UNDERGROUND MINING METHODS AND EQUIPMENT

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Contents

Summary

The first section gives an overview of underground mining methods and practices as used commonly in underground mines, including classification of underground mining methods and brief explanations of the techniques of room-and-pillar mining, sublevel stoping, cut-and-fill, longwall mining, sublevel caving, and block caving. The second section describes underground mining equipment, with particular focus on excavation machinery such as boomheaders, coal cutters, continuous miners and shearers.

1. Underground Mining Methods

1.1. Classification of Underground Mining Methods

Mineral production in which all extracting operations are conducted beneath the ground surface is termed underground mining. Underground mining methods are usually employed when the depth of the deposit and/or the waste to ore ratio (stripping ratio) are too great to commence a surface operation. Once the economic feasibility has been verified, the most appropriate mining methods must be selected according to the natural/geological conditions and spatial/geometric characteristics of mineral deposits. Considerations include:

1. Spatial/geometric characteristics of the deposit concerned: the shape, size, thickness, plunge, and depth.

2. Strength of the hanging wall, footwall, and ore body.
3. Economic value of the ore and grade distribution within the deposit.

The selection of underground mining methods is primarily based on the geological/spatial setting of the deposit. Candidate methods can therefore be chosen and ranked based on estimated operational/capital costs, production rates, availability of labors and materials/equipments, and environmental considerations. The method offering the most reasonable and optimized combination of safety, economics, and mining recovery is then chosen.

Reflecting the importance of ground support, underground mining methods are categorized in three classes on the basis of the extent of support required: unsupported, supported, and caving.

Unsupported methods are essentially naturally or self-supported and require no major artificial system of support to carry superincumbent loads, instead relying on the natural competence of the walls of the openings and pillars. This definition of unsupported methods does not exclude the use of rock/roof bolts or light structural sets of timber or steel, provided that such artificial supports do not significantly alter the load-carrying ability of the natural structure. The followings are considered unsupported methods:

- Room-and-pillar mining
- Shrinkage stoping
- Sublevel stoping

Of the unsupported methods, room-and-pillar mining is employed for extraction of flat-dipping and tabular deposits, whereas shrinkage and sublevel stoping are applied to vertical or steeply inclined ore bodies. Shrinkage stoping has in the past been very popular, particularly in non-coal mining. Gravity can be utilized for ore transportation and broken ore stored within the stope may function as a working platform and temporary wall supports. It was quite attractive in the period before mechanization became widespread, when small-scale operations on vein-type deposits prevailed. However, with rising costs, the scarcity of skilled labor and the trend toward mechanization, the method has been largely displaced by sublevel stoping and cut-and-fill. Sublevel stoping will therefore be the only unsupported methods examined in detail here.

Supported methods require substantial amounts of artificial support to maintain stability in exploitation openings, as well as systematic ground control throughout the mine. Supported methods are used when production openings (stopes) are not sufficiently stable to remain open during operation, but the opening required to be held open to prevent caving or surface subsidence. In other words, the supported class is employed when the other two categories of methods, unsupported and caving, are not applicable. The supported class of mining methods is intended for application under ground conditions ranging in competency from moderate to incompetent. In the design of artificial support systems to provide varying degrees of controlled wall closure and ground movement, an evaluation of load-carrying capacity of the natural rock structure is a prerequisite. The most satisfactory forms of artificial support are backfilling/stowing, timbers/stulls, cribs/packs, and hydraulic/frictional props. There are three specific methods in the supported class.

- Cut-and-fill stoping
- Stull stoping
- Square-set stoping

Cut-and-fill and stull stoping are intended for moderately competent rock, whereas square-set stoping is suitable for the least competent rock. Supported methods have declined in use since World War II, primarily because cut-and-fill stoping is the only method that lends itself to mechanization. Stull stoping and square-set stoping are infrequently used and relatively unimportant today, because of excessive labor intensity and very low productivity, in addition to a scarcity of skilled work forces and available timber resources. Only cut-and-fill stoping will be described later in detail.

