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Open Pit Mining

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Abstract

Open pit mining method is one of the surface mining methods that has a traditional cone-shaped excavation and is usually employed to exploit a near-surface, nonselective and low-grade zones deposits. It often results in high productivity and requires large capital investments, low operating costs, and good safety conditions. The main topics that will be discussed in this chapter will include an introduction into the general features of open pit mining, ore body characteristics and configurations, stripping ratios and stripping overburden methods, mine elements and parameters, open pit operation cycle, pit slope angle, stability of mine slopes, types of highwall failures, mine closure and reclamation, and different variants of surface mining methods including opencast mining, mountainous mining, and artisan mining.

Keywords: open pit mine, slope stability, mine reclamation, stripping ratio, production cycle

1. Introduction

Open pit mining is defined as the method of extracting any near surface ore deposit using one or more horizontal benches to extract the ore while dumping overburden and tailings (waste) at a specified disposal site outside the final pit boundary. Open pit mining is used for the extraction of both metallic and nonmetallic ores. Open pit mining is considered different from quarrying in the sense that it selectively extracts ore rather than an aggregate or a dimensional stone product.

Open pit mining is applied to disseminated ore bodies or steeply dipping veins or seams where the mining advance is toward increasing depths. Backfilling usually occurs until the pit is completed; even then, the high cost of filling these pits with all of the waste removed at the end of the mine life would seriously risk the project's economics. Few large open pits in the world could support such a costly obstacle. Open pit method is usually nonselective, and it includes all high and low-grade zones; whereas mining rate is nearly over 20,000 tons mined per day and often necessitates a large capital investment but generally results in high productivity, low operating cost, and good safety conditions [1]. The main purpose of this chapter is to discuss the general features of open pit mining, ore body characteristics and configurations, stripping ratios and stripping overburden methods, mine elements and parameters, open pit operation cycle, pit slope angle, stability of mine slopes, types of highwall failures, mine closure, and reclamation. The chapter will also discuss different variants of surface mining methods including opencast mining, mountainous mining, and artisan mining.

1.1 Features, technical and economic indicators of open pit development

Compared to underground mining methods, the open pit mining method requires removing significant amount of overburden from the pit and moving it outside the mine. The cost of extraction of the ore from open pit constitutes the bulk of the total cost of mining operations, because the access to the ore body is so fast and requires less time compared to underground mining, i.e., extracting the ore below overburden can only begin with some lag time from the start of removing overburden. Also, open pit has virtually an unlimited ability to create and use high-performance large-sized mining and transportation equipment that can provide the highest technical and economic parameters. Open pit mining has higher productivity (3–5 times of underground methods), lower production costs, more safe and hygienic working conditions, more complete recovery of a mineral, and lower per unit production cost.

Open pit mining is characterized not only by its high share of total minerals production, but it is also considered as one of the surface mining methods that contributes to the construction of powerful performance quarries (100–150 million tons of rock a year reaching to a depth of 500 m). Capital cost of such huge open pits/quarries is very high, and the total cost for excavation of rock in the long term reaches hundreds of millions of dollars or more. Therefore, decisions on the construction of new or existing quarries should be economically justified. **Table 1** shows the advantages and disadvantages of open pit mining method [2, 3].

1.2 Ore body characteristics and configurations

Open pit mining is widely used with metallic ore bodies (aluminum, bauxite, copper, iron), and nearly all nonmetallic (coal, uranium, phosphate, etc.). It is a traditional cone-shaped excavation (although it can be of any shape, depending on the size and shape of the ore body) that is used when the ore body is typically pipe-shaped, vein-type, and steeply dipping stratified or irregular [4]. The major open pit and ore body configurations are classified into the following:

- Flat lying seam or bed, flat terrain (e.g., platinum reefs, coal), as shown in **Figure 1**.
- Massive deposit, flat terrain (e.g., iron-ore or sulfide deposits), as shown in **Figure 2**.
- Dipping seam or bed, flat terrain (e.g., anthracite), as shown in **Figure 3**.
- Massive deposit, high relief (e.g., copper sulfide), as shown in **Figure 4**.
- Thick-bedded deposits, little overburden (e.g., iron ore, coal) as shown in **Figure 5**.

