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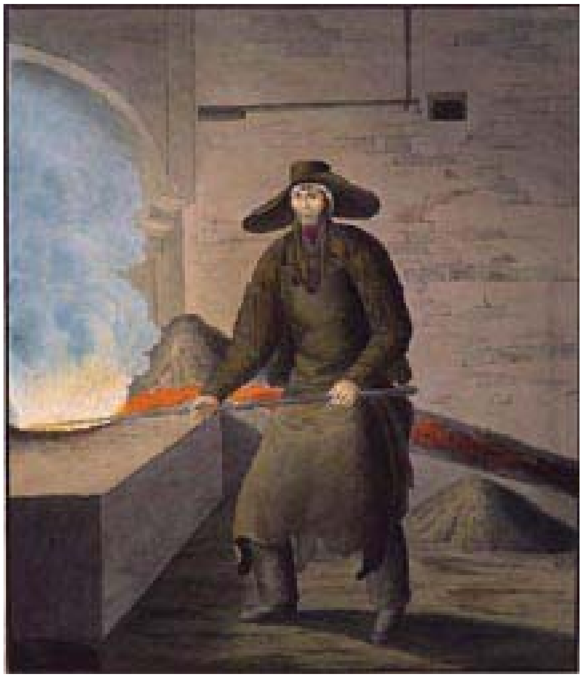
1. HISTORY OF MINING[1]

The contribution of mining has played a big part in the development of civilization, more than is usually recognized by the average citizen. In fact, products of the mineral industry pervade the lives of all members of our industrialized society.

The chronological development of mining technology bears an important relation to the history of civilization. In fact, as one of the earliest of human enterprises, mining and its development correlate closely with cultural progress. It is no coincidence that the cultural ages of people are associated with minerals or their derivatives (i.e., Bronze Age). Today, products of the mineral industry pervade the lives of all people.

Mining began with Paleolithic people, perhaps 300,000 years ago, during the Stone Age, when flint implements were sought for agricultural and construction purposes. Primitive miners first extracted and fashioned the stone raw materials that they needed from deposits at the surface, but by the beginning of the New Stone Age (c. 40,000 BC), they began to mine underground as well.



Although records are nonexistent, human fossils and artifacts substantiate an early record of mining all over the world. Like other aspects of human civilization, mining originated in Africa. At first, it was done crudely, and then with some technological sophistication. For example, early miners devised ways to chip and free fragments from the solid, to hoist ores by simple lifts, to illuminate their workings by torches and lamps, and even to ventilate underground openings.

Early people relied upon wood, bone, stone, and ceramics to fashion tools, weapons, and utensils. Civilization was advanced by the Early people relied upon wood, bone, stone, and ceramics to fashion tools, weapons, and utensils. Civilization was advanced by the discovery of abundant supplies of high-quality flint in northern France and in the chalk beds of southern England. Culture after culture occupied the sites around the Acheuleum communities over a span of 200,000 years. Clay deposits supplied material for storage vessels as agriculture was introduced, and the metallic residues from pigments in the potters' kiln may have provided the first clue to these ancient peoples of the secrets of extraction of metals through **smelting**. Likewise, salt was recognized as essential in the human diet and, along with flint became a prime medium of exchange that dictated early trade routes. During the initial development, the use of metallic minerals was in the form of pigments, decorative beads, and native metals that could be shaped into simple objects by hammering.

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[1] This section together with section 2 and 3 are prepared strongly based on the published online course notes of Introduction to Mining Engineering, Delta Mine Training Centre, Alaska.

Eventually, the first technological breakthrough that significantly advanced mining occurred in the breakage of rock in place. Fire setting, applying heat to expand, and water to quench, contract, and crack rock, was discovered by an unknown miner. It was a revolutionary advance in **geomechanics**, one not surpassed in mining history until the deployment of explosives to break rock in the later Middle Ages.

Most discoveries of these useful minerals were made by accident along trade route. However, Egypt, which was not well endowed with mineral resources, sent out expeditions exploring for turquoise and gold as early as 4500 BC, resulting in an era of warfare for the acquisition of metals. The Mycenaeans followed by the Phoenicians broke this cycle of war and became wealthy, exchanging minerals for goods. These traders/**prospectors** sought deposits of silver, tin, lead, copper, and gold, acquiring them by barter rater than by conquest. by 1200 BC They had sea trade routes throughout the Mediterranean work, acquiring lead and silver from Spain, copper from Cyprus, and tin from Cornwall.

By 100 BC trade routes between China and the West, primarily for silk and spices, were well established. The roads passed through many countries and disseminated knowledge of "seric" iron (steel) and metallurgic technology to the known world. By 620, during the T'ang Dynasty, China had become the most advanced society in the world culturally and technologically. The fact that mining technology never fully developed in china can probably be attributed to Guatarma (563-483 BC), who taught that "suffering is caused by the craving for that which one has not," resulting in governmental policies that alternately discourages and encouraged mining.

The discovery of copper on Cyprus c. 2700 BC resulted in the fabrication of tools, weapons, and household utensils made of metal and turned the island into an important trading center. Wealth poured into the island allowing for luxuries an artistic and religious development.

Work in the mines by the Greeks and Romans, was first done by slaves, either prisoners of war, criminals, or political prisoners. Easily exploitable deposits were eventually exhausted and mine economics demanding mining skills. As a result, beginning with the reign of Hadrian (AD 138), the Roman Empire began to recognize a degree of individual ownership and permitted mining by freedmen in increasing numbers. There was gradual improvement of mining technology through the Roman Empire tat accompanied replacement of slaves by skilled artisans, though **villeinage** was still practiced.

One legacy largely the result of Phoenician trading was to create a system whereby power and prosperity could thereafter be measured in terms of actual, exchangeable wealth. In this capacity, gold and silver throughout history have been universally accepted coinage. Thus debasement of the Roman **denarius** resulted in its loss of credibility as the standard of exchange, contributing to the fall of the Roman Empire, and by the end of the 6th century, the Latin West reverted to an agrarian economy and abandoned coinage and trade. The center of culture and technology shifted to the Byzantine and Islamic empires.

Charlemagne (768-814) recognized the need for metals and began the mining of lead, silver, and gold at Rothansberg, Kremnitz, and Schemnitz by enslaved captives. He also reformed the coinage of his Holy Roman Empire leading to the establishment of new mints during the 10th century. As Charlemagne's empire gave way to more local kingdoms, a demand for precious metals had been created that aroused the spirit of enterprise and wakened the interest in the development and use of metals. Europe saw a birth (or rebirth) of the traditions originally carried by the Celts of nomadic mining expertise. This birth was characterized as "bergbaufreihet," or the rights of the free miner, whereby the poorest villein could become his own master merely by marking his own mining claim and registering its boundaries after making discovery -subject to a tribute or royalty paid to the royal land owner. Thus the miner ceased to be a serf and became a free person. In 1185, the Bishop of Trent initiated a treaty where miners were invited to explore and mine that region of northern Italy as free men with rights of discovery. In 1209 various princes in the Germanic empire granted similar rights to miners. Edward II of England in 1288, ordered to memorialize the ancient customs and practices of miners within his realm. Thus the right of ownership based on discovery by a free miner became the foundation for mining laws carried by individual miners throughout Europe, then to the Americas, Australia, and South Africa.

As mining extended underground, the free miners found they could do little by themselves, and thus formed partnerships. As operations grew, more men were required and self-governing associations were born whose ownership and financial stake were supported by contributions recorded in a "cost-book." The cost-book organization formed the model for company organization before the practice of issuing stocks. Initially, production was divided among the shareholders, but as treatment and marketing became more complex, the sale became centralized. When a profit was made, it was divided among the "adventurers," but when losses were experienced the adventurers were required to contribute in proportion to their holdings or risk loss of their ownership. Rarely was any money set aside as reserve, and consequently, a decline in metal prices or grade generally resulted in mine closure.

Growing demands for capital forced a search for outside capital and gradually operators lost control to investors. The miners became contract workers. Guilds, originally organized by miners for charity and insurance, assumed objectives of industrial aggression.

During the 18th century, iron **metallurgy** made great strides and made possible the Industrial Revolution in Britain. Village craftsmen evolved into the factory system and the "Friendly Societies" legally took on the function of the trade unions after 1825. When public financing in Britain was made possible though the enactment of the Limited Liabilities Act of 1855-1862, British capitalists came to the forefront in financing mineral development worldwide. Goldsmiths assumed a banking function and issued printed receipts (or notes) payable to any bearer - the forerunner of present paper currency. Stimulated by the availability of energy and available resources, similar industrial revolutions other countries (France, United States, Germany, Japan, Russia, Sweden, Canada, Taiwan, and Korea) transformed into industrial economies.

The machine age, introduced by the Industrial Revolution of the late 18th century, also required minerals as raw materials and as a source of energy. Industrial power thus became a measure of political and military power, and the exploration for attainable mineral resources extended to nearly all parts of the world. Nations' economies became interdependent. In an attempt to control the large-scale international flow of mineral resources, various commercial and political measures have been tried: **monopolies**, **cartels**, **tariffs**, **subsidies**, and **quotas**, to name a few. The final result was that political and commercial control over mineral resources and their distribution played a leading role both in the maintenance and destruction of world peace (Leith et al., 1943).

Since the latter part of the 19th century, Britain, the United States, the Soviet Union, Japan, West Germany, and France primarily have developed the world's mineral resources. These countries have furnished the necessary science, technology and capital and have supplied the markets. With the final peace settlement after World War I, Germany lost 68% of its territory, all of its gold, silver, and mercury deposits, 80% of its coal mines and iron-producing capacity, and entered into a period of depression and starvation. The German economy managed to recover with imported ores and a high degree of technical skill and efficient labor. The depression years of the 1930's resulted in economic nationalism and protective tariffs, and many markets were effectively closed. Since Germany and Japan were both dependent upon international trade, their standard of living plunged, and hunger, bitterness, and resentment flared. The Nazis came to power in Germany with promises of work, food, and prestige; rearmament began in 1933, and Japan followed suit shortly thereafter, leading the world into World War II (Lovering, 1943).

Local mineral wealth throughout history and social development has made first one nation rich and powerful, then another. The Phoenicians established worldwide trade and gained great wealth by developing and exchanging minerals for all manner of goods. Athens financed its ancient wars and "Golden Age" with silver from Laurium, Alexander funded his early conquests with gold from Macedon, the Romans expanded their Empire to acquire the silver of Carthage and the copper of Spain, and the Catholic crown of Spain became a world power by the exploitation of old and silver from the New World. During the Middle Ages, Germany became the center of lead, zinc, and silver production and the leader in mining technology. Britain moved into the forefront during the Industrial Revolution of the 19th century and was successively the world's leading producer of tin, copper, lead, and then coal. Bolstered by the resources of a vast empire, Britain became the wealthiest nation in the world. The greater resources of the United States subsequently supported its advance to become the richest nation; however, the future is already foreshadowed. Most of the Greek, German, and British high-grade mines are exhausted, and the United States is fast becoming dependent upon imports and preservation of peaceful world trade. Near East countries have experienced a rapid rise to great wealth based upon petroleum resources. This has been important in technological developments, but historically of short duration. New discoveries of high-grade metal deposits are very likely in the Soviet Union and China, but less likely in the United States.

Future Contributions of the Mineral Industry

With few exceptions, no nation can achieve a high level of prosperity without a reliable source of minerals to supply its manufacturing industry. Through mining, emergent countries can finance growth progressively by the export of raw mineral resources, then by processing these raw materials prior to export, and finally by achieving progressive industrial development.

Mineral reserves, upon which the future of the human race depends, occupy less than 0.1% of the continental areas. Unfortunately, we are not at present sufficiently skilled to determine exactly where they occur or how large they may be. They remain elusive targets. Therefore, research in mining and metallurgical technology is essential. A new discovery may locate a mine, but a technological breakthrough can open up mines all around the world.

The economic evolution of society that began in Neolithic prehistory was based then, as it is now, on minerals, and has led people into modern times. The 104 elements of the periodic table, all but a few of which are recovered widely spaced often remote, mineral deposits using a variety of complex mining and metallurgic techniques, form the foundation of modern society. They provide its light, heat, shelter, transportation, communication, and food. The standards of living of the industrialized nations - which developing nations are striving to attain - are based upon minerals, and societies could not continue in their material wealth (and contribute to the gross national product) only by being mined. Among the benefits to the state are an increase in employment levels, and enhanced level of self-sufficiency, and improved balance of trade. The latter results from fewer imports and greater exports of commodities mined, a spirited search for more minerals and a build-up of technical manpower levels by in-service training, attraction of overseas investment capital and creation of national wealth (Gregory, 1980).

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GLOSSARY

Cartel- an international syndicate formed to regulate prices and output in some field of business

Denarius- a silver coin and monetary unit of ancient Rome, first used in the latter part of the 3rd century

Geomechanics-the science and engineering of soil and rock

Metallurgy- technique or science of separating metals from their ores

Monopoly- exclusive control of a commodity in a particular market

Prospector- a person who systematically explores, searching for a mineral discovery

Quota- a share or proportional part of a fixed total amount or quantity

Smelting- fusing or melting of ore in order to separate out metal

Subsidy- direct aid provided by a government (usually) to a private industrial undertaking

Tariff- duties imposed by a government on imports or exports

Villeinage- the holding of land at the will of a feudal lord

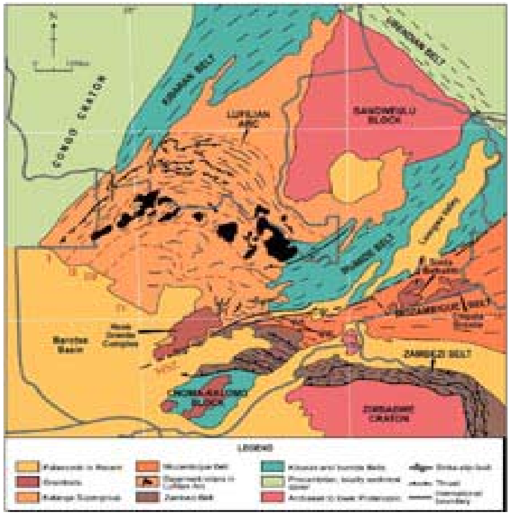
2. MAPS AND MAJOR REGIONAL DISCOVERIES

When prospecting, exploring or applying for permits, a map is a critical tool. One must give exact locations when filing for a claim or to keep data of where the samples were collected. Geologists using the **direct method** of discovery, use the aerial photography along with **topographic** and structural maps to locate **ore bodies.**

Maps

Maps are one of the most important media used to communicate information in exploration geology. Maps are a two dimensional representation of the surface of the earth and its features. Maps are a kind of shorthand language media with two main purposes: 1) to convey detailed information about a specific area, and 2) to indicate the position of the specific area relative to other parts of the earth. The first objective is accomplished by recording information in graphic form, either directly from field observation or indirectly from air photographs or a wide variety of other sources. The second objective is accomplished by showing reference marks (or a coordinate system), or by showing a small scale location map with well known landmarks. A coordinate system is nothing more than a graphical means of locating any point on the map, with two coordinates for each point giving positions with respect to the X axis and Y axis.

Most maps have more than just a map area, they often have lots of other information that is given in the space around the main map area. A complete map generally has several main components. In addition to the main map area, a complete map will usually include the following information in various positions adjacent to the main map area: 1) title, 2) author(s), 3) date, 4) scale, 5) indication of true and magnetic north, and 5) coordinates or reference points. Additionally, almost all geologic maps, as well as geophysical and geochemical maps, contain an explanation. The explanation is where the code for reading the map is provided. This may include the colors, symbols and all other abbreviations used on the map.

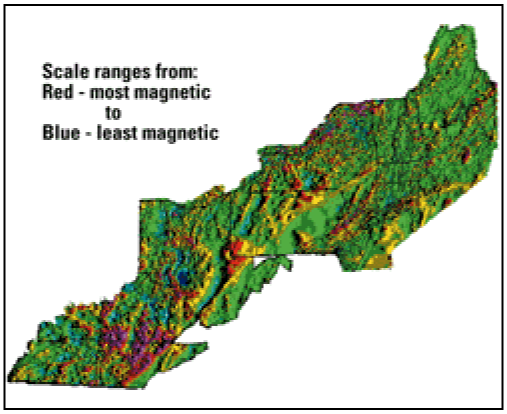


Geological Terrain Map (Zambia) below:

Many types of maps are used in exploration geology. Topographic maps are the most widely used maps. These depict the surface morphology by showing lines of equal elevation (or contour lines). The most basic and essential type of map used by geologists is the geologic map. A geologic map shows rock types (or **lithologies**) and their geometry. Geologic maps are very often constructed on a topographic base map.

Geophysical Map below:

Other types of maps which are used in conjunction with geologic maps include geophysical maps and geochemical maps. Geophysical maps show readings of magnetism, gravity, electrical conductivity, radioactivity, or other physical properties of rocks in an area. Geochemical maps, likewise, show geochemical values of samples collected in an area. These may be samples of soil, rock, stream



sediments or water. There may be numerous values or readings from an area, so typically a derivative map will be created from these maps which summarizes the information or otherwise depicts the data in a fashion such that it can be more quickly evaluated. Typically this is done by designing a map which delineates or emphasizes the anomalous (outside normal) readings or values. One way these derivative maps can highlight anomalous values is by contouring the data similar to the way elevations are used to create topographic contours. This method clusters data points with similar high values and shows the gradient towards lower values just in the way hills and valleys show up on a topographic map. The other method of creating a derivative map is to create a thematic map. A thematic map uses colors or symbols to code the values on the map.

Coordinate Systems

There are many, many types of coordinate systems used for maps, but relatively few are in common usage in exploration geology. These include latitude-longitude, UTM, metes and bounds and local grids. As stated, the map is a two dimensional representation of an irregular surface forming a portion of a sphere of the earth (also called a geoid). Problems arise when trying to fit a flat piece of paper onto a rounded object. The result is a flat map which contains distortion, particularly in the corner areas. This distortion is accommodated by using a projection, which is a mathematical or geometric means of minimizing the problem.

Latitude-longitude has historically been the most frequently used coordinate system for both navigation purposes as well as for conducting exploration geology. In this system the coordinates consist of degrees, minutes and seconds. The latitude, which represents the Y value, is the angular distance north of the equator, which ranges from 0 degrees at the equator to 90 degrees at the poles. The longitude, which represents the X value, is the angular distance westward from the 0 degree meridian, also known as the prime meridian.

The UTM (Universal Transverse Mercator) coordinate system is rapidly becoming the coordinate system of choice in creating maps for exploration geology. The major advantage to this system is that it is based on the metric system, using meters (or kilometers) for distance units. This greatly simplifies mathematical calculations concerning scale and distance measuring. The UTM system is based on a series of geographic zones, each containing a rectangular grid. The Y value of the grid system is referred to as the Northing and increases towards the north. The X value of the grid system is referred to as the Easting and increases towards the east.

Another coordinate system used in exploration geology, more for legal descriptions of land than for navigation purposes, is the system of metes and bounds. This system is referenced to a known meridians (north-south and east-west lines), which is stated on the USGS topographic map of the area. The largest subdivision is the township, which consists of 36 square miles. The township is six miles in length per side. Each township is defined by a township number, which refers to the Y coordinate, and by Range number, which refers to the X coordinate. For example, Township 3 North, Range 4 E refers to the thirty six square mile area extending from 18 to 24 miles in an easterly direction from the meridian, and from 12 to 18 miles in a northerly direction from the specified meridian. The ìsectionsî (one square mile each) are numbered in a standard pattern, starting in the upper right corner of the township with Section 1 and increasing to the west to Section 6. The pattern begins with Section 7 assigned below Section 6, and across to the east to Section 12. Sec. 13 is below Sec. 12, etc... The next level of subdivision is the quarter section, which, as the name implies, is one fourth of the Section. The quarter sections are labeled with the quadrant direction specified as NE, NW, SE, and SW. The last subdivision is the quarter of the quarter section, again labeled as to the quadrant direction.

Land Status Research

Research of the land status for a project area involves obtaining the land status records at the nearest state or federal office, whichever applies. Many states have land status information available on-line now.

Geologic Maps

Geologic maps are central to almost any geological exploration projects. First, all previous geologic maps and data for an area needs to be sought after. Once the previous geologic maps have been assessed, there may be need for additional geologic mapping to be completed at a smaller scale to show more detail. Geologic maps may be created at different scales to show different levels of detail. For example, a reconnaissance geologic map will generally have less detail than an underground mine map. When trench or underground mapping requires the illustration of great detail, so must be made at a larger size.

Rocks can be exposed at the surface in three main ways. They can be present in outcrop, which is a direct observation of bedrock. They can be present in the form of rubble, which is loose rock having no obvious connection with bedrock. Rubble is generally pretty consistent, and thus may frequently be used to represent bedrock. Float is defined as loose rock material which has no obvious origin. Float generally is less consistent, ice, there is more variability in composition. The type of rock exposure observed in the field should be noted as outcrop, rubble or float. The map should eventually document what type of rock exposure is being used to provide the basis for the interpretation of the geology shown on the map. Outcrop maps are more reliable to predict the subsurface geology.

There are several different types of outcrop geologic maps commonly made at an early stage in the exploration of a prospect or area. The decision as to which lithologies to show is a matter of mappers opinion. Each lithology can be made into a separate map unit, or lithologies can be combined into one map unit. The amount of detail needs to fit the map scale chosen, such that it will fit within the map units and be legible. Within each outcrop, the various contacts between differing map units and structural features are shown.

Geologic Mapping Methods

The aim of geologic mapping is to create a map which summarizes the geologic data gathered in the field. Every place that an observation is made, a sample is gathered, or any type of data collection takes place, it is positioned on the map at the appropriate X ñ Y coordinates. Conventionally, reconnaissance geologic maps are created with true north toward the top edge of the map. The map can be small scale and show much detail, or be large scale and generalized. At each point, sometimes called a station, two essential pieces of information need to be recorded, including the lithology and the geometry (or structure), which are defined using color, shading, patterning, and symbology Generally the key to the graphics are shown in an explanation near one edge of the map. The information shown graphically on the map is generally also recorded in writing in a field notebook.

As each contact between lithologies is traced on the map, the type of contact needs to be defined. The possible types of contacts include different types of sedimentary contacts, intrusive contacts, and fault contacts. Sedimentary contacts may be either normal, which is called a conformable contact, or show an erosional surface as the contact, which is called an unconformable contact. Intrusive contacts are often sharp, but can be gradational over a large zone. This could be illustrated graphically using dashed or stipple lines.

