Minerals and metals: the lifeline of global growth

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. After a severe downturn, global investments in mining are rebounding as economic recovery is driven by the emerging economies.

The past decade in the mining industry has been marked by record production levels as well as serious setbacks as the financial crisis that struck in the latter half of 2008 put the growth of the world economy at risk and sparked a global recession. Mineral and metal prices lost nearly half of their value between August and December 2008. Since 2009, however, prices have recovered and by the start of 2011 the International Monetary Fund’s (IMF) metals and minerals price index had exceeded its pre-bust price levels.

The global economy is rebounding and growth is returning. It continues to be driven by emerging economies, with mineral and metal prices now stabilizing close to their pre-recession levels. In 2012, the influential economies of Brazil, India, Russia and China (BRIC) accounted for 20% of the global economic output, a figure that is expected to rise to close to 25% by 2017. Of the expected growth in the world economy in the next five years, nearly 40% will be accounted for by these emerging countries.

The Chinese, Indian and Brazilian economies, like many other countries in a state of rapid development, are passing through a resource-intensive stage of economic growth. They are 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.

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 in urban centers. The largest increase in this rural-to-urban migration will be seen in cities in emerging and developing countries.

China alone intends to urbanize 350 million more people by 2025, resulting in 221 cities with over one million inhabitants. China’s 12th five-year plan continues, like its predecessors, to include a range of infrastructure expansion goals. As Brazil prepares to host the 2014 FIFA World Cup and the 2016 Summer Olympic Games, its infrastructure spending will increase. Russia has ambitious plans to spend USD 1 trillion on infrastructure between 2007 and 2017. Such increased demand for urbanization, infrastructure development, consumer goods and energy will contribute to increased demand for minerals and metals.

