



Handbook of Mining Techniques

Lawrence Tuttle

First Edition, 2012

ISBN 978-81-323-2779-0

WWT

© All rights reserved.

Published by:
Orange Apple
4735/22 Prakashdeep Bldg,
Ansari Road, Darya Ganj,
Delhi - 110002
Email: info@wtbooks.com

WORLD TECHNOLOGIES

Table of Contents

Chapter 1 - Surface Mining

Chapter 2 - Surface Mining Concepts & Techniques

Chapter 3 - Hydraulic Mining and Landfill Mining

Chapter 4 - Open-Pit Mining

Chapter 5 - Placer Mining

Chapter 6 - Underground Mining (Hard Rock)

Chapter 7 - Underground Mining (Soft Rock)

Chapter 8 - Underground Mining Techniques

Chapter 9 - Copper Extraction Techniques

Chapter- 1

Surface Mining



Coal strip mine in Wyoming

Surface mining (also commonly called **strip mining**, though this is actually only one possible form of surface mining), is a type of mining in which soil and rock overlying the mineral deposit (the overburden) are removed. It is the opposite of underground mining, in which the overlying rock is left in place, and the mineral removed through shafts or tunnels.

Surface mining is used when deposits of commercially useful minerals or rock are found near the surface; that is, where the overburden is relatively thin or the material of interest is structurally unsuitable for tunneling (as would usually be the case for sand, cinder, and gravel). Where minerals occur deep below the surface—where the overburden is thick or the mineral occurs as veins in hard rock—underground mining methods are used to

extract the valued material. Surface mines are typically enlarged until either the mineral deposit is exhausted, or the cost of removing larger volumes of overburden makes further mining no longer economically viable.

In most forms of surface mining, heavy equipment, such as earthmovers, first remove the overburden. Next, huge machines, such as dragline excavators or Bucket wheel excavators, extract the mineral.

Types

There are five main forms of surface mining, detailed below.

Strip mining



The Bagger 288 is a bucket-wheel excavator used in strip mining

"Strip mining" is the practice of mining a seam of mineral by first removing a long strip of overlying soil and rock (the overburden). It is most commonly used to mine coal or tar sand. Strip mining is only practical when the ore body to be excavated is relatively near the surface. This type of mining uses some of the largest machines on earth, including bucket-wheel excavators which can move as much as 12,000 cubic meters of earth per hour.

There are two forms of strip mining. The more common method is "area stripping", which is used on fairly flat terrain, to extract deposits over a large area. As each long strip is excavated, the overburden is placed in the excavation produced by the previous strip.

"Contour stripping" involves removing the overburden above the mineral seam near the outcrop in hilly terrain, where the mineral outcrop usually follows the contour of the land. Contour stripping is often followed by auger mining into the hillside, to remove more of the mineral. This method commonly leaves behind terraces in mountainsides.

Among others, strip mining is used to extract the oil-impregnated sand in the Athabasca Tar Sands in Alberta. It is also common in coal mining. Bucket-wheel excavators are widely used for this purpose, however, they are prone to damage and require many millions of dollars to repair.

Open-pit mining



The El Chino mine located near Silver City, New Mexico is an open-pit copper mine.

"Open-pit mining" refers to a method of extracting rock or minerals from the earth through their removal from an open pit or borrow. Although open-pit mining is sometimes mistakenly referred to as "strip mining", the two methods are different.

Mountaintop removal

"Mountaintop removal mining" (MTR) is a form of coal mining that uses explosives to blast "overburden" off the top of some Appalachian mountains. Excess mining waste or "overburden" is dumped by large trucks into fills in nearby holler or valley fills. MTR involves the mass restructuring of earth in order to reach the coal seam as deep as 400 feet (120 m) below the surface. Mountaintop removal replaces previously steep forested topography with government approved post mining reclamation land uses. Economic development attempts on reclaimed mine sites include prisons such the Big Sandy Federal Penitentiary in Martin County, Kentucky, small town airports, golf courses such as Twisted Gun in Mingo County, West Virginia and Stonecrest Golf Course in Floyd County, Kentucky, as well as industrial scrubber sludge disposal sites, solid waste landfills, trailer parks, explosive manufacturers, and storage rental lockers.

The technique has been used increasingly in recent years in the Appalachian coal fields of West Virginia, Kentucky, Virginia and Tennessee in the United States. The profound changes in topography and disturbance of pre-existing ecosystems have made mountaintop removal highly controversial.

Advocates of mountaintop removal point out that once the areas are reclaimed as mandated by law, the technique provides premium flat land suitable for many uses in a region where flat land is at a premium. They also maintain that the new growth on reclaimed mountaintop mined areas is better able to support populations of game animals.

Critics contend that mountaintop removal is a disastrous practice that benefits a small number of corporations at the expense of local communities and the environment. A U.S. Environmental Protection Agency (EPA) environmental impact statement finds that streams near valley fills sometimes may contain higher levels of minerals in the water and decreased aquatic biodiversity. The statement also estimates that 724 miles (1,165 km) of Appalachian streams were buried by valley fills from 1985 to 2001.

Blasting at a mountaintop removal mine expels dust and fly-rock into the air, which can then disturb or settle onto private property nearby. This dust may contain sulfur compounds, which some claim corrode structures and tombstones and is a health hazard.

Although MTR sites are required to be reclaimed after mining is complete, reclamation has traditionally focused on stabilizing rock and controlling erosion, but not always on reforesting the area. Quick-growing, non-native grasses, planted to quickly provide vegetation on a site, compete with tree seedlings, and trees have difficulty establishing root systems in compacted backfill. Consequently, biodiversity suffers in a region of the United States with numerous endemic species. Erosion also increases, which can intensify flooding. In the Eastern United States, the Appalachian Regional Reforestation Initiative works to promote the use of trees in mining reclamation.

Dredging

"Dredging" is a method often used to bring up underwater mineral deposits. Although dredging is usually employed to clear or enlarge waterways for boats, it can also recover significant amounts of underwater minerals relatively efficiently and cheaply.

Highwall mining

Highwall mining is another form of surface mining that evolved from auger mining. In highwall mining, the coal seam is penetrated by a continuous miner propelled by a hydraulic Pushbeam Transfer Mechanism (PTM). A typical cycle includes sumping (pushing forward) and shearing (raising or lowering the cutterhead boom to cut the entire height of the coal seam). As the coal recovery cycle continues, the cutterhead is progressively pushed into the coal seam for 20 feet (6.1 m). Then, the Pushbeam Transfer Mechanism (PTM) automatically inserts a 20-foot (6.1 m) long rectangular pushbeam into the center section of the machine between the powerhead and the cutterhead. The

pushbeams system can penetrate nearly 1,000 feet (300 m) into the coal seam. Some highwall mining systems use augers enclosed inside the pushbeams that prevent the mined coal from being contaminated by rock debris during the conveyance process. Using a video imaging and/or a gamma detector, the operator can see and guide the continuous miner's progress. Highwall mining can produce thousands of tons of coal in contour-strip operations with narrow benches, previously mined areas, or trench mine applications.

Recovery is much better than augering, but the mapping of areas that have been developed by a highwall miner are not mapped as rigorously as deep mined areas. Very little spoil is displaced in contrast with mountain top removal, however a large amount of capital is required to operate and own a highwall miner.

Mapping of the outcrop as well as core hole data and samples taken during the bench making process are taken into account to best project the panels that the highwall miner will cut. Obstacles that could be potentially damaged by subsidence and the natural contour of the Highwall are taken into account, and a surveyor points the Highwall miner in a line mostly perpendicular to the highwall. Parallel lines represent the panels cut into the mountain (up to 1,000 feet (300 m) deep), because changing the azimuth during mining results in missing a portion of the coal seam. Recently highwall miners have penetrated more than 1050 feet into the coal seam, and today's models are capable of going farther, limited only by the amount of cable on the machine. The maximum depth would be determined by the stress of further penetration and associated power draw.

