MINING ENGINEERING AND MINERAL TRANSPORTATION

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Contents

Summary

In this chapter, the author firstly indicates the features of mining from industrial point of view. These features bring various technical problems in the field of mining engineering including mine safety and environmental impact. The technical processes, from economic and technical evaluation of mineral deposit, through mine development, up to extraction and transportation of mineral ores, are briefly explained.

There are mineral deposits with various geometrical, geological and physical features. They need various mining technologies which are appropriate to the respective technical features of mineral deposits.

Various technical aspects of mining engineering including mineral transportation are divided into two categories: underground and surface mining. Then, various technologies and equipments in these two mining methods are described. A short historical review is given on the technical development equipment and operations in mines.

Finally, the author outlines prevention of environmental impact of mining operation and reclamation of mined out area, because they are indispensable for the sustainable development of mining as well as human society.

1. Introduction

Mining engineering is defined as the engineering that is applied to take mineral resources out of earth-crust to be utilized in the human society and used as materials or fuel in the industry as well as individual house. The mineral resources appear as solid or fluid minerals. The former includes such metallic minerals as iron, copper, gold, silver, lead, zinc, etc., and such non-metallic minerals as diamond, coal, rock salt, potash salt, limestone, etc. The latter includes petroleum, natural gas which consists mainly of methane gas, but sometimes such various gases as carbon monoxide, hydrogen-sulfide, helium, and so on.

Mining engineering of fluid minerals is usually distinguished from mining engineering of solid minerals, and called as petroleum engineering from the technical and industrial points of view, because petroleum and natural gas are taken out of the earth-crust by deep borehole which is drilled from ground surface or offshore platform (see *Offshore Drilling and Production Equipment*). The access of miners into the underground space is not only unnecessary, but also impossible for mining of petroleum and natural gas. Hence, in a narrow sense, mining is understood as mining of solid mineral resources. Furthermore, surface works for extraction of building stone, slate, and other gravels are called as quarry, and frequently excluded from mine or mining.

The mining methods of solid mineral resources are classified into two groups, i.e., underground and surface mining from technical point of view. The mineral deposit exposed at ground surface or covered with thin soil or rock formations is extracted by surface mining. However, the mineral from deep underground deposit is extracted by underground mining.

Mining as an industry is substantially different from other industries in the following features:

1. Mineral resources (mineral deposits) are natural resources like as atmosphere, water, and various biological resources. However, a mineral deposit is impossible to reproduce. In this point, mining is different from agriculture and other industries concerned with biological resources which are renewable.
2. Mineral deposits are not unlimited, but finite in mass or volume. Thus, every mine shall be closed down with expiration of ore reserves, after profitable mining operation during several tens years.
3. Every mine must be operated at the site of mineral deposit, the location of which we can neither select nor remove. The location of rich and big mineral reserves is frequently distant from the area with big consumption and market of mineral products.

Under these three inherent conditions, all mines are operated and every mining engineering technique has been developed. Mining consists of various processes and technologies from the exploration boring, through drifting of roadway, extraction of mineral ore, and haulage of extracted ore, up to the shipping of concentrated mineral ore as raw materials for the smelter or other various industries.

2. A Historical Review of Mining Engineering

Mining is one of the oldest industries of human civilization. The Bronze Age would not appear without mining of natural copper as well as tin exposed at ground surface.

The history of mining may be traced up to the Stone Age. For an example, some vestiges of flint quarry operated in the Stone Age in England and France have been found. In China, there is a vestige of copper mine operated in the years before 400 B.C. In a vestige of copper mine operated in the period of the Han dynasty (B.C. 206 – A.D.220) of China, a vertical shaft has been found, which was sunk down to a depth of 40-50 m, and supported with wooden square frames. In this shaft, several parts of winding equipment have been found. During the time of Roman Empire, various metals such as gold, silver, copper, lead, and iron were mined and smelted in various areas in Europe as well as Middle East. Steiermark district of western Austria was famous for its rich production of iron ore since the age of Roman Empire. Erzberg Mine was one of the most famous iron mines in this district. It was operated as an open pit mine.

In the 10-11th centuries, silver mines were developed in Harz Mountain Area in Germany. Furthermore, silver mines in Freiburg produced much of silver ore in the 12-13th centuries. In the late 15th century, many mines had produced plenty of silver, copper, mercury, etc. in Thuringen, Boehmer, Slovakia, and other areas in Central Europe. The state of art of mining and smelting in this period is described in a book entitled " De Re Metallica " which was written in Latin by G. Agricola and published in 1556. This book is well known as the first technical textbook of mining and smelting, and explained various technologies and equipments for water drainage, stope making, and mineral transportation in the underground mine as shown in Figure 1 for an example.