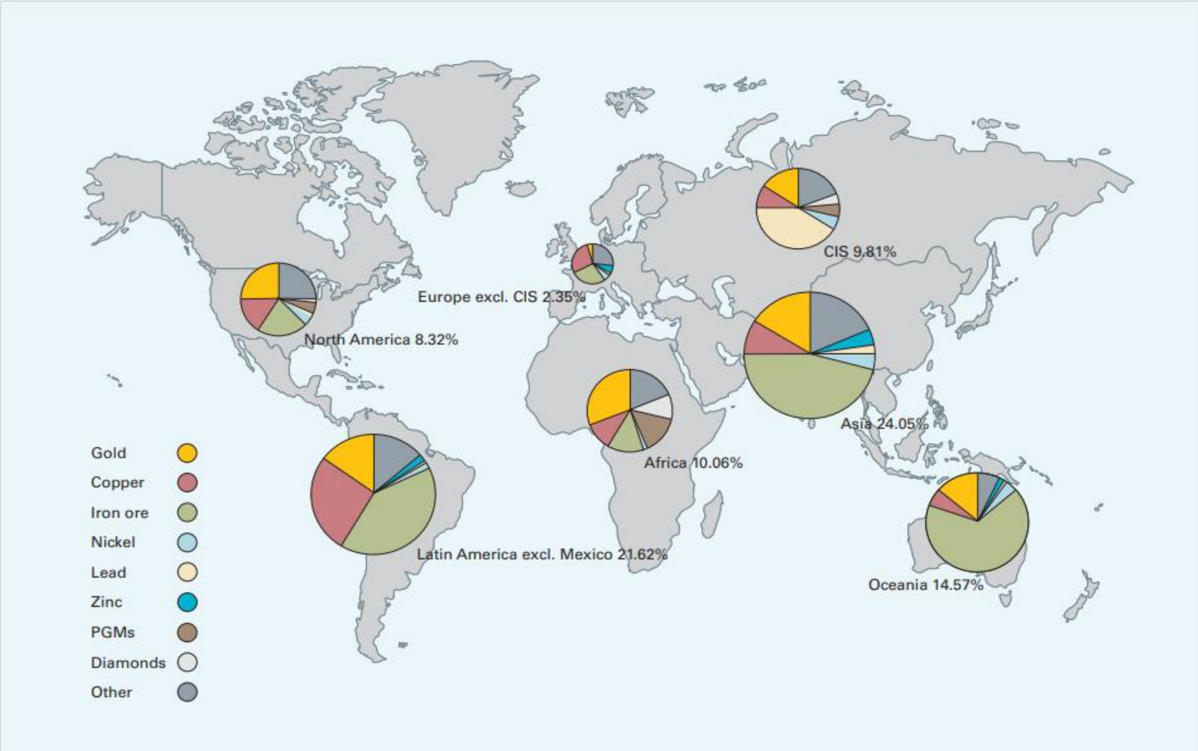
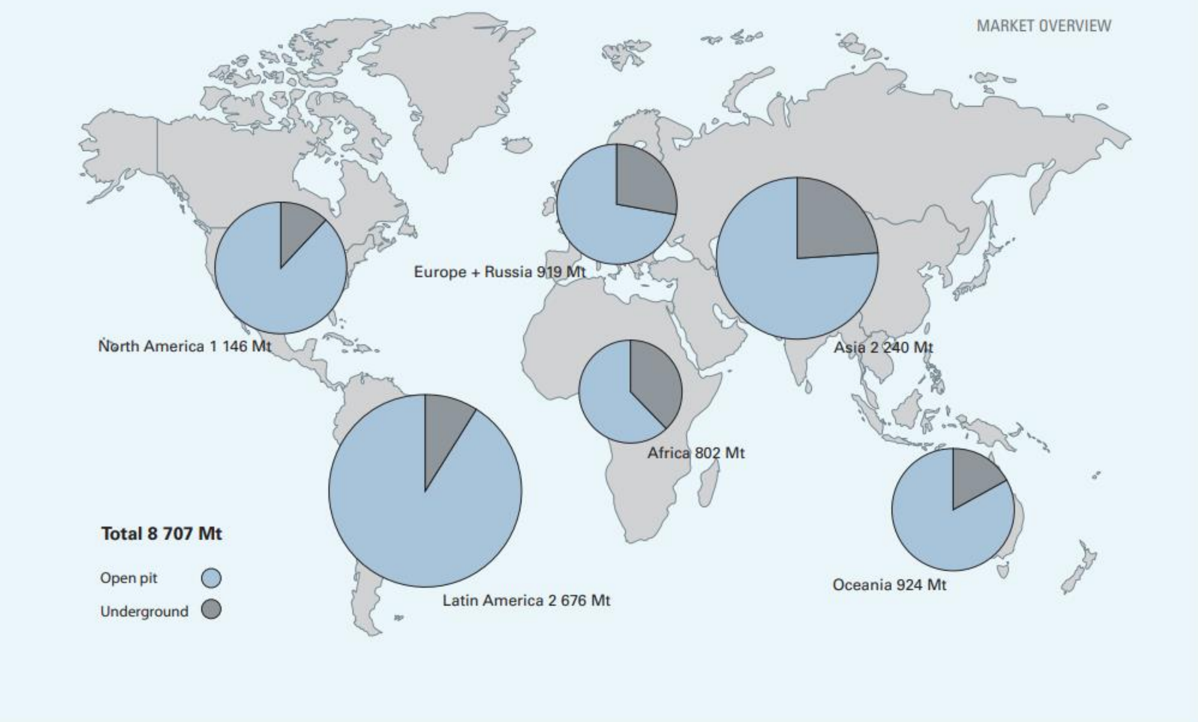


Figure 1: Global distribution of mined minerals based on the value of mined quantities. (Source: Raw Materials Data)



Total quantity of materials mined in the world by open pit and underground operations.

Mining sector continues to expand

Compared to the slowdown in the global economy, the mining industry has stood up well and continues to expand with the total value of mineral and metal output increasing from USD 680 billion in 2010 to USD 850 billion in 2011. 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 (see Figure 1).