Environmental and health issues

The large impact of surface mining on the topography, vegetation, and water resources has made it highly controversial.

Surface mining is subject to state and federal reclamation requirements, but adequacy of the requirements is a constant source of contention. Unless reclaimed, surface mining can leave behind large areas of infertile waste rock, as 70% of material excavated is waste.

In the United States, the Surface Mining Control and Reclamation Act of 1977 mandates reclamation of surface coal mines. Reclamation for non-coal mines is regulated by state and local laws, which may vary widely.

Human health

The United Mine Workers of America has spoken against the use of human sewage sludge to reclaim surface mining sites in Appalachia. The UMWA launched its campaign against the use of sludge on mine sites in 1999 after eight UMWA workers became ill from exposure to Class B sludge spread near their workplace.

On August 20, 2004 at 2:30 a.m. a boulder accidentally pushed off an A&G Coal surface mine above the town of Inman, Virginia rolled 649 feet (198 m) down the mountain and

into a home. Three-year-old Jeremy Davidson was crushed in his bed while he slept. The Davidson family settled with A&G Coal for \$3 million in 2006, and left the region.

Environmental impact

According to a 2010 report in the journal *Science*, mountaintop mining has caused numerous environmental problems which mitigation practices have not successfully addressed. For example, valley fills frequently bury headwater streams causing permanent loss of ecosystems. In addition, the destruction of large tracts of deciduous forests has threatened several endangered species and led to a loss of biodiversity.

WWT

Chapter- 2

Surface Mining Concepts & Techniques

Clay pit

A **clay pit** is a quarry or mine for the extraction of clay, which is generally used for manufacturing pottery, bricks or Portland cement.

The brick factory is often located alongside the clay pit to reduce the transport costs of the raw material. These days pottery producers are often not sited near the source of their clay and usually do not own the clay deposits. The other essential raw material is fuel for firing and potteries may be located near to fuel deposits rather than the clay.

Former claypits are sometimes filled with water and used for recreational purposes such as sailing and scuba diving. The Eden Project at Bodelva near St Austell, Cornwall, UK is a major development of a former china clay pit for educational and environmental purposes.

Costean

Costeaning is the process by which miners seek to discover metallic lodes. It consist in sinking small pits through the superficial deposits to the solid rock, and then driving from one pit to another across the direction of the vein, in such manner as to cross all the veins between the two pits.

Glory hole



Abandoned open pit mine in South Africa, the Big Hole



Glory hole produced by collapse, Henderson mine, Colorado, USA.

In mining and excavation, a **glory hole** is an informal term for a large and impressive excavation open to the surface. The term may refer to:

- A deep mine shaft
- An open-pit mine
- In the block caving method of underground mining, ore collapses from above into a mine tunnel. If enough ore is removed, the ground surface collapses into a surface depression called a glory hole. Examples include the Climax and Henderson molybdenum mines in the U.S. state of Colorado
- Excavations in construction sites may also be referred to as glory holes.

Gravel pit



A gravel pit in Germany

Gravel pit is the term for an open cast working for extraction of gravel. Gravel pits often lie in river valleys where the water table is high, so they may fill naturally with water to form ponds or lakes. Old, abandoned gravel pits are normally used either as nature reserves, or as amenity areas for water sports, camping and walking. In addition, some gravel pits are used for explosive ordinance disposal.



A naturalized gravel pit, now Silver Springs Park in East St. Paul, Manitoba

Many gravel pits in the UK have freshwater fish such as the common carp artificially introduced to create popular coarse fishing locations.

Quarry

A **quarry** is a type of open-pit mine from which rock or minerals are extracted. Quarries are generally used for extracting building materials, such as dimension stone, construction aggregate, riprap, sand, and gravel. They are often colocated with concrete and asphalt plants due to the requirement for large amounts of aggregate in those materials. The word *quarry* can include underground quarrying for stone, such as Bath stone.



Portland stone quarry on the Isle of Portland, England

Problems

Quarries in level areas with shallow groundwater or which are located close to surface water often have engineering problems with drainage. Generally the water is removed by pumping while the quarry is operational, but for high inflows more complex approaches may be required. For example, the Coquina quarry is excavated to more than 60 feet (18 m) below sea level. To reduce surface leakage, a moat lined with clay was constructed around the entire quarry. Ground water entering the pit is pumped up into the moat. As a quarry becomes deeper water inflows generally increase and it also becomes more expensive to lift the water higher during removal - this can become the limiting factor in quarry depth. Some water-filled quarries are worked from beneath the water, by dredging.

Many people and municipalities consider quarries to be eyesores and require various abatement methods to address problems with noise, dust, and appearance. One of the more effective and famous examples of successful quarry restoration is Butchart Gardens in Victoria, BC, Canada.

Many quarries naturally fill with water after abandonment and become lakes. Others are made into landfills.

Quarry swimming

Water-filled quarries can be very deep with water, often 50 feet or more, that is often surprisingly cold. Unexpectedly cold water can cause a swimmer's muscles to suddenly weaken; it can also cause shock and even hypothermia. Though quarry water is often very clear, submerged quarry stones and abandoned equipment make diving into these quarries extremely dangerous. Several teenagers and young men and women drown in quarries each year. However, many inactive quarries are converted into safe swimming sites.

WWT

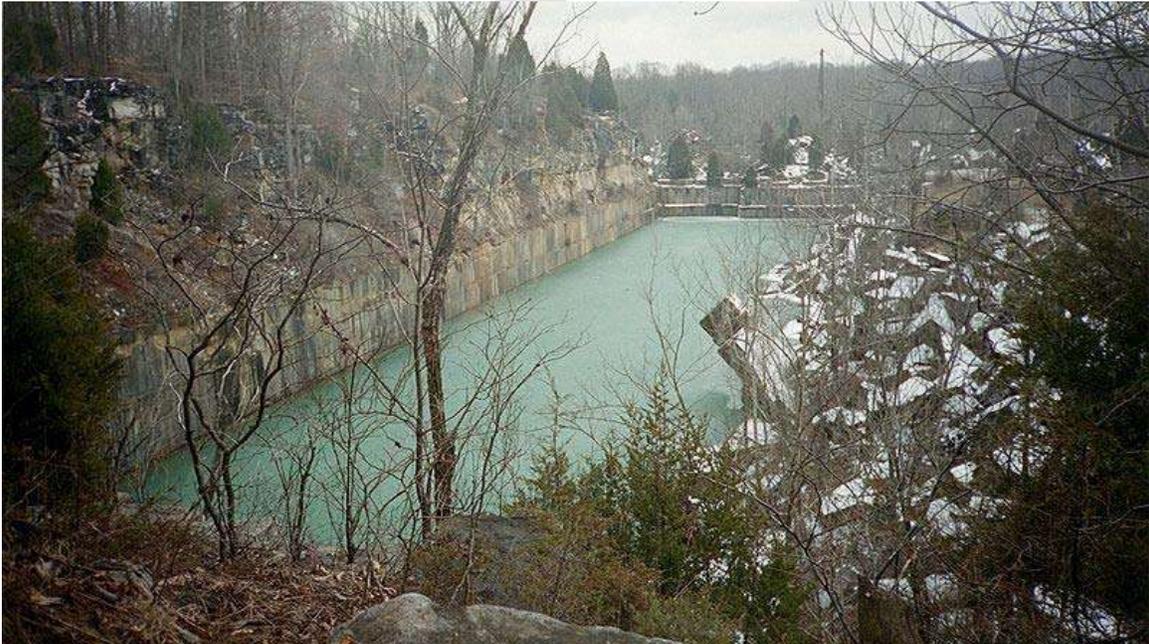
Types of rock



Delabole Slate Quarry, Delabole, Cornwall, UK



An abandoned construction aggregate quarry near Adelaide, South Australia



An abandoned limestone quarry

Types of rock extracted from quarries include:

- Cinder
- Chalk
- China clay
- Clay
- Coal
- Coquina
- Construction aggregate (sand and gravel)
- Granite
- Gritstone
- Gypsum
- Limestone
- Marble
- Ores
- Phosphate rock
- Sandstone
- Slate



Chapter- 3

Hydraulic Mining and Landfill Mining

Hydraulic Mining

Hydraulic mining, or **hydraulicking**, is a form of mining that uses high-pressure jets of water to dislodge rock material or move sediment. In the placer mining of gold or tin, the resulting water-sediment slurry is directed through sluice boxes to remove the gold.