1.3 Stripping ratio

The parameter known as the *stripping ratio* represents the amount of uneconomic material that must be removed to uncover one unit of ore, i.e., the ratio of the number of tons of waste material removed to the number of tons of ore removed. Also, the ratio of the total volume of waste to the total volume of ore is defined as the *overall stripping ratio*. A lower stripping ratio means that less waste has to be

Advantages	Disadvantages
High productivity, i.e., highly mechanized and labor conserving (around 100–400 tons per employee-shift including both ore and waste)	Limited by depth ~500 m; technological limit imposed by equipment; and deposit beyond pit limits must be mined underground or left in place
High production rate (essentially unlimited, although small surface mines also possible)	Limited by stripping ratio
Lowest cost along with open cast mining	High capital investment associated with large equipment
Early production, development can be programmed to permit early start-up	Surface damaged may require reclamation; a bond has to be added to the production cost
Low labor requirement; can be unskilled except key operators (e.g., drill, shovel)	Requires large deposit to realize lowest cost, unless very high grade
Relatively flexible; can vary output if demand changes	Weather can be detrimental; it can impede operations.
Suitable for large equipment; permit high productivity	Slope stability must be maintained; proper design and maintenance of benches plus good drainage are essential
Fairly low rock-breakage cost (drilling and blasting); superior to underground mining where bench faces are less easily maintained	Requires provision of large waste disposal/dump area
Simple development and access; minimal openings required although advanced stripping may be considerable	
Little if any bank support required; proper design and maintenance of benches can provide stability	
Good recovery; good health and safety; no underground hazards	

Table 1.
Advantages and disadvantages of open pit mining method [2, 3].

Figure 1.
Flat lying seam or bed, flat terrain.

removed to expose the ore for mining which generally results in a lower operating cost [5]. The major types of stripping ratios are overall, instantaneous, and break-even.

In order to specify the maximum allowable stripping ratio (SR_{max}) of a surface mine, break even ratio can help to establishes the pit limits. SR_{max} defined as the ratio of overburden to ore at the ultimate boundary of the pit, where the profit margin is zero. It can be calculated as:

$$SR_{max} = (\text{Value of ore} - \text{Production cost}) / \text{Stripping cost} \tag{1}$$

or,

Figure 2.
Massive deposit, flat terrain.

Figure 3.
Dipping seam or bed, flat terrain.

Figure 4.
Massive deposit, high relief.

Figure 5.
Thick-bedded deposits.

$$SR_{max} = \text{Stripping allowance } (\$/\text{ton}) / \text{Stripping cost } (\text{m}^3/\text{ton}) \tag{2}$$

The maximum allowable stripping ratio enables us to locate the ultimate pit boundary or limit based on prevailing economic, physical, and geometric conditions in the pit. A copper pit designed in this manner with varying ore grades and critical $SR_{max} \sim 2.5 \text{ m}^3/\text{ton}$ ($3.0 \text{ yd}^3/\text{ton}$) is shown in **Figure 6**. Ore occurring in the ore body beyond this maximum stripping ratio will have to be left or mined underground.

Example 1:

A seam of coal has a density of 1.36 t/m^3 and is 2.5 m thick. It is covered by 27 m of shale which has a density of 1.7 t/m^3 . Calculate the stripping ratios?

Solution:

- Volumetric stripping ratio = $27/2.5 = 10.8 \text{ m}^3$ of overburden per m^3 ore
- Weight stripping ratio = $(27 \times 1.7)/(2.5 \times 1.36) = 13.5$ tons of overburden per ton ore
- Stripping ratio = $27/(2.5 \times 1.36) = 7.9 \text{ m}^3$ of overburden per ton ore

Example 2:

The head assay of a copper ore is $0.8\% \text{ Cu}$. The expected overall copper recovery from the ore is 88% . Calculate the maximum stripping ratio if the total cost of production (excluding overburden removal) is $\$5.90$ per ton of ore and overburden removal costs are $\$0.3$ per ton of waste. Assume copper values of $\$1.00$, $\$1.25$, and $\$1.50$ per kg of refined metal at the smelter.

Solution:

$SR_{Max} = \text{Value of ore} - \text{Production/Stripping cost per ton overburden}$

Recoverable copper per ton ore = $0.8\% \times 88\% \times 1000 = 7.04 \text{ kg}$

At $\$1.00/\text{kg}$ $SR_{max} = (7.04 - 5.90)/0.3 = 3.8$ tons waste per ton ore

At $\$1.25/\text{kg}$ $SR_{max} = (7.04 \times 1.25) - 5.90/0.3 = 9.7$ tons waste per ton ore

At $\$1.50/\text{kg}$ $SR_{max} = (7.04 \times 1.50) - 5.90/0.3 = 15.53$ tons waste per ton ore

To check that maximum stripping ratio has been reached; for $\$1.50$, it is possible to strip 15.53 tons waste for each ton ore.