Investments maintain upward trajectory

Investments and capital expenditure in the mining sector have continued on their steady upward trajectory since 2003. Although the financial crisis and economic recession did dampen expenditure in 2009 and 2010, industry expenditures is expected to stay above the USD 300 billion level over the next few years (Figure 2).

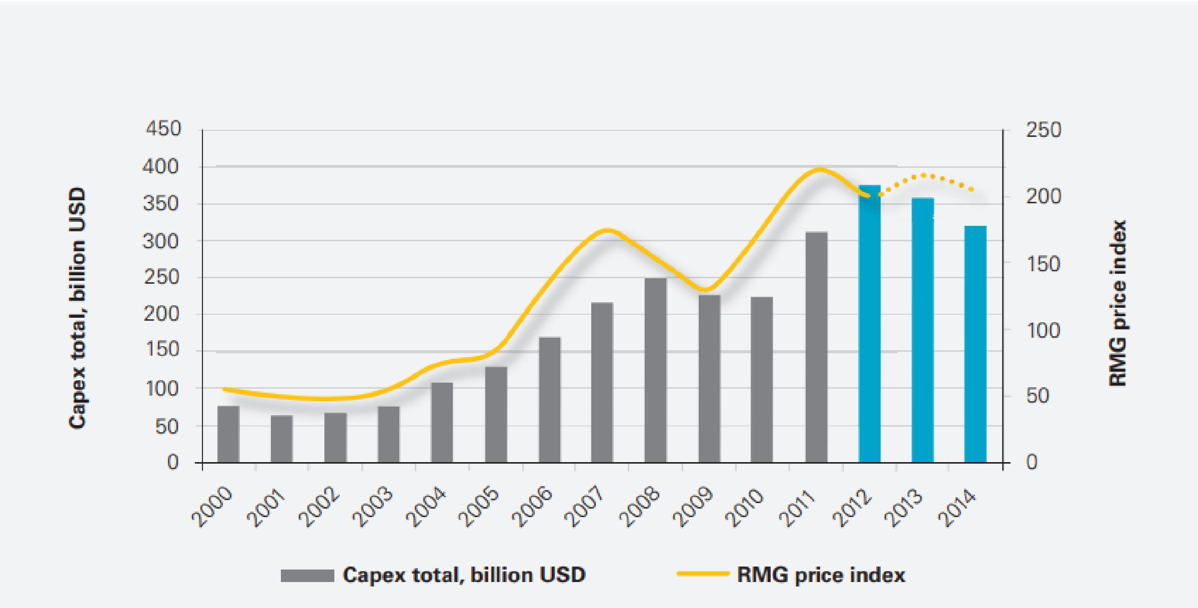


Figure 2: Capital expenditure in the global mining industry and Raw Materials Group price index.

Open pit vs. underground

Around 1 billion tonnes of ore were extracted in 2011 from underground hard rock mines worldwide and closer to 1.2 billion tonnes if taken together with industrial minerals. In South Africa, underground mining accounts for nearly half of the sector's output, but in other regions such as the U.S. Peru and Brazil, the majority of the output is accounted for by open pit mines.

Among the economically most important metals, zinc and lead are primarily extracted using underground mining methods, with over 70% of all zinc/lead ore deposits being excavated underground. While the majority of coal is produced from underground mining, open pit mining accounts for the majority of the production of iron ore, gold, copper and nickel. Open pit mining accounts for the majority of the production. Overall, the 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. Thus the ratio of ore volumes between open pit and underground mining has not seen a major change over the last decade.

Ore grades

The increase in metal and mineral prices over the past decade has pushed for higher output in the sector, but this has led to lower ore grades to be mined to fulfill such demand, as shown in Figure 3.