Precursor - ground sluicing

Hydraulicking had its precursor in the millennia-old practice of ground sluicing, also known as "hushing", in which surface streams of water were diverted so as to erode gold-bearing gravels. The Romans used ground sluicing to remove overburden and then gold-bearing debris in Las Médulas of Spain, and Dolaucothi in Britain. The method was also used in Elizabethan Britain for developing lead, tin and copper mines.



Panoramic view of Las Médulas

Roman era

Water was used on a large scale by Roman engineers in the first centuries BC and AD when the Roman empire was expanding rapidly in Europe. Using a process later known as hushing, the Romans stored a large volume of water in a reservoir immediately above the area to be mined; the water was then quickly released. The resulting wave of water removed overburden and exposed bedrock. Gold veins in the bedrock were then worked using a number of techniques, and water power was used again to remove debris. The remains at Las Medulas and in surrounding areas show badland scenery on a gigantic scale owing to hydraulicking of the rich alluvial gold deposits. Las Medulas is now a UNESCO World Heritage site. The site shows the remains of at least seven large aqueducts of up to 30 miles in length feeding large supplies of water into the site. The gold-mining operations were described in vivid terms by Pliny the Elder in his *Naturalis Historia* published in the first century AD. Pliny was a procurator in Hispania Terraconensis in the 70's and must have witnessed for himself the operations. The use of hushing has been confirmed by field survey and archaeology at Dolaucothi in South Wales, the only known Roman gold mine in Britain.

California hydraulicking



Hydraulic mining for gold in California, from *The Century Magazine* January 1883

The modern form of hydraulicking, using jets of water directed under very high pressure through hoses and nozzles at gold-bearing upland paleogravels, was first used by Edward Matteson near Nevada City, California in 1853 during the California Gold Rush. Matteson used canvas hose which was later replaced with crinoline hose by the 1860s. In California, hydraulic mining often brought water from higher locations for long distances to holding ponds several hundred feet above the area to be mined. Insofar as California hydraulic mining exploited primarily river gravels, it was one form of placer mining, that is, working of alluvium (river sediments).



Gold miners excavate an eroded bluff with jets of water at a placer mine in Dutch Flat, California sometime between 1857 and 1870.

Early placer miners in California discovered that the more gravel they could process, the more gold they were likely to find. Instead of working with pans, sluice boxes, long toms, and rockers, miners collaborated to find ways to process larger quantities of gravel more rapidly. Hydraulic mining became the largest-scale, and most devastating, form of placer mining. Water was redirected into an ever-narrowing channel, through a large canvas hose, and out through a giant iron nozzle, called a "monitor." The extremely high pressure stream was used to wash entire hillsides through enormous sluices.

By the early 1860s, while hydraulic mining was at its height, small-scale placer mining had largely exhausted the rich surface placers, and the mining industry turned to hard rock (called quartz mining in California) or hydraulic mining, which required larger organizations and much more capital. By the mid-1880s, it is estimated that 11 million ounces of gold (worth approximately US\$7.5 billion at mid-2006 prices) had been recovered by hydraulic mining in the California Gold Rush.

Environmental consequences



A man leans over a wooden sluice. Rocks line the outside of the wood boards that create the sluice.

While generating millions of dollars in tax revenues for the state and supporting a large population of miners in the mountains, hydraulic mining had a devastating effect on riparian natural environment and agricultural systems in California. Millions of tons of earth and water were delivered to mountain streams that fed rivers flowing into the Sacramento Valley. Once the rivers reached the relatively flat valley, the water slowed, the rivers widened, and the sediment was deposited in the floodplains and river beds causing them to rise, shift to new channels, and overflow their banks, causing major flooding, especially during the spring melt.

Cities and towns in the Sacramento Valley experienced an increasing number of devastating floods, while the rising riverbeds made navigation on the rivers increasingly difficult. Perhaps no other city experienced the boon and the bane of gold mining as much as Marysville. Situated at the confluence of the Yuba and Feather rivers, Marysville was the final "jumping off" point for miners heading to the northern foothills to seek their fortune. Steamboats from San Francisco, carrying miners and supplies, navigated up the Sacramento River, then the Feather River to Marysville where they would unload their passengers and cargo. Marysville eventually constructed a complex

levee system to protect the city from floods and sediment. Hydraulic mining greatly exacerbated the problem of flooding in Marysville and shoaled the waters of the Feather River so severely that few steamboats could navigate from Sacramento to the Marysville docks.

The spectacular eroded landscape left at the site of hydraulic mining can be viewed at Malakoff Diggins State Historic Park in Nevada County, California. A similar landscape can be seen at Las Médulas in northern Spain, where Roman engineers ground sluiced the rich gold alluvial deposits of the river Sil. Pliny the Elder mentions in his *Naturalis Historia* that Spain had encroached on the sea and local lakes as a result of ground sluicing operations.

Legal ramifications

Vast areas of farmland in the Sacramento Valley were deeply buried by the mining sediment. Frequently devastated by flood waters, farmers demanded an end to hydraulic mining. In the most renowned legal fight of farmers against miners, the farmers sued the hydraulic mining operations and the landmark case of *Edwards Woodruff v. North Bloomfield Mining and Gravel Company* made its way to the United States District Court in San Francisco where Judge Lorenzo Sawyer decided in favor of the farmers in 1884, declaring that hydraulic mining was “a public and private nuisance” and enjoining its operation in areas tributary to navigable streams and rivers. Hydraulic mining was recommenced after 1893 when the United States Congress passed the Camminetti Act which allowed such mining if sediment detention structures were constructed. This led to a number of operations above brush dams and log crib dams. Most of the water-delivery infrastructure had been destroyed by an 1891 flood, so this later stage of mining was carried on at a much smaller scale in California.

Beyond California



The Oriental Claims near Omeo, Australia were mined between the 1850s and 1900s; hydraulic sluicing left man-made cliffs up to 30 metres (98 ft) high such as seen here throughout the area



Lee Moor china clay pit in Devon showing hydraulic mining

Although often associated with California due to its adoption and widespread use there, the technology was exported widely, to Oregon (Jacksonville in 1856), Colorado (Clear Creek, Central City and Breckenridge in 1860), Montana (Bannack in 1865), Arizona (Lynx Creek in 1868), Idaho (Idaho City in 1863), South Dakota (Deadwood in 1876), Alaska, British Columbia (Canada), and overseas. It was used extensively in Dahlonega, Georgia and continues to be used in developing nations, often with devastating environmental consequences. The devastation caused by this method of mining caused Edwin Carter, the "Log Cabin Naturalist," to switch from mining to collecting wildlife specimens from 1875-1900 in Breckenridge, Colorado, USA.

Hydraulic mining was also used during the Australian gold rushes where it was called hydraulic sluicing. One notable location was at the Oriental Claims near Omeo in

Victoria where it was used between the 1850s and early 1900s, with abundant evidence of the damage still being visible today.

Hydraulic mining was used extensively in the Central Otago Gold Rush that took place in the 1860s in the South Island of New Zealand, where it was also known as *shuicing*.

Starting in the 1870s, hydraulic mining became a mainstay of alluvial tin mining on the Malay Peninsula.

Hydraulicking was formerly used in Polk County, Florida to mine phosphate rock.

Hydraulic mining is the principal way that kaolinite clay is mined in Cornwall and Devon, in South-West England.

In addition to its use in true mining, hydraulic mining can be used as an excavation technique, principally to demolish hills. For example, the Denny Regrade in Seattle was largely accomplished by hydraulic mining.