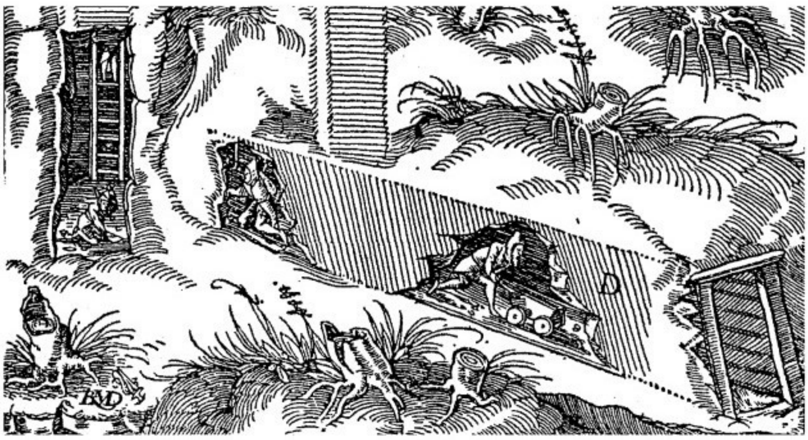

Figure 1: Driving of vertical shaft and level roadway in underground mine, in 16th century (byAgricola,G.(1556): De Re Metallica, Book V, p.103)

In the 16th century, vertical shafts deeper than 30 m were constructed and the winding equipment was driven by horse power or water wheel. However, barrow or cart pushed by miners was used for transportation of mineral ore in the level roadway in underground mines.

In the time of the Industrial Revolution, demand for iron and coal had rapidly increased and many iron and coal mines were developed and operated in England and districts along valley of the lower Rhein. In the 18th century, although most of iron ore was produced from open pit mines, most of coal mines was operated as the underground mines. As the annual output of underground mine increased, the water inflow into the mine openings increased; consequently, water drainage had become one of the most important tasks of mining engineering to deal with. Steam engine was invented and developed mainly to be used as the engine for water drainage pump of underground coal mine.

In the late 18th century, the steam engine was used to drive the winding equipment, water pump as well as ventilation fan, which were installed at the pit mouth, because it is difficult to install the boiler as steam generator in the underground opening. Some time later, the steam is supplied to the steam engine installed underground by means of the insulated steel pipe from the boiler plant installed at the pit mouth. In the late 19th century, the pneumatic motor which is driven by compressed air was developed and used in underground mines. The compressed air was produced by air compressor installed at the pit mouth and driven by a steam engine, which was gradually replaced by electric motor, in the early 20th century. In the field of mineral transportation, although the steam locomotive was used in the open pit mines, horse power was widely used for mineral transportation in the level roadway of underground mines. The horse power was replaced by various rope haulage systems which are driven by pneumatic or electric motor. Although the steam engine as power source of mine equipment was replaced by electric motor in the early 20th century, the pneumatic motor was used as power source of various small equipments in underground mine, up to the middle 20th century.

In the field of rock breakage technology, drilling and coal cutting technology had shown remarkable progress since the 16th century. In the 16th century, miners had broken rock and mineral ore exclusively with chisel and hammer which are at present used as the symbol mark of mine. The hard rock was sometimes broken by fire heating. Black gunpowder as explosive was invented in Tang dynasty (7-8th centuries) in China. It was introduced to Europe through Mongolian invasion and the trade with Islamic countries in 13th century. Although German monk Berthold Schwarz succeeded to produce black gunpowder in the early 14th century, it was exclusively used for military purposes, surely as the “gunpowder” up to 17th century.

In 1627, the black gunpowder was applied for blasting of mineral rock in Austrian mine. Then, it was gradually used for rock breakage in the mine. However, the blasthole was yet drilled by hand-chisel and hammer. The rock drill driven with steam power was invented in 1813, and modified to be driven by compressed air in 1861. Productivity of drilling and rock breakage had remarkably increased with the application of the pneumatic rock drill and dynamite as industrial explosive which was invented by A. Nobel in 1866. Since the early 20th century, the drill-and-blast method has been one of the most important technical methods of rock breakage.

Up to the middle 19th century, coal seam of underground coal mine was cut and broken exclusively with pickaxe (mandrel) handled by miner. In 1861, a prototype of coal cutter was invented in England and used in underground coal mine in the next year. This machine driven by compressed air and called as “ Iron Man” had simulated the picking action of miner for undercutting the coal seam, as shown in Figure 2.