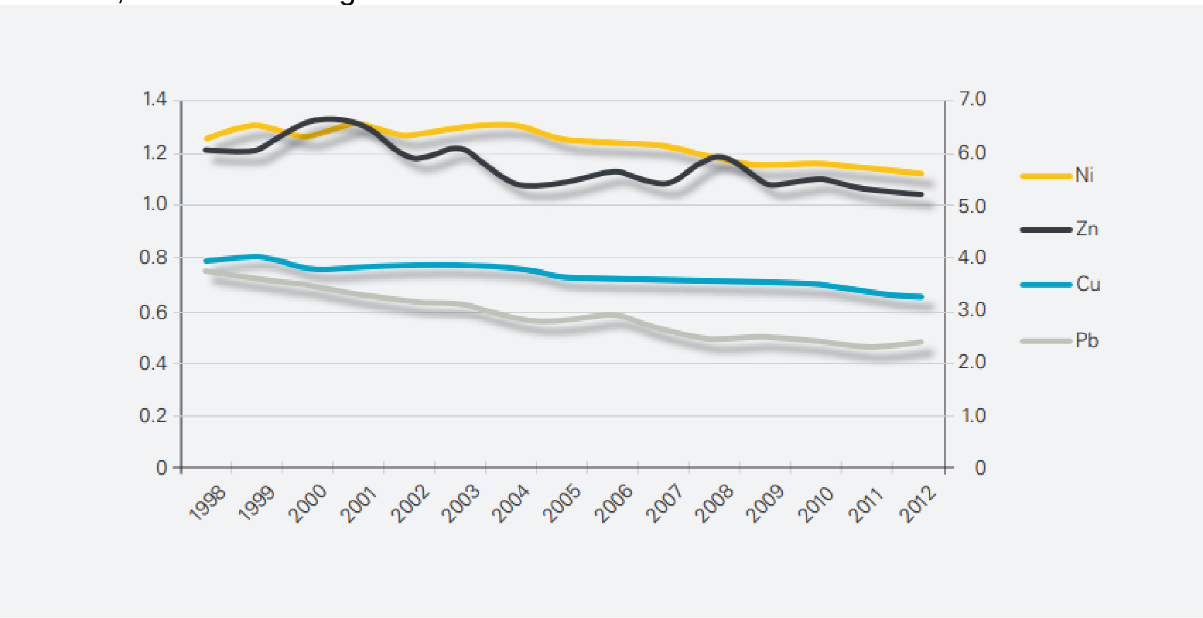


Figure 3: Falling ore grades (%) for nickel, zinc, copper and lead.

Recycling

More sustainable use of metals and minerals has encouraged recycling of a number of these products, but recycling rates still remain low. The United Nations Environment Program (UNEP) estimates that for 30 metals the end-of-life recycling rate is above 30%, while for another 34 elements this rate is below 1%. There are differences for ferrous and non-ferrous metals; for example, iron and steel have an estimated end-of-life recycling rate between 70–90%, while for copper it is lower (43–53%) and lower still for zinc (35–60%). In terms of recycled content (fraction of secondary metal in the total metal input of metal production) between 28 and 52% of iron, 20–37% of copper and 18–27% of zinc production includes scrap metal.

While the importance of recycling metals is increasing, both in the public and private spheres, which is in line with promoting sustainable use of resources, the share of this sector is still outweighed by “new” production. Given that the major consumers of metals are now to be found in emerging economies, metals in use in these countries are at the beginning stages of their life cycles and it will be decades before they enter their recycle phases. For example, new construction in China consumes metals and on average it takes 40 years for a building to be replaced. Hence these materials will not enter the recycled metals category during this time.

Trends for the future

2012 was a difficult year for the global economy; however, with anticipated improvements in China’s economic growth (the Chinese economy accounting for almost half of global consumption of metals), a stronger Eurozone and continued restoration of the U.S. economy, the future is expected to improve. As global growth heads towards more positive numbers in the future, drilling and exploration activity is expected to follow 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.