Underground hydraulic mining

High-pressure water jets have also been used in the underground mining of coal, to break up the coal seam and wash the resulting coal slurry toward a collection point.

Landfill mining

Landfill mining and reclamation (LFMR) is a process whereby solid wastes which have previously been landfilled are excavated and processed. The function of landfill mining is to reduce the amount of landfill mass encapsulated within the closed landfill and/or temporarily remove hazardous material to allow protective measures to be taken before the landfill mass is replaced. In the process, mining recovers valuable recyclable materials, a combustible fraction, soil, and landfill space. The aeration of the landfill soil is a secondary benefit regarding the landfill's future use. The combustible fraction is useful for the generation of power. The overall appearance of the landfill mining procedure is a sequence of processing machines laid out in a functional conveyor system. The operating principle is to excavate, sieve and sort the landfill material.

The concept of landfill mining was introduced as early as 1953 at the Hiriya landfill operated by the Dan Region Authority next to the city of Tel Aviv, Israel. Waste contains many resources with high value, the most notable of which are non-ferrous metals such as aluminium cans and scrap metal. The concentration of aluminium in many landfills is higher than the concentration of aluminum in bauxite from which the metal is derived.

Practical applications

Landfill mining is also possible in countries where land is not available for new landfill sites. In this instance landfill space can be reclaimed by the extraction of biodegradable waste and other substances then refilled with wastes requiring disposal.

Mining construction landfill sites is the simplest form of landfill mining. Construction landfills contain three basic components, wood, scrap metal and gypsum, or drywall, along with a minimal amount of other construction materials. The wood collected can be used as fuel in coal burning power plants and the scrap metal reprocessed.

Mining of municipal landfills is more complicated and has to be based on the expected content of the landfill. Older landfills, in the United States before 1994, were often capped and closed, essentially entombing the waste. This can be beneficial for waste recovery. It can also create a higher risk for toxic waste and leachate exposure as the landfill has not fully processed the stewing wastes. Mining of bioreactor landfills and properly stabilized modern sanitary landfills provides its own benefits. The biodegradable wastes are more easily sieved out, leaving the non biodegradable materials readily accessible. The quality of these materials for recycling and reprocessing purposes is not as high as initially recycled materials, however materials such as aluminum and steel are usually excluded from this.

Landfill mining is most useful as a method to remediate hazardous landfills. Landfills that were established before landfill liner technology was well established often leak their unprocessed leachate into underlying aquifers. This is both an environmental hazard and also a legal liability. In the US, Environmental Protection Agency fines can tax the local economy up to 30 years after the site has closed. Mining the landfill simply to lay a safe liner is a last, but sometimes necessary resort.

Tools and machinery

The parts of the mining process are the different mining machines. Depending on the complexity of the process more or fewer machines can be used. Machinery is easily transported on trucks from site to site, mounted on trailers. The following machines are added in order in increase of mining complexity:

- Excavators
- Moving floor and elevator conveyor belts
- A coarse rotating trommel screen
- A fine rotating trommel screen
- A magnet
- Front end loader
- Odor control sprayer

The mechanics of mining

An excavator or front end loader uncovers the landfilled materials and places them on a moving floor conveyor belt to be taken to the sorting machinery. A trommel is used to separate materials by size. First, a large trommel separates materials like appliances and fabrics. A smaller trommel then allows the biodegraded soil fraction to pass through leaving non-biodegradable, recyclable materials on the screen to be collected.

An electromagnet is used to remove the ferrous material from the waste mass as it passes along the conveyor belt.

A front end loader is used to move sorted materials to trucks for further processing.

Odour control sprayers are wheeled tractors with a cab and movable spray arm mounted on a rotating platform. A large reservoir tank mounted behind the cab holds neutralising agents, usually in liquid form, to reduce the smell of exposed wastes.

Operational flow

Excavators dig up waste mass and transport it, with the help of front end loaders, onto elevator and moving floor conveyor belts. The conveyor belts empty into a coarse, rotating trommel. The large holes in the screen allow most wastes to pass through, leaving behind the over-sized, non-processable materials. The over-sized wastes are removed from inside the screen. The coarse trommel empties into the fine rotating trommel. The fine rotating trommel allows the soil fraction to pass through, leaving mid-sized, non-biodegradable, mostly recyclable materials. The materials are removed from the screen. These materials are put on a second conveyor belt where an electromagnet removes any ferromagnetic debris. Depending on the level of resource recovery, material can be put through an air classifier which separates light organic material from heavy organic material. The separate streams are then loaded, by front end loaders, onto trucks either for further processing or for sale. Further manual processing can be done on site if processing facilities are too far away to justify the transportation costs.

Chapter- 4

Open-Pit Mining



El Chino, located near Silver City, New Mexico, is an open-pit copper mine

Open-pit mining refers to a method of extracting rock or minerals from the earth by their removal from an open pit or borrow.

The term is used to differentiate this form of mining from extractive methods that require tunneling into the earth. Open-pit mines are used when deposits of commercially useful minerals or rock are found near the surface; that is, where the *overburden* (surface material covering the valuable deposit) is relatively thin or the material of interest is structurally unsuitable for tunneling (as would be the case for sand, cinder, and gravel). For minerals that occur deep below the surface—where the overburden is thick or the

mineral occurs as veins in hard rock— underground mining methods extract the valued material.

Open-pit mines that produce building materials and dimension stone are commonly referred to as **quarries**. People are unlikely to make a distinction between an open-pit mine and other types of open-cast mines, such as quarries, borrows, placers, and strip mines.

Open-pit mines are typically enlarged until either the mineral resource is exhausted, or an increasing ratio of overburden to ore makes further mining uneconomic. When this occurs, the exhausted mines are sometimes converted to landfills for disposal of solid wastes. However, some form of water control is usually required to keep the mine pit from becoming a lake.



A coquina quarry

Extraction

Open-pit mines are dug on benches, which describe vertical levels of the hole. These benches are usually on four metre to sixty metre intervals, depending on the size of the machinery that is being used. Many quarries do not use benches, as they are usually shallow.

Most walls of the pit are generally dug on an angle less than vertical, to prevent and minimise damage and danger from rock falls. This depends on how weathered the rocks are, and the type of rock, and also how many structural weaknesses occur within the rocks, such as a fault, shears, joints or foliations.

The walls are stepped. The inclined section of the wall is known as the batter, and the flat part of the step is known as the bench or berm. The steps in the walls help prevent rock falls continuing down the entire face of the wall. In some instances additional ground support is required and rock bolts, cable bolts and shotcrete are used. De-watering bores

may be used to relieve water pressure by drilling horizontally into the wall, which is often enough to cause failures in the wall by itself.

A haul road is situated at the side of the pit, forming a ramp up which trucks can drive, carrying ore and waste rock.

Waste rock is piled up at the surface, near the edge of the open pit. This is known as the waste dump. The waste dump is also tiered and stepped, to minimise degradation.

Ore which has been processed is known as tailings, and is generally a slurry. This is pumped to a tailings dam or settling pond, where the water evaporates. Tailings dams can often be toxic due to the presence of unextracted sulfide minerals, some forms of toxic minerals in the gangue, and often cyanide which is used to treat gold ore via the cyanide leach process. This toxicity has the potential to negatively impact on the surrounding environment.



Open-cast, or strip, coal mining at Garzweiler, Germany



Open-pit sulfur mining at Tarnobrzeg, Poland currently in land rehabilitation process

Rehabilitation

After mining finishes, the mine area must undergo rehabilitation. Waste dumps are contoured to flatten them out, to further stabilise them. If the ore contains sulfides it is usually covered with a layer of clay to prevent access of rain and oxygen from the air, which can oxidise the sulfides to produce sulfuric acid, a phenomenon known as acid mine drainage. This is then generally covered with soil, and vegetation is planted to help consolidate the material. Eventually this layer will erode, but it is generally hoped that the rate of leaching or acid will be slowed by the cover such that the environment can handle the load of acid and associated heavy metals. There are no long term studies on the success of these covers due to the relatively short time in which large scale open pit mining has existed. It may take hundreds to thousands of years for some waste dumps to become "acid neutral" and stop leaching to the environment. The dumps are usually fenced off to prevent livestock denuding them of vegetation. The open pit is then

surrounded with a fence, to prevent access, and it generally eventually fills up with ground water. In arid areas it may not fill due to deep groundwater levels.

