# An introduction to surface mining

## The wealth of nations

A well-accepted principle is that the wealth of a nation comes from the earth. In the world of mining, a corollary to this is that "If it can't be grown, it must be mined." Surface mining techniques are the principal means used to extract minerals from the earth. The yearly rock production yielding metals, non-metals and coal in the world totals 16.6 billion tons*. Of this, the production from surface mines is about 70% or 11.5 billion tons. Crushed rock, sand and gravel - the fundamental materials required for construction - are largely produced using surface mining techniques. Their yearly production rate totals 23.5 billion tons. To this must be added the materials needed for the production of cement, another 2.3 billion tons. Finally, the amount of waste that must be moved in the process of extracting the valuable materials is estimated at 30 billion tons. Summing, one finds that the total amount of material extracted per year using surface mining techniques is of the order of 67.3 billion tons (Bagherpour et al, 2007).
*1 ton = 907 kg

Photo: Copper mine in the southwest USA.

## An increasing demand

Today, the population of the world stands at about 6.5 billion people. In simple terms, this means that every year approximately 10 tons of material is extracted using surface mining techniques for every person in the world.

If one looks to the future, the UN estimates that in 20 years (2038) the world's population will have reached about 8.5 billion people. By simply applying the current utilization rate of 10 tons/person, one would expect the amount of material extracted yearly by surface mining techniques to climb to 85 billion tons. One must keep in mind, however, that today about 95% of the population growth is in the developing countries of the world. Based on their expectations for improved living standards in the future, the actual estimate of materials mined using surface mining techniques in the year 2038 is 138 billion tons (Bagherpour et al, 2007).

The ability of the earth to meet this type of demand is not really a question of resources, since they are clearly there, but rather a matter of price and cost. In looking at the mineral resource base, one must conclude that, in general, the mining conditions will be significantly more difficult than today. In addition, ever-increasing environmental and health and safety conditions are expected to be in place. This means that the entire mining process from prospecting to exploration to development to extraction and finally to reclamation will have to become much more advanced. In many places of the world today, mine closure must be fully and satisfactorily addressed before a surface mine can be opened. This translates into requirements for applying first rate engineering and technology for meeting today's requirements and especially those of the future. Atlas Copco is at the forefront in producing the equipment and technologies required today and for addressing the challenges of the future.

## A brief synopsis of quarrying and open pit mining

This introductory chapter will focus on those surface deposits that require the application of drilling and blasting techniques as part of the overall extraction process. Excluded from the discussion will be strip mining, the mining of sand and gravel deposits and the quarrying of dimension stone.

As indicated, large quantities of raw materials are produced in various types of surface operations. Where the product is rock, the operations are known