For more meaningful supply to come online, a longer time period is required. Therefore, the full impact of the price boom that set off in 2003 will continue to be realized in the next few years. New mines have often been 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. 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. Coupled with increases in the costs of equipment, increased lag times (compared to pre-2003 level) for equipment delivery, rising labor costs and slow growth in production capacity, the upward pressure on metal and mineral prices remains in place.

While the global economy, particularly the global financial markets, has, to some extent, affected the ability of exploration and mining firms to raise capital, the vigor of the mining sector remains robust. Commodity prices are expected to continue to remain strong and above their pre-2003 levels. Mining firms have been cautious in the last few years and, in some cases, have responded by scaling back planned expansions, but overall the underlying demand for metals remains strong. Even for projects that have been currently mothballed, an increase in price will solicit their return to operations quickly. As global economic growth recovers, mining activity and investments will continue expanding. The mining sector will remain in good health in the future.

Navigating the underground universe

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, designing the rock support system and a dozen other key decisions that will affect the success of an underground mine, 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 (see 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 an underground 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.

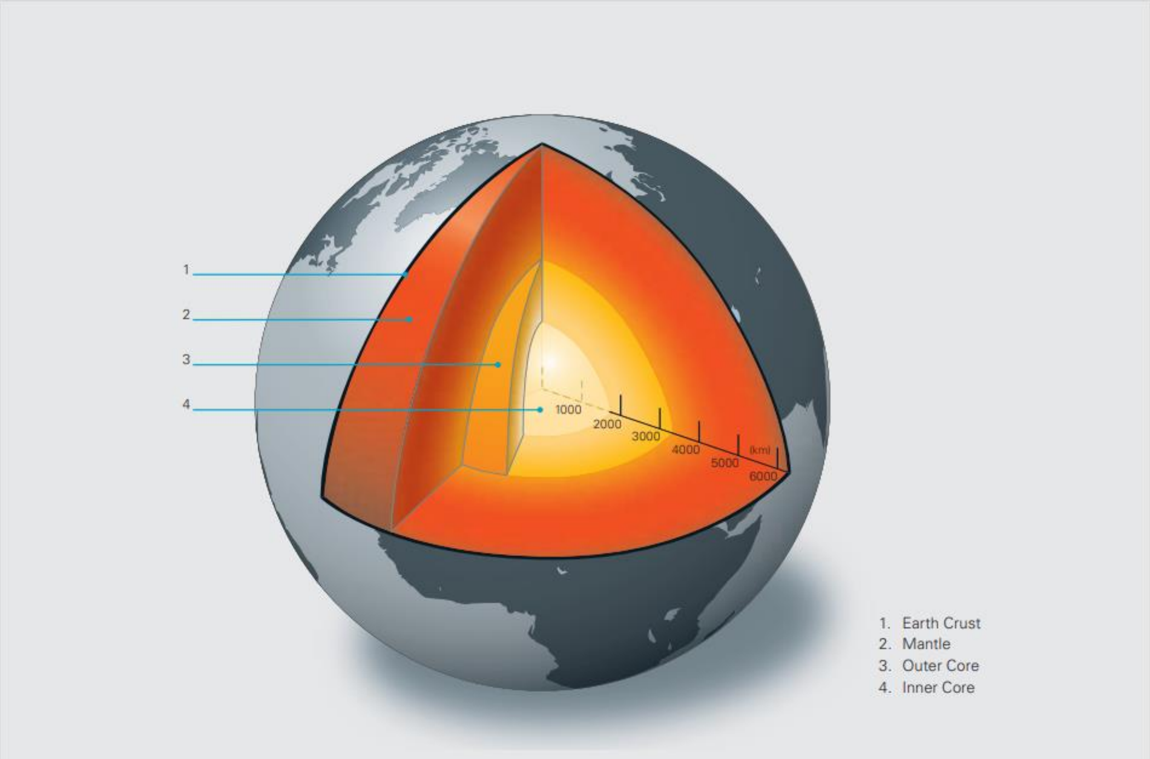


Figure 1: The Earth's interior consists of four main layers. Heavy metals such as iron and nickel are most abundant in the core.