Typical open cut grades

Gold is generally extracted in open-pit mines at 1 to 2 ppm (grams per ton) but in certain cases, 0.75ppm gold is economical. This was achieved by bulk heap leaching at Alkane Minerals Ltd. Peak Hill mine in western New South Wales, near Dubbo, Australia.

Nickel, generally as laterite, is extracted via open-pit down to 0.2%. Copper is extracted at grades as low as 0.15% to 0.2%, generally in massive open-pit mines in Chile, where the size of the resources and favorable metallurgy allows economies of scale.

Materials typically extracted from open-pit mines include:

- Clay
- Coal
- Coquina
- Diamonds
- Gravel and stone (stone refers to bedrock, while gravel is unconsolidated material, as found in glacial or fluvial deposits)
- Granite
- Gritstone
- Gypsum
- Limestone
- Marble
- Metal ores, such as copper, iron, gold, and molybdenum

Open-pit mines



Super Pit gold mine

Argentina

- Bajo de la Alumbrera Mine; gold and copper mine located near Belén, Catamarca.
- Cerro Vanguardia Mine; gold and silver mine located near Puerto San Julián, Santa Cruz.
- Pascua Lama – binational gold and silver mine in San Juan, Argentina and Atacama, Chile (in project).
- Veladero Mine; gold mine located near Jáchal, San Juan.

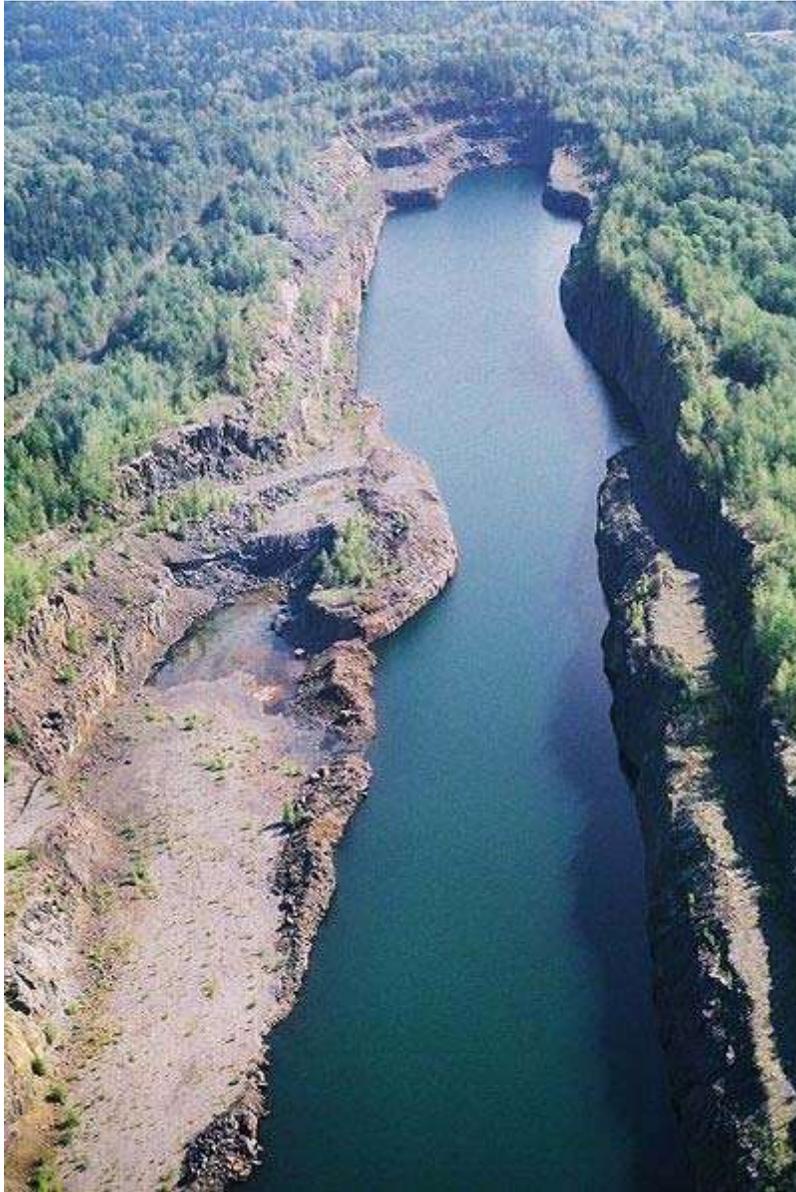
Australia

- Super Pit – gold mine near Kalgoorlie, Western Australia.
- Cadia mine – gold and copper mine located near Orange, New South Wales.
- Boddington Gold Mine – Boddington, Western Australia.
- Telfer Mine – Gold and copper mine in Pilbara, Western Australia
- Ranger Mine – Uranium mine east of Darwin in the Northern Territory, Weipa, Queensland

Bulgaria

- Maritsa Iztok Mines – coal mine near Radnevo, Stara Zagora Province, Bulgaria.

Canada



East Pit of Sherman Mine in Temagami, Ontario, Canada

- Adams Mine – abandoned mine in Kirkland Lake, Ontario.
- Sherman Mine – abandoned iron mine in Temagami, Ontario.
- Colomac Mine – gold mine in Northwest Territories.
- Diavik Diamond Mine – diamond mine in Northwest Territories.
- Ekati Diamond Mine – diamond mine in Northwest Territories.

- Pine Point Mine – lead and zinc mine in Northwest Territories.

Chile

- Chuquicamata – copper mine.
- Escondida – copper mine.
- Pascua Lama – binational gold and silver mine in San Juan, Argentina and Atacama, Chile (in project).
- Radomiro Tomic – copper mine.

Colombia

- Cerrejón – coal mine in Guajira Department.

Egypt

- Sukari gold mine

Germany

- Tagebau Garzweiler – lignite mine.
- Tagebau Hambach – lignite mine.

Indonesia

- Batu Hijau mine – copper and gold mine on the island of Sumbawa.
- Grasberg mine – located in the mountains of the Papua province.

Kyrgyzstan

- Kumtor Gold Mine – gold mine in Tian Shan Mountains at 4,000-4,400 m (14,000 ft) above sea level.

Mongolia

- Boroo Gold Mine – gold mine 110 km (70 mi) WNW of the capital Ulan Bator.

Namibia

- Rossing – uranium mine.



Open Cast Mine, Uncovered Coal Seam, Kai Point Coal Mine, New Zealand

Peru

- Yanacocha – gold mine.
- Toquepala – Porphyry copper.

Portugal

- Sao Domingos Mine – copper mine.

Romania

- Berbești Coal Mine – coal mine.
- Motru Coal Mine – coal mine.
- Rovinari Coal Mine – coal mine.

Russia



The Udachnaya pipe in Russia.

- Mirny Mine – diamond mine in Mirny, Eastern Siberia
- Udachnaya pipe – diamond mine in Yakutia, Russia.

South Africa

- The Big Hole, former diamond mine in Kimberley, more than 1,000 m (3,300 ft) deep; now a museum.
- The Jagersfontein Mine.

Spain

- Corta Atalaya is the largest open-pit mine in Europe and was at one time the largest in the world.

Sweden

- Aitik-gruvan in Gällivare, copper mine with side production of gold and molybdenum.

United Kingdom

- Penrhyn Quarry – slate quarry in Wales.