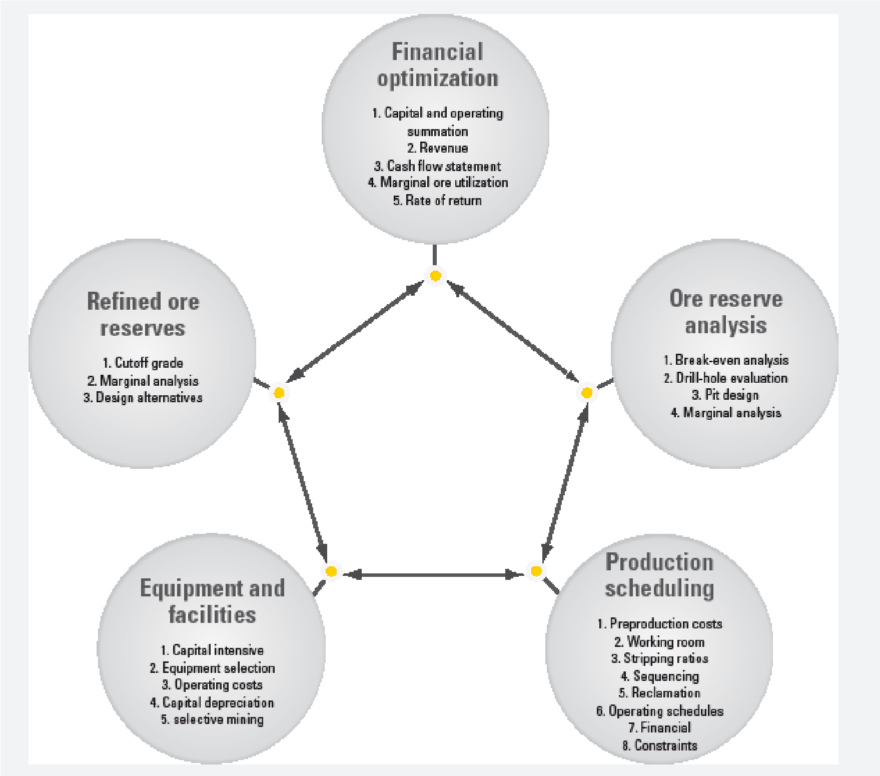


Figure 1. Financial optimization using circular analysis (Dohm, 1979).

as quarries. Where metallic ore or non-metallic minerals are involved, they are called open pit mines. There are many common parameters both in design and in the choice of equipment.

When examining a deposit for potential mining and even when expanding a current operation, one often employs a process called circular analysis. As shown diagrammatically in Figure 1, the process consists of five components. Although the figure applies specifically for the open pit mining of ore deposits, a similar procedure is followed for quarries.

One naturally begins with a description of the deposit and using some assumed costs a preliminary pit design is obtained. By adding the desired production rate into the model a production schedule is generated. Based on the schedule, one determines the required equipment fleet, staffing, etc. to satisfy the schedule. This leads allows one to calculate the capital requirements and the operating costs. With these now-estimated rather than assumed costs, the ore reserves are re-examined and design alternatives evaluated. Eventually, an overall financial evaluation is performed. The double-headed arrows indicate the highly repetitive nature of the process.

## Quarries

A rather simple but useful definition of a quarry is a factory that converts solid bedrock into crushed stone. Quarries can be either of the common pit type or, in mountainous terrain, the hillside type. Pit type quarries are opened up below the level of surrounding terrain and accessed by means of ramps (Figure 2). The excavation is often split into several benches depending on the minable depth of the deposit. When the terrain is rough and bulldozers cannot provide a flat floor, a top-hammer construction type drill rig can be used to establish the first bench. Once the first bench is prepared, production drilling is preferably carried out using DTH- or COPROD techniques.

The excavated rock is crushed, screened, washed and separated into different size fractions, for subsequent sale and use. The amount of fines should be kept to a minimum. Not all types of rock are suitable as raw material for crushed stone. The material must have certain strength and hardness characteristics and the individual pieces should have a defined shape with a rough surface. Igneous rock such as granite and basalt as well as metamorphic rock such as gneiss are well suited for these purposes. Soft sedimentary rock and materials which break into flat, flaky pieces are generally unacceptable. The final products are used as raw material for chemical plants (such as limestone for cement manufacturing, the paper and steel industries), building products, and for concrete aggregates, highway construction, or other civil engineering projects.

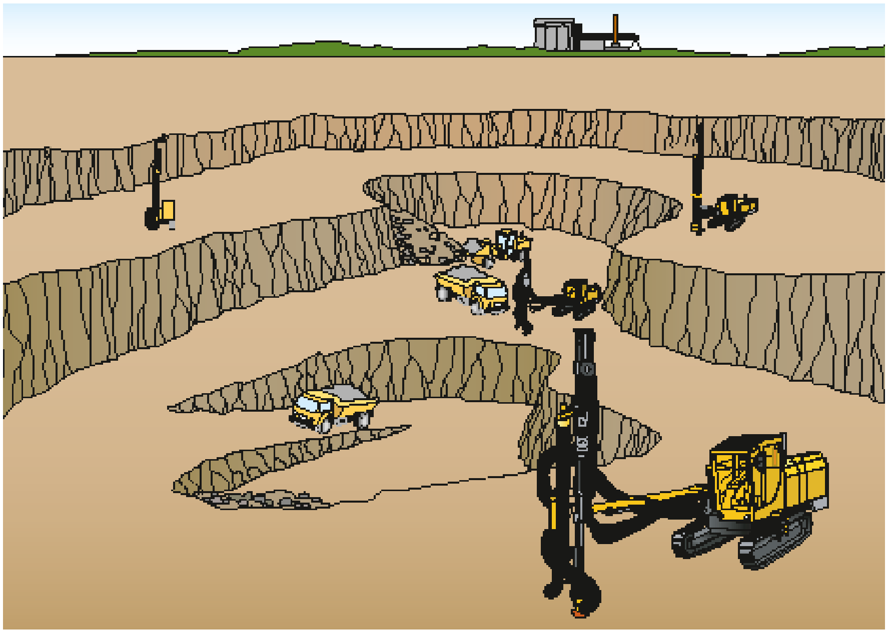

Figure 2. A diagrammatic representation of a quarry operation.