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 aluminium, iron, calcium, sodium, potassium, magnesium and titanium making up 99% of the Earth's crust. Silicon, aluminum and oxygen occur in the most common minerals such as quartz, feldspar and mica. 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.

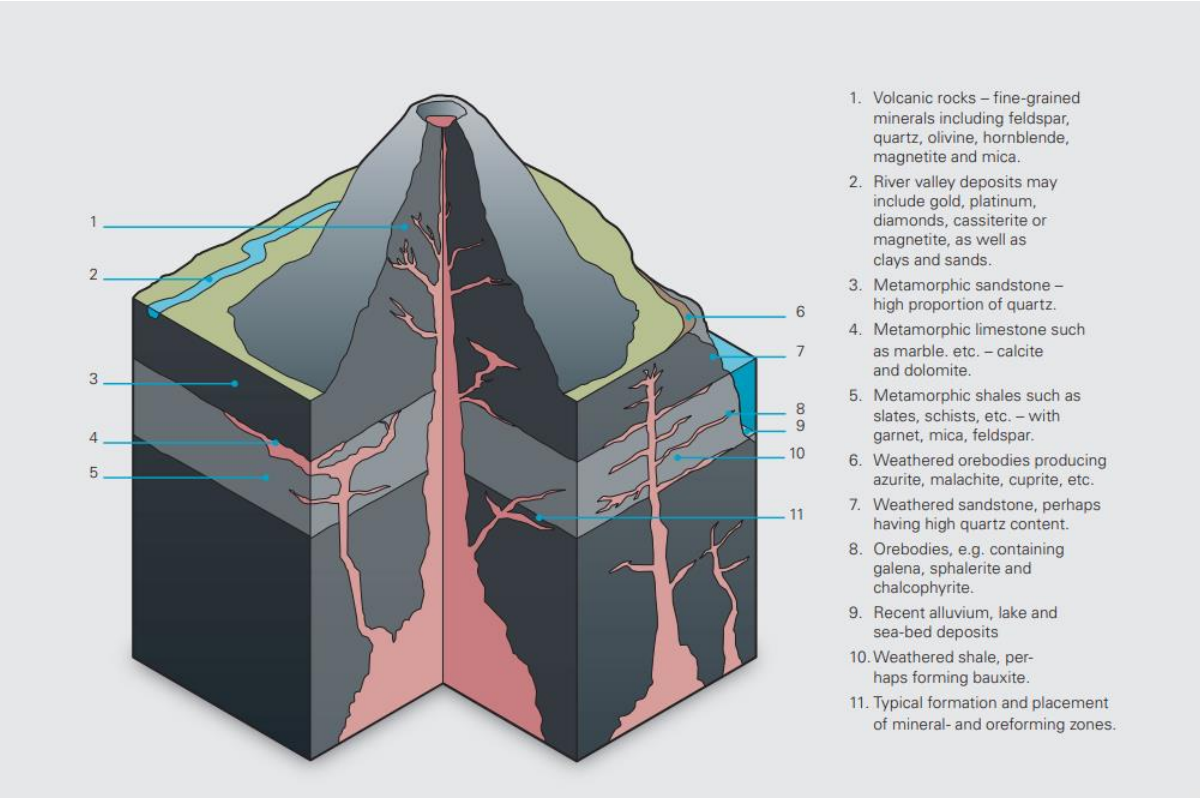


Figure 2: Typical formation and placement of mineral- and ore forming zones.

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.