Caving methods are defined as those associated with induced, controlled, massive caving of the ore body, the overlying rock, or both. The exploitation workings in caving methods are designed to collapse, with intentional caving of the ore and/or host rock. The three major caving methods are:

- Longwall mining
- Sublevel caving
- Block caving

Longwall mining is used in horizontal, tabular deposits (mainly coal), while the others have applications in inclined or vertical, massive deposits, almost exclusively metallic or nonmetallic. Because the exploitation openings are intentionally destroyed in the progress of mining, the caving class is truly unique. Rock mechanics principles are applied to induce caving rather than to prevent the occurrence of caving. Moreover, development openings have to be designed and located to withstand moving and caving ground. Surface subsidence is inevitable and must be allowed for in the case of sublevel and block caving. Production must be maintained at a steady and continuous level to avoid disruptions or stoppages in the caving activity. Highly advanced mining technology as well as experienced management is indispensable to a successful caving operation.

1.2. Underground Operations in General

Figure 1 shows a schematic mine layout for an underground mine as an explanation of common mining terms.

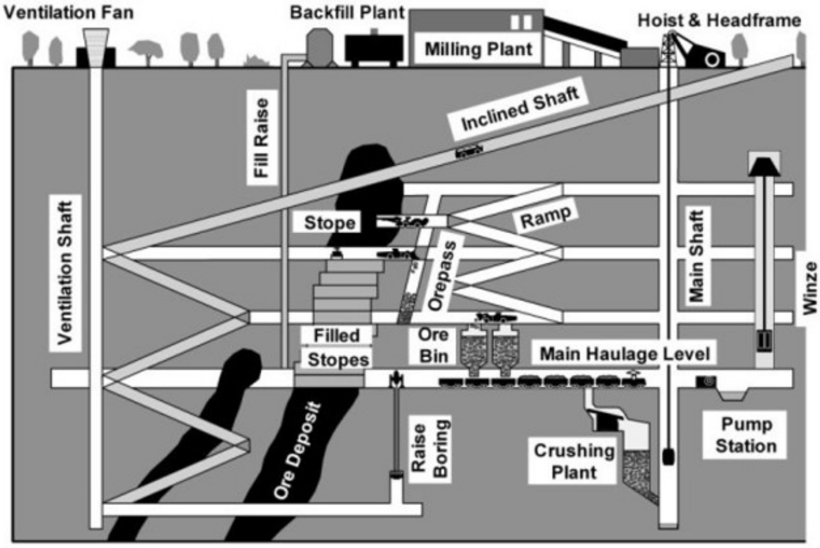

Figure 1: Example layout of an underground mine

An inclined shaft is excavated for transportation of personnel and supplies in addition to a vertical shaft for hoisting mined ore and a ventilation shaft for enhancing circulation of fresh air with the aid of a fan. Alternatively, an inclined shaft can be used for main ore transportation and ventilation, and the vertical shaft can act as the main thoroughfare for employees and materials. The functions of inclined and vertical shafts are usually versatile in mining operations.

Main levels are arranged for main haulage and connection between underground key facilities. A small number of sublevels may be situated between main levels within a stoping area for production. Raises and winzes are either vertical or sub-vertical openings driven between one level and another or the surface. Raises are driven upward, and winzes are driven downward. A ramp is an inclined opening connecting levels or stopes to enable the passage of vehicles and an orepass is a vertical or sub-vertical hole through which ore is transferred to lower levels.

If backfilling (to fill mined-out spaces with rock, soil or tailings) is part of the underground operation for improving mining recovery, safety, and mitigating surface subsidence, a fill raise will be constructed for transporting backfill materials prepared at the backfill plant on the surface to underground stopes. If necessary, additional ventilation raises will be driven to improve underground climates.

The primary operations required in underground are rock breakage and material handling. If the target is sufficiently soft (e.g., coal and rock salt), mechanical excavation utilizing continuous miners, shearers, ploughs/plows, and so on, can be employed. In contrast, drilling and blasting are usually employed when the ore is too hard for cutting. A drifting jumbo equipped with one or multiple rock drills is employed for penetrating horizontal blastholes and used for driving horizontal drifts and inclined ramps as well as production by crosscutting in room-and-pillar mining and cut-and-fill stoping. Fan/ring/parallel longhole drill rigs are commonly employed for large-scale production in sublevel stoping and sublevel caving. Ammonium nitrate and fuel oil (ANFO), slurries, and emulsions are widely used as explosives in mining operations. The explosive is usually charged by hand if available in cartridge form, or pumped into blastholes for liquid or bulk explosives. The explosives are then fired by electrical or other means.

