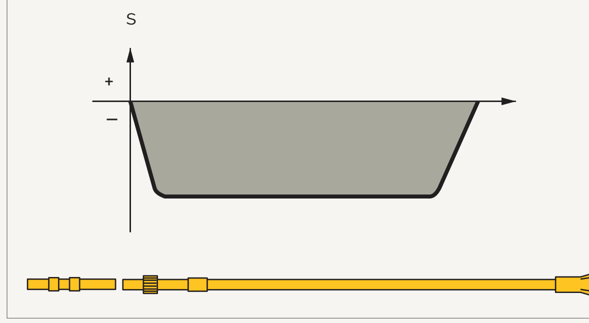


Figure 4
Shock wave generated by pneumatic rock drill.

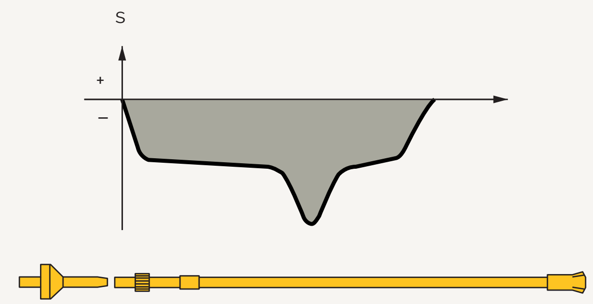


Figure 5
Stress level generated by different pistons of same weight.

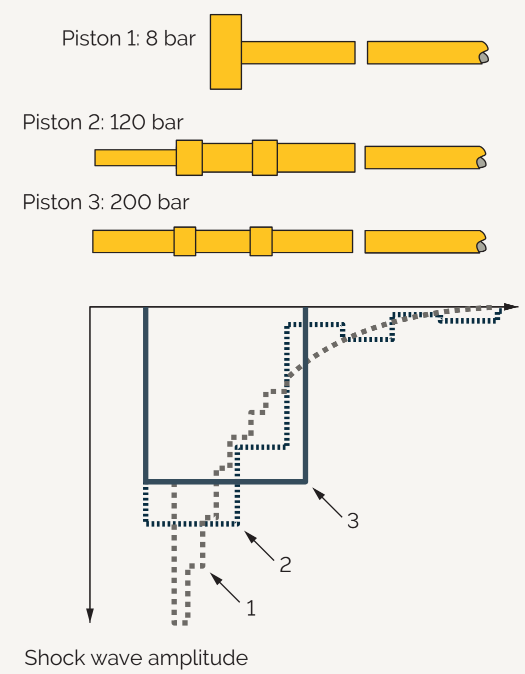


Figure 6
Poor contact between bit and rock results in poor efficiency.

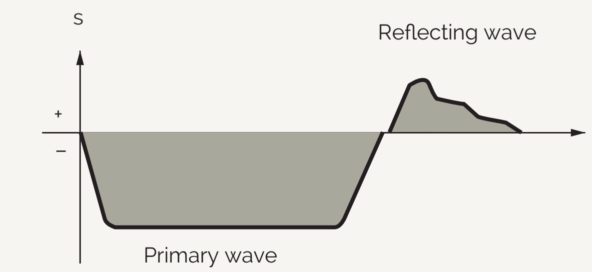


Figure 7
To reduce reflected energy, percussion pressure is lowered.

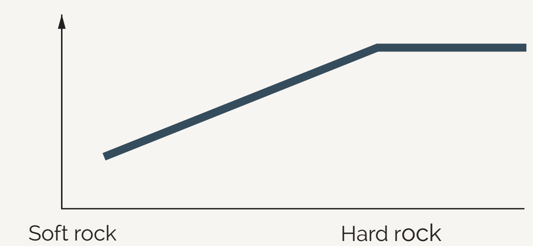
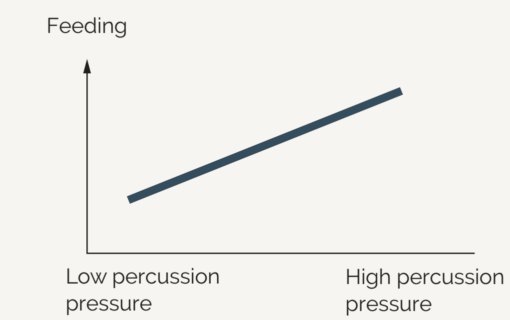


Figure 8
Feed force must be matched to percussion pressure.



starts, the feed is adjusted to get even and smooth rotation. If this does not occur, which will be indicated by low shank adapter life, the percussion pressure can be progressively reduced until even and smooth rotation is achieved.

The temperature of the adapter sleeve can be checked to ensure that the drilling parameters are correctly set. Immediately after drilling, the temperature should be 60–70°C for dry drilling, and approximately 40°C for wet drilling. Drilling problems, mainly related to loose couplings, may arise whatever parameters are used. In order to tighten the couplings during drilling, the friction of the bit against the hole bottom has to be increased. This can be done by increasing the feed, increasing the rotation rate, or changing the bit.

Flushing

Drill cuttings are removed from the hole bottom to the surface by air blowing or water flushing. As the power output from rock drills increases, accompanied by increased penetration rate, efficient flushing becomes gradually more important. The flushing medium is normally air for surface drilling, and water for underground drilling. The required flushing speed will depend on: specific gravity – material having a density of 2 t/cu m requires at least 10 m/sec, whereas iron ore, for example, having a density of 4 t/cu m, requires an air speed of 25–30 m/sec; particle size – the larger the particles, the higher flushing speed required; particle shape – spherical particles require more speed than flaky, leaf shaped particles.

Rotary drilling

Rotary drilling can be subdivided into rotary cutting and rotary crushing. Rotary cutting creates the hole by shear forces, breaking the rock's tensile strength. The drill bit is furnished with cutter inserts of hard metal alloys, and the energy for breaking rock is provided by rotation torque in the drill rod. This technique is limited to rock with low tensile strength, such as salt, silt, and soft limestone not containing abrasive quartz minerals. Rotary crushing breaks the rock by high point load, accomplished by a toothed drill bit, which is pushed downwards with high force. The bit, being of tricone roller type fitted with tungsten carbide buttons, is simultaneously rotated, and drill cuttings are removed from the hole bottom by blowing compressed air through the bit. Drill rigs used for rotary drilling are large and heavy. The downwards thrust is achieved by utilizing the weight of the drill rig itself, and the rotation, via a hydraulic or electric motor, applied at the end of the drill pipe. Common hole diameters range from 200–440 mm (8 to 17.5 in) and, because adding the heavy drill pipes is cumbersome, most blasthole drill rigs use long masts and pipes to accommodate single-pass drilling of maximum 20 m (65 ft). Electric power is usually chosen for the large rigs, whereas smaller rigs are often powered by diesel engines.

Rotation rates vary from 50 to 120 rev/min, and the weight applied to the bit varies from 0.5 t/in of bit diameter in soft rock, to as much as 4 t/in of bit diameter in hard rock. Recent technical advances include: improved operator cabin comfort; automatic control and adjustment of optimum feed force and rotation speed to prevailing geology and bit type and diameter; and incorporation of the latest technology in electric and hydraulic drive systems. Rotary drilling, which is still the dominant method in large open-pits, has limitations in that the rigs are not suited to drilling holes off the vertical line. As blasting theories and practice have proved, it is generally beneficial to design, drill and blast the bench slopes at an angle of approximately 18° off vertical.

Many rotary rig masts have pinning capabilities permitting drilling at angles as much as 30° off vertical. However, the inclined hole drilling capabilities in rotary drilling are limited by the heavy feed force required, since part of this force is directed backwards. This causes rig stability problems, reduced penetration, and shorter life of drilling consumables. Consequently, most blasthole drilling using rotary drill rigs is for vertical holes

Productivity and methodology

During the past century there has been a rapid and impressive increase in efficiency and productivity related to tophammer drilling. Starting from hitting a steel manually by a sledge hammer 100 years ago, today's hydraulically powered rock drills utilize the latest state-of-the-art technology. Every drilling method has its pros and cons, making an objective comparison quite cumbersome. In view of this, the table in Table 1 can serve as a guideline when comparing the various percussion drilling alternatives which Epiroc can offer. The choice of best drilling method to apply depends on hole size and type of application. In addition to the hole sizes mentioned above, the bench height also needs to be considered. COPROD and Down-The-Hole (DTH) always give straighter holes. Normally, the tophammer drill string starts to deviate from 17–25 m. Hole deviation problems largely depend on the geological conditions.

Drilling method	Tophammer	DTH	COPROD
Hole diameter, mm	76–140	90–203	105–180
Penetration rate	2	2	3
Hole straightness	1	3	3
Hole depth	1	3	1
Production capacity (tons rock/shift)	2	3	3
Fuel consumption/drill meter	2	1	3
Service life of drill string	1	2	3
Investment in drill string	2	2	1
Suitability for good drilling conditions	3	3	3
Suitability for difficult drilling conditions	1	3	3
Simplicity for operator	2	3	1
Adjustability of flushing capacity	1	2	3

Table 1: Comparison for 20 m bench drilling in a limestone quarry
Ratings: fair = 1, good = 2, very good = 3

Principles of rock blasting

Blasting by design results from a large number of factors, all of which need to be brought under control in order to achieve the right result.

These include the choice of drill rig and tools, the layout of the holes, the explosives, and the skill of the operators. Geology is the governing factor, and experience is a major ingredient.

Blasting

To understand the principles of rock blasting it is necessary to start with the rock fragmentation process that follows the detonation of the explosives in a drill hole. The explosion is a very rapid combustion, in which the energy contained in the explosives is released in the form of heat and gas pressure. The transformation acts on the rock in three consecutive stages (Figures 1–3).

Compression

A pressure wave propagates through the rock at a velocity of 2 500–6 000 m/sec, depending on rock type and type of explosives. This pressure wave creates microfractures which promote rock fracturing.

Reflection

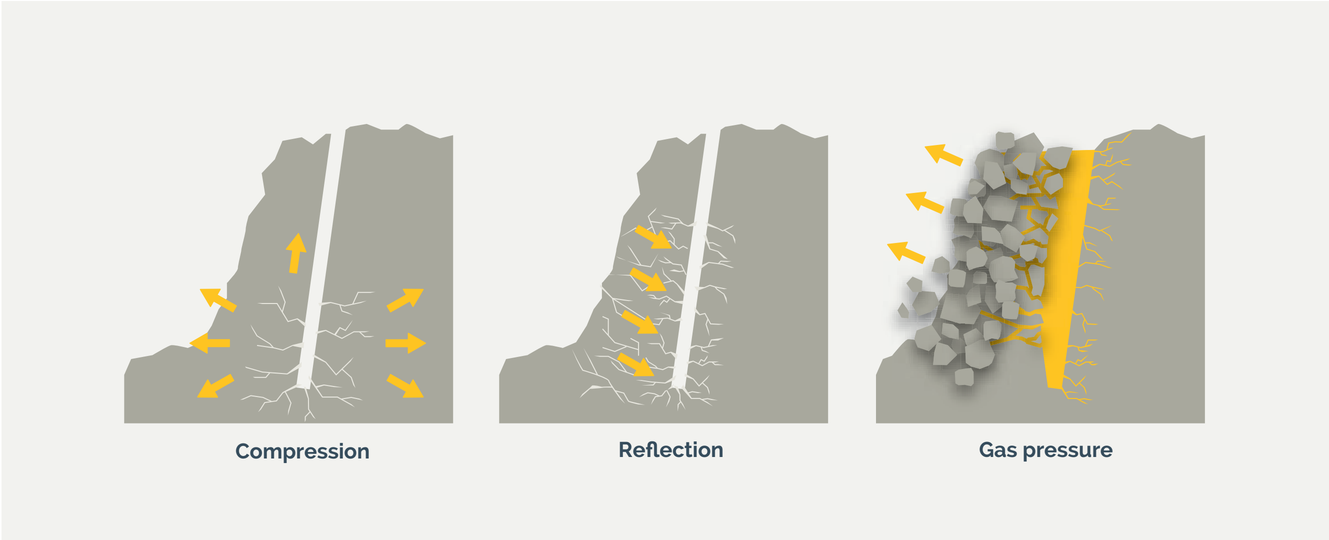
During the next stage, the pressure wave bounces back from the free surface, which is normally the bench wall or natural fissures in the rock. The compression wave is now transformed into tension and shear waves, increasing the fracturing process.

Gas pressure

Large volumes of gas are released, entering and expanding the cracks under high pressure. Where the distance between the blasthole and the free face has been correctly calculated, the rock mass will yield and be thrown forward.

Benching

Bench blasting is normally carried out by blasting a large number of parallel holes in each round. Considering the blasting mechanics, with a compression-reflection-gas pressure stage in consecutive order for each charge, it is of vital importance to have a proper delay between each row, and even between individual holes in each row. A proper delay will reduce rock throw, improve fragmentation, and limit ground vibrations.



Figures 1-3: Rock breaking sequence in a normal blast.

The blast should be planned so that the rock from the first row of holes has moved about one third of the burden, when the next row is blasted (Figures 4 and 5).

The horizontal distance between the hole and the free face is the burden, and the parallel distance between holes in a row is the spacing. The ratio between spacing and burden will have great impact on the blasting result, with 1.25 considered as an average ratio.

The optimum burden depends upon a number of parameters, such as rock type, required fragmentation, type of explosives, hole deviation, and hole inclination. Nevertheless, as large drill holes can accommodate more explosives, there is a distinct relationship between burden and hole diameter (Figure 6).

As the bottom part of the blast is the constricted and critical part for successful blasting, it is used as a basis for deciding all other parameters. The bottom charge, normally 1.5 x burden, from where the initiation should start, requires well packed explosives of higher blasting power than is needed in the column charge (Figure 7).

Stemming of the top part of the hole is used to ensure that the energy of the explosives is properly utilized. It will also reduce and control the fly rock ejected from the blast. This tends to travel long distances, and is the main cause of on-site fatalities and damage to equipment. Dry sand or gravel having a particle size of 4 to 9 mm constitutes the ideal stemming material. Inclined holes give less back break, safer benches and less boulders, when compared to vertical holes.

Types of explosives

The geology frequently has more effect on the fragmentation than does the explosive used in the blast. The properties that influence the result of the blast are compressive strength, tensile strength, density, propagation velocity, hardness, and structure. In general, rock has a tensile strength which is 8 to 10 times lower than the compressive strength. The tensile strength has to be exceeded during the blast, otherwise the rock will not break. High rock density requires more explosives to achieve the displacement.

The propagation velocity varies with different kinds of rock, and is reduced by cracks and fault zones. Hard, homogeneous rocks, with high propagation velocity, are best fragmented by an explosive with high velocity of detonation (VOD). An extensive range of different types and grades of explosives is available to suit various blasting applications.

A breakdown is presented in Table 1. In dry conditions, ANFO has become the most used blasting agent, due to its availability and economy.

The blasthole diameter, together with the type of explosive used, will determine burden and hole depth. Practical hole diameters for bench drilling range from 30 to 400 mm. Generally, the cost of large diameter drilling and blasting is cheaper per cubic meter than using small holes. However, rock fragmentation is better controlled by higher specific drilling.

The explosives are initiated with detonators which can be electric, electronic or non-electric. Electric systems have the advantage that the complete circuit can easily be checked with an ohmmeter to ensure that all connections and detonators are correct before blasting.

Despite higher unit price, the usage of electronic detonators is growing. As the detonation intervals are extremely accurate without any time deviation, fragmentation of blasting material can be improved. To eliminate the risk for spontaneous ignition from lightning, non-electric systems, including detonating cord, are used.

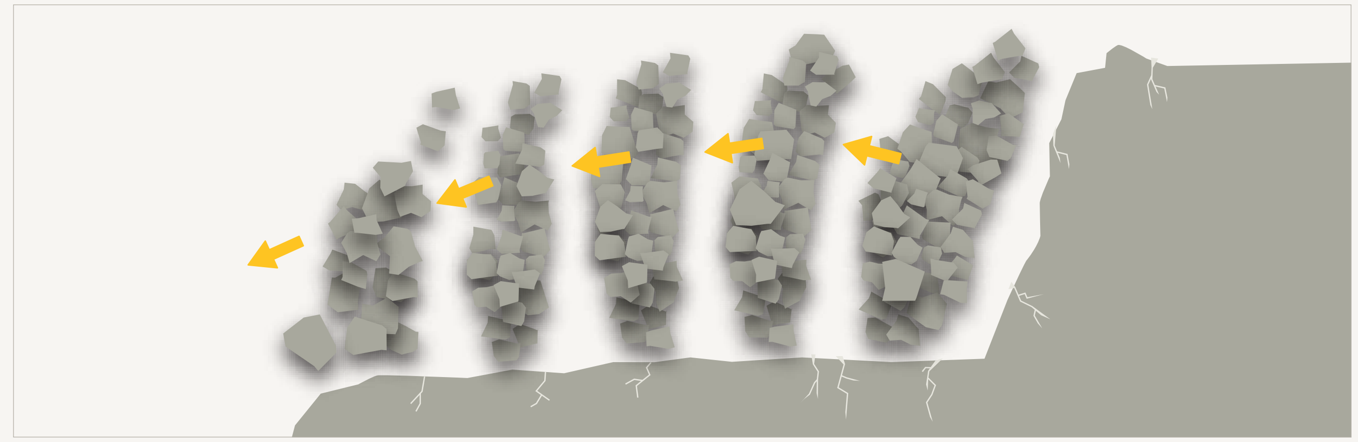


Figure 4: Delay detonation of a typical bench blast.

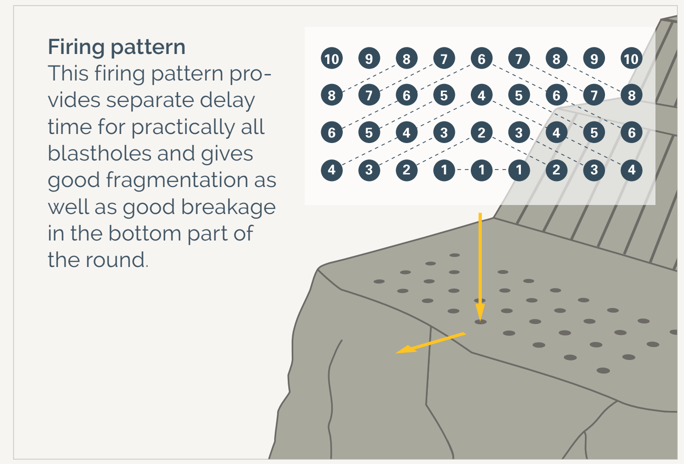


Figure 5: Firing sequence in delay blasting.

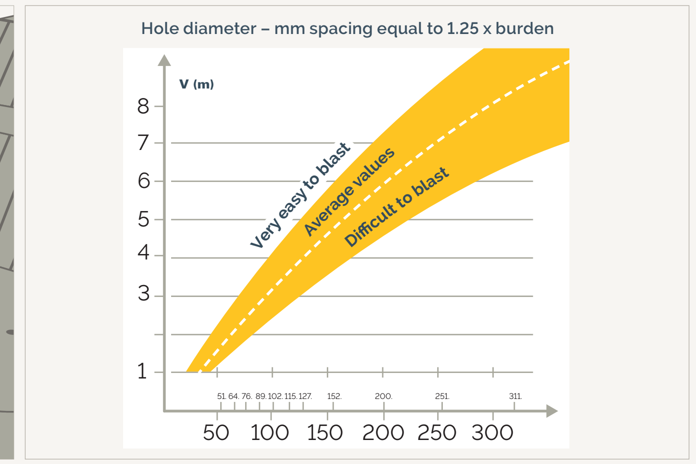


Figure 6: Burden as a function of drill hole diameter.

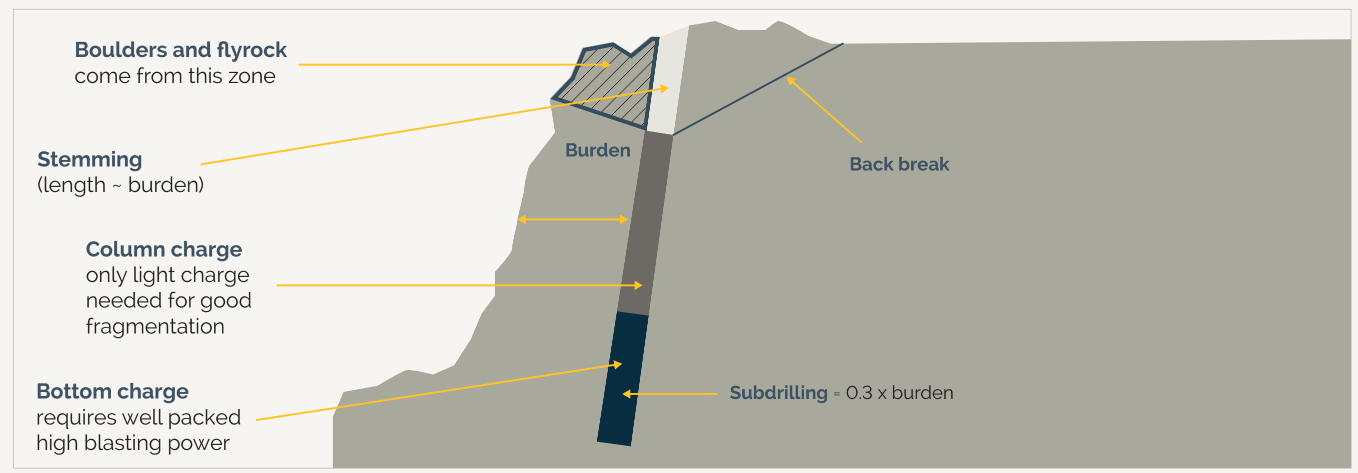


Figure 7: Charging for optimum fragmentation.

Base	Type	Detonation velocity	Features
Nitro-glycerine	Dynamite gelatin	5 500–4 500	Highly adaptable cartridged excellent in smaller holes
Ammoniumnitrate	ANFO	2 500	Low cost, high safety, easy to pour or blow no water resistance, contains 5–6% fuel oil
Water	Slurry	4 000–3 000 watergel	Basically ANFO made water resistant gel
		5 000 emulsion	Stable oil/water emulsion heavy ANFO
		Range depends on storage time	Packaged or pumpable

Table 1: Features of common types of explosives.

Plan for success

Achieving overall operational efficiency in drilling and blasting is a journey rather than a single step. It is a matter of continuous trial and error to create long-lasting improvements. This all boils down to the people engaged in companies, the information at their disposal and the tools they rely on.

Operations planning is no easy task today. Rising energy costs, increasing fuel prices, looming CO_2 taxes, stricter regulations and tougher scrutiny from communities are all major concerns. So where do you begin? While the quarrying process will largely stay the same, management can work to raise awareness about efficiency at every step of the production cycle. However, trying to be as "lean" as possible will only get you so far. Hence the saying – "what gets measured, gets done."

Technology offers a measure of relief. Epiroc's modern range of SmartROC drill rigs puts a strong emphasis on generating production, operation and utilization data. Getting staff into a documented trial and error process is easy and will lead to more optimized drill and blast results. Being proactive in drill and blast operations means you can affect the rest of the quarrying process, and mitigate rising energy costs through improved performance.

It is no secret that the quality of the blasted material directly affects the cost of loading. Are buckets easily filled or does loading involve heavy digging? Good blasting and well-fragmented rock can make all the difference in the process. The same applies to crushing where dealing with large boulders will slow down the throughput or even damage equipment. An excess of fines will result in waste material. In short, there is a delicate balance to be struck and money to be saved.

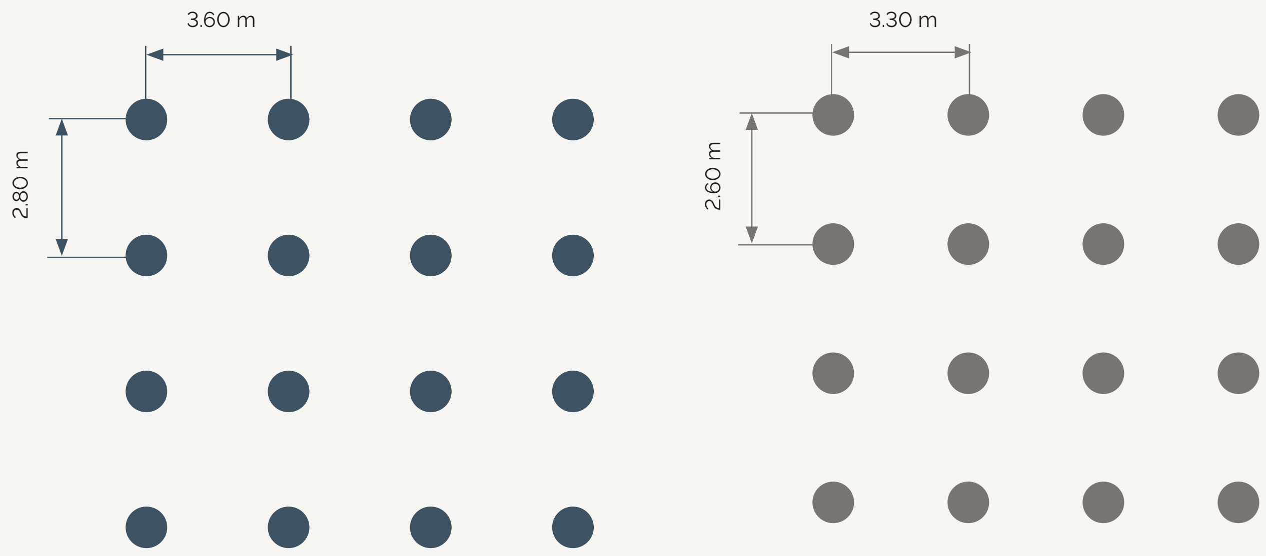


Figure 1: Different drill patterns will result in different fragmentation.

Documentation and precision

With the ability to document and repeat operations we have laid the foundation for drilling improvements. Before planning any major changes to your position you need to know where you are. In other words, create a baseline. By establishing a precise baseline you can move on to the next step of creating a floor for the bench blast. Drilling all holes in the right place, with high precision, greatly improves the energy distribution in the rock, which enables good breaking and, in turn, correct size and dimension of fragmented rock. By moving the holes, in other words changing the drill patterns, you can change the fragmentation according to preference.

Quarrying personnel will know this, but they need equipment that allows for precision and controlled flexibility and which is also simple to use. The images show a carefully laid out bench drill pattern (Figure 1). By changing the pattern and testing different charges, the rock fragmentation can be fine-tuned. Different technologies are available, such as electronic detonators with simulation software that will show impressive results, but they all need a bench drilled accurately to deliver what they promise.

Customer experience

References from drillers using Epiroc's SmartROC drill rigs prove the importance of high precision drilling and its relation to cost savings. In a Norwegian limestone quarry, operated by Brønnøy Kalk, several Epiroc drill rigs are deployed. One model being the SmartROC T40 (Figure 2). Recently,the management decided to ramp up the productivity of its existing fleet. Loading capacity was a major bottleneck. By reducing the bench pattern from 2.80x3.60 m to 2.60x3.30 m (Figure 1), they were able to improve loading productivity from an average of 5 500 tons per shift to 7 000 tons per shift, thanks to the lean, two-shift operation of the Epiroc fleet. Costs related to a slightly higher specific charge was outweighed by better productivity, which is what they needed at the time.

Conclusion

Drilling performance has a direct impact on the overall economy of quarrying operations. There are always improvements and cost savings to made, not least in terms of energy consumption. Many quarries and mines are finding it harder and harder to hire young people into the industry, and the retention of experienced operators is equally challenging.

At the same time, the opportunities available today for improving performance, economy and sustainability are vast. When everything can be measured using new technologies, operators of all ages with an interest in digital tools can make a real difference in these types of drilling operations.

Figure 2: The SmartROC T40 surface drill rig.

COPROD leads the way

When ground conditions become tough, drillers need to ensure productivity, quality as well as minimized cost per drill meter. The COPROD concept has proved its worth for almost three decades.

Drillers always dreamed of a system that would combine the straightness and accuracy of Down-The-Hole drilling with the enormous capacity of hydraulic tophammer drilling. Efforts to combine the advantages of the two techniques were unsuccessful, until the introduction of COPROD in 1992.

COPROD was developed by Epiroc (former Atlas Copco) and the drilling system has proven its value time and again. In fact, this drilling concept is still as fresh as it was almost three decades ago – there is simply nothing that rivals the technique in terms of drilling speed, large diameter capacity and hole straightness.

Introduction to COPROD

In the simplest of terms, percussive drilling systems go back to manually hitting a steel rod with a bit at one end and, as recoil makes the rod jump back, rotating it at a small angle between blows to ensure that the hole is round and that solid rock is crushed.

Many benching operations are carried out with tophammers, using extension rods connected by threaded coupling sleeves, and an exchangeable drill bit at the bottom end.

This equipment works well for smaller hole diameters in solid rock, but it is not so effective in larger hole diameters, or in deteriorating ground conditions. There are problems in transmitting sufficient energy to the bit, especially in deeper holes, and in obtaining satisfactory flushing and hole straightness.

In tophammer drilling, the thrust has to be applied from the top to keep the bit in contact with the bottom of the hole. This can cause the relatively slender drill string to bend, steering the bit off its intended alignment. Increasingly powerful hydraulic rock drills send more percussive energy down the drill string, allowing larger hole diameters in benching. However, due to the microscopic movements between mating parts in the threaded drill string, energy is lost and heat develops. The energy loss may be considerable by the time the shock wave reaches the bit, and there will be thread wear and reduced life of the drill string components.

The Down-The-Hole (DTH) system was developed to overcome some of the problems associated with hole straightness suffered by tophammer drills. Rigid guide tubes, with a large outer diameter, were developed to keep the drill string on a straight course and to improve flushing. With a DTH hammer, a series of tubes offers far greater stiffness and runs closer to the hole walls, resulting in considerably less deviation than the tophammer drill string, but with increased energy utilization.

Power with rigidity

COPROD combines a threaded drill tube with an unthreaded drill rod. The drill tube provides rotation while the impact rod, fitted in floating suspension inside the tube (Figure 1 and Figure 3), transmits impact energy and feed force. The flushing air passes between the tube and the rod through the bit rod to the front of the drill bit.

When the COPROD sections are joined, the impact rods stand on top of each other inside the drill tube. This means that the impact energy is directly transmitted to the rock without passing a single thread. This results in superior drilling performance and hole straightness, high energy efficiency and low wear and tear on components. Thanks to the unique double recoil dampening system of the COP rock drills, the rod ends remain in permanent contact, energy losses are almost zero, and drilling efficiency is maintained from start to finish of the hole. This allows for high drilling rates compared to the tophammer drilling method and large hole diameters and straight holes compared to the DTH drilling method.

During drilling operations, if the bit enters a cavity and drops down in its splines in the bit chuck, the Rig Control System (RCS) detects it and percussion is interrupted. Rotation is maintained, however, and percussion restarts automatically when the bit meets resistance again.

Flushing air enters the bit via a center channel (Figure 2), which connects to the cylindrical surface in the bit rod. A small amount of air, containing a little oil, escapes via the splines in the chuck and the bit, and lubricates them. On its way up, the flushing air travels between the smooth outside of the tubes and the hole wall, providing a constant

Figure 2: COPROD drilling method.

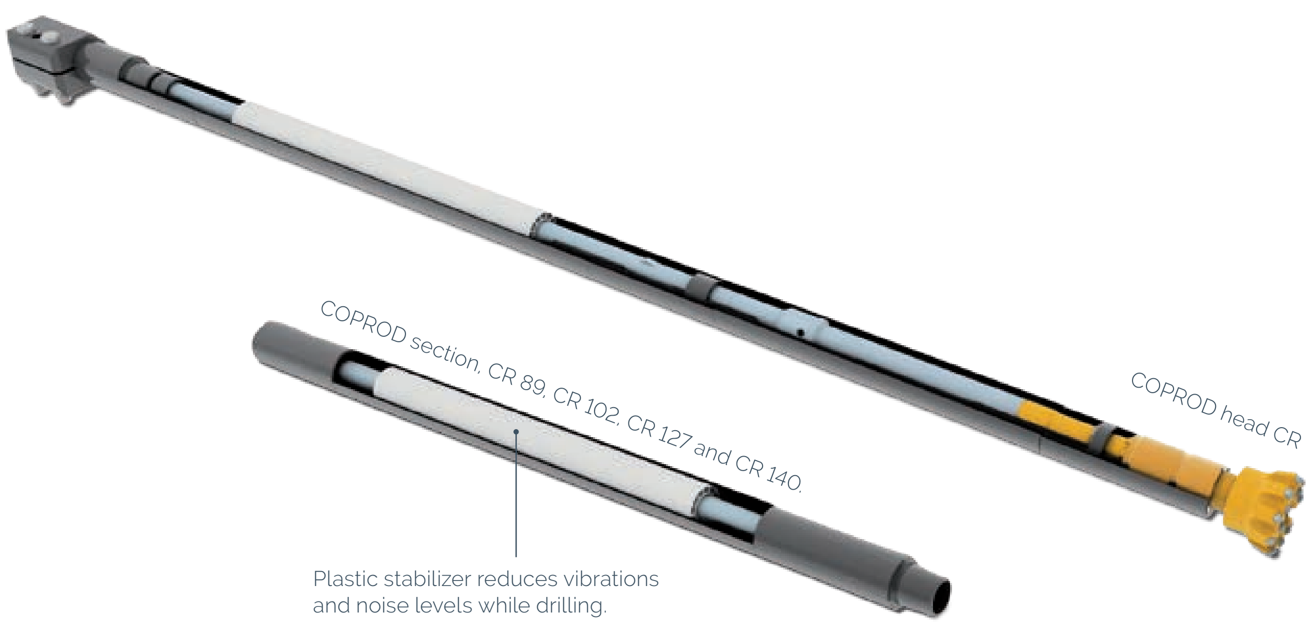
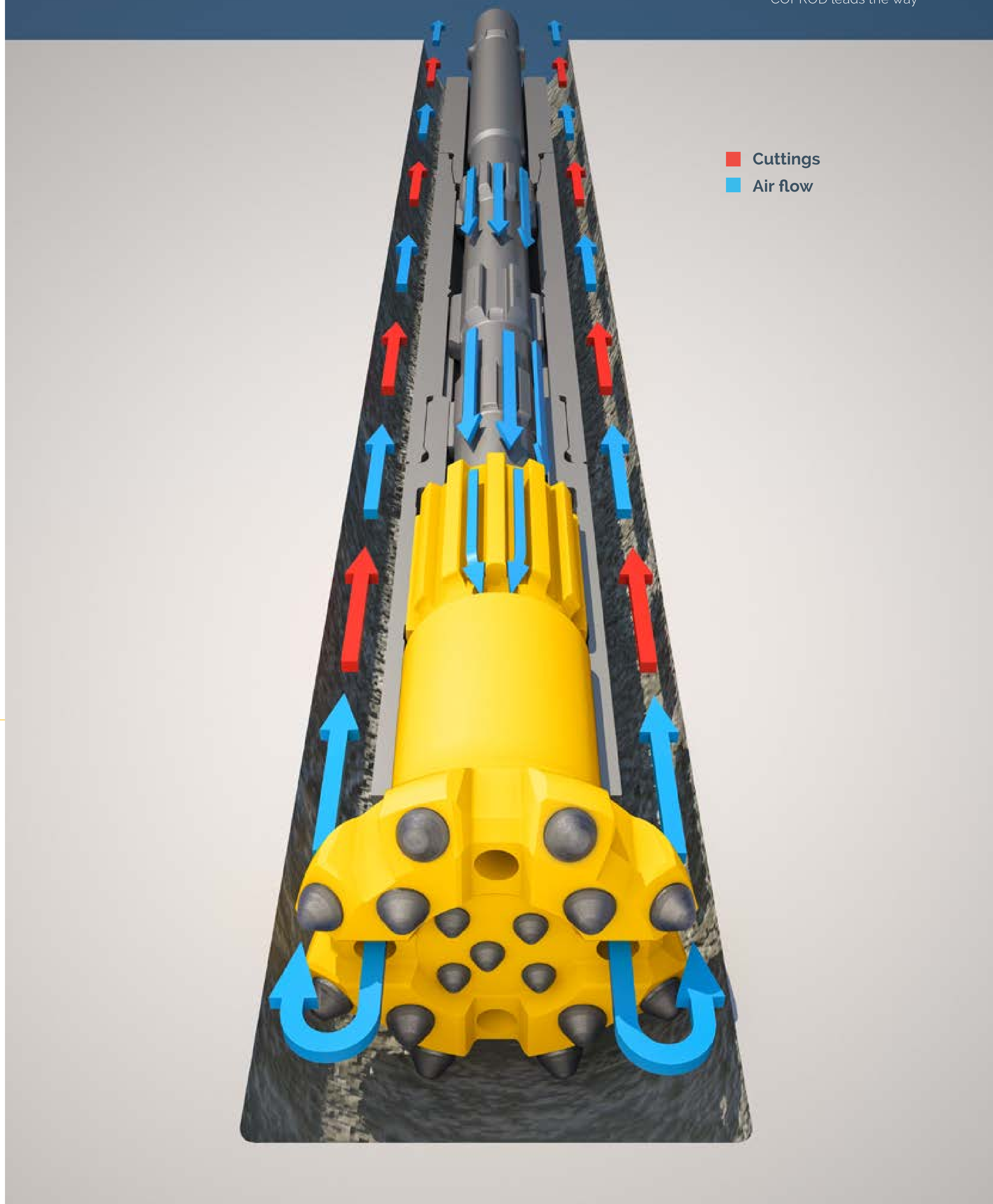


Figure 1: The COPROD drill string and a COPROD section.



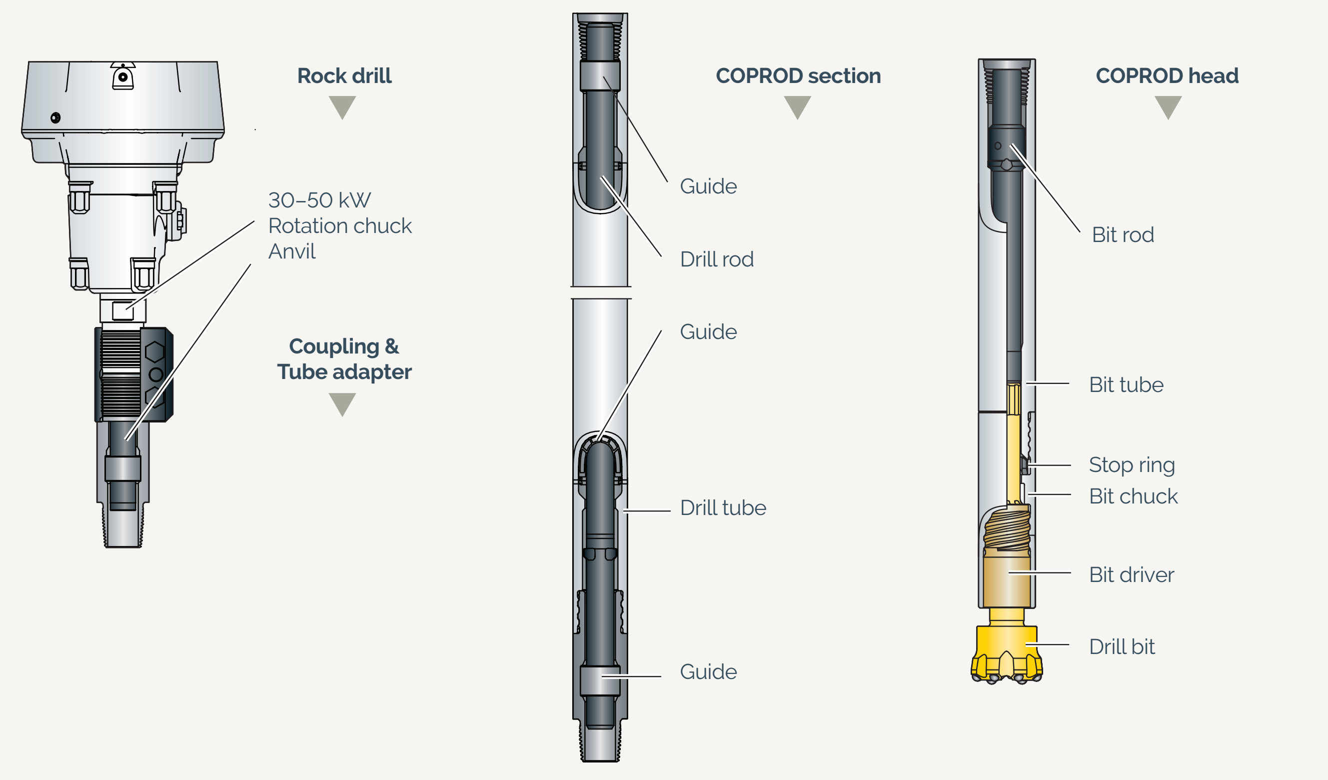


Figure 3: COPROD drilling system.

cross section, and ideal conditions for flushing the drill cuttings. COPROD offers unique features for drilling holes fast and straight. And the more troublesome the ground becomes, the more the incomparable drilling system comes into its own.

Latest developments

Epiroc is always looking for ways of improving products. The goal this time was to develop a third generation of COPROD drill strings with exceptional hole straightness and lower noise emission. The solution was to replace the welded center guides in the drill tubes with a full length specially designed inner tube. This plastic stabilizer with its unique geometry acts as an inner lining which reduces vibrations in the COPROD tube and dramatically reduces noise levels, not to mention the improved hole straightness. Field tests have shown that this reduction in noise has not only made the operator's environment more pleasant, it also allows COPROD rigs to operate without disturbing surroundings with unnecessary noise pollution. In addition, the benefits of using COPROD drill strings in combination with advanced features of the Rig Control System (RCS) have proven to be outstanding, especially in terms of increasing the service life of rock drilling tools.

The COPROD product range consists of two surface drill rigs and five different drill strings. SmartROC C50 is the smaller of the two drill rigs. For this drill rig, three drill strings are available: COPROD 76 mm, 89 mm and 102 mm giving blastholes ranging between 90–140 mm in diameter. The larger drill rig, SmartROC CL can be equipped with COPROD 102 mm, 127 mm or 140 mm drill strings. This means SmartROC CL can drill 115 mm to 216 mm blastholes.

Conclusion

Economy is sometimes a critical challenge when drilling becomes difficult due to demanding ground conditions. COPROD's superior penetration rate contributes to a lower cost/m drilled than DTH. Compared with tophammer drilling using extension steel, COPROD's better gross penetration and hole quality provide lower cost/t in difficult rock formations. Together with the Rig Control System, COPROD also provides drilling contractors with excellent fuel economy and service life for rock drilling tools.

Most importantly, COPROD is reliable option for drilling holes with maximum straightness as fast as possible, and it comes into its own in difficult ground conditions. Due to the number of components involved, a COPROD drill string carries a higher value than comparable extension rods or DTH strings.

However, because the holes are drilled fast and without deviation, permitting the drilling pattern to be opened up, COPROD leads to lower costs per excavated volume of rock. Time is also saved in retracting the drill string in broken ground, or through blasting debris left on top of the bench. The latest COPROD system improves on these advantages, offering longer drill string life and better availability than ever before.

Open-pit drilling

Open-pit mining provides significant proportions of many of the world's major mineral commodities. In hard rock mining, which is the primary focus here, much of the world's annual output of copper, gold and iron ore is won from open-pit operations. Other commodities produced from open-pits include diamonds, molybdenum, manganese, lead and zinc, uranium and a variety of industrial minerals, such as borates, talc and specialist clays.

The list is extensive, although the relative proportions mined underground and on the surface vary from mineral to mineral. Massive tonnages of hard coal and lignite are also produced from surface mines, although the terminology used – open cast or open cut, rather than open-pit – indicates that the technology and engineering concepts used are often markedly different from those employed in the hard rock environment.

Open-pit mining differs from quarrying (with the possible exception of iron ore) in that the valuable mineral constitutes only a small proportion of the total tonnage of rock produced. In quarrying (as described on pages 64–71 of this book), the rock itself is the valuable commodity, with virtually all of the raw rock that is won being

Typical operations in an open-pit mine.

processed (often only by crushing and screening) to give saleable products (Figure 1). In open-pit mining, on the other hand, the metal content of the ore produced may be only fractions of a percent, meaning that a huge proportion of the rock produced is effectively waste material. In addition, the ore body geometry may mean that large tonnages of barren rock also have to be mined and transported in order to access the ore in which the valuable mineral (or minerals) makes up only a small proportion. This has to be recovered from the rock matrix through both physical (crushing and grinding) and/or chemical processes such as flotation, meaning that processing costs are higher. This is reflected in metal commodity prices, with a ton of copper or zinc being valued much more highly than a ton of granite or basalt.

To give an example of the tonnages involved, the Radomiro Tomic mine in Chile, owned and operated by Codelco, processes approximately 320 000 tonnes of copper ore per year with a grading of 0,59%. This means that the mine also handles an additional 41%, or 131 000 tonnes of waste rock, all of which has to be drilled and blasted before being transported from the pit.