The structure data which should be recorded include the geometry of the bedding in the case of sedimentary or volcanic rocks. It would include the foliation in the case of a metamorphic rock. In some cases, layering within plutonic igneous rocks can also be measured. Jointing in igneous rocks can also be an important type of structural data to collect. Where faults are present, the surface must also be measured for its orientation. Fault traces on maps are often shown as heavy, dashed or squiqqly lines. There may be lineations, such as streaks on fault surfaces or alignment of elongate minerals, which can be measured if they are present at the location. These are shown graphically as a small arrow in the direction of the lineation. As mentioned, it is important to not only show the information graphically on the map.

The geometry of many types of planar features are shown using the strike and dip symbol. The strike is the bearing of a horizontal line in the plane of the feature. It is measured with a compass and plotted on the map. The direction of inclination of the same plane is called the dip, and is measured, using an inclinometer, in a direction perpendicular to the strike. The inclination direction is shown by the small mark on the side of the strike line, and the measurement is placed next to it.

The methodology of determining lithology and structure for map units is the same for reconnaissance, trench or underground mapping. However, the normal convention of north at the top edge of the map is not always the case for trench or underground maps, or any other type of geologic map where a lot of detail is desired.

Field Data Collection

Field data collection, done in conjunction with field mapping, is frequently done in one of two ways. The first way is to record information chronologically in a field notebook. The notebook represents a daily log of the field activities which were completed. Each day should begin with a header consisting of the date. Then it is customary to summarize the general location. Then a systematic list of stations, observations, sample numbers, etc... should follow. The second method of collecting field data is to use a standard data collection form which is designed for the project. This method requires a separate form for each station or sample location.

When scanning the globe, looking at major current operating mines, one will find the same company names many times. Many small companies seek funding from major mining companies after the prospecting stage is completed and it becomes a good prospect or discovery. An example would be Placer Dome, one of North America's largest gold mining companies. Placer Dome Mining Co operates fifteen mines in Australia, Canada, Chile, Papua New Guinea, South Africa and the United States. You will also discover company names such as Outokumpu Lead and Zinc

Mining Company, Rio Tinto Copper Mines, De Beers Diamond Mines, and Newmont Gold Mines operating in many parts of the globe.

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Glossary

Direct method of discovery- They use the aerial photography along with topographic **and** structural maps to locate orebodies**.**

Ore bodies- A continuous, well-defined mass of material of sufficient ore content to make extraction economically feasible.

Topographic-Topographic maps show the location and shape of mountains, valleys, plains, the networks of streams and rivers, and the principal works of man.

Lithologies The rock types in the earth's crust and part of the upper mantle.

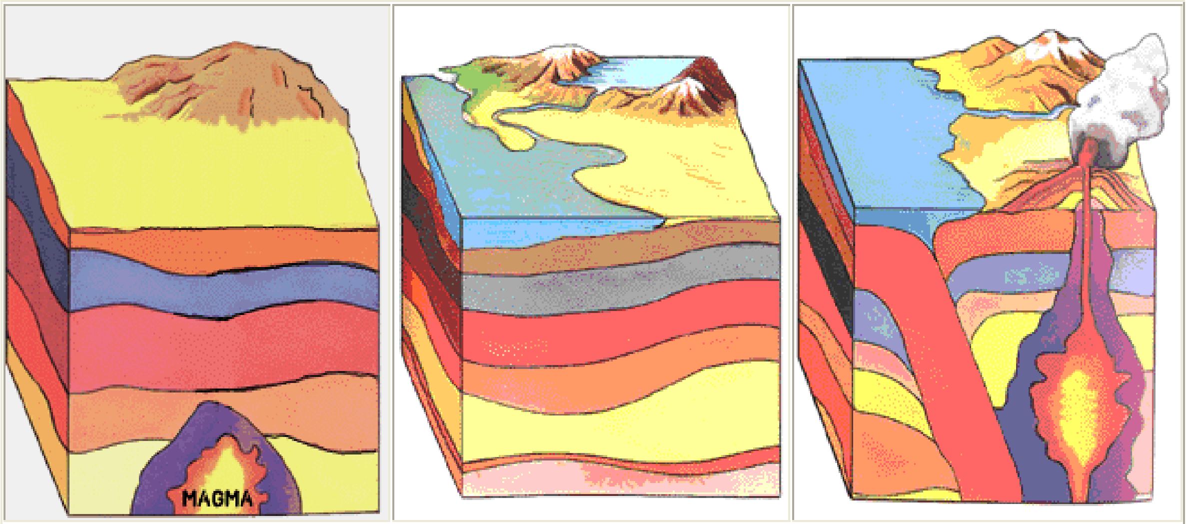
3. GEOLOGICAL EXPLORATION

3.1. Rocks and Rock Structure

To find a particular ore, one must begin by looking in regions where the ore is formed and/or concentrated. Therefore before exploration one must have an understanding of the geologic forces that form rocks and ore deposits.

A rock is a mineral, or aggregate of minerals, that forms an essential part of the earth's crust. In other words, enough of a particular mixture of minerals exists, so that the rock can be named and recognized in many localities throughout the world. Rocks differ from minerals in that rocks are merely physical mixtures of minerals, while the minerals themselves are chemical compounds of fairly uniform composition. For most prospectors, the study of rocks is more complicated than the study of minerals. The study of rocks should not be overlooked because valuable minerals often are found associated with specific types of rocks. Rock structures can be indicative of ore deposits as well as the potential size of an ore deposit. Therefore, solid knowledge of ore deposits and structural geology is an important tool for seeking large ore deposits.

Any rock can be classified as one of three types: **igneous**, **sedimentary**, or **metamorphic**. This method of classification is based on the mode of formation of the rock. Igneous rock is formed from a molten state. The sedimentary rocks are formed from sediments or erosion fragments deposited in lake and ocean beds. Metamorphic rocks form when great heat and pressure, caused by deep burial, alter the physical condition of sedimentary, igneous, or another metamorphic rock.



Igneous rock formation | **Sedimentary rock formation** | **Metamorphic rock formation**

Figure 3.1Rock types and structures

Igneous (fire formed) rocks are formed in deep-seated areas of the earth's crust. They may be fine grained, large grained or a combination of large and small grains. The grain size indicates the cooling rate of the rock. Fine grained (dense) igneous rocks form when rapid cooling occurs. Conversely, coarse-grained rocks cooled slowly and crystals grew large.

Fundamentally, igneous rocks are classified as either intrusive or extrusive. Intrusive rocks originate from magmas (molten rock materials combined with gases) at depth in the earth. Intrusive rocks occur as massive structure or as in "injection" structure. This latter structure forms when the hot, liquid or plastic rock is injected into fractures in the surrounding solid rock. Intrusive action leads to the formation of **batholiths**, **laccoliths**, **stocks**, **dikes**, and **sills**. Weathering and erosion later expose these structures on the earth's surface. Extrusive rocks are formed by volcanic activity at the surface of the earth. These rocks cool rapidly. Examples of some common igneous rocks are: rhyolite, andesite, basalt, granite, diorite, gabbro.

The formation of sedimentary rocks begins with the breaking down of other rocks into fragments. The forces of weathering and erosion, such as running water or freezing and thawing, accomplish this mechanical and chemical breakdown. Fragments are transported to and deposited in lake and ocean bottoms. Later, spaces between the fragments are filled with a cementing material or are eliminated by pressure. After some time passes, a massive rock layer results. Sedimentary rocks are classified based on the size of the particle of the sediment, or fragment. Shale (dense, fine particles), sandstone (particles distinguishable to the naked eye) and conglomerate (pebbles and gravel cemented together) are examples of sedimentary rocks.

Metamorphic rocks are formed from previously existing igneous, sedimentary or possibly other metamorphic rocks. Great heat and pressure, yet not enough to completely melt the rock, alter the rocks original physical composition. Sometimes the process of metamorphism aligns the grains in parallel layers or bands. This layering is called foliation. When broken, a metamorphic rock usually breaks along the plane of foliation. Metamorphic rocks are classified based on their grain size and degree of foliation. Some examples of metamorphic rocks are: slate, schist, gneiss.

Some Rocks and Mineral Associations	
Rock Type	Elements or Minerals
Andestite-Basalt	Copper, Platinum, Mercury, Gold
Diorite or Quartz Diorite	Magnietite, Molybdenum, Copper, Tin, Tungsten, Gold, Silver, Zinc, Lead
Gabbro	Nickel, Copper, Magnetite, Platinum, Ilmenite, Cobalt
Granite and Pegmatite	Beryl, Uranium, Tin, Tungsten, Gemstones
Peridotite-Kimberlite	Diamond, Pyrope
Periotite or Dunite	Chromium, Platinum
Nepherite-Jadite, Uvarovite	
Rhyolite	Gold, Mercury, Uranium
Serpentine	Asbestos, Chromium, Platinum, Talc-Soapstone,
Syenite	Bauxite, Magnetite, Copper, Gold, Corundum

3.2. Ore Deposits

The ultimate source of ore deposits is deep in the igneous rocks in the earth. The original concentration takes place within bodies of **magma** through a process called differentiation. The concentration of some simple high temperature oxide minerals occurs within the liquid magma itself. The vast majority of minerals, however, are deposited in the surrounding rocks from the cooling liquid by replacement of wall rock and by the filling of the cavities. In addition, important deposits may be formed by the reworking of older deposits of magma origin, by weathering and erosion acting at or near the earth's surface.

The cause of molten areas, or magma, is not fully known. It is probable tat several factors work together to form them. Radioactivity is an important contributor to the heat since it has been shown that igneous rocks in general are higher in content of radioactive minerals than are other rocks. Pressures and friction in zones of mountain building and release of pressure as a result of failure of the rock also are probable factors in the melting of rocks. Whatever the source of energies involved in its formation, the magma is very important in the filed of ore deposits since a great bulk of these deposits is found as a direct result from magma activity. The nature and location of deposition is influenced by factors outside the magma, such as structure, nature of rocks invaded, depth below surface, and abundance of ground water. The main source of mineral, however, is the magma itself and therefore, it must be of considerable size in order to have sufficient mineral present.

The term "**direct magma deposits**" refers to deposits of mineral, which have formed within the body proper of magma, mass. As magma ceases to rise and encroach upon the rocks in which has been invading, it begins to cool. The rate depends upon such factors as total amount of heat present and the amount of overlying, insulating rocks present. Depending on their temperatures of formation in the magma solution, minerals begin to crystallize out and rise or sink depending on their specific gravities. By this method of differential crystallization, high temperature minerals, such as magnetite and chromite are formed. They separate into localized concentrations and upon solidification of the magma, become ore deposits. As cooling continues minerals continue to crystallize out of the magma solution, the remaining liquid becomes increasingly rich in low temperature minerals, such as quartz, and volatile minerals, such as water. The great bulk of metallic ore minerals are concentrated in this late-stage residual solution.

Pegmatites are vein-like or dike-like formations that often contain very large crystals, some of which are valuable minerals. Usually pegmatites are closely associated with an igneous mass. They likely are the end stage of differentiation of cooling magma. The **hydrothermal** or water deposits include high temperature gas and liquid magma solutions that react with the invaded rock. The most favorable host rock for hydrothermal deposits is limestone since it is readily replaced by the mineralizing solutions. The factors involved in dropping the metals from the solution to form ore are varied and complex. They include temperature, pressure, nature of the host rock, reaction with other solutions, concentration, rapidity of movement of solutions, and perhaps many others, all acting separately and/or in complex relationships with one another. In general, one can expect a certain order of mineralization ranging outward from high temperatures and pressures near the magma to low temperatures and pressures away from it.

A large group of important mineral deposits is formed by action of surface agents upon earlier magmatic or hydrothermal deposits. Reworking of older material and reposition or reconcentration by mechanical, chemical or organic means form them. Sedimentary ore deposits may be divided into the following:

- Mechanical deposits form by concentrating valuable materials with relatively high specific gravities and comparative resistance to chemical and physical breakdown. These are placer deposits. Gold, platinum, tin, monazite, and gemstones occur in mechanical deposits. Other less resistant minerals, such as scheelite, cinnabar, and magnetite, form, when conditions are favorable.
- Residual deposits from in place by selective leaching and removal of worthless material while the valuable mineral is left behind, thus building a concentration that is worth mining. Examples are iron, manganese, nickel, and aluminum deposits.

- Chemical deposits form by the precipitation of material from solution into bodies of surface water such as lakes or seas. Generally, these deposits are non-metallic, for example, dolomite, gypsum and salt deposits.
- Supergene enrichments form by solution of minerals of percolating ground waters above the water table and re-precipitation at or near the water table. Copper deposits of New Mexico and Arizona are notable examples.

Metamorphic deposits result from rearrangement of minerals already existing in a rock, from heat and pressure. No outside minerals are added. Graphite, asbestos, talc, garnet, jade are examples of minerals which form economic deposits of this type.

3.3. Structural Control of Ore Deposits

The formation of valuable mineral deposits result from a combination of factors, conditions, and events which go hand in hand to determine the areas in which metals, otherwise scattered through masses of rock somehow are gathered into concentrations greatly exceeding the average for rocks in general. **Differentiation** of large masses of rock material in a molten state is a major means of metal accumulation. Highly mobile and volatile solutions contain high concentrations of metal and carry them to some point where chemical and physical conditions are favorable for deposition. Hydrothermal and secondary deposits are found in areas where rocks have been "prepared" in advance by some kind of structural deformation. Areas of mountain building activity combine structural deformation and igneous activity. They are therefore, favorable places for ore deposits.

There are two divisions of rock structures, which control ore formation, primary structures, and secondary structures. Primary structures are features such as bedding in sediments, igneous contacts, pillows in lavas, and other minor features that developed during the formation of the rock mass. Such structures might have had important local influence on the size, shape, or grade of a deposit. Bedding surfaces, igneous contact, or intergranular spaces might act as zones along which a solutions move to points of deposition. High permeability can be important for providing channels for solutions.

Secondary structures develop after the formation of the rock. They are such features as faults, joints, and folds, and are of greater importance in control of ore deposition than are the primary structures.

Faults - Faults are fractures in rock masses with major slippage. Tensional stresses, or pulling apart, cause normal faults. Compression yields reverse or thrust faults. Strike-slip faults displace blocks horizontally, with little up or down movement.

Joints - Different from faults, joints are cracks in which there has been no movement of the rock on side of the opening relative to the other side. Junctions of joints with faults or other joints can be areas of marked increase of width and grade of ore.

Folds - The influence of folds in localization of ore is more or less indirect, their primary functions being that of confining and directing solutions to restricted channels or localizing fractures during fault movement. The common relationship between folds and ore is that a fold might cause deposition in conjunction with faults and other fractures.

References

Delta Mine Training Centre, *Introduction to Mining Engineering,* online course notes, Alaska.

Glossary:

Batholiths-A large, discordant, intrusive body of igneous rock.

Differentiation -state of difference

Dikes-A tabular igneous intrusion that cuts across the surrounding rock.

Direct magma deposits- deposits of mineral, which have formed within the body proper of magma, mass

Hydrothermal-water deposits that include high temperature gas and liquid magma solutions that react with the invaded rock

Igneous-rock that is formed from a molten state

Laccoliths-A concordant igneous intrusion with a flat floor and a convex upper surface, usually less than 8 km across and from a few meters to a few hundred meters thick at its thickest point.

Magma-molten rock materials combined with gases)

Metamorphic-A rock changed from its original form and/or composition by heat, pressure, or chemically active fluids, or some combination of them.

Pegmatites- vein-like or dike-like formations that often contain very large crystals, some of which are valuable minerals.

Sedimentary Rock-Rock formed from the accumulation of sediment, which may consist of fragments and mineral grains of varying sizes from pre-existing rocks, remains or products of animals and plants, the products of chemical action, or mixtures of these.

Sills-A tabular igneous intrusion that parallels the planar structure of the surrounding rock.

Stocks-A small batholith

4. SURFACE MINING

Deposits that occur near the surface can be mined by surface mining methods. Surface mining methods can be categorized into two major groups, the mechanical extraction and aqueous extraction methods, each is composed of several different sub methods (refer to the table below).

Class	Subclass	Method
Mechanical	– –	Open Pit Mining Quarrying Strip Mining Auger Mining
Aqueous	Placer	Dredging Hydraulic Mining
	Solution	Surface Mining In Situ Leaching

Broadly applicable, the open pit and open cast methods employ a conventional mining cycle of operations to extract mineral: Rock breakage is usually accomplished by drilling and blasting, followed by the materials-handling operations of excavation and haulage. Quarrying and augering are specialized and less frequently used methods where breakage is achieved by alternative means and explosives are essentially dispensed with. Mechanical methods are also distinguishable from the aqueous methods, where extraction depends upon hydraulic action or solution attack.

4.1. Open Pit Mining

Introduction

In open pit mining, any overburden is stripped and transported to a disposal area to uncover the mineral deposit. Both stripping and mining are conducted from one or a sequence of benches. A thick deposit, typical of metallic ores, requires many benches and resembles a roughly circular pyramid, inverted in the earth (Fig.4.1), each successive bench being cut to a smaller radius because of the slope imposed by safety consideration. A single bench may suffice if the deposit and overburden are relatively thin (15-45m), typically when mining the coal and other non-metallic ores.

Multiple bench operation is also designed to ensure that enough length of face is exposed to allow sustained, uninterrupted production when large quantity of materials is required to feed the mill. Individual benches are designed to accommodate the materials-handling equipment to work efficiently. The height is limited by the reach of the excavator, and the width of the benches is determined to allow for the loading and haul equipment to work in a safe and productive environment.

In order to allow for the materials mined in the pit to be transported to the surface for further processing and for the mining equipment to go into the production site in the pit, in pit roads are constructed on the pit wall, either in spiral form or in switch back (zig-zag) form.

Although the basic concept of an open pit is quite simple, the planning required to develop a large deposit for surface mining is a very complex and costly undertaking. In one mine, it may be desirable to plan for blending variations in the ore so as to maintain, as nearly as possible, a uniform feed to the mill.

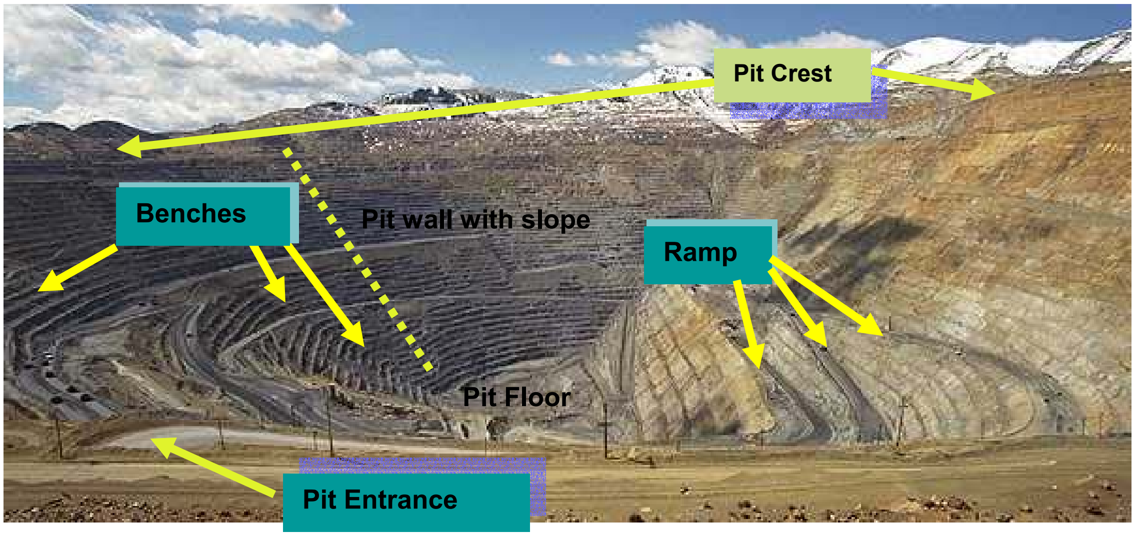


Figure 4.1 Open pit geometry

At another operation it may be desirable to completely separate two kinds of ore, as for example, a low- grade deposit where one kind of "oxide" ore must be treated by acid leach, but a second kind of "sulfide" ore must be treated by different methods.

The grade and tonnage of material available will determine how much waste rock can be stripped, and there is often an ultimate limit to the pit that is determined more by the economics of removing overburden than a sudden change in the ore deposit from mineral to nonmineral bearing material. The ultimate pit limit and the slope of the pit walls are therefore determined as much by economics and engineering as by geological structure. Material that is relatively high grade may be left unmined in some awkward spot extending back too deeply beneath waste.

The typical large open pit mining operation that has been in production for 10 years and more is operating under conditions that could not possibly have been foreseen by the original planners of the mine. Metal prices, machinery, and milling methods are constantly changing so that the larger operations must be periodically reevaluated, and several have been completely redeveloped from time to time as entirely different kinds of mining and milling operations.

Sometimes the preliminary stripping of the waste overburden is contracted to firms specializing in earthmoving.

Stripping Ratio Considerations

The term **stripping ratio** is almost universally used and represents the amount of uneconomic materials that must be removed to uncover one unit of ore. The ratio of total volume of waste to ore volume is defined as the **overall stripping ratio**.

$$R = \frac{Volume\ of\ waste\ removed\ to\ depth}{Volume\ of\ ore\ recovered\ to\ depth}$$

While a volume relationship, calculated in cubic yards/cubic yards (cubic meters/cubic meter). It is more commonly expressed as tons/tons. Note that in mining certain mineral commodities, however, *stripping ratio* is expressed in units of cubic yards/ton.

Although surface mining is commonly considered the cheap mining method comparing with underground operation, this advantage diminishes as the mining goes deeper when the amount of waste material removal increases. A critical stripping ratio, **the economic stripping ratio (ESR)**, is frequently used to determine whether the deposit should be developed using surface or underground mining. This stripping defines the maximum overall stripping ratio to ensure the surface mining operation to generate greater profit than an underground operation working on this deposit. If the stripping ratio goes beyond this point, then underground mining should be considered.

Cutoff stripping ratio is the one that the costs of mining the ore and waste are matched by the revenue for that block of ore. Factors used to determine costs should include the added costs of mining as the mine deepens and the interest charges on the prestripping of waste.