These characteristics are:

- **Hardness**
- **Density**
- **Colour**
- **Streak**
- **Lustre**
- **Fracture**
- **Cleavage**
- **Crystalline form**

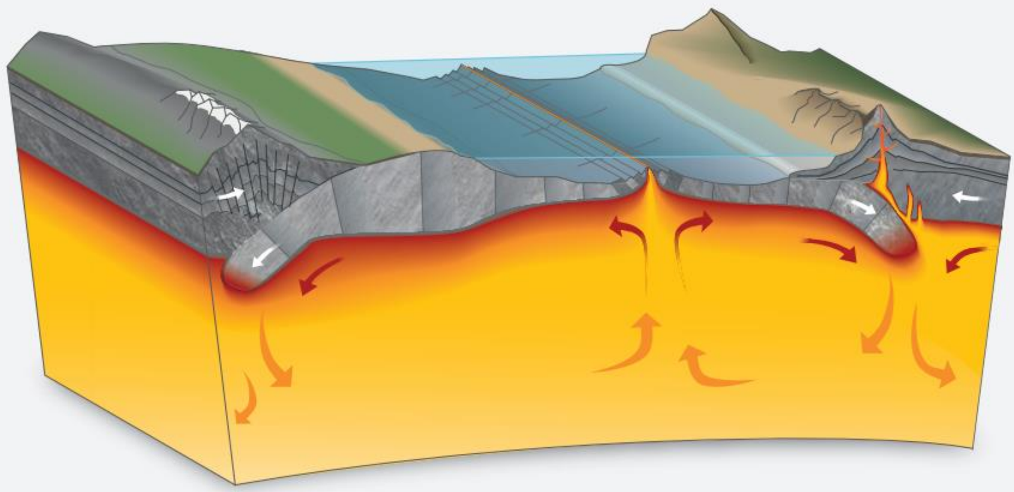
The particle size and the extent to which the mineral is hydrated (mixed with water) indicate the way the rock will behave when excavated.

Hardness is commonly graded according to the Mohs 10-point scale. The density of light-coloured minerals is usually below 3. Exceptions are barite or heavy spar (barium sulphate – $BaSO_4$ – density 4.5), scheelite (calcium tungstate – $CaWO_4$ – density 6.0) and cerussite (lead carbonate – $PbCO_4$ – density 6.5).

Dark-coloured 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 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 colour 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.

GEOLOGY FOR MINING



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.

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. 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 the 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.

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

Figure 3: Main igneous rock types according to chemical composition (silica content) and location where magma turned into solid rock.

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 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 drillstring 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. Therefore, it is 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 (Figure 3). 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 illustrated (Figure 3).

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).

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

Figure 4: Typical sedimentary rock types and the material from which they originate.

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 (see Figure 5), metamorphic zones will probably be associated with increased faulting and structural disorder, making the planning of mine development and efficient drilling more difficult.

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

Figure 5: Typical metamorphic rock types and their origin, followed by the degree of metamorphism that is needed.

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 pre-grouting 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 will form the structure around the underground openings can be a major factor in determining the feasibility of exploiting a mineral deposit. This is mainly because of its effect on the degree of support required for both production level drives and for development drifts.

It is a delicate economic balance to choose between an investment in development drifts in stable ground, perhaps without useful mineralization, and drifts within the mineral deposit, which may have a shorter life but require more support measures. Although it is beneficial to minimize development drifts and ramps in non-productive waste rock and to make them as short as possible, stability and longevity are prioritized. When it comes to major development assets such as shafts or transport levels, these are nearly always placed in the most stable ground areas that can be found, as they are expected to last a long time, with further drifts or levels made from them. In extreme cases, it may be found that the mineral deposit cannot support development workings without considerable expense. In these circumstances, it might be better to install development drifts near and below the mineral deposit. This could then be exploited by using long hole drilling and blasting, with the ore being drawn off from below. This, however, is rare and the recommended procedure is to let the mining method dictate how drifts are developed, while taking critical rock areas into consideration.

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.
Having said this, there is low profile mining machinery available today that can help miners to excavate as little as possible of the waste rock, and the demand for this type of equipment is expected to grow.

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 civil tunnelling, good results will yield benefits both in terms of production and safety. Minimized overbreak will prevent the excavation of too much waste rock, and a good contour preserves the structure of a drift and facilitates rock support.
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 mineral 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 under-ground, as well as 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.