However, commodity markets, especially those for major metals such as copper and iron ore, are often volatile, responding to external influences such as global economic cycles at one extreme and local supply constraints such as labor disputes and power shortages, at the other. In consequence, the mining reserves held in a deposit can vary over time, as can parameters such as the cut-off and mill head grades. Overall, mining companies need to minimize their costs at all stages of the production process, including the drilling and blasting that is needed, both to excavate the ore and waste rock, and to ensure the long-term stability of the pit.

Open-pit mining technology

Open-pit mining clearly offers a number of economic advantages over underground mining, especially now that mineral-processing technology has advanced to the stage where very low-grade ores can be treated profitably. A hundred or 150 years ago, this was not the case, and mining was still much more selective. However, the introduction of flotation technology for recovering base metal minerals, and the cyanidation of gold (particularly heap-leaching) changed all that, and large-scale open-pit mining has developed steadily since the latter part of the 19th century.

While the scale of open-pit operations may have changed, the fundamental concepts have not. The challenge is always to access ore grade mineralization without having to strip excessive amounts of barren waste rock or overburden. An additional constraint is that the definition of ore can change over time as technology advances and commodity

Figure 1: Financial optimization using circular analysis (Dohm, 1979).

Figure 2: General principles of open-pit mining.

markets fluctuate. In some cases, where resources are defined by clear differences in the geology of the ore and waste, this will have little effect. In others, such as with low-grade porphyry copper deposits, a minor reduction in cut-off grade resulting from the introduction of higher capacity mining equipment, or a long-term rise in the copper price, can result in a significant increase in the resource tonnage available, and what may have been considered as waste in the past can now be reclassified as ore.

Obviously, the reverse can also apply when commodity markets fall dramatically, although the effect is more likely to be seen in terms of a life span reduction rather than operating expensive equipment at partial capacity. Two main changes have occurred in open-pit mining technology over the past 100 years. The most obvious has been the increase in the scale of operations as higher capacity equipment has been developed. For instance, in the 1920s, a mining shovel with a 5 m^3 bucket was exceptional. Today, large open-pits use rope shovels or hydraulic excavators with bucket sizes ten times that capacity.

The other change has involved the evolution of transport systems from rail-bound to haul truck and, in an increasing number of cases, to in-pit primary crushing of the ore (but not the waste rock) followed by belt conveyor transportation out of the pit. In addition, in tandem with the growth in loading-shovel capacities, haul trucks have increased in size with the top-of-the-range 45 t capacity hauler of the 1950s having been replaced by the 400 t hauler that takes three- or four-pass loading from the current generation of shovels.

Equipment sizes have increased, and the operational throughputs of individual mines have expanded as well. These days, the need to process for example 250 000 t/d of ore is not exceptional. Add to that the tonnage of waste rock that has to be removed, and the challenge facing the drilling and blasting side of the operation becomes clear. Blasthole drills must perform reliably, week in, week out, producing the drill meters needed to keep the mine's production schedule on track.

Open-pit engineering

While the precise layout of an open-pit will vary from mine to mine, depending on the deposit geometry, the basic idea remains the same. Following the stripping of near-surface waste rock or low-grade mineralization, the pit is developed as a series of benches, with the areal extent of the pit increasing as it gets deeper. Bench heights are standardized in order to optimize the use of drilling and loading equipment, with typical heights of 10–15 m. Haulage ramps are constructed to carry trucks from the operating areas to either the primary crusher or the waste rock storage areas, with permanent haul roads being fed by temporary connections to individual working places.

Pit wall stability is critical in open-pit mining, especially as pits become deeper. The precise pit slope angle that will remain stable over long periods of time depends on factors such as the rock mass strength, and the presence of faulting and other potential areas of weakness, with sophisticated rock mechanics techniques being used to design safe pit walls. Clearly, there is an economic incentive for the pit wall to be cut as steep as possible, since this reduces the volume of waste rock that has to be removed, with a difference of 1° or 2° having the potential to increase or reduce the rock-shifting volume substantially in a large operation.

Regional stability issues must also be considered, since additional safety factors will have to be designed into pit slope calculations in those parts of the world that are prone to earthquakes, for instance. Open-pit design is also affected by the topography of the landscape that hosts the deposit. Clearly, the worst-case scenario is where a pipe- or lens-shaped deposit angles down into the ground from a relatively flat landscape, since increasing depth will inevitably involve longer uphill haul runs for both ore and waste. Conversely, a deposit that lies within a hillside offers much better opportunities for downhill haulage, at least for part of the way, with increasing pit depths having only a limited impact on transport systems.

The economics of rock transport by both electric trucks and belt conveyor can be significantly altered by changes in the gradients encountered, with steep uphill hauls much more expensive to operate than those on the level, or downhill. In-pit crushing and conveying systems can offer major operating-cost advantages over truck haulage in both situations, as well as the potential for electricity generation from the conveyor if long downhill runs are involved between the pit and the processing plant.

Drilling in open-pit mines

High performance drilling is key to successful open-pit mining, with two principal areas of operation: blasthole drilling, and drilling presplit holes that help to enhance pit wall stability. These operations have different requirements, in terms of both their aim and the equipment used.

Blasthole drilling is an integral part of the production process, and needs large, heavy drill rigs that can produce high meterage of often large diameter holes. These are then charged with bulk explosives, such as ANFO or emulsions, to produce broken rock that can be handled by the loading shovels. Drilling is carried out on a specifically defined grid system, taking into account the relationships between the hole diameter, the burden (the distance between each row of holes) and the spacing (the distance from hole to hole along the bench).

Fragmentation requirements for ore and waste may be different, so affecting the drilling layout. Better fragmentation at the blasting stage may mean less work for the primary crusher, so a closer drilling grid may be needed, albeit at a higher drilling cost. Conversely, waste rock fragmentation is governed by the capabilities of the loading and hauling fleet to handle large rocks, meaning that the drill pattern can be widened.

High performance drilling is key to successful open-pit mining.

A bench height of 10 m or 15 m makes various demands on the drilling equipment, not least on its capability to drill to the required depth, plus a certain amount of sub-drilling, in one pass. Having to add and remove rods during drilling can add substantially to the drill cycle time, even with automated systems, so there are distinct benefits in being able to drill the entire hole in one pass, and move from one hole set-up to the next without having to lower the rig's feed.

Accurate positioning according to the mine's drill plan is also critical, since holes that are drilled in the wrong place can not only result in unwanted fragmentation characteristics (too large or too small), but can be unsafe through the generation of flyrock. The increasing use of GPS-based navigation systems has meant that blasthole rigs of all sizes – from the smallest tophammer or Down-The-Hole (DTH) machines to the largest rotary drills – can be positioned accurately on the bench automatically, leaving the operator to concentrate on hole drilling.

Drilling technology

The need for reliable, high-performance blasthole drilling led to the development of a new generation of mining drill rigs, designed exclusively for rotary drilling using tricone bits. With a rotary rig, percussion is not needed in the drilling process, with the weight of the rig providing the stability and down-force used to drive the bit and drill pipe into the hole. The downwards pressure generated on the tricone bit

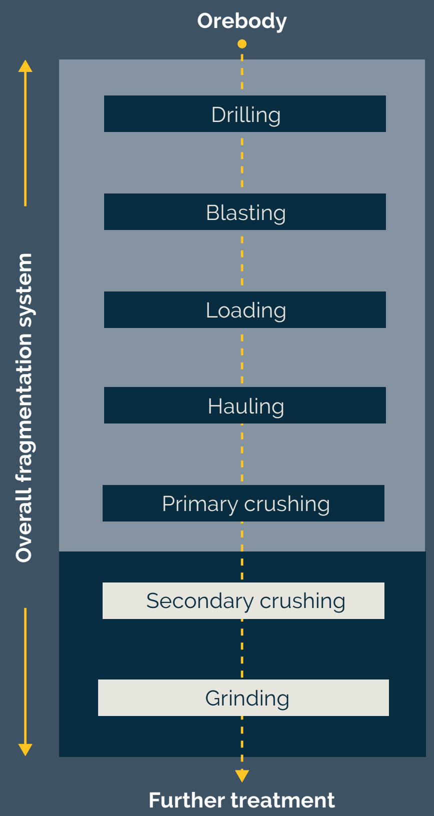


Figure 3: Diagrammatic representation of the overall mine-mill fragmentation system and the mine and mill subsystems (Hustrulid, 1999).

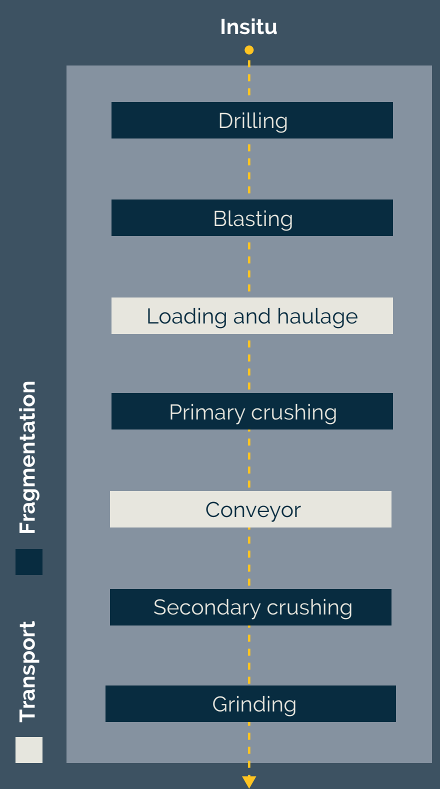


Figure 4: The mine-mill system represented as fragmentation and transport unit operations (Hustrulid, 1999).

buttons fragments the rock beneath the bit, and today, rotary blasthole rigs form the mainstay for open-pit mining, capable of working in all types of rock conditions from tuff to taconite. Epiroc's large blasthole rig range covers more than ten individual machines, most of which can be used for either DTH or rotary drilling, depending on the application, with both single-pass and multiple-pass capabilities. Three examples from the range, the DM30 II, the PV-235 and the PV-351, illustrate the capabilities of this type of rig. With a weight of around 34 t, the DM30 II is designed for multi-pass drilling holes in the 140–200 mm (5.5–7.9 in) range to depths of 8.5 m in standard configuration, or up to 44 m with a full carousel. Relatively light-weight, this type of machine provides rotary or DTH drilling capabilities for both soft rock and hard rock conditions.

The Pit Viper PV-235, by contrast, weighs twice as much, and has a much greater hole-depth capability as a result. While it can drill 12.2 m depth single-pass, with a pipe carousel it can reach depths of up to 73.2 m. Providing a bit load of 29.5 t in rotary drilling set-up, the PV-235 is designed to drill 171–270 mm (6.75–10 625 in) in hard, moderately abrasive rock conditions.

Where really large tonnages are required to be drilled and blasted on a regular basis, larger-diameter holes allow greater volumes of explosives to be charged, and this in turn demands even bigger drill rigs. The PV-351, with an all-up weight of around 180 t, is one such rig, and is designed for single-pass rotary drilling to depths of 19.8 m. Hole diameters cover the range 270–406 mm (10.625–16 in), with the machine exerting a maximum bit load of 56.7 t. As with other rigs offered by Epiroc, both diesel- and electric-powered versions of the rig are available, allowing operators to choose the most economical drive option for their specific mine circumstances.

Of course, there are situations – as in smaller open-pit operations or where blasting tonnage requirements are lower – where the use of a dedicated rotary drill rig would be difficult for a mining company to justify, since its capabilities would outstrip the actual need. In this case, a better solution might be to operate a fleet of two or three smaller DTH rigs, which would provide greater drilling flexibility at lower capital costs.

Options here might include the SmartROC CL or the SmartROC D65 from Epiroc's family, machines that provide an alternative approach in terms of both the drilling technology used and the hole size range covered. The SmartROC CL uses COPROD technology, combining a tophammer drill with rotary pipe, and having a hole diameter range capability of 115–216 mm (4.52–8.5 in). With a maximum hole depth of 42.5 m, this clearly aimed at maintaining high-efficiency drilling for smaller-tonnage operations, with the advantage that the COPROD system can work effectively in fractured and weathered rock where hole stability can be an issue. The use of a hydraulic drill also offers advantages over compressed air-powered DTH at high-altitude mine sites, since the machine's drilling performance is not affected by the thinner air. Meanwhile, the SmartROC D65 can handle 110–229 mm (4.3–9 in) holes, meaning that it effectively bridges the gap between smaller-capability machines that are aimed more at the quarrying industry, and the surface mining industry's rotary drills.

Presplit: The key to long-term stability

Presplit drilling is nothing new. It is widely used around the world and is generally accepted as the standard method of creating safe final pit slopes for open-pit mining. At the same time, however, many mines still fail to take advantage of the huge savings that can be gained by optimizing this operation by using modern presplitting technology.

Presplitting involves drilling a precisely angled row of closely spaced holes around the final pit wall perimeter. As the stability of the rock in an open-pit determines the slope angle, and stability can vary from area to area, the final pit wall slope can vary as well. This means that accurate presplit drilling demands a highly flexible rig that can drill inclined holes at precise angles and is not restricted to the fixed angle capabilities offered by larger rotary production drilling machines.

Although widely used for presplit drilling, rotary rigs are oversized for this application, which makes them difficult to position accurately. They are also less flexible in terms of their angled hole capabilities than smaller rigs, and drill bigger diameter holes than are needed for presplitting. This in turn means that these holes are overcharged, leading to the potential for the damage to the pit wall that presplit blasting is designed to avoid.

For this application, Epiroc's FlexiROC and SmartROC drill rigs in the D60-D65 family offer the versatility needed. Benefits offered by this type of DTH rig include their ability to drill straight, parallel holes, their maneuverability, and their capabilities in terms of hole depths and diameters – and hence accurate hole charging. These rigs can also be positioned automatically using GPS/GNSS navigation, resulting in improved hole accuracy in the short-term, and better long-term stability for the pit wall.

Examples of mines that currently use Epiroc rigs specifically for presplitting include Codelco's Chuquicamata in Chile and Boliden's Aitik in Sweden. At Chuquicamata, a contractor uses a fleet of 20 rigs to handle a presplit drilling requirement of some 100 000 m a month, while at Aitik, presplitting uses 165 mm-diameter holes drilled at a 20° angle on 33 m-height double benches. The holes here are spaced 1.8 m apart and are fired just ahead of the blastholes, cracking along the line of the final pit wall and cushioning it from the impact of the main blast. The outcome: presplit holes that are perfectly straight and parallel, slopes that are close to the planned angle of the final pit wall, and benches that are smooth and stable.

Quarrying rock for aggregates

The concept of quarrying has been around since the dawn of civilization, with many different working techniques having been developed.

A quarry is typically defined as being a surface excavation for the production of rock as the principal product. As such, it differs from an open cast, open-cut, surface or open-pit mine in that the rock itself is the valuable commodity, rather than a specific mineral within the rock mass.

Quarrying is used mainly in the production of construction and building materials, such as solid stone or crushed rock for aggregates, or for raw materials for processes such as cement manufacture. As a technique, quarrying is normally only used where raw materials of adequate quality and size cannot be obtained economically by other means. Since natural sand and gravel are not always readily available, for example, a large proportion of the world's annual output of aggregates is produced by quarrying and processing rock.

Historical quarrying techniques

Rock has been quarried for the construction of buildings and monuments since before recorded history. There is certainly evidence for stone production in ancient times from numerous sites around the world, although it is unclear at which stage formal quarries began to emerge, rather than people just making use of naturally occurring boulders.

Within recorded history, we have a better understanding of some of the techniques used in quarry operations. In the Egyptian dynastic period, for instance, construction of the earlier pyramids depended mainly on limestone that was quarried using copper hand tools, while later pyramids, although built mainly of mud brick, still used quarried stone for facing. Granite was also a major building material, especially for detail work, and was quarried directly from the bedrock at locations close to some of the country's largest monuments. Ancient Egyptian stoneworkers cut trenches all the way around the blocks of granite that they wished to extract, isolating them from the bedrock, with the rock then being broken free using massive wooden levers.

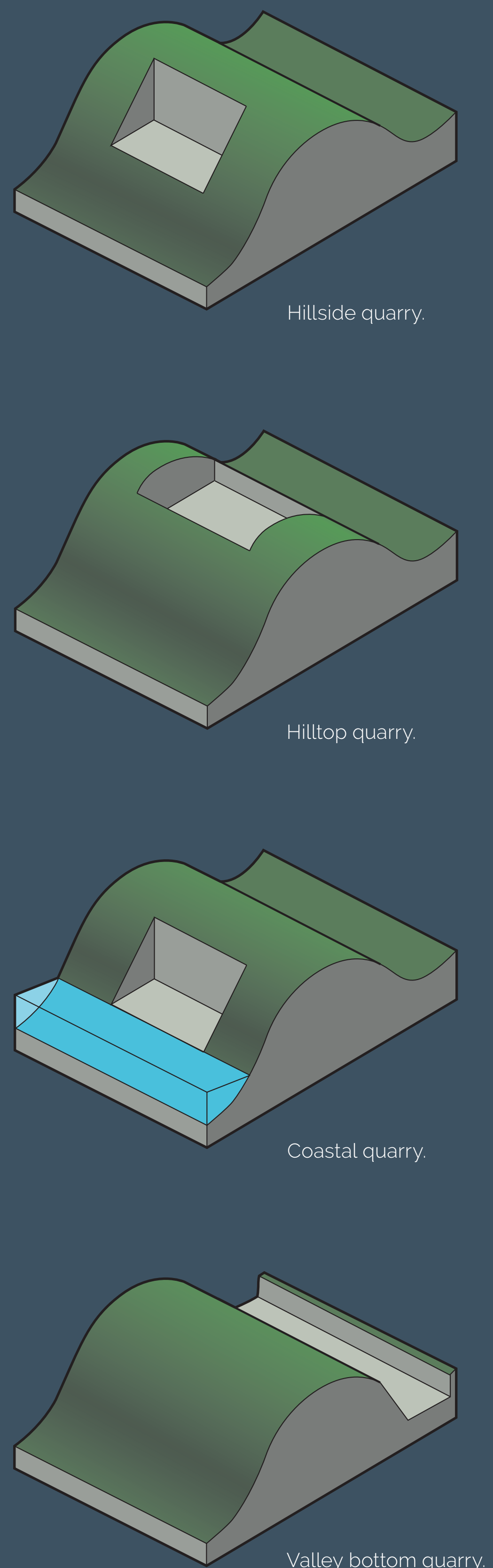


Figure 1: Secure and sustainable final slopes for aggregate quarries. Source: MIRO, UK (2004).

The Romans also quarried rock on a vast scale for their construction projects, both for buildings and monuments. A wider range of rock types was produced, including fine marble, which was used for artwork such as sculptures and in public architecture. The Romans used quarry hammers to isolate the blocks they wanted, then used metal wedges to pry them free from the bedrock.

In the absence of modern technology such as drills and explosives, rock-splitting required the use of other approaches, such as wedging or fire setting. The use of wetted wooden wedges inserted in natural cracks or in shallow holes, with the swelling of the wood causing the rock to split, dates back to ancient times, as does fire-setting. Producing the stone needed for the construction of Great Zimbabwe, for example, is believed to have relied on fire-setting to split building blocks from natural granite outcrops, making use of the observation that the local rock weathers naturally along planes of weakness that could be exploited in this way.

Modern quarrying techniques

Development of most modern rock quarries involves stripping the overlying soil and weathered rock to get to the hard rock underneath. This is then worked in a 'bench' system, removing the rock in layers that can be returned to year after year as the quarry is developed. The quarry becomes deeper with each subsequent bench, with stepped benches reaching up to the original surface.

With few exceptions, modern quarries rely on drilling and blasting to fragment the rock, which is then loaded onto off-highway trucks or belt conveyors for transport to a processing plant of some sort. Loading is usually done with wheel loaders or excavators, which combine adequate loading capacity with maneuverability. This allows them to move from area to area within the quarry, as needed. Where blasting results in the formation of large boulders that are too big for the loading equipment to handle, secondary breaking will be needed, either by drilling and blasting individual boulders or by using excavator-mounted hydraulic hammers to break them.

The exceptions to drill-and-blast include the production of dimension stone, where the demand is for large pieces of rock rather than fragmented material for further processing. The production of dimension stone, which is covered in a separate chapter in this book, involves carefully splitting large blocks of raw stone away from the quarry face, using wedges or diamond-impregnated wire saws. Another exception is where the rock is soft enough to be ripped, using a large dozer or a ripper tine mounted on a hydraulic excavator, with the dozer then being used to push the broken rock onto a hopper or mobile crusher which feeds a belt conveyor system.

Quarry design depends on a number of factors including the pre-existing topography, intended output, infrastructure and

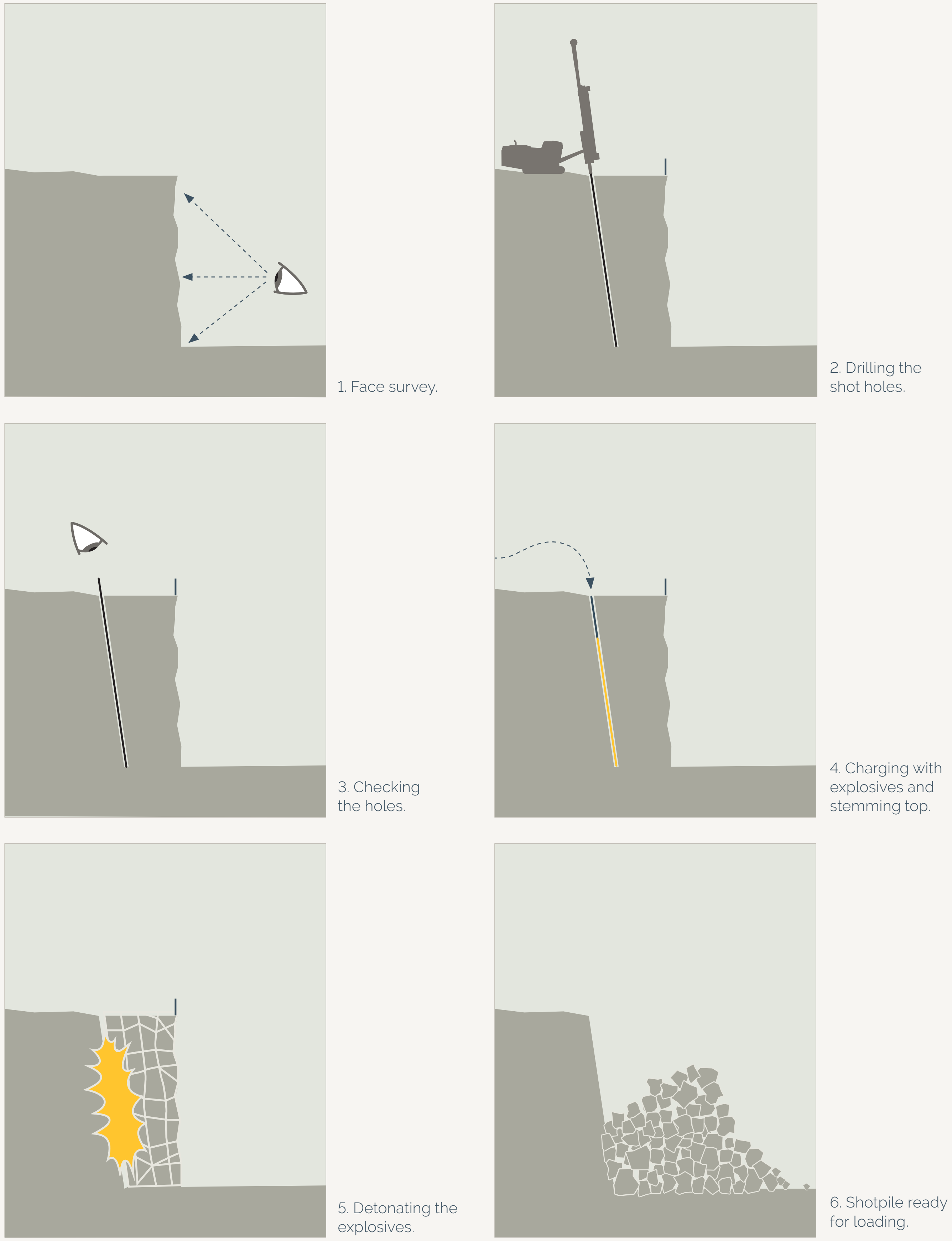


Figure 2: Stages in the drilling and blasting sequence for quarry operations.

Quarrying rock for aggregates

environmental footprint. In general, however, quarries can be grouped into five principal types – hillside, hilltop, valley bottom, coastal and combined – as illustrated in Figure 1.

Bench blasting is the most widely used method of production blasting in quarrying, strip mining and construction excavation. This involves drilling inclined, vertical or horizontal blastholes in single- or multiple-row patterns to depths ranging from a few meters to 30 m or more, depending on the desired bench height. Where the excavation is shallow, less than 6 m (19.7 feet), one level may suffice. In deep excavations, a series of low benches, offset from level to level, are recommended for operational convenience. The bench height is often two-to-five-times the burden distance, while the ratio between the burden and the spacing is typically between 1:1.25 and 1:2.

The material must have a certain strength and hardness, and the crushed particles must acquire a defined shape, quite often with a rough surface. Consequently, soft sedimentary rocks and material that breaks into flat, flaky pieces are often unacceptable as raw materials for aggregate. On the other hand, igneous rocks such as granite and basalt, as well as highly metamorphosed rocks such as gneiss, are well-suited to aggregate production.

The importance of drilling in quarries

Since drilling is a critical part of the quarry production process, the best planning, figuring, calculations and explosives are worthless if the area to be blasted is not drilled properly and responsibly. Basically, if the drilling goes bad and is off pattern, the entire blasting operation will fail. Drilling in any surface mining or quarrying environment invariably follows a pattern that has been designed to take into account natural parameters of the rock including hardness and strength, the presence of planes of weakness such as faults or fracturing, and the degree of fragmentation needed in the blasted product.

The drill pattern will be designed according to hole spacing (along the bench) and burden (distance from the front free face) for a given hole diameter, and thus stipulate the amount of explosives needed for each charged hole. Generally, a less powerful drill rig that produces small diameter holes will have to drill on a closer pattern than a machine driving a larger-diameter bit. Drilling is normally done using heavy-duty Down-The-Hole (DTH) and tophammer drill rigs. In Epiroc's case, these rigs can be equipped with the Hole Navigation System (HNS) which gives operators the ability to drill parallel holes with precision and complete drill plan accuracy.

The drilling and blasting sequence is shown schematically in Figure 2. If the drill rig operator is instructed to remain on a specific pattern, he must do so and not alter it unless authorized. The operator must also keep the blaster-in-charge informed of any changes in the rock while drilled, or indeed any mistakes, so that the blaster can make any necessary adjustments to the charge.

The drill rig operator should tell the blaster about fractures or other abnormalities in the rock, changes in the strata and sand or mud seams in the rock, so that explosives can be loaded in the hole with these factors taken into consideration. The operator must also inform the blaster-in-charge of any 'short' holes – holes that are not drilled to the expected or planned depth. In other words, the driller is the blaster's eyes on the ground and, as such, can make or break a blasting operation. This information can also be extracted from the quality log available on SmartROC drill rigs.

Quarry operators commonly design fragmentation blasts for safety, economy, ease of use at the primary crusher, and even public relations, but they often forget about quality. The blast layout must be properly engineered, documented and adhered to for maximum consistency. Varying the blast pattern may mean changes in the product size across the operation. Smaller shot rock, resulting in less crushing at the secondary and tertiary stages, may mean less improvement through crushing, so the mineral quality and/or physical properties of the product may be affected. Conversely, it is important to remember that size-reduction through crushing becomes more expensive as the material being crushed gets smaller, so in some respects it can be beneficial to reduce the crushing duty by increasing the initial fragmentation at the quarry face. There is also the question of transport, since loaders, trucks and belt conveyors will have a maximum rock-size constraint, above which boulders will need expensive secondary breaking.

The importance of crushing and screening

Processing begins after the raw rock has been extracted from the quarry or pit. Many of the processing steps, are common to recycled materials, clay, and other manufactured aggregates, as well as to quarried rock.

The first stage in most operations is reduction and sizing by crushing. Some operations, however, include an initial scalping step prior to primary crushing, to remove material that would be too large for the crusher to handle. Fines may also be screened out, so as to improve the quality of the crusher feed and reduce the tonnage passing through the crusher. Crushing can be done in three or four stages, from primary to tertiary or quaternary, with different crusher designs often being used for the primary (jaw or gyratory crushing) and later (cone or impact crushing) stages. Crushed rock, or product, is usually transported through the process line on belt conveyors, with the crushers being used in conjunction with sequential screening that segregates over- and undersize material at each stage. Screening is also used to separate out the final products, either as single-sized fractions or in defined size ranges depending on the intended end use.

The crushing and screening processes are adapted to give the desired shape and size fractions to the end-product. Cubic-shaped particles are specified for asphalt, to give a stable road surface, whereas a spherical shape is preferred for concrete mixes, in order to save on cement and to help

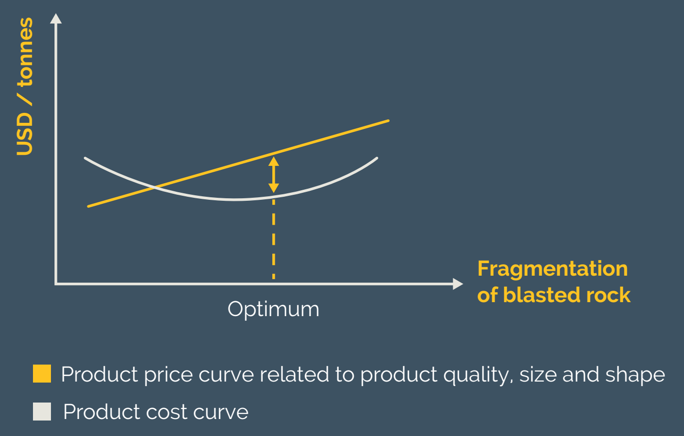


Figure 3: Operational targets for a typical aggregates producer.

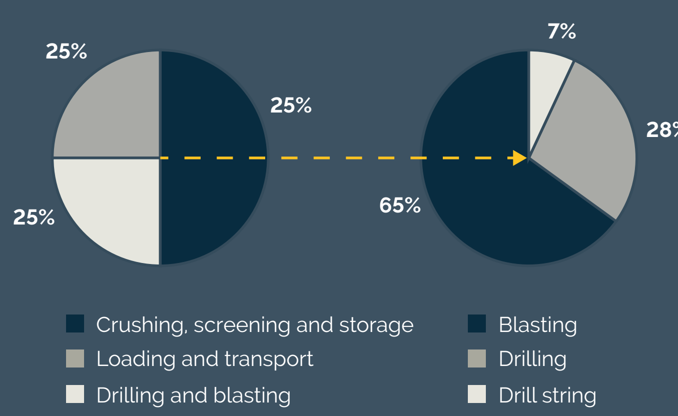


Figure 4: Operational cost distribution at quarries.

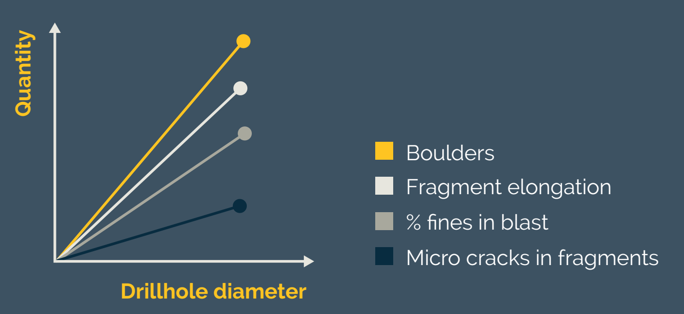
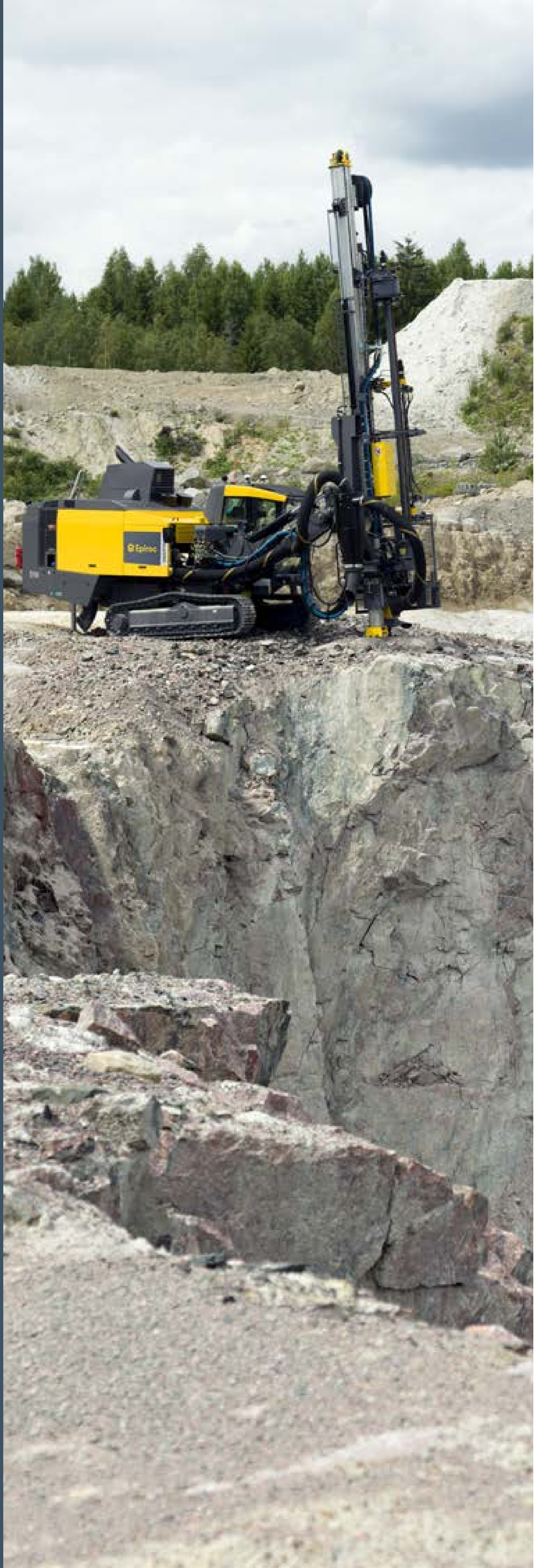


Figure 5: Effect of drill-hole diameter on fragmentation parameters.



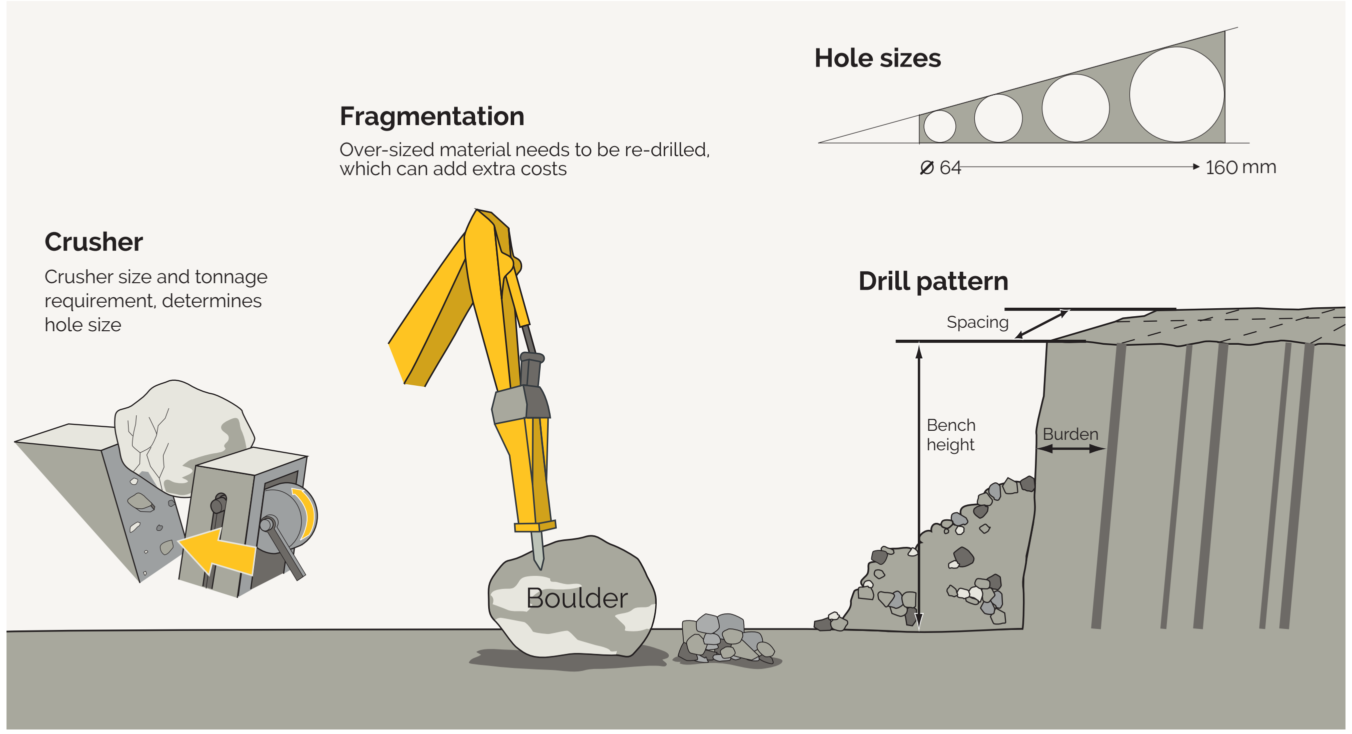


Figure 6: Fragmentation in quarries, hole size and blasting techniques determine other parameters.

the wet concrete flow better during pouring. Being crystalline, rock-forming minerals have the tendency to break into endless numbers of sizes and shapes every time they are subjected to crushing energy. The solution lies in the art of limiting the number of over- and under-sized particles produced during reduction. If this is not controlled, the mineral will follow its natural crystal behavior which normally results in the production of too high a proportion of fines.

Optimizing efficiency

There are various factors to be considered when trying to achieve optimum efficiency and overall economy from quarrying operations. The difference between product revenues and the costs of production must be maximized. Operational targets are shown in Figure 3. For aggregate quarries, the production of fines should be avoided as the finest fractions are of no value.

Figure 4 illustrates a typical cost distribution between drilling and blasting, loading and haulage, and crushing, including screening and storage. It should be noted that crushing, screening and storage represent almost half of the costs, whereas drilling represents less than 15%. More often than not, the crushing operation is a bottleneck in the overall work cycle. It is sometimes the case that extra expenditure in drilling and blasting might be the only way to assure free flow through the crusher and full capacity in the plant, which improves the operation's economics. Achieving an even fragmentation and the creation of smooth benches will also have a positive effect on loading and transport equipment. In the 1980s, a trend among rock producers shifted attention away from large-diameter holes, which produced more boulders and more fines, in favor of medium-size (89–165 mm; 3.5–6.5 in) holes (Figure 5). In addition, limiting the blast size reduces micro-cracking, and hence the production of fines. The opposite situation occurs in open-pit mining where the generation of fines is favorable, as these will pass through the mill with a minimum of costs.

Large crushing equipment enables boulders to pass through the primary crusher. However, large crushers are primarily designed to handle large volumes of rock material rather than large-size material. Therefore, it is worth assessing the rock fragmentation derived from the drilling and blasting cycle, in case some additional investment in drilling could be the answer (Figure 6). The entire chain of activities leading to the final production of crushed material must be considered when optimizing total costs. Drilling costs depend on the hole size and drilling density, in which drilling accuracy is a key factor.

Blasting costs depend on the amount and type of explosives, and the number and type of detonators. Loading, transport and crushing costs depend on the fragmentation achieved, and the state of the quarry floor. An uneven, rough floor will lead to higher maintenance costs for loading and haulage equipment and will result in longer cycle times as trucks will have to travel more slowly than on well-maintained haulage roads.

For most drilling applications, the optimum ratio between the bench height and the burden is in the range of 3 to 4, indicating that hole diameters of 125–165 mm (5–6 in) are best for a bench height of approximately 18 m.

Rock excavation in construction

Rock excavation has been a feature of the construction industry for centuries. Soil excavation predates it as a technique, but since the invention and widespread use of dynamite in the 19th century, rock excavation has been a major feature of the construction process.

Rock excavation is primarily used to prepare the foundations for structures that have to be very strong, such as skyscrapers, bridges and dams. However, rock excavation can also involve simply removing unwanted rock from an area, as well as taking in the extraction of any mineral deposits that occur on an excavation site.

Nonetheless, the most obvious – and visible – use of rock excavation is in the creation of new infrastructure, both above and below ground. A good example here was the construction of the transcontinental railway in the USA during the 19th century, which was built primarily to facilitate the easy movement of people and goods from one side of the country to the other. Since the line ran through the Rocky Mountains, as well as other rugged terrain, over considerable distances, its construction involved extensive rock excavation.

Rock excavation typically involves ripping, drill-and-blast or breaking and splitting, depending on the rock type, quality and quantity. Ripping can be used only where the rock is naturally soft, or is heavily fractured. The rock is split mechanically by dragging a heavy tine (steel point) through it, causing the rock to disintegrate along pre-existing planes of weakness.

The most common system uses single or multiple ripper tines mounted on the back of a bulldozer, which provides the weight and force needed to pull them through the rock. An alternative is to fit a ripper tine to a hydraulic excavator, in place of the bucket, although this can only be used in specific circumstances where the movement of the excavator boom and stick can prise the rock apart, perhaps along bedding planes.

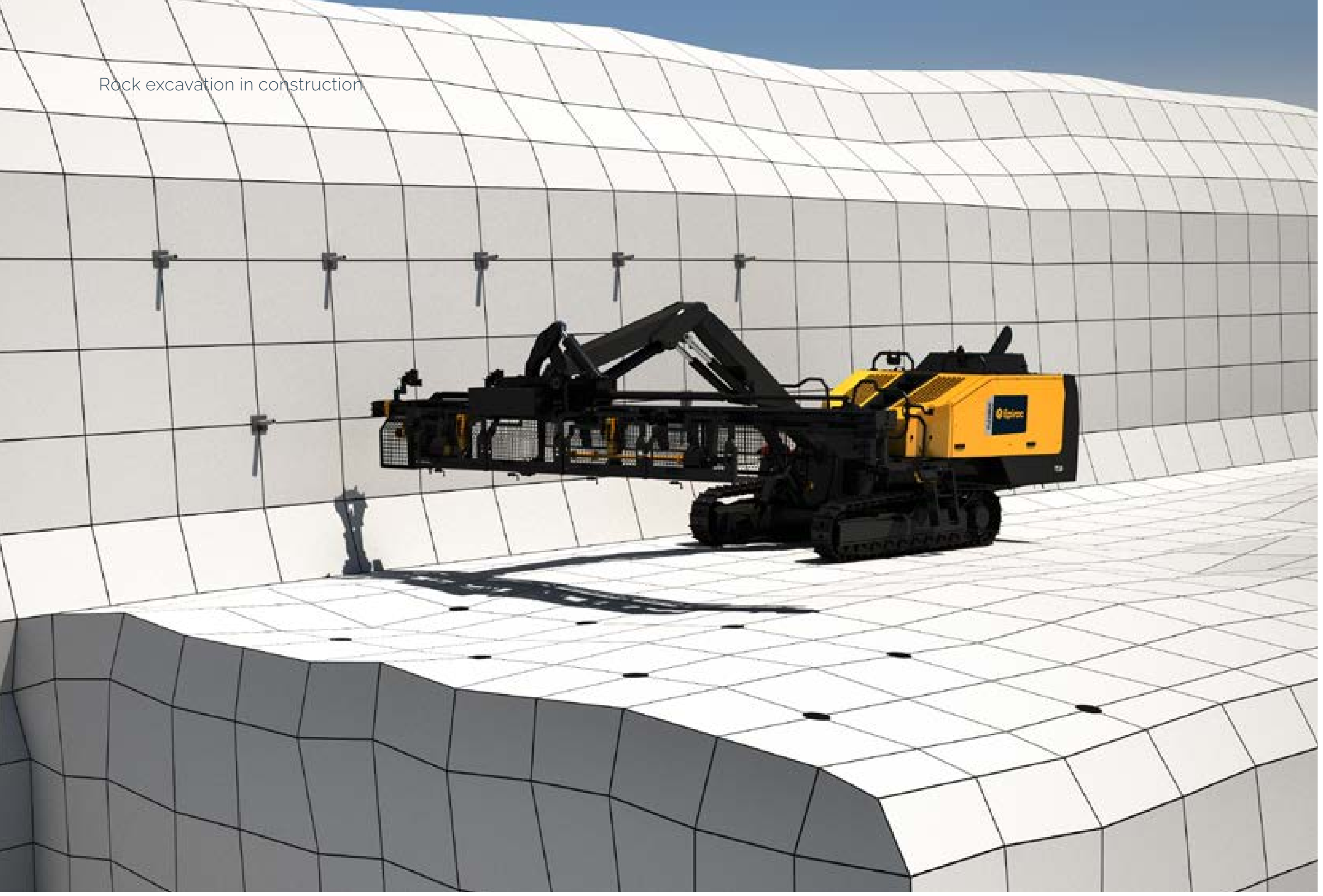


Figure 1: Slope stabilization using a surface drill rig.