The most common equipment for material handling such as loading and hauling excavated ore are slushers, gathering-arm loaders, front-end loaders, overhead loaders, Load-Haul-Dump units (LHDs), and rubber-tired shuttle cars and trucks, as well as transportation by conveyor, rail, and gravity flow. Ore is loaded into underground equipment and transferred to orepasses, where the ore is dumped. A drawpoint or chute is usually situated at the outlet of the pass on the lower level, where the ore is loaded and transported to the underground ore bins or directly to the main haulage level. Finally, ore is collected on the main haulage level and transferred to an underground crusher for size reduction to facilitate transportation by conveyors or skips through shafts (see *Underground Mining Transportation Systems*).

The auxiliary/supporting operations required underground include:

1. Health and safety: ventilation, gas control (particularly in coal mines), dust suppression, noise reduction.
2. Ground control: supporting (rock-bolting, timbering, setting steel arches, etc.), scaling (removing rock fragments from working roofs).
3. Power supply and lighting
4. Drainage and flood control: pump stations and sumps are usually constructed at the bottom level to collect and drain water from underground after removing suspended solids.
5. Maintenance and repair of equipment: underground workshops and warehouses.

In addition, surface facilities such as an administration office, milling plant, hoist & headframe, electric substation, emergency power generator, air compressor, and tailings pond are necessary.

1.3. Room-and-pillar Mining

Room-and-pillar mining is suitable for flat or nearly horizontal tabular deposits. If the ore bodies are moderately inclined (>30°) it is impractical to utilize tired mobile equipment, resulting in reduced productivity. If the competence of the hanging wall and/or the ore is insufficient, additional labor is also required for ground control, which is likely to cut productivity and raise auxiliary costs.

A schematic illustration of room-and-pillar mining is given in Figure 2.

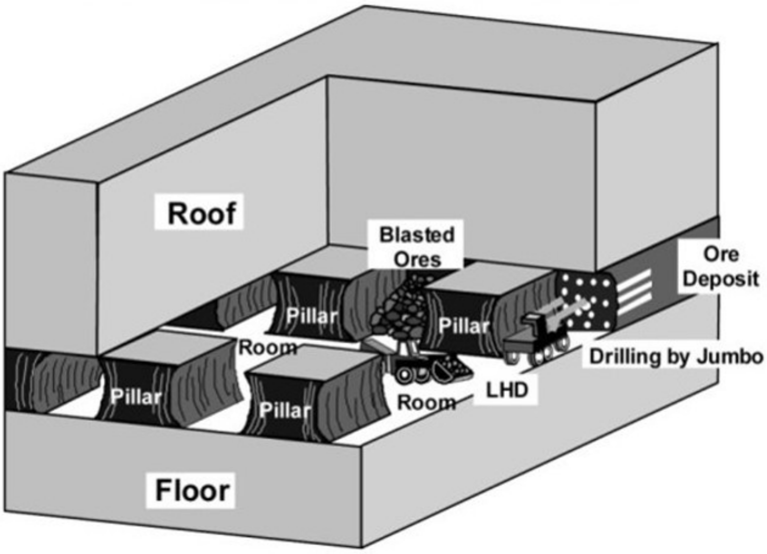

Figure 2: Room-and-pillar mining

Pillars of original bedrock are left to support rock pressures and to protect personnel. Drill jumbos are usually used for driving crosscuts and connecting them. Blasted ore is mucked and hauled by LHDs. In coal mines, seams are generally large in scale and relatively uniform, and mechanical excavation is also applicable in such cases. Openings are driven orthogonally and at regular intervals to leave rectangular or square pillars for natural support, which gives the plan view a checkerboard-like appearance. It is not uncommon in non-coal mining for the pillars to be irregularly shaped, sized, and randomly located (Figure 3). The objective in placement of pillars is to locate them in areas of low-grade ore or waste rather than follow a systematic mining plan so long as adequate roof support is provided. In the case of a considerably thick deposit, a fairly high back is liable to degrade the safety of mining in a single pass, necessitating benching or slabbing (Figure 4). Partial extraction of a pillar, called “robbing”, is sometimes practiced, particularly if the pillars are larger than necessary to support the back, allowing more ore to be recovered safely.