In the most complete analysis, the entire ore body is mined on paper. The production from each time period is determined, the costs and revenues listed, and a cash flow generated. The profits are projected. The result is to be the value of the mine or production. Mining is continued until it no longer increases the value, and so a pit limit is determined. The ratio of the total volume of waste to total volume of ore is then the overall stripping ratio,

Conditions

Open pit mining method may be adopted for mining any types of minerals as long as the costs and benefits is more favorable than that of using underground mining method. However, the following conditions should be considered to make the open pit mining favorable:

- Ore/Rock strength – any
- Deposit shape –any, but preferably lenticula or tabular
- Deposit dip – any, preferably horizontal or low dip
- Deposit size – large and thick
- Ore grade – can be very low
- Ore uniformity – preferably uniform or variable horizontally
- Deposit depth – shallow to intermediate, but can go deeper as long as it economically sounds comparing with underground operation

Overburden stripping and ore mining

In open pit operation, the overburden and waste mining usually uses the same mining system, including the mining equipment, material handling system, etc, as the ore mining. The working cycle is also very similar. This feature of open pit mining provides great possibility to interchange the equipment as needed for both ore and waste mining, largely reduces the total amount of equipment required for either of the activities, and simplified the production control.

The production experiences 2 major steps, rock breakage and material handling. Rock breakage usually involves drilling and blasting, and material handling can be different systems but in general excavation and material transportation.

Drilling

Drilling, as the first step of the production cycle, can be quite critical to the mining productivity and profitability. The selection of drill is directly related to the bench height and production requirement. The drillhole diameter can range from several centimeters to nearly half a meter. Usually large drillholes are favorable when high productivity is emphasized, but large drillhole lead to poor rock fragmentation and therefore higher costs of the subsequent material handling and rock crushing as well grinding in the plant. The trade-off of productivity and production costs should be studied. This relationship is illustrated in Figure 4.2.

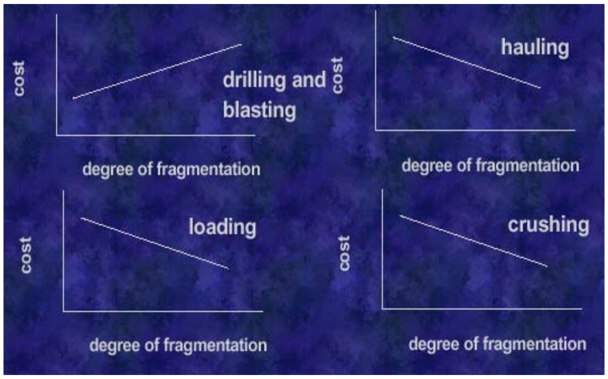


Figure 4.2 Relationships among drilling fragmentation and subsequent costs

Figure 4.3 P.H. rotary drill

Normally auger drills are used in drilling in weak rocks; roller bits are used in average rocks. For hard rock drilling, percussion and large rotary drills are usually used (Figure4.3). To improve the rock fragmentation and save explosive, different drilling patterns are usually adopted together with different detonation sequences using delay techniques. Figure?? demonstrates several most frequently applied drilling patters.

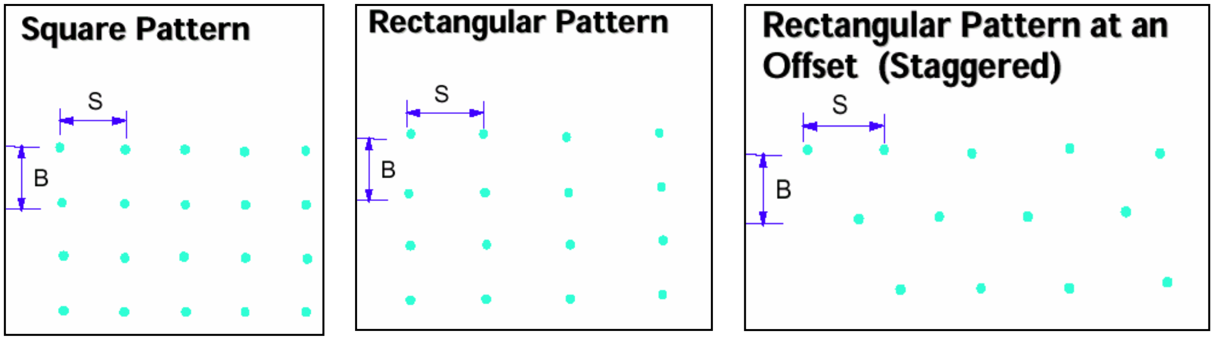


Figure 4.4 Typical drillhole patterns at open pit mines

Blasting

Different rock needs different explosives to generate sufficient energy to break it. ANFO or AN slurry and ANFO plus different additives are the most often used explosives for open pit mining operation. Explosive loaders are widely used for loading the explosives in bulk blasting. In order to improve the rock fragmentation, and make best use of the explosive energy, electricity or detonating cord are used for firing the blastholes, and suitable delays are applied to differentiate the hole firing time. The most frequently observed firing patterns are illustrated in Figure4.5

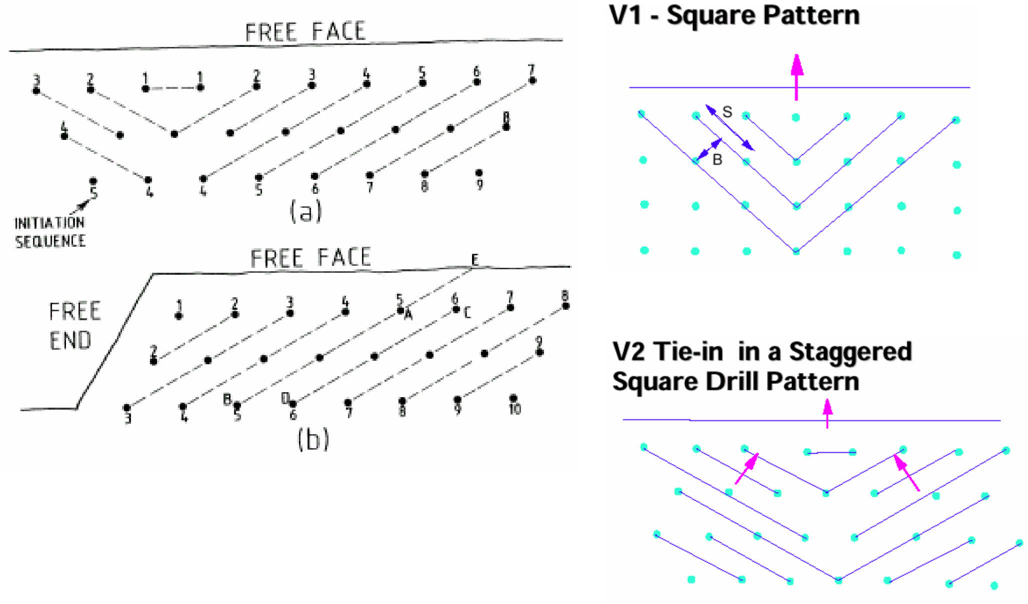


Figure 4.5 Most frequently used drillhoe firing patterns

Excavation

The blasted rocks are excavated using different excavation equipment. Shovel, front-end loader, dozer, scraper, dragline are normally used in different open pit mines amenable to the requirement of production. For thick top soil excavation, dozers and when the site condition suits, bucket wheel excavators are used. In most of metallic open pit mines, shovels are the most selected excavation equipment due to its high productivity. In the past decades, the production scale has become lager and larger. Accordingly, large mining equipment has been developed to support the production requirement. Nowadays a shovel with a huge bucket is no longer a strange thing. The largest shovel running at the mine site can load 130 tonnes of rock in a single pass (Figure 4.6).

Transportation

So far, truck remains the most flexible and high productive material transportation equipment at open pit mine site, although other material handling systems are also frequently used, such as belt conveyor, dozer, scraper etc. The use of belt conveyor is limited by the fact that the open pit mining goes usually quite deep. Dozers and scrapers are limited by their short transportation distance. In recent year, trolley assisted truck haulage system become more and more popular as its advantage of low operating costs and high ability of working on steep haul road. Refer to Figure 4.8 for haul truck.

Figure 4.6 Rope shovel for blasted material excavation

Figure 4.7 Haul truck working at open pit mine

Advantages and disadvantages

Compare with the other type of mining methods, open pit mining has obvious advantages but also has its drawbacks. The typical advantage of open pit mining is its high productivity, high production rate and the induced low operating costs. However, large capacity also implies high initial capital input at the development and planning stages. Environmental protection may be another critical issue that affects the feasibility of an open pit operation.

Major advantages:

- Highly mechanized and labor conserving bulk mining method – high productivity
- Low cost
- High production rate
- Early production while development
- Quantity and quality requirement of labor is low
- Permit the use of large equipment
- Low rock support need
- Flexible and high recovery
- Good health and safety

Major Disadvantages

- Limited depth (usually <300m) (vs. UG)
- Economic imposes limits (stripping ratio limited)
- Intensive initial capital costs
- Needs large deposits to dilute the costs
- Reclamation is required for the damaged surface
- Production affected significantly by climates
- Disposal sites must be available
- Slope stability maintenance can be critical and costly

4.2. Open Cast (Strip) mining

Strip mining is also referred to as open cast mining. This is a type of surface mining activity which is carried out specifically for the recovery of coal, tar sands and other types of minerals occurred shallowly from the surface. This method differs from open pit mining significantly in size, types of equipment used and orebody configuration, end use of land and so forth. One of the most obvious difference of strip mining from open pit operations is that the waste which is removed in order to gain access to the ore in strip mining is usually not transported away for separate storage, but instead, directly dumped (or casted) in the mined out area as backfilling.

Two general forms of strip mining can be observed in the mining industry, the area mining and contour mining. Area strip mining is a technique used for the recovery of flat-lying or gently dipped, near surface ore deposits. Contour strip mining is adopted usually for recovering the ore in hilly or mountainous terrain, where coal or like seams, which are not flat lying, are exposed close to the surface. The mining operation involves removal of overburden along sequential hill contours until ore is recovered at some depth into the hillsides. In both forms of strip mining, unlike open pit operations, waste that overlies the ore is often not rock or rock-like materials but usually soil or overburdens. The overburdens are in most cases are characteristically very soft or weak and does not need drilling and blasting to fragment, and therefore can be excavated directly by the excavation equipment, typically draglines, stripping shovels and continuous mining units, such as bucket wheel excavator. In some occasions, only a few though, the overburden may be hard enough to prevent such direct excavation. In the cases, drilling and blasting operation are exercised.

Drilling and blasting operation may also be required when mining in the cold regions, such as in northern Canada where the temperature can go as low as -50^{0}C or even cold in the winter time, when the earth is deeply frozen.

4.2.1. Area Dragline Method

The area strip mining, also referred to as "deep plowing", process is particularly suited for recovery of large, flat lying to moderately dipping coal seams or tar sands layers which in general lie with 50 meters form the surface, preferably with constant overburden depths. The typical area strip mining operation will be developed over zones which can be distributed over several kilometers in extent. The mineral processing plant, or coal washing plant is normally located in the centre of the mining area. Special consideration is needed for storage of the topsoil that is moved from on top of the overburden for future reclamation.

Mining process involves opening an initial cut, the box cut or sometimes called sinking or dropping cut, along an edge of a prospective mining zone, removing the coal exposed in the cut and then placing the overburden from the next cut, parallel to the initial cut, into the mined out cuts. The procedure is then repeated on a cut-by-cut basis till the whole area is mined out. Reclamation work is done by machineries. Figures 4.8 and 4.9 illustrates the procedure of the area stripping mining.

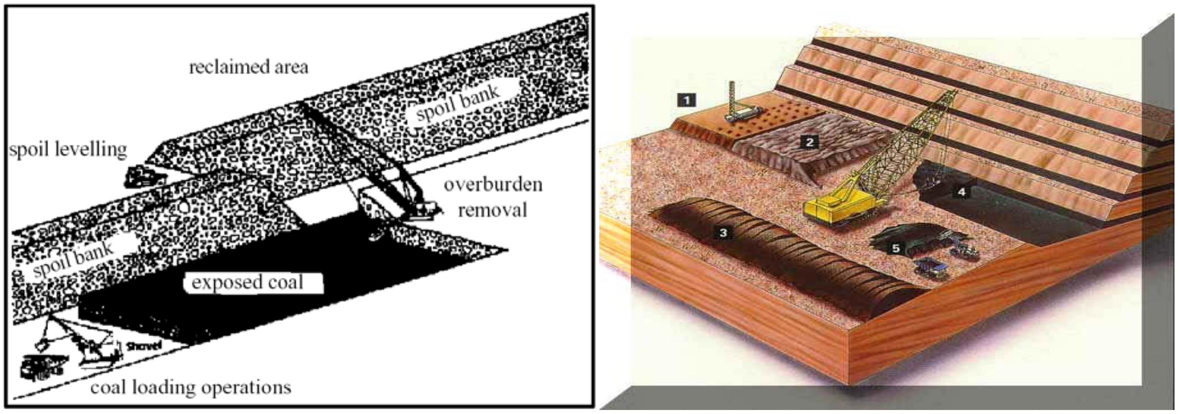


Figure 4.8 Illustration or area stippling coal mining

Removal of overburden proceeds along the paths parallel to and away from the initial sinking cut to expose the surface of coal seams below. As overburden is picked up by various forms of equipment, it is staked as spoil in a series of spoil piles in the mined area. After the overburden has been removed and the spoil been stacked, equipment is moved into the excavations created so that the coal seam can be extracted.

A simplified dragline operation is illustrated in Figure 4.10. The stripping cycle begins with the dragline at position 1, cutting a trench, referred to as the **key cut,** along the newly formed highwall. The distance from the previous key cut position to the new position is referred to as the **digout** length. The key cut is made to maintain the panel width and uniform highwall. Without a key cut, the panel width would narrow with each subsequent digout, because the dragline could not control the bucket digging against an open face. The dragline deposits the key cut material in the bottom of the mined-out pit off the coal and against the previous spoil pile. More stable spoil from the key cut may be placed in the very bottom next to previous spoil to form the buckwall which provides a more stable spoil slope that can be steepened if deemed necessary.

Figure 4.9 Dragline stripping coal operation

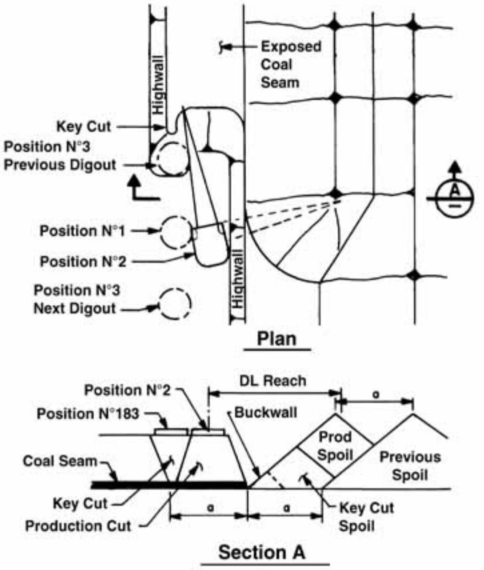


Figure 4.10 Typical dragline operation

When the key cut has been completed, the dragline is moved to position 2 to complete excavation of the digout. This is known as the **production cut,** and the material is cast on top of the key cut spoil. When the digout has been completed, the dragline is moved to position 3, the beginning of the next stripping cycle (next digout).

The operating cycle of the dragline consists of five basic steps:

1. The empty bucket is positioned, ready to be filled.
2. The bucket is dragged toward the dragline to fill it.
3. The filled bucket is simultaneously hoisted and swung over to the spoil pile. If the swing motion must be slowed to permit hoisting, the dragline is said to be **hoist critical**. When hoisting to the dump position is completed before the boom is in position to dump, the dragline is said to be **swing critical**.
4. The material is dumped on the spoil.
5. The bucket is swung back to the cut while simultaneously being lowered and retrieved to the digging position.

Efficient dragline operation is realized by minimizing the time required to position, drag, and dump while synchronizing the swing and hoisting motions. Synchronization of hoisting and swinging is dependent on the time the boom is in motion.

Full Key Cut vs. Layer Cut

At the beginning of a new digout, the dragline generally is placed directly over the toe of the new highwall to be formed. From this position, the dragline can establish a uniform and safe highwall if the burden is sufficiently stable.

In this position, the dragline excavates the key cut which is more than the width of the bucket at the bottom of the cut. When the cut has been completed, the dragline moves over to make the production cut. The two positions generally are required because of the limited reach of the dragline in relation to the panel width being stripped. Large draglines, operating under ideal conditions, may be able to excavate the total digout from the one position over the highwall. Such situations are the exception, not the rule.

When operating conditions permit excavation of the dig out from one position over the highwall, the dragline generally excavates the digout in layers. The key cut is formed, one layer at a time, by excavating along the highwall before the completion of each layer. Cutting in layers can be performed from the production cut position; however, the high wall slope will require dressing by dozer while the dragline is digging. Under such circumstances, some mines also have adequately dressed the highwall by dangling a heavy section of chain from the bucket and dragging the chain along the wall. Other mines, because spoil area is critical, have progressively stepped the dragline toward the spoil while excavating in the layer cut method. This procedure has the tendency to pack spoil as tightly as possible on the spoil slope.

Layer cutting generally increases dragline productivity with a corresponding decrease in operating cost. Increased productivity is realized by progressively decreasing the average swing angle as the dragline walks in the direction of the spoil pile.

Dragline Panel Width: Panel width is defined as the width of the cut taken by the dragline, as it progresses from digout to digout, along the highwall from one end of the pit to the other. Panel width, one of the most important parameters affecting dragline productivity, is influenced by depth of overburden, dragline boom length, hoist and swing time, and available spoil area. Since panel width becomes the available operating area in the pit bottom, coal loading operations are also affected.

Several operational factors must be considered in the selection of panel width. A wide pit generally is favorable for coal loadout and permits greater safety for men and equipment. The minimum practical pit width is dictated by the maneuverability of coal loading and hauling equipment.

If the available space for placement of spoil is critical, such as might occur when crowding spoil to open haul roads through the spoil, narrow panels permit greater flexibility to deal with such problems. In general, the wider the panel, the less dragline walking time is required.

Bench Height: The height above the coal seam at which the dragline is positioned is defined as the bench height. Selection of the bench height is based on numerous operational factors and topographic restraints.

The complex relationship of bench height (which could be equal to overburden depth), panel width, dragline dumping reach and dumping height, as well as material characteristics such as swell and angle of repose, influence greatly the dragline's capability to dispose of burden off the coal. The dragline's digging depth, while related to burden depth, rarely becomes a factor in dragline performance.

The bench height must be selected primarily on the basis of fitting the dragline's specific characteristics to the required pit geometry. In general, the bench height should be as high as possible within the limit of required dragline reach.

Undulating topography may complicate a simplified selection of bench height. Two alternatives are available to alleviate the problem:

1. The dragline can be used to cut and fill to develop a common bench elevation. Cutting, termed **chopping** or **overhand digging,** increases the cycle time and reduces the bucket fill factor, thereby reducing effective productivity. Fill material must be rehandled, thus reducing overall production. Chopping has very special advantages: the dragline reach required may be shortened, rehandling of burden may be avoided, fill may not be required to create a level working surface, a level return path for deadheading can be provided, and subsoil can be placed back in its relative position on top of the spoil.
2. Auxiliary equipment can be used to perform the cut and fill operation. Care must be exercised to ensure that filled areas are stable. Utilizing auxiliary equipment offers the benefit of freeing the dragline for its primary function of stripping burden from the coal.

Whether the dragline cuts and fills its working pad or auxiliary equipment is utilized to prepare a level working surface depending on several variables. Dragline chopping decreases overburden stripping productivity and may involve abnormal wear and tear on dragline equipment. Auxiliary equipment for prestripping adds to the capital and operating costs of operations. Depending on the thickness of the material to be chopped, the cost differential between chopping and using auxiliary equipment is not likely to be high when small draglines are compared. For large draglines, prestripping with auxiliary equipment will very likely be preferable.

Digout Length: The selection of digout length, the length between major digging cycles, is based on the relationship of the dragline's operating characteristics with respect to pit geometry. In general, the digout should be as long as possible. However, dragline size may greatly influence digout length for specific pit geometry. For example, digout length is sensitive when using a dragline with slow hoist speed working in deep overburden. Spoil critical pits may utilize a less than desirable digout length in order to pack the maximum material onto the spoil bank.

Pit Shape: The new dragline pit begins with the initial cut, termed the **box cut**, made along the outcrop, subcrop, or property boundary. To open the box cut, excavated material is spoiled to one or both sides of the cut. The material lying on the newly created highwall must be moved or spread out evenly by auxiliary equipment. The material lying on the cut wall that will become the spoil side may, or may not, have to be moved depending on reclamation requirements.

Because of rolling topography, the mine engineer may be inclined to design the box cut along a uniform contour. Generally, succeeding cuts are designed parallel to the box cut. As a result, this type of pit develops a meandering design. In Figure 4.11, the effects of pit curvature are illustrated. The figure is an idealized compound curve with equal radii of curvature to illustrate the difference in spoil area between an inside and outside curve. Obviously, outside curves provide more spoil area. Depending on depth of overburden, panel width, radius of curvature, and operating parameters, severe operating problems may occur on inside curves. Dragline cycle time will increase, spoil crowding will occur, and coal may be lost by being covered with spoil.

To remedy the problems caused by inside curves, several options can be considered. Panel width may be decreased, material may be cast short and rehandled by extending the bench, a small auxiliary dragline may be utilized on the spoil to pull back excess spoil, the spoil pile may be steepened, or the pit may be straightened by stripping a series of short panels. Generally, the most favorable solution is to straighten the pit. Spoil steepening is also an effective method for disposing of relatively small amounts of excess spoil. The dragline bucket is positioned on the spoil slope where steepening is desired and dragged down and across the top of coal. The bottom part of the spoil pile is steepened and coal is cleaned in the process. Digging efficiency during this process is reduced, cycle time increased, and rehandling reduces effective productivity. Steepened spoil slopes may present special hazards to equipment and personnel because they are more prone to failure.

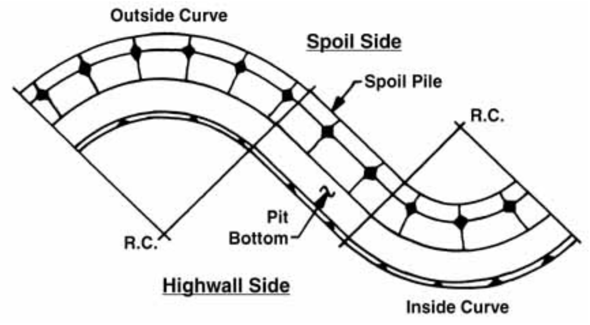


Figure 4.11 Pit curvature

Spoil Patterns: There are three basic methods of spoiling. When using short digouts and casting at a near 90^0 angle, a uniform ridge line can be created. This configuration makes maximum use of the available spoil room. As the digout length is increased, uniformity of the ridge line is lost and individual peaks of spoil are created.