Rock breaking with a hydraulic hammer is used when there is only a small volume of rock to be removed, or where blasting is not feasible because of the location or for environmental reasons. Epiroc's medium- and heavy-weight hammers are designed for mounting on an excavator for this purpose, with a range of machine sizes to suit the power and weight output requirements for the task.

Drilling and blasting is by far the most common rock excavation method. From the earliest days of blasting with black powder, there have been steady developments in explosives, detonating and delay techniques, and in our understanding of the mechanics of rock breakage by explosives. However, the topic of principal interest here is not the development of blasting technology, but rather the application of this technology to the excavation of rock, and the influence of excavation techniques on the stability of the rock that remains behind.

Accurate tendering

Before a new project is commenced, it is normal for design and pre-investigation work to be undertaken, coupled with the allocation of financing. Most civil engineering contracts are awarded through a tendering procedure, where scope of work, bill of quantities, drawings, geological information and time schedule are disclosed, to give all the interested parties standard information on which to base their bids.

The contractor, or a consortium of contractors, makes its bid after evaluating the equipment requirements, the work methods involved, the availability of skilled labor, the time schedule, and local conditions and regulations, to arrive at its cost estimates. Past experience, derived from similar projects, plays an important role in estimating future costs.

Rock excavation projects can involve a wide range of equipment, and careful selection is important in order to achieve overall optimum performance. There is also the potential for different types of machine to be better suited to specific parts of the work. Hence, for example, the variation and complexity of the work involved on a drilling project might require both heavy drill rigs and hand-held rock drills. Where possible, of course, equipment should be selected to cover a wide range of applications, since this will simplify spare parts and maintenance requirements and enable opportunities for using the machines in subsequent projects. Tophammer drill rigs are often the first choice for this type of work on account of their flexibility, versatility and ability to drill small diameter holes.

Road construction

Meeting special aesthetic criteria is often required for highway development projects that cross land with special scenic or recreational characteristics. However, the topographic setting of most highway projects means that

Radio Remote Controlled (RRC) drill rig FlexiROC T35 R in a construction application.

it is impossible to replicate exactly natural landforms in engineered rock cuts. Natural landforms almost always involve flatter slopes than can economically be designed for highway embankments, and even where the natural landscape is sufficiently rugged, the natural rock slopes are generally much more degraded than is desired for the sides of highway cuttings. In consequence, it is difficult to make cut slopes look 'natural'.

Road cuttings formed by blasting tend to be rougher than those formed by heavy ripping, unless controlled blasting techniques are used. The traditional method of forming highway embankments is to use smooth-blasting techniques, but this is often not allowed where natural-appearing slopes are required. Figure 1 shows a typical drilling and blasting pattern for a road cut where special emphasis is being placed on the final rock wall contour. Presplitting or smooth (trim) blasting are commonly used to obtain smooth and stable sides to the excavation, and are quite often specified in the tender documents. Contour holes are normally not larger than 64 mm in diameter, and charging is carried out using special, light explosive to minimize the effect of the shock waves. Presplit holes are fired simultaneously ahead of the other holes, whereas smooth blasting uses the longest detonator delay, after the main part of the blast has gone off. Roughened slopes can be produced using cushion (buffer) blasting, horizontal hole blasting or, for flatter slopes, step drilling. These techniques can be modified to qualify as controlled blasting.

The design of any blasting done for the creation of permanent slopes must take into account the role of the burden. The most important blast design parameter, burden is the 'work' done by any given blasthole, and represents the distance from the hole to the closest free face. Carefully balancing the burden with the strength of the rock mass that remains behind is the key to attaining stable slopes with minimum disturbance. The chief difference between the various methods of controlled blasting is the burden at the time the controlled holes are fired. Either presplit or trim blasting can be used where the aesthetic enhancements cater only to the long range perspective. Because these methods provide a high degree of slope angle control, they can be used effectively to achieve slope variation and slope warping. However, smooth-wall blasting techniques will not be suitable if machine scars and drill-hole traces (half-barrels) must be avoided.

Urban blasting

Drilling in urban environments presents a number of challenges, of which noise reduction is key. Blasting constraints include keeping ground vibration to a minimum, and preventing both air blast and flyrock. For this reason, drilling and blasting on urban sites is much more tightly

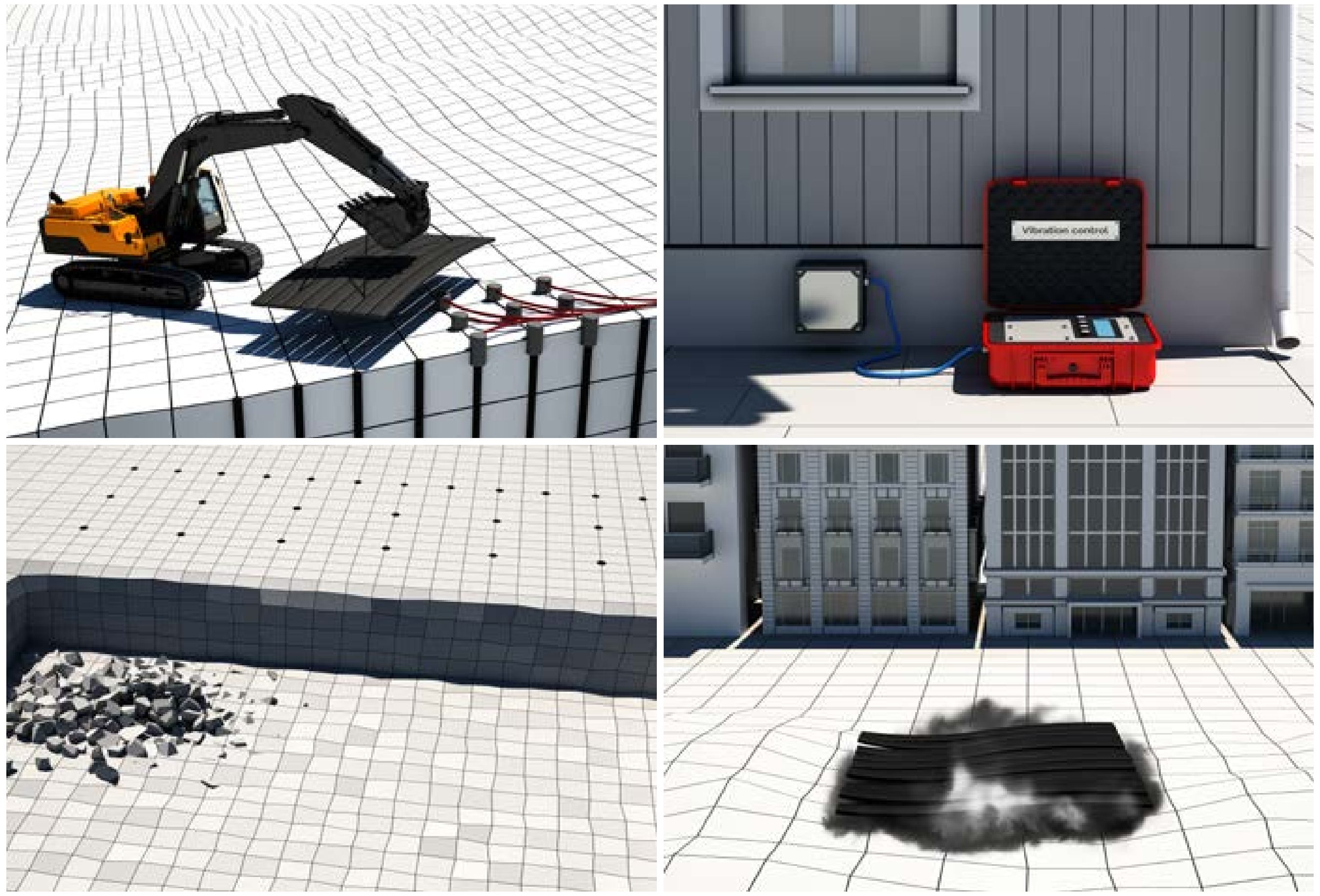


Figure 2: Precautions for drilling in urban areas.

controlled than elsewhere, with impact minimization becoming increasingly important. Indeed, in some situations, drilling and blasting is no longer an option, and in extreme conditions, technologies such as excavator-mounted rock cutters/diamond wire machines/ hydraulic hammers and splitters may be the only way to achieve the required excavation. There has been a growing trend for non-blast rock excavation in urban areas. In competent rock formations, the most common method is large size hydraulic splitters that are driven and attached to an excavator. A large number of drill holes are required in patterns from 0.2x0.2 m up to 0.8x08 m depending on hole size and power of the splitter device. To reduce the vibration from blasting the sensitive foundation or structure can be separated from the rock by a deep cut close to the structure. The cut is done by diamond wire machines such as SpeedCut 75 and SpeedCut 100.

The types of drill rigs favored by construction drilling contractors, typically tophammer drill rigs, are inherently noisier than for example a DTH rig. One reason for this is that the rock drill is mounted on the feed instead of Down-The-Hole. Nonetheless, the need for noise reduction on urban construction sites can be addressed by equipping the rig with a noise reduction kit, which Epiroc has been offering since 2005. An updated version, is available for use on rigs such as the SmartROC T35 and SmartROC T40, cutting the noise output from these machines from 127 dB(A) unsilenced to 115 dB(A), and making it possible to hold a conversation next to the operating drill rig. A more sophisticated Rig Control System (RCS) also play its part in cutting noise, with the engines on the current generation of rigs responding to second-by-second requirements, rather than running at full speed all the time.

Air blast is a particular phenomenon that is invariably caused by the detonation of unconfined – or inadequately confined – explosives. The resulting pressure wave is manifested as noise and in damage to surrounding properties; even low overpressure levels can break windows, while high energy waves can cause structural damage. Risk minimization is achieved by using careful blasting procedures, and by ensuring that all explosives are confined with an adequate amount of stemming or cover material in place before detonation (Figure 2).

Ground vibrations result from blasting, with the aim of a good blast design being to minimize the peak particle acceleration associated with the propagation of shock waves through the ground. It is quite common for specialized blasting consultants to be involved to assist the contractor with vibration control and the design of drill patterns, as well as to carry out a thorough survey of adjacent structures before the drilling and blasting can begin. The key to minimizing ground vibrations is to optimize the blasting sequence in terms of the amount of explosives being detonated at one time, through the use of a properly designed detonator delay program. In addition, the drill hole diameter should be kept as small as possible, normally in the range 30–50 mm. To eliminate the risk of fly rock, blasts can be covered with inert material such as sand, or by using heavy mats made of timber, rubber or tires, cut into sections and bound together with steel wire. Weighing around 1 tonne each, these mats absorb energy and prevent loose rock from being dispersed, while their structure allows the gases produced by the blast to flow through (Figure 2).

Trenching

Trenches are often excavated for the installation of gas, oil, water and sewage pipelines, as well as for power cables. Trench blasting is often defined as rounds with a width of less than 4 m, meaning that the width of the round can be considerably smaller than its length. By its nature, a trench blast is more constricted than a normal open-pit blast, so has a higher explosives consumption per cubic meter of blasted rock. The drill hole diameter used is normally smaller than in other construction or quarrying applications. This provides for better distribution of the explosive in the rock and avoids excessive overbreak outside the theoretical contour. As a rule of thumb, the hole diameter should be one-sixtieth of the width of the trench, so if the width is 2.0 m, a 33 mm hole diameter would be suitable. Two methods are used for trench blasting: traditional and smooth wall. In traditional trench blasting, the middle hole/holes are placed in front of the edge holes (Figures 3 and 4), and all the holes are charged with the same amount of explosives. In smooth wall trench blasting, all the holes in each row are in line, in (Figures 3 and 4). The middle hole or holes are quite heavily charged, while the edge holes have light charges.

Ports

Rock excavation in or around harbours is likely to be focused on one of two requirements: the production of heavy stone boulders for rip-rap or armoring for sea defences or breakwaters, and the excavation of material in order to deepen existing channels or remove potential underwater hazards to shipping. Stone used to clad breakwaters and other shoreline defences has to be quarried carefully, since both the size and shape of the resulting boulders are important.

The size is a governing factor in the durability of the structure, since waves are less likely to be able to move larger pieces of rock, while the shape is critical in terms of creating an interlocking 'fabric' of stone to protect the structure or shoreline. Individual pieces of armor stone typically weigh several tonnes, so require special handling equipment, both at the quarry and during emplacement.

In practice, it is often as difficult to produce large-sized rock as it is to produce small-size fragmentation. The greatest

Figure 3: Small diameter blasting in urban areas using 30–45 mm holes.

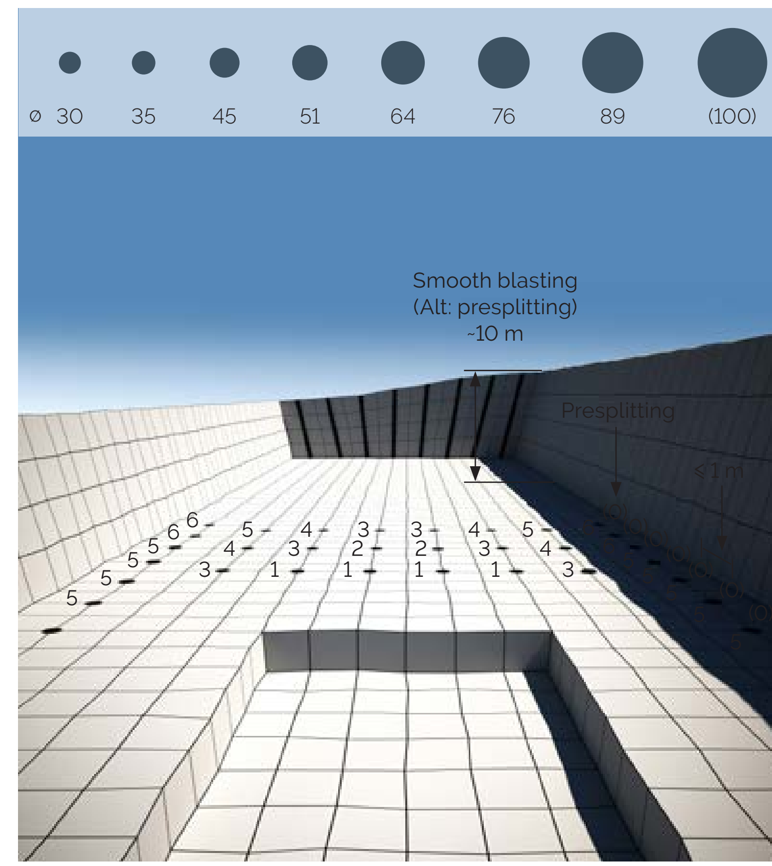


Figure 4: Trenching for pipelines outside urban areas using 51–89 mm holes.

The FlexiROC T35 in tramming mode.

obstacle is the geology, with homogeneous rock being preferred to rock that contains natural discontinuities such as fissures or fractures. In fact, the boulders used for armor stone are usually a by-product from normal quarrying operations, and represent oversize material that would otherwise need secondary breaking.

The specific charge should be low, 0.2 kg/m^3, being designed merely to loosen, but not to move, the rock. The charge must be well distributed within the drillholes, with a reasonable, smaller-than-normal, bottom charge. The spacing: burden ratio is between 0.5 and 1, and blasting is carried out one row at a time, without delays between the holes, so as to produce boulders that are within the required size range and size distribution.

Smaller than armor stone, rip-rap typically consists of boulders in the 10–90 kg size range that are used for shoreline protection or as in-fill within an armor stone facing. Rip-rap is more likely to consist of large stone from conventional quarrying, which may or may not have been run through a primary crusher. The deliberate production of rip-rap material requires careful fragmentation control, in order to reduce the proportions of both fines and oversize. The other aspect of rock excavation in relation to ports and harbors is where underwater obstacles need to be removed to allow free passage for ships. Over the years, there has been a trend to use larger and larger vessels within the sea freight business, with demands for deeper water at many ports. While dredging can remove unconsolidated material, such as sand and gravel, the only way to get rid of hard-rock outcrops is by drilling and blasting. Underwater rock excavation requires the use of special blasting techniques and equipment.

Traditionally, drilling is carried out from a supported or floating platform or barge, while divers may be the only option in deeper water. Where holes cannot be drilled into the rock to be removed, special shaped charges for crater blasting can be used.

The importance of accuracy

Productivity, and the need to control ground vibrations, mean that drillers need effective instrumentation for guidance. Hole orientation, deviation and depth errors must be minimized if production is to be optimized, together with the quality of the end result. Instrumentation for angle setting and hole-depth control increases the accuracy of drilling and reduces the potential for human error. Improved accuracy in setting out the drill pattern saves time, drill meters and explosives. The hole must be collared at the right location and maintain the correct alignment, as well as end at the predetermined depth – which may or may not make an allowance for sub-drilling below the required final level. Modern hole alignment instruments offer greater drilling precision, with automatic depth control and drill feed stop. This leads to less overdrilling, better fragmentation, and the formation of flat benches after blasting, all of which add up to lower drilling and blasting costs. In addition, ground vibration will be minimized, which is particularly important in urban areas.

Good reach and coverage area with the FlexiROC T15 R.

Alignment instrumentation can be used to confirm the hole angle, while laser sensors can monitor drilling to the proper depth, regardless of the surface conditions. More sophisticated instruments feature automatic compensation, regardless of the ground conditions where the rig is set up. In such a system, a tripod-mounted rotating laser beacon is used to generate a horizontal reference plane, with a sensor fitted to the rock drill cradle reacting to this and automatically adjusting the hole depths to match the plan, to an accuracy of within 50 mm.

Epiroc's surface drill rigs are designed for stability, featuring a rugged carrier with a flexible boom system. This, in turn, carries a rigid feed beam with double drill steel support, which simplifies accurate drill hole positioning. The use of the double drill steel support also allows the operator to raise the sliding support for better visibility while collaring. Meanwhile, the company's COPROD or TAC tube guide systems help to improve accuracy during drilling by reducing the potential for hole deviation.

Dimension stone: the new face of an ancient industry

Dimension stone is one of the most sustainable materials used in construction, cladding, paving and other applications. Dating back to the Moai statues on Easter Island, its popularity is now rising again and, with the right equipment, quarrying is more affordable than ever.

Over the last 20 years, the global production of dimension stone has grown rapidly, especially for building projects where architects are making increasing use of the wide variety of colors, textures and finishes that natural stone can offer. And, while the use of stone is growing, our ability to cut and process hard rock more efficiently has led to a vast increase in the types and colors of material being supplied to the market.

In addition to its use in construction, dimension stone is also needed for monumental masonry, as the raw material for sculpture, monuments and tombstones. Today, seven countries – China, India, Turkey, Iran, Italy, Brazil and Spain – account for around two-thirds of the world's output of dimension stone. In general, there is a trend towards using stone whenever this is economically possible, in effect marking a return to traditional practices.

As a consequence of this rising demand, there is definitely an opportunity to develop and expand the dimension stone industry (DSI) worldwide. While the prospects are looking favorable, development of the DSI will often depend on local factors such as location, quality and suitability of stone deposits, and the availability of funding to develop or expand appropriately sized quarries, as well as logistical issues such as the provision of adequate transport infrastructure to link stone producers with customers.

The scale of dimension stone production has increased dramatically, with the industry becoming much more capital intensive while production costs have

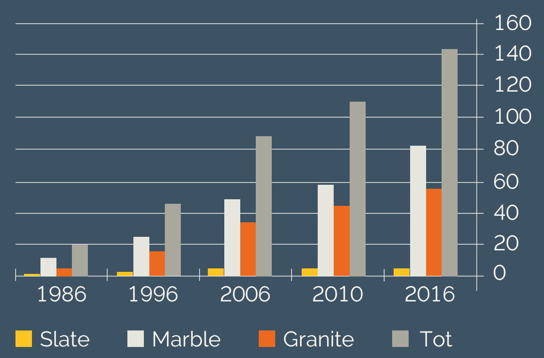
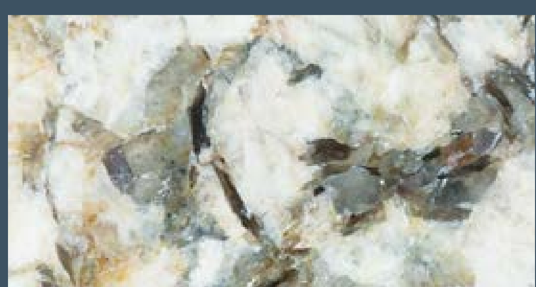


Figure 1: World Production Stone (Raw material) - Millions of tons. Source: Directory 2018 – Confindustria Marmomacchine.

Granite.

Sandstone.



Marble.

Slate.

fallen. Ten years ago, for example, a large factory would produce perhaps 10 000 m² per month of finished stone, with relatively few plants in the world capable of achieving this. Today, by contrast, there are several plants worldwide that have a capacity of over 80 000 m² per month (Figure 1).

What is dimension stone?

Dimension stone is the name given to natural rock that has been quarried and shaped to certain dimensions or specifications for use in building and construction, and in the production of sculpture, monuments and memorials. In essence, the term refers to any stone that is capable of being quarried in large blocks and subsequently processed into slabs, blocks, tiles or flagstones. In practice, there is a somewhat grey area between classical dimension stone, which is largely ornamental in use, and sized natural construction materials, where the physical characteristics of rocks are used to produce regularly shaped building stone.

From a historical perspective, dimension stone production and use goes back a long time with, for instance, Mesolithic and Neolithic monuments in Europe, the Middle East and elsewhere clearly having been built using shaped stone. Classical Greek and Roman architecture features high levels of skill in dimension stone use. For example, the Romans discovered and exploited the world's only known source of purple porphyry rock for use in decorative columns for their Temple of Jupiter. This task involved quarrying the stone in column-sized pieces in the Red Sea Hills of eastern Egypt, then transporting them over land and sea to Rome. Elements of the Great Pyramid were also sourced from great distances before being hewn to precise dimensions, while other examples of high-quality stone masonry can be found on every continent.

The most commonly used commercial stones today include marble, granite, slate and sandstone, all of which can be found in a vast array of visual and physical properties. This is by no means an exhaustive list, however, with rocks such as limestone, basalt, gabbro, travertine and tufa also widely used where their properties are suitable. Volcanic in origin, tufa is essentially a very soft rock, but is easy to work with. Examples of its use range from a construction and cladding material on many buildings in Armenia to the giant moai statues of Easter Island. The main qualities of dimension stone that determine its popularity and use include its color, patterns and texture, its durability and the consistency of supply. Different markets demand different quality characteristics.

Rock characteristics

This section provides a brief overview of the key features of some of the principal rock types that are suitable for use in dimension stone applications. It is important to remember that within each rock type, there can be wide variations in both physical and aesthetic characteristics, providing end users with a vast array of materials from which to choose. On the other hand, users may also be constrained by the

SpeedROC 1F in a block dressing operation.

non-availability of specific rock types within economic transport distances, meaning that in practice the selection range for a particular application may be quite limited.

Granite

One of the most common igneous (intrusive) rocks, granite consists primarily of crystalline quartz, feldspar and mica in varying proportions. Within the DSI, the term 'granite' is used to cover a huge range of granitoid rocks, including true granites as well as materials such as syenite, norite and gabbro, and gneiss, which is metamorphic rather than igneous but exhibits similar coarse graining. In essence, these are typically coarse crystalline rocks, free from impurities, that can be cut and polished. Granitic rocks are characteristically hard and resistant to erosion, although advanced weathering can alter the feldspar component to much softer kaolin (clay), which would make the rock crumbly and unsuitable for dimension stone use. Various types of granite have been excavated for their dimension-stone properties since ancient times, with the stone's durability and its ability to take high polishing key features of its attractiveness.

Sandstone and quartzite

Both sandstone and quartzite consist mainly of fine quartz grains that are cemented together either by silica or some other material. Sedimentary in origin, sandstone represents bonded detrital material, typically of beach sand or desert sand origin, whereas quartzite may be either sedimentary or metamorphic, with remobilization of the silica in an earlier sandstone having produced a harder, more durable rock. Another key difference is that quartzite is less porous and is easier to polish than sandstone. Natural bedding means that some sandstones (and indeed, some limestones) can be split relatively easily to produce thin sheets or slabs that can be used in applications as diverse as building cladding and paving stones for pavements, public areas and domestic flooring. The generic term 'flagstone' is often used for stone used for paving.

Marble, travertine and limestone

Usually formed through metamorphic activity on earlier limestone, marble is typically crystalline, often massively so, and can take a high polish. The principal components are calcite and dolomite, in varying proportions. While some marbles, especially those prized for monumental work, are pure white, others exhibit a wide range of colors, depending on the mineral constituents, degree of metamorphism and other factors.

In practice, the term 'marble' is often used to denote any limestone-based material that can be polished. Travertine, by contrast, is a material derived from the deposition of calcium carbonate from ground or surface water. The material can exhibit a wide range of banding and other patterning that makes it particularly suitable for ornamental floor and wall tiles, especially where it is hard enough to be honed. However, travertine can also be very porous, with individual slabs or tiles requiring filling before honing in order to produce an acceptable surface.

While many types of limestone are fundamentally unsuitable for use in the DSI on account of their poor physical

The SpeedROC 3F with three feeds and a protective guard.

characteristics, others such as Portland Stone, are keenly sought for their aesthetic appearance in architectural design. In an historical context, limestone slabs have also been widely used to clad poorer-quality building materials, although it has proved to have limited resistance to atmospheric pollution, with increased acidity resulting in unsightly erosion of the stone facing.

Slate

A fine-grained, laminar metamorphic rock derived from shale, slate has the major advantage of having natural cleavage that allows blocks to be split easily and predictably into thin sheets. For this reason, it is used extensively as a roofing material. Other applications include landscaping, as decorative stone, and in monumental masonry where flat surfaces are needed.

Typically hard and durable, slate resists moisture penetration through the rock mass, although water ingress along the laminations can result in exfoliation and weathering. The color is usually grey or black, although green, brown and red varieties are produced locally. When split, slate retains a natural appearance while remaining relatively flat and easily stackable.

Dimension stone production

Dimension stone is quarried by cutting, or separating by some other means, large blocks of stone from the natural rock mass. The size of individual block produced depends on a number of factors, including the homogeneity of the rock itself, the ability of the quarry operator to handle the rough stone, and the required end use for the stone once it has been shaped. A typical block size might be in the order of 6 m^3 (200 ft^3), which would relate to a block weight of 10–18 t, depending on the density.

The way an individual quarry is operated can vary enormously. The physical characteristics of the rock mass (how homogeneous it is, and whether there are defined lines of weakness such as regular fracturing or lamination), the size of both the resource and the market for its products, and the financial resources of the operator, all play a role in deciding the quarry design and capacity. In a large-scale operation, the first stage in production is to loosen individual blocks that may contain thousands of cubic meters of material, from quarry benches 10 m or more in height. Conversely, a small-scale quarry may have a very limited output, produce raw blocks weighing 5–10 t, and have a lower bench height that is suited to available production technology.

The overall concept is the same, however: to produce raw blocks that can then be processed into a higher-value product. Looked at in this way, the raw block is a valuable asset in its own right, and has to be handled carefully – small, irregular fragmented blocks are less marketable than large ones. As a result, high-value blocks are treated gently. For example, some operators use a 'pillow' of soil or sand

to support newly loosened raw stone blocks while they are being handled in the quarry.

For harder material such as granite or other intrusive rocks, blocks are usually split away from the quarry face by drilling a line of closely spaced, accurately aligned holes, then inserting wedges and shims (sometimes called plugs and feathers) into them. Driving the wedges into the holes sequentially causes the rock to crack along the line of the holes, thus allowing the block to be pried free. Softer rock, such as marble, can be cut with diamond-impregnated wire saws, while blocks of soft (but not crystalline) limestone are often cut out using mechanical saws. Large volumes of materials like slate can be loosened by the careful use of low-energy explosives such as black powder, placed in pre-drilled holes along a quarry bench.

The aim here, of course, is to loosen the raw stone sufficiently without fragmenting it, which would render it useless for roofing-slate or monument manufacture. Small amounts of explosives can also be used to free blocks of harder material from the quarry bench floor. The stone blocks are moved from the quarry to the processing plant using large frontend loaders and flatbed trucks. The rough blocks can then be stored at the quarry as inventory or taken immediately for processing at a fabrication plant; these are often integrated with the quarrying operation, or are located nearby to reduce transport costs (Figure 2).

Raw blocks are put through a series of processing steps, depending upon the end product required. This usually involves the use of wet cutting into precisely dimensioned blocks or thin slabs with diamond-impregnated wires or circular saws, followed – if required – by polishing or honing. The thickness of individual slabs again depends on the end use, with architectural cladding or commercial paving demanding a thicker section than, for instance, material destined for use as domestic interior floor or wall tiling.

Individual quarries are often quite small operations that supply local demand. In addition, dimension stone companies sometimes have several quarries for different stone types or colors that operate intermittently, depending upon the demand for a particular stone. Unusable stone rubble is crushed and sold as construction aggregate.

Technical aspects

Over recent years, there has been marked improvement and consolidation in the technology available to the DSI, which has provided a firm foundation for the above-average growth seen within the industry around the world. There has been a consistent advance in technology across all of the stages in the dimension stone production process, from quarrying the raw stone to achieving closer and closer product tolerances, with increasing standardization of the operating procedures involved. Overall, there has been a general trend towards investment in systems that can optimize productivity and improve product quality, with

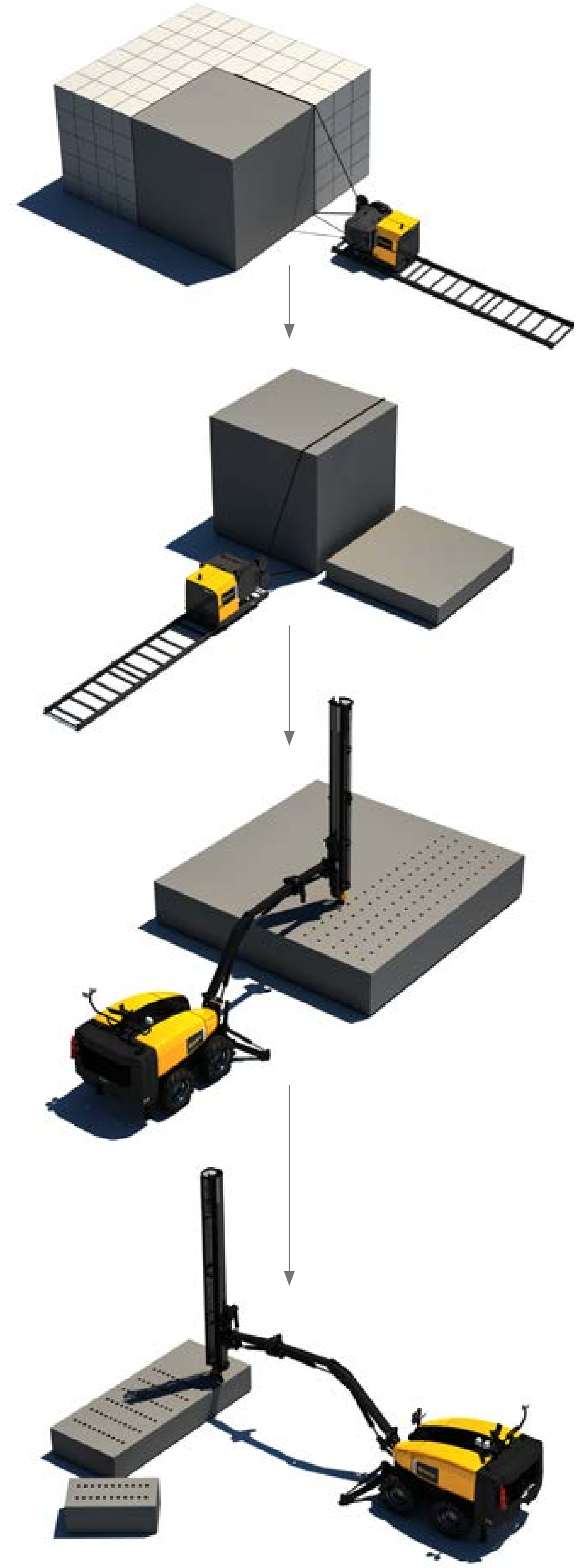


Figure 2: Dimension stone quarrying process.

The SpeedROC D30 drilling a pilot hole for diamond wire cutting.

dimension stone producers looking for new, economically viable technical solutions. For example, the use of explosives in dimension-stone production is now very limited, even in developing countries. The main exception here is in the very early stages of quarry development when the initial bench layout is being established. Instead, operators have a range of technology investment options, including multiple hole drilling using large mobile rigs, the growing use of diamond wire cutting technology, and the use of waterjet cutting.

The widespread introduction of multiwire cutting machines has reduced the amount of intermediate work needed within the quarry, while allowing the sizing of the rough stone to be programed to meet processing requirements for orders coming in. The main trend in the cutting stage has been to program work that can be standardized in a continuous process.

Equipment-selection criteria

Flexibility and drilling precision are key factors in selecting appropriate equipment for producing DSI raw materials. The need for flexibility results from typical DSI quarrying practice, with individual blocks being selected on the basis of their suitability for the intended end use, and the probability that the block will remain intact while being won from the quarry face. As a result, drilling equipment has to be very mobile and maneuverable, while at the same time providing the level of drilling accuracy needed in terms of hole straightness, alignment and parallelism to produce accurate break-lines for high quality block production. Hole diameters used for DSI drilling are typically less than 45 mm, given that the purpose of the holes is to provide a line of weakness within the rock mass for splitting, rather than to hold explosives, as in conventional quarrying.

However, holes also need to be closely spaced, so that crack propagation between them is enhanced once the wedging process begins. In addition, hole deviation must be minimized in order to achieve as clean a break as possible. This in turn places constraints on the depth of hole that can be achieved with one-pass drilling at small diameters, with the use of extension drill steel more likely to result in increasing deviation with depth unless strict control systems are in place.

Depending on the intended end use for the raw block, it is perfectly feasible to use conventional drill rigs, such as Epiroc's FlexiROC T15 R hydraulic rig, which has a single boom and provides a high level of maneuverability both for the machine itself and for positioning the boom. Its application is somewhat limited, of course, since it can only drill one hole at a time, and the boom and feed inclination have to be reset accurately for each hole in sequence. The next step in providing an answer to this type of problem is to progress to the custom-designed, specialist DSI drill systems

The SpeedCut 100 with a wire speed of up to 45 m/s.

that make up Epiroc's range, such as the SpeedROC 1F. Similarly equipped with a single boom, and also completely self-contained, this differs from the more general purpose FlexiROC T15 R in that its boom carries a guide frame that allows sideways movement of the tophammer drill feed. Because of this, the machine can drill a 3.5 m long series of holes from one set-up on the bench, reducing down-time and ensuring drilling accuracy to hole depths of up to 2.4 m in one pass, or 9 m using extension rods.

Being able to drill for longer during a shift means higher productivity, of course, with the SpeedROC 1F capable of drilling up to 400 linear meters a day. Achieving yet higher productivity still requires the use of more than one drill feed on a rig, as found on Epiroc's SpeedROC 2F and SpeedROC 3F. A larger machine than the SpeedROC 1F, this carries two and three separate hydraulic rock drill feeds on its 4 m wide guide frame, giving the potential for drilling up to 1 000 linear meters a day. Single-pass hole drilling of up to 4 m is possible, while its maximum hole depth reach is again 9 m. The extending boom allows the drilling of parallel rows of holes along a bench from a single set-up, with the rig having a maximum surface coverage of nearly 260 m^2 without being moved. The hole depth needed in any particular applications depends on the size of block being won, and there are circumstances where drilling and splitting is simply not achievable, either because the block would be too big, or the rock is not competent enough to withstand the forces imposed during splitting. In this case, and assuming that the rock is not too hard or abrasive, sawing using diamond impregnated wire can be a solution.

Epiroc's SpeedCut system provides an example of what can be achieved using this type of technology. Mounted on its own 3 m long toothed track to allow for adjustment backwards and forwards, the system can handle wire speeds of up to 45 m/s and can cut up to 800 m^2/d in suitable rocks types. Load cells control the pressure being applied by the wire as it cuts through the rock, and adjust the wire tension accordingly, while the system can be used to make both vertical and horizontal cuts for winning complete blocks from a quarry bench.

The SpeedCut, SpeedROC 1F, SpeedROC 2F, SpeedROC 2FA and SpeedROC 3F can also be used for secondary work on blocks that have been extracted from a bench, either by drilling rows of holes across the block or by cutting through it again. In each case, the aim is to maximize the yield from a block while minimizing the amount of waste generated, with small-diameter holes and thin wires going a long way to achieving this.

More about our DSI equipment

Product naming structure

The Epiroc portolio of surface drill rigs is extensive. For better understanding of the products we have differentiated them according to their sophistication level - SmartROC, FlexiROC, PowerROC and AirROC.

The majority of our products are surface drill rigs. Spanning from the smallest AirROC to the largest SmartROC there are many drill rigs and many variations of these. To differentiate the products we have divided them into families according to their level of sophistication. The product families are: AirROC, PowerROC, FlexiROC and SmartROC. This is, however, not enough to make a comprehensive differentiation since many products within the families have similar characteristics.

The naming structure is built up in a logical way, with the aim to simplify the understanding of the products. There are several products with similar, basic technical specifications, such as drilling method, hole range, installed power and flushing capacity in order to operate effectively in their respective applications. There are also various control systems to meet the basic requirements for different levels of sophistication.

The naming structure follows a system where T, D and C represent the drilling methods tophammer, Down-The-Hole and COPROD. The number that follows indicates the optimal nominal hole size of the drill rig. For example; FlexiROC T30 has an optimal hole size of 3 inch since 30 equals 3.0 inch, 25 equals 2.5 inch and so on. It is important to understand that the drill rigs can perform very well even outside of the stated optimal hole size. In some cases there will also be a complementary code to end the product name. For example; if the drill rig is radio remote controlled and has no cabin, there will be an R at the end, like for the product FlexiROC T30 R. (Figure 1)

The four different categories; AirROC, PowerROC, FlexiROC and SmartROC clarifies the different characteristics of each product, as well as better define the segment and applications for which they are intended. The dimension stone industry drill rigs follow a similar naming structure. These drill rigs are named SpeedROC 1F, 2F, 2FA and 3F. Here, the model part of the product name states the number of feeds. For example, the SpeedROC 2F has two feeds and SpeedROC 2FA is sold as an attachment, which is indicated by the A.

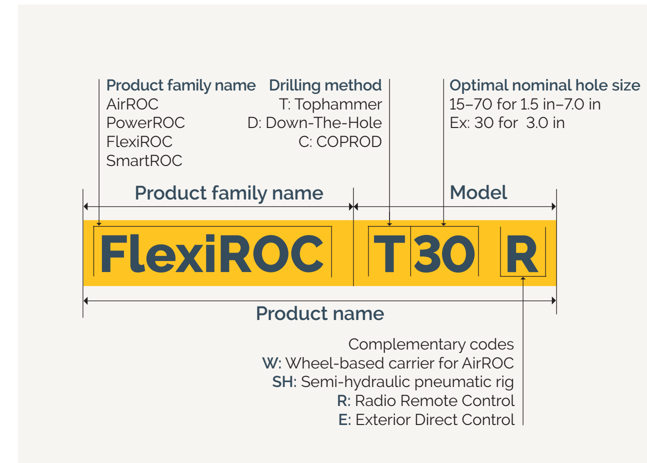
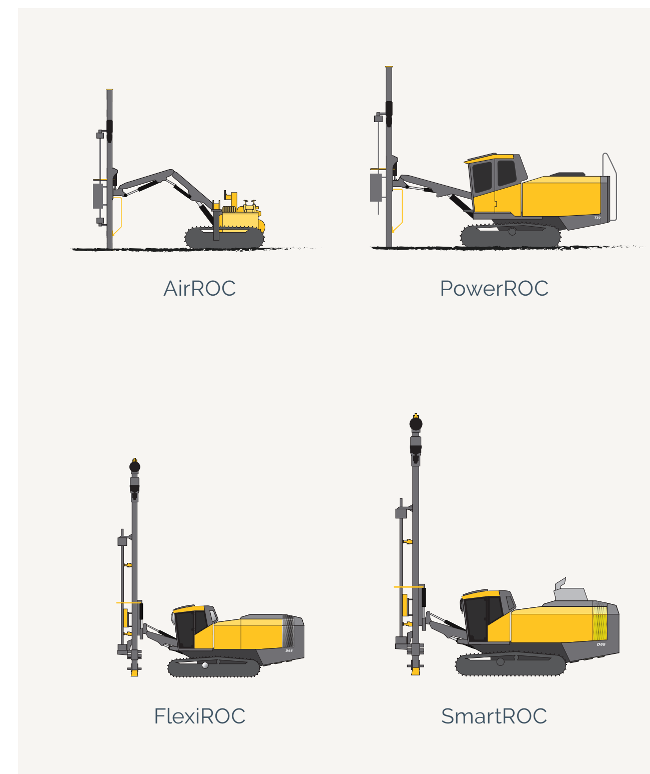


Figure 1: FlexiROC T30 R, product naming structure!



Pneumatic and semi-hydraulic surface drill rigs

Widely used in surface mining, in quarrying for cement raw materials and aggregates, and in construction, pneumatic drill rigs deliver hole diameters typically in the range 35–140 mm.

These machines always use a portable compressor as the power source, which differentiates them in appearance from hydraulic drill rigs when on site. They also have an advantage over hydraulic drill rigs in terms of their compact size and low initial investment cost, so are an attractive choice for smaller-scale operators and contractors. This type of drilling equipment is used all over the world, especially in emerging markets, with some models being light enough to allow them to be transported by helicopter to otherwise inaccessible work sites. Major advantages of this type of rig include the ease with which they can be transported and set up, and their flexibility in operation. Typically designed to be as straightforward as possible to operate, they are built around a small parts inventory. Another feature is the ease with which they can be maintained, while no special operator training is needed, making them ideal for use in parts of the world where technical training levels are still being developed. However, simplicity does not necessarily equate to reduced versatility. Epiroc's AirROC range of pneumatic drill rigs can be crawler-mounted and offer both tophammer and Down-The-Hole (DTH) drilling options. In general, however, tophammer technology is more often found on fully hydraulic rigs, and the vast majority of pneumatic rigs are used for DTH drilling.

AirROC

Tophammer

- AirROC T25 W
- AirROC T25
- AirROC T35

Down-The-Hole

- AirROC D35
- AirROC D40
- AirROC D40 W
- AirROC D45
- AirROC D45 SH
- AirROC D50
- AirROC D55
- AirROC D65

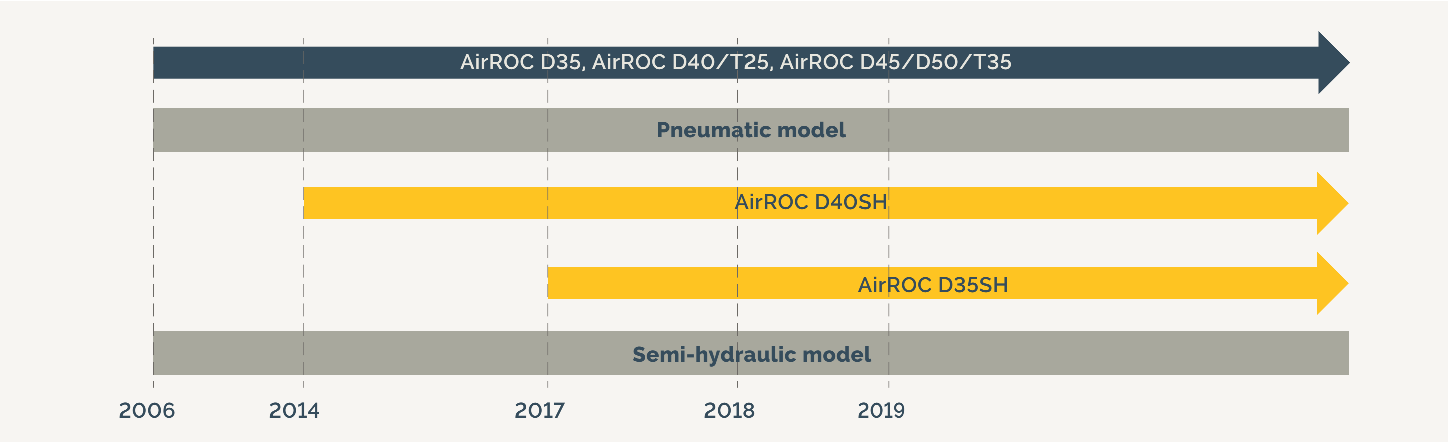


Figure 1: AirROC models and their year of launch.