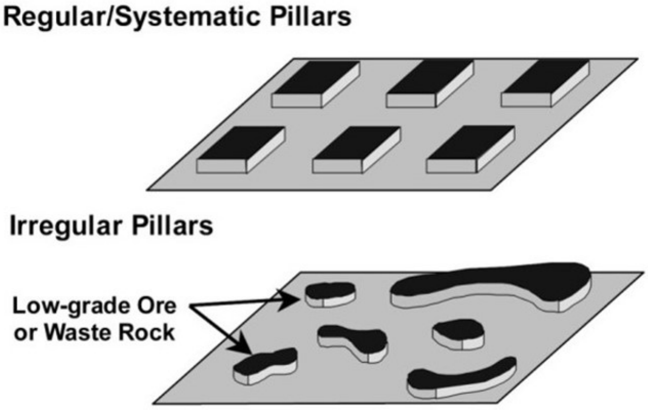

Figure 3: Pillar layouts for room-and-pillar mining

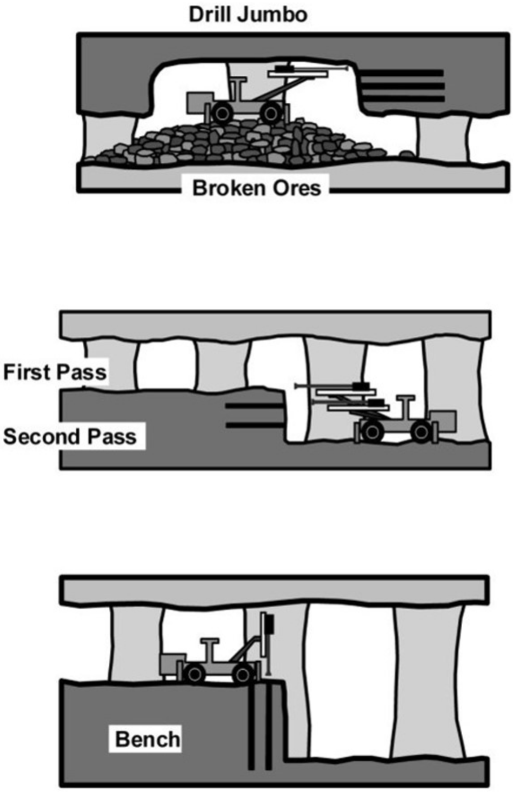

Figure 4: Room-and-pillar mining for a thick deposit

Room-and-pillar mining is moderately favorable in terms of productivity and cost. Accordingly, it is appropriate for a large deposit with relatively low economic value, that is, deposits where some ore may be left without significant economic impact. The method is also flexible, allowing the production rate to be adjusted by varying the number of stopes. The method can also be regarded as selective. Moreover, it requires a less amount of development. For these reasons, the room-and-pillar mining is most popular among underground mining methods and prevailed worldwide.

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Biographical Sketches

Prof. Dr. Seisuke Okubo (born 1947), is an expert on mining machinery and rock mechanics. He studied at the Mechanical Department of the University of Tokyo, where he obtained his PhD. His post-graduate studies at West Virginia University, USA, involved work in mine ground control and rock-pressure measurement. Working at the University of Tokyo, he designed several servo-control testing machines and carried out versatile rock testing. He also developed computer programs to simulate the complicated behavior of excavation machinery. He is now professor of the University of Tokyo.

Prof. Dr. Jiro Yamatomi (born 1949), is professor of mining engineering and rock mechanics at the Department of Geosystem Engineering of the University of Tokyo. He obtained his PhD in the Mining Engineering Department of the University of Tokyo. He also worked for the Mining College, Akita University, for seven years, and during that time took study leave at the Department of Mineral Engineering, of Pennsylvania State University, USA.