Profit = value of ore – production costs – stripping cost

Profit = $(7.04 \times \$1.5) - \$5.9 - (15.53 \times \$0.3) = 0$

Figure 6.
A copper pit designed in this manner with varying ore grades and critical SR_{max} .

1.4 Stripping overburden methods

Overburden is a waste rock material that must be removed to expose the underlying ore body. It is preferred to extract as little overburden as possible in order to access the ore of interest, but a larger volume of waste rock is removed when the mineral deposit is deep. Most removal operations (which includes drilling, loading, blasting, and haulage) are cyclical. This is true for hard rock overburden which must be drilled and blasted first. An exception to the cyclical effect is dredging method used in hydraulic surface mining and some types of loose material mining (soil) with bucket wheel excavators. The percentage of waste rock to ore excavated is defined as the stripping ratio. Stripping ratios of 2:1 up to 4:1 are common in large mining operations. Ratios above 6:1 tend to be less economically feasible depending on the type of ore extracted. Once removed, overburden can be used for road and tailings' construction or may have a non-mining commercial value as a backfilling material. In selecting a particular stripping method and its corresponding equipment, the ultimate aim is the removal of material (waste and burden) at the least possible cost [6]. Stripping methods are classified into:

- a. declining;
- b. Increasing; and
- c. constant.

1.4.1 Declining stripping method

In this method, each bench of ore has to be mined in sequence, and the waste in the particular bench has to be removed to the pit limit. The ore is easily accessible in the subsequent benches and the operating working space is widely available. Furthermore, all equipment usually work in the same level and so no contamination from waste blasting is left above the ore body. This method is highly productive especially at the beginning where equipment required is at minimal toward the end of the mine life. The primary disadvantage of this method is that the overall operating costs are at maximum during the initial years of operation when the maximum repayment of capital is needed and so cashflows are required to handle interest and repayment of capital (see **Figure 7**).

1.4.2 Increasing stripping method

In this method, stripping of overburden is performed as needed to uncover the ore. The working slopes of the waste faces are essentially maintained parallel to the overall pit slope angle. This method also allows for maximum profit in the initial years of operation and greatly reduces the investment risk in waste removal for ore to be mined at a future date. It is considered as a very popular method whereas mining economics or cutoff stripping ratio is likely to change in a very short time. This method is sometimes impractical because of its small spaces (narrow benches). It is available for operating a large number of equipment especially at the beginning of stripping (see **Figure 8**).

1.4.3 Constant stripping method

This method aims to remove the waste at a rate estimated by the overall stripping ratio. The working slope of the waste faces starts very shallow, but increases as mining depth increases until it equals the overall pit slope. This method has the

Figure 7.
Declining stripping method.

Figure 8.
Increasing stripping method.

advantage of removing the extreme conditions of the former two stripping methods outlined. Equipment fleet size and labor requirements throughout the project life are relatively constant. In this method, a good profit can be generated initially to increase cash flows. The labor and equipment fleet can be increased to maximum capacity over a period of time, and then, they can decrease gradually toward the end of the mine life. Distinct mining and stripping areas can be operated simultaneously, allowing flexibility in planning (see **Figure 9**).

1.5 Mine elements and parameters

Open pit mines are constructed of series of benches that are bisected by mine access and haulage roads angling down from the rim of the pit to the bottom. The bench height is the vertical distance between each horizontal level of the pit. The elements of a bench are illustrated in **Figures 10** and **11**, unless geological conditions dictate, otherwise all benches should have the same height. The bench height should be designed as high as possible within the limits of the size and type of the machine or equipment selected for the required production. The bench should not be so high

Figure 9.
Constant stripping method.

Figure 10.
Main mine elements and parameters.

that it will cause safety problems. The bench height in open pit mines will usually range from 15 m in large mines (e.g., copper) to as little as 1 m in small mines (e.g., uranium) [7]. The slope angle of the pit walls is a critical factor. If the slope angle is too steep, the pit walls may collapse. If it is too shallow, excessive waste rock may need to be removed. The pit wall has to remain stable as long as mining activity continues. The stability of the pit walls should be examined as carefully as possible. For example, rock strength, faults, joints, and fractures are key factors in the evaluation of the proper slope angle.