United States



The Lavender Pit, Bisbee, Arizona

- Berkeley Pit - former copper mine in Butte, Montana; now a toxic lake and tourist attraction.
- El Chino Mine – copper mine in Grant County, New Mexico.
- Hull-Rust-Mahoning Mine – largest open pit iron mine in the world near Hibbing, Minnesota.
- Bingham Canyon Mine – copper mine in Salt Lake County, Utah.
- Lavender Pit – copper mine in Cochise County, Arizona.
- Cresson Mine – a gold mine in Victor, Colorado.

Zambia

- Nchanga Open Pit Mine, Chingola. The second largest open cast mine in the world , covering nearly 30 km² and up to 400m deep.

WWT

Chapter- 5

Placer Mining



Miners operate a hydraulic sluice in San Francisquito Canyon, Los Angeles County. The placer mine machine consists of adobe columns, pulleys, ropes, and wood boxes. Donkeys are loaded with ore bags.

Placer mining is the mining of alluvial deposits for minerals. This may be done by open-pit (also called open-cast mining) or by various forms of tunneling into ancient riverbeds. Excavation may be accomplished using water pressure (hydraulic mining), surface excavating equipment or tunneling equipment.

The name derives from Spanish, *placer*, meaning "sandbank." It refers to mining the precious metal deposits (particularly gold and gemstones) found in alluvial deposits—deposits of sand and gravel in modern or ancient stream beds. The metal or gemstones, having been moved by stream flow from an original source such as a vein, is typically only a minuscule portion of the total deposit. Since gems and heavy metals like gold are

considerably more dense than sand, they tend to accumulate at the base of placer deposits.

The containing material may be too loose to safely mine by tunneling. Where water under pressure is available, it may be used to mine, move, and separate the precious material from the deposit, a method known as hydraulic mining, hydraulic sluicing or hydraulicking.

History



A sluice box used in placer mining

Placers supplied most of the gold for a large part of the ancient world. Hydraulic mining methods such as hushing were used widely by the Romans across their empire, but especially in the gold fields of northern Spain after its conquest by Augustus in 25 BC. One of the largest sites was at Las Médulas, where seven 30 mile long aqueducts were used to work the alluvial gold deposits through the first century AD. (Inclusions of platinum-group metals in a very large proportion of gold items indicate that the gold was largely derived from placer or alluvial deposits. Platinum group metals are seldom found with gold in hardrock reef or vein deposits.) In North America, placer mining was famous in the context of several gold rushes, particularly the California Gold Rush, the Fraser Canyon Gold Rush and the Klondike Gold Rush. Placer mining continues in many areas of the world as a source of diamonds, industrial minerals and metals, gems (in Myanmar and Sri Lanka), platinum, and of gold (in the Yukon, Alaska and British Columbia).

Methods

A number of methods are used to mine placer gold.

Panning



Coarse Alaskan gold in pan

The simplest technique to extract gold from placer ore is panning. In panning, some mined ore is placed in a large metal or plastic pan, combined with a generous amount of water, and agitated so that the gold particles, being of higher density than the other material, settle to the bottom of the pan. The lighter gauge material such as sand, mud and gravel are then washed over the side of the pan, leaving the gold behind. Once a placer deposit is located by gold panning, the miner usually shifts to equipment that can treat volumes of sand and gravel more quickly and efficiently.

Sluice box



Miners working a sluice on Lucky Gulch, Alaska

The same principle may be employed on a larger scale by constructing a short sluice box, with barriers along the bottom called riffles to trap the heavier gold particles as water washes them and the other material along the box. This method better suits excavation with shovels or similar implements to feed ore into the device. Sluice boxes can be as short as a few feet, or more than ten feet (a common term for one that is over six feet +/- is a "Long Tom"). Similar in principle to a sluice is a *rocker*, a cradle-like piece of equipment that could be rocked to sift sands through screens, which was introduced by Chinese miners in British Columbia and Australia, where the practice was referred to as "rocking the golden baby". Another Chinese technique was the use of blankets to filter sand and gravels, catching fine gold in the fabric's weave, then burning the blankets to smelt the gold. Chinese were noted for the thoroughness of their placer extraction techniques, which included hand-washing of individual rocks as well as the complete displacement of streambeds and advanced flume and ditching techniques which became copied by other miners.

Trommel



Trommel at the Potato Patch, Blue Ribbon Mine, Alaska

A trommel is composed of a slightly-inclined rotating metal tube (the 'scrubber section') with a screen at its discharge end. Lifter bars, sometimes in the form of bolted in angle iron, are attached to the interior of the scrubber section. The ore is fed into the elevated end of the trommel. Water, often under pressure, is provided to the scrubber and screen sections and the combination of water and mechanical action frees the valuable minerals from the ore. The mineral bearing ore that passes through the screen is then further concentrated in smaller devices such as sluices and jigs. The larger pieces of ore that do not pass through the screen can be carried to a waste stack by a conveyor.

Environmental effects

Although not required, the process water may be continuously recycled and the ore from which the sought after minerals have been extracted ("the tailings") can be reclaimed. While these recycling and reclamation processes are more common in modern placer mining operations they are still not universally done.



A pan used to extract gold.

In earlier times the process water was not generally recycled and the spent ore was not reclaimed. The remains of a Roman alluvial gold mine at Las Médulas are so spectacular as to justify the site being designated UNESCO World Heritage status. The methods used by the Roman miners are fully described by Pliny the Elder in his work *Naturalis Historia* published in about 77 AD. The author was a Procurator in the region and so probably witnessed large-scale hydraulic mining of the placer deposits there. He also added that the local lake Curacado had been heavily silted by the mining methods.

Environmental activists describe the hydraulic mining form of placer mining as environmentally destructive because of the large amounts of silt that it adds to previously clear running streams (also known as the "Dahlongega Method" <Dahlongega, Georgia>). Most placer mines today use settling ponds, if only to ensure that they have sufficient water to run their sluicing operations.