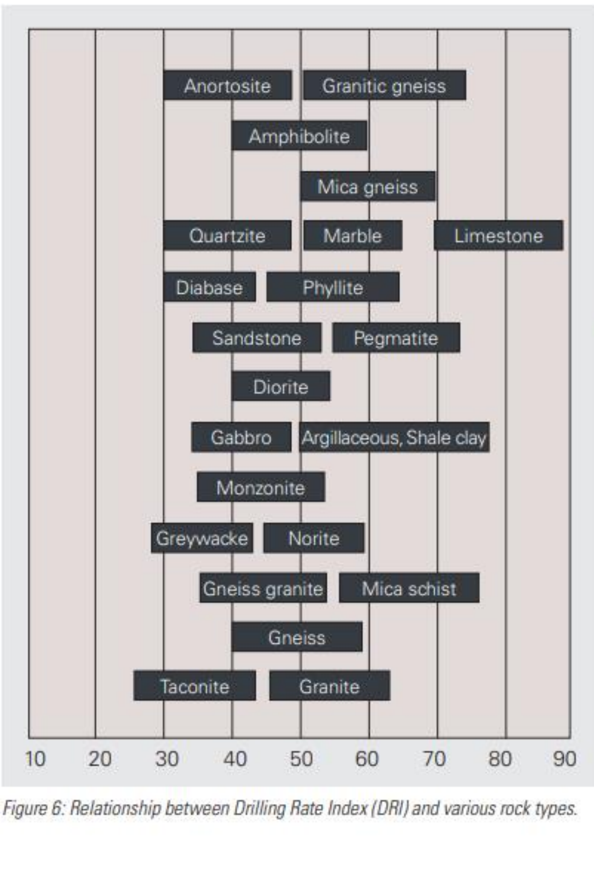
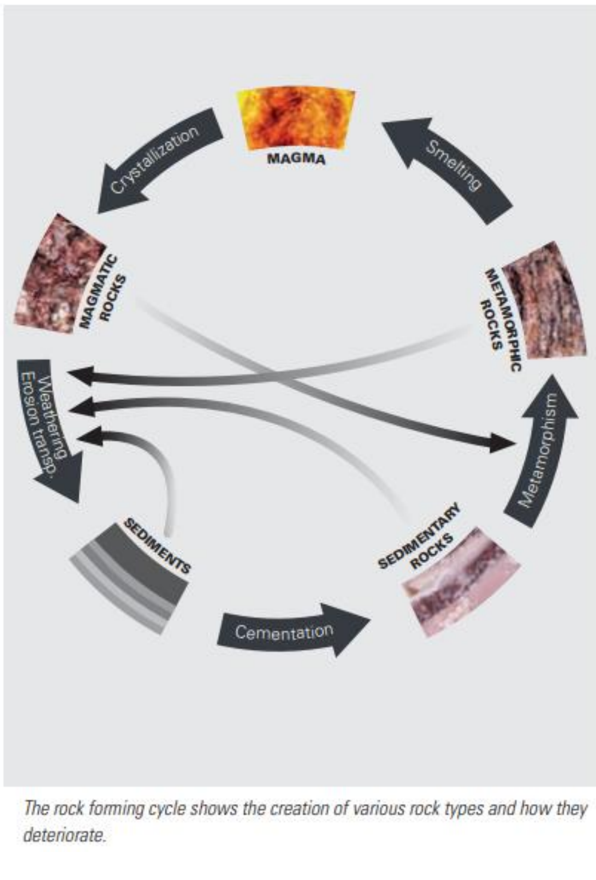


Figure 6: Relationship between Drilling Rate Index (DRI) and various rock types.



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

Rock classification

A number of rock classification systems have been developed in order to systematically determine the excavation and support requirements, whether a particular method is suitable, and the amount of consumables required. generally defined by an intended purpose, such as the level of support required or the rock's drillability. 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 6).

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, Secoroc 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 behaviour and to compare results.