2. Open pit mine operations

The main economic goal in open pit mining is to remove the smallest amount of material while obtaining the greatest return on investment by processing the most marketable mineral product. The higher the grade of the ore, the greater the value received. To reduce the capital investment, an operation plan has to be developed in order to precisely dictate the way in which the ore body has to be extracted. Open pit mines vary in scale from small private enterprises processing a few hundred tons

1. Excavator
2. Truck
3. Bulldozer
4. Drilling machine
5. Mining level
6. Detonated mass
7. Ore body
8. Blasting boreholes
9. Fourth level haulage Bench
10. First level access
11. O.B. Tips
12. Mining face

Figure 11.
Detailed mining operation in an open pit.

of ore a day to large companies operated by governmental and private corporations that extract more than one million tons of material a day. The largest mining operations can involve many square kilometers in area. The production cycle also referred to as the mine unit operation that consists of ripping and dozing, drilling, blasting, loading, and hauling (see **Figure 12**).

2.1 Ripping and dozing

Typically, bulldozer, wheel dozers, and motor graders are the most common equipment used, in which material transport distance is short and it can be pushed by a blade. The dozer has a large blade capacity and it is designed specifically for bulk material excavation, whereas the motor grader is a machine with a long blade used to create a flat surface during the grading process. These machines cannot “lift” the material, i.e., they do not have a load elevation capacity (**Figure 12**).

2.2 Drilling and blasting

The ore deposit can be mined by means of drilling and blasting in order to fracture the rock into a loadable size. Blasting parameters should be matched with mechanical machines for drilling of blast holes and charging of explosives. Blast holes are drilled in well-defined patterns, which consist of several parallel rows. In bench blasting, the normal blast hole patterns are square, rectangular, and staggered, **Figure 13**. The most effective pattern is the staggered pattern, which gives the optimum distribution of the explosive energy in the rock.

Figure 12.
Open pit operations cycle.

Figure 13.
Blast holes drilling patterns.

2.3 Loading and hauling

Nowadays, surface mining is conducted using shovels, front end loaders or hydraulic shovels. In open pit mining, loading equipment is matched with haul

trucks that can be loaded in 3–5 cycles of the shovel. Many factors determine the preference of loading equipment. For example, with a hard digging rock, tracked shovels are more advisable. On the other hand, rubber-tyred loaders have lower capital cost and are better for loading materials that are low in volume and easy to dig. Furthermore, loaders are very mobile and well applicable for mining scenarios requiring rapid movements from one area to another. Loaders are also often used to load, haul, and dump material into crushers from blending stock piles placed near crushers by haul trucks, **Figure 14**.

Hydraulic shovels and cable shovels are common equipment used in open pit mining. Hydraulic shovels (**Figure 15**) are not chosen for digging hard rock, and cable shovels are generally available in larger sizes. Large cable shovels (**Figure 16**) with payloads of about 50 cubic meters and greater are used at mines where production exceeds 200,000 tons per day, whereas hydraulic shovels are more

Figure 14.
Loading material using front end loader.

Figure 15.
Hydraulic shovels.

Figure 16.
Cable or rope shovels.

flexible on the mine face and they enable greater operator control to selectively load from both directions (top and bottom of the mine face).

The importance of haul trucks in the history of surface mining cannot be overstated. Hand labor, wheelbarrows, horse-drawn vehicles, and ore cars were the principal means of earth-moving equipment until the early twentieth century. The advent of the internal combustion engine led to the development of the haul truck in the mining industry. Open pit mining requires a great demand for truck transport of ore and waste rock. The efficiency and greater load capacity of electrical and diesel-powered haul trucks became the preferred method for hauling in surface mining, gradually replacing rail haulage by the 1960s. Today, the average cost of a new haul truck is \$3.5 million [8]. Most trucks have capacities ranging from less than 50 tons per load to 363 tons per load in large trucks such as Caterpillars 797 series load truck. Some mining companies choose to replace trucks with conveyor belt systems. For example, the Brazilian mining company “Vale” has recently replaced its mine trucks with 23 miles of conveyor belts at its iron ore mine, linking the ore deposits to the company’s processing plant [9, 10].

3. Pit slope angle and stability

Slope angle is required during the early feasibility study. The degree of confidence on calculating slope angle depends upon the condition applicable. The major pit slope angle conditions can be divided into:

- a. mining a shallow high-grade ore body in favorable geological and climatic conditions. Slope angles are unimportant economically and flat slopes can be used. No consideration of slope stability is required;
- b. mining a variable grade ore body in reasonable geological and climatic conditions. Slope angles are important but not critical in determining economics of mining. Approximate analysis of slope stability is normally adequate; and
- c. mining a low-grade ore body in unfavorable geological and climatic conditions. Slope angles are critical in terms of both economics of mining and safety of operation. Detailed geological and groundwater studies followed by comprehensive stability analysis are usually required.