There are different ways of classifying pneumatic drill rigs based either on the power system or on the pressure capabilities. Classified by the power system, there are:

Pure pneumatic drill rigs

This type of rig is fully powered by a portable compressor, which provides compressed air to:

- The tramming motors for traction
- Drive a hydraulic system for the positioning cylinders (air-driven hydraulic power pack)
- The rotation unit and feed motor
- The DTH hammer and flushing

Semi-hydraulic rigs

This type of rig is powered by an on-board engine together with a portable compressor. The engine drives the hydraulic system, which operates positioning, rotation, feed and tramming, while the compressor powers the DTH hammer and flushing. Since the engine-driven hydraulic system has a higher efficiency than systems driven by compressed air, semi-hydraulic drill rigs offer better fuel efficiency than pure pneumatic machines.

Classified by their working pressure, pneumatic rigs fall into three general types (Table 1).

- High-pressure rigs, with a working pressure of 16–20 bar
- Medium-pressure rigs, where the working pressure is in the range 10–16 bar
- Low-pressure rigs, which operate at working pressures of 6–10 bar

To summarize, current machines generally fall into one of the following:

- Pure pneumatic rigs – Low, High and High pressure
- Semi-hydraulic – Medium and High pressure

Comparison

There are clear differences between semi-hydraulic and pure pneumatic drill rigs, especially in relation to their consumption of compressed air. Take for example two representative crawler-mounted machines available on the Indian market, the pure pneumatic rig AirROC D45 and the semi-hydraulic AirROC D40 SH equipped with a 43 kW on-board engine.

While both rigs require a stand-alone portable compressor, the semi-hydraulic rig needs a smaller capacity unit, since it is needed to power just the DTH hammer and for hole flushing, rather than all the rig functions. Typical compressors used with these rigs have outputs of 358 and 277 liters per second respectively.

The pure pneumatic rig requires around 100 liters per second more compressed air than the equivalent semi-hydraulic machine, due to air needed for rotation and feed. This assumes that neither is fitted with dust collection equipment, which would increase the air consumption equally for both types of rig, while an allowance is made for tramming and positioning the pneumatic rig.

In terms of fuel consumption, the semi-hydraulic rig has been shown to be more economical during tramming with a fuel consumption of approximately one quarter that for the pneumatic type. This reflects the higher efficiency provided by hydraulic motors, which are powered by the on-board engine and not by the compressor's engine.

When it comes to drilling, the semi-hydraulic rig is again more economical in terms of its fuel usage, having an advantage of 25% higher efficiency than the pure pneumatic machine. By estimation, the semi-hydraulic rig's overall fuel savings for drilling and tramming are approximately one-third compared to equivalent pure pneumatic rigs.

AirROC D40 SH in operation.

Figure 2: AirROC models

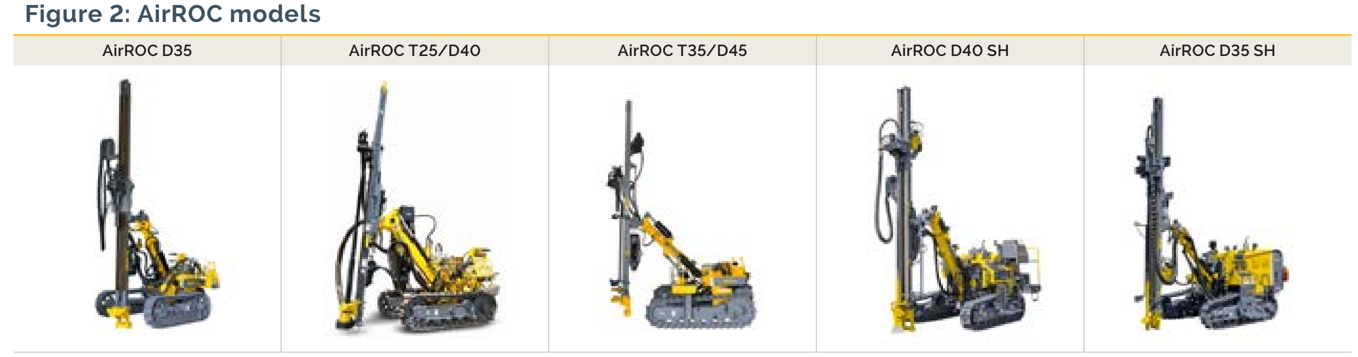


Table 1: Working pressure

Pneumatic	
Low Pressure (6–10 bar)	AirROC T25 , AirROC T35
Medium Pressure (10–16 bar)	AirROC D35 , AirROC D40
High Pressure (16–20 bar)	AirROC D45 , AirROC D50
Semi-hydraulic	
Medium Pressure	AirROC D35SH
High Pressure	AirROC D40SH

Table 2: Semi-hydraulic rigs in operation

Benefits
• Low fuel consumption • High performance • Heavy duty feed and rotation unit • Operation friendly

More about the AirROC family

Compressed air for drilling equipment

Air compressors are devices that convert power using a diesel engine into potential energy stored in pressurized air tanks. Used in a wide range of drilling applications, they are designed to force more and more air into the storage tank which increases the pressure.

When the tank pressure reaches its engineered upper limit the air compressor shuts off. The compressed air is then held in the tank until called into use.

The energy contained in the compressed air can be used for drilling equipment in a variety of applications, utilizing the kinetic energy of the air as it is released while the tank depressurizes. When tank pressure reaches its lower limit, the air compressor turns on again and re-pressurizes the tank.

Customers are always looking for better efficiency, using higher pressure and more capacity. On modern tophammer and Down-The-Hole (DTH) drill rigs, for instance, the onboard compressor both powers the hammer and flushes the hole, using most of the energy generated by the engine. Having the most reliable and efficient compressor makes all the difference. Towed compressors are just as important, with fuel economy high on the agenda. Surface drilling methods where compressd air is used are Down-The-Hole and tophammer.

Down-The Hole (DTH). Tophammer.

Tophammer

In tophammer drilling, the way compressed air used also depends on the drill rig type, but it should always be either fully hydraulic or fully pneumatic. In the case of fully hydraulic rigs, compressed air is used for flushing, dust collection and other functions. On fully pneumatic rigs compressed air is also used to drive air motors and pneumatic drifters for hammering. The compressor can be either onboard or towed.

Down-The-Hole (DTH)

In DTH drilling, the drill string rotates while the drill hammer strikes into the rock and breaks it into fragments and dust. Whether or not compressed air is used will depend on the drill rig type. The DTH drill should be fully hydraulic, semi-hydraulic or fully pneumatic. With fully hydraulic drill rigs, compressed air is used to drive the DTH hammer, flushing, dust collection and other functions. On semi-hydraulic drill rigs, compressed air is only used for drilling whereas on fully pneumatic drill rigs, compressed air is used for drilling and air motors for tramming. The compressors can be onboard or towed,

DTH hammers hammers are used in a wide range of applications. The holes are straighter and, because hammering is done at the bottom of the hole, there are less energy losses. For efficient DTH performance, a higher pressure will be an advantage. The higher the pressure, the higher the penetration rate. Also, high volume Free Air Delivery (FAD) is important for optimal flushing. If flushing is poor, efficiency is lost at the bit as the cuttings are recrushed. DTH hammers have a lower noise level and longer service life than tophammer rock drills.

Choosing the right compressor

The choice of compressor will depend on the hammer size and hole depth while drilling in very hard rock, very deep, or with high back pressures. Epiroc products are widely used in surface mining, in quarrying for cement raw materials and aggregates, and in construction. For pneumatic drill rigs, the hole range starts from 35 mm to 140 mm and suitable compressors are used to get optimum results. The availability of equipment can be summed up as reliability plus service, which is the most crucial factor in the profitability equation. An Epiroc surface drill rig, equipped with an efficient and reliable compressor, and first class service, ensures availability and drill string performance which underpins profitability.

Epiroc's range of pneumatic and semi-hydraulic surface drill rigs covers a hole range of 35–140 mm

Model	Recommended operating Pneumatic pressure in bar	Recommended CFM
AirROC D35	10.5–12	380–480
AirROC D40	10.5–12	400–500
AirROC T25	7	400–500
AirROC D45	12–17	450–600
AirROC D50	14–20	500–650
AirROC T35	7	650–700
AirROC D35SH	12	450–500
AirROC D40SH	14–17	450–600

Getting it done

While many drilling applications demand high levels of automation, sophistication and technology, other jobs simply require a tough machine that can get the work done with just enough technological input and maintenance requirements.

Epiroc's PowerROC family provides this straightforward approach, with a series of machines that provide high-powered performance based on a modular design with low maintenance needs. PowerROC is built to operate in tough construction and quarrying applications and, in some cases, at surface mining sites, and customers are typically operation owners or contract drillers.

The PowerROC family is the right choice for customers that are:

- Focusing on straightforward utilization in basic drilling applications.
- Looking for a robust drill rig that is easy to maintain so that operators, if necessary, can manage all maintenance and repair tasks.
- Looking for straightforward and well-proven systems and solutions.
- Giving equal importance to initial investment costs and running costs.

PowerROC rigs come either with or without operator cabins, allowing them to be used under a wide range of drilling conditions. Some machines are equipped with a fixed boom, while others feature a boom that can be extended to increase the coverage from each set-up, which offers greater flexibility. Further variation comes with the choice of both tophammer and Down-The-Hole (DTH) drilling capabilities.

Key features of the PowerROC family include the widespread commonality of parts between models, allowing operators to focus on fewer spare parts in their inventory, and the use of easy-maintenance components, such as simplified hydraulic and electrical systems, which lead to higher availability and reliability.

PowerROC

- **Tophammer**
  - PowerROC T25 E
  - PowerROC T25
  - PowerROC T30 E
  - PowerROC T30
  - PowerROC T35 E
  - PowerROC T35
  - PowerROC T40
  - PowerROC T45
- **Down-The-Hole**
  - PowerROC D40
  - PowerROC D45
  - PowerROC D55
  - PowerROC D60

The PowerROC T45 is modular designed with a low number of moving parts.

A straightforward design with the PowerROC D55.

Easy set-up

PowerROC rigs are designed for sites and operators that need quick results. The whole concept of the PowerROC family is built on simplicity of use coupled with good production capability. PowerROC tophammer rigs are suited for quarrying, civil engineering, construction and open-pit mining. Capable of drilling 51–152 mm (2–6 in) holes, horizontally, vertically or on incline, they are also sufficiently maneuverable and stable to climb steep grades over rough terrain. An on-board compressor provides the air needed for hole flushing, while the diesel engine also provides the power for the drill.

The smallest members of the family, the PowerROC T25DC, PowerROC T25 E, PowerROC T30 E and PowerROC T35, are powered by either a 119 or 142 kW engine (160 or 190 hp), with compressors that produce from 95 to 130 liters/second (201–275 cfm). The PowerROC T25 DC has a fixed boom and is suitable for both vertical drilling and front face toe-hole drilling in small aggregate quarry and construction applications. The PowerROC T35 has an extension boom, while a drilling angle indicator provides the operator with visual assistance in setting up the rig correctly for each hole. Meanwhile, the larger PowerROC T45 builds on this foundation, giving drillers in the construction and quarrying industries the capability to drill holes in the 76–127 mm (3–5 in) diameter range to a depth of 25 m (82 ft).

The DTH members of the PowerROC family, the PowerROC D45, PowerROC D55 and PowerROC D60, take its straightforward concepts beyond construction and quarrying applications to surface mining. Powered by a 194 kW (260 hp) engine and carrying a 270 liter/second (575 cfm) compressor, the PowerROC D45 can drill a 90–130 mm (3.5 in–5.1 in) hole to a depth of 21 m (69 ft), while the PowerROC D55, with its 261 kW (350 hp) engine and 271 liter/second (575 cfm) compressor, is the next step, with a 90–165 mm (3.5 in–6.5 in) hole capability to 29 m (96 ft). The PowerROC D60 tops the product family with a hole range of 110–178 mm (4.3–7 in), powered by a 379 kW (505 hp) engine and a 428 l/s (906 cfm) compressor. It can drill down to 30 m (98.4 ft).

Easy operation

A direct-drive arrangement on the hydraulics means that all the power that is needed travels from the valve to the function, virtually eliminating troubleshooting time and increasing reliability and up-time.

PowerROC rigs do not need complicated electronic controls, which again makes for easy maintenance. Demand-sensing allows the pump to provide only the amount of hydraulic power that is needed, which is reflected in the engine speed and helps to cut the amount of fuel used. Epiroc's COP Logic system is also available for some of the tophammer rigs, helping to optimize the drilling performance in relation to the condition and hardness of the rock being drilled.

Built for challenging ground: the PowerROC T50 is the largest and most robust tophammer drill rig in the PowerROC family.

The larger rigs in the PowerROC family, with their greater depth capability, also have a mechanized rod or pipe changing system, which again is designed around the minimum level of complexity needed to make the operator's job easier and safer. A basic set of solenoid valves actuates the hydraulic cylinders on the unit with on/off switching, while the rod changer works without needing more complicated electronic components.

Quarrying applications

Drilling in quarries is one area where PowerROC rigs have established a strong reputation worldwide. For example, a drilling contractor working at a large limestone quarry in Japan uses a PowerROC T35 on the site, which is located in an environmentally sensitive area close to residential districts. The contract involves drilling 95 mm holes to a depth of 15.5 m and the rig is equipped with a rod changing unit.

At another site in Japan, again in a quarry, a local contractor is using the PowerROC T35 to drill 76 mm holes, 12 m long, with two operators working in hard rock conditions.

In Chile, the PowerROC T25 DC is proving its worth in high-altitude drilling for the construction of a new telescope in the Atacama Large Millimeter/submillimeter Array (ALMA). Read about it on page 172 in this reference book.

Two PowerROC T35 drill rigs form part of the fleet operated by a contractor in Queensland, Australia, which provides services for clients in the quarrying and construction industries in the state. Put to work just three days after delivery, these rigs are used to drill holes in the 76–102 mm range, up to 20 m deep. Their straightforward design and low fuel costs compared to larger rigs have been major factors in operator acceptance of the new machines, as well as better productivity and lower drill string wear.

More about the PowerROC family

Versatility in surface drilling

Setting a productivity benchmark in most surface drilling applications, Epiroc's FlexiROC-family of surface drill rigs combine high technology with a medium level of sophistication. Taken together, this provides good productivity, overall efficiency and high flexibility in construction, quarrying, mining and niche drilling applications.

The FlexiROC-family is extensive and can be sub-classified in a number of ways. Taking a simple approach, Figure 1 illustrates one such system based on type of application, the operator environment, the tramming system and the drilling method. This does not, of course, mean that a Down-The-Hole (DTH) drill rig cannot be used in construction or that a rig without an operator's cabin cannot be used in mining; it just shows the more usual combinations of parameters by which the majority of uses and equipment features can be described.

FlexiROC

Tophammer	Down-The-Hole
FlexiROC T15 R	FlexiROC D50
FlexiROC T20 R	FlexiROC D55
FlexiROC T25 R	FlexiROC D60
FlexiROC T30 R	FlexiROC D65
FlexiROC T35	
FlexiROC T35 R	
FlexiROC T40	
FlexiROC T40 R	
FlexiROC T45	

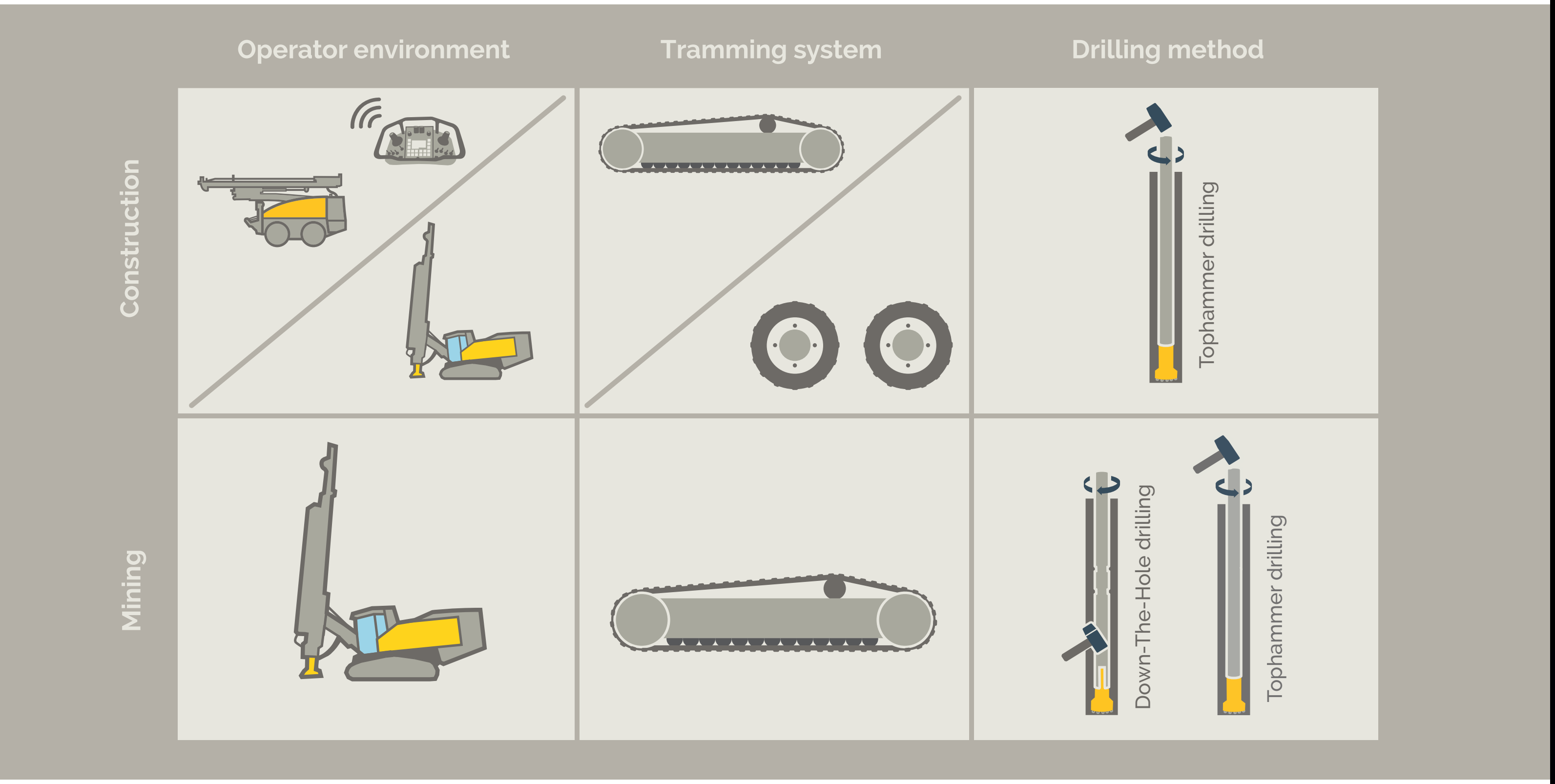


Figure 1: Drill rig parameters and features.

As Figure 1 also shows, FlexiROC drill rigs can be used for tophammer or Down-The-Hole drilling. With the choice depending on factors such as the job at hand and site conditions, as well as the aim of drilling and blasting.

Here, for instance, there are important differences between drilling in a construction project where the intention is to remove rock to provide space for building something, and in mining and quarrying, where the rock itself is the valuable output.

Safety and ergonomics play an important role in the choice of the right drill rig for the job, with the operator often having a lot of influence in this respect. After all, a comfortable working environment means that the operator is more likely to operate the machine better, especially when conditions outside the cabin are tough.

The operator environment, the tramming system and the drilling method are key factors, among others, that must be considered when selecting a drill rig to match a specific application type. The ability to change from one drilling method to another without involving too many modifications to the rig can be another important consideration, especially in contract drilling where rock conditions and drilling requirements may well change from job to job.

Exploring the options

The FlexiROC-family consists of a range of rigs (denoted by T in the model name) that are designed for tophammer drilling, and another parallel group of generally larger DTH drill rigs (D). Tophammer drill rigs range from the FlexiROC T15 R, which is a compact, wheel-based machine capable of drilling 27–51 mm holes for smaller-scale construction and quarrying applications, to the crawler-track mounted FlexiROC T45. Designed for heavy duty work on large construction sites and in quarries and surface mines, this rig drills holes in the 89–140 mm (3.5–5.5 in) diameter range, marking the top of the hole sizes that can be most economically drilled using this type of drilling technology.

Since holes drilled for construction projects are often smaller diameter and shallower than those needed for mining and quarrying, tophammer drilling is widely accepted as being the best method to use here because of its productivity. Both the FlexiROC T20 R and the crawler track-mounted FlexiROC T35 R are good examples of construction drill rigs, without operator cabins, where size, stability and safety are key drivers for selection.

All FlexiROC drill rigs without cabins are equipped with full Radio Remote Control (RRC) systems for maximum safety and overview during operation (Figure 2). This class of drill rigs offers a very high performance in relation to its size which is beneficial on narrow construction sites and to ease transportation.

By contrast, drilling and blasting in mining and quarrying forms the productivity and efficiency foundation for the whole production process. Deeper, larger diameter

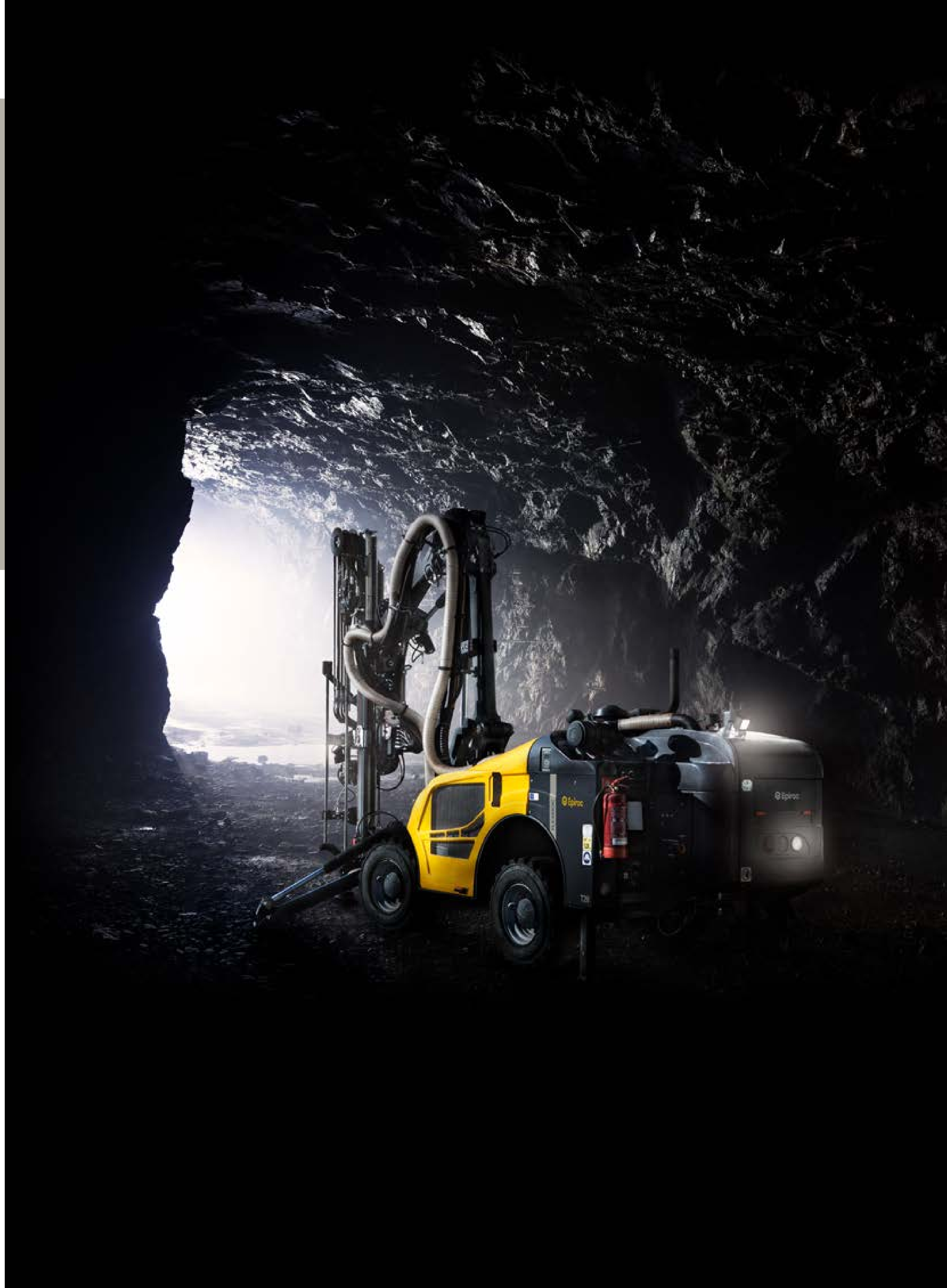


Figure 2: Radio Remote Control (RRC) is a available on many FlexiROC surface drill rigs.

holes are usually needed. In these applications, DTH and COPROD drilling systems are advisable options due to both the quality of the holes produced and their hole depth capability, especially in operations where volume and Total Cost of Ownership (TCO) are decisive factors.

DTH FlexiROC drill rigs include the FlexiROC D50, FlexiROC D55, FlexiROC D60 and FlexiROC D65. With a hole capability of 90–152 mm (3.5–5 in), the FlexiROC D50 and FlexiROC D55 use 76–102 mm pipe to drill high quality holes to depths of up to 45 m (148 ft), using the automated pipe carousel.

The FlexiROC D60 and FlexiROC D65, meanwhile, extend the hole diameter range up to 203 mm (8 in) at similar depths, with on-board compressors that can deliver 405 or 470 liter/second (858 or 995 cfm) respectively.

FlexiROC in the field

Reflecting the size of the FlexiROC-family, FlexiROC drill rigs are used in a wide range of applications across construction, quarrying and mining. Versatility and maneuverability are key factors in their use, providing contractors and owner-users with drilling capabilities to cover many different drilling tasks. At the smaller end of the scale, the FlexiROC T15 R and FlexiROC T20 R, wheel-based rigs with radio remote control find uses in light construction but also fulfill the requirements as service rigs in larger tunneling projects and mines.

The FlexiROC T15 R and FlexiROC T20 R also perform excellent in niche applications such as drilling rows of holes for splitting stone blocks in the dimension stone industry (DSI). Larger scale rock excavation in quarries or for major construction projects demands more powerful drilling performance, which is where machines such as the FlexiROC T45 are more appropriate.

The FlexiROC T45 has proved its versatile performance at many worksites worldwide. When the company Mineral Baustoff GmbH, one of Europe's leading raw materials producers, decided to conduct an extensive field test, the results were overwhelmingly positive. The company operates some 200 quarries in Europe producing high quality material such as limestone, granite, gneiss and granulite.

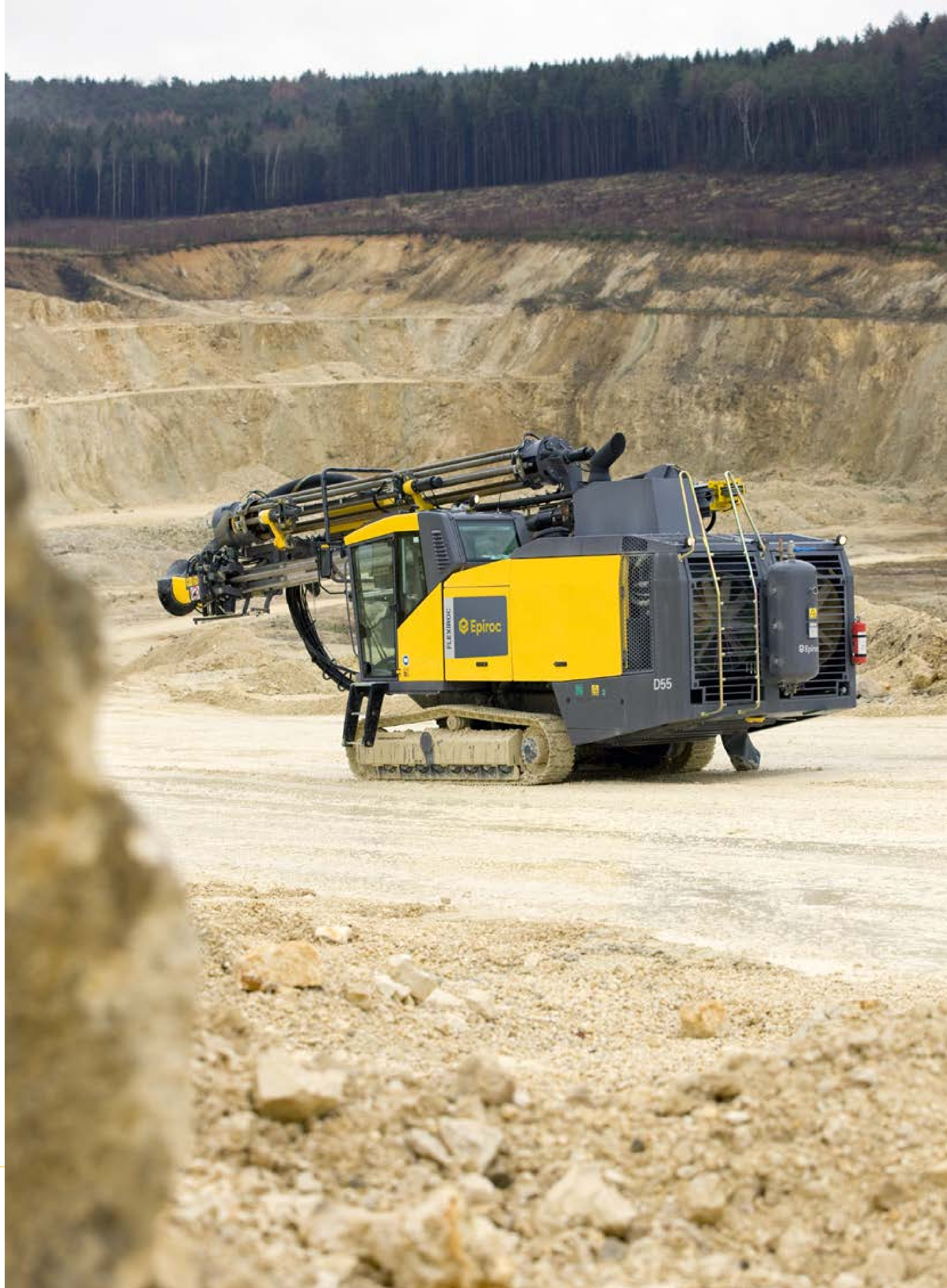
The FlexiROC T45 outperformed all other equipment in several areas. For example, the drill rig's ability to collar the holes with extreme accuracy resulted in excellent hole straightness, particularly in comparison to drill rigs of similar size. Morever, the FlexiROC T45 reduced fuel consumption by 50% and enhanced the user experience. The onboard Certiq system also unlocked real-time performance data which opened up new opportunities for continuous optimization of drilling.

In applications where production demands are relatively low, the small and medium sized FlexiROC drill rigs are well suited to do the job. Only the bigger drill rigs in the FlexiROC-family offer the drilling capability for larger tonnage requirements. While rotary blasthole drill rigs are more widely used for the bulk of drilling, the larger FlexiROC drill rigs frequently play a supporting role – and further illustrate the versatile strengths and dual-role applications of the FlexiROC-family.

As a final field example, during deployment in Poland, the FlexiROC D50 enabled the country's largest drill and blast contractor MAXAM to achieve major improvements in overall quality and efficiency. The company provides services to granite, dolomite, sandstone, basalt and melaphyre aggregate quarries, as well as limestone quarries for the production of cement and other components for construction chemicals production.

Drilling approximately a million meters of blastholes per year in Poland, MAXAM uses Epiroc equipment to continuously keep total operating costs down. The FlexiROC D50 meets this objective, for example by increasing hole precision, reducing the need for secondary drilling while also running at lower rpm – which means longer engine life, less fuel consumption and low lifetime cost.

More about the FlexiROC family



The FlexiROC D55 tramming in an open-pit mine.

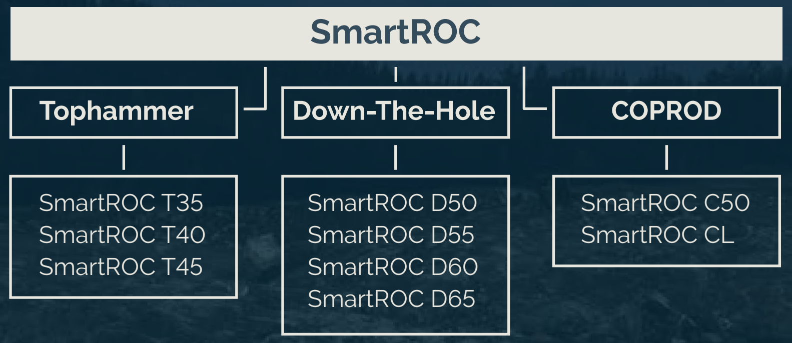
Raising the game in surface drilling

Total efficiency is the driller's best guide to success in any operation, on any worksite. The SmartROC family has been developed to help operators achieve just that.

Accuracy and optimized economy are two of the key factors that identify successful surface drilling, whether the aim is to produce bulk rock for aggregates, raw materials for cement, presplitting and productive drilling in surface mines, or merely to remove unwanted rock during a construction project.

Whatever the required end result may be, incorrectly positioned or aligned drill holes will significantly reduce the efficiency of blasting, even to the extent of blasts being ineffective and having to be re-drilled. This can obviously have a major impact on costs, and so can the way that the drill rig is operated. Running a rig's engine at full power when it is not needed not only wastes fuel in the short term, but also means that it will require more frequent maintenance and consume more spare parts.

Epiroc's SmartROC family of surface drill rigs has been designed to answer both of these issues, firstly by using sophisticated automation systems to optimize drilling procedures, and also by making sure that the rig's power is only used as and when needed. SmartROC drill rigs use the latest generation Rig Control System (RCS) platform, which optimizes the performance of Epiroc drill rigs. The system also enables faster troubleshooting and maintenance which, in turn, means increased availability.



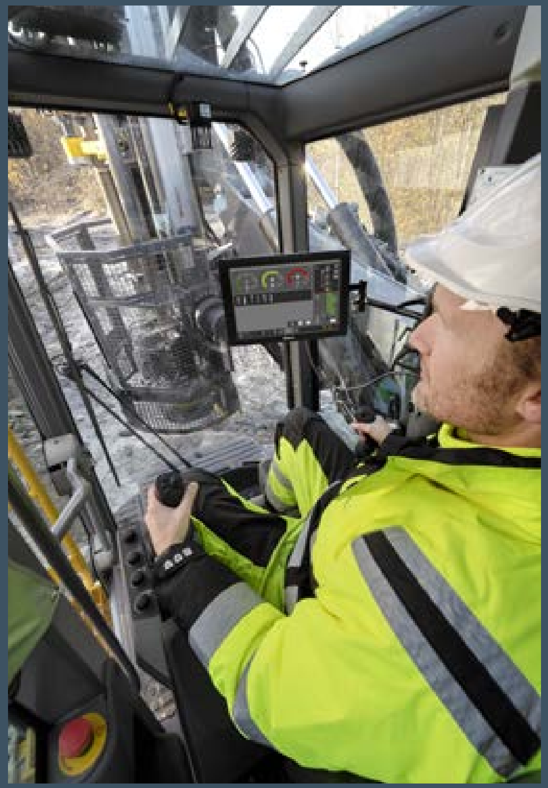


Figure 1: 15-inch touch screen displaying real-time Measure While Drilling (MWD) data.

Figure 2: Surface drill rig SmartROC CL with the COPROD drilling system.

The SmartROC family of rigs makes use of the latest technology to optimize the complete drilling process. The high level of automation improves operational safety while taking productivity to a new level. The optional Hole Navigation System (HNS) removes the need to survey and mark-up hole positions manually, saving time and increasing safety. In addition, HNS helps to cut rig set-up-times by guiding the operator to the correct hole position – including the hole inclination and collaring position.

Tophammer, Down-The-Hole and COPROD

The initial three models within the SmartROC family consisted of the SmartROC T35, SmartROC T40 and SmartROC D65, with the SmartROC T45 introduced in 2013. The 'T' in the model name denotes a tophammer rig, while the 'D' shows that it is designed for larger-diameter Down-The-Hole (DTH) drilling.

Since then, a new generation of Epiroc surface drill rigs have raised the bar for hole precision, low energy consumption and intelligent control. The SmartROC D50 and D55 models are both equipped with the latest automation technology. They are driven by powerful (328 kW), low-emission engines and are designed to drill holes in the 90–152 mm range (3.5–6 in) with a maximum hole depth of 45 m.

At the next level up, the SmartROC D60 provides ample opportunities for achieving top notch drilling performance in tough terrain, in the 110–178 mm (4.3–7 in) hole range with a 55.5 m maximum hole depth. The SmartROC D60 has been designed for lowest possible total cost of ownership focusing on three areas: increased fuel economy, reduced wear on parts and minimized waste of compressed air. Orientated towards surface-mining applications rather than quarrying or construction, the SmartROC D65 is powered by a 403 kW (540 hp) engine and a high-pressure 470 liters /second (995 cfm) 30 bar compressor that drives both the DTH hammer and hole-flushing systems.

In the COPROD range of drill rigs, the SmartROC C50 combines the most important advantages of tophammer drilling and Down-The-Hole drilling in the 90–140 mm range (3.5–5 in) hole range – providing high penetration rates, superior accuracy and hole quality. Similarly, the SmartROC CL (115–216 mm, 4.5–8.5 in) uses the COPROD method to provide groundbreaking performance – increasing penetration rates by 50% and reducing fuel consumption by 45% compared to traditional DTH-drilling (Figure 2).

More than just a name

One of the most successful ways of increasing productivity in all types of surface drilling is to maximize equipment utilization. Time spent in setting up and positioning the rig,

Figure 3: The characteristic HNS antenna on a SmartROC C50.

Figure 4: Customer reports show the SmartROC T40 drill rig reduces fuel consumption by up to 50%.

establishing correct drill feed orientation and then, during drilling, manually changing drill steel or pipe, is all idle time from the point of view of utilization. The rig may be available for drilling, but is not actually doing so. As a result, the utilization factor becomes redundant.

Automation is a powerful tool for improving rig utilization. Various options are available, such as automating the alignment of the feed before collaring a hole, automated rod changing when holes are drilled that are deeper than the single-pass feed length, and the use of GPS/GNSS-based systems that will assist the operator to maneuver to each new hole collar position (Figure 3).

SmartROC drill rigs are packed with the latest technologies for precision drilling and automation. It all begins with the advanced rock drill control system which incorporates rotation pressure feed control and an anti-jamming function. This maximizes the lifespan of shank adapters, rods or pipes and drill bits, and makes drill string extraction easier by optimizing the joint tightness between the rods or pipes. It also helps to maximize the penetration rate in different rock conditions and drilling directions.

The automated Rod Handling System (RHS) is another invaluable function that drillers have come to rely on around the world – saving time and allowing more holes to be drilled per shift. Other key features such as the Hole Navigation System (HNS), a GPS compass aiming unit, Measure While Drilling (MWD) and Rig Remote Access (RRA) put the SmartROC family at the forefront of surface drilling productivity.

The level of sophistication within the Rig Control System (RCS) system depends on the drilling task or worksite conditions. Some relatively simple tasks benefit by using only the basic RCS level.

On the other hand, large-scale, repetitive work that requires a high degree of accuracy and operator input can benefit significantly from higher levels of automation and data collection. For example, Epiroc's wireless or hard-wired Rig Remote Access (RRA) option provides fast data transfer to and from drill rigs as well as secure storage. This information typically includes drill hole set-up parameters, performance data and machine health data updates for maintenance personnel.

It is also possible to use the rig to obtain new, in-depth information about the rock being drilled, in order to build up a more detailed picture of the rock mass before it is broken by blasting. Epiroc's Measure While Drilling (MWD) technology collects drilling data on penetration rate, feed force, rotation speed and other parameters, while the machine is in operation (Figure 1). It can then store the data for download at a later stage or transmit the data in to the mine, quarry or construction site engineers, giving them an overview in real time of the conditions being encountered. Different rock types; fractured zones; hard and soft material; these are all shown graphically for both the operator and the engineering office.

Enhancing drilling economy

Rising fuel costs are a major concern to drilling contractors worldwide, with diesel prices set to continue on a rising trend virtually everywhere. With this in mind, every liter of diesel saved is a bonus that helps to keep overall drilling- and blasting costs to a minimum. Epiroc SmartROC drill rigs have shown that the automation and control technology used can enable major reductions in fuel costs, as well as benefits such as lower hydraulic fluid consumption, lower carbon dioxide emissions and reduced maintenance costs. This improved performance, availability and cost-efficiency is achieved jointly through the use of the Rig Control System (RCS) and cutting edge technologies as well as user-friendly controls. In this context, the RCS provides the foundation for controlling the engine output on the rig, so that the engine speed is reduced automatically when maximum power is not needed, such as when the drill bit encounters softer rock. The control system responds instantly to changing power demands and adjusts the engine output accordingly.

From the operator's point of view, second-by-second decision making is no longer needed, which does away with the tendency to leave the engine running at full output regardless of conditions, and whether the rig is actually drilling or not. In addition, the operator has time to fine-tune the rig's performance, such as adjusting the capacity of the flushing air and the dust collector, by simply pushing buttons. This ensures that the rig generates only the amount of energy that is needed for each function, while providing full hydraulic power at lower engine speeds than previously. In many documented deployments of SmartROC drill rigs, results show that fuel consumption is cut by up to 50% (Figure 4). That means approximately 15 liters/hour for SmartROC T35 and T40, compared to similar machines with older technology. Hydraulic fluid usage is reduced by 65% and lubricating oil requirements are one-fifth of previous levels. The reduced fuel usage and greater efficiency of the rigs' Tier 4/Stage V-compliant engines also means that CO_2 emissions are cut by 25–30 kg/h.

This is done thanks to a combination of functions, for example by feeding cooled excess gas back into the cylinder to reduce all emissions, CO_2 and NOx. Equally importantly in sensitive locations, noise output levels are significantly reduced since the engine and compressor outputs are optimized for the drilling conditions. The compressor can even be closed down when it is not needed, reducing the engine speed and saving fuel.

Cutting fuel consumption is only one aspect of the cost benefits of increased automation on drill rigs. Less fuel used equates to longer intervals between tank refills, and consequently more time available for drilling. At the same time, lower hydraulic fluid consumption means that smaller tanks are needed which leaves more space and enables better maintenance access. Faster maintenance, in turn, results in less down-time and an overall increase in machine availability and utilization. Other advanced technology features such as BenchREMOTE, which enables one operator to control up to three drill rigs at once, working remotely from a safe distance, lay the foundation for continuous drilling. Epiroc's Surface Manager system monitors the drilling performance and tracks consumables against actual results. In addition, the Certiq telematics solution provides a complete visualization of production data for a single machine or an entire fleet of drill rigs as required – providing an overview of operations in real time.

SmartROC drill rigs are making great strides in all corners of the world. For example, at a German quarry producing diabase stone, for road and railway construction, and concrete aggregate, a SmartROC T40 was used to drill 98 mm-diameter holes to depths ranging from 8 to 25 m. The average penetration rate for this hard, compact rock reached 1.4 m/minute, averaging a fuel consumption of 14–16 liters per hour. In more agreeable rock conditions, far greater results have been achieved. In 2017, the SmartROC T40 set a record during a field test in Sweden – drilling 100 meters (328 feet) in less than two hours using only 40 liters of fuel. Hole straightness was recorded at 90% which meant that 18 of every 20 drill meters were drilled perfectly straight.

In Norway, meanwhile, a drilling contractor reported 10–15% higher rig utilization when using a SmartROC drill rig equipped with automated hole positioning and Epiroc's Hole Navigation System. The contractor, which is involved in drilling for road construction projects, achieved 15–20% more drill meters with virtually no sub-drilling needed. Other major benefits included a 10–15% reduction in the amount of explosives needed, thanks to the positioning system, and a similar reduction in the amount of overbreak since the drill holes were better aligned and always drilled to the correct depth.

A similar system used at a limestone quarry that provides feed rock for a cement plant achieved even more savings in explosive, up to 30%, while the fragmentation achieved from the initial blast was much better. The drill rig operator was also able to reduce the hole diameter while maintaining the same hole spacing. Another major benefit was improved safety, since better control of the hole orientation and depth means that there is less chance of holes being drilled into hidden explosives remaining from previous blasts.

More about the SmartROC family

Automation – a powerful tool for change

For centuries, the mining, construction and quarrying industries have been generally regarded as three of the toughest industries in the world. Now that reputation is rapidly fading as technology takes automation to a whole new level.

The biggest single driver of change in the rock excavation business is, without doubt, the advent of automation.

The possibility to automate functions and operations that make the work safer and more efficient has had a profound effect on the way these industries work, even though it has been a slow process.

Many companies have been reluctant to jump on the automation bandwagon while traditional methods still produced good results and have only invested in automation in certain areas and usually on a small scale. Today, however, interest in automation has soared and it is now largely seen as the only feasible way to solve the many challenges facing contractors, ranging from skilled labor shortages to lower profit margins.

But perhaps the biggest motivating factor is the impressive development of automation technology in recent years. It is now possible to automate many more aspects of mining, construction and quarrying tasks than ever before, and at a lower cost.