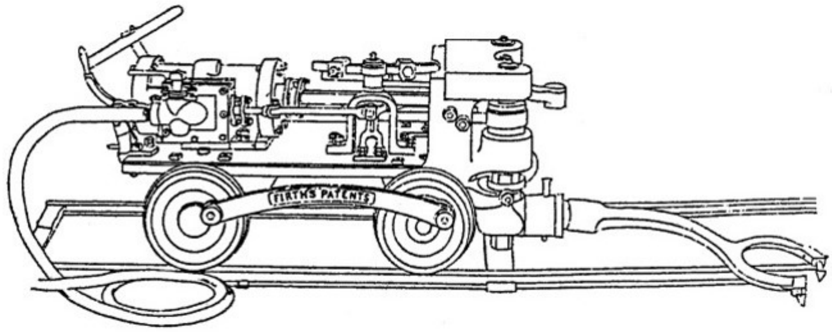

Figure 2. The First Coal Getting Machine “Iron Man” (by Walker, S.F.(1902).Coal-cutting by Machinery in the United Kingdom , p.21, Colliery Guardian, London)

In the late 19th century, before propagation of dynamite, various types of coal cutter are invented to increase productivity as well as yield of lump coal. They were used to undercut the coal seam in underground coal mine in England and the U.S.A. In the early 20th century, their power source was modified from the compressed air to the electric power. Among them, the chain coal cutter (jib type coal cutter) had enjoyed the most prosperity up to the end of the World War II.

3. Features of Mining

3.1. Industrial and Technical Features

Mineral resources (mineral deposits) are natural resources like air, water, land, and various biological resources. Then, mineral resources are impossible to be reproduced, and not infinitive in volume and mass. They are expired after mining and extraction of existing reserves. Hence, mining is substantially different from other industries in several industrial and technical points of view.

Firstly, every mine shall be closed down with exhaustion of ore reserves, after profitable operation in some decades or centuries.

Secondly, the mine can be neither constructed, nor operated without the existence of mineral deposit.

This is the inherent and most important feature of mining. The first step of mining is to find and explore the mineral deposit, if the mineral concentration and volume are attractive for economical operation of the mine. The development of a mine is affected by various natural conditions including geographical location as well as various social and political conditions including legal regulation, tax, and such public utilities as railway, road, water and electric power supplies, etc. at the area and country where the mine is constructed and operated.

Thirdly, development of a mine needs a long time span, from exploration of mineral deposit, to the first shipping of concentrated ore or raw metal as the product. During this long time span or lead time, the market price of mineral ore or metals fluctuates frequently and remarkably in the international market, but the cost of mineral ore as well as raw metal is nearly constant, because the cost mainly consists of depreciation and interest of capital investment, cost of such operations as extraction, transportation, and environmental protection including safety of miners.

Fourthly, mining operation can not avoid some environmental impacts. Hence, environmental protection has become recently more and more important in the technical as well as economical points of view for development and operation of mines in the world. The important environmental impacts have been surface subsidence caused by underground mining, and water pollution caused by acidic ground water pumped out of mine. However, every effect on such elements of nature as animals, birds, forest, and scenic sight is recently evaluated as environmental impact related to mining.

3.2. Geographical Separation between Production and Consumption of Minerals

Many European countries had explored their colonies of other continents since 15th century. They found many mineral resources and developed them as mines. For example, the Spanish had explored and operated many rich silver mines in their colonies of American continents, and the English explored and operated many gold and diamond mines in South Africa. The coal reserves and mineral resources in West Europe have been gradually exhausted through the periods of two World Wars.

However, most of the metal smelters including ironworks and petroleum refineries have been constructed and operated in the vicinity of consumers i.e. developed countries including West Europe, and Japan, where many other industrial works are operated as consumers of mineral ore, coal and petroleum.

In the 20th century, particularly after the World War II, many large scale mineral reserves including petroleum have been found in the developing countries. For examples, huge petroleum reserves was found around the Persian Gulf and North-West Territories of Canada and Alaska. Many copper and other non-ferrous metal mineral deposits have been found in the inland area of Africa and Andes Mountain area of South America.

In the late 20th century, most important mines as well as oil wells are located in the developing countries or frontier districts which are far from any smelters or refineries or most of the consumers. Hence, mineral transportation from the producing countries to the consuming countries has been important in technical and economical points of view. In the technical point of view, mineral ores such as those of copper, lead, zinc, iron, and coal are transported by railroad, and/or bulk carrier ship, and most of such fluid minerals as petroleum and natural gas are transported by pipelines and/or tank vessels.

The geographical distance between the consumer and the producer of mineral resources needs to form the international trade market. For example, there are important international exchanges of non-ferrous metals in London, and of petroleum in New York and Rotterdam, at present. However, international market price of petroleum has been remarkably affected by the policy of OPEC, since1974. Some international organizations of producing countries of such metal resources as copper, bauxite, etc. was founded in the 1960's and the 1970's., but they have failed to control the international market price of copper and bauxite.

4. Development and Operation of Mines

In the following sections, the author exclusively describes mining of solid minerals except such fluid minerals as petroleum and natural gas, because the technology and industry of petroleum and natural gas mining are remarkably different from those of solid minerals mining, although they have a common purpose- to extract and utilize mineral resources.