Quarries are often run by operators who sell their products to nearby contractors and road administrators. Because the products are generally of relatively low value, they are transport cost sensitive. Hence, wherever possible, quarries are discreetly located as close as feasible to the market. Special measures are required to minimize adverse environmental impacts such as noise from drilling, vibrations from blasting, and dust from crushing and screening to the neighboring areas.

## Open pit mines

Two major differences between open pit mining and quarries are the geological conditions and the demands placed on the characteristics of the blasted material. For quarries, a majority of the rock products eventually delivered to the customers has only undergone crushing and screening in order to obtain the desired size fractions. An open pit metal mine, on the other hand, attempts to deliver the ore as pure as possible via crushers to a concentrator consisting of mills, separators, flotation and/or biochemical systems, etc. The resulting concentrates/products are eventually sent for further processing before emerging as a final product. For certain metals, this latter process involves smelting and refining. The deposits mined using open pit methods have a variety of sizes, shapes and orientations. Sometimes the distinction between the valuable material and the waste is sharp such as shown in Figure 3 and in other cases the distinction is more subtle - based upon economics. As in quarries, the minerals are extracted using a series of benches. If the orebody does not outcrop, the overlying material must first be stripped away to expose the ore. As the initial pit is deepened, it is widened. The pit geometry is controlled by a number of factors including orebody shape, grade distribution, the stability of the slopes, the need to provide access, operating considerations, etc.

For the geometry shown in Figure 3, a significant amount of waste must be removed (stripped) to access the next bench of ore at the pit bottom. Without jeopardizing slope stability, it is of prime importance to keep the pit slope angle as steep as possible, thereby keeping the excavated waste to a minimum. There becomes a point where the quality of the material contained in the next "ore" bench is not sufficiently high to pay the costs of the associated waste. At this point in time either the open pit mine closes or, if conditions are favorable, continuation may proceed using some type of underground method.

Figure 4 shows the Aitik copper/gold mine in northern Sweden. It is Europe's largest copper mine producing 18 Mton of ore per year. Currently at a depth of 480 m it is expected to reach of depth of 800 m before decommissioning. The Bingham Canyon mine in Utah (Figure 5)

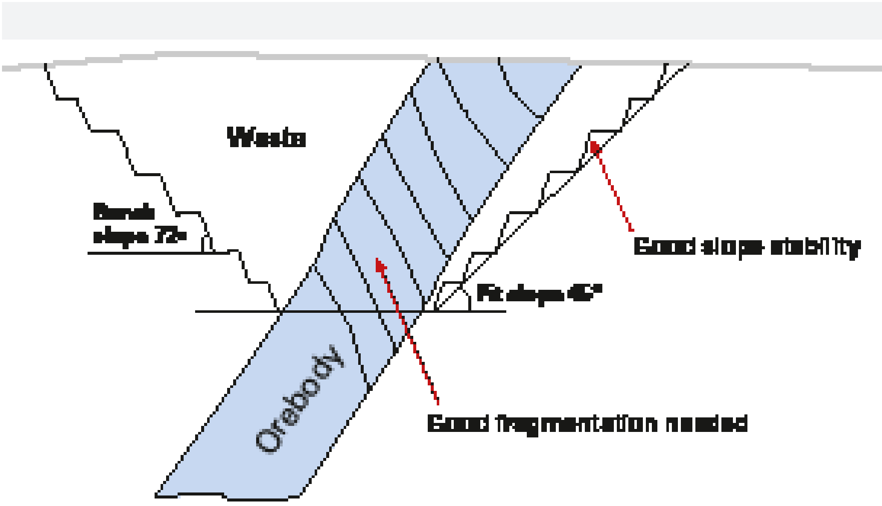


Figure 3. General principles of open pit mining.

Figure 4. The Aitik mine in northern Sweden (www.boliden.com).