Behind the scenes

Epiroc offers an extensive portfolio of automation innovations as part of a continuous drive to make rock excavation safer, more efficient and more productive. Today, digital technologies are changing the landscape of options and automation is becoming more data-driven and reliant on connected machines that coordinate tasks. At Epiroc, we have a way to optimize our customers' value chain through automation, system integration and information management. We call this 6th Sense and it enables a smart, safe and seamless operation.

Figure 1: BenchREMOTE remote operator station used in a quarry application.

In this context, it is interesting to take a brief look behind the scenes at how automation development at Epiroc is organized. Epiroc's research and development is focused on three categories: Machine Automation, Process Automation and System Integration.

Machine Automation covers the full spectrum of drill rig functionality from automatic hole navigation to rod handling and control. The SmartROC range of drill rigs is a typical case in point – these machines are chock full of automated systems that make the operator's job lighter, easier and safer at the same time as it boosts efficiency and productivity to levels that were previously unattainable.

The SmartROC series is equipped with Epiroc's advanced Rig Control System (RCS) which constantly monitors the load on the compressor and the engine. The system, which is also standard on all Pit Viper drill rigs, ensures that the right amount of energy is always matched to the work load, keeping fuel consumption to an absolute minimum.

But that's not all. The SmartROC rigs are equipped with rod handling systems which means the operator no longer has to do the heavy lifting. It also features the Hole Navigation System (HNS) which guides the rig to exactly the right spot on the ground and eliminates the need for manual mark-ups on the benches. There's a semi-automatic feed alignment system, too, ensuring that the correct drilling angle is achieved during set-up, which is key for optimal blasting. Process Automation deals with the automation of workflows and covers a range of essential tools for planning drilling operations and collecting performance data. These include:

- Measure While Drilling (MWD) – A monitoring tool that enables drillers to collect relative rock hardness data
- Auto Feed Fold – Moves the feed to tramming position with one-touch functionality, which minimizes the risk of damage the machine.
- Certiq – A telematics solution that gathers, compares and communicates vital equipment information
- ROC Manager/Surface Manager – Office-based software tools which enable the planning and evaluation of surface drilling operations
- Rig Remote Access (RRA) - Enables two-way communication between the drill rig and the RRA server using the site wireless network. The RRA server detects when a drill rig is connected to an access point and then sends and/or retrieves data.

Epiroc's BenchREMOTE system is a further example of how automation technology helps to reduce work site injuries and fatalities by keeping people out of harm's way. It allows operators to control the rig from a distance using the exact same console and without causing delay to operations.

BenchREMOTE was specifically developed for increasing safety in mines and quarries where benches may be unstable or prone to collapse in bad weather (Figure 1).

System Integration ensures that all component sub-systems are fully compatible and integrated into one system, and is a major consideration for project planners as they prepare for automation. Mining sites typically operate with equipment from different suppliers which creates "islands of automation". By moving towards open API:s and standardized platforms, Epiroc is helping to maximize the potential of automation projects (Figure 2).

Regardless of where in the world worksites are located, customers reap the benefits in terms of less down-time, fewer delays, higher production output and increased profits. In addition, they achieve greater precision in their operations, resulting in higher quality, less reworking and overall cost optimization.

Innovation leads the way

With every new series of Epiroc drill rigs that launches onto the world market, the boundaries of automation technology move another significant step forward. At the same time, Epiroc gratefully acknowledges the pivotal role played by a great many customers in this process. Without their experience, close cooperation and valuable input, the pace of development would have been slower and the current level of automation offered would have been more difficult to achieve.

Implementing automation innovations is not an easy choice. In many cases it can be a tough challenge. There are many parameters to take into consideration such as the need for extra training, a potential resistance to change within the organization, the solid commitment required from management, and of course, the cost.

Automation is a journey and Epiroc helps customers every step along the way. Here's how:

- Insight – Data is collected and analyzed to identify where improvements can be made and how. The analysis covers the complete production cycle, from pre-planning to drilling performance and optimal service intervals.
- Control – New technologies are leveraged to monitor performance, measure changes and KPIs and provide real-time visualization of operations.
- Optimize – Parameters are checked and measured continuously by Epiroc technicians and adjusted to maximize drilling performance and economy.

Epiroc's innovations have helped to keep customers at the forefront of their professions and are radically changing the way things are done in mining, construction and quarrying. Rod Handling System (RHS), Rig Control System (RCS) and Measure While Drilling (MWD) are just a few examples of Epiroc's intelligent and upgradable systems.

Figure 2: System Integration of a drill rig.

Fully autonomous operations, with minimal operator interaction, are also underpinned by other process-enhancing technologies. Certiq, the telematics solution mentioned previously, not only gathers, compares and communicates equipment and production data about individual units, but for entire fleets of equipment.

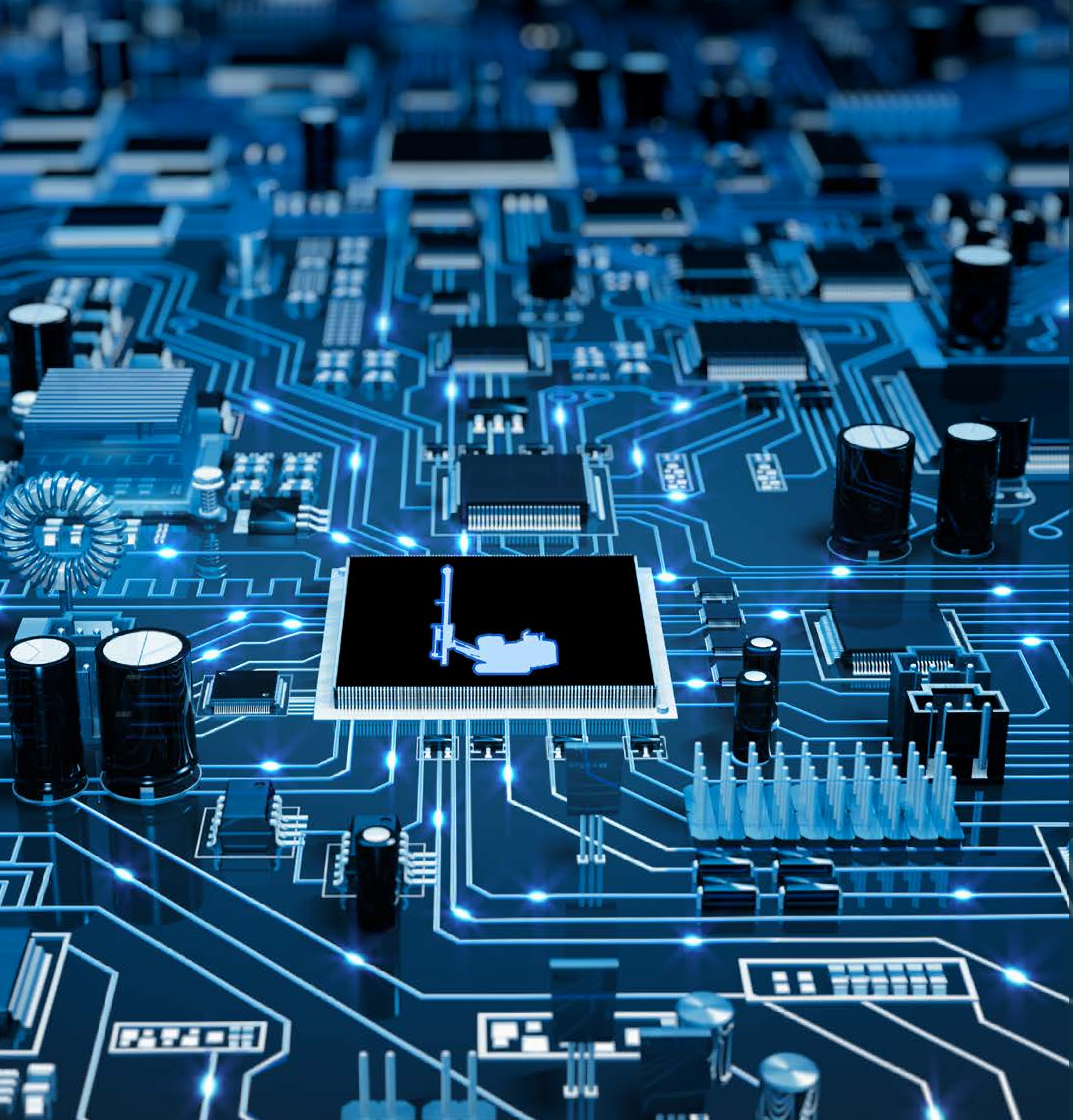
Meeting the challenges

In this fast changing world where much of the accepted methodology and conventional ways of working are being questioned, uncertainty has become the new normal. Against this background, Epiroc is convinced that serious investment in automation will solve many of the challenges facing customers.

Quite simply, automation is a very powerful tool to have in the rock excavation toolbox and the higher the degree of automation, the better life will be for all stakeholders. It paves the way for smarter production and low total cost of ownership.

It alleviates shortages of skilled labor, makes the worksite a safer place for humans, vastly improves efficiency and running costs and boosts productivity. That's why automation is becoming universally accepted as the road to a more profitable future.

Read more about innovation and technology



Digitalization comes of age

The game changer in almost any industry one can name is automation and digitalization – and the drilling industry is no exception. As one of the world's leading suppliers, Epiroc is driving the transformation needed for 21st century construction, quarrying and surface mining.

Industry 4.0, better known as the age of connectivity and automation, has prompted a paradigm shift in the way industry works. Previous methods, tried, tested and trusted over many years, are going through a massive transformation as new technologies that previously only existed in our imaginations enter the mainstream (Figure 1).

Today, not only are these advanced technologies readily available, they are also more affordable, which mitigates risk and increases the advantages.

As a major supplier to the construction, quarrying and mining industries, Epiroc has a significant role to play in ensuring that our customers are aware of these technological advancements and get full access to them through our products.

Raising the bar

Epiroc has long been in the forefront of technology, pioneering innovations year after year that raise the bar in terms of automation, safety, productivity, and energy efficiency. In this regard, our drill rigs and related equipment for construction, quarrying and surface mining have consistently represented the best that money can buy.

But today's digital advancements in the age of Industry 4.0 allows us to adopt a much more holistic approach to these activities, and therefore, greater possibilities to lower the total cost of operations than ever before.

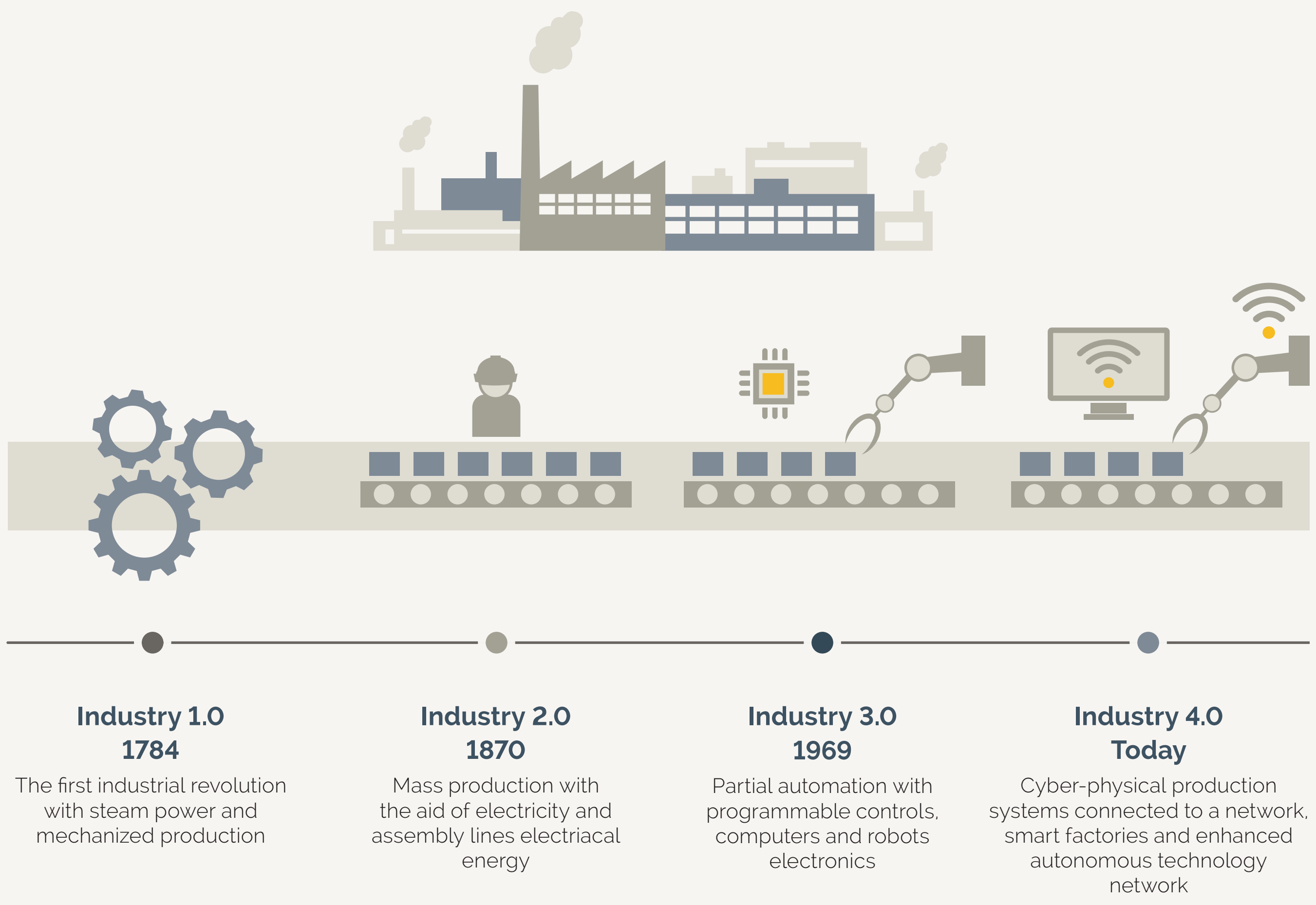


Figure 1: The evolution of manufacturing processes.

For example, today we no longer question whether a certain function can or should be automated but rather which parameters to focus on in order to ensure that automation will get the best possible results in each case.

In other words, automation, underpinned by broad-based digitalization and data analysis, is no longer a barrier or a risk. It is the obvious way to go. In the construction industry, we can see how artificial intelli-gence is beginning to play a larger role in terms of improving productivity, quality, and safety on the jobsite.

More powerful than the human mind, AI captures, processes and analyzes large amounts of data and enables the information to be used for problem-solving and improving work performance. AI creates better awareness and provides us with the means to make decisions that are more informed and intelligent.

Data driven decision-making

The age of making calculations based on previous experience, educated guesswork and reasonable assumptions is coming to an end. Digitalization brings new opportunities, and with the vast amount of data now available, decision-making could not be more underpinned nor better informed. In the construction, quarrying and surface mining industries, it has great importance in terms of measuring the performance and general condition of on-site equipment. For example, drill rigs equipped with built-in sensors enable performance data to be constantly monitored which, in turn, makes it easier to ensure consistently high productivity. These sensors, mounted in key components such as hydraulic cylinders and electric motors, provide all the information the user needs in order to operate and maintain the equipment in the most optimized way possible.

Against this background, connectivity is key. With the wide range of technology that exists today – 3G, 4G, 5G, LTE, WiFi, cloud solutions for data storage and so on – we ensure that our products are constantly updated to meet the latest demands. And this not only means creating data collecting systems for certain types of equipment, a drill rig for example, but designing and building integrated communications systems that enable data to be shared seamlessly across different platforms, fleets and applications (Figure 2). For project supervisors who may be stationed many miles away from a worksite, this is invaluable as it gives them the possibility to manage the progress of their operations

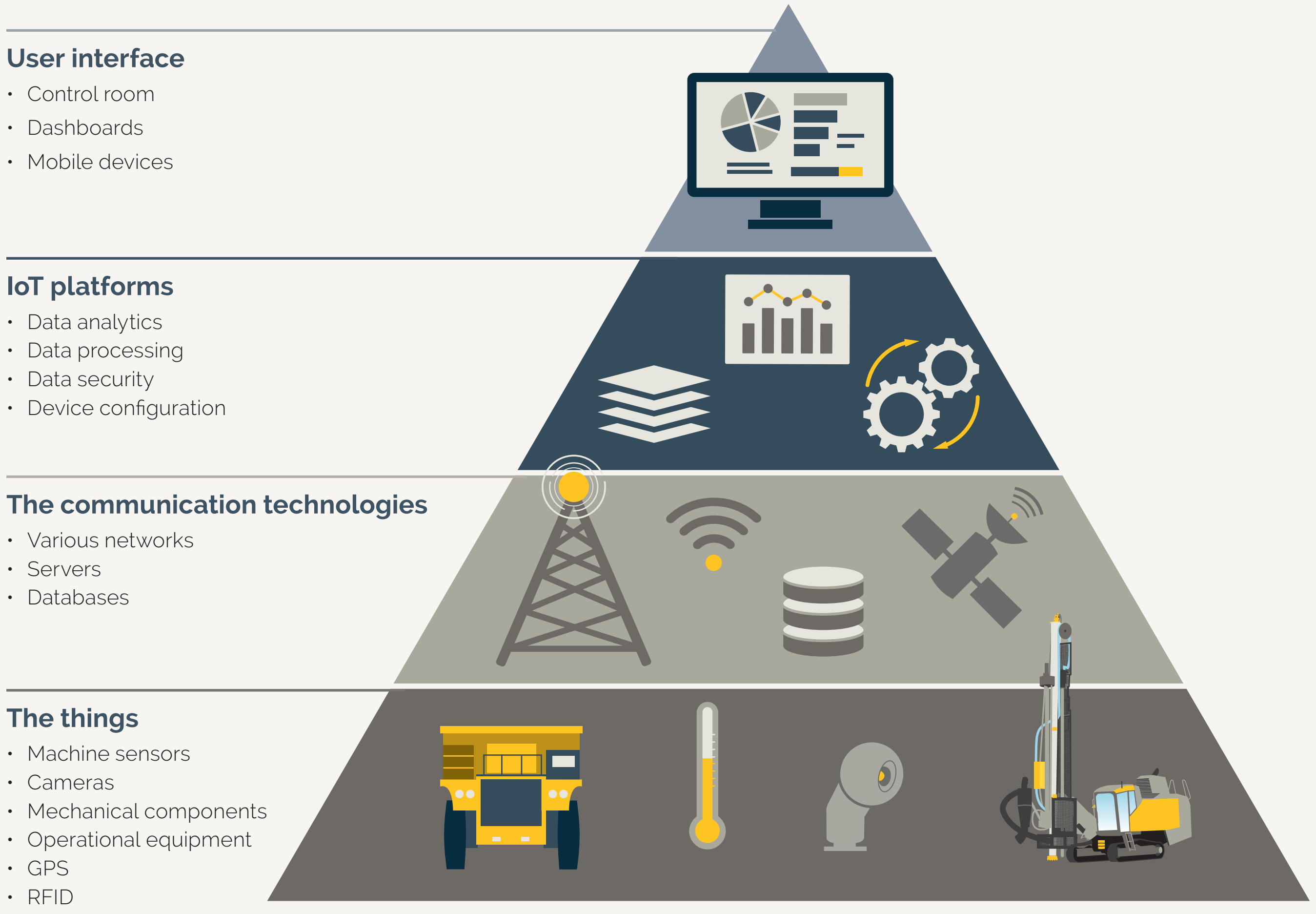


Figure 2: The Internet of Things technologies in mining.

by keeping track of performance as well as costs in terms of consumption of parts, maintenance and service needs. An added bonus is that the same data can also be shared by Epiroc's specialists who can assist the customer with decision-making to keep the operation as efficient and productive as possible.

Great strides

The digitalization of construction equipment such as Epiroc's range of SmartROC drill rigs, is making great strides in helping construction entrepreneurs to become more efficient and profitable, and lays the foundation for competitiveness in the years ahead.

The same goes for contractors in quarrying and surface mining where the greater the level of digitalization, in terms of connectivity, automation and autonomy, have a direct influence on safety, productivity, utilization and efficiency. For further inspiration and insight, it is useful to look at the difference that new technologies have made for Epiroc's customers in recent years. A good example is the company MAXAM, a leading contractor for drilling and blasting in Poland, which drills approximately a million meters of blastholes per year at quarries around the country.

With a view to reduce total operating costs, MAXAM invested in Epiroc equipment that took drilling performance to whole new level. Tools such as Measure While Drilling (MWD) and Hole Navigation System (HNS) increased hole accuracy and paved the way for continuous improvements. Total costs were reduced by 30%, largely due to reduced consumption of explosives and fuel compared with previous performance when poor quality holes needed to be remedied.

Digital solutions are rapidly changing mindsets and ways of working while unlocking unprecedented gains in drilling and blasting. Information is a powerful competitive tool and Epiroc aims to remain at the forefront of the technology revolution to ensure that drilling contractors obtain easy access to the data they need to make the best possible choices.

Read more about innovation and technology

Safe and ergonomic surface drilling

The days when safety and environmental features were considered secondary in fleet planning are long gone. Today, responsible surface drillers put these two issues front and center of equipment selection.

At Epiroc, we firmly believe that maximum performance and productivity can only be achieved by having safety, ergonomic and environmental solutions integrated in all rock excavation equipment. And that's why we place extra emphasis on these features in Epiroc's market-leading range of surface drill rigs. In this section we will review some of the latest innovations in the field of safety, which is a key part of overall drill rig design. When operators are working in a safe and comfortable environment, it allows them to focus all their attention on delivering good results.

Operator first

A safe and comfortable working environment enhances operator efficiency in every way. Although operators may be willing to tolerate old, inadequate operating systems, it has been shown that a well thought-out working environment is highly appreciated by operators, regardless of their experience level.

For this reason, Epiroc has partnered with external ergonomics experts from car and truck design. Together, we have applied a modern design language resulting in better, safer and more comfortable drill rig cabin interiors. The available space is large and even has extra storage to avoid cluttering the operators' work area. Cabins are equipped with efficient heaters as necessary and forced ventilation to prevent entry of exterior pollutants. The aim is not just to make the operator more comfortable but also to improve work performance.

Protection from rock fall and other flying rock is an essential feature of Epiroc's cabin designs. These are not only compliant with ROPS/FOPS standards but encompass a host of other features too. For example, the front window on all cabins is sloped at a reverse/negative angle, and all windows are fitted with safety glass. The rear window functions as an emergency exit and has hardened glass. All other windows are acoustic laminated to lower the noise level inside the cabin. This design provides all the protection the operator needs. The SmartROC cabins also provide protection from accidental explosions and flying rock. In addition, the cabins are 'dry' which means that the previous hydraulic pipes and valves have been excluded through all electronic controls connecting to the hydraulic systems on the exterior. This has greatly reduced noise, vibration and reverberation levels which were previously experienced by operators.

Figure 1: Easy access to service parts at eye-level, from a secure position, is crucial in drill rig design, not least for reaching parts that may need frequent attention such as filters.

Figure 2: A Radio Remote Control (RRC) unit for a FlexiROC T15 R. Using radio remote control where necessary adds safety and easier positioning in challenging locations.

Better ergonomics

Much has been said about good ergonomic design in construction equipment over recent years but rarely based on research evidence, and even less has been done about establishing correct standards. Bearing this in mind, Epiroc decided to develop its own internal standards together with external specialists, resulting in the Human Machine Interface (HMI) with a view to facilitate the most comfortable and efficient operating positions and movements.

When the operator is busy he or she may not notice a single excessive movement, but repetitions of such a movement throughout a working shift can certainly cause physical damage in the long term. This is where good design based on research comes in. Epiroc, together with the external ergonomics experts, studied the operator's natural hand and arm movements both with older style controls and with proposed new designs and arrangements to select the optimum human machine interfaces (Figure 3). The frequency and degree of repetitive movements in the drilling cycles were studied in detail to give early warning of possible long-term strain problems, and the work continues at pace.

Ergonomics does not end in the cabin. When maintenance is required, tasks are made much easier and safer if all necessary access points can be grouped together. In recent Epiroc rig designs all access points requiring frequent attention are grouped together in a lockable panel at a height that is between the waist and shoulders of 90% of the population (Figure 1). This ensures safety without any strain to reach service points. In older designs of various mobile rigs, high-level maintenance points have led to accidental falls if the operator loses concentration. All other maintenance points are located for the easiest possible access with similar aims. Drill steel and bit changing can be a particular problem for one-man rig operation and runs the risk of breaching local safe handling regulations. Therefore, Epiroc offers efficient and easily operated drill steel storage and changers.

Easier controls

Not only is push button control used wherever possible on Epiroc drill rigs, the SmartROC models have automatic control systems with more sophisticated software. Although there is no substitute for experienced operators, especially when working on difficult ground, these skilled experienced operators are in relatively short supply. The latest control systems make it easier for new operators to complete each hole with high efficiency. Today's rigs have become self-adjusting which, for example, means that decisions about the amount of feed to apply and when are made automatically, according to the detected bit performance. This greatly reduces the risk of bits and drill strings getting stuck, and mitigates drill string wear, further improving economy in consumables.

One definite advantage of easier controls is drilling accuracy. The finger-tip control buttons and optional automatic

Figure 3: Operator comfort and efficiency start with a well-designed cabin.

drill control and logging systems can more easily ensure accurate collaring and drilling progress to achieve the blast design spacing between holes and the required depth. In turn, this promotes more efficient blasting operations that can reduce the number of holes required, the amount of explosives used and/or the degree of subsequent crushing.

Greater stability

Wherever local safety regulations allow, a growing trend is that drill rigs are operated by one person since the rig operator can carry out most tasks efficiently. Drilling contractors visiting a quarry for a comparatively short time are a case in point. Clearly, if someone is operating the rig alone or at a remote distance from any form of assistance, work safety must be assured.

Tramming and positioning is potentially one of the most hazardous aspects of operations, particularly for a lone operator. Epiroc engineers have paid careful attention to his or her problem too within the overall rig design and operational advice.

Drill rigs today are increasingly designed to be as compact as possible, not only for easier road transportation between drilling sites if necessary, but also for better observation of the drill rig perimeter, to avoid collisions and hazardous areas, and to facilitate more accurate positioning. An additional benefit for operators working on their own is the rear view CCTV camera which gives a clear, all-round view of surrounding conditions and possible obstructions. Epiroc engineers have been designing or procuring smaller modules and components that aid the development of more compact drill rigs, including the packing of more useful power into a smaller space. The center of gravity on drill rigs is also designed as low as possible for better stability. As the drill feed could be a source of instability, the drill boom can be used as an active counterweight to improve stability during self-propelled tramming.

The crawler track itself is also very important for stability. Epiroc crawler chassis have oscillating tracks for better handling of rough ground, whether tramming or positioning. Occasionally a rig may have to operate in a position that may not be considered safe, whether due to the steepness of a slope or the proximity of a rock face, such as when breaking new ground. In such cases the oscillating crawler track again helps stability by creating a firm base for working (Figure 4).

For additional safety, certain models already have a Radio Remote Control (RRC) unit which means that operators can work from a safe distance, which may also give a better view of the drilling operation (Figure 2). The units are an alternative to on-rig, arm-mounted consoles on lighter cable-less models. Other safety options include a drill rig winch which can anchor the rig to the rock as an additional safety measure, which can also be useful in transit or when positioning the rig in extreme conditions.

When it comes to using remote control for cabbed drill rigs, Epiroc's advanced system BenchREMOTE gives surface drillers the ability to reinforce safety at hazardous worksites, for example where wall stability is a risk factor, or in difficult locations. BenchREMOTE can be used up to 100 m from the drilling area and 30 m above the rig's position and uses a series of connected cameras to provide the driller with a

Figure 4: Safe tramming over uneven ground with an oscillating undercarriage.

complete view of the site. The screen, joystick and control console are identical to the controls on the rig (Figure 4).

Dust

There may be a tendency among miners and quarry workers to tolerate rock dust as just a nuisance. But it can be far more serious than that, in some cases leading to breathing difficulties and lung disease. Rock dust with high silica content is especially dangerous. Excessive dust also poses a risk to the engine and other vital parts, which could be 'clogged up', leading to overheating, or subjected to excessive wear from abrasive dust. Epiroc's approach is to manage dust rather than rely solely on filters fitted on the rig, efficient though they are.

The operator and other workers nearby should also be protected from dust, which needs to be collected as near to the source as possible. Dust should either be collected or deposited in a manageable pile at the rear of the drill rig. Dust collectors are available as an option on all percussive drill rigs and come as standard on most models, including all models with cabins. Less dust spreading in the atmosphere also reduces the impact of operations on local residents or office workers near the drilling operation. As mentioned previously, the operator in the cabin has additional protection from dust as the cabin is force ventilated to create a slight positive pressure compared to the outside air. This prevents dust from entering the cabin. Naturally, high capacity air filters protect the engine and hydraulic systems, but tackling the dust problem in other ways avoids the overloading and excessive attention to this last line of defense, and reduces the need for unscheduled maintenance.

Quietly does it

Noise pollution has a negative impact on operators and anyone else within earshot. All Epiroc surface drilling rigs generate sound levels that do not exceed 80 dB(A) in the cabin. The cabins are very well insulated against both airborne noise and that generated or transmitted by the drill rig structure. For particularly sensitive areas such as urban blasting and near educational facilities or hospitals, special 'silent' rig models are available fitted with noise reduction kit around the drill and boom. These have generated great interest in the market as environmental regulations become stricter for surface drilling, to protect neighboring residential or commercial areas.

Vibration, which can also have a bearing on noise pollution, has been addressed in many ways by Epiroc, primarily by tackling the source of vibration rather than alleviating the effects. Modern engines run more smoothly and more economically than ever. In fact, thanks to the Rig Control

System (RCS) and a well designed hydraulic system, it has been possible to reduce engine speed with the SmartROC range at idle from 1 200 to 800 rev/min, which significantly cuts noise. The average engine speed while drilling has also been reduced without a negative impact on performance.

Fuelling debate

Fuel consumption is a major concern today due to rising oil prices, dwindling resources and the negative carbon footprint of fossil fuel in the fight against global warming. Apart from using the very latest Tier 4 Final/Stage V engine technologies, which have slashed CO_2, NOx emissions and particulate, Epiroc development engineers have made important strides by addressing overall system efficiency. As a result of nearly six years of intensive research and development, the new rig system platform has been introduced for nearly all SmartROC models. This greatly increases the energy efficiency of the machines, reduces the number of components, incorporates cabin improvements and reduces environmental impact. But that's not all – it greatly reduces the cost of ownership. The rig platform therefore bene-fits owners and operators as well as the environment as a whole.

The platform features a completely new way of controlling engine power. The system only delivers the exact amount of power needed for each operation, measured by the speed (rev/min) determined from the amount of oil needed by the hydraulic pumps and air from the compressor. This shift has introduced new types of hydraulic pumps and flow control methods for the compressor, rather than simply relying on pressure control.

The quest for reduced fuel consumption has made dramatic progress. In field tests using Epiroc's SmartROC drill rigs in Sweden, Poland and Turkey, an average reduction of 45% was achieved compared to similar equipment, without compromising drilling performance. Apart from saving fuel, carbon dioxide emissions were cut as well. Added benefits were an engine load reduction of 40–50%, which increases engine life expectancy, and a life extension of drill consumables of around 30%.

Hydraulics

The hydraulic system on the SmartROC platform has dramatically reduced the number of components. This includes 50% fewer hoses and 71% fewer fittings. The component interfaces are also of the plug-in type featuring soft seals. All of these achievements bring the 'leak-free' rig closer to reality. Again, this saves oil and minimizes oil losses that could contaminant ground and contravene increasingly enforced environmental controls.

Another advanced feature of the hydraulic system is the return line to the hydraulic oil tank. Here, a cyclone in the line pushes out air bubbles from the oil, reducing its volume and hence the necessary size of tank. This means the volume of oil required in the system is reduced by more

Figure 5: With the BenchREMOTE, an operator can control up to three drill rigs simultaneously.

than 75%. The feature can be fitted on all rigs regardless of size. Even Epiroc's filters have been praised for environmental care. The return oil and breather filter currently has no steel parts and can be discarded after use according to best recycling practices.

In the matrix

In different regions of the world and among different companies, drilling teams will have their own preferences regarding the level of sophistication in equipment fleets, to suit their operation and/or market conditions. Epiroc has adopted a product market matrix approach to its drill rig product range, cross-matching the level of sophistication and maximum productivity against customer value, thus presenting a wide variety of customer choices using standard components and systems.

The safety features mentioned above are complemented by new innovations on a regular basis. A protective guard is now mounted on most lower rotating parts while new technologies such as Auto Feed Fold revolutionize set-up and alignment procedures.

The drive toward smarter drilling practices is intensifying with Epiroc in the forefront. Whatever the application may be, surface drillers can rest assured that optimum care features for operator safety and reduced environmental impact are fully integrated into drill rig design, helping them to set a new benchmark for sustainability in all areas.

A new frontier in engine efficiency

Sustainability is without question a key concern in mining and construction operations today. Fortunately, great strides are being made in engine technologies – with Epiroc at the forefront of drill rig innovation and green thinking.

Epiroc has long been committed to sustainable productivity and protecting the environment in all phases of rock excavation. While this unwavering, fundamental value has always been highly appreciated by customers, companies are now turning the spotlight on sustainability as a fundamental building block for competitiveness.

In most parts of the world, environmental regulations and standards have become stricter than ever. At the same time, public awareness has penetrated everyday thinking, influencing habits and choices in the quest for sustainable solutions. This development is likely to define domestic and working lifestyles – from what we eat for breakfast to how we choose to travel to workplaces; from recycling household waste to decisions made about industrial activities such as drilling.

There is no difference in visual appearance on the Tier 4 Final/Stage V drill rigs.

Embracing Tier 4 Final/Stage V

Commitment means action. As a new industrial era begins based on smarter, more sustainable and data-driven processes, Epiroc is taking center stage. Apart from complying with the latest regulations for off-road diesel engines, Epiroc equipment benefits from the latest advances of Tier 4 F/Stage V-engines which significantly reduce emissions and particulate. This makes it easier than ever for customers to set goals for sustainability and reduce their environmental footprint in drilling operations.

A stepwise approach

In the global drive toward environmentally-friendly engine technologies, Epiroc has adopted the Tier 4 F/Stage V standard as the next step towards reducing emissions from off-road diesel engines. The name "Tier 4" comes from the U.S. Environmental Protection Agency (EPA) and equates to "Stage 3B" and "Stage 4" of the European Emission Standards and to "Step 4" of the Japanese regulations (Figure 1). "Stage V" is the latest European Emission Standard and, for the time being, there are no plans for a Tier V in North America.

These developments have represented a massive improvement on the technologies and processes used to reduce hazardous emissions including carbon monoxide (CO), hydrocarbons and nitric oxide (NO), emissions of nitrogen oxide (NOx) and soot particles (PM), all of which are harmful to both humans and the environment.

Tier 4 Interim was designed to reduce NOx emissions by 50% compared to Tier 3, and to reduce particle matter by 90%. The next stage, Tier 4 F, added a further reduction in NOx emissions of 80% compared with Tier 4 I. Not every country is affected by the same changes: each region follows its own approach and timetable with North America, Europe and Japan in the front line. Other countries to follow are China, India and most likely, Australia.

Environmental entities can perform audits to ensure emission level compliance on delivered drill rigs. The European Union's emissions standard Stage V came into force in 2019 and now applies to engine power below 56 kW and above 129 kW. From 2020, it will be introduced in the span between 56 to 129 kW. The Stage V standard has introduced a new limit for particle number emissions. The PN limit is designed to ensure that a highly efficient particle control technology—such as wall-flow particulate filters—be used on all affected engine categories. The Stage V regulation also tightened the mass-based PM limit for several engine categories, from 0.025 g/kWh to 0.015 g/kWh.

Talking technically

Engine manufacturers used one of two paths towards emissions reduction shown in (Figure 2) – either the "blue" way

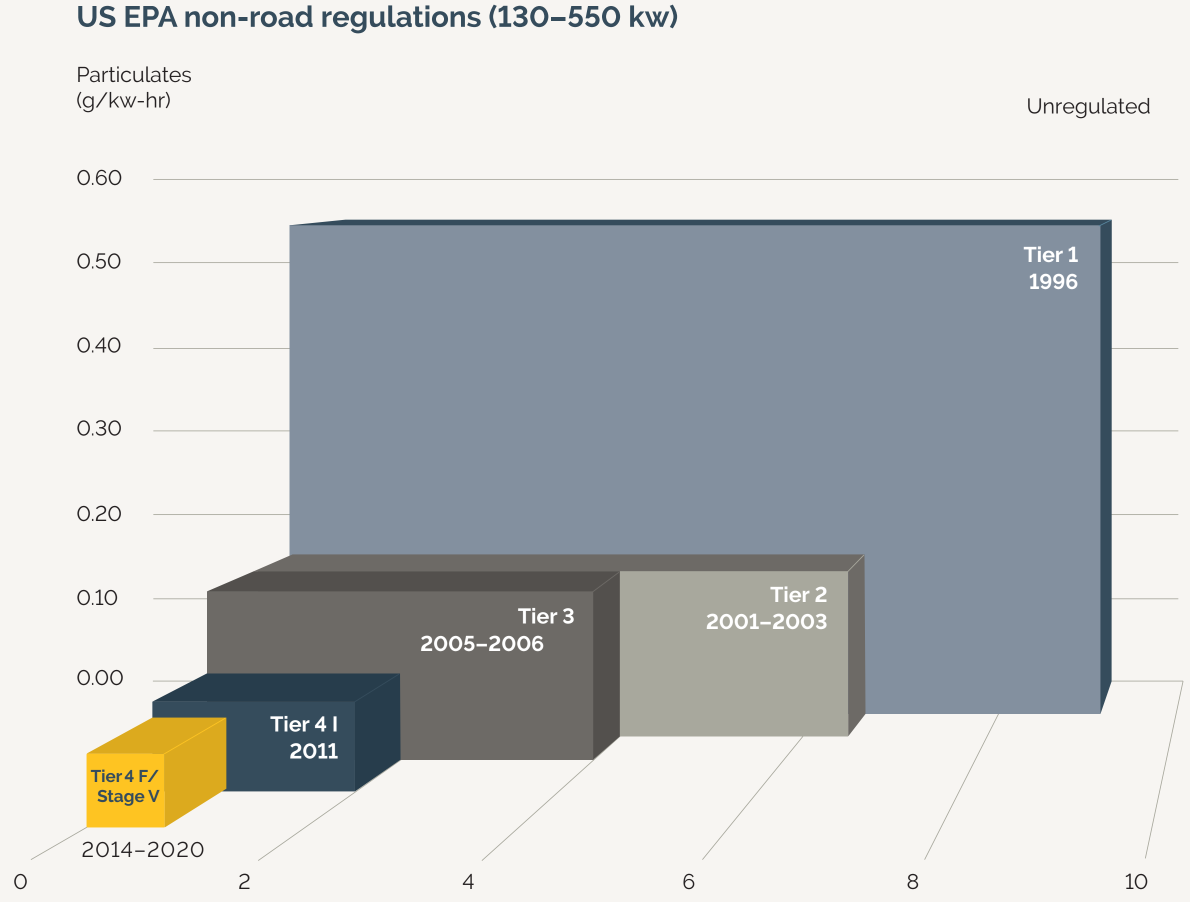


Figure 1: Step by step reduction of emissions.

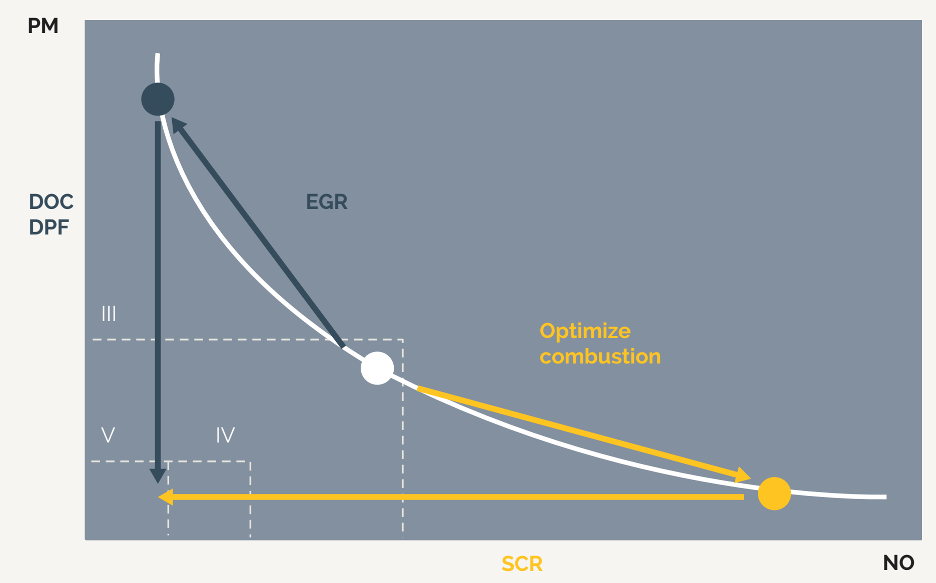


Figure 2: Paths towards emissions reduction.

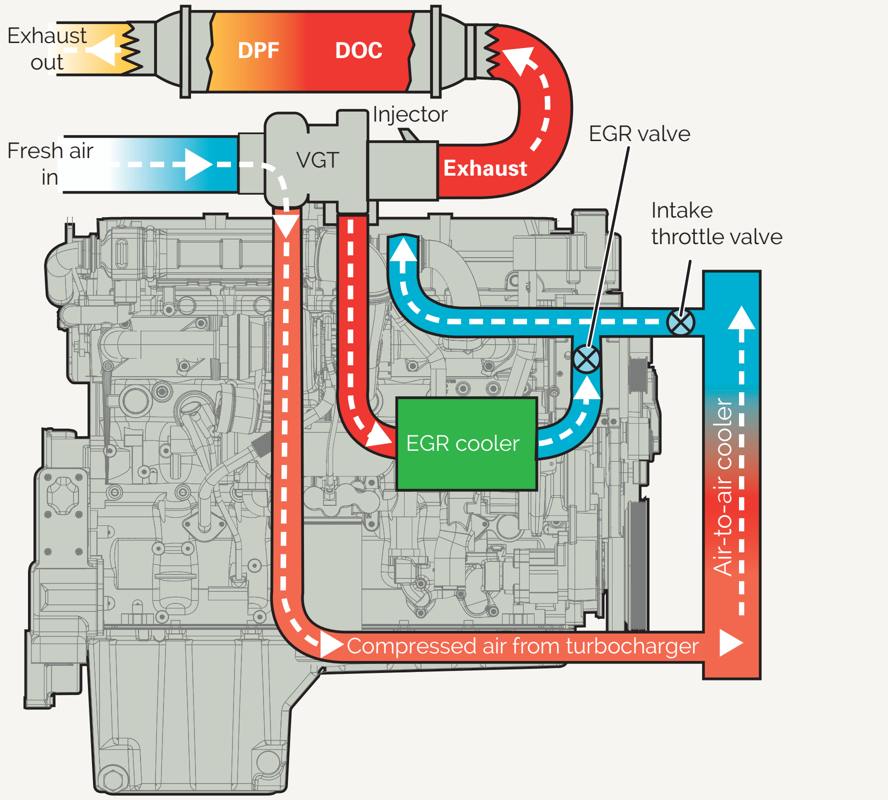


Figure 3: The blue way.

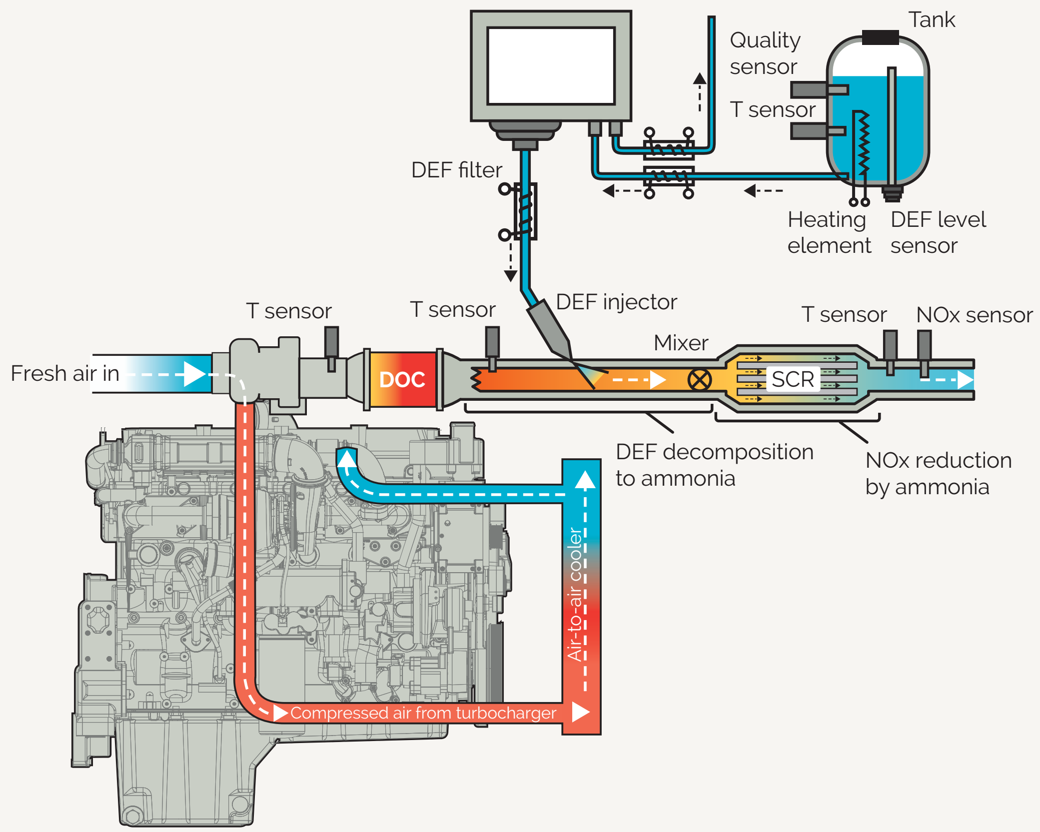


Figure 4: The yellow way.

shown in (Figure 3) or the "yellow" way shown in (Figure 4). Most engine manufacturers followed the blue path for Tier 4 I / Stage 3B development, especially on the engines used in Epiroc surface drill rigs.