With sufficient spoiling area, the dragline operator may cast material from both the key cut and production positions at angles less than 90^0. While the dragline stripping cycle will improve, spoil piles appear to be ragged and irregular. An aerial view of the operation will show a definitive pattern to the irregularity. In reality, spoil peak grading will be reduced by this method of spoiling.

Dragline cycle time can be reduced by dumping the loaded bucket on the fly, that is, before the dragline swings to the ultimate dumping position. This procedure, termed **radial casting**, gives the spoil a cross bedded appearance. Provided that there is sufficient spoil room, radial casting tends to spread the spoil more effectively, reducing spoil grading costs.

Since distance between spoil ridges is equivalent to the panel width, narrower panels will reduce spoil grading costs. However, such reductions in cost generally will be offset by increases in dragline operating cost if the dragline is not swing critical.

Dragline Extended Bench Systems

Where overburden depth or the panel width exceeds the limit at which the dragline can sidecast the burden from the coal, a bridge of burden can be formed between the bank and the spoil which effectively extends the reach of the dragline. The bridge extends the bench on which the dragline is operating. The bridge is formed by material falling down the spoil bank or by direct placement with the dragline. To remove the bridge material from the top of coal, it must be rehandled.

Extended bench systems are adaptable to many configurations of pit geometry. Figure 4.12 demonstrates a dragline forming its working bench by chopping material from above the bench and forming the bridge, then moving onto the bridge to remove it from top of coal.

Figure 4.13 demonstrates a two-dragline extended bench stripping sequence. The primary dragline strips overburden and spoils it into the previously excavated panel. This material is leveled, either by tractor-dozers or the secondary dragline, to form the bench for the secondary dragline. The secondary dragline first strips material near the highwall, then moves on to the bridge to move the rehandle material. In a two-dragline system, one machine must operate at the pace set by the other. Therefore, mine design must consider their respective capacities when assigning respective digging depths.

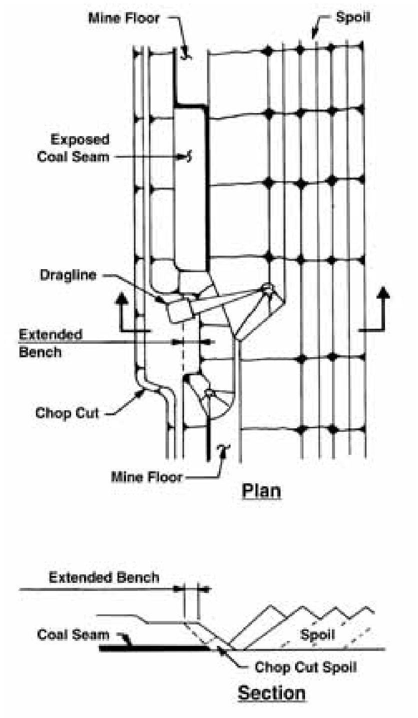


Figure 4.12 Extended bench and crop cut single dragline

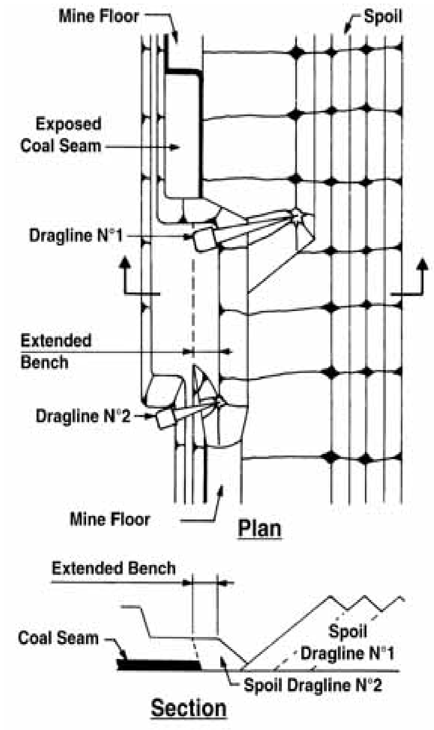


Figure 4.13 Two dragline extended bench system

Figure 7.11 illustrates an extended bench operation in which three coal seams are to be recovered. The primary dragline strips overburden to the top of the first seam. Coal is removed, then a small parting dozed into the pit and the second coal seam removed. The secondary dragline strips the large interburden to the third and final seam.

Extended bench systems must be designed carefully in order to maximize the dragline(s) productivity and to minimize the amount of rehandle.

Contour Stripping with Draglines

In this method, dragline stripping proceeds along the coal outcrop or subcrop, with each successive panel following the line of the original panel. In rolling terrain, the pit twists and turns, developing a series of **S** curves. If the dragline is operating at near maximum geometric limits, it will become **spoil-bound** (unable to deposit stripped burden) when working an inside curve. Under such conditions a smaller secondary dragline may be used to pull back the spoil sufficiently to permit the primary dragline to complete stripping of the coal. Haul roads generally are designed into an outside curve where some spoil crowding is possible because of the wider spoil bank arc.

Drilling and Blasting of Overburden for Draglines

Overburden drilling and blasting is more critical for dragline stripping than for shovel digging. Shovels have the ability to crowd the dipper into the bank, providing leverage to dig difficult or poorly blasted material. Draglines have leverage only by dragging the bucket over the material. Such leverage is translated to severe strain on the bucket lip and teeth. In poorly blasted material, dragline productivity can drop more rapidly than that of shovels working in similar material.

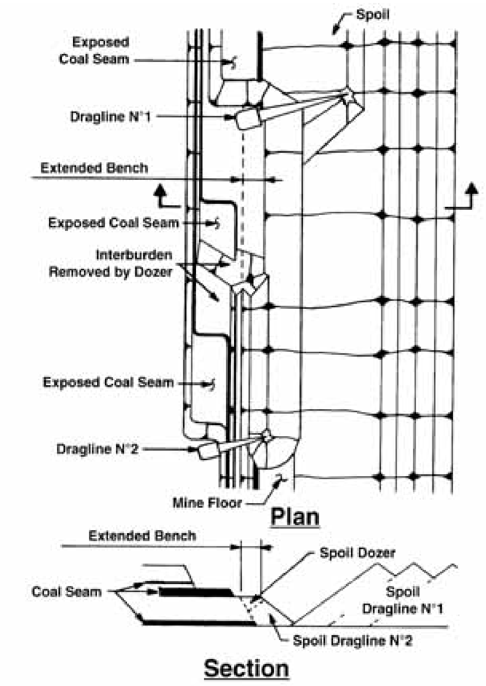


Figure 4.14 Two dragline extended bench for three coal seams

Selective placement of explosives and blasting agents may be critical to the surface coal mine operation. Many coal seams are overlain with sedimentary beds of varying hardness and thickness. Improper placement of the charge in the blasthole can cause blast energy to travel along planes of greater weakness and through softer material. Under such conditions, harder beds of material will tend to break in large blocks or fragments. To ensure adequate placement of the blast charge, it is necessary that drill operators log differences in material or drill penetration rates and provide this information to the blasting foreman.

For dragline stripping, there are two general methods of blasting overburden in common use. One method utilizes a blasthole pattern with a buffer zone to contain the blasted material against the highwall. Figure 4.15 illustrates this pattern. The advantage of this pattern is to contain the blasted material within the dragline working area and avoid large broken material that must be handled with difficulty.

The width of the buffer zone, combined with the powder factor, are critical elements in efficient utilization of this method. This method is useful, especially if the dragline is performing a chop cut prior to the key and production cuts.

The other method of blasting overburden is similar to the standard open pit blasting procedure. Its purpose is to blast as much material into the spoil area as possible, thereby reducing the amount that must be stripped by the dragline. The resultant advantage is debatable in the author's opinion, since considerable grading is necessary before the dragline can begin casting. Frequently the dragline is called upon to rebuild its working pad by retrieving material from the pit. Time lost in pad preparation may completely offset the original reduction in stripping volume. If the dragline can safely work on the spoil side of the pit, building its working pad ahead on the spoil, there may be justification for blasting material from highwall to the spoil. Increased costs of explosives, pad building costs, and highwall scaling delays must be weighed against the difference in overburden volume to be stripped. Figure 4.16 illustrates this blasting method with the dragline working from the highwall side.

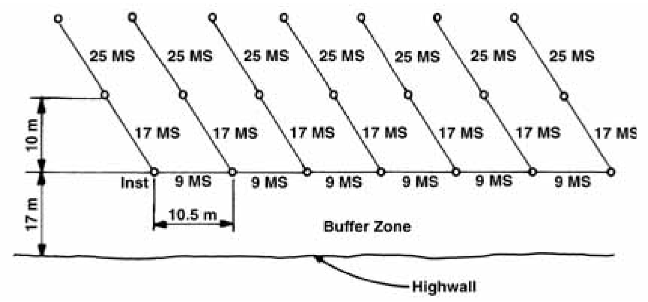


Figure 4.15 Blasting pattern to provide maximum fragmentation with a buffer zone (Anon., 1981).

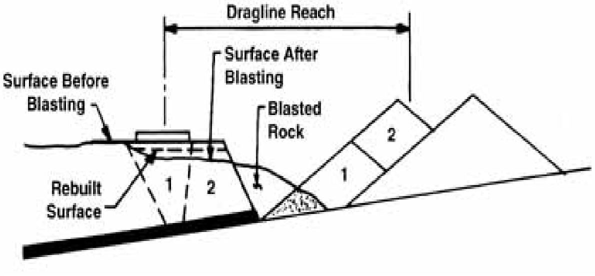


Figure 4.16 Blasting burden into pit. (Note small area of muck requiring no dragline handling.)

Drilling and blasting techniques are covered more thoroughly in another section.

4.2.2. Stripping Shovel System

Stripping shovels fitted with long booms and long dipper sticks remove overburden from coal while sitting on the top of coal. Stripping shovels up to 138 m^3 (180 cu yd) have been used for overburden removal in the midwest. Interest in stripping shovels has waned in the past decade because of their limited operating depth and relatively higher operating cost than the newer, longer boom, draglines. Where currently in use, stripping shovels are limited to relatively flat-lying seams and shallow burden. Because of their large crawlers, it is difficult to change their working bench level to follow undulating or pitching coal seams. As burden depths have increased, the mine engineer has been required to utilize auxiliary stripping equipment to remove near surface material in order to keep the stripping shovel working (Figure 4.17).

The pit configuration for a stripping shovel is similar to the basic dragline pit. The major parameters controlling its operation are the operating and dumping radii and dumping height.

The new, larger draglines with long boom and large bucket capacity have tended to render the stripping shovel obsolete.

4.2.3. Bucket Wheel Excavator Systems

Given suitable geologic conditions, the bucket wheel excavator (BWE) can compete with dragline and shovel/truck systems. The BWE, a continuous mining system with high productivity, can be used as a primary or secondary excavator and is adaptable to all hauling and materials handling systems (Figure 4.18).

BWEs vary in size from an approximate theoretical output of 200 to 20,000 m^3/h (262 to 706,300 cu yd per hr). The larger BWEs have been used extensively in German and Australian brown coals. The smaller BWEs have found wide acceptance in many East European countries, but only sporadically in the US and other parts of the world where their size is proportionate to material thickness or production requirements. The BWE generally is limited to excavating material having a cutting resistance less than 70 kg/cm (4,700 lb per ft).

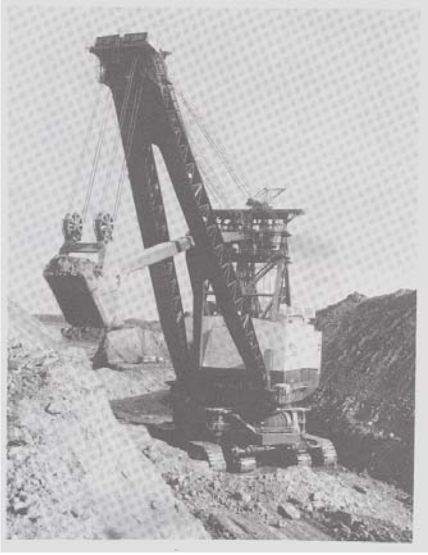


Figure 4.17 Stripping shovel

Figure 4.18 Bucket wheel excavator

The methods of BWE operation are described according to the position of the BWE when excavating the face: **frontal** or **face mining**, **full block mining**, and **half block mining**. In each method, there are two alternative cutting techniques: horizontal, termed **terrace cutting**, and vertical, termed **drop cutting**. Each operational method and cutting technique has specific uses and affects mine design differently.

The frontal or face mining method is especially useful in separating soil or sublayers requiring special placement in the backfill. In this method, the BWE moves along the face using either the terrace or drop-cut technique of slicing. For handling soil or sublayers, terrace cutting is preferable. The face mining method does not require a slewable boom, but does require a long boom crowd. Face mining may be desirable if stable bench slopes can be maintained and if material is cast directly to the spoil side of the pit. Figure 4.19 illustrates face mining with direct overcast.

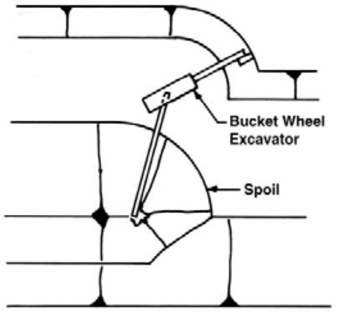


Figure 4.19 BWE face mining with direct overcast

Full block mining is the most common method utilized for removal of large, thick deposits of loosely to semiconsolidated material. The BWE continuously slews across the face block while the boom is crowded into the face. Terrace cutting the block is more common than drop cutting. If the boom cannot be extended (crowded), the depth of the terrace cut will be limited by the distance the BWE can advance. Use of crowdless machines must take into consideration the soil-bearing characteristics over which the machines must travel. Also, their crawlers are subjected to more mechanical wear and tear. Full block mining with shiftable bench conveyor is illustrated in Fig. 4.20.

Face block mining is particularly useful when it is desirable to remove extensive layers of overburden by terracing. The BWE, traveling parallel to the face, continuously slews across the face block in making the terrace cut. This method requires machines with long bucket wheel booms. Face block mining is especially useful in the selective excavation of topsoil or toxic layers requiring preferential placement. Figure 4.21 illustrates the face block mining method.

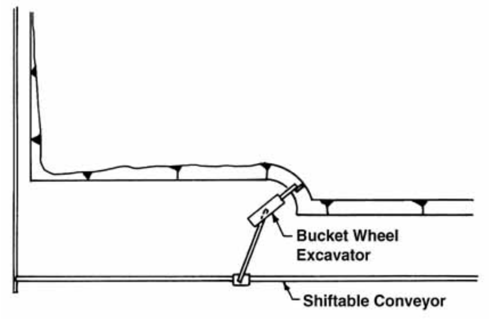


Figure 4.20 BWE full block mining technique.

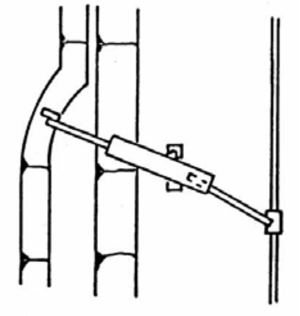


Figure 4.21 BWE face block mining technique

Material removed by a BWE is overcast directly onto the spoil pile, transferred to large haul units, or to belt conveyors that transport material around the pit to the spoil.

A typical BWE mining system utilizing conveyors to transfer material to the spoil side of the pit will consist of several equipment units that comprise the system. These units may consist of:

BWE excavates in situ material and discharges it either directly into the traveling hopper on the face conveyor or into the load hopper of a band wagon or belt wagon.

Band wagon or **MTC** (mobile transfer conveyor) receives material from a BWE and discharges it into the traveling hopper on the face conveyor. Its primary function is to add horizontal and vertical range to the digging capabilities of the BWE, thus limiting the frequency of face conveyor moves.

Belt wagon is similar to a band wagon, but has a longer discharge boom and is also used as a stacker.

4.2.4. Coal Removal Methods

Conditions encountered in coal removal vary as much as in overburden removal. Coal removal must be matched to overburden removal in order to maintain a properly balanced production cycle. Since the stripping cycle generally is more cost sensitive than the coal loading and hauling cycle, coal loaders and coal haul fleets generally are oversized to actual production requirements to ensure sufficient capacity to recover coal production lost by nonrelated stripping delays.

Coal loading from seams in narrow pits requires loaders with large operating reach and/or dumping height. Loading in narrow pits generally begins with the haul truck located on the top of coal and the loader in the pit bottom. The loading sequence ends with both units on the pit bottom. Figure

4.22 illustrates a shovel with extended boom loading trucks in this manner. In unusual cases of bad pit bottom conditions, all coal removal may take place from the top of coal.

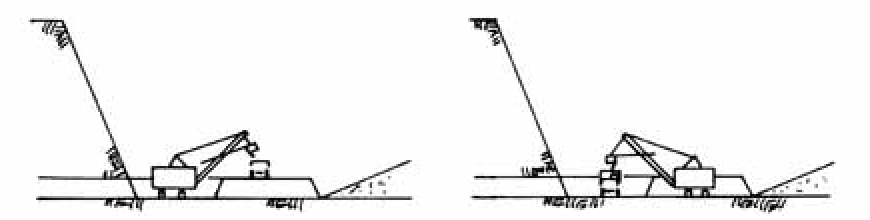


Figure 4.22 **Coal loading sequence in narrow pits**

For normal loading operations, the engineer has the option of cable or hydraulic shovels or front end loaders. When pit bottom conditions are unsuitable, backhoes may be used for loading from top of coal. Scrapers also may be used for loading and hauling. In recent years, a new type of coal loading machine has been tested and, under specific conditions, has been found to perform satisfactorily.

Parameters affecting the coal loading elements of mine design are similar to those affecting overburden removal. Thickness and stability of coal seams, presence of removable partings, and stability of bench or pit bottom must be considered when making equipment selections. Selected equipment will have specific mechanical parameters such as operating radius and dumping height. Operating parameters such as production rate and equipment productivity will affect equipment selection and pit design. Generally, several iterations of analysis of selected mechanical and operational parameters are required in order to develop a mine design compatible to both overburden removal and coal loading/hauling operations.

Each coal loader and hauler has different advantages. Of particular importance is the need to minimize the production of coal fines during the loading and hauling process. Coal loading equipment frequently is used to remove coal partings. The parting is either directly casted off coal or loaded into end-dump trucks for disposal in mined-out pit areas.

4.2.5. Block Area/Dozer-Scraper Method

The block area method uses construction-type equipment and was first conceived in the mid 70's as an alternative to the dragline method. Because the dragline equipment was so difficult to procure, the dozer/scraper method began to take hold. This method takes advantage of the scrapper's ability to move material over a short distances at low costs and the scrapper's ability to elevate material overstep grades for short distances at reasonable costs.

4.3. Quarrying

Quarrying denotes a method designed for dimensional-stone production, typically granite, marble, sandstone, and block limestone etc. Geometrically, the quarries are similar to open pit mines, but usually have lower bench height and nearly vertical slope (Figure 4.23). The overall pit wall may appear to be high (in special cases can be up to 300m). The term quarry we are using for crushed industry minerals mining is simply a mis-concept of quarrying to open pit operations, because these “quarries” are in any ways open-pit operations for nonmetallic minerals. The quarry operation is a very simple operation system, which involves lots of manual work, and therefore the productivity is limited by very limited use of large machinery. Since there is no chemical treatment required for the processing the minerals, the mineral processing plant is quite simple, only for cutting and polishing, and therefore normally located nearby the quarry.

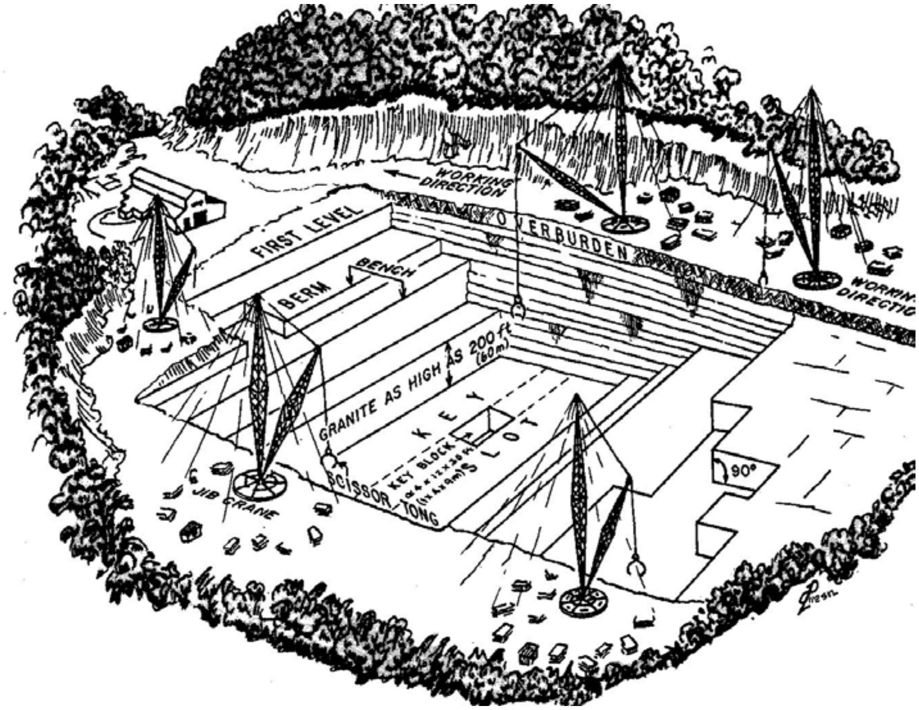


Figure 4.23 Granite quarry operation

In quarrying operation, special attention is paid to the physical natures of the minerals rather than chemical contents. The development is different from the other surface mining methods, which usually follows the process below:

- Development of each level starts from a cut from cutting or channeling a key block which is then extended to a slot
- Nearby processing plant (mainly sawing and polishing)
- Nearby disposal sites
- All the heavy equipment sets are settled at the edge of the quarry

Cycle of operation

- Overburden stripping – similar to the open pit mining, but in some cases the waste materials can be casted on site.
- Stone quarrying
  - Cutting – rotary, chain, or wire-rope saw (for soft stone), flame-jet or water-jet (for hard stone)
  - Wedging – drill and broach; wedge, plug and feathers, or light blasting
  - Excavation/hoisting – crane, derrick, or hoist
- Ore strength – any but preferably well structured

Conditions of the quarrying operation

- Orebody shape -Thick, massive and bedded orebodies, which preferably has large areal extent
- Deposit size – large and thick, uniform
- Ore grade – High physical quality, assay not critical
- Depth – shallow to intermediate

Advantages

- Simple operation with low capital requirement
- Suited for small deposit, low capacity though
- Good accessibility
- Very stable walls, little wall support needed
- High selectivity
- Good health and safety

Disadvantages

- Low productivity
- Limited depth operation (<90m)
- Low capacity
- Skilled-labor intensive, lots of training work needed
- Low flexibility, nearly no quarrying plan change can take place at depth
- Complicated and costly rock breakage because blasting is avoided
- Waste disposal can be difficult

4.4. Aqueous Mining Methods

4.4.1.Placer Mining

Placer mining, also called alluvial mining by the British, is an aqueous extraction method intended for recovery of heavy minerals from placer deposits using water to excavate and transport the mineral.