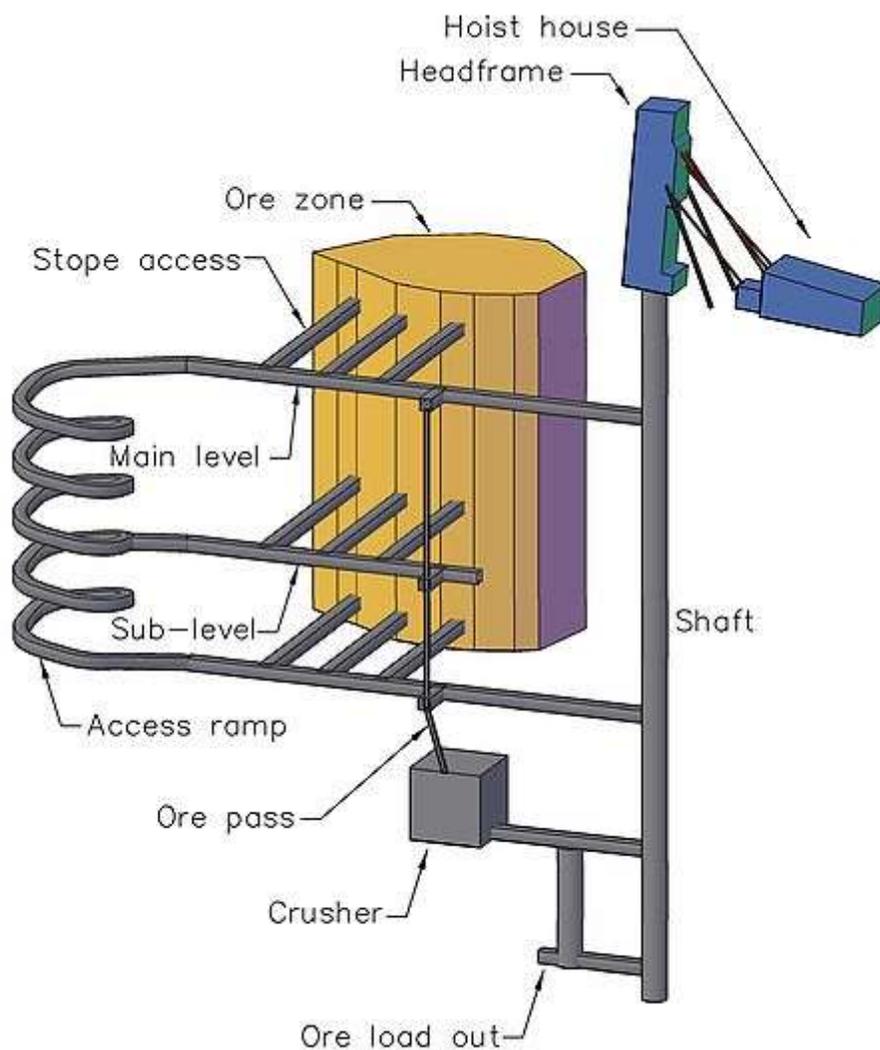


Panoramic view of Las Médulas

In California, from 1853 to 1884, "hydraulic mining" of placers removed an enormous amount of material from the gold fields, material that was carried downstream and raised the level of the Central Valley by some seven feet in some areas and settled in long bars up to 20 feet thick in parts of San Francisco Bay. The process raised an opposition calling themselves the "Anti-Debris Association". In January 1884, a United States District Court banned the flushing of debris into streams, and the hydraulic mining mania in California's gold country came to an end.

Chapter- 6

Underground Mining (Hard Rock)



A three dimensional model of an underground mine with shaft access

Underground hard rock mining refers to various underground mining techniques used to excavate *hard* minerals, mainly those minerals containing metals such as ore containing gold, copper, zinc, nickel and lead, but also involves using the same techniques for excavating ores of gems such as diamonds. In contrast soft rock mining refers to excavation of softer minerals such as salt, coal, or oil sands.

Mine access

Underground access

Accessing underground ore can be achieved via a decline (ramp), inclined vertical shaft or adit.



Decline portal at Wiluna Gold Mine

- **Declines** can be a spiral tunnel which circles either the flank of the deposit or circles around the deposit. The decline begins with a box cut, which is the portal to the surface. Depending on the amount of overburden and quality of bedrock, a galvanized steel culvert may be required for safety purposes. They may also be started into the wall of an open cut mine.
- **Shafts** are vertical excavations sunk adjacent to an ore body. Shafts are sunk for ore bodies where haulage to surface via truck is not economical. Shaft haulage is more economical than truck haulage at depth, and a mine may have both a decline and a ramp.
- **Adits** are horizontal excavations into the side of a hill or mountain. They are used for horizontal or near-horizontal ore bodies where there is no need for a ramp or shaft.

Declines are often started from the side of the high wall of an open cut mine when the ore body is of a payable grade sufficient to support an underground mining operation but the strip ratio has become too great to support open cast extraction methods. They are also often built and maintained as an emergency safety access from the underground workings and a means of moving large equipment to the workings.

Ore access

Levels are excavated horizontally off the decline or shaft to access the ore body. Stopes are then excavated perpendicular (or near perpendicular) to the level into the ore.

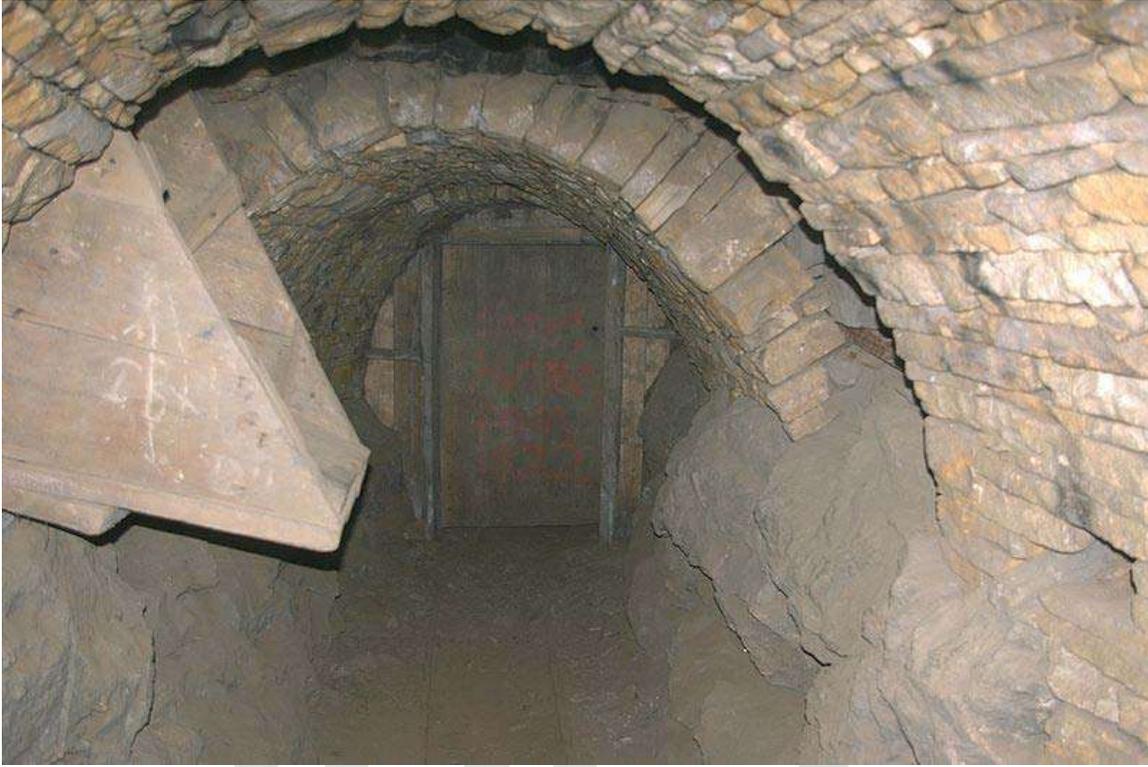
Development mining vs. production mining

There are two principal phases of underground mining: development mining and production mining.

Development mining is composed of excavation almost entirely in (non-valuable) waste rock in order to gain access to the orebody. There are six steps in development mining: remove previously blasted material (muck out round), Scaling (removing any unstable slabs of rock hanging from the roof and sidewalls to protect workers and equipment from damage), support excavation, drill rock face, load explosives, and blast explosives.

Production mining is further broken down into two methods, long hole and short hole. Short hole mining is similar to development mining, except that it occurs in ore. There are several different methods of long hole mining. Typically long hole mining requires two excavations within the ore at different elevations below surface, (15 m – 30 m apart). Holes are drilled between the two excavations and loaded with explosives. The holes are blasted and the ore is removed from the bottom excavation.

Ventilation



Door for directing ventilation in an old lead mine. The ore hopper at the front is not part of the ventilation.

One of the most important aspects of underground hard rock mining is ventilation. Ventilation is required to clear toxic fumes from blasting and removing exhaust fumes from diesel equipment. In deep hot mines ventilation is also required for cooling the workplace for miners. Ventilation raises are excavated to provide ventilation for the workplaces, and can be modified for use as emergency escape routes. The primary sources of heat in underground hard rock mines are virgin rock temperature, machinery, auto compression, and fissure water. Other small contributing factors are human body heat and blasting.

Ground support

Some means of support is required in order to maintain the stability of the openings that are excavated. This support comes in two forms, local support and area support.

Area ground support

Area ground support is used to prevent major ground failure. Holes are drilled into the back (ceiling) and walls and a long steel rod (or rock bolt) is installed to hold the ground

together. There are three categories of rock bolt, differentiated by how they engage the host rock. They are:

Mechanical bolts

- **Point anchor bolts** (or expansion shell bolts) are a common style of area ground support. A point anchor bolt is a metal bar between 20 mm – 25 mm in diameter, and between 1 m – 4 m long (the size is determined by the mine's engineering department). There is an expansion shell at the end of the bolt which is inserted into the hole. As the bolt is tightened by the installation drill the expansion shell expands and the bolt tightens holding the rock together. Mechanical bolts are considered temporary support as their lifespan is reduced by corrosion as they are not grouted.