The blue way explained

A DOC and Diesel Particulate Filter (DPF) are included in the exhaust system instead of the existing muffler and exhaust system. Pipes and placement may be different to Tier 3. In this case, a portion of the exhaust gas re-circulates back into the combustion chamber after cooling (EGR).

For the new Stage V and for Tier 4 Final most engine manufacturers combine the two paths, which means removing the EGR in order to aim for optimized combustion, while handling the higher NOx-levels with efficient SCR. The after-treatment system is now a complete system with DOC, DPF and an SCR system.

Some key definitions:

Exhaust Gas Recirculation (EGR): Cooled exhaust gas re-enters the cylinder to reduce NO_x emissions.

Diesel Particulate Filters (DPF): A DPF is used to remove excess particulate matter from the exhaust gas. This system consists of a Diesel Oxidation Catalyst (DOC) and a filter module, to remove 99% of the particulate matter; if any is left in the filter system it is subsequently burned in a process called regeneration. The DOC converts CO, hydrocarbons, and NO_x into carbon dioxide CO_2 and water.

Optimized combustion: High-pressure common rails are used to optimize combustion. These systems are extremely sensitive to contamination (dirt) in the fuel system.

Selective Catalytic Reduction (SCR): the nitrogen oxides (NOx), are chemically reduced to nitrogen N2 and water vapor in a special catalyst.

Diesel Oxidation Catalyst (DOC): Diesel Oxidation Catalyst, promote chemical oxidation of CO and HC as well as the organic fraction (OF) of diesel particulates. The DOC will also oxidize sulfur dioxide, which is present in diesel exhaust from the combustion of sulfur containing fuels.

A Tier 4 Final/Stage V engine installation.

Selecting the right tophammer drilling tools

Extension equipment for surface drilling is by far the most commonly used range of products on the market when drilling small to medium blastholes. Epiroc's comprehensive range of extension equipment includes everything from R25 rope thread equipment all the way up to T-WiZ60 trapezoidal thread equipment.

Four thread systems

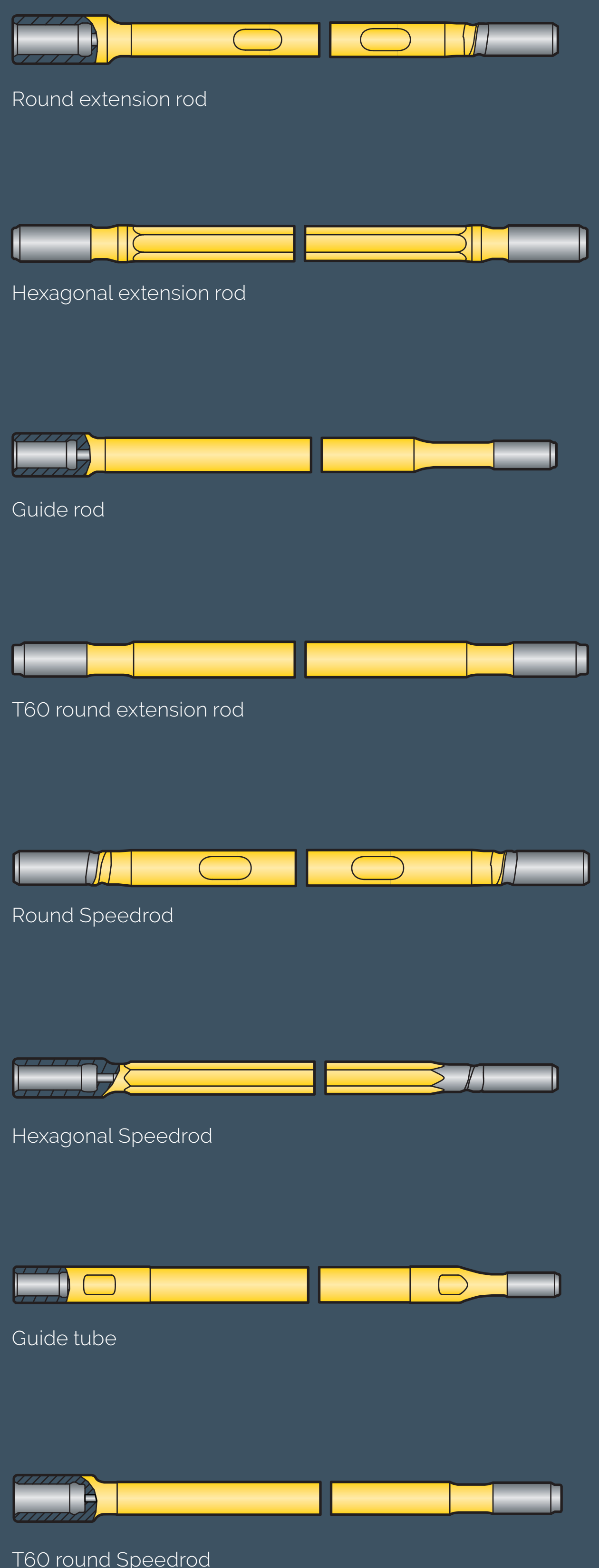
There are four types of threads used today: R and SR rope threads and T-WiZ- and TC threads. The R rope thread system is the oldest type of extension thread used. This rounded thread is ideal for rod sizes up to 38 mm (1.5 in). They are durable and easy to loosen or "break open". In larger rod sizes and especially in deep hole applications they can become very difficult to break open. The T-WiZ-thread system was therefore introduced. This thread is trapezoidal and is more durable and easier to loosen on rods above 32 mm (1.25 in) in diameter. Epiroc's patented Secoroc SR system is a conical rope design that has been very successful in underground applications. This system has been developed for modern high pressure hydraulic rock drills. It is now also being used in tophammer surface applications.

The TC-thread is a new conical system with trapezoidal threads. Based on the SR-concept, the TC-thread has been specially developed for surface drilling with high performance drilling rigs. These are ideal for straight holes from 48 mm (1.875 in) to 57 mm (2.25 in) in diameter (64 mm for drilling anchor holes).

Optimizing penetration rates

In order to achieve best possible penetration rate, a bit should be chosen where the total contact area between the cemented carbide and the rock creates the best possible penetration per blow. As a rule of thumb, the following penetration rate index can be used: button bit with full-ballistic buttons, 150; button bit with ballistic buttons, 130; button bit with spherical buttons, 115; insert bit, 100.

Figure 1: Rods and guides



However, when bits are compared for hole straightness, a different order emerges, with the insert bit on top followed by the button bit with ballistic buttons, and lastly, the button bit with spherical buttons. This article is intended to guide the driller through the range of bits, rods and shank adapters to assist with the best choice of rock tools for the particular job.

Drill bit selection

Button bits are used for 99% of surface drilling applications. When designing the Secoroc Powerbit, for example, Epiroc engineers have taken all aspects of drill bit technology into account in order to ensure the longest possible service life. The result is a button bit that can take on any type of rock. The shape is new and a stronger bit body steel has been used. The Powerbit technology has been so successful and effective that it has been patented several times over.

Easy bit selection

The Powerbit product range covers all types of rock – from hard to soft, and from abrasive to non-abrasive. Thorough research, simulation and testing have allowed us to make the Powerbit range much more compact and versatile than before. Approximately 30% fewer bits now handle all tophammer surface drilling applications – making bit selection easier than ever.

Drill rod selection

For bench drilling, three types of drill rods can be chosen: surface hardened rods, in which only the thread parts are hardened; carburized rods, where all surfaces including the inside of the flushing hole are hardened; and Speedrods which feature integrated couplings with male and female threads at opposite ends. Speedrods are offered in two versions; carburized Speedrods and Speedrods where the female thread is carburized and the male thread is surface hardened.

Surface hardened rods

Surface hardened rods, in which only the thread parts are hardened, are the toughest rods and can take more abuse than carburized rods. However, they have the lowest fatigue strength. They are a good choice when drilling in faulted or folded formations when driller abuse, or lack of care and maintenance, are factors in the drilling operation (Table 1).

Carburized rods

A carburized rod, where all surfaces including the inside of the flushing hole are hardened, has better wear resistance and a higher fatigue life compared to surface hardened rods. It demands good treatment and hole deflection should be limited by putting guiding equipment in the string, at least when drilling holes deeper than 10 m. The service life of carburized rods will be 20–30% longer if they are handled correctly and if guiding equipment is used when necessary. When lighter drill rods are required for manual rod handling, the carburized hexagonal rod is recommended (Table 1).

Table 1

	Surface hardened	Carburized
Hex. rods	R32, SR25, T-WiZ38, T-WiZ45, T-WiZ51	R32, R38, T-WiZ38
Hex. Speedrods	–	T-WiZ38
Round rods	R32, T-WiZ38, T-WiZ45, T-WiZ51	R32, T-WiZ38, T-WiZ45, T-WiZ51, T-WiZ60
Round Speedrods	R32, T-WiZ38, T-WiZ45, T-WiZ51	R32, SR32, R38, SR38, TC35, TC42B, T-WiZ35, T-WiZ38 T-WiZ45, T-WiZ51, T-WiZ60
Guide rods	T-WiZ38	TC42B, T-WiZ45, T-WiZ60
Guide tubes	–	R32, T-WiZ38, T-WiZ45, T-WiZ51, T-WiZ60

Figure 2: Standard, Full-bridge, Cross-over coupling.

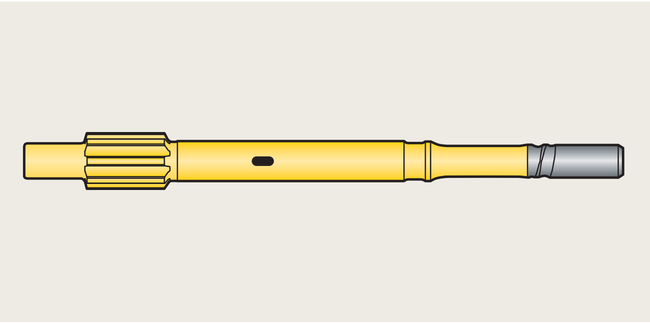


Figure 3: Shank adapter.

T-WiZ an ideal combination

The T-WiZ rods from Epiroc are specially developed for surface drilling applications. They are composed of selected steels that boost service life and enable superior performance. The female thread is fully carburized while the rest of the rod is surface hardened – providing the ideal combination. These rods are friction-welded, so that the best steel grade can be selected for each section. The T-WiZ drill string offers up to 30% longer service life, which means fewer rod changes and more productivity per shift.

Round extension rods and round Speedrods

Round rods are available in two different models: round extension rods and round Speedrods. The difference between the two is that round extension rods have "male" threads at both ends and need a coupling sleeve to enable the string to be extended. In contrast, round Speedrods use an MF thread, i.e. a "male" thread at one end of the rod and a "female" thread at the other. This makes the coupling sleeve redundant and facilitates quicker and easier rod changes. Round extension rods and round Speedrods are used as standard from R32 to T-WiZ60. They are the most common rod models available today for surface drilling. Originally called MF rods, they are also manufactured today by most of the major OEMs (Figure 1).

Hexagonal ext. rods and hexagonal Speedrods

Hexagonal rods are available in two different models: hex extension rods and hex Speedrods. They differ in the same way as the round rods mentioned above. The hexagonal rods are available as R25 and R28 and are similar in construction to taper rods. Hex extension rods are also offered as a lightweight option on T-WiZ38 and T-WiZ45 when manual rod changes are needed. The hexagonal Speedrods are available as R25, R28 and SR28.

Guide rods and guide tubes

The Epiroc range of guide rods and guide tubes helps drillers avoid unnecessary hole deviation. They provide higher accuracy than standard rods, which means higher productivity and reduced risk of rod breakage. The difference between a guide tube and a guide rod is the level of hole straightness needed at the quarry or mine.

For example, a T-WiZ38 guide rod has 7 mm larger diameter than a standard drill rod. Hole deviation is minimized as the space between the guide rod and hole decreases. This particular guide rod increases the flushing velocity while also improving rock cuttings removal. In tricky rock formations with a high risk of hole deviation, guide tubes are the best option (Figure 1). The diameter of the T-WiZ38 guide tube can be as large as 64/76 mm which is 26/38 mm diameter larger than the standard T38 rod. This enables deviation to be reduced almost to zero. Guide tubes are too thick for a drill rod cassette and, therefore, are mounted first on the drill string.

Thanks to straighter holes made possible by Epiroc guide tubes, drill and blast contractors can reduce explosives consumption and achieve smoother bench floors, minimized secondary drilling and optimal fragmentation of rock, not to mention the longer service life of the entire drill string.

T-WIZ60 round extension rods and round speedrods

T-WiZ60 is built to handle the most powerful hydraulic rock drills, delivering higher power output for optimization of the drilling pattern. The entire drill string is more rigid which enables increased hole straightness, higher penetration rate and a boost to drilling productivity and economy. Featuring a cross-section 40% bigger than standard T-WiZ51 rods, the T-WiZ60 rod is designed to reduce hole deviation in all rock formations. The flushing hole is also bigger, ensuring a 10% increase in flushing capacity for up to 30 m deep holes.

Couplings

There are three types of couplings; standard, full-bridge and cross-over. Standard couplings are threaded the whole length of the coupling but with a slight bridge in the middle. The connecting rods are tightened so they meet in the middle of the coupling. As this coupling wears, there is an occasional tendency for the bridge to wear down and the coupling to thread its way along one of the rods. This can be eliminated by choosing the full-bridge version. As the name suggests, there is a bridge in the middle of the coupling. The rods are tightened against this bridge forming a better connection. The cross-over coupling is a full-bridge coupling designed to connect two rods of different sizes (Figure 2).

Energy transmission

When drilling with a number of rods in a string, using standard rods and couplings, the loss of energy in every joint is about 3–6% if the connection is tight. When drilling with open threads, the energy loss at each joint can easily climb to 10%. Therefore, it is advantageous to use the maximum rod length possible. If Speedrod carburized rods with integrated couplings are used, the energy loss per joint is less, since the mass (weight) of the joint is less than that of standard coupling joints. The energy loss is about 3.5%, which is 60% of that of standard joints.

In practice, the energy advantage of Speedrod joints compared to standard couplings is even greater, since it is easier to keep the Speedrod joint tight during drilling. Field tests have shown that, when drilling 20 m holes with 4 m rods, the penetration increase is approximately 15% when using Speedrods. Faster penetration and easier handling increases the productivity and, thanks to better energy transmission, the joints are easily loosened. Rods that are as rigid as possible for the drilled hole diameter are the best choice for drilling straight holes. A guide rod, or guide tube, should be used as the first rod after the shank adapters.

Shank adapters

The task of the shank adapter is to transmit rotation torque, feed force, impact energy and flushing medium. It is made from specially selected material that withstands transmission of impact energy and rotation from the rock drill to the drill string, and is hardened through carburizing. Around 400 different shank adapters are currently available from Epiroc (Figure 3).

Powerbit Surface.

Introducing T-WiZ

Epiroc has launched the latest innovation in T-thread drilling systems, T-Wiz, which offers up to 30% longer service life. The T-WiZ range of drill strings combines T-WiZ Speedrods and T-WiZ shank adapters in a system that enables fewer rod changes and more productivity per shift.

Wear out before breakage

T-WiZ is a tough system that provides excellent thread stability. It is robust enough to prevent product breakage in the blasthole. This means a shift in focus from time-consuming rod and shank changes to maintaining a much leaner stock.

Boosts bench and production drilling

Whether used underground, in surface mines or on construction sites, the impact of T-WiZ is far more than noticeable. It is ideal in tough formations and fractured rock where it enables greater thread stability and faster rod changes. T-WiZ unlocks a real boost in productivity. Thanks to higher capacity, it drills more holes per shift, while opening up the possibility for quicker blasting and a more rapid advance. With lower labor costs, minimized stock, less admin and fewer rods and shanks in circulation are further advantages. In short, T-WiZ helps drillers to set a higher performance standard.

The T-WiZ drilling system comes in three diameters; T-WiZ35, T-WiZ38, T-WiZ45 and T-WiZ51 Speedrods and shank adapters designed for extension or drifting drill strings. The Epiroc range of tophammer bits matches the T-WiZ drilling rods well – with the added benefit of being easier to release and change.

Read more about tophammer drilling tools

Selecting the right DTH drilling tools

Epiroc manufactures drill rigs and develops systems to suit all rock types and has the experience to recommend the most suitable approach to all ground conditions, which enables optimum performance and results.

In addition, Epiroc offers the most comprehensive range of Down-The-Hole (DTH) hammers, bits, and related equipment of any supplier in the world, backed up by the strongest support network in the industry. Whether drilling contractors need reliable hammers that keep investments to a minimum, or highest possible productivity to ensure maximum rig output, Epiroc has the solution.

With premium performance and advanced technology, the new M-series of 152 mm (6 in), 178 mm (7 in) and 203 mm (8 in) hammers offer superior productivity, sustained performance, high reliability and outstanding fuel economy. All together, this means the lowest total cost per drilled meter than any other DTH hammer.

All hammers in the M-series are modular and available in two different versions depending on the air package on the drill rig and/or the altitude of the drilling worksite.

Figure 1: COP M-series – Modularity and flexibility

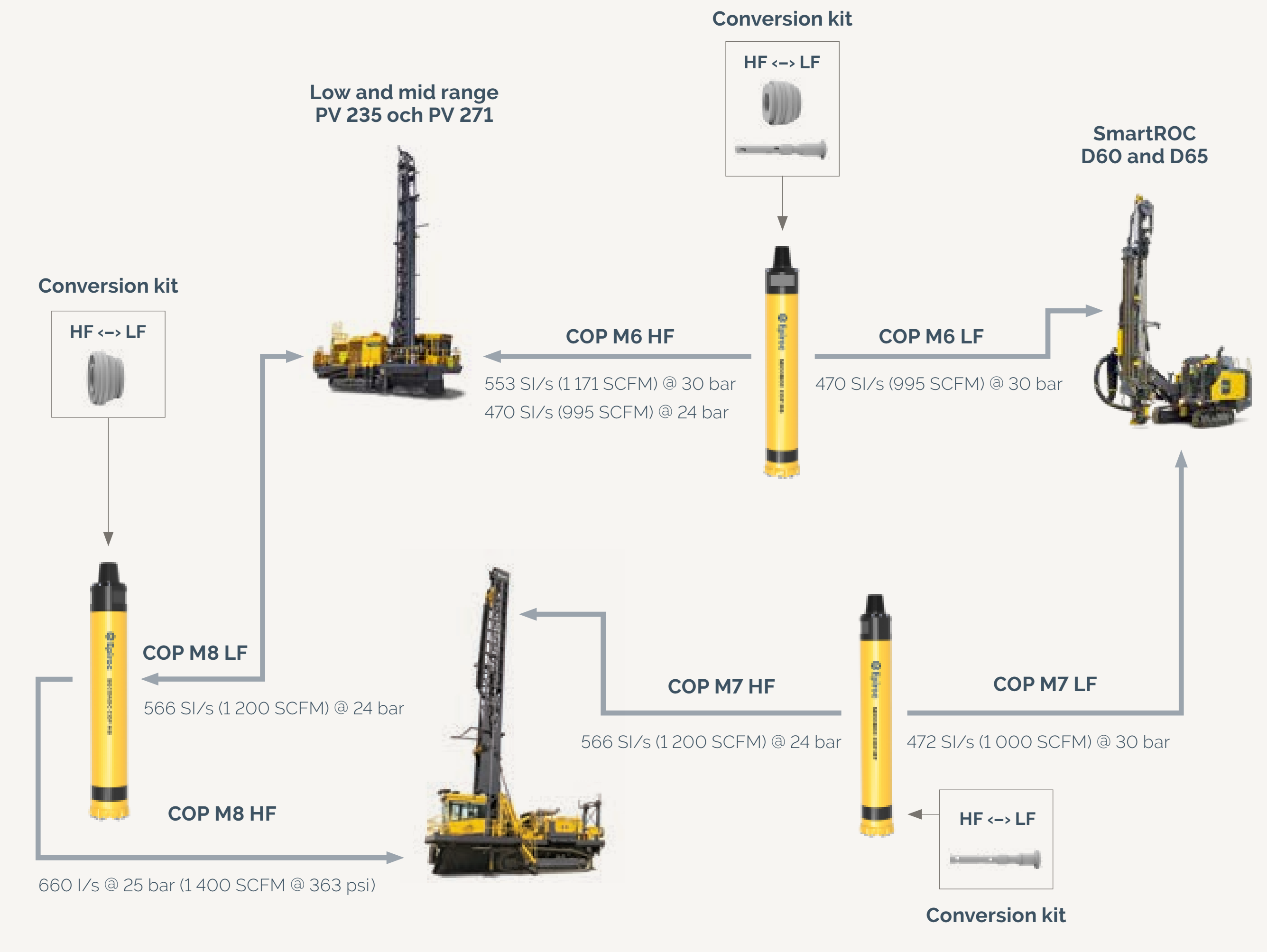


Table 1: M-series hammers

Bit sizes	mm inch	165 6.5	171 6.75	200 7.875	203 8	216 8.5	222 8.75	225 8.875	229 9	241 9.5	251 9.875	254 10	279 11	305 12
Hammer type	COP M6													
	COP M7													
	COP M8													

Selecting the right bit for M-series hammers

Each hammer has its optimum drill bit size and the M6 hammer will be most productive with bit sizes 165–171 mm. Larger holes can be drilled using bits up to 216 mm for special applications where productivity is not the main focus.

For the M7 hammer, the optimum bit size is 200–219 mm and for special applications up to 254 mm. The M8 hammer is best utilized in the 222–241 mm range with 305 mm as a maximum size for special applications (Table 1).

For the 127 mm range (5 in) the COP 54 Gold is outstanding for customers demanding the highest productivity. These hammers are recognized as the most reliable and productive hammers in this category of hammers.

Epiroc COP W4 is our premium hammer in the 102 mm range (4 in) range with a more than 10% increased productivity compared to the "old workhorse" COP 44, considered to be the best ever 102 mm (4 in) hammer.

For the 76 mm (3 in) range, the COP 35QLX, a time-tested and field-proven design, offers good productivity and ease of service. Dimension stone quarrying demands consistent hole straightness, and these operations typically use smaller size holes of 90–105 mm in limestone, granite and marble.

Normally, a DTH-hammer used in production drilling should be replaced when it has lost 10% in net penetration rate. The total drilling cost per meter increases drastically when productivity drops. All Epiroc hammers have the rebuild option with an E-kit, a kit consisting of external and internal wear parts (Figure 2). This is a valuable option particularly in abrasive to medium abrasive formations. With unique combination of highest quality in design, production and material, the hammers can be rebuilt with sustained performance.

This series of DTH drilling tools is accompanied by an extensive network of distributors and customer centers that offer a complete range of parts, service and support.

Mineral exploration

Mineral exploration takes place in very remote locations, requiring robust hammers capable of running high pressures, in sometimes dirty environments. When using reverse circulation (RC) drilling with face collection and in-pit grade control, the Epiroc range of RC hammers, perform particularly well.

Open-pit mining

Mining operations typically have high equipment utilization, drilling up to 80% of the working day with DTH. The typical applications are normally 130–254 mm diameter blastholes, 140–171 mm buffer holes, or 115–140 mm presplit holes.

Selecting the right hammer

The optimum range of hole size for DTH drilling is 90 mm (3.5 in) to 254 mm (10 in). Smaller holes are generally drilled using tophammer drill rigs, and larger holes generally use rotary drill rigs.

As a rule of thumb, the smallest hole diameter a DTH hammer can drill is its nominal size. In other words, standard 102 mm (4 in) hammer will drill a hole down to a minimum diameter of 102 mm (4 in). The limiting factor is the outside diameter of the hammer, because as the hole diameter reduces due to diameter wear of the bit, air flow is restricted. Maximum hole size for production drilling is the nominal hammer size plus 25 mm (1 in), so for a 102 mm (4 in) hammer the maximum hole size is 127–130 mm (5 in).

Choosing the right hammer is largely determined by type of application, hole size and type of rock formation. Ideally, the size of the hammer should match the required hole dimension as closely as possible, leaving just enough space for cuttings to evacuate the hole efficiently.

Epiroc hammers are purpose-matched for all rock types and applications where high performance and low total cost per drill meter are the main criteria. The standard design is a suitable choice for production drilling in quarries, shallow waterwell drilling, and underground blasthole drilling. For demanding conditions in abrasive formations, the QM (quarry master) version is the optimum selection. It has the same internal components as the standard, but with larger outer diameter of the chuck and wear sleeve, and a top sub-fitted with tungsten carbide buttons for wear protection in harsh and abrasive conditions. These also protect the top sub from excessive wear when rotating out of the hole through broken rock.

Highest performance

The Epiroc M-series, Gold and QLX hammers are designed for the most demanding drilling conditions and for applications that require premium performance. These hammers feature state-of-the-art technology and deliver both maximum productivity and profit.

Benefits of the COP M-series:

- Superior longevity and reliability
- No foot valve means less breakdowns
- Solid bit shank
- 30% lighter compared to standard hammers
- Shorter and lighter makes series operator-friendly
- Easy to service and rebuild
- Best suited for production drilling thanks to excellent external wear resistance and longevity
- Internal components coated for wear and corrosion protection. Permits multiple rebuilds
- Three start chuck thread for easy bit changes
- Bit replacement possible without using drill rig break-out chains and wrenches

Benefits of the COP Gold and QLX-series:

- Superior longevity and reliability
- Easy to service and rebuild.
- Suited for production drilling thanks to excellent external wear resistance and longevity
- Internal components coated for wear and corrosion protection. Permits multiple rebuilds
- Three start chuck thread for easy bit changes
- Bit replacement possible without using drill rig break-out chains and wrenches

Selecting the right bit

While not an easy task, choosing the right bit is essential for good drilling results. Epiroc has the most comprehensive range of DTH drill bits to match all conceivable applications. Each bit is made from quality alloy steel and has been precision-machined to produce a perfect body, heat treated to the required hardness, given surface compression for fatigue resistance, and fitted with precision buttons manufactured in-house.

Selecting the optimum bit design is probably the most critical choice in order to achieve lowest total cost per drilled meter. There are bits designed for specific applications in all rock types, hardness and conditions. Bit life and rate of penetration are the most important criteria in selecting the right bit for an application.

In order to find the most suitable design for customers, several design features are involved including bit size, bit front, button shape, button diameter, number of buttons and position, protrusion of buttons, carbide grade, cutting removal, backout buttons, side buttons, hard facing, flushing hole size and position. Buttons are available in different sizes, shapes and unique Epiroc grades for compounds such as tungsten carbide, even used in combination for different rock types depending on hardness and abrasiveness.

In most cases, productivity is the key focus which means an emphasis on features for fast cuttings removal to ensure the buttons are clean when in use. This helps to minimize recrushing which is crucial. In hard and abrasive formations, a strong gauge with large spherical buttons is needed to withstand wear and tear. In softer, non-abrasive rocks ballistic buttons are preferred to achieve high productivity. Bits are manufactured to match all diameters of all Epiroc hammers. The Epiroc range of DTH bits ensures that every driller can demand a solution for every application.

Selecting the right tube

Key features of a high quality DTH tube are durability, accuracy and manageability. Epiroc tubes are made from cold drawn tubing, providing a superior surface finish and tolerance compared to conventional tubes made from hot rolled tubing.

This drastically reduces the risk of scaling from tubes entering the hammer, a major cause of premature hammer failure. The joints are friction-welded to achieve maximum strength, and the threads of the end pieces are heat treated for optimum durability and strength of the thread profile. This not only ensures long thread life, but also makes coupling and uncoupling quick and simple which reduces drilling time.

The tube diameter should be close to the hammer diameter in order to provide optimum flushing and reduce the risk of getting stuck. Epiroc also offers a wide range of subs and crossover subs to meet an array of demands, all manufactured to the same standards as the tubes. Different thread designs are also available including API, BECO and the Z-thread. The robust Z-thread is preferred by many customers in demanding drilling conditions in mines and quarries.

COP Backhammer

The COP Backhammer is a tool that can save and recover a drill string that is stuck in a hole. It can be fitted easily in a suitable tube joint between the drill support and the rotation head to provide an effective combination of backward hammering and vibration to loosen stuck drill strings.

Selecting the right oil

Lubrication is critical for the sustained performance and reliability of the hammer. Using the wrong oil can easily damage the performance of even the best hammer. Epiroc Rock Tool Oil is specially developed for DTH drilling to ensure a minimum of internal wear for sustained performance, protect the internals from rust and, being degradable, to minimize environmental impact.

Service and support

Epiroc service, support and training follows every purchase to ensure that customers extract maximum productivity from their drilling operations. Having a knowledgeable Epiroc drilling engineer on site or on-line makes the difference between going it alone or tapping the experience and know-how of a world class partner.

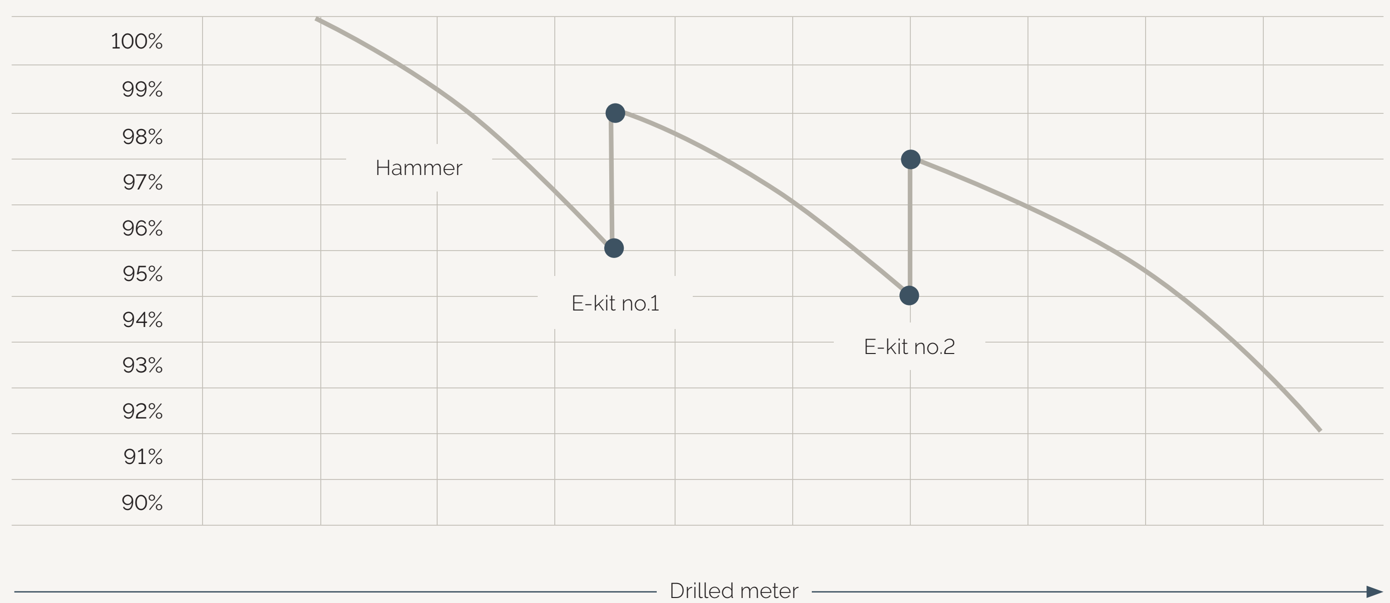
For example, Epiroc knows that using high productivity bits reduces the cost of each drilled hole, and the simplest way to cut costs is to drill holes faster. This has been a focus of product development and is at the core of Epiroc technology – ensuring that every generation of products drills faster and more efficiently.

It takes a support team to apply this knowledge, so that customers can be assured they run a profitable and efficient drilling operation in an increasingly competitive business climate. That's why customers worldwide rely on Epiroc service and support, supplied by the largest, most dedicated manufacturer of DTH drilling.

Read more about DTH drilling tools

Selecting the right DTH drilling tools

Figure 2: Sustaining the performance of DTH hammers



Why routine bit grinding is a good idea

Drilling quality holes with maximum straightness and cost efficiency depends on a range of factors, not least the utilization and service life of button bits. Regrinding bits at regular intervals can make all the difference to the drill and blast lifecycle.

The button bit was originally developed to do the job of an insert bit, without the necessity for frequent grinding. However, it was soon found that the service life of a button bit increased considerably if the cemented carbide buttons were reground. Nowadays, it has become extremely important to grind button bits at fixed intervals, in order to extend the service life of the rock drilling tool, maintain penetration rates, and drill straight holes.

Cutting hole costs

In all rock excavation operations, the cost is usually expressed in cost per drilled meter (cost/dm), in cost per cubic meter (cost/m^3), or in cost per ton. The cost to produce a hole depends on how fast it can be drilled, and how many tools will be consumed. The cost of producing a cubic meter of rock depends on the cost of the hole, and the cost of blasting. If the blasthole is of poor quality, more explosives will be needed to blast the rock. Unsharpen bits result in very poor quality holes with deviation. Grinding accounts for around 2% of the costs of the entire drilling operation. To run the business without grinding could multiply this cost, with up to 100% added when production losses are taken into account. Labor and material represent the highest costs, while machine investment cost is low when utilization is high, with a large number of bits to be ground.

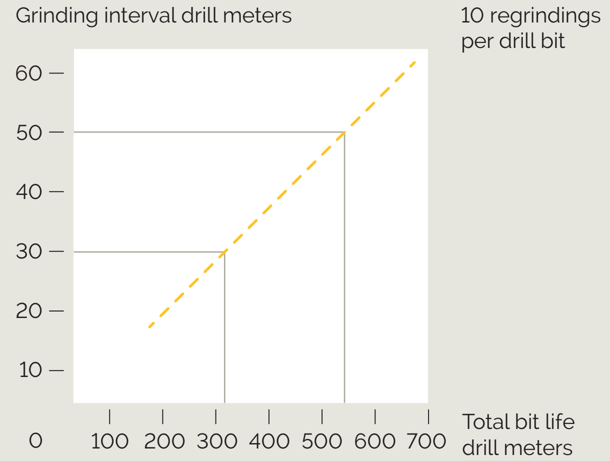


Figure 1: Typical bit life grinding at different intervals.

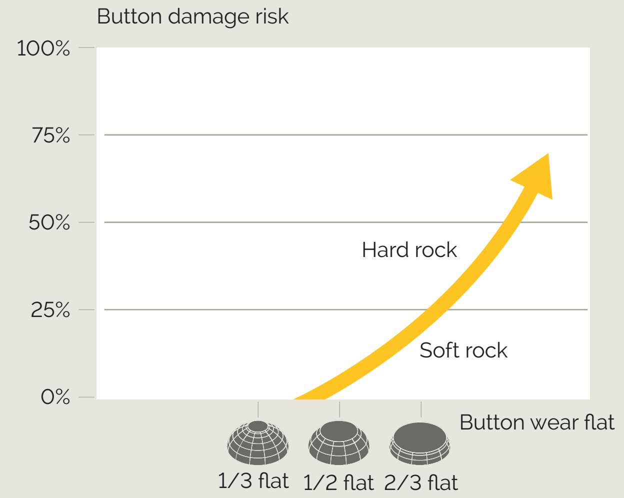


Figure 2: Risk of total loss when a bit is overdrilled.

Grinding methods

There are two different ways of restoring buttons from bit grinding. The preferred method uses a diamond coated profiled wheel, and the other, a grinding cup. The profiled wheel provides a smooth and efficient grinding operation, which, throughout its life, maintains the correct button shape and protrusion. It features correct centring on all buttons, producing a high quality cemented carbide surface, with no risk of cemented carbide nipple. Good quality grinding will result in longer bit life and higher penetration rates.

A disadvantage of using the grinding cup is that it may produce an incorrect button shape and protrusion, resulting in a lower penetration rate. Furthermore, there is also a risk of producing a sharp cemented carbide nipple on the button. Several tests have been carried out to establish which method provides the best bit performance. The grinding wheel gives the correct shape to the button, regardless of the amount of wear on the wheel, ensuring that the bit will achieve acceptable penetration rate throughout its entire life. Results have also shown that bit life increases considerably when grinding wheels are used, rather than grinding cups. Wheels also excavate steel around the button, simplifying the grinding task, while giving the bit a more exact profile.

Bit life

With so many parameters involved, it is difficult to estimate bit service life. First, a proper grinding interval must be established, preferably at the stage when the button has a wear flat of one third of the button diameter. When the number of drilled meters to reach this stage has been established, a calculation of bit life can be made by multiplying the number of times it can be reground.

As a general rule, a bit can be reground 10 times, but smaller bits may achieve slightly less than this figure, while larger bits may achieve more. So, if the grinding interval has been established as 60 drill meters, then the average bit life will be 660 drill meters (Figure 1). If a bit is overdrilled, and the wear flat is more than half of the button diameter, there is a tendency towards cracked buttons.

There is always a sharp edge created on the button, and this becomes sharper the more the bit is overdrilled. This sharp edge, especially on ballistic buttons, is very brittle. Once the edge cracks, pieces of cemented carbide break away and circulate in the hole, causing secondary damage to the buttons. When a bit doesn't show any visible wear flat, it may still be suffering from micro cracks on the cemented carbide surface. This is known colloquially as snakeskin, and can be clearly seen when using a magnifier. In this case, the surface has to be ground away, otherwise the micro cracks lead to more severe damage on the buttons. Likewise, buttons that protrude too much must be ground down to avoid damage (Figure 2).

Penetration rate

When the right bit has been chosen for the rock condition, it will provide maximum penetration rate, along with acceptable hole straightness. In rock conditions such as Swedish granite, with a compressive strength of around 2 200 bar, the bit gets a wear flat after just 10–20 drill meters, accompanied by a small drop in penetration rate. When it has a wear flat equivalent to one-third of the button diameter, the penetration rate will have dropped by 5%. If the bit is used further until it has a two-thirds wear flat, the penetration rate will have dropped more than 30% (Figure 3).

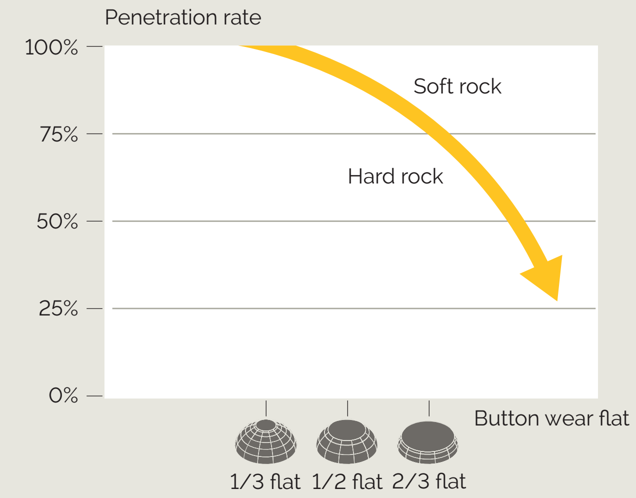


Figure 3: Penetration rate drops as the button profiles flatten.

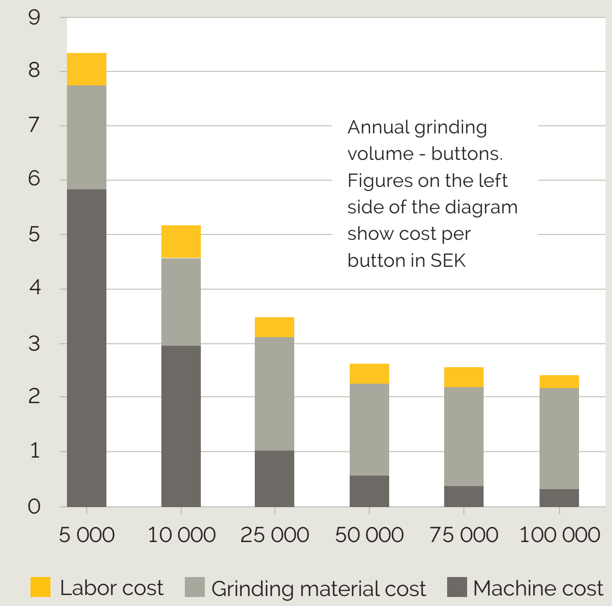


Figure 4: Cost of grinding reduces dramatically with volume.

When a bit has a heavy wear flat it tends to deviate, and, by the time it reaches the bottom of the hole, it will have deviated far more than planned. As a result, the blast will produce coarse fragmentation and extensive secondary blasting may be required. In slope hole drilling, it is of utmost importance that straight holes are drilled. If the holes deviate, the slope walls will be uneven, making rock reinforcement more difficult than expected. Rock formations with different layers and joints are often characterized by heavy hole deviation, putting extra stress on the remaining rock tools in the drill string. A sharp bit always cuts better, and will prevent deviation and its disadvantages.

Grinding machines

Two parameters guide the selection of the right grinding machine; the number of bits or steel to be ground and whether the machine should be portable or stationary. Several types of grinding machines are available to satisfy these parameters. In most cases, a simple machine will suffice for a small operation, grinding only a few bits.

The semi-automatic machines are more suitable for larger operations, such as mines and construction sites, where the machine can be stationary, and the rock tools can be brought to it. Grind Matic HG is a water or air-cooled handheld machine for grinding cups. Spherical, ballistic and Trubbnos cups are available. The machine is driven by up to 7 bar compressed air, and is suitable for a small grinding operation.

Grind Matic Manual B is an air-driven portable grinder using diamond-coated grinding wheels for spherical, ballistic and Trubbnos buttons. The machine is mounted in a box fitted with wheels and handles for easy set up. This is made for threaded button bits. A steel spring is mounted in the profile of the grinding wheel where it functions as a centring device, allowing for easy grinding.

Grind Matic Manual B-DTH is similar to the Grind Matic Manual B. It is mainly intended for DTH- and COPROD bits, but can also be used for threaded bits with a special bit holder.

Grind Matic RH3 is a very flexible grinder that can grind both threaded, tapered, DTH- and COPROD bits, in spherical and Trubbnos versions. The hole range is from 35 mm to 171 mm.

Grind Matic BQ3 is a fast semi-automatic machine, with many features such as efficient working light, optimal cooling nozzle, soft start of grinding table, water filter and sleeve coupling for ventilation plus all features the previous version had. These features, coupled with an ergonomic design, ensure high productivity, and the machine is designed to handle large volumes of threaded button bits. Cooling water is recycled after the waste product has been separated in a container, thus making the cooling process more efficient.

Grind Matic BQ3-DTH is the fastest grinding machine for mainly DTH and COPROD bits. It can also be used for

Bit grinding in the field with a Grind Matic RH3.

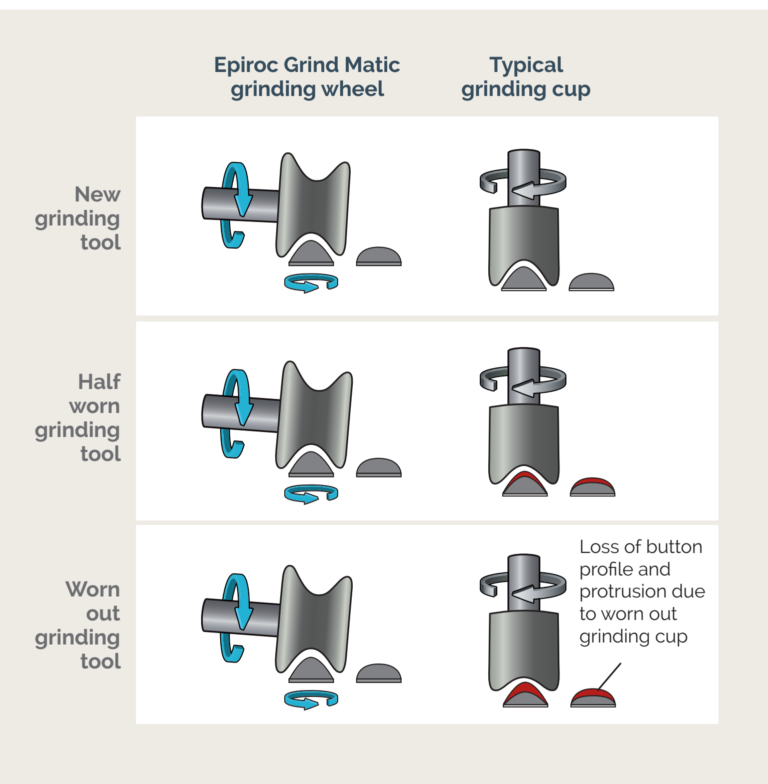


Figure 5: Comparison of grinding wheel with grinding cup.

threaded bits with a special bit holder. The machine has the same features as Grind Matic BQ3, and can grind bits up to 178 mm (7 in) diameter. Grind Matic Senior and Swing are grinders for integral steel.