During the pre-production period, the operating slopes should, however, be as steep as possible. The working slope can then be flattened until they reach the outer surface intercepts. The horizontal flow of stress through a vertical section both with and without the presence of the final pit is shown in **Figure 17**.

With the excavation of the pit, the preexisting horizontal stresses are forced to flow beneath the pit bottom. The vertical stresses are also reduced due to the removal of the rock. The rock lying between the pit outline is largely distressed. As a result of stress removal, cracks and joints can open. Cohesive and friction forces restraining the rock in place are reduced. Groundwater can more easily flow reducing the effective normal force on potential failure planes. With increasing pit depth, the extent of the stressed zone increase and the failure becomes more severe.

3.1 Types of highwall failures

There are several mechanisms by which highwall instability can occur. While we cannot expect to prevent all highwall failures, a better understanding of these

Figure 17.
Mine slope geomechanics.

mechanisms will enable us to identify potential problems before they become actual problems and to limit exposure to dangerous conditions. The most common types of failure include plane failure, wedge failure, toppling failure, and circular failure. Except for the circular failure, these usually occur along preexisting discontinuities. Example of each are the following:

3.1.1 Planar failure

This slide in **Figure 18** illustrates a typical plane failure of a highwall. Notice that the rockslide occurs along this discontinuity which daylights on the highwall and dips toward the pit. If this sliding plane does not daylight, or dips away from the pit, the slope is stable. Even if the joint daylights, in order for the slide to occur, the weight of this sliding block must exceed the frictional resistance along the discontinuity. **Figure 19** shows an example of a slope, which is plagued by large planar failures, and leads to a slide off rocks along natural, parallel, and bedding planes.

3.1.2 Wedge failure

A wedge failure occurs when two discontinuities meet and their intersecting line daylights on the slope face and dips toward the pit. If these conditions do not occur,

Figure 18.
Planar failure.

Figure 19.
Large planar failure.

you cannot have a wedge failure. The weight of the block also has to exceed the frictional resistance along the failure surface to have failure, **Figure 20**.

As shown in **Figure 21**, the failure can follow trends since joints tend to occur in repeating patterns. Note here the failure on the top bench, and on the next bench, should probably expect another at the next level down.

3.1.3 Toppling failure

Toppling failures look like **Figure 22**. A toppling failure can occur when the discontinuities dip very close to vertical but away from the pit. The discontinuities can be natural or they can be caused by the mining process.

If the mine progresses from left to right, there will be continuous problems, because of the way these cracks are oriented. On the other hand, if the mine goes from right to left, mine operators do not have to worry about toppling-type failure; so, decisions made during mine planning can have a profound effect on the stability

Figure 20.
Wedge failure.

Figure 21.
Trend in wedge failure.

Figure 22.
Toppling failure.

Figure 23.
Toppling failure example.

Figure 24.
Circular failure mechanism.

of the highwalls. **Figure 23** shows a picture of a toppling failure that resulted in a fatality to a blast hole drill operator.

3.1.4 Circular failure

In slopes excavated in soil or highly jointed and weathered rock mass where there are no geological structures to control the failure, the most unstable failure surface is approximately a circular arc. This circular failure surface (**Figures 24** and **25**) results from a process of localization of deformations. It is an arch type of landslides; however, the specific shape of this failure surface and the associated failure mechanism cannot be generalized [11].

Figure 25.
Circular slope failure at the open pit of the Bingham Canyon Mine in Utah.

4. Mine closure and reclamation

In general, mining has a significant negative impact on environment. Due to its nature, it leads to severe degradation of the landscape. Many factors such as drainage, air, soil and water quality, noise levels, ground vibrations, human health, and habitation are mostly affected by mining activities. When the extraction of mine reserve is over, the distorted landscape has to be reclaimed in order to reduce the damaging effects of open pit mining and bring back the landscape and its surroundings, see **Figure 26**.

Figure 26.
Open pit mining before and after reclamation.