The Process of development of a mine begins with the evaluation of the explored mineral deposit from technical and economical points of view. This process is frequently called as *feasibility study* (see *Mining and Exploration for Mineral Resources*). In this process, various factors related to the operation of the mine including geometry and ore grade of mineral deposit, market price of minerals, interest of capital to be invested, climate, and infra-structure of the district and/or country and so on, are considered. On the basis of the result of feasibility study, it is decided whether the mineral deposit shall be developed or not as a new mine.

Mining engineering includes all technologies necessary for development and operation of a mine, to produce valuable mineral ore from the mineral deposit. It starts from construction of access roads, through breakage of rocks to extract the mineral ore, and transportation of the extracted ore, separation and concentration of raw and low grade mineral ore, and ends at shipping of the produced valuable and concentrated minerals to smelters or other consumers. There are substantial technical differences between underground and surface mining in every aspect of development and operation.

In underground mining, entry roadway is driven from ground surface to the underground mineral deposit, as the first step of development of a new mine. In a mountain area, the entry roadway may be a level roadway called as adit level. However, a vertical or an inclined shaft is used as the entry in most of the underground mines. As the second step, principal level roadways are driven to the mineral deposit from the bottom and a few intermediate levels of the shaft. The principal level roadways are sometimes connected to each other with blind shafts and/or ramp- ways to construct the framework of the mine. The principal level roadway is used for ventilation as well as transportation of the extracted mineral ore, debris, various supply materials and equipments necessary for mining operations, and miners. Furthermore, water drainage pipeline, electric power cables, and compressed air pipeline are installed in the principal level roadway.

At the pit mouth (top of shaft), the main winding equipment and/or ventilation fan are installed. At appropriate locations in the principal level roadway, such installations as water drainage pump stations, machine shops, gunpowder stores, etc. are constructed.

Thirdly, the roadway for prospecting and/or extraction of mineral ore is driven towards the mineral deposit from the principal level roadway, and the stope (working face) to extract the mineral ore is constructed and operated. Most of metallic mineral ores are extracted by the drill-and- blast method, but most of coal is extracted with coal cutter or other coal getting machines, because coal seam is usually weaker and more friable than metallic mineral deposit.

In order to extract exclusively valuable mineral ore as effectively as possible and break the barren rocks around the mineral deposit as little as possible, various mining methods have been invented, tried in practice, and modified. It is particularly important to select and develop an appropriate mining method for each mineral deposit of such non-ferrous metals as gold, silver, copper, lead and zinc, because it shows remarkable variation in mechanical properties, geometry and ore grade. The mining methods in underground mines are classified into two types. One is the filling type in which underground openings appearing after extraction of the mineral ore are filled with debris or waste of mineral dressing plant (see *Mineral Comminution and Separation Systems*). the other is the caving type in which the underground opening mined out remains open but is gradually filled with mineral ore or fragmented rock which falls into the opening by its own weight.

If a mineral deposit appears at ground surface or exists in shallow depth underground, surface mining is conducted. Most of coal and iron mines with big annual output are operated by surface mining. Furthermore, many important and big copper mines are developed and operated as open pit mines. In a big open pit mine, the geometry of the mine pit extends more than several kilometers in width and a few hundreds meters in depth.

The decision on the development of open pit mine substantially depends upon the stripping ratio which is defined as the weight of surface soil and cover rock to be removed for extraction of unit weight of mineral ore.

In an open pit mine, mine development begins from excavation and removal of surface soil, which is called as stripping. Stripping is carried out with such large scale excavating machines as dragline, bucket-wheel-excavator, power shovel, and so on. The mineral deposit exposed by stripping is extracted directly with power shovel, or broken firstly by the drill-and-blast method, then, the broken ore is usually loaded by means of the with front-end loader into dump truck and transported to the crushing plant. In some open pit mines, the loaded ore is dumped firstly into the in-pit crusher, and then the crushed ore is transported by a belt conveyor. The extraction of mineral ore continues and the mining area extends, then the bench with ten to several meters high is formed successively. The design and construction of bench should be decided on the basis of mining plan in which location of transportation road and slope stability are considered and evaluated.

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Biographical Sketch

Y.Nishimatsu was born in Nagasaki City , Japan, in 1932. He graduated from the Department of Mining, The University of Tokyo in 1954. During 1954-1956 he was a Mining Engineer in Futase Coal Mine of Nittetu Mining Co. Ltd., during 1957-1962 a Research Engineer in the Coal Research Institute, Tokyo, during 1962-1976 an Associate Professor in the Department of Mining, The University of Tokyo, and during 1976-1992 a Professor in the Department of Mineral Development Engineering, The University of Tokyo. Since 1992 he is Technical Advisor in the Mineral Resources Division, Sumitomo Metal Mining Co. Ltd.