Placer deposits consist of some valuable mineral that accumulates in weathered rock or overburden (**eluvial placers**), in stream sediments (**alluvial placers**), or in beach deposits (**beach placers**) as a result of natural weathering and erosion processes. **Glacial till and moraine placers** are poorly sorted until subjected to stream action. **Residual placers** are mineralized rock weathered and in place principally through chemical change. **Stream or fluvial placers** are formed by running water that carries the lighter materials away faster than the heavier minerals, thus concentrating them. Historically, fluvial placers have been the most important.

The higher specific gravity minerals concentrate under placer- forming conditions. The process creates minerals that are tough and chemically inert. Typical minerals recovered by placer mining are gold, platinum, tin, diamond, titaniferous and ferrous iron sands and gemstones.

Hand mining

Panning is the earliest mining and recovery method. The material is scooped into a pan and covered with water. The pan is shaken to get the heavier materials to settle towards the bottom. The pan is swirled to allow the lighter materials to flow out of the pan with the swirling water. The heavier materials are saved by hand picking.

Another simplistic method is the **ground sluice**. This setup is a series of boards set across the flow of water in a channel. Ore is shoveled into the head of the sluice and broken up with the shovel to run down the sluice with the water. The lighter materials are washed away with the current. The heavier materials settle beyond the riffle boards.

The **rocker** is portable and more sophisticated. It is hand rocked tabling device using dippers of water poured over fine-screened particles of ore that are washed and recovered from the bottom.

Suction dredge

Suction dredges are small jet assisted dredges that use gas powered engines to feed floating or shore based sluice box. The miner wades or dives in stream bottoms to pick the recent concentration of heavy materials. Recreational miners generally use this as it is difficult and does not move very much material in a day.

Some gold and gem miners have had success with this method but the dangers for these underwater miners are high.

Drift mining

This method is often used with minerals in relatively thin horizons that precludes excavation from the surface. The zone of concentration may extend into bedrock or on a false bedrock, often clay, or be in an intermediate horizon of gravel. Typically this has been used to mine gold and platinum. This method was largely responsible for the recovery of high grade gold in the Klondike. valued at 250 million. 75% of this was taken in the first ten years by drift miners.

Floating plants

Washing plants mounted on barges are similar to the plants mounted on bucketline dredges but are of lower capacity. If not operated in large bodies of water or a flowing stream (and it is rarely legal to do so), these plants require ancillary water supplies and finely suspended solids- removal capability.

Until the advent of dependable backhoe excavators, dragline excavators were most commonly used to feed floating washing plants. Where the the material to be mined is not suited to a backhoe, the draglines are still used. The dragline method does not have the control or power that backhoe buckets do. The floating plant must be designed to coordinate with the excavator. The excavator must be able to elevate its bucket high enough to dump cleanly into the washing plant's hopper. Backhoes used with washing plants are usually limited to a shallower digging depth than their maximum in order to clean up bedrock over a reasonable working radius.

Bucketline dredges are capable of continuous excavation with mineral separation plants aboard, are very y efficient mining machines. they mine ore, process it, and discard tailing to waste in continuous stream. The process of dredge mining suffers from the in ability to stockpile material during malfunction of any piece of machinery in that sequence. As a result, a mineral dredge must be overdesigned in comparison with other mining plants, but there are almost none of the transportation problems of other mining methods. Ore flows from the mine face to the tailings area in an unbroken stream. On a bucketline dredge, the stream often moves through the system under the force of gravity once it was dumped from the buckets. Bucketline dredges are capable of high excavation rates in the hardest alluvial ground dredgeable because they are capable of transmitting to the mine face the greatest amount of digging force of any kind of dredge.

Hydraulic mining-Hydraulic mining uses energy in a fluid to do work and represents a practical application of Bernoulli's equation.

Hydraulicking- The process of breaking up and suspending the subject matter into a slurry is hydraulicking. This is done by using energy in a stream of water, and reducing the material to a slurry (Figure 4.24).

Sluicing

The process of moving the slurry is called sluicing (Figure 4.25). The slurry may proceed by gravity alone for several miles or require frequent or even continuous water/energy addition to move mere yards. Most mining operations use the hydraulicking monitor for sluicing. The movement of the slurry is affected by the unfavorable gradients and low energy water. The sluicing path should be short as possible, and water addition and pond formation should be minimized.

Figure 4.24 Hydraulicking

Figure 4.25 Sluicing

Educing

This is the lifting or pumping of slurry from its sluicing delivery point into a contained or enclosed circuit. Hydraulic mining is possible without educing but normally employs pumps, less frequently eductors (water-jet pumps) and rarely hydraulic elevators. These devices have physical constraints that limit the maximum particle sizes they can handle. This usually means they will need screening apparatus.

4.4.2.Solution Mining

Since 1922 solution mining method has been tested and applied for certain types of mineral production. At the beginning, the mining method was limited to mine the evaporates, soluble minerals, such as salt, sulfur. Later, the application of the method was extend to the extraction of metallic minerals, such as copper. Now this method has been used for producing a significant percentage of the total silver and uranium as well as gold production.

Two major categories of solution mining method can be observed, the borehole mining and leaching.

Borehole Mining

In borehole mining, water is injected by wells into a mineral formation where it dissolves, melts, or slurries the valuable minerals and is the returned to the surface through **wellbores**. Sometimes reagent or solvent is added to the water, and an aqueous solution is injected into the underground formation. The following minerals are suitable for the application of borehole mining:

- Soluble minerals, such as salt, potash, and trona - By dissolution
- Dissolvable minerals
  - sulfur – by melting
  - Phosphate, kaolin, oil sand, coal, gilsonite and unranium – by slurring
- Leachable minerals, such as uranium and lignite, gold – by chemical leaching

This method has its unique advantages such as low mining and development costs, high productivity and continuous operation, etc., but the application can only be limited the minerals that may dissolve, melt or slurry in water, and the disadvantages can be quite significant, such as low selectivity, high dilution, low recovery, and potential environmental hazard.

Leaching

Leaching can be mined ore **heap leaching** or **in-situ leaching**. It is a chemical extraction method. The process of mineral production is basically chemical but sometimes may be bacteriological as well. The chemicals used for leaching are distributed by spraying system to the ore. After a certain period waiting for the chemical leaching process to finish, the valuable minerals are dissolved and carried by the solution which is termed pregnant solution, which is in turn pumped to the processing plant for further treatment.

In-situ Leaching - If the extraction is carried out on mineral in place, then it is called in-situ leaching. Technically, In-situ leaching requires, the ore deposit be located in a water-saturated zone and be confined both above and below impervious layers. Environmentally, it requires the leaching operation causes no groundwater contamination.

Heap leaching - If, for any technical or environmental restriction reasons, in-situ leaching is not feasible, heap leaching may be applied. The ore has to be moved to a place where a leaching pad is built, on which the ore is piled or heaped. And the leach operation takes place on the heaped materials.

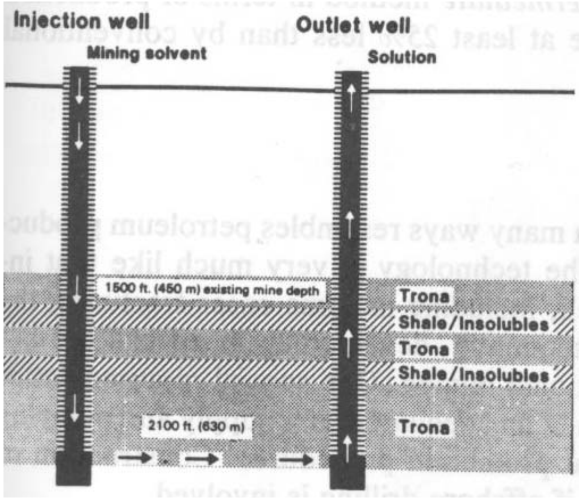


Figure 4.26 Borehole mining

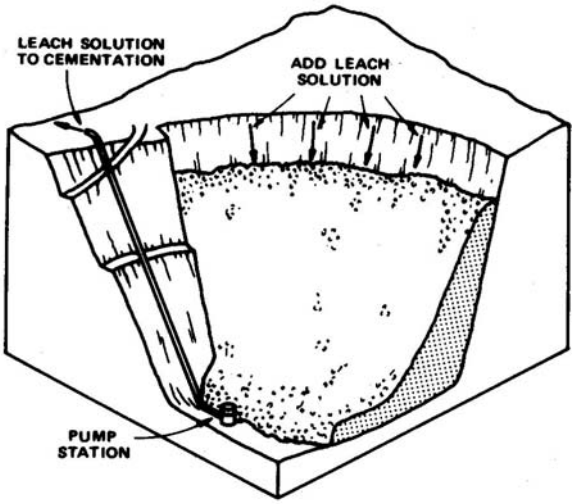


Figure 4.27 In-situ leaching

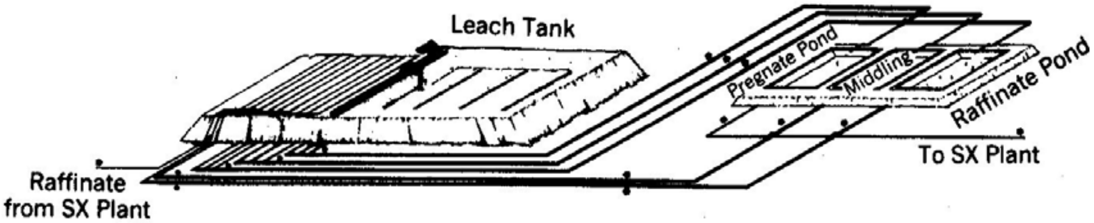


Figure 4.28 Heap leaching

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5. UNDERGROUND MINING[2]

Systematic Approach to Design

The variety of ore deposits encountered in practice makes it difficult to define a perfectly valid classification system for problem analysis associated with the planning and design of a new underground mining program. However, a basic distinction can be made between ore recovery by stoping (excavative type mining) versus solution mining (in-situ type mining). Nearly all the ore being mined currently is obtained from stoping and this review is limited to an analysis of the application of alternative stoping methods.

Geometry of the ore deposit, strength of the ore and surrounding rock and economics are the fundamental parameters influencing the planning and design process. Considering geometry, the dip, size and shape of the ore body have a major bearing on design. Thus, a distinction can be made between orebodies which have significant vertical dimensions (essentially three dimensional mining) and those which are small in one dimension and are either steeply or shallow dipping (less than 45°). Orebodies which have significant vertical dimensions are accessed through drifts developed at successive depths and connected vertically (Figures 5.1, 5.2). Gravity is used to advantage in rock breaking and ore handling operations to direct broken ore to convenient collection points. On the other hand, ore is removed from moderately dipping orebodies by mechanical means and may be transported considerable distances laterally to collection points. Men and equipment often work inside the excavation when the orebody is thin and a prime consideration under these circumstances is the design to ensure a safe working environment by providing protection from falling rock as the mining face is advanced. However, when the orebody is large in all dimensions, men and equipment usually operate in drifts of small dimensions, outside of or remote from the main excavation.

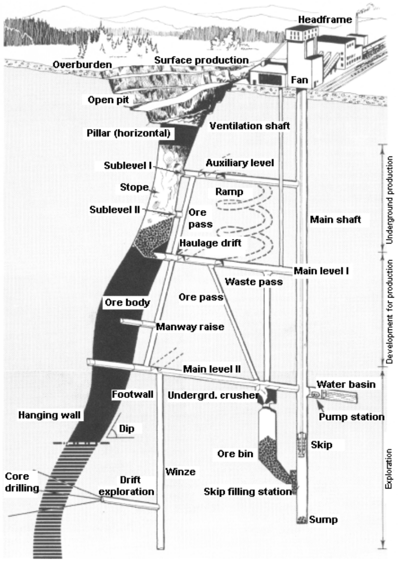

Figure 5.1 Underground mining – concept and terminologies

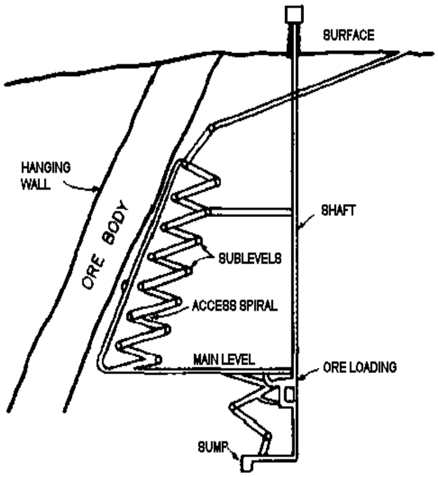

Figure 5.2 Access arrangement to orebodies of significant vertical dimensions

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[2] This section is prepared on the basis of Part 9 of the online EduMine course notes "Underground Mining Practice", Kenneth E. Mathews for professional development section of InfoMine. Most of the figures used in this section are from the InfoMine website.

The basis for classification of stoping methods is the strength of ore and surrounding rock. This takes into account geological conditions, structural features, physical and mechanical properties of the ore and surrounding rock, etc. All this information is used as input for the design of excavations and the sequencing of mining operations. These activities are part of the science of rock mechanics.

Economics are all important and the type, grade, size and location of the deposits are considerations in this regard. Mining methods used for the extraction of low grade orebodies cannot be selective for economic reasons, hence dilution of ore and incomplete recovery of the deposit are factors that must be taken into account in the design process. Also, the larger the deposit, the greater the economies resulting from large scale operations, therefore it is important that low grade deposits be extensive. On the other hand, high grade deposits may be fully extracted using costlier, close support techniques.

Basically, the design and selection of a mining system is a process of optimization and unfortunately, each deposit must be considered on its own merits because of the many parameters involved. The key to success is a systematic approach to problem-solving and design.

Caving vs. Non-Caving Methods of Mining

The basic classification of mining methods devised by the U.S. Bureau of Mines in 1936 is still valid. The names are the same, but techniques and relative importance have altered and some additions must be made. This classification is based on a transition from strong rocks and ore to weak rocks and ore. These are still major factors in a choice of mining method and the classification is summarized below (Thomas (1973)) .

- Stopes naturally supported
- Stopes artificially supported
- Caved stopes
- Combination of supported and caved stopes (naturally supported stopes followed with pillar caving).

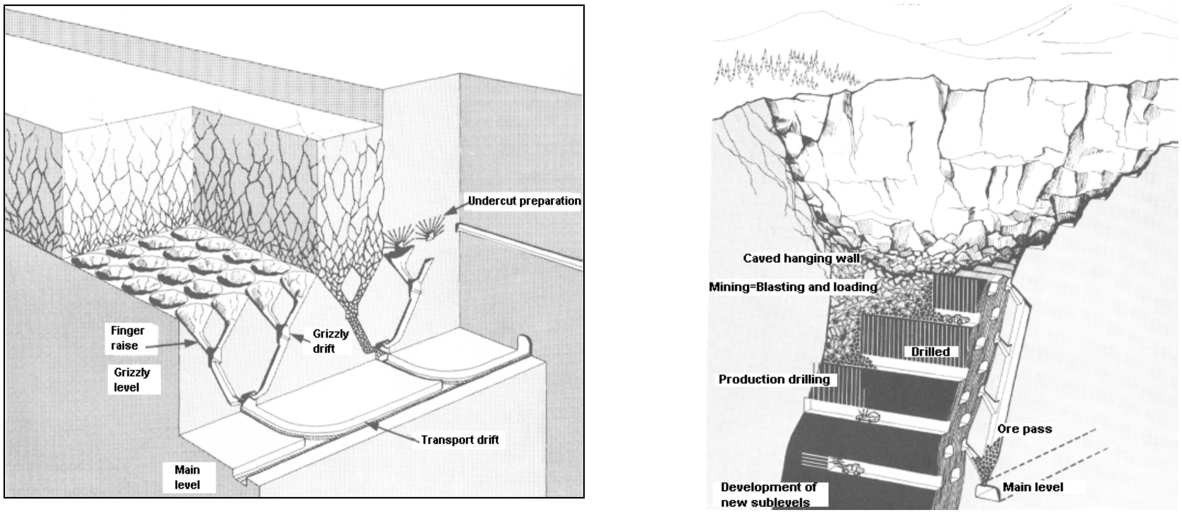
The development of continuous, mechanized mining systems, using artificial support where necessary for ground control has made many of the old, labor-intensive mining methods obsolete. As a result, it is considered that mining systems can now be generally classified as either caving or non-caving . In this context, caving is defined as the application of a mining method(s) designed for progressive extraction of the ore, leading to the collapse, and caving of the ground above the workings. The direction of mining retreat is towards the permanent access openings and downdip when caving methods are used. All stope and adjacent block development is lost as mining progresses. The application of caving methods usually results in surface subsidence, the extent of which depends mainly on the height and lateral extent of the workings. Examples of caving are longwall caving of bedded deposits, block caving and sublevel caving.

Non-caving mining systems rely on the use of rock pillars and/or artificial support such as cemented fill to limit ground movement to the vicinity of the excavations. Development openings adjacent to and remote from the mining areas can be regarded as permanent. Typical examples of non-caving mining methods are sublevel open-stoping, room-and-pillar stoping and cut-and-fill stoping.

Considering the over-all design of an underground mine, the first decision that must be made is whether or not a caving system of mining will be used. Accordingly, sufficient information should be obtained to permit a realistic decision before major development plans for access to the orebody are finalized.

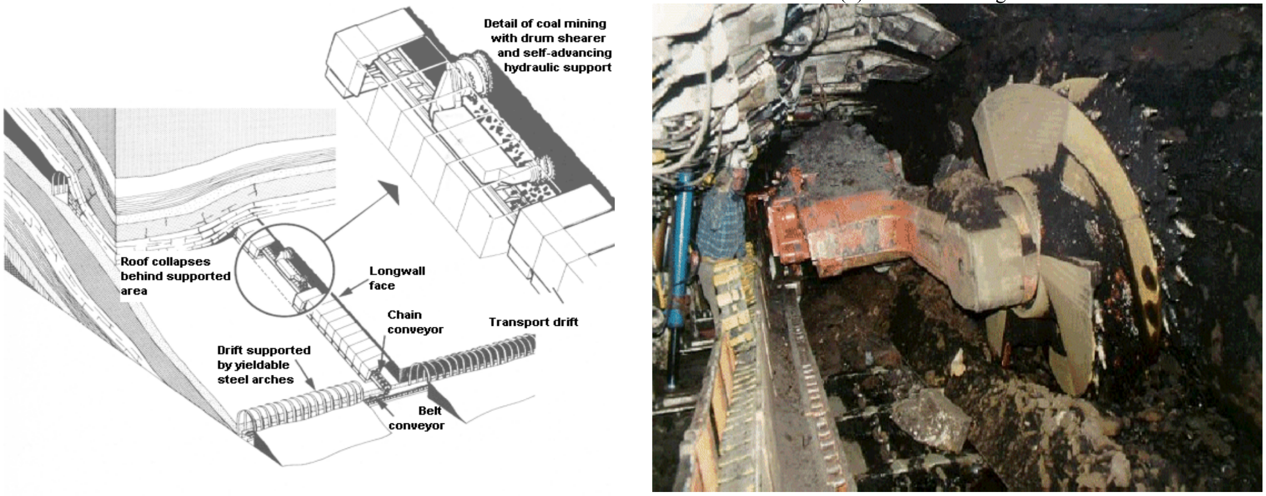
5.1. Caving Mining Methods

Top slicing is a labor intensive caving method and as a result is now virtually obsolete. The basic variations of the caving methods currently applied are block caving, sublevel caving and longwall caving (Figure 5.3 (a) (b) (c) and (d)). Block caving is a low cost, bulk mining method of major importance and effort is currently being directed towards increasing the mechanization of ore extraction and ore handling operations to reduce labour. The application of sublevel caving increased dramatically throughout the world when layouts using slushers for ore extraction were replaced with layouts designed for rubber tired front-end loading equipment. Longwall caving is an elegant mining method used for the extraction of comparatively thin, shallow dipping seams. The method is amenable to mechanization and automation and applications will continue to increase. Currently, the most highly developed variations of longwall caving are used to mine coal.



(a) Block caving method

(b) Sublevel caving method



(c). Longwall caving (coal)

(d) Longwall mining in coal - drum-shearer in operation

Figure 5.3 Different caving methods

5.1.1. Block Caving

Initially, a horizontal slit-like opening called an undercut is excavated beneath the block of ore to be caved. The undercut is then increased in area until the ore caves or collapses. The caved ore should break into fragments small enough to permit efficient extraction through inverted cone shaped openings developed beneath the undercut. Ore extraction continues until the ore is diluted by waste capping to economic limits (cut-off grade), (Figure 5.4).

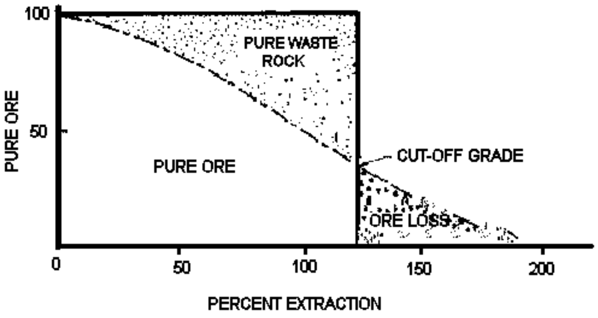


Figure 5.4 **Diagram indicating dilution and ore loss**

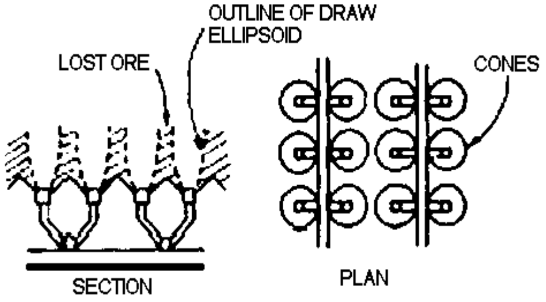


Figure 5.5 Pre loss when draw points too widely spaced

Block caving is best suited to fairly massive orebodies in which the mineral values are well disseminated. Additional features that are necessary include well developed sets of fractures (3-5 sets), within the orebody that have not been recemented and a capping material that is weak enough to cave along with the ore (Julin (1975)). The intensity of fracturing is therefore a critical parameter to be analysed. Ideally, three of the fracture sets should be mutually perpendicular and the blocks formed should not exceed 5 ft in dimensions at the drawpoint to ensure efficient extraction. Spacing of the drawpoints and cones is influenced by the expected size distribution of the ore. The finer the ore, the closer the spacing to reduce dilution and vice-versa (Julin (1975)), (Figure 5.5). Also, dilution is a function of the height of the ore column drawn and increases with the height.