Land use plan at the end of mining has to be set in order to determine what the mine site will look like and how the lands will be used after the mine is closed and fully reclaimed. The mine must operate and close such that the land and water in and around the mine site are less disturbed and environmentally safe and sound like original. It is the responsibility of the mining company to pay for reclamation and closure costs. To ensure that funds are available for closure, the mining company will normally be required to post a financial security (a reclamation bond) before mining starts.

“Progressive reclamation” is usually part of the overall closure plan. Progressive reclamation means that once a part of the mine site is no longer needed, it will be reclaimed rather than waiting for all aspects of operation to cease. For example, waste rock piles will be reclaimed as soon as they have reached their permitted size.

The general rehabilitation goals require rehabilitation of areas disturbed by mining to result in sites that are safe to humans and wildlife, nonpolluting, stable, and able to sustain an agreed postmining land use. The process of reclamation normally involves the following steps [12–14]:

- a. *Recontouring*: the ground is re-sloped and contoured to a profile that will be stable and that provides proper drainage, facilitates the growth of vegetation, and provides various habitats for wildlife.
- b. *Capping with a growth medium*: waste rock piles and other areas of the mine site will need to be covered with a soil material that is suitable for the growth of plants.
- c. *Seeding and fertilizing*: this usually takes place over many years. Fast growing grasses may be planted in order to stabilize the soil followed by shrubs and trees depending on the end use plan.
- d. *Monitoring*: plants in areas that are to be used for grazing will be tested to ensure they contain acceptable levels of metals and other possible contaminants.

5. Variants of surface mining methods: strip mining, mountainous mining, and artisan mining

Variants of open pit mining are limited to a number of other surface mining methods, which include strip mining, high wall mining, and quarrying. Strip (open cast) mining is used extensively for the surface mining of important commodities such as coal and phosphate ores. Casting is the process of excavation and dumping into a final location. This type of mining involves removing the overburden and extracting the valuable mineral deposit. Strip mining is applicable to shallow, flat-lying deposits [15]. It is a method that is generally applied on a large scale with low mining costs and high productivity and that has minimum land degradation [16, 17]. In Jordan, strip is used for the extraction of oil shale and phosphate ores. These mines are located at the central and southern parts of the country (e.g., **Figure 27**).

Strip mining differs from open pit in that the overburden is not transported to waste dumps but cast directly into adjacent mine-out panels, i.e., reclamation is contemporaneous with extraction. These mines often occupy a large area of land for ore excavation and overburden disposal. Strips are large rectangular parallel pits that extend to more than a mile in length [18]. After the removal of vegetation and topsoil, the mining begins with an initial rectangular box cut. The dragline is used

Figure 27.
Oil shale extraction project at Attarat Oil Shale mine, Jordan.

Figure 28.
Typical dragline operation [20].

Figure 29.
During loading A1 phosphate layer at Al-Shidiyah phosphate mines.

for overburden removal. As the overburden is removed from one portion of a mineral deposit, it is used to fill in the trench left by the previous removal [19]. The backfilled area is then replanted during the reclamation process.

Figure 28 shows typical dragline operation. Stripping process continues along parallel strips. Where the deposit becomes thinner, or dipping more below the surface, or in the case of dramatic increase in the stripping ratio, the mining operation must be ceased [19]. Shovel-truck system is currently adapted for extracting phosphate ore in several phosphate mines in Jordan (**Figure 29**); especially in Al-Shidiyah, Al-Abiad, and Al-Hasa mines. Since shovel truck removal of

Figure 30.
Dragline removes overburden at Al-Shidiyah phosphate mine, Jordan.

Figure 31.
Overburden removal at Attarat Oil shale mine, Jordan.

overburden generally costs at least three times as much as dragline stripping, the dragline is currently implemented for removing overburden from phosphate ore in those mines (**Figure 30**). On the other hand, shovel truck removal of overburden is currently used in Attarat oil shale mine (**Figure 31**).

In the mountainous and hilly terrains, contour mining is applied. It is also known as mountaintop mining. The mining of flat deposits in these areas follows the contour around the hill and into the hillside up to the economic limits. The extraction becomes difficult with inclination and depth increase. The top of a mountain is removed to recover the ore contained in the mountain that resulted in huge quantity of excess spoil that is placed in valleys that affected the streams flowing within these valleys [21].

Artisanal mining is a small scale mining method, which includes enterprises or individuals that employ workers in developing countries who are poor and have few other options for supporting their families and who usually use manually intensive methods for mining (e.g., panning in case of gold). Artisanal miners use elementary techniques for mineral extraction and often operate under hazardous, labor-intensive, highly disorganized, and illegal conditions [20, 22].

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