Grinding advice

The Epiroc Grind Matic grinding machine's secret of success is that both the grinding table and the diamond grinding wheel rotate. This results in perfectly ground button surfaces, regardless of the buttons' profiles.

In addition, the machine's unique diamond grinding wheel is designed to ensure even wear on its grinding surface, while still retaining its profile. This, in turn, guarantees the button shape throughout the life of the wheel.

Epiroc's advice is to use Grind Matic machines, with profiled diamond grinding wheels, for grinding button bits. It is the only solution capable of consistently delivering perfectly shaped buttons on customers' bits, which gives longer service life to all rock drilling tools, rock drills and drill rigs.

Correct grinding is important for every drilling operation, particularly in these days of cost consciousness and fierce competition. It can make a world of difference to the bottom line.

Grind Matic Manual B.

Grind Matic BQ3.

Grind Matic Manual B-DTH.

Grind Matic BQ3-DTH.

Grind Matic RH3.

Grind Matic HG.

Parts and services – the backbone of high availability

No piece of mechanical equipment, however intelligent and well-designed, can perform to the best of its ability all the time without genuine parts and regular servicing. That's why Epiroc's parts and services are easily found worldwide.

These days, smart drilling companies rarely buy a drill rig. They buy a function, or indeed a service – consistent, high productivity at the lowest total cost and with maximum flexibility.

In response to this demand, Epiroc engineers select the best combination, tailor-made for every individual task. The package generally consists of hardware, software and, not least, ready access to original parts and services irrespective of where in the world the customer may be at work.

Over more than 150 years Epiroc has built a global sales and service network and we now serve customers in all corners of the world. This means that wherever drillers are at work, they can count on Epiroc's full support in our mutual effort to keep productivity up and costs down.

No question

The importance of using original parts and regular servicing can never be overstated. Without these elements, no mechanical equipment, however advanced and skillfully built, can be expected to perform well in difficult environments, year after year.

But there are many other aspects to a complete support package that may sometimes be overlooked. Here, we explore at some of the most important elements of the Epiroc portfolio of parts and services:

Rock drills and rotation units

These are core components of Epiroc drilling systems and to ensure safe and efficient operation, they are fully supported through replacement units, spare parts, rebuild kits and service tools.

Figure 1: Reman cylinders from Epiroc feature the latest and greatest improvments to your mining equipment.

Replacement parts and kits

Genuine replacement parts are engineered to ensure proper, safe and easy maintenance in compliance with Epiroc's quality standards. Kits are sophisticated combinations of genuine parts designed to streamline maintenance operations. The portfolio includes wear parts, replacement parts, preventive maintenance kits and repair kits.

Reman solutions

This is Epiroc's remanufacturing service, providing remanufactured components for a wide variety of equipment (Figure 1). All reman solutions are developed to meet demands for continued sustainability, safety, reliability and minimal down-time and are covered by a warranty policy. In addition, the customer receives:

- An Original Equipment Manufacturer (OEM) certified quality
- Quality approvals with traceability documents
- Components that have been rigorously tested on purpose-built test equipment

Service agreements and audits

In cooperation with our customers we have developed different solutions aiming to enhance operations, improve performance and productivity and give equipment owners and managers peace of mind.
These include visit agreements, audits and on-site agreements with technicians stationed full time at customer worksites.

Telematics

Certiq is our telematics solution that gathers, compares and communicates vital equipment information. The system collects important data from individual drill rigs as well as entire fleets, providing detailed and instant overviews of drilling performance, fuel consumption, wear and tear, service needs and much more. It is available for most mining and construction drill rigs, both on the surface and underground.

Midlife services

Flexibility is a key building block of Epiroc's parts and services strategy. That's why midlife services are offered in three different categories filled with options to increase productivity – Midlife Basic, Midlife Plus and Midlife Tech+.

Customers can choose if they want standard parts replacement or an advanced upgrade which lays the foundation for automation.

The ability to provide first class support to drillers on worksites all over the world has become just as important as delivering first class equipment. To meet this demand, we focus heavily on a truly global service organization and worldwide network for the distribution of parts.

In the years ahead, Epiroc aims to continue developing technology-driven services that reinforce productivity and safety even further.

Read more about parts and services

Case stories

For more case stories, plaese visit **epiroc.com**

Looking for a revolution?

The Hollinger mine in Canada is where it all happens. This is an open pit gold mine located in downtown Timmins, a city with a population of 45 000 in the province of Ontario. This site is part of Newmont Goldcorp Porcupine's operations in the area. Once the remaining gold has been recovered, this mine will be transformed into a public park. But for now, it is a gold mine in full operation and center stage for the latest innovation in surface drilling automation.

Ever since the first industrial revolution in the late 18th century, innovation and technological development have been aimed towards making human life easier, safer and more efficient. With the advent of steam and water power, electricity, assembly lines and computerization, the possibilities for mass production steadily increased.

We have now entered into the era of the fourth industrial revolution, also known as Industry 4.0. This sprint includes technologies such as cyber-physical systems, the Internet of Things and the Internet of Systems. It is predicted that these new technologies will have an impact on all industries and economies. The rock excavation industry is no exception.

As a company that not only adopts the latest technology but aims to lead the development of innovation in our industry, Epiroc recently reached an important milestone. Together with our long-term partner Newmont Goldcorp, we have now put the world's first fully autonomous SmartROC D65 surface drill rig, in production.

Let's take a minute to contemplate what that actually means. Traditional surface drilling requires a person to physically be in the cabin while operating the drill rig. Alternatively, the operator can be in the vicinity of the drill rig with a radio remote control or with Epiroc's remote operator station, BenchREMOTE.

What is unique about this latest achievement is that the surface drill rig, SmartROC D65, is now able to drill an entire pattern autonomously. The operator can be located in an office, several kilometers from the work site. However, given that there is an internet connection, this office could potentially be located on the other side of the globe.

When the perimeter of autonomous operations, also known as the geofence, have been set up, the SmartROC D65 is good to go. Within this area it can carry out the required operations needed to drill not just one hole autonomously, but a complete drill pattern. This means that the drill rig can tram to and position the feed foot correctly at the collaring point. It then drills the hole to the desired depth and will also handle rod change during the drill cycle. When the hole is drilled and the rods are retrieved, the rig moves on to the next hole until the entire drill pattern is completed.

Not only will this remove the operator from potentially hazardous benches in a mine or a quarry, it will let the operator carry out other tasks while the rig is drilling. Other benefits are increased productivity and better hole quality. When the SmartROC D65 is used for autonomous drilling, it will put more holes in the ground per shift. In part because automating the drilling process results in continuous operations without breaks and with less wear on drilling tools. In addition to this, positioning is faster and more accurate. This is all made possible since autonomous drilling employs already existing technologies developed by Epiroc.

Mayya Popova, Product Manager Automation at Epiroc explains: "To make this work we are using the smart functions on the drill rig that are already there. Since we developed these functions over the years we have a good understanding of how to incorporate them in the autonomous mode. I'm talking about functions such as the Rod Handling System, the Hole Navigation System and Auto Positioning. Of course, some mechanical modifications and an upgrade of the Rig Control System is also required."

Most autonomous operations still need human monitoring and this paves the way for a new generation of drill rig operators. Annie Levasseur is one of the first operators in the Hollinger mine to work with the autonomous SmartROC D65. She has been operating surface drill rigs the traditional way for many years and is now embracing the new technology.

"In my opinion, this is awesome. After our morning brief, instead of spending 30 minutes going by truck to the drill rig down in the pit, I just go to the office upstairs and start it up. I'll check the drill rig status, load the drill pattern and I'll be up and drilling in a matter of minutes."

She continues. "Operating the drill rig this way, I'm not concerned about my own safety and I can be more efficient. For example, I can prepare for sampling while the drill rig is working autonomously on the drill pattern. Also, the working environment in this office is obviously more pleasant than down in the pit. By not having to go from warm and cold temperatures even my asthma has actually gotten better."

When visiting the Hollinger mine, it immediately becomes clear that safety is a top priority for Newmont Goldcorp. Since this priority is shared by Epiroc and the fact that operator safety is one of the main benefits of autonomous drilling, the successful partnership between the two companies comes as no surprise.

Shahn Cybulski of Newmont Goldcorp Porcupine shares his view of the project. "The most important part for me as Fleet Management Coordinator at Newmont Goldcorp Porcupine is basically to ensure the safety of all personnel entering the Hollinger open-pit operations. As well as maintaining the highest level of productivity possible."

"Newmont Goldcorp and Epiroc have entered into this project for the same reasons. Both companies strive to be at the forefront of innovation and development in the rock drilling industry. We currently have two SmartROC D65 autonomous drill rigs running in the Hollinger open-pit and to date I have yet to see any downside to this project."

In the age of Industry 4.0 that we have now entered, the boundaries between digital, physical and biological is getting more and more hazy.

From the smartwatch on your wrist to fully autonomous SmartROC D65 drill rigs in an open-pit gold mine. If you're looking for a revolution - look around you. Or take a trip to Timmins, Canada.

Annie Levasseur, drill rig operator.

Her view in the office.

The fully autonomous SmartROC D65.

Battling the mountain

Anglo American is turning to remote-controlled operations of mining equipment to protect personnel at its El Soldado copper mine in central Chile.

Reached through a road winding up to the peaks of the Coastal Mountains, the El Soldado may be one of the country's oldest mines but it is testing technologies that will shape the industry's future.

People have been mining the El Soldado for copper since 1889. Many of the people working here were recruited from the surrounding towns and villages, including Nogales and El Melon, while others commute from Santiago or the beach resort of Viña del Mar, 76 kilometers away.

An underground mine until just a decade ago, the hillside is pitted with tunnels and shafts from over a century of subterranean activity. But nine years ago, the diversified mining group Anglo American, which acquired El Soldado in 2002 when it bought the copper operations from oil giant Exxon, made the decision to switch to open-pit mining to extend the life of the mine. This has brought its own challenges. A decade of open-pit mining has turned the side of the El Soldado mountain into a series of gray, dusty terraces descending from the ridge towards the green valley below.

While organized in sections, elsewhere one can see where the fractured massif has crumbled, sending stones and boulders tumbling down the hillside. As a result, personnel are constantly on the lookout for signs that the rocks all around them are shifting.

Although El Soldado is small compared to the giant copper mines that make Chile the world's largest producer of copper (it produces just 50 000 metric tons a year of copper in cathodes and concentrates versus the 400 000 tons produced annually by Anglo American's Los Bronces mine), it has other advantages.

"The ore grade is high at 1%. That's practically unheard of in an open-pit mine in Chile, today," explains Mine Manager Hernan Rodriguez. "But, the high grade of the ore is related to structures and faults in the rock," he says.

The enormity of the challenge became apparent when a huge section of the mine wall collapsed five years ago, sending 400 000 metric tons of rock crashing down. No one was hurt, but the rockslide prevented staff from accessing key areas of the mine and severely hampered production. "It almost forced us to close the mine," explains Rodriguez.

The company instead looked for workarounds to the challenging geological conditions. Four radars constantly monitor the hillside for the tiniest movement that can indicate when a rockfall or collapse is imminent. When the alarm goes off, workers and equipment are evacuated.

But this can significantly hamper operations, with some areas of the mine closed off for days and weeks at a time. So, the company begun looking to new technologies, such as automation and remote control equipment, that would allow it to continue blasting and extracting the valuable ore without putting people in harm's way.

"The company installed a remote-controlled hydraulic shovel and is looking to add a remote-controlled bulldozer," says Rodriguez.

Meanwhile, explosives supplier ENAEX will test a robot device to load blasting holes. One of the most critical tasks at El Soldado is presplit drilling, which seeks to ensure a clean cut when blasting. But the work must be performed right under the pit wall, exposing rig operators to rock falls and other dangers. So, last year Anglo American acquired two Epiroc SmartROC D65 drill rigs that can be controlled remotely from a vehicle located in a safe part of the mine using Epiroc's BenchREMOTE system.

With support from Epiroc technicians, Anglo American personnel have become skilled in using the system, ensuring that a critical task can be performed regardless of the conditions on the ground. Thanks to these new technologies, El Soldado is now looking ahead to the future, and is currently seeking environmental approval to lift the height of its tailings dam, which would enable the mine to remain in production until the end of 2027.

"As well as providing a solution to complicated geological conditions and bad weather (the mine loses approximately 34 days a year to sea mists rolling in off the Pacific Ocean), automation also improves productivity since machines do not tire as the shifts goes on and ensures parts last longer since they are no longer exposed to jolts and misuse that human operators can impose," says Rodriguez.

The personnel also appreciate not being exposed to the noise, dust and vibration that come with standing next to a powerful drill rig. Anglo American is now looking to install the BenchREMOTE system in a building onsite so operators can do their vital job in even greater comfort.

Process optimization with SmartROC C50

SmartROC C50 with COPROD technology helps the customer Max Bögl to optimize their operation.

The family-owned company Max Bögl, founded in Neumarkt 1929, is one of the largest construction companies in Germany. Around 6 000 people are employed in the fields of building construction, civil engineering, road construction, tunneling, civil engineering, infrastructure projects, wind energy and raw material extraction. In total the Max Bögl fleet consists of around 1 000 large machines including excavators, dumpers, compactors etc. The company also owns two Atlas Copco COPROD drill rigs, a ROC F7 and a new SmartROC C50.

> "When choosing our suppliers, we place particular emphasis on individual offers and competent counseling."
>
> **Christoph Zimmermann,**
> Max Bögl Roh- und Baustoffe

In the area of raw material extraction Max Bögl is operating gravel, sand and dimensional stone quarries throughout Germany. The development of the quarrying industry in Germany is very much connected with construction projects. Regional, social and economic developments are also affecting the construction industry and, accordingly, the production of raw materials. In Germany, the production of raw materials has been constantly developing, whereas the natural stone industry has seen a rising trend. This is due to the higher demand for sustainable products. In order to keep up with this trend the Max Bögl Group is always working on optimizing the operation of these quarries and is therefore looking for equipment that improves operational processes with a special focus on occupational health and safety.

Looking at drill rigs it is important for the Max Bögl Group, that the machine itself consists of quality components and is durable. However, the main focus is still work safety and the people. The drill rig needs to be equipped with the latest safety and ergonomic standards, the control has to be easy and intuitive. Ultimately, all relevant employees from the operator to the purchaser are involved in the decision making process to guarantee that only the best fitting equipment is being acquired. The quarry manager Christoph Zimmermann is convinced that these requirements are met by their two Atlas Copco COPROD drill rigs, a ROC F7 and a SmartROC C50. Other advantages of the machines, from the perspective of the Max Bögl Group, are "the quality drill steel and the longevity of the machine." Using the ROC F7 for more than 17 years the Max Bögl company was able to experience the longevity of Atlas Copco drill rigs themselves. The initial decision to buy the ROC F7 with the COPROD drilling system was mainly influenced by the geological conditions. The fissured rock with high quartzite content caused severe hole deviation and presented special challenges for the production process, since blasting and crushing are directly affected by the drilling results. Another problem was the excessive wear on the drill bits and the jamming of rods in the hole. This resulted in a drastic increase of consumables costs. After a demonstration with the ROC F7 CR, it became clear that the COPROD system will be able to solve these problems by producing quality holes with reduced wear on drill steel and bits.

Therefore, the expectations of the new machine were very high. So far the SmartROC C50 was able to live up to these expectations, since it proved to be a high quality, robust and compact drill rig with many advantages. "The COPROD system is simply ideal for our Rock conditions with a high Quartz content. Further we were also excited by the new technology and electronics of the SmartROC C50.", says Mr. Zimmermann. This aspect is especially of importance since the rigs are used in three different quarries with challenging geological formations like gneiss or granite.

> "Operational cost reduction, innovative technology, operator comfort and sustainability aspects were ultimately the decisive purchasing factor."
>
> **Christoph Zimmermann**,
> Max Bögl Roh- und Baustoffe

Operational facts about the Max Bögl SmartROC C50

- COPROD 76
- 95 mm ballistic bits
- Hole depths between 15 and 33 m
- 250–350 m drill meters per shift
- Fuel consumption of 0.53 liters per meter

Max Bögl´s focus on "sustainability" is also supported by using the SmartROC C50. The fuel consumption has been reduced enormously allowing to lower exhaust emissions and operating costs in the long term. The operators benefit from the intuitive Atlas Copco control system, as well as from their ergonomic design. With these benefits the job satisfaction of the operator has been increased along with the productivity throughout the entire operation. Another reason for Max Bögl, represented by Mr. Zimmermann, to recommend Atlas Copco drill rigs is the excellent relationship between the two companies. The key to the successful cooperation over the years has always been the fair communication among each other and the great service coverage.

Epiroc operated under the trademark "Atlas Copco" prior to January 1, 2018.

Muffled rig solves sensitive problem

At St. Göran's Hospital in Stockholm, a project requiring extensive blasting work is in progress. Moving rock close to a hospital filled with sensitive equipment, patients and staff, requires careful planning - and a drill rig with reduced noise level.

Between the start of Skanska's rock drilling work early in February 2017 and the middle of March 2018, around 100 rounds were fired. Before the blasting was complete in spring 2018, around 200 blasts were carried out. This corresponds to around 10 000 m³ rock mass.

In this strictly controlled building project, there were fixed times for blasting. For each blasting, there were at least ten guards stationed for extra safety. Around 30 vibration meters were positioned around the hospital to monitor the blasting.

The blasting work was required for the construction of new culverts, foundations for two new hospital buildings, and a new ambulance entrance. The renovation work also included existing hospital buildings, such as the rebuilt administrative offices, a new radiography department, new operating theatres, and BB room and maternity unit.

"If we hadn't had a muffled drill rig, we couldn't have carried out the work. That was a condition imposed by Locum and the hospital from the start. Before the project started, we bought an Epiroc FlexiROC T30 R – a medium-size drill rig specifically for this project and suitable for work in tight urban environments."

Carita Broberg, Project Manager, Rock, at Skanska Roads & Construction

During the building process, activities in the hospital continued largely as usual. The greatest challenge of the project was the sensitive environment. Great consideration was required for patients, staff and sensitive equipment. The technical equipment includes magnetic radiography machines, the hospital's switchgear systems, computer tomography systems etc.

To achieve the high requirements, extensive planning and risk analysis were required. Because of the sensitive environment and lack of space, excavation of the rock was sometimes carried out with steel cutters or splitters (cracking). These are sometimes the only alternatives for minimizing vibrations.

"The planning was focused on how we could carry out the work safely with great care for the environment and minimum disruption," said Robin Andersson, who is Skanska's blasting manager for St. Göran's Hospital.

"They didn't know we had already drilled"

As well as the detailed planning, the muffled drill rig played a very important role in fulfilling the high requirements. A positive effect of the reduced noise level of the drill rig was noticed as soon as drilling had begun. "The drill rig was so quiet that the people working in the hospital didn't know that we'd already started drilling."

Rig operator Gustav Andersson sees a range of other benefits from using a muffled drill rig, most of which concern the environment.

"The most positive effect is for your health, above all from the reduced noise level. I can talk to my colleagues while the machine is drilling", said Gustav Andersson. He also thinks that the attached noise reduction kit gives a cleaner working environment with less oil waste and less effect from cuttings.

Brings great advantages

There are many advantages, but Carita Broberg also sees certain challenges for the operator.

"It can be difficult to drill close to a wall or piling because the muffler takes up space. It can also be difficult to see what's happening at the drill base, since the drill operator can't see the collaring site properly."

Carita Broberg points out that a muffled rill rig brings great advantages in a project such as this, which would otherwise not have been possible. If Skanska had more muffled drill rigs, more jobs for them would be found. "There's a lot of talk about investing in a new rig in the future", she said.

Epiroc operated under the trademark 'Atlas Copco' prior to January 1, 2018.

Facts about the project

St. Göran's Hospital has been extended and modernised to meet the healthcare needs of Stockholm's growing population. Locum AB, property administrator for Stockholm's Regional Council, has concluded a collaboration agreement with Skanska for the construction of two new treatment buildings and the renovation of existing buildings.

Limak Holding

- The Yusufeli Dam and Hydroelectric Power Plant Project, built in the Çoruh basin, will be Turkey's highest dam at an elevation of 275 meters
- The total storage volume will be approximately 2.2 billion cubic meters
- The power plant will generate 1 888 billion kilowatt hours of energy annually

River deep mountain high

Limak holding is innovating for success in challenging conditions. With a height of 275 meters, the Yusufeli Dam is a construction project of epic proportions. Its remoteness and size place great demands on contractor Limak Holding. Epiroc rigs are helping the company to meet these efficiently.

From a distance, driving through the valley, it looks slightly surreal. Small dots float in mid-air, slowly moving away from the mountainside. On closer inspection it's no less intriguing. The bigger dots are drill rigs, while the smaller ones are platforms and other pieces of equipment. All the objects are being carried downwards by a cableway connected to either side of the valley.

"We are working in tough geological conditions and this pushes us to find alternative methods for the continuity of our operations," says Atilla Coskun, Machine Supply Chief of Limak Yusufeli Dam Construction.

The bottom of the valley would normally be filled by water from the Çoruh river, flowing from the mountains of the eastern Anatolia region – referred to as "the roof of Turkey" – to the Black Sea. Since 2013, however, this has been a huge construction site. When operational, tentatively in 2020,

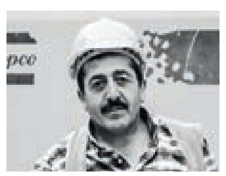
the Yusufeli Dam will be able to store 2.2 billion cubic meters worth of water and the underground power station will generate almost two billion kilowatt hours of energy.

Limak, Cengiz & Kolin JV was awarded the contract to build the dam. Limak Construction Company is responsible for

Innovation is key in challenging projects. A cableway was built to get the equipment in place.

Atilla Coskun
Machine Supply Chief, Limak Holding

Mustafa Doğan
Operator, Limak Holding



Mikail Celik
Operator, Limak Holding

Limak Holding

- Limak Construction was founded in 1976 and has specialized in all types of infrastructure and superstructure projects
- Operating in 10 countries
- Approximately 66 000 employees
- Ranked 85 in the ENR (Engineering News-Record) top 250 international construction companies list

both the dam and the power station construction, facing many challenges along the way. A big one is to make sure that the walls of the dam stay intact.

Operator Mustafa Doğan positions the SmartROC T40 drill rig at the bottom of the basin wall. Parts of the wall are covered with concrete boxes, placed in a check pattern. He drills a hole in the wall and repositions the rig to the side.

"The next step, using another machine, is to place a rock bolt in the hole," says Doğan. "Then dolly devices are put round it, so that the pressure from the rock is distributed over a bigger area."

He gestures at the check pattern on the wall. "That's the boxes, covered in concrete."

The anchor drilling is a way of dealing with the unstable rock conditions on site. Pieces of rock falling from the walls would pose a great danger during construction of the dam, so keeping everything in place is hugely important. Horizontal drilling is more difficult to perform than vertical drilling, but the flexibility of the SmartROC T40 makes it possible, which is a big bonus for Limak Holding. This is not least due to the folding boom, which enables the rig to reach further – thus covering a larger area – than other rigs.

"Basically, I can make an extra row of holes – so there's more drilling and less tramming. Also, it's easy to make holes of very high quality. I perform drilling operations of 35–40 meters per hour during a shift on a partly hard rock."

Rock bolts aside

There are many more figures that show Limak Holding's gargantuan task. For instance, 86 kilometers worth of roads – including tunnels – will be built, and more than 3 000 people are working on the project. The natural valley is very deep, but in order to build the dam Limak Holding has to remove a lot of rock when shaping the dam body. The level will be lowered by 275 meters.

"At this point, the level we're operating at is roughly 500 meters. We're planning to lower the dam body from 715 to 440 meters above sea level."

Coskun continues:
"The rock quality – as in hard and fractured formations – and the climate have a negative impact on operations. Being aware of the challenges we would face here in Yusefeli, we were very selective when it came to choosing equipment. For instance, saving fuel in such a big and longrunning project is vital."

Limak has used Epiroc equipment many times in the past. Its first collaboration was on the Devoll Hydroelectric Power Plants in Albania, and Limak has partnered with Epiroc for a number of dam projects in Turkey. For the Yusufeli project, various brands were compared during the pre-purchasing period, after which Limak decided to proceed with the SmartROC T40 as the main drilling rig. A total of nine SmartROC T40 rigs are being used on site, as well as two older-generation SmartROC rigs, five Boomer 282 and three Boomer L2 D rigs.

"Epiroc gave us a commitment that the SmartROC T40 would provide fuel savings of up to 40 percent. At first glance that sounds utopic, but the machine has lived up to the promises. The fault rates are also low, which is a big advantage – especially since this location is so remote. The SmartROC T40 that started working on site in June 2015 has reached almost 10 000 hours of working performance – and it still fully meets our expectations," says Coskun.

Standing on the floor of the basin looking up, the magnitude of the project hits home. The rigs positioned on the platforms on the dam walls look toysized. Down here, three SmartROC T40 rigs are drilling vertical holes that will be filled with explosives.

> "I think that Epiroc machines –and the SmartROC T40 in particular – have certain qualities that set them apart"
>
> **Mikail Celik,** Operator Limak Holding

Exiting from one of the rigs, a SmartROC T40, Operator Mikail Celik has just finished a drilling cycle.

"Efficiency is always important, especially in a project this big," he says. "You want to drill fast without compromising on quality. With this rig, I can use the rod handling system to program the drilling cycle and then the machine will drill to the exact desired length no matter what the type of rock. I just supervise. It's super easy and saves a lot of time. The hole quality is great, too."

The dam body in what will be the Yusufeli Dam is being lowered by 275 meters. SmartROCT40 rigs are the key to success.

Celik elaborates:
"I've been doing this job since 2002. Having worked with many different brands, I think that Epiroc machines – and the SmartROC T40 in particular – have certain qualities that set them apart. The design provides for maximum efficiency without compromising performance during operation. For instance, the combined effect of the hydraulic system and the control method means that the machine can move a lot quicker."

Some of the rock excavated from the valley will be used to produce portions of the concrete needed on site. With the project getting closer to completion, vast quantities will be needed. Yusufeli is a double-curvature arch dam and the total volume of high-strength concrete to be poured during dam body construction is four million cubic meters. As for the tunnels passing through the mountains, eight Epiroc Boomer face drilling rigs are used during tunneling operations. To sum up, the Yusufeli Dam project is a challengingbut, aboveallelse, rewardingonefor Limak Holding.

"The Yusufeli Dam will be the sixth highest arch dam in the world and of great importance to Turkey. We're very proud to be playing a part in this," says Atilla Coskun.

Epiroc operated under the trademark 'Atlas Copco' prior to January 1, 2018

It´s a blast!

MAXAM drills a million meters of blastholes per year in Poland and wanted to reduce its total operating costs. The SmartROC T40 drill rig with Hole Navigation System more than fulfilled the company's wishes.

MAXAM is the world leader in the production of explosives and the largest company in the market for drilling and blasting services in Poland. Its fleet is distributed across Poland and provides services to granite, dolomite, sandstone, basalt and melaphyre aggregate quarries, as well as limestone quarries for the production of cement and other components for construction chemicals production.

Drilling approximately a million meters of blastholes per year in Poland, using mainly Epiroc drill rigs, MAXAM was looking to reduce its total operating costs.

"The main challenge was to find a way for MAXAM to avoid excess drilling, to improve the quality of the holes and to reduce the number of boulders after blasting. Traditionally, the majority of blastholes in Poland were designed using the traditional method, without consideration of the wall profile or the possibility of verifying the quality of completed holes immediately after drilling. The Boretrak system was in use, but due to the time-consuming nature of hole sampling and the risk of blocking, its use was very limited," says Marcin Plachta, Business Manager Surface Drilling at Epiroc Poland.

MAXAM was also aiming to decrease the seismic vibrations attributable to blasting.

"Minimizing seismic vibrations is always desirable, particularly when operating close to populated areas, so that was a distinct goal for MAXAM," says Marcin Plachta.

The Solution

In 2016, Epiroc Poland presented the latest available tophammer drill solutions to MAXAM. The next step was to let the customer carry out drilling tests with a SmartROC T40 drill rig equipped with a COP 2560+ rock drill, HNS (Hole Navigation System), Certiq and remote control. Testing took place in a granite quarry in Rogoźnica operated by Colas Poland.

"We trained the operators and then they tested the rig under our supervision. Our customer was very pleased that they could perform extended tests at one of the company's sites. MAXAM had heard about HNS but hadn't experienced the benefits. The system made it possible to perfectly maintain the depth level of all drilled holes and to avoid uncontrolled excess drilling," says Marcin Plachta.

After completing the entire grid, the operator can save the data and transfer it to ROC Manager software. ROC Manager is used to plan the drill grid and compare it with data received after drilling. Marcin Plachta says:

"Using HNS, the customer could create the drill plan on the computer and upload it to the rig, so that the operator could follow it on a screen in the cabin. Thanks to the system, the start points and end points of the holes were a lot more accurate and it was easier for the customer to analyze data after blasting."

The result

After two months' worth of testing, MAXAM could make a reliable assessment of the costs of drilling and also get an idea of the actual wear on drilling tools. To begin with, elimination of excess drilling meant that total drilling decreased by 70 meters per 1 000 drilled meters

"These rigs drill 60 000–70 000 meters per year, so the decrease measures up to a lot of money over time. Fuel consumption dropped by 50 percent, as did seismic vibrations. The penetration rate increased by 10 percent, the hole quality improved and there was no need for horizontal drilling. The total operating cost was reduced by more than 30 percent, so the results exceeded the customer's expectations," says Marcin Plachta.

Later in 2016, MAXAM purchased three SmartROC drill rigs with HNS, as well as three FlexiROC D50 rigs. Epiroc's technology initiated further modernization at MAXAM, such as the purchase of state-of-the-art 3D scanners. It opened up a new stage in the improvement of drilling and blasting works and gave the opportunity to carry out more precise projects with improved quality. More recently, MAXAM purchased another SmartROC with HNS and recommended the rig to MAXAM Germany and Spain, resulting in the sale of an additional three SmartROC rigs with HNS.

Epiroc operated under the trademark 'Atlas Copco' prior to January 1, 2018.

Top of the world

In some of the toughest conditions imaginable, an Epiroc PowerROC T25 DC is helping to build the road to what will one day be the world's highest observatory.

At 5 000 meters above sea level, life is hard. The air is so thin that even a brisk walk can leave you gasping for breath, and changes in the weather are known to be extreme. Snowstorms are common and the thermometer can fall to twenty degrees below freezing at night.

These are the conditions faced by the team building the road in northern Chile to the new Tokyo Atacama Observatory. Backed by Japan's University of Tokyo, the project promises to be the world's highest observatory, sitting more than 5 600 meters above sea level on the summit of Mount Chajnantor.

"The original road leading to the University's existing observatory was little more than a narrow track," explains Claudio Alvarado, contract manager at earthmoving specialists Movitec, the company behind the project.

The new road must be nine meters wide and as flat as possible to ensure a smooth ride to the summit for all of the telescope's parts, including a flawless mirror measuring six and a half meters in diameter.

All aspects of the project are challenging. To keep lubricants and fuels from freezing into unusable gel overnight, Movitec uses generator-powered heaters to warm its fleet of backhoes and bulldozers.

"Otherwise, we could not be able to start them in the morning," Alvarado explains.

Since January 2019, Movitec has been using one of Epiroc's PowerROC T25 DC drill rigs to help eliminate the huge boulders that sometimes block the path. The team cannot use conventional explosives because the expansive waves would upset the delicate measurements of nearby observatories. So, the PowerROC T25 DC drills a 51-millimeter hole up to 2 meters into the rock. Water is then injected into the hole. When a pulsed electric charge is applied, the rock is shattered into tiny pieces.

This technique causes less noise and dust than conventional blasting and involves no chemical substances. It is also cheaper and more reliable than breaking up the rock by machine.

"It has worked very well, better than we expected, so we are very happy with the functionality that the equipment has displayed in the project," notes Alvarado.

"We have had absolutely no problems with fluids freezing or starting up in the morning. Nor has it lost pressure when working at altitude."

Northern Chile's crystal-clear skies and lack of light pollution have made the region a global leader in astronomy. Institutions from Europe, North America and Asia have built some of the world's largest telescopes here, such as the European Southern Observatory's Very Large Telescope at Cerro Paranal and the German-owned Atacama Pathfinder Experiment.

The nearby Atacama Large Millimeter Array (ALMA), consisting of sixty-six movable radio telescopes, played a key role in taking the first-ever photograph of a black hole, which was unveiled to great fanfare in April 2019. Five years ago, the Chilean government created South America's first astronomical park from 36 000 hectares of state land in order to attract more foreign research institutes to the country, of which the University of Tokyo is the latest.

Once built, the Tokyo Atacama Observatory will offer unbeatable views of the universe that could help unlock more of its mysteries – but building the observatory's installations has not been easy. Altitude sickness is a potentially deadly condition and the team must be eagle-eyed for any signs that a colleague is suffering dizziness, headaches or nausea. Even a brief fainting spell can be fatal on the mountain. To combat its effects, Movitec provides all workers with portable oxygen tanks that make conditions slightly more bearable. Every employee must undergo a full medical test at ALMA's nearby health clinic before beginning a seven-day shift, while the onsite nurse checks everyone's vital signs each morning and at lunchtime.

But even with these precautions, plenty of time must be set aside for even the most basic of tasks.

"One day's worth of administrative chores takes four days up here at the camp (4 950 meters above sea level)…If we have any major decisions to make about the project, we do it below 2 500 meters," explains Alvarado.

The extreme climate has also caused setbacks. In the winter of 2018 (the season runs from May to September in the Southern Hemisphere), so much snow fell that the project was closed for six weeks. Another twelve days were lost during the Bolivian rainy season (January and February).

"You're lucky – you've got almost perfect conditions," Alvarado tells visitors, looking up to a cloudless sapphire sky and bright sunshine. But the temperature is just a few degrees above freezing and a razor-sharp wind races down the mountainside.

Turning up the heat

At a mine in the north of Australia, Roc-Drill is joining the quest for copper with a pair of Epiroc's SmartROC CL rigs. But here, hours from the nearest town and in a place where temperatures can inch towards 50°C, man and machine are pushed to their absolute limits.

The first thing you notice is the dust. It's red – bright red – and it gets into everything.

"It's a nightmare," says Roc-Drill Area Manager Graeme Jones. "And then it rains and it's the mud."

This is Crusader, an open pit copper mine in Northwest Queensland. We're a two-hour drive from Cloncurry, the nearest town; 20 hours from Brisbane, the state capital. It's the Australian desert, jagged Martian peaks dotted with knee-high ant hills and desiccated trees – yet it still rains.

A few weeks ago a years-long drought broke here, creating a vast inland sea. Crusader and its base camp at Mount Cuthbert, 25 kilometers (over 15 miles) away, were cut off for days, workers eventually needing to be helicoptered out.

"When you hear Julius Dam has spilled you have eight hours to leave," Jones says, idling his Landcruiser on the Leichhardt River as a bask of freshwater crocodiles crosses a weir in front of him. "Otherwise, you're stuck."

This is the "wet" season in Australia's north and storms can appear out of nowhere. We experience it firsthand when a dark bank of clouds causes an early end of shift, Jones whisking us away from the pit in a line of LVs, orange lights flashing. A black curtain of rain and wind and dust rushes in the other direction, stabs of lightning and electrical activity enforcing an exclusion zone around a loaded shot. Jones grins. This is mining in the extremes.

" If you want to test something, bring it to Australia."

Nigel Deveth,
Managing Director of Roc-Drill, a Brisbane-based drilling contractor.

Roc-Drill was established in 2012 as an offshoot of Deveth's existing company, Deveth Drilling Qld. Deveth's own history with drilling dates back 28 years via companies such as Geothermal Industries, Deveth Drilling and the formerly family-owned Straitline Australia. For much of that time he has specialized in running Epiroc equipment. Roc-Drill currently boasts one of the largest fleets of Epiroc crawler drills in Australia. It's no surprise, then, that Deveth was the first in the country to take on a pair of new SmartROC CL drills. Roc-Drill wanted to put the COPROD-equipped rigs to work in some of the more difficult ground jobs it tackles across Australia and Papua New Guinea. With Epiroc's patented COPROD system, the high penetration rate and low fuel consumption of tophammer equipment is married with the hole straightness and quality of a Down-The-Hole drill.

"They have the potential to change how we drill into difficult rock," Deveth says. "It gives you increased penetration rate because you don't lose percussive energy through the drill string, because there are no joints. There's better hole accuracy on a low pressure air system, and you've got no excessive wear through the increased velocity that you run a Down-The-Hole drill with. And there's a much lower fuel burn."

Not that Roc-Drill didn't have to work to get the rigs operating effectively in Australian conditions. Deveth's team spent months going back and forth with Epiroc to break in the SmartROC CLs at a mine near Cloncurry, adjusting hammer, feed and rotation pressures to better handle the mix of soft and hard terrain typical of Australian mines.

Crusader is throwing up similar challenges for Roc-Drill. This mine has existed in one form or another for over a century. Ancient rail infrastructure lies abandoned, blackened by the sun. Back then it was gouging and underground operations. In 2019, mine owner Malaco Leichhardt is involved in something much more complex, extracting copper sulfide ore from an area rich in dolomite, quartzite, talc and magnetite. Working on a cutback in the mining pit, Roc-Drill's two SmartROC CLs sit above the flooded pit void, drilling into one of Crusader's old waste dumps. The earth is soft and progress slow, sodden clay regularly clogging up the drill bits. Operator Glen Hoyle takes care to collar his holes, expertly mixing the gray earth like a cake batter. It's time consuming and chews through water, but it's worth it.

"It will be a couple of days before the bomb crew get here," Hoyle says as he finally locks the CL into auto and lets it go to work. "The last thing you want is all that earth falling back down your hole. They'll mark it up as a redrill."

In some ways, Hoyle is simply biding his time. One of Roc-Drill's 12-strong fleet of trusty SmartROC D65s would be just as capable on this soft terrain. But peer into the pit and you see what the SmartROC CLs are here for – the harder bedrock with its rich deposits of copper.

"In good hard rock, this and a D65 together? It would flog it to pieces," Hoyle says. "Hard rock is where these go really well."

Still, the penetration rates for this kind of earth are already high, and the SmartROC CLs are paying off in other ways. With a wider rod, the rigs can carry a smaller compressor to clear their holes, meaning a smaller engine and some eye-popping savings on fuel – "maybe half of what the 65s use," Graeme Jones says. At Crusader, where temperatures can climb towards a whopping 50°C (122°F) deep in the pit, it has other benefits.

"With a smaller compressor, your engine isn't working as hard," Hoyle adds. "That's keeping pressure off the engine. Here, you need all the help you can get. It's as hot as hell."

Otherwise, the SmartROC CLs drill straight and true, something not lost on Mark Killip, Mining Engineer for Malaco Leichhardt. Killip was already impressed by Roc-Drill's ability to mobilize to site so quickly, and speaks effusively about the new rigs.

"Those COPROD drills are fantastic," he says. "For being able to get really good, consistent drilling on a range of grounds, they're great … They have GPS, which takes away the hazard of putting people in the field. If there's a slight change in ground conditions and it moves a couple of hundred millimeters, the GPS automatically accounts for that." "Once we get to that harder rock, we're going to get really consistent pen rates. They're really good machines."

Then again, with Roc-Drill breaking them in you'd perhaps expect nothing less. "We don't mind being pioneers," Deveth says. "These machines might not reach their full potential if introduced by another company. We don't allow that to happen."

"We've got a great reputation," he continues. "There's not one job where we haven't been under budget for the client. We strive to continually cut costs for our business and these can be passed on to our clients. That's what sets us apart. That's why we have CL drills."

SpeedROC 2F demonstrates productivity in Greece

On the mountainside of Falakro, near Drama in the northeastern part of Greece, a unique collection of quarries are located. A total of four connected quarries make up the largest operation of the dimension stone industry company, F.H.L Kiriakidis Group. Here, they extract the beautiful Volokas marble all year around.

This stone is named after the nearby village of Volokas and the surrounding area is known as "the Carrara of Greece", the reason for this is the perfect whiteness of the marble being quarried here. With strands of brown and light grey interspersed in the stone it is highly appreciated in the dimension stone industry.

F.H.L Kiriakidis Group controls around 50% of the total Volakas marble production worldwide. This is largely thanks to the optimized setup of operations and infrastructure. For example, the four quarries are connected to each other and although they are mainly of open-pit type, the marble is also extracted from underground tunnel excavation. This adds significantly to the total output. Another beneficial factor is that the quarries are connected to the national road network with asphalt streets. This allows for the stone to be processed, loaded and shipped straight from the quarry to the Thessaloniki port and from there to the rest of the world. The numbers clearly show that this is a high capacity dimension stone producer; 9 000 containers of marble blocks are shipped every year. This equals to approximately 70 000 m^3 of marble.

To run four dimension stone quarries at this level of output, demands equipment that can deliver the highest productivity possible. That is why F.H.L Kiriakidis Group turned to Epiroc when they were to expand their fleet of drill rigs. In March of 2017 the company received a SpeedROC 2F and the company now had the chance to really put this DSI drill rig to the test. Only two months later the verdict was in – an order of two additional SpeedROC 2F rigs was placed. Simply because the results exceeded all expectations.

The SpeedROC 2F is equipped with two 10 kW rock drills mounted on a rail bar. Together with an advanced Electronic Control System (ECS) a long service life of the drill steel is maintained. A Doosan carrier in combination with well-proven parts such as compressor from Atlas Copco, dust collector and control system results in very low fuel consumption.

One of the SpeedROC 2F operators in the Falakro quarry, Christos Gravalos, comments:

"SpeedROC 2F is the necessary tool for separating large marble bands into smaller marble blocks, the commercial ones. It is accurate in positioning and very fast in drilling. Its extended boom can rotate 360° covering large area. It is equipped with two rock drills and suitable for vertical drilling with four support legs that ensures the stability of the machine. As an operator, I am very satisfied using the radio remote control that allows me to work in safe distance and gives me the advantage of easier positioning and a better overview of operations. Also, the dust collector improves the working environment."

Epiroc operated under the trademark "Atlas Copco" prior to January 1, 2018.

Baltic Brown granite goes to the big world

Palin Granit's granite quarry in Ylämaa, Finland is an amazing sight to see. The smooth, sparkling boulders of Baltic Brown granite are lined up, the drill rig drills new blocks for removal, and the diamond wire cutting machine works it into smaller parts. A customer from Italy ambles between the rocks, selecting the right stone.

From the start, Palin Granit has been a family-run, Loimaa-based Finnish company. Its story begins in 1921, when the itinerant stonemason Antti Palin established a stoneworks facility in the town. The crude stone was transported to the stoneworks facility by train and horse carriage, and was formed by hand into cemetery headstones by Antti Palin. The company's current domicile is Lappeenranta, and Heikki, its CEO, represents the third generation of Palins. A great deal has occurred in almost a hundred years: machines have replaced the work by hand, and Palin Granit's business operations have changed from that of a stone refinery to raw stone production. The largest export nation is China with a 60% share, followed by Italy, Spain and Egypt. Finland's share is also increasing.

Granite world market

The demand for Finnish granite has declined from its peak years, but the belief in stone as a raw material on the part of fourth-generation representative, Business Developer Kira Palin, is solid. "Stone is an ecological material with a perpetual lifecycle and minimal maintenance requirement," Kira emphasises. Baltic Brown, which is mined in Ylämaa, usually goes to large projects, such as skyscrapers, facades and indoor spaces. The sector is heavily cyclical and dependent on cycles and trends; and recently, ceramics and artificial stone, for example, have taken the place of real stone. As a producer of raw material, Palin Granit does not always have information on where the end products finally go, and a familiar type of stone may, surprisingly enough, be occasionally encountered in, for instance, the floor of a building in Shanghai.

The sales and marketing of granite is the responsibility of Lundhs AS, a Norwegian family company with whom Palin Granit signed a cooperation agreement in 2014. As a result of the cooperation agreement, Lundhs also became one of Palin Granit's owners. The companies together represent the largest excavator of utility stone in Northern Europe.

Stone is a natural material, and its character includes the element of surprise. Only intact blocks are valid for export, and because of the fragmentation of the stone, its efficiency is low: the goal is that 20% of the stone can be utilised. Attempts are being made with waste rock to develop its practical use in, for example, the form of crushed rock, or larger chunks for embankments or surrounding walls.