Ideally, the entire area above the undercut should subside uniformly towards the surface (Figure 5.6) and the rate of progress of the cave can be estimated if the swell factor is known (Swell factor is defined as the ratio of the density of unbroken rock to the density of the caved rock.) However, rock has a natural tendency to arch (Figure 5.7) and all the factors that tend to increase the possibility of arching in both the ore and capping should be thoroughly investigated at the feasibility study stage.

Arching results in increased loads on supported extraction openings beneath the undercut, particularly on openings adjacent to the boundary of the undercut. Arching in ore can be controlled by developing vertical boundary slits on one or two sides of the block. However, when an arch develops in the capping, it can be difficult to bring down. Sometimes the arch must be broken from access openings developed in abutments (Figure 5.8), and this can be a difficult and costly operation. Therefore, monitoring systems should be installed which measure the progress of the cave front and the cave void above the broken waste to permit early corrective action. Funnelling, which leads to dilution of the ore may occur if the capping material is weaker than the ore (Figure 5.9).

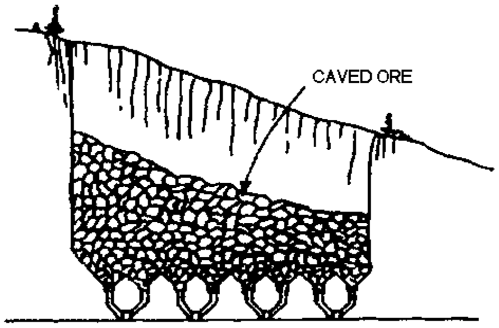


Figure 5.6 Good caving and uniform subsidence

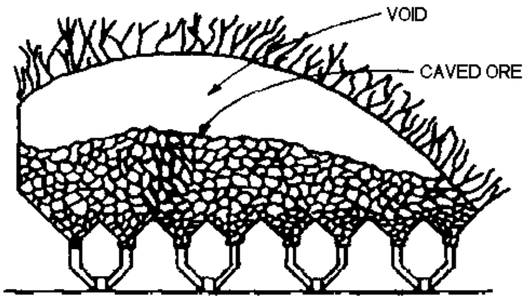


Figure 5.7 Undesirable stable arching

Orebodies of major vertical extent are mined by developing undercuts at successive depths, spaced at 200-300 ft intervals vertically. The maximum depth mined is usually governed by the cost and difficulties encountered in supporting extraction openings and controlling convergence. Loads on openings beneath the undercut are a minimum when the cave has broken through to the surface. Therefore, orebodies close to the surface can usually be mined more cheaply than deep-seated orebodies, assuming similar rock conditions.

All access openings and the like must be located outside the boundary of gross rock movement (Figure 5.10). The actual distance will depend on the type of installation or structure and whether it is located on the surface or underground.

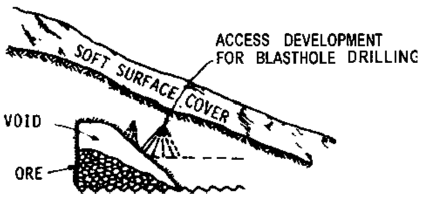


Figure 5.8 Development and drilling to induce caving

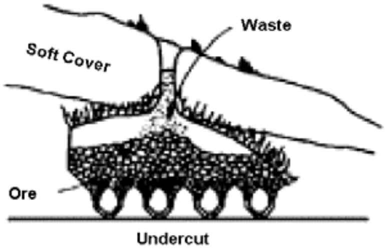


Figure 5.9 Arching with funneling

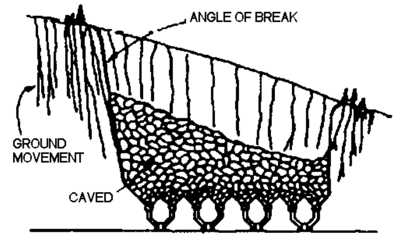


Figure 5.10 Typical Subsidence and Tension Cracks

5.1.2. Sublevel Caving

Initially an undercut is developed in ore at the top of the ore body until caving of the overlying waste capping commences. Mining then proceeds downwards, sublevel by sublevel, the ore being broken by drill-and-blast techniques and extracted slice by slice under and alongside caved waste material (Figure 5.11). Hence, ore may be comparatively strong and not very fractured, but the waste capping must be weak and behave similarly to the capping above a block cave. Therefore it is important to assess the caveability of the capping. Ideally, the ore broken by drill-and-blast techniques should be finer than the caved waste to reduce dilution.

Sublevel caving is used to extract moderately to steeply dipping orebodies greater than 20 ft wide and surrounded by a weak to moderately weak rock. Access to the sublevels is gained from the footwall and a typical layout is given in Figure 5.12. Up to 25% of the orebody is extracted in the development openings and ideally the ore should be comparatively strong to reduce the cost of ground support, which can have a significant effect on economics. Broken ore is extracted from the retreating production headings using rubber tired front-end loaders.

The geometry of the caving zone changes as mining advances. The initial horizontal slit-like opening tends towards a vertical slit as mining progresses downwards and the horizontal stresses on the working sublevels gradually increase. The design of the layout of a sublevel caving system is basically a problem in solid geometry. A large number of dimensions have to be determined, each of which is dependent on the other. Selection of these dimensions in a fixed order is one means of simplifying the design procedure. A suggested order is, a) extraction heading width, b) sublevel interval, c) height of draw, d) extraction heading spacing, e) extraction heading height, f) ring gradient and ring burden (Just (1972)).

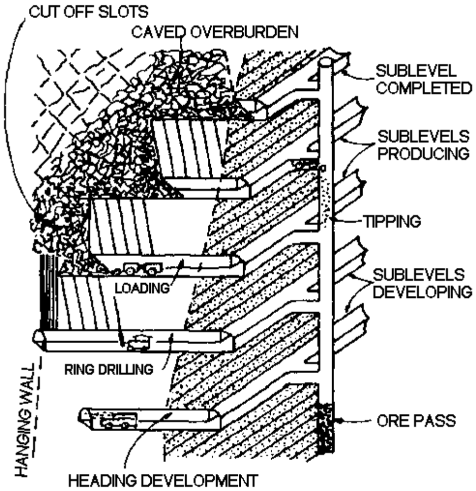


Figure 5.11 Vertical cross-section of sublevel caving scheme

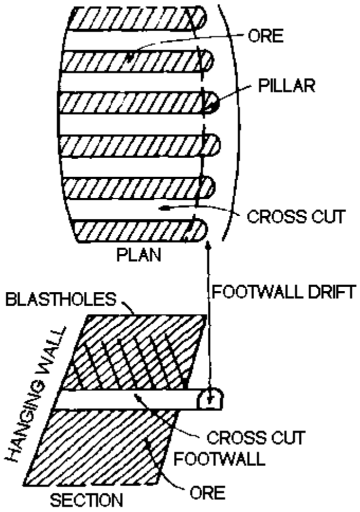


Figure 5.12 Sublevel caving layout

Extraction Heading Width

Dilution is reduced as the width of the extraction heading increases, but support costs also increase, therefore a compromise must be made depending on the strength of the rock. Extraction heading widths vary from 9 to 18 ft and the larger widths are preferred to accommodate the largest possible mechanized equipment.

Sublevel Interval

Selection of the sublevel interval is usually based on blast hole drilling accuracy with respect to drilling the fans of holes for blasting. If the holes deviate excessively at the ends, poor fragmentation results leading to increased dilution (Figure 5.13). Sublevel intervals vary from 25 to 50 ft apart vertically.

Height of Draw

The maximum height of draw depends on the sublevel interval and is less than double the sublevel interval (Figure 5.14). The minimum height depends on:

- the extraction heading width
- the sublevel interval
- eccentricity of the ellipsoid of draw.

The minimum height is twice the sublevel interval minus the height of the extraction heading.

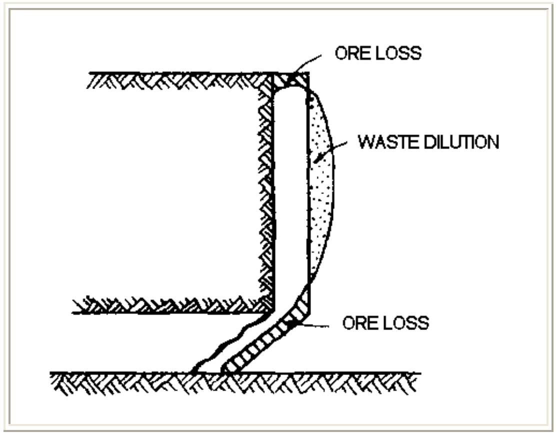


Figure 5.13 Transverse section of draw ellipsoids showing areas of ore losses and waste rock dilution in caving.

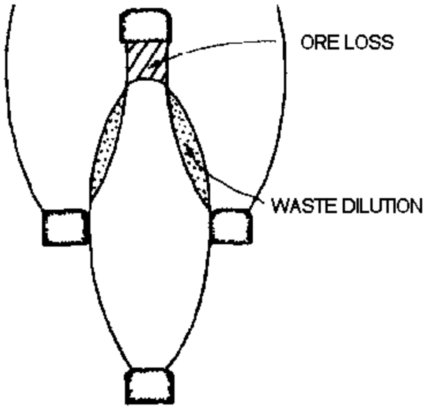


Figure 5.14 Longitudinal section of a draw ellipsoid showing areas of ore loss and waste rock dilution.

Extraction Heading Spacing

The maximum spacing of extraction headings depends on the width of the draw ellipsoid (Figure 5.15). The minimum spacing cannot be less than the extraction heading width, and is usually greater to maintain stability of the intervening pillar, particularly if the ore is weak. Values of spacing range from 2.0 to 3.5 times the extraction heading width.

Extraction Heading Height

The extraction heading height should be a minimum to reduce ore losses due to the drilling of material from the back of the heading (Figure 5.16). The volume of ore lost is related to the ring burden and the heading height.

Ring Gradient and Burden

Ring gradient can vary between 70 and 90 degrees and is usually 90 degrees. Assuming an ellipsoid shape of draw, the ring burden should be equal to the semi-minor axis of the draw ellipsoid to minimize dilution from the previous blast (Figure 5.16). For draw heights of 30 to 60 in in actual operations, ring burdens vary from 4 to 7 ft.

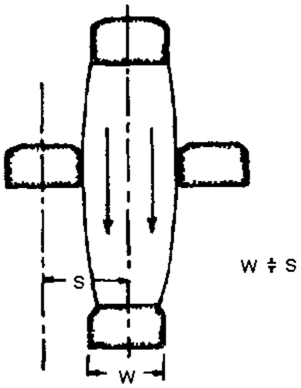


Figure 5.15 Parallel gravity flow occurring when extraction heading width is extremely large.

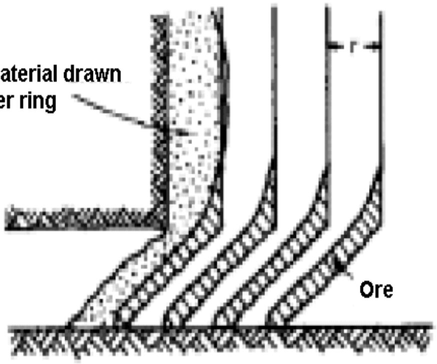


Figure 5.16 Sectional view showing ore pockets remaining in an extraction heading after drawing ceases

The main problems encountered in sublevel caving operations concern:

- Reducing dilution, which can range from 20 to 50%.
- Recovering the ore blasted. Overdraw of up to 20% is usually necessary to obtain a reasonable recovery of the metal.
- Reducing the cost of both ground control and ground support.

Basically, sublevel caving is a sophisticated mining method requiring close engineering control and experienced miners to ensure success.

5.1.3. Longwall Caving

Longwall caving can be likened to a continuously advancing undercut, with the overlying waste rock caving behind the advancing face of the undercut. The method is applicable to the extraction of thin, continuous orebodies of flat to moderate dip. Ideally, the overlying waste rock should be weak enough to collapse close to the advancing face to minimize stress levels in this region. The method is used to mine strong orebodies at great depth (South African gold mines), but has achieved the greatest sophistication with respect to mechanization and automation in the longwall mining of coal deposits (Figure 5.17, 5.18).

The orebody is usually divided into a series of panels having a down dip length ranging to about 600 ft. The panels are often separated by strike pillars to facilitate mining operations (Figure 5.1, 5.17). The face is then advanced towards or away from the access drifts with the ore being broken along the face by drilling and blasting in the case of hard rock or by mechanized and continuous cutting machines in the case of coal mining. Conveyors remove the ore cut along the face and discharge to conveyors installed in the access drives developed on strike (Figure 5.19, 5.20). Powered supports advance the conveyor and cutting machine forward after each sweep of the face.

It is not the purpose of this paper to deal with coal mining practice, but it is worth noting that a major research and development program is underway in South Africa to replace drill and blast techniques used in the hard quartzites of the Witwatersrand gold bearing reefs with fully mechanized cutters, conveyors and powered supports.

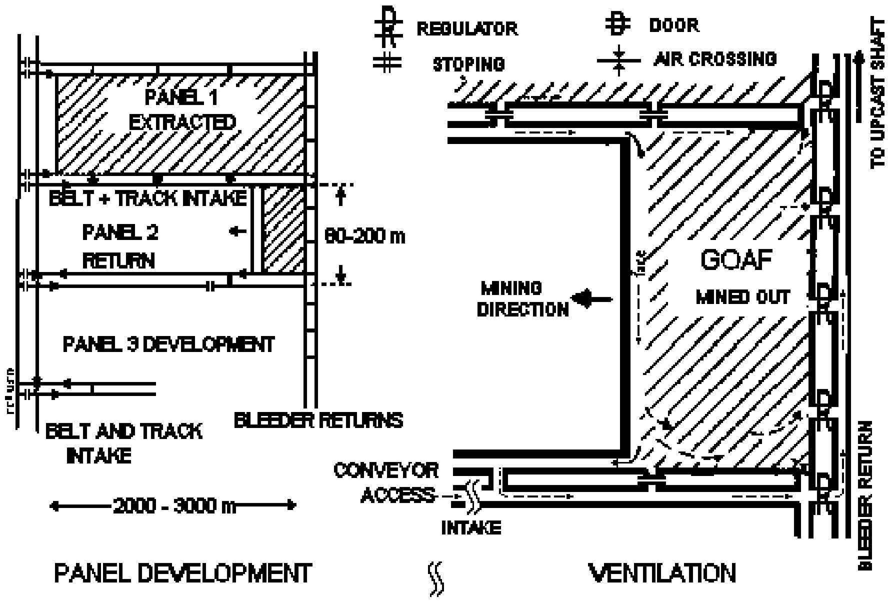


Figure 5.17 Longwall retreating layout caving.

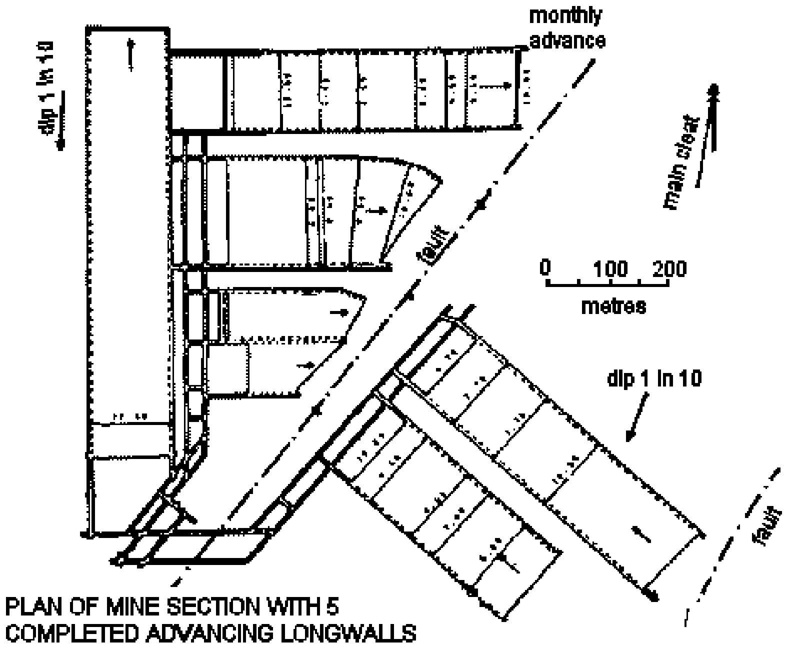


Figure 5.18 Longwall advancing layout.

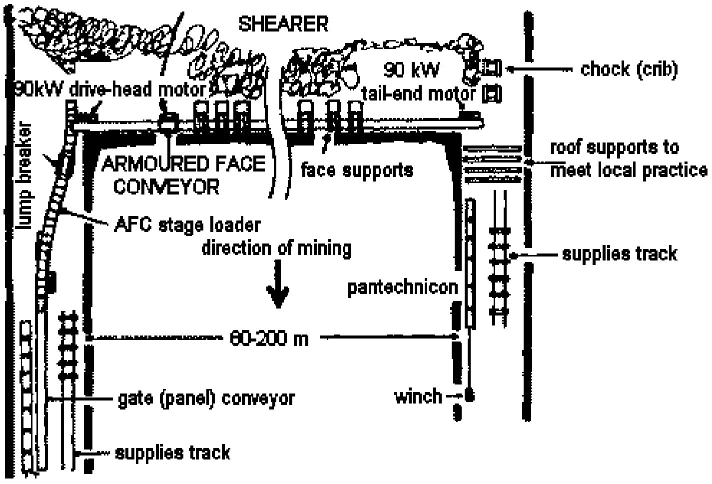
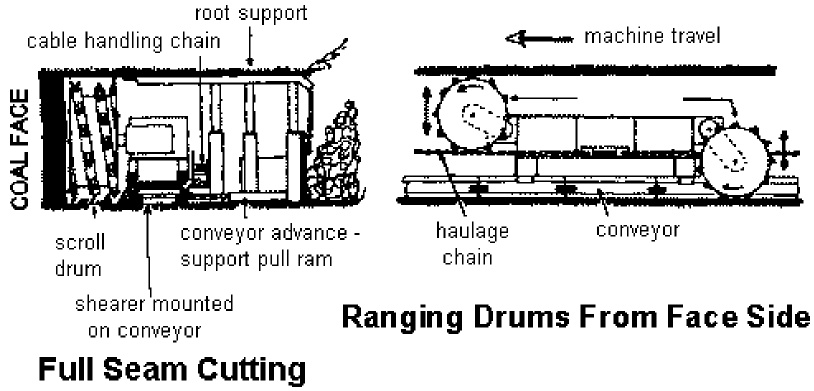


Figure 5.19 Longwall face equipment layout.



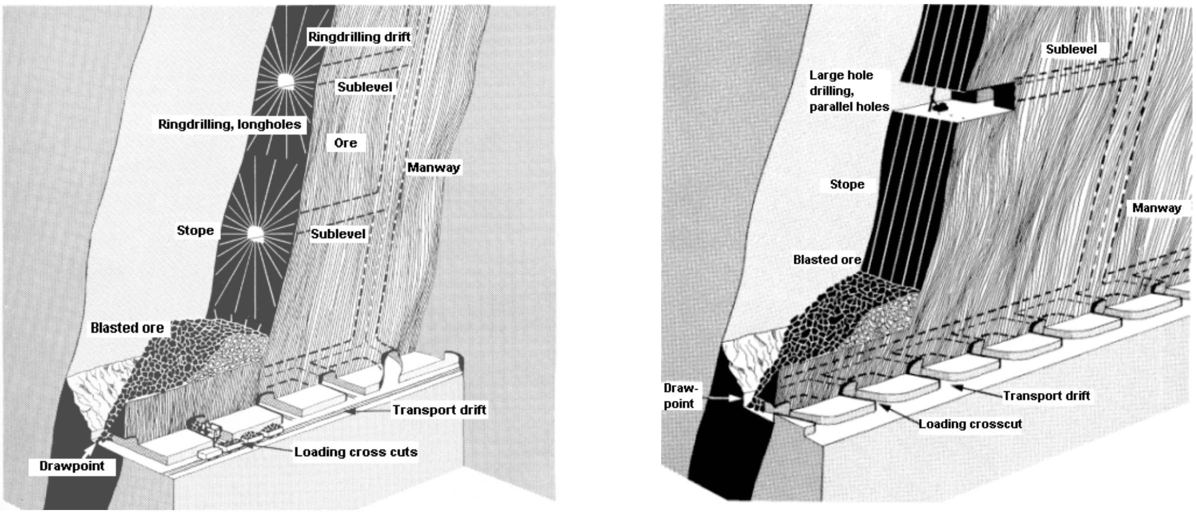
Ranging Drums From Face Side

Full Seam Cutting

Figure 5.20 Longwall shearer loaders.