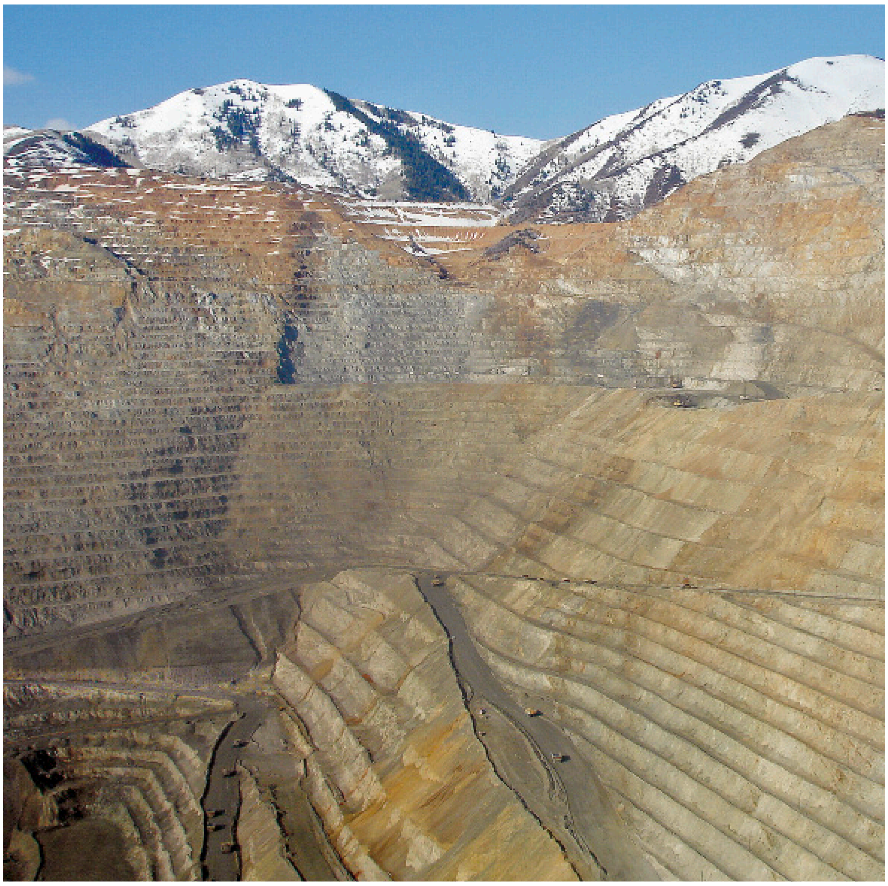

Figure 5. The Bingham Canyon copper mine near Salt Lake City, Utah, USA. (www.kennecott.com)

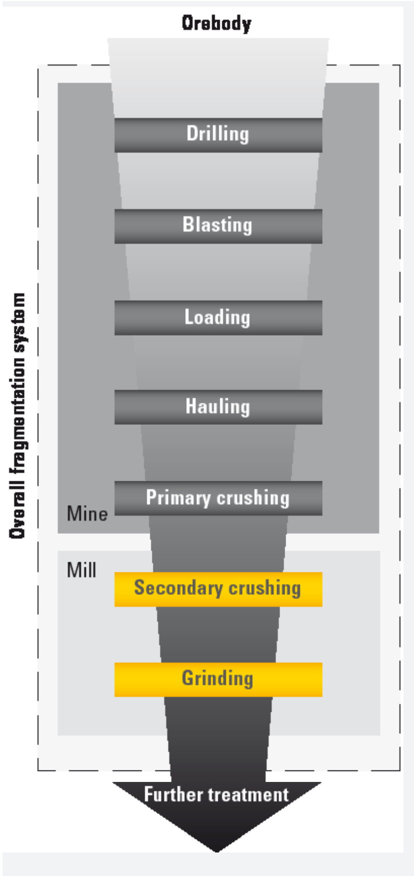


Figure 6. Diagrammatic representation of the overall mine-mill fragmentation system and the mine and mill subsystems (Hustrulid, 1999).

has been in production since 1906 and is one of the largest man-made structures in the world, measuring 1200 m deep and 4400 m across the top. It has produced more copper than any other mine in history and has many years remaining. With respect to waste removal, the fragmentation demands are simple. Since, the material is not required to pass through a crusher, the maximum size is controlled by the limitations imposed by the equipment used to load and haul the material to the waste dump. On the other hand, good fragmentation of the blasted ore offers great savings in the total costs of the mineral dressing process.