Diamond wire cutting instead of drilling

It has been possible to raise the efficiency of stone production acceptable for processing by developing methods for the purpose. In 2014, Norwegian partner Lundhs introduced Palin Granit to diamond wire cutting and slot drilling, formerly used, has now been completely replaced by cutting, which has brought many benefits. "In addition to better quality, cutting is cheaper and faster, less dust is generated, and there are savings in the costs of explosives," Pauli Salmela, Technical Director, says, listing the benefits of cutting. Mr Salmela anticipates that the amount of cutting will increase all the time, and new operations are being planned that could be replaced by cutting.

Their first diamond wire cutting machines were the Italian Pellegrini brand, but in 2016 the brand was changed to Epiroc (Atlas Copco). The change of brand was decided by Epiroc's close-at-hand maintenance, even if diamond wire cutting machines are relatively service-free. At the moment, there are two Epiroc SpeedCut machines in use which can cut both vertically and horizontally.

In June 2018, the Epiroc SpeedROC D30 drill rig was introduced. SpeedROC D30 is used to drill vertical and horizontal pilot holes for SpeedCut, and it is designed to increase the use of cutting also at new work stages. The horizontal holes to be drilled are 30 m long, which corresponds to a dimension of four granite blocks and a diameter of 72 mm.

The work methods have been revised over the last few years, and according to Pauli Salmela, this development certainly has not ended. "After a few years, the methods will surely be different again," Mr Salmela forecasts.

Epiroc operated under the trademark "Atlas Copco" prior to January 1, 2018.

Green horizon in China's quarries

PowerROC D55 unlocks next level of productivity and efficiency in Nanjing. A limestone quarry in Nanjing achieves new milestone for productivity and green mining with a reliable PowerROC fleet scoring top marks.

Following a new standard of blue sky and green operations in the mining, quarrying and construction industry in China, many small mine owners and contractors have quickly disappeared from the market along with fleets of outdated equipment. Nanjing Anjite Mining Engineering CO., Ltd. (commonly referred to as Anjite) is a surface drilling contractor established back in 1972 which has steadily expanded its business from Nanjing to other regions of China.

Anjite was awarded the highest qualification for Green Mining and Master Blasting Company in Jiangsu province, successfully cooperating with the public security bureau for ammunition destruction, and it is now a key player in China's blasting industry.

The Baota Hill Mining site is located northwest of Nanjing city, just 40 km away from downtown. Although the mine is situated close to residential areas, no air pollution affects local residents. When entering the worksite, it looks more like a lush garden than a mine, with green trees and plants on both sides of the open-pit ramp. Finished exploitation benches are located a distance away and are flat and green, which contrasts typical perceptions of open-pit mining or quarrying.

Anjite's capabilities in mining and handling blasting tasks rely on the use of a drill rig fleet from Epiroc acquired since 2008. This includes the FlexiROC T35, FlexiROC D50 and PowerROC D45. The limestone quarry has a production capacity of up to fourteen million tons per year. The high productivity and good working environment, with minimized dust, has been achieved thanks to the introduction of two PowerROC D55 drill rigs, products that were designed and manufactured in Nanjing.

The PowerROC D55 units work in favorable conditions at an altitude of 250 m in a normal temperature, limestone quarry. The drill rigs have demonstrated outstanding performance and reliability with low fuel consumption of 35 liters per hour, as well as an availability of up to 98% per year. Drilling 140 mm holes in rock conditions of 60~80 MPa, the PowerROC D55 achieves a maximum penetration rate of 40 meters per hour to ensure the high annual productivity. The rigs work on +-20 m high benches using a drilling pattern of 4 x 6 m.

Easy to operate

The PowerROC D55, a Down-The-Hole surface drill rig, provides both high performance and low total cost of ownership for drilling 90–165 mm holes, as Wei wen Xu, Business Line Manager at Epiroc's product company in Nanjing, points out.

"The straightforward design of PowerROC D55 is easy to operate and maintain which is very appreciated by customers. Other reliable components of proven Epiroc technology enable high availability, ensuring the high productivity that customers need to expand their business."

"The RHS and the Down-The-Hole drilling method help to drill straight holes with very good quality," Wei wen Xu adds.

This assessment is echoed by Sheng Wang, General Manager at Anjite: "We trust the performance of Epiroc branded machines as Epiroc is a leading company in the mining and construction industry. The strong cooperation between us began with our previous General Manager, and we continue to order drill rigs due to their reputation for excellent reliability ever since."

"Thanks to the dust collection system, Epiroc products have helped us achieve the Green Mine Star and other awards of distinction from the government," Wang continues. "We are the only company in Jiangsu Province that promotes the electric digital detonator in domestic China, which together with Epiroc equipment has contributed to our Green Mine distinction. We hope the cooperation will continue to advance our goals for sustainable productivity."

Workhorse in the quarry

Following the successful deployment, there are now three PowerROC D55 units in daily operation at the limestone quarry. Another hydraulic surface drill rig, the PowerROC D45, is used to help Anjite complete a national water conservancy project requiring powerful and timely capability by state waterways, for the renovation of Qinhuai River.

"The outstanding availability surprised us as the drill rigs can work 4 800 engine hours per year, with three shifts per day. That is why we call it the workhorse on site," says Zhoujun Jiang, Site Equipment Chief at Anjite.

He continues: "I appreciate the ergonomic design of the cabin with FOPS and ROPS certification, which protects operators from injuries if the equipment rolls over on the bench. The drill rig is easy to operate and maintain due to its straightforward design. And the rigs can work twenty hours per day with regular maintenance twelve times a year."

Thanks to the partnership and continued use of Epiroc products, Anjite stands ready to expand its footprint across China with cutting-edge productivity and a "green mine" profile that sets a new benchmark for future operations.

Small drill rig with large output

In one year, Dala Spräng och Grävteknik doubled their turnover of explosives. This was all thanks to one of the smallest hydraulic drill rigs on the market, which enabled the Borlänge, Sweden-based company to accept blasting jobs that they previously could only dream of.

After getting a tip from an industry colleague, blasting foreman Viktor Eriksson decided to test one of the industry's smallest drill rigs with their hope of streamlining the work. One year later, it has proven to be a brilliant idea.

> "Because the machine is a bit more efficient than the competitors, we can handle several different types of jobs. This enables us to take on a larger variety of jobs," says Viktor Eriksson.

The family-run company Dala Spräng och Grävteknik has 15 employees. Their jobs range from excavation and draining to blasting. Since the company bought the Epiroc FlexiROC T15 R drill rig a year ago, earnings from the blasting department have doubled.

> "Our blasting work has grown a lot within the past year, from small and medium-sized jobs to pretty big jobs of up to 5 000 cubic meters (approximately 6 540 cubic yards) of rock. We would never have been able to do this with our previous drilling machine." says Viktor Eriksson.

At the Brotorpsskolan school in Lindesberg, Sweden, intensive work is underway to make room for an expansion. The terrain is challenging, there is limited space for maneuvering, and the close proximity to the school makes precision a must. Viktor Eriksson handles parts of the blasting work, which is running smoothly thanks to the small, flexible drill rig.

> "By using our machine to support the overall work, we have been able to increase the production rate between blastings. Despite its small size, the machine can drill deeper and harder in the same amount of time as before. So, it also improves the bottom line."

The little drill rig is particularly popular with smaller companies like Dala Gräv och Sprängteknik. According to Epiroc Master Driller Stefan Löfdahl, its flexibility is one important reason behind its success.

> "A lot of customers are using this for smaller jobs, like landscaping work and digging pools. It also works well when you need to get into tight spaces. Another plus is that it sits on wheels so it doesn't cause as much destruction."

Dala Spräng och Grävteknik also opted for a service agreement with Epiroc – all to maintain their production rate. This not only gives them ongoing service, but Service Technician Fredrik Norlinder is just a phone call away if anything were to break down.

> "I took part and started up their machine. It's worked well from day one. We have a personal contact. They call me directly and I then go out and perform service or repair work – whatever is needed. Through the agreement, we also monitor the status of the machine," says Fredrik Norlinder.

> "A phone call is often enough to get things worked out pretty quickly," says Viktor Eriksson.

Down-time can be very costly, and the job of getting the machine up and running as soon as possible can be crucial. Thanks to the well-oiled partnership, the machine has only stood still just a few days in the past year.

> "Because the production rates are so much higher now, the stops are not as noticeable. But, it's still great to not have to worry so much about service and just keep working," says Viktor Eriksson.

Fredrik Norlinder, Service engineer, Epiroc.

Viktor Eriksson, Owner, Dala Spräng och Grävteknik.

Stefan Löfdahl, Master Driller, Epiroc.

A brave new world

Very few things can bring chaos and mayhem to a country such as war. Kuwait, the small Middle East nation nestled in between Saudi Arabia, Iraq and the Gulf, have seen its fair share of destruction through the years. Since the mid 90's however, the country have been rebuilt and development of new cities is now well underway.

Kuwait City is the nation's capital and largest city. The car ride from here to the South Al-Mutlaa Housing Project takes about 45 minutes. When stepping out of the air conditioned vehicle, the 50°C heat is intrusive. It is so warm in fact, that government regulations prevents people from working outside between 11 am and 4 pm during the summer period. So work on sites like this is predominantly carried out during night and the early hours of morning.

Here, in one of the driest and least-hospitable deserts on Earth a new city is being constructed. From scratch. South Al-Mutlaa will eventually house some 400 000 residents whom will enjoy the services of 116 schools, 156 mosques, 48 mini-markets, 12 public health centers and much more. To build a new city of this size from the ground up, you need fearless men and women. You need strong partnerships. To build a brave new world you need brave contractors to do so. The Chinese company China Gezhouba Group Co. (CGGC) is just that – brave. This construction company has quite the track-record with successful development projects all around the globe. One of their tasks in the South Al-Mutlaa Housing Project is to level the ground for infrastructure such as roads and pipelines but also for residential houses and other structures. In this desert jobsite there is rock that needs to be removed in order to prepare the ground. The rock types are mainly soft to medium-hard and range from limestone and sandstone to gabbro. The conventional method for excavating rock in an application with this type of geology, is to use excavators. But after investigating the site and considering the demands for efficiency, CGGC did something that no one had ever done before in the history of Kuwait. They brought in surface rock drilling rigs.

In this specific geographical location and in this application, the drill- and blast method of rock excavation has never been used. So it is crucial for CGGC to be able to trust their equipment for both performance, straightforward operation and easy maintenance. They opted to go with the PowerROC T25 DC from Epiroc and have purchased six drill rigs of this model to carry out the drilling operations in South Al-Mutlaa.

The PowerROC T25 DC drill rigs are working side-by-side completing designated drill patterns, the hole diameter is 76–89 mm and hole depths range from 2–12 m. This is largest blasting project in Kuwait with as much as six blasts being carried out every day. During summertime, blasting is carried out 2–3 times every day, all days except Fridays. Each drill rig has a four-man team that consist of two operators and two drilling assistants in two shifts, the latter carrying out tasks needed outside the cabin, such as drill bit change and collaring preparation.

Cheng Yunfei is CGGC's Deputy General Manager for the South Al-Mutlaa Housing Project. He gives his view on why the PowerROC T25 DC drill rigs were chosen for the project:

"It was not a difficult choice for us to go with Epiroc drill rigs for this project. Epiroc is a very well-known company around the world."

To be part of constructing a new city in the middle of a scorching hot desert is a challenging endeavor on its own. To employ a rock excavation method that has never been used in the country before, doesn't make it less challenging. The six PowerROC T25 DC drill rigs are first-on-market in Kuwait which means that Epiroc presence is not yet fully developed.

"We are the first ones to use drill rigs here so it's only natural that we are facing some challenges. But together with Epiroc we solve the issues as we go along." says Yang Bo, the Deputy Manager of Drill and Blast division for CGGC.

He is especially pleased with the fact the PowerROC T25 DC is outperforming competitor drill rigs used by other contractors in South Al-Mutlaa, when it comes to drill meters per day. He also gives the thumbs up to that it is easy for operators to get familiar with the equipment. Many of the operators hired for this project had never set foot inside a surface drill rig before. Since the operators are the ones to use the drill rigs on a day-to-day basis, it goes without saying – it's very important that they feel comfortable with the equipment.

"The machines are very easy to learn. One week of training and our operators were up and running. Once we got assistance on the mechanical side, operations were even more efficient." says Yang Bo

He continues: "Another benefit we see is that regular maintenance is easy on these drill rigs. We have experienced minor delays in getting spare parts but every time we ask for service – Epiroc comes."

Cheng Yunfei is CGGC's Deputy General Manager for the South Al-Mutlaa Housing Project in Kuwait. He agrees with Yang Bo and adds:

"We are confident working with Epiroc, it is an established supplier of drill rigs that many other companies in China has partnered with. Generally, we are satisfied with the aftermarket and service that Epiroc provide. Of course there are things to improve and that's expected for a project like this."

He concludes: "I trusted my colleagues in the Drill and Blast department when they recommended that we should purchase these six PowerROC T25 DC drill rigs from Epiroc and I don't regret it. We have a long history of working with Epiroc and Atlas Copco before that, for projects all around the world. We are very happy with the equipment and the strong partnership."

A strong partnership is crucial when embarking on a journey like this - building an entirely new city using first-on-market equipment. For two companies to develop such a partnership they need to share similar values and that is certainly the case with CGGC and Epiroc.

The text on a wall-sign outside of CGGC's field office in the Kuwaiti desert provides perfect examples of such values. It reads: "Fairness. Honesty. Win-win."

Cheng Yunfei
CGGC's DeputyGeneral Manager, South Al-Mutlaa Housing Project, Kuwait

Product specifications

SmartROC C50

COPROD

Hole range Ø		Drill rod Ø		Drill steel length		Max hole length		Compressor capacity	At pressure
mm	in	mm	in	m	ft	m	ft	l/s	bar
90–140	3.5–5.5	CR 76 CR 80 CR 102	3 3.1 4	4.5	14.8	36	118	223	12

Main benefits
- The superior precision in the drilling gives you optimal blasting results, increased safety and quality throughout the whole operation.
- The low fuel consumption, the low amount of energy loss and the long service life reduces your total running cost.
- SmartROC rigs deliver – shift after shift. We know what is important to you in the end: productivity and profitability.

SmartROC CL

COPROD

Hole range Ø		Drill rod Ø		Drill steel length		Max hole length		Compressor capacity	At pressure
mm	in	mm	in	m	ft	m	ft	l/s	bar
115–216	4.5–8.5	CR 102 CR 127 CR 140	4 5 5.5	6.1	20	42.5	139	254	14

Main benefits
- Super-efficient COPROD drill rig that boosts drilling productivity.
- Exceptionally low total cost of ownership thanks to high penetration rate and low fuel consumption.
- Smart high efficiency thanks to auto drill cycle, Hole Navigation System and BenchREMOTE.

SmartROC D50 and D55

Down-The-Hole

Hole range Ø		Drill rod Ø		Drill steel length		Max hole length		Compressor capacity	At pressure
mm	in	mm	in	m	ft	m	ft	l/s	bar
SmartROC D50									
90–130	3.5–5.1	76–102	3–4	5	16.4	45	148	295	25
SmartROC D55									
90–152	3.5–6	76–102	3–4	5	16.4	45	148	354	30

Main benefits
- High penetration rate and low fuel consumption thanks to the intelligent control of the engine and compressor.
- High productivity and efficiency due to automated drilling and rod-handling.
- Extreme accuracy thanks to Epiroc's Hole Navigation System (HNS).

SmartROC D60

Down-The-Hole

Hole range Ø		Drill rod Ø		Drill steel length		Max hole length		Compressor capacity	At pressure
mm	in	mm	in	m	ft	m	ft	l/s	bar
Short Feed (SF)									
110–178	4.3–7	89–140	3.5–5.5	5	16.4	45	148	405	25
Long Feed (LF)									
110–178	4.3–7	89–140	3.5–5.5	7.5	24.6	55.5	182	405	25
Extra long Feed (XLF)									
110–178	4.3–7	89–140	3.5–5.5	8	26.2	56	183.7	405	25

Main benefits
- Reduced fuel consumption thanks to the intelligent control of compressor-load and engine rpm.
- Consistent productivity through automated drilling and rod handling.
- Rugged and efficient design which offers high availability and flexibility.

SmartROC D65

Down-The-Hole

Hole range Ø		Drill rod Ø		Drill steel length		Max hole length		Compressor capacity	At pressure
mm	in	mm	in	m	ft	m	ft	l/s	bar
Short Feed (SF)									
110–229	4.3–9	89–140	3.5–5.5	5	16.4	45	148	470	30
Long Feed (LF)									
110–229	4.3–9	89–140	3.5–5.5	7.5	24.6	55.5	182	470	30
Extra long Feed (XLF)									
110–229	4.3–9	89–140	3.5–5.5	8	26.2	56	183.7	470	30

Main benefits
- Reduced fuel consumption thanks to the intelligent control of compressor-load and engine rpm.
- Consistent productivity through automated drilling and rod handling.
- Rugged and efficient design which offers high availability and flexibility.

SmartROC T35 and T40

Tophammer

Hole range Ø		Drill rod Ø	Drill steel length		Max hole length		Compressor capacity	At pressure
mm	in	type	m	ft	m	ft	l/s	bar
SmartROC T35								
64–115	2.5–4.5	T38 T45 T51	5.5	18	33.5	109.9	127	10.5
SmartROC T40								
64–127	2.5–5	T45 T51	5.5	18	33.5	109.9	153	10.5

Main benefits
- Lowest fuel consumption in its class.
- High productivity with great hole quality.
- Easy to service and maintain thanks to low number of components.

SmartROC T45

Tophammer

Hole range Ø		Drill rod Ø	Drill steel length		Max hole length		Compressor capacity	At pressure
mm	in	type	m	ft	m	ft	l/s	bar
SmartROC T45 with folding boom								
89–127	3.5–5	T45 T51	7.3	24	29	95	223	12
SmartROC T45 with standard boom								
89–140	3.5–5.5	T51 T60	7.3	24	36	118	223	12

Main benefits

- Efficiency with increased capacity and performance while reducing fuel consumption.
- Safety and availability thanks to the new and intuitive design.
- Excellence through precise drilling and consistent operation, resulting in improved blasting results.

BenchREMOTE

Down-The-Hole, COPROD, Tophammer

Length		Width		Height		Weight	
mm	in	m	in	mm	in	kg	lb
1 205	47.5	1 120	44	1 369	54	250	551

Main benefits

- **Increased productivity and efficiency.** One operator can run up to three SmartROC rigs from the same BenchREMOTE.
- **Enhanced safety.** The best way to protect the operator is to remove them from unstable and hazardous benches. BenchREMOTE makes it possible to drill close to the wall without anyone needing to be in the drilling area.
- **Improved operator working conditions.** BenchREMOTE dramatically reduces noise and dust levels for the operator. It's also possible to site several BenchREMOTE stations together, making direct communication between operators and management much more direct and effective.

FlexiROC D50 and D55

Down-The-Hole

Hole range Ø		Drill rod Ø		Drill steel length		Max hole length		Compressor capacity	At pressure
mm	in	mm	in	m	ft	m	ft	l/s	bar
FlexiROC D50									
90–130	3.5–5.1	76–102	3–4	5	16.4	45	148	295	25
FlexiROC D55									
90–152	3.5–6	76–102	3–4	5	16.4	45	148	354	30

Main benefits

- High productivity thanks to the robust and powerful feeding system.
- Availability and serviceability due to high degree of parts commonality.
- Durability based on well-proven and trusted design.

FlexiROC D60 and D65

Down-The-Hole

Hole range Ø		Drill rod Ø		Drill steel length		Max hole length		Compressor capacity	At pressure
mm	in	mm	in	m	ft	m	ft	l/s	bar
FlexiROC D60									
110–178	4.3–7	89–140	3.5–5.5	6	19.7	55.5	182	405	25
FlexiROC D65									
110–203	4.3–8	89–140	3.5–5.5	6	19.7	55.5	182	470	30

Main benefits

- Productive and efficienct thanks to impressive DTH performance.
- Broad utilization due to flexibility and multi-task capability.
- Proven and rugged to get the job done.

FlexiROC T15 R

Tophammer

Hole range Ø		Drill rod Ø	Drill steel length		Max hole length		Compressor capacity	At pressure
mm	in	type	m	ft	m	ft	l/s	bar
27–51	1–2	HEX 22x108 R28 SR28 R32 SR32	3.7	12.1	9	29.5	23	8.5

Main benefits

- Large boom coverage makes the rig suitable for a variety of construction applications.
- Advanced rock drill design for great Free Air Delivery (FAD) capacity.
- Excellent tramming stability for go-any-where accessibility.

FlexiROC T20 R

Tophammer

Hole range Ø		Drill rod Ø	Drill steel length		Max hole length		Compressor capacity	At pressure
mm	in	type	m	ft	m	ft	l/s	bar
With 8' feed and RAS								
38–64	1.5–2.5	SR32, R32 TC35, T35	2.4	8	4.2	13.8	50	12
With 10' feed and RAS								
38–64	1.5–2.5	SR32, R32 TC35, T35	3.1	10	5.1	16.7	50	12
With 12' feed and RAS								
38–64	1.5–2.5	SR32, R32 TC35, T35	3.7	12	6.4	21.1	50	12

Main benefits

- Application versatility thanks to the COP SC14 rock drill.
- Extensive boom reach means fewer set-ups.
- Optimized for small spaces thanks to three different feed lengths.

FlexiROC T25 R Construction Edition

Tophammer

Hole range Ø		Drill rod Ø	Drill steel length		Max hole length		Compressor capacity	At pressure
mm	in	type	m	ft	m	ft	l/s	bar
38–64	1.5–2.5	SR32 R32 TC35 T35	4.3	14.1	14.8	48	80	8.5

Main benefits
- Fast and accurate drilling thanks to high frequency rock drill.
- Excellent rig stability means operator safety and productivity.
- Extensive boom reach means fewer set-ups.

FlexiROC T30 R Construction Edition

Tophammer

Hole range Ø		Drill rod Ø	Drill steel length		Max hole length		Compressor capacity	At pressure
mm	in	type	m	ft	m	ft	l/s	bar
45–89	1.8–3.5	R32 T35 TC35 T38 T45	4.3	14.1	14.8	48	80	8.5

Main benefits
- Excellent rig stability means operator safety and productivity.
- Application versatility thanks to the COP SC16 rock drill.
- Extensive boom reach means fewer set ups.

FlexiROC T30 R Quarry Edition

Tophammer

Hole range Ø		Drill rod Ø	Drill steel length		Max hole length		Compressor capacity	At pressure
mm	in	type	m	ft	m	ft	l/s	bar
45–102	1.8–4	R32 T35 TC35 T38 T45	4.3	14.1	14.8	48	95	8.5

Main benefits
- Excellent rig stability means operator safety and productivity.
- High bench drilling thanks to great flushing capacity.
- Sturdy boom and feed means more power and straight holes.

Tophammer

FlexiROC T35 and T40

Tophammer

Hole range Ø		Drill rod Ø	Drill steel length		Max hole length		Compressor capacity	At pressure
mm	in	type	m	ft	m	ft	l/s	bar
FlexiROC T35								
64–115	2.5–4.5	T38 T45 T51	3.6	11.8	28	92	127	10.5
FlexiROC T40								
64–127	2.5–5	T38 T45 T51	3.6	11.8	28	92	149	10.5

Main benefits
- Optimal use of rock drill and increased tool life thanks to a cylinder-operated feed system.
- Long boom reach is ideal for demanding construction jobs.
- Supreme productivity thanks to proven COP rock drill series.

FlexiROC T35R and T40R

Tophammer

Hole range Ø		Drill rod Ø	Drill steel length		Max hole length		Compressor capacity	At pressure
mm	in	type	m	ft	m	ft	l/s	bar
FlexiROC T35 R								
64–115	2.5–4.5	T38 T45 T51	3.6	11.8	28	92	127	10.5
FlexiROC T40 R								
64–127	2.5–5	T45 T51	3.6	11.8	28	92	149	10.5

Main benefits
- Unique, durable cylinder-operated feed system optimizes rock drilling and increases rock tool life
- Long boom reach is ideal for demanding construction jobs
- Supreme productivity thanks to proven COP rock drill series

FlexiROC T45

Tophammer

Hole range Ø		Drill rod Ø	Drill steel length		Max hole length		Compressor capacity	At pressure
mm	in	type	m	ft	m	ft	l/s	bar
FlexiROC T45 with folding boom								
89–127	3.5–5	T45 T51	4.2	13.8	29	95	223	12
FlexiROC T45 with standard boom								
89–140	3.5–5.5	T51 T60	6.1	20	35	115	223	12

Main benefits
- Lowest possible fuel consumption and highest possible fuel efficiency.
- Continuously delivers result due to robust hydraulics and reliable control system.
- High availability guaranteed thanks to the dependable construction.

PowerROC T25 E

Tophammer

Hole range Ø		Drill rod Ø	Drill steel length		Max hole length		Compressor capacity	At pressure
mm	in	type	m	ft	m	ft	l/s	bar
51–89	2–3.5	T38 T45	4.2	13.8	18.3	60	101	8.8

Main benefits

- Straightforward design – for ease of operation and maintainance.
- Reliable workhorse with long service intervals.
- Fast penetration rates – more meters per liter of fuel means greater cost efficiency.

PowerROC T25 DC

Tophammer

Hole range Ø		Drill rod Ø	Drill steel length		Max hole length		Compressor capacity	At pressure
mm	in	type	m	ft	m	ft	l/s	bar
51–89	2–3.5	T38 T45	4.2	13.8	18.3	60	101	8.8

Main benefits

- Straightforward design – for ease of operation and maintainability.
- Reliable workhorse with long service intervals.
- Fast penetration rates – more meters per liter fuel means greater cost efficiency.

PowerROC T30 E

Tophammer

Hole range Ø		Drill rod Ø	Drill steel length		Max hole length		Compressor capacity	At pressure
mm	in	type	m	ft	m	ft	l/s	bar
45–89	1.8 – 3.5	T35 T38 T45 R32 TC35	4.3	14.1	17.5	57	95	8.5

Main benefits

- High productivity with Epiroc COP rock drills and compressors from Atlas Copco.
- Efficient operations with direct controls, good reach and a well balanced design.
- Great mobility thanks to compact size and ease of transportation.

PowerROC T35

Tophammer

Hole range Ø		Drill rod Ø	Drill steel length		Max hole length		Compressor capacity	At pressure
mm	in	type	m	ft	m	ft	l/s	bar
64–115	2.5–4.5	T38 T45 T51	4.2	13.8	25	82	130	9.7

Main benefits

- Easy to operate and maintain due to straightforward design and ergonomic cabin.
- Straight holes and long drill steel life by using COP Logic system.
- High penetration rate due to COP rock drills.

PowerROC T35 E

Tophammer

Hole range Ø		Drill rod Ø	Drill steel length		Max hole length		Compressor capacity	At pressure
mm	in	type	m	ft	m	ft	l/s	bar
64–102	2.5–4	T38 T45 T51	6.7	22	25	82	130	9.7

Main benefits

- Higher productivity with increased air and Epiroc COP rock drills as a standard feature
- Improved performance due to less maintenance with a reliable control system and ergonomic design
- Fast penetration rates – more meters per liter fuel means greater cost efficiency

PowerROC T40

Tophammer

Hole range Ø		Drill rod Ø	Drill steel length		Max hole length		Compressor capacity	At pressure
mm	in	type	m	ft	m	ft	l/s	bar
89–127	3.5–5	T51	4.2	13.8	25	82	148	8.5

Main benefits

- Easy operation and service thanks to straightforward design.
- Folding boom for easy positioning and great reach.
- Reliable components and robust structure for low maintenance cost.

PowerROC T45 — Tophammer

Hole range Ø		Drill rod Ø	Drill steel length		Max hole length		Compressor capacity	At pressure
mm	in	type	m	ft	m	ft	l/s	bar
76–127	3–5	T45 T51	4.2	13.8	25	82	175	9.8

Main benefits
- Power built in thanks to the COP SC25-HE rock drill & FAD 175 l/s Atlas Copco air compressor.
- Maintainability with two side maintenance doors as well as robust & simplified rock drill.
- High mobility and fast positioning with compact machine size and extendable boom system.

PowerROC D45 — Down-The-Hole

Hole range Ø		Drill rod Ø		Drill steel length		Max hole length		Compressor capacity	At pressure
mm	in	mm	in	m	ft	m	ft	l/s	bar
90–130	3.6–5.13	76	3	3	9.8	21	69	225	17

Main benefits
- Easy operation and maintenance due to direct control system.
- High reliability due to straightforward design.
- Robust performance thanks to the use of the proven Epiroc technology.

PowerROC T50 — Tophammer

Hole range Ø		Drill rod Ø	Drill steel length		Max hole length		Compressor capacity	At pressure
mm	in	type	m	ft	m	ft	l/s	bar
102–152	4–6	T51 T-Wiz 60	6.1	20	35	118	232	10.5

Main benefits
- Reliability – tough, Epiroc quality.
- High performance – fast penetration rates give more meters per shift.
- Easy and quick positioning thanks to the extendable boom.

PowerROC D50 — Down-The-Hole

Hole range Ø		Drill rod Ø		Drill steel length		Max hole length		Compressor capacity	At pressure
mm	in	mm	in	m	ft	m	ft	l/s	bar
90–152	3.6–6	102	4	6	19.7	12	39.4	283.3	20

Main benefits
- High performance thanks to well-proven Epiroc technology and extensive experience.
- High reliability due to a tried-and-tested design and reliable, high-quality components.
- Easy operation and maintenance thanks to a simple design.

PowerROC D55 — Down-The-Hole

Hole range Ø		Drill rod Ø		Drill steel length		Max hole length		Compressor capacity	At pressure
mm	in	mm	in	m	ft	m	ft	l/s	bar
90–165	3.6–6.5	102	4	5	16.4	30	98.4	283.3	20

Main benefits
- Ease of operation and maintenance in drilling applications.
- High reliability due to straightforward design.
- Robust design and high productivity thanks to proven Epiroc technology.

PowerROC D60 — Down-The-Hole

Hole range Ø		Drill rod Ø		Drill steel length		Max hole length		Compressor capacity	At pressure
mm	in	mm	in	m	ft	m	ft	l/s	bar
110–191	4.3–7.5	102–114	4–4.5	5	16.4	30	98.4	428	25

Main benefits
- High performance thanks to well-proven Epiroc technology and extensive experience.
- High reliability due to high-quality components.
- A straightforward design makes the machine easy to operate and easy to maintain.

AirROC T25 and D40

Tophammer and Down-The-Hole

Hole range Ø		Drill rod Ø		Drill steel length		Max hole length		Compressor capacity	At pressure
mm	in	mm	in	m	ft	m	ft	l/s	bar
AirROC T25									
35–64	1.5–2.5	32 38	1.25 1.75	3.6	11.8	15	50	N/A	N/A
AirROC D40									
85–115	3.75–4.5	76	3	3	9.8	29.4	96.5	N/A	N/A

Main benefits
- Application compatibility due to interchangeability between tophammer and Down-The-Hole (DTH).
- Toe-hole drilling option by quick re-pinning.
- Optimized air consumption by rock drill BBC 120 means low fuel consumed.

AirROC T35 and D50

Tophammer and Down-The-Hole

Hole range Ø		Drill rod Ø		Drill steel length		Max hole length		Compressor capacity	At pressure
mm	in	mm	in	m	ft	m	ft	l/s	bar
AirROC T35									
64–102	2.5–4	38 45	1.5 1.75	3.6	11.8	15	50	N/A	N/A
AirROC D50									
105–140	4.13–5.5	76 89 102	3, 3 5, 4	3	9.8	29.4	96.5	N/A	N/A

Main benefits
- The unique VL 140 rock drill takes up to 102 mm (4") hole diameter.
- Application compatibility due to interchangeability between tophammer and Down-The-Hole (DTH).
- Transportation is made easier by fixed length boom and drill width.

SpeedROC 1F

DSI equipment

Hole range Ø		Rock drill	Drill steel length		Dust collector capacity		Compressor capacity	At pressure
mm	in	type	m	ft	l/s	cfm	l/s	bar
28–45	1.1–1.8	COP DS5 x 1	3.2	10.5	97	206	22	6

Main benefits
- Tailor-made for the dimension stone industry.
- Parallel and straight holes means high quality output.
- High drilling capacity means better productivity.

SpeedROC 2F

Hole range Ø		Rock drill	Drill steel length		Dust collector capacity		Compressor capacity	At pressure
mm	in	type	m	ft	l/s	cfm	l/s	bar
28–45	1.1–1.8	DF 500X x2 DF 530X x2	3.2	10.5	200	424	28.3	8

Main benefits
- Fast drilling and positioning offers high productivity.
- 360° carrier rotation and extensive boom reach means large coverage area.
- Outstanding terrainability and low fuel consumption means efficiency in operations.

SpeedROC 2FA

DSI equipment

Hole range Ø		Rock drill	Drill steel length		Dust collector capacity		Compressor capacity	At pressure
mm	in	type	m	ft	l/s	cfm	l/s	bar
28–45	1.1–1.8	DF 500X x2 DF 530X x2	3.2	10.5	200	424	28.3	8

Main benefits
- Fast drilling and positioning gives high productivity.
- Safety first with radio remote controlled positioning and drilling operations.
- Good working environment with dust collection system (DCT) or water mist (option).

SpeedROC 3F

DSI equipment

Hole range Ø		Rock drill	Drill steel length		Dust collector capacity		Compressor capacity	At pressure
mm	in	type	m	ft	l/s	cfm	l/s	bar
28–45	1.1–1.8	COP DS5 x 3	3.2	10.5	320	678	42.5	8

Main benefits
- Three rock drills for high productivity
- 360° carrier rotation and extensive boom reach gives a large coverage area
- High capacity dust collector for better working environment.

SpeedROC D30

DSI equipment

Hole range Ø		DTH hammers	Dust collector capacity		Drill steel length		Drill rod Ø		Drill steel length	
mm	in	type	l/s	cfm	m	ft	mm	in	m	ft
70–105	2.75–4.1	COP 20 COP 32 COP 35	222	471	2.2	7.2	63–76	2.5–3	1.5–2	4.92–6.56

Main benefits
- Tailor-made for the dimension stone industry.
- Drills straight holes just 8 cm from the ground to the hole center.
- Quick positioning time and low fuel consumption.

SpeedCut 75

DSI equipment

Diamond wire max speed		Motor output		Flywheel Ø		Track length	
m/s	ft/s	kW	hp	mm	in	m	ft
45	148	55	75	Main: 1 000 Guide: 425	Main: 39.4 Guide: 16.7	3	9.8

Main benefits
- Highest cutting capacity on the market.
- Low wire consumption.
- Full control of the cutting process.

SpeedCut 100

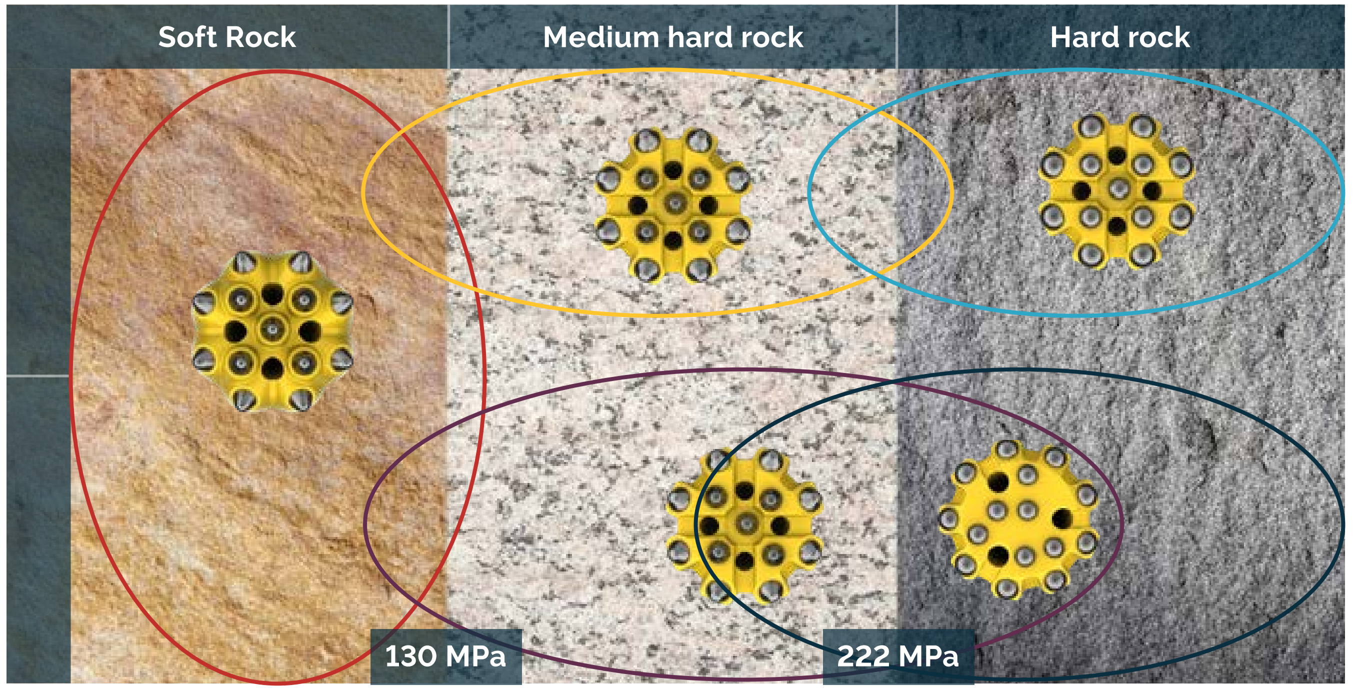
DSI equipment

Diamond wire max speed		Motor output		Flywheel Ø		Track length	
m/s	ft/s	kW	hp	mm	in	m	ft
45	148	75	100	Main: 1 000 Guide: 425	Main: 39.4 Guide: 16.7	3	9.8

Main benefits
- Highest cutting capacity on the market.
- Low wire consumption.
- Full control of the cutting process.

Tophammer bit selection

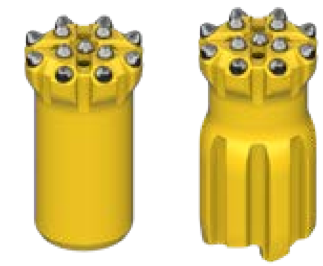
Secoroc Powerbit



Rocket bit

■ Full-ballistic buttons

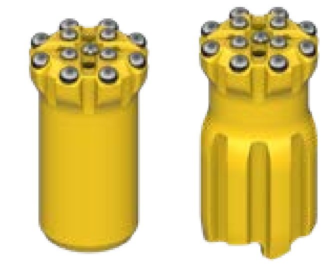
The best choice for soft rock conditions. Full-ballistic buttons and large vertical flushing grooves effectively remove larger chips, greatly increasing penetration rate.



Powerface bit

■ Trubbnos buttons, heavy duty (HD)

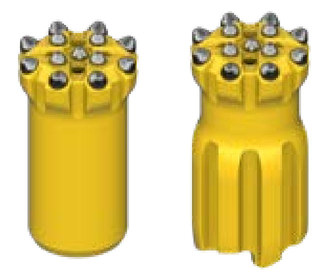
Ideal for abrasive, medium hard to hard rock. Larger Trubbnos buttons and flushing grooves give the ideal balance between service life and penetration rate. Available with a short retrac for straight holes in broken rock.



Powerface bit

■ Spherical buttons, standard or heavy duty (HD)

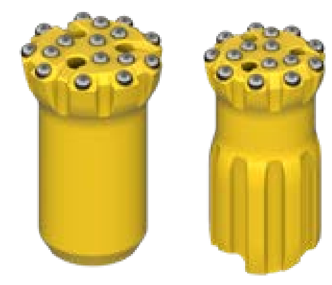
For tough conditions in hard and abrasive rock. Optimised face and body design and with standard or large spherical buttons for long service life. Available with a short retrac for straight holes in broken rock.



Powerface bit

■ Trubbnos buttons

Designed for medium hard to hard rock. Trubbnos buttons provide better penetration rate than spherical buttons, and a longer service life than semi-ballistic ones. Available with a short retrac for straight holes in broken rock.



Flat face bit

■ Spherical buttons, standard or heavy duty (HD)

Ideal for hard, medium abrasive rock. The flat face, with many spherical buttons, offer an optimised energy transfer. Available with a short retrac for straight holes in broken rock.

Dome bit

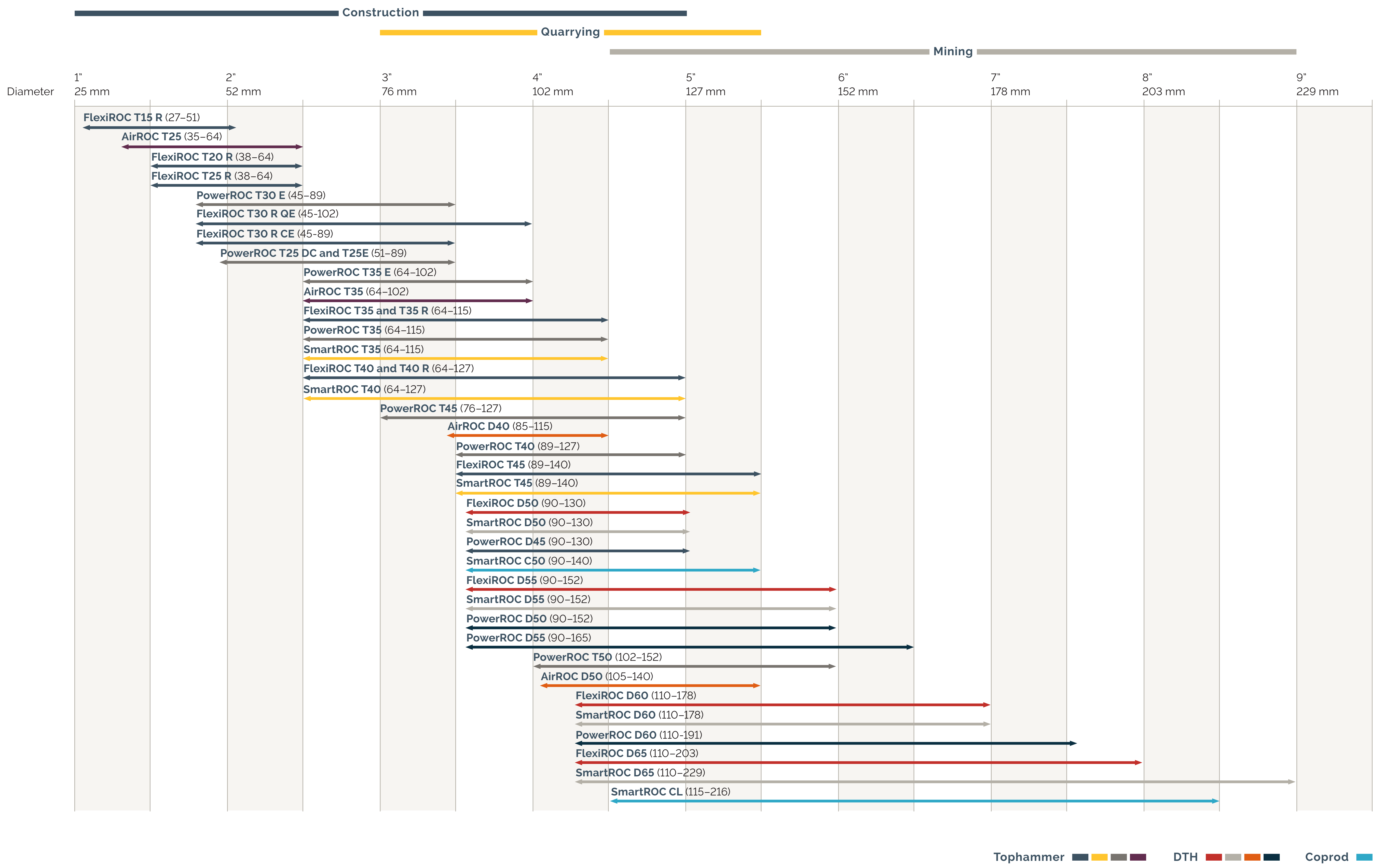
■ Spherical or Trubbnos buttons

Can be used as an alternative to traditional reaming equipment in a pre-drilled hole and in all types of rock formations. Optimised face design for better removal of cuttings. Available with spherical or the effective Trubbnos buttons.

Hole range and applications

On this fold-out you will find an overview of the surface drill rigs for quarrying, mining and construction in our portfolio. It shows the optimal hole range for each drill rig and in what application it is most commonly used. Please note that these guidelines are subject to change. Exceptions to the specified hole ranges may occur in the field.

Surface drill rigs – Hole range and application



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Epiroc is a leading global productivity partner for the mining and infrastructure industries. With cutting–edge technology, Epiroc develops and produces innovative, safe and sustainable drill rigs, rock excavation and construction equipment and tools. The company also provides world–class service and solutions for automation and interoperability. Epiroc is based in Stockholm, Sweden, had revenues of SEK 38 billion in 2018, and has more than 14,000 passionate employees supporting and collaborating with customers in more than 150 countries. Learn more at www.epirocgroup.com

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