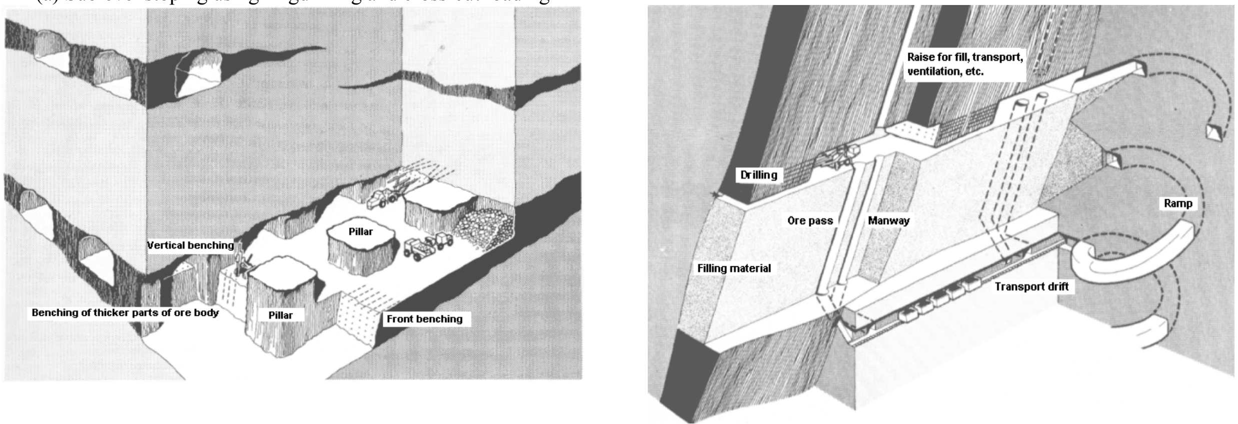
5.2. Non-Caving Mining Methods

Shrink stoping and square-set stoping are labor intensive non-caving mining methods and are now rapidly becoming obsolete. The basic variations of non-caving methods currently applied are sublevel open stoping, room-and-pillar stoping shrinkage stoping and cut-and-fill stoping (Figure5.21 (a)-(e)). Sublevel open stoping in steeply dipping deposits is a comparatively low cost bulk mining method and effort is currently being directed to increasing the mechanization of ore extraction, improving rock breaking practice and applying cemented fills to facilitate recovery of pillar ore in mass blasts. Room-and-pillar stoping operations in shallow dipping deposits are fully mechanized and productivity is very high in orebodies where continuous cutting equipment can be operated. Cut-and-fill stoping has also been mechanized during the last 10-15 years and improved ground support techniques are under development. The application of this mining method will continue to increase. Vertical crater retreat stoping (VCR) is a new technique that becomes more and widely practiced for mining vertical massive orebodies due to its high productivity. (Figure 5.21(f)).



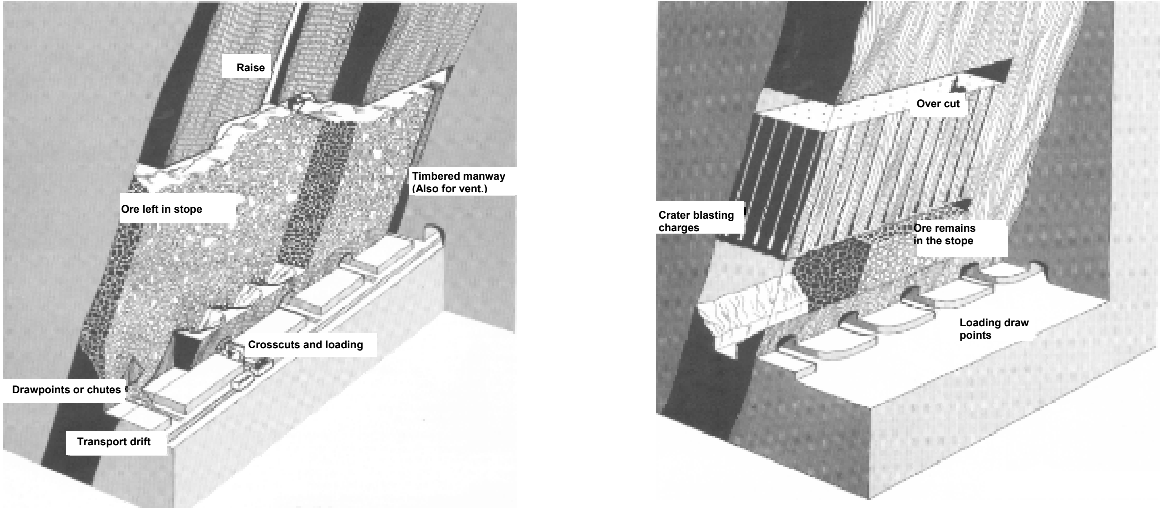
(a) Sublevel stoping using ringdrilling and cross-cut loading

(b) Stoping with large hole blasting and drawpoint loading



(c) Room and pillar mining of an inclined orebody

(d) Cut-and-fill mining with chute loading into rail cars



(e) Shrinkage stoping with cross-cut loading

(f) Vertical retreat stoping with crater blasting and drawpoint loading

Figure 5.21 Non-caving underground mining methods

5.2.1. Open Stoping - Sublevel Open Stoping and Room-and-pillar Stoping

Both sublevel open stoping and room-and-pillar stoping are mining methods designed for progressive extraction of specified ore blocks between pillars of surrounding material (Figure 5.22, 5.23, 5.24).

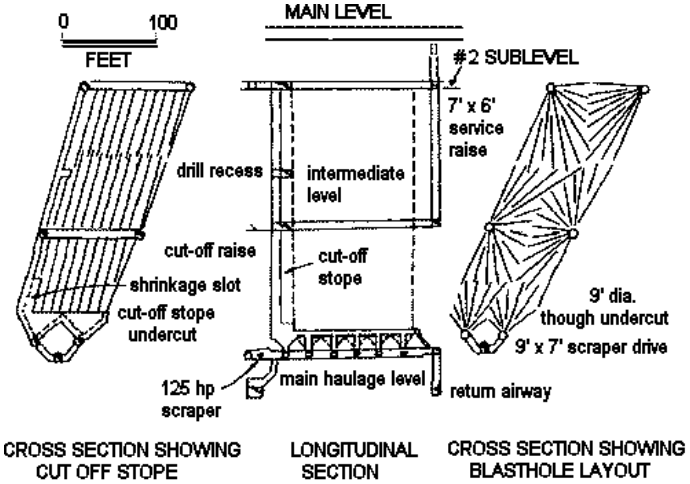


Figure 5.22 Diagrammic Layout of typical sublevel open stope

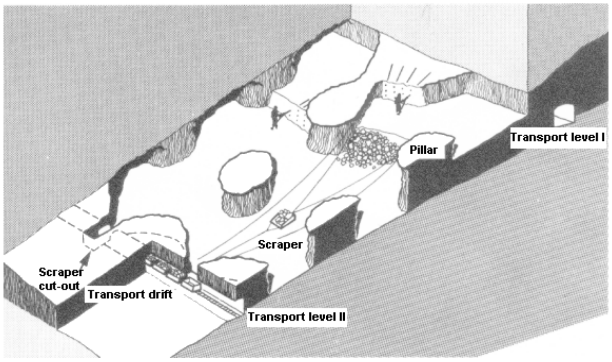


Figure 5.23 General layout of room-and-pillar stoping

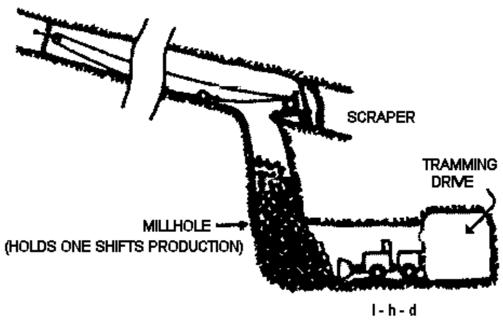


Figure 5.24 Room and pillar stoping: cross section below stope

The basic objective is to mine as much of the deposit as possible at low risk of ground movement in the initial open stopes or rooms without jeopardizing the recovery of adjacent pillar ore, if the latter can be recovered economically. Thus open stoping is often the first stage of an integrated and staged system of total ore recovery. Primary stoping is usually followed by secondary and sometimes tertiary extraction phases to recover pillar ore.

The method is used for the mining of thin-to-wide dipping deposits of medium to high grade within 3,000 ft of the surface (sublevel open stoping) or the mining of thin, shallow dipping tabular deposits (room-and-pillar stoping). The walls and back (roof) of the rooms must be strong enough to ensure that the excavation is stable to permit mining without dilution in the primary extraction phase. The ore should also be comparatively strong to ensure stable pillars. Mining usually advances down dip.

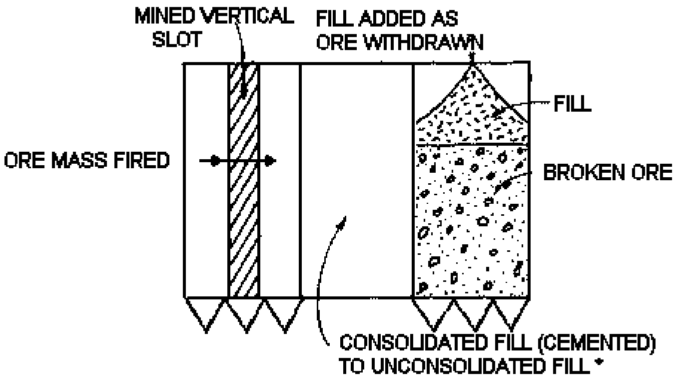
Ore is broken in sublevel open stopes by drilling and blasting and the sublevel interval ranges from 60 to 200 ft depending on the drilling equipment used. However, the trend is to use drilling equipment that permits the maximum sublevel interval consistent with good fragmentation, because the ore is extracted from bin-like excavations through cones and drawpoints. Layouts for ore extraction vary, depending on the equipment used (slushers or front-end loaders), but the trend is to use front-end loaders as this equipment can handle larger fragments of ore. Considering near horizontal deposits, ore is broken in the rooms using drilling and blasting techniques or mechanized cutting equipment in softer ores.

Factors to be considered in the design of an open stoping system of mining include:

- The ratio of primary extraction to total volume of the deposit. This ratio decreases with depth of mining, thus the size of the pillars must increase as the workings deepen to ensure stability. (Pillar volume is normally 50% of the ore reserve at depths approaching 2000 ft beneath the surface.)

- Design of the pillars to facilitate recovery and the ground control measures necessary to ensure recovery of pillars. (Small pillars are not normally recovered because of economic considerations.)
- Control of dilution from the walls and back.
- Accuracy of ore limits to permit realistic design of the excavations and rock breaking system to achieve good fragmentation.

Artificial support (rock bolts, props, etc.) is often required to maintain a stable back in shallow dipping deposits (room-and-pillar stoping), but is rarely necessary in steeply dipping deposits (sublevel open stoping). Caving results when pillar recovery operations are carried out by blasting them into the adjacent open void. When ground movement must be prevented, pillars are sized to ensure the long-term strength necessary to achieve this objective. If minor ground movement can be tolerated, pillars may be designed for short-term strength only and empty stopes immediately filled with waste materials of low cohesion. Recovery of pillars is carried out between filled stopes when ore grade is adequate to justify the higher cost of mining. An example is the complete recovery of pillars between cemented fill walls (Figure 5.25). The role of fill in mining is receiving increasing attention to facilitate ground control. Cohesive and non-cohesive fills are now being used that permit a wide range of options with respect to the design for pillar recovery. Strong cohesive fills are now being placed that permit almost complete extraction of extensive, medium to high grade ore deposits. On the other hand, fills of low cohesive strength can be placed to



* Note: If the ore is low grade, place weak cemented fill and accept some dilution. If the ore is high grade, place strong cemented fill and omit adding fill as broken ore is withdrawn.

Figure 5.25 Integrated open stoping and pillar recovery

permit extraction of lower grade orebodies with good ground control, provided some dilution can be accepted (Figure 5.25).

5.2.2. Cut-and-Fill Stoping

Cut-and-fill stoping is defined as systematic extraction of an orebody using fill as a platform and to facilitate ground control (Figure 5.26,5.27,5.28). It is applied to thin, steeply dipping deposits or deposits of considerable vertical extent. Men and equipment work in the stope and mining advance is generally upwards in increments ranging from 5 to 15 ft. Fill materials (usually deslimed mill tailing) are placed after each cycle of operations to prevent regional ground movement by supporting the walls and providing a safe working platform. Artificial support in the form of rock bolts, dowels or props is normally required to maintain safe working conditions beneath the advancing face. The fill materials placed have a much lower modulus compared with the rock removed. As a result, the load taken up by the fill is usually quite small and minor ground movement adjacent to the opening occurs. However, regional collapse is prevented and ground movement is usually small enough to permit footwall development openings to be regarded as permanent. Openings in the hanging wall may require progressive reinforcement to keep them open on a permanent basis, depending in the main on the depth, orientation and thickness of the filled excavation.

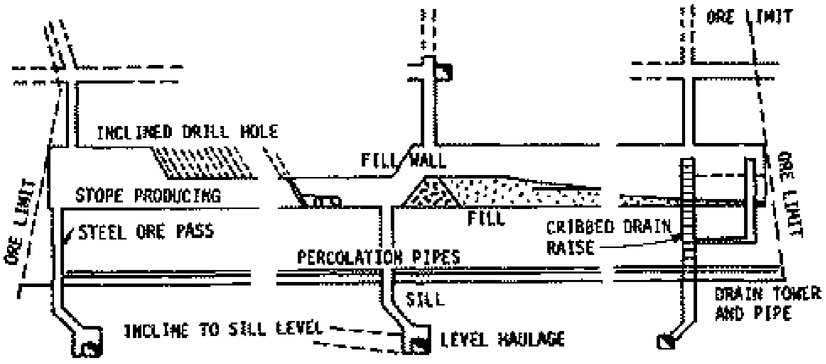


Figure 5.26 Diagrammatic layout of mechanized cut and fill stope

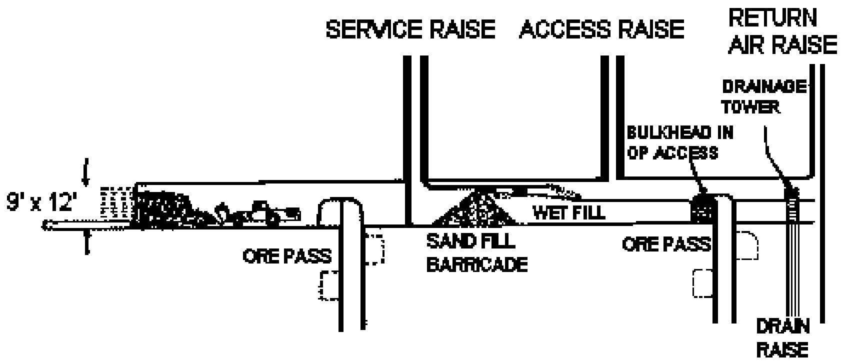


Figure 5.27 Layout of flat back cut-and-fill stope.

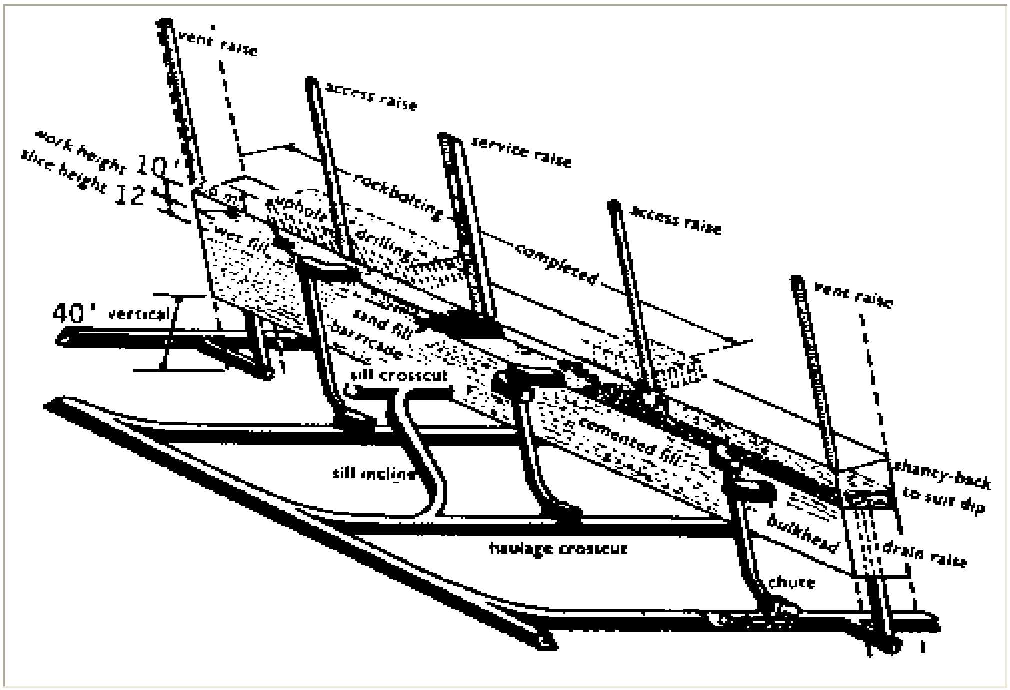


Figure 5.28 Isometric view of mechanized cut-and-fill stope

Cut-and-fill stoping is usually applied when the walls are too weak to support a large excavation. Ideally, the ore should be stronger to ensure reasonable costs for ground support and safe working conditions for men and equipment in the stope. Normally, openings will not stand unsupported over spans exceeding 30 ft, but wider spans can be accommodated if some of the ore is left as pillars for support of the back (post-pillar cut-and-fill mining) (Figure 5.29).

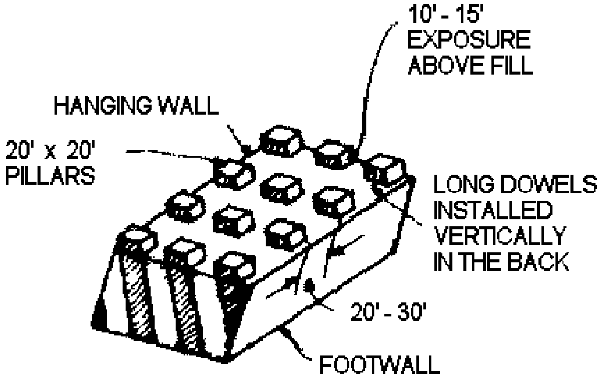


Figure 5.29 Diagram showing support by post pillars and long cable dowels.

Mining has been carried out in thin, steeply dipping deposits to depths around 7,000 ft and in multiple or wide orebodies to depths of 3,000 ft. Cut-and-fill stoping is not as sophisticated as sublevel caving as the method permits ready control of dilution. Variations include (Figure 5.26, 5.27, 5.28, 5.29)

- mechanized cut-and-fill

- shrink cut-and-fill (applied to take high lifts prior to filling)
- post-pillar cut-and-fill (applied to thick orebodies)

Ore is usually broken by drilling and blasting and transported by front-end loaders to ore passes reared in the fill or developed in the footwall. The basic cycle of operations comprises rock breaking, ore removal, ground support and filling. These operations may proceed concurrently if vertical blast holes are used for ore breaking, or in sequence if the ore is broken with horizontal blast holes (analogous to the cycle of activities in advancing a drift). Horizontal blast holes (flat backing) are used when the hanging wall is too weak to permit the larger exposures resulting from the use of vertical blast holes.

Factors to be considered in the design of a cut-and-fill system of mining include:

- The cost to exercise ground control as mining proceeds to depth. Men and equipment work under an exposed roof and the ground must be supported to prevent falls of rock. The cost to support the destressed and broken skin of rock in the back and exposed walls can be expensive, but the introduction of long, untensioned steel dowels for back support in recent years has been a major breakthrough in this regard (Figure 5.30).
- Ensuring high productivity in the cyclic operations of ore breaking, ore handling, ground support and filling.

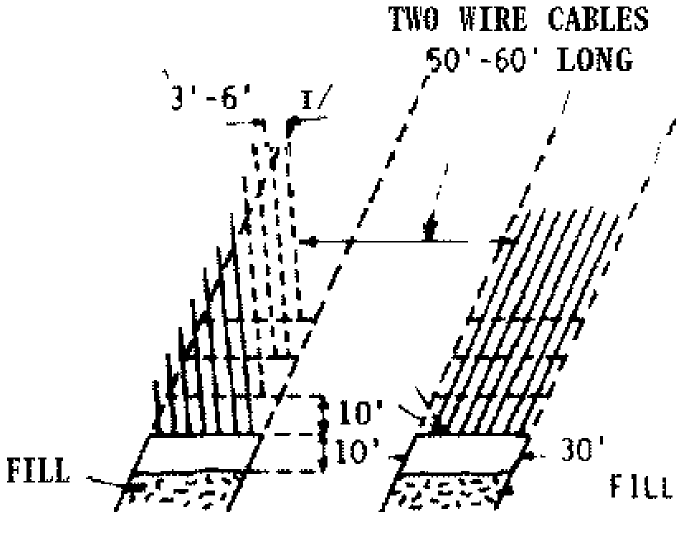


Figure 5.30 Cross sections 30' wide, dipping orebodies showing alternative installation procedures for long cable dowels in uphole drill and blast cut-and-fill stoping.

Overall, the mining method permits high ore recovery at low levels of dilution. Changes in ore limits can be accommodated within reason and mining can be carried out at depths ranging to 7,000 ft. The method involves mining close to the advancing face but fill materials take part of the transverse load and help reduce stresses near the advancing face. Post-pillars can be used to permit the mining of relatively wide orebodies. However, ground support costs increase as the depth of mining increases.

5.2.3. Shrinkage stoping

A mining method in which ore is mined from a vein from the bottom up. First, a drift is dug at one level of the orebody (usually vein type). Progressively higher levels are blasted and allowed to fill in much of the void (except for a working space). The blasted broken ores are usually kept in the stope to create a platform for mining the slice of ore immediately above it. Since broken up rock has air spaces between the pieces (or “swollen”), the overall volume is larger than the original intact ore slice, and therefore in most cases part of the broken ore must be removed from the stope before mining of each new cut starts (Figure 5.21(e) and 5.31).

The mining activities are always on a surface of blasted broken up ore, until eventually the entire stope has been blasted and is filled with broken ore. The broken materials are then pulled out from the stope and extracted by a process similar to block caving. Shrink stoping is used for high-grade vein orebodies.

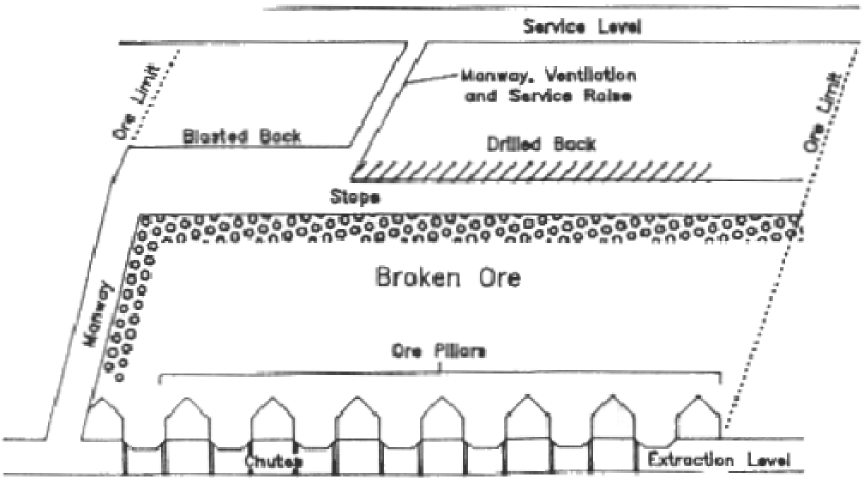


Figure 5.31Shrinkage stopping

5.2.4. VCR

Blasthole mining is a general term applied to mining methods that employ longhole drilling for the production of ore. In most Blasthole methods the ore is blasted into a vertical opening. In most blasthole methods the ore is blasted into a vertical opening. The blastholes may be small diameter long hole carbide drill holes or larger diameter holes drilled with in-the-hole (ITH) drills, or they may be a combination of both.