Photo: Blasthole drilling of 40 ft (12 m) benches at Newmont's Phoenix mine, Nevada, USA. See page 91.

## Some forward thinking

Extraction of the valuable mineral whether in quarries or open pits requires a number of unit operations. Generally, the rock is drilled, blasted, loaded, hauled to a primary crusher and then transported further to a plant of some type for further processing. Figure 6 shows a schematic of the process.

Often, mines are organized so that the individual unit operations are separate cost centers. Although there are advantages to this approach, one result,

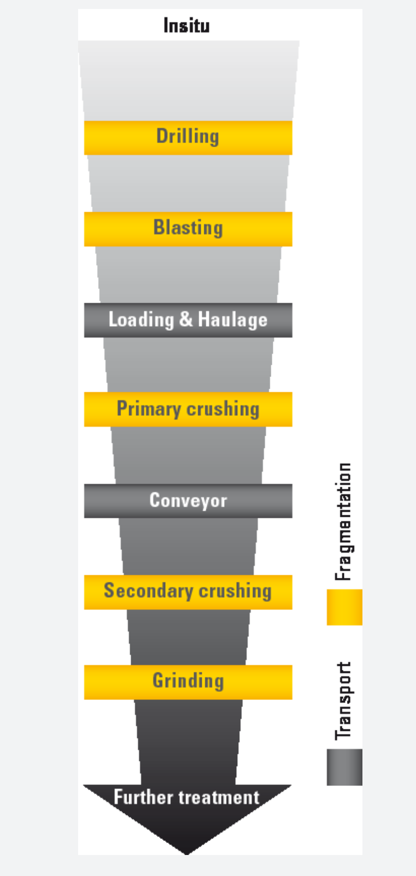


Figure 7. The mine-mill system represented as fragmentation and transport unit operations (Hustrulid, 1999).


Figure 8. Simplified view of the five different stages of fragmentation, each with a different energy-product profile.

unfortunately, can be that the individual managers look at minimizing the cost of their center rather than on the overall objective of overall cost minimization. In reviewing the components in Figure 6, it can be shown that they can be replaced by two operations, fragmentation and transport. In the simplified view shown in Figure 7, there are five different stages of fragmentation each with a different energy – product profile.

One must carefully examine the best opportunities for applying fragmentation energy in the various stages on the final product cost. For example, increased fragmentation energy can be relatively easily introduced in the mine by modifying the drill patterns and explosive characteristics. This action may provide an inexpensive alternative to adding the fragmentation energy in the grinding circuit. This process of considering all elements of the fragmentation system, logically dubbed "mine-to-mill" is a recognized part of mine-mill optimization. In addition to production, there are some other important customers for blast engineering. One is termed the "Internal Environment" and the other the "External Environment." These are shown in Figure 8.

Both for safety and economic reasons, it is important to preserve the integrity of the pit wall. Large diameter blast holes, energetic explosives and wide patterns will be used in the production blasts which will be subsequently loaded out using large excavators and haulage units. Near the pit wall, much more precise techniques involving smaller diameter holes, specially designed explosives, and special timing procedures are employed to minimize wall damage (Figure 9). Unless great care is taken, large loading equipment can easily spoil the results of the trim blasting. The result is that special loading and hauling fleets may be required. Failure to protect the pit walls, translates into the need for flatter slopes and additional waste removal and/or the loss of reserves. These, in turn, translate into higher overall costs for the mining operation. In carrying out an evaluation of the appropriate drilling and blasting practices, emphasizing mine-to-mill aspects without taking into account the care of the slopes can result in lower production costs but at the sake of higher investment (capital) costs due to greater stripping or lost reserves. Therefore care must be taken to include all the costs when making the analysis. The "external environment" component falls into the category of a potential "show-stopper" since if proper measures are not taken to fully comply with standards, the operation could very well be shut down.

## Final remarks

Atlas Copco has the advantage of long experience in all types of surface drilling operations, with a product range to match. With its history of innovative

Figure 9. Near the pit wall more precise techniques are employed to minimize wall damage.

engineering, the company tends to think forward, and is able to advise the user on improving design elements of the operation that will result in overall cost savings.

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Photo: Blasthole drilling and haulage at a mine in the southwest USA.