Vertical crater retreat is a comparatively new method of blasthole mining in which only large diameter ITH holes are used to blast down horizontal slices of ore into an opening below the block of ore being mined. The method is based on the 'cratering' effect of an explosive charge being blasted close to the end of the hole. Mining retreats vertically as successive horizontal slices are blasted.

In the case of narrow stopes where drillhole deterioration is a problem, a slot is brought up at one end of the block via cratering and the remainder of the block is slashed into it. Mining retreats horizontally as successive vertical slices are blasted (Figure 5.21(f) and 5.32).

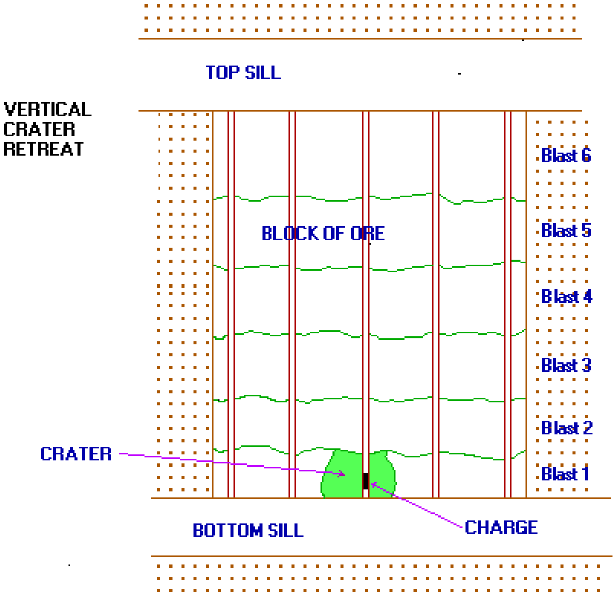


Figure 5.32 Vertical crater retreat stopping

5.3. Mine Development

Mine development consists of two basic activities called shaft development and level development respectively. Shafts provide access to the orebodies for purposes of materials handling, ore handling, access, ventilation and the like. These services must be provided for the life of the mine and because of the large capitalization involved, damage caused by ground movement from mining operations can be disastrous when major installations are sited incorrectly. Main development is carried out to provide access between shafts and orebodies on one or more horizons (refer to Figure 5.1 and 5.2). Layouts must be designed for exploration, materials handling, ventilation and general servicing of production operations and as with shafts, they must be permanent. Main level and shaft development is usually capitalized and completed ahead of production. On the other hand, stope development is part of the production operation and may be carried out on sublevels located between the main level horizons. Stope development is an operating cost and the tendency is to minimize the amount completed ahead of production. Good examples of this are advancing longwall coal mining operations.

Whether or not a caving system of mining is applicable has a major bearing on the selection of alternative sites for shaft and main development openings. Thus early information to permit an assessment of the extent and location of ground movement is essential.

Most of the information required to determine whether a caving or non-caving system of mining will be used must come from geological assessment based on surface mapping and information obtained from diamond drill holes. Information from drill holes should include:

- data to permit calculation of ore limits at varying grades (average grades and cut-off grades)
- data on structure and strength of the orebody and surrounding rock

All core should be photographed in color in the core box and then re-photographed after careful assembly and orientation to provide information after it has been split for assay.

The basis for selecting any mining method is a knowledge of the behavior under load of the material surrounding the proposed excavations. Fractures should be classified according to their potential to affect the stability of an excavation underground. This includes large-scale fractures and small-scale fractures. Fractures indicating visible shear displacement deserve the highest priority, particularly when on such a scale that continuous failure surfaces are likely to be generated across key components such as pillars or main access development. This class of fractures must be explored and mapped in detail, whether displacement is proved or not. On the other hand, small-scale fracturing leading to the generation of small blocks and localized failure can only be considered in a general manner in the design context because of the prohibitive cost of detailed exploration.

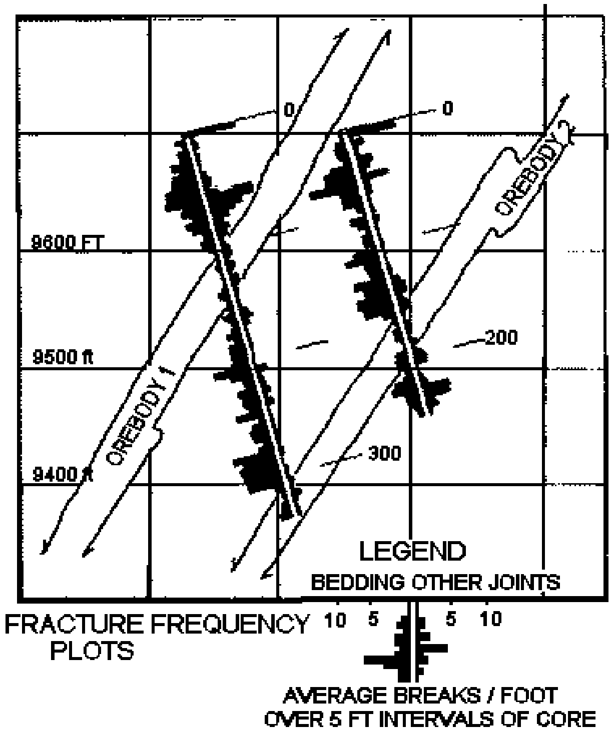


Figure 5.33 Example of a fracture showing stacked histograms.

The nature of small-scale fracturing, however, has a major bearing on the choice of mining method appropriate to the size and disposition of the orebody and stress environment (Figure 5.33). Sampling programs should be planned to obtain data for:

- the design of excavations, including their orientation and sequencing
- studies associated with drilling, ore breaking and the assessment of caveability
- the design of artificial support systems
- The most significant properties of fractures in relation to mechanical behavior can be discussed in terms of:

- nature and regularity, whether the defect occurs as a singular feature of large extent or as a family of minor features such as a fracture set
- orientation, expressed as a dip or preferably as dip direction and dip
- frequency, expressed as the number of fractures per unit distance normal to the fracture plan (the inverse of frequency is the average spacing between consecutive fractures in a set)
- continuity, expressed as the areal extent of a given fracture
- properties of individual fractures, including data on planarity, roughness, surface coating and previous movement of the surfaces

The capital required to bring a new underground mine into production can range from 50 to 300 million dollars. The accent is on rapid development once the decision has been made to mine the orebody in order to establish a cash flow as quickly as possible. On the other hand, it is apparent that a cut-off must be made concerning the information required to initiate development for ultimate production versus the information necessary for detailed, design of production operations. In summary, the information required to initiate major development should be sufficient to determine whether the orebody is viable or not and whether a caving or non-caving system of mining will be used.

Information related to the stoping method can then be obtained more cheaply from underground development openings and diamond drilling closer to the stoping areas. If a caving system of mining is selected, sufficient information is required to assess ultimate caving limits in order to reduce the amount of horizontal access development from the shafts.

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1. ORE RESERVE ESTIMATION

1.1 Definition of ore

Ore is an association of minerals that may, under favourable conditions, be worked commercially for the extraction of one or more metals

1.2 Classification of reserves

The classification of ore reserves is a much debated subject and will probably stay like that. One can find various terms for the same subjects: *MARGINAL RESERVES; ECONOMIC RESERVES; RESERVE BASE; PROVEN, PROBABLE, POSSIBLE RESERVES.*

A generally accepted terminology with the major companies is:

1.2.1 Mineral resource

A deposit or concentration of base metals, coal or industrial minerals for which there is sufficient sampling information and geological understanding to outline a deposit of current or potential economic merit.

1.2.1.1 Inferred resource

Data are only sufficient to outline a deposit of potential economic merit.

1.2.1.2 Indicated resource

Grade, tonnage and other characteristics (geology, continuity) are established so well that they can serve as a base for decisions on major expenditures.

1.2.1.3 Measured resources

Is a well established resource. There is no reasonable doubt that any variance from the stated grade and tonnage would not affect an economic appraisal based on them.

1.2.2 Ore reserves

An ore reserve is that part of the resource that can be mined at a profit under current or reasonably anticipated economic conditions which are specified. In addition to the information required for a resource estimate, the technical, operating, legal and financial factors must be considered in a reserve estimation.

1.2.2.1 Possible reserves

That part of an inferred resource that is determined from limited sampling information and reasonable extrapolation. It does not stand alone but is an extension of, or additional to, proven or probable reserves.

1.2.2.2 Probable reserves

That part of an indicated resource for which economic viability has been demonstrated at a confidence level which would justify a commitment to major expenditures.

1.2.2.3 Proven reserves

That part of a measured resource for which technical and economical factors have been established at a high confidence level. The term is generally restricted to that part of a reserve which has been developed or mined or for which there exists a detailed mining plan.

Key factors are:

- Economic viability;
- Degree of certainty of the geological and technical information;
- Competence of the individuals making the estimates.

Reserves can change category because:

- Change in economic circumstance such as change in operating cost, or commodity price;
- Change in information availability through mining or additional drilling.

The reserve base is often used as collateral in the raising of capital either through the equity markets or by borrowing from the financial institutions. For precious metal producers, the reserve is an important factor in the overall valuation of the company.

1.3 RESERVE CALCULATION

The calculation of an ore reserve involves four basic items:

- Volume calculation
- Specific gravity
- Calculation of grade
- Value component

1.3.1 Volume calculation

The volume calculation is a straight geometrical calculation of ore grade material deliniated by diamond drill hole intercepts. It is found by the application of sound geological interpretation based on adequate diamond drilling. The following are critical:

- Any ore intersection is a true thickness;
- The diamond drill holes are where they are predicted to be, i.e. that they have not wandered.

There have been major miscalculations, the variation of the coal seam thickness at Quintette for example. Volume variation can also occur when a mining method causes ore losses giving rise to the concept of geological reserves vs. mining reserves.

In terms of project economics this will be less critical when it means that the life of the deposit is shortened as the cash flows in the future are not as important as the flows at the start of a project. It is more critical if the error means that less ore volume is available per unit of cost as it directly affects the up front cash flow.

1.3.2 Specific gravity

Regardless of the density of a material, the assay is always reported as a percent by weight so the yield per unit volume will be quite different for different materials. A material with 2% copper disseminated throughout an orebody without other related sulphides will be quite different from an orebody with massive sulphides. While this may seem rediculously simple, a B.C. gold mine recently had to reduce its reserves by some 25% due to a miscalculation of the S.G.

S.G. calculations should be carried out on ore lump, not on ground material. Pososity and cavities can reduce the S.G. significantly.

1.3.3 Calculation of grade

The problem associated with grade calculation is to assign a grade to a very large rock mass from the limited sample available from diamond drilling. In sampling an ore body by diamond drilling, for example, it can be assumed that the grade of the core to a volume of 2 meter radius surrounding the hole can be assigned with certainty.
The volume then sampled with certainty, based on varying drill spacing is as follows:

Hole Spacing (m)	Area of Grid ($m^{2)}$	Sampled
25	625	2%
50	2500	0.5%
100	10000	0.0125%

There are two manners of reporting the grade. The normal procedure is to report an average or global grade for the deposit. This is often not adequate for a feasibility study as the cash flow at the beginning of the operation is critical. Reporting a local reserve grade allows the calculation of the cash flow in certain time periods. Grade errors can be fatal to new project economics.

1.3.4 Value component

While the problem does not enter into base metal or precious mines, certain commodities have other valuation complications:

- Asbestos - The fibre length is important in determining product price so 4% fibre ore with average price of $400 per ton is worth $16 per ton while 13% fibre ore worth $100 per ton is worth only $13 per ton.
- Diamonds - The number of carats recovered does not dictate price as it is the % of gem quality and size are important.
- Coal - The price depends on B.T.U. value, ash content, sulphur content etc.

It is the job of the mine feasibility to evaluate the potential of a deposit through putting together:

- The economic environment of capital cost, operating cost and product price
- The certainty of the ore reserve calculations
- The technology to extract the product
- The generally accepted economic evaluation techniques to predict the economic outcome.

1.4 Cut off grade

The lowest economical grade or value of mineralization, which still covers the marginal mining costs is called the *cut off* grade. It is one of the most important and most complicated parameters in the evaluation of mining projects.

In case of several metals in the ore, the determination becomes even more complicated. The cut off grade must then be calculated as an equivalent, or as Net Smelter Revenu (NSR). Cut off grades can be based on operating costs only (in case of an operation), or it can also include a depreciation of the investments (especially in the decision stage of an investment).

Within one operation the cut off grades for different areas with different mining methods can (and should be) different. E.g. a mine with an area where (cheap) bulk mining methods are used and areas where higher grade narrow veins are present.

1.5 Loss of ore and dilution

Ore is that part of the “resource” that may be utilised economically, waste rock are those parts which are uneconomical to exploit, plus the host rock surrounding the mineralization.

Factors influencing dilution are:
- Mining method
- Rock structure
- Ore shape
- Ore properties

Main sources of dilution are:
- Waste rock between the stope and the ore boundaries
- Internal waste in the ore
- Unexpected caving during production

The dilution d (in %) is the waste tonnage T_w divided by the ore tonnage in the stope T_s.

Loss of ore (e.g. in unrecoverable pillars) results in a lower recovery from the mine (stope): Rs, which is the tonnage of ore mined (planned to mine) from the stopes divided by the total tonnage from the reserves.

2. CAPACITY AND MINE LIFE

In preliminary analyses the capacity of a project is selected on an experimental basis. In practice the rule of thumb by Taylor is often used. It is based on data from several operating mines.

The capacity Q (tonnes per year) for an ore reserve R is: $\boldsymbol{Q = 5.0\, R^{0.75}}$

The mine life L is the ore reserves divided by the capacity or $\boldsymbol{L = 0.2\, R^{0.25}}$

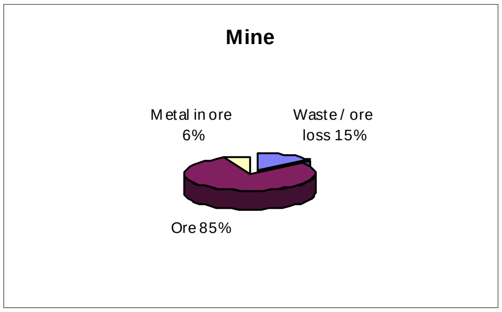
1. ORE TONNAGE AND GRADE

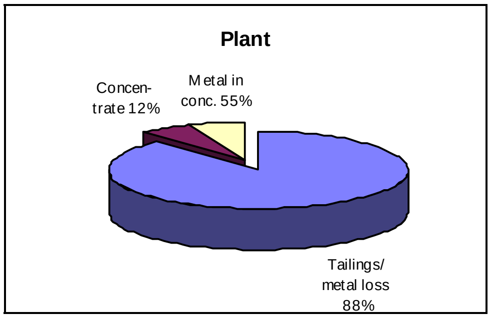
1.1 Definition of ore

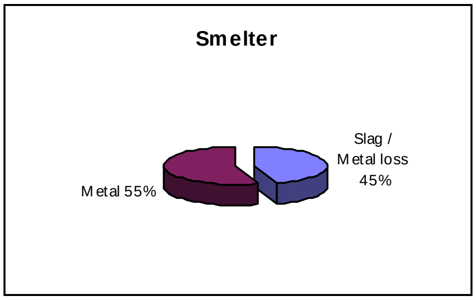
Ore is an association of minerals that may, under favourable conditions, be worked commercially for the extraction of one or more metals

1.2 Tonnage and grades of the mill feed

Loss of ore and dilution, for geological and technical reasons, during the mining process, are causing a lower grade than the ore in situ. Typical for the mining process is the great amount of raw material extracted compared to the amount of final product.







1.3 Tonnage and grades for the feed

The mill feed grade is defined as follows:

$$g_f = (g_o + g_w d) / (1 + d) \qquad (1)$$

g_f = grade of the mill feed
g_o = grade of the ore
g_w = grade of the waste dilution
d = proportion of waste rock and in-situ ore in the feed.
Grades are in percent, or unit of weight per tonne.

The amount of mill feed can be calculated from the in-situ ore with mine recovery and dilution:

$$T_f = R_f T_o (1 + d) \qquad (2)$$

T_f = amount of feed
R_f = mine recovery of ore
T_o = amount of ore

1.4 Tonnage and grades for the concentrate

The grade of the main metal of the concentrate is kept relatively constant. Typically with low metal grades, the feed recovery of concentrating is lower than with high grades. In the process the grade is also optimised between alternatives of good recovery with high grade of concentrate, or lower recovery with a high grade of concentrate. The tonnage of a concentrate is calculated as follows:

$$T_c = (R_{cm} g_{fm} T_f) / g_{cm} \qquad (3)$$

T_c = amount of concentrate
R_{cm} = recovery of main metal to concentrate
g_{fm} = grade of the main metal in the feed
g_{cm} = grade of the main metal in the concentrate

The grade of the main metal of the concentrate can be calculated as follows:
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2. VALUE OF CONCENTRATES AND FEED

2.1 Concentrate pricing

The value of a concentrate is determined on the basis of the main and secondary metals in the concentrate. For each metal the amount of payable metal is determined and valued based on the market prices of the metals. Treatment and refining charges are then deducted from that gross value. Additional costs of harmful elements are covered by penalties. From the metal grade of the concentrate a unit deduction is applied. Unit deduction covers the loss of metal during the treatment process. Also a payment percent for the deducted metal grade is quite generally applied to cover metal losses. The quality of the concentrate can affect unit deduction. The price for the payable
metal is based on market prices of the metals.

Treatment or smelting charge is calculated according to dry ton of concentrate and it depends on the quality and type of concentrates. Refining charge covers the refining costs of the metal and it is calculated for the payable amount of a metal, sometimes it relates to the metal price. The purpose of penalties is to correct the value of the concentrate to the same level as the value of clean concentrate from the viewpoint of the smelter. Penalties are fixed according to grade, per unit above the penalty limit. Penalties also have a maximum limit.

Concentrate pricing is based on agreements between buyers and sellers when exact pricing data is not available. Pricing depends strongly on the main metals in the concentrates and for different concentrate values. Also evaluation parameters of concentrates differ considerably. For the most common concentrates, general pricing data is available as shown in the table below. Market prices also have a big effect on concentrate pricing. Concentrating parameters change with metal prices and also smelter terms change at the same time.

Table 1. General pricing data of common concentrates.

Concentrate	Deduction unit	Payment	Refining charge $ per unit		Smelting charge $ / tonne
Cu-concentrate					95 - 120
- Cu (%)	1,0	95 - 98	0,09 - 0,12	lb	
- Au (oz/t)	0,03 - 0,05	90 - 95	5,00 - 6,00	oz	
- Ag (oz/t)	1,0	95	0,30 - 0,50	oz	
Pb-concentrate					145 - 175
- Pb (%)	1,5 - 3,0	95	-		
- Au (oz/t)	0,02 - 0,05	95	6,00	oz	
- Ag (oz/t)	0,5 - 0,2	95	0,30 - 0,35	oz	
- Cu (%)	-	(< 40)			
Zn-concentrate					185 - 200
- Zn (%)	8 (Zn< 53%)	85 (Zn> 53%)			
- Au (oz/t)	0,01	80 - 85	6,00	oz	
- Ag (oz/t)	3,0 - 4,0	70	0,30 - 0,50	oz	
- Cd (%)	(0,1 - 0,2)	(60 - 70)	(1,00)	lb	
- Pb (%)	(3,0)	(50)			
- Cu (%)	-	-			

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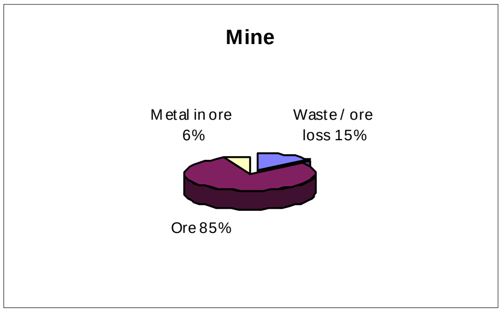

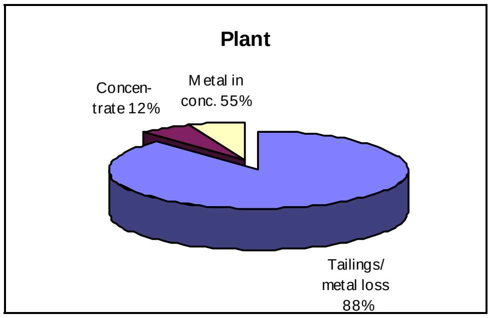

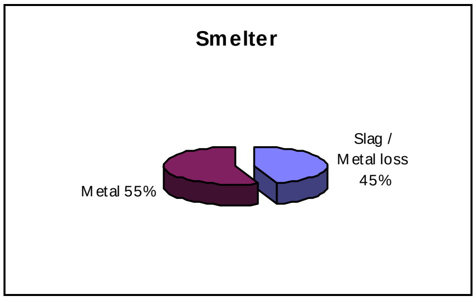

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- Ag (oz/t)	1,0	95	0,30 - 0,50	oz	
Pb-concentrate					145 - 175
- Pb (%)	1,5 - 3,0	95	-		
- Au (oz/t)	0,02 - 0,05	95	6,00	oz	
- Ag (oz/t)	0,5 - 0,2	95	0,30 - 0,35	oz	
- Cu (%)	-	(< 40)			
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- Zn (%)	8 (Zn< 53%)	85 (Zn> 53%)			
- Au (oz/t)	0,01	80 - 85	6,00	oz	
- Ag (oz/t)	3,0 - 4,0	70	0,30 - 0,50	oz	
- Cd (%)	(0,1 - 0,2)	(60 - 70)	(1,00)	lb	
- Pb (%)	(3,0)	(50)			
- Cu (%)	-	-			