Grouted bolts

- **Resin grouted rebar** is used in areas which require more support than a point anchor bolt can give. The rebar used is of similar size as a point anchor bolt but does not have an expansion shell. Once the hole for the rebar is drilled, cartridges of epoxy resin are installed in the hole. The rebar bolt is installed after the resin and spun by the installation drill. This opens the resin cartridge and mixes it. Once the resin hardens the drill spinning tightens the rebar bolt holding the rock together. Resin grouted rebar is considered a permanent ground support with a lifespan of 20–30 years.
- **Cable bolts** are used to bind large masses of rock in the hanging wall and around large excavations. Cable bolts are much larger than standard rock bolts and rebar, usually between 10–25 metres long. Cable bolts are grouted with a cement grout.

Friction bolts

- **Friction stabilizer** (frequently called by the genericized trademark *Split Set*) are much easier to install than mechanical bolts or grouted bolts. The bolt is hammered into the drill hole, which has a smaller diameter than the bolt. Pressure from the bolt on the wall holds the rock together. Friction stabilizers are particularly susceptible to corrosion and rust from water unless they are grouted. Once grouted the friction increases by a factor of 3-4.
- **Swellex** is similar to Friction stabilizers, except the bolt diameter is smaller than the hole diameter. High pressure water is injected into the bolt to expand the bolt diameter to hold the rock together. Like the friction stabilizer, swellex is poorly protected from corrosion and rust.

Local ground support

Local ground support is used to prevent smaller rocks from falling from the backs and walls. Not all excavations require local ground support.

- **Welded Wire Mesh** is a metal screen with 10 cm x 10 cm (4 inch) openings. It is held to the backs using point anchor bolts or resin grouted rebar.
- **Shotcrete** is fibre reinforced spray on concrete which coats the backs and walls preventing smaller rocks from falling. Shotcrete thickness can be between 50 mm – 100 mm.
- **Latex Membranes** can be sprayed on the backs and walls similar to shotcrete, but in smaller amounts.

Stope and retreat vs. stope and fill

Stope and retreat



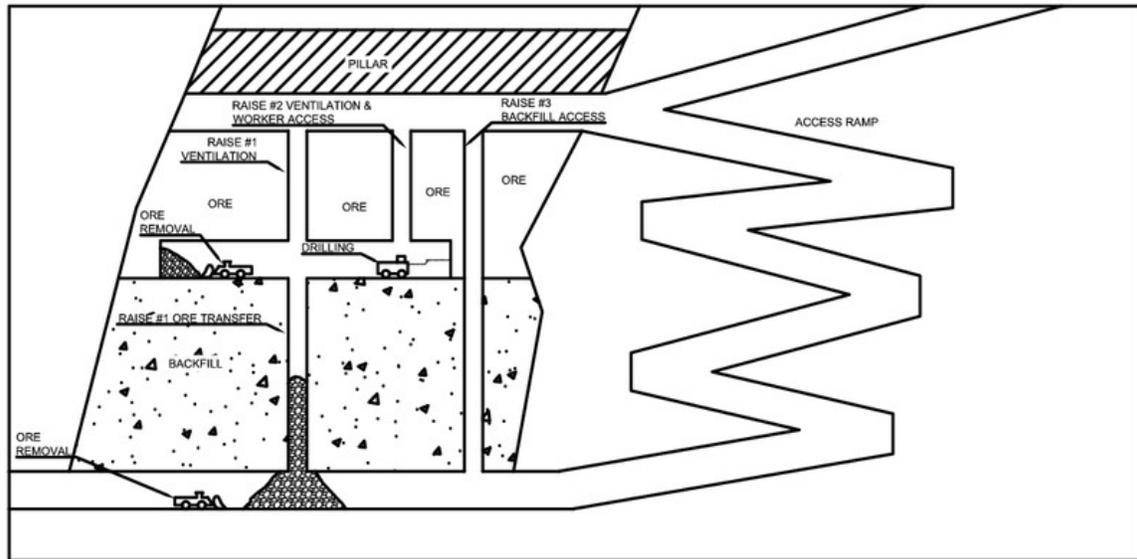
Sub-Level Caving Subsidence reaches surface at the Ridgeway underground mine

Using this method, mining is planned to extract rock from the stopes without filling the voids; this allows the wall rocks to cave in to the extracted stope after all the ore has been removed. The stope is then sealed to prevent access.

Stope and fill

Where large bulk ore bodies are to be mined at great depth, or where leaving pillars of ore is uneconomical, the open stope is filled with backfill, which can be a cement and rock mixture, a cement and sand mixture or a cement and tailings mixture. This method is popular as the refilled stopes provide support for the adjacent stopes, allowing total extraction of economic resources.

Mining methods



Schematic diagram of Cut and Fill mining

Selective mining methods

- **Cut and Fill** mining is a method of short hole mining used in steeply dipping or irregular ore zones, in particular where the hanging wall limits the use of long hole methods. The ore is mined in horizontal or slightly inclined slices, and then filled with waste rock, sand or tailings. Either fill option may be consolidated with concrete, or left unconsolidated. Cut and fill mining is an expensive but selective method, with low ore loss and dilution.
- **Drift and Fill** is similar to cut and fill, except it is used in ore zones which are wider than the method of drifting will allow to be mined. In this case the first drift is developed in the ore, and is backfilled using consolidated fill. The second drift is driven adjacent to the first drift. This carries on until the ore zone is mined out to its full width, at which time the second cut is started atop of the first cut.
- **Shrinkage Stopping** is a short hole mining method which is suitable for steeply dipping orebodies. The method is similar to cut and fill mining with the exception that after being blasted, broken ore is left in the stope where it is used to support the surrounding rock and as a platform from which to work. Only enough ore is removed from the stope to allow for drilling and blasting the next slice. The stope is emptied when all of the ore has been blasted. Although it is very selective and allows for low dilution, since the most of the ore stays in the stope until mining is completed there is a delayed return on capital investments.

- **Room and Pillar mining** : Room and pillar mining is commonly done in flat or gently dipping bedded ore bodies. Pillars are left in place in a regular pattern while the rooms are mined out. In many room and pillar mines, the pillars are taken out starting at the farthest point from the stope access, allowing the roof to collapse and fill in the stope. This allows for greater recovery as less ore is left behind in pillars.

Bulk mining methods

- **Block Caving** is used to mine massive steeply dipping orebodies (typically low grade) with high friability. An undercut with haulage access is driven under the orebody, with "drawbells" excavated over the undercut. The drawbells serve as a place for caving rock to fall into. The orebody is drilled and blasted above the undercut, and the ore is removed via the haulage access. Due to the friability of the orebody the ore above the first blast caves and falls into the drawbells. As ore is removed from the drawbells the orebody caves in providing a steady stream of ore. If caving stops and removal of ore from the drawbells continues, a large void may form, resulting in the potential for a sudden and massive collapse and potentially catastrophic windblast throughout the mine.

Orebodies that do not cave readily are sometimes preconditioned by hydraulic fracturing, blasting, or by a combination of both. Hydraulic fracturing has been applied to preconditioning strong roof rock over coal longwall panels and to inducing caving in both coal and hard rock mines.

Ore removal

In mines which use rubber tired equipment for coarse ore removal, the ore is removed from the stope (referred to as "mucked out" or "bogged") using center articulated vehicles (referred to as boggers or LHD [short for Load, Haul, Dump]). These pieces of equipment may operate using diesel or electric engines and resemble a low-profile front end loader.

The ore is then dumped into a truck to be hauled to the surface (in shallower mines). In deeper mines the ore is dumped down an ore pass (a vertical or near vertical excavation) where it falls to a collection level. On the collection level, it may receive primary crushing via jaw or cone crusher. The ore is then moved by conveyor belts, trucks or occasionally trains to the shaft to be hoisted to the surface in buckets or skips and emptied into bins beneath the surface headframe for transport to the mill.

In some cases the underground primary crusher feeds an inclined conveyor belt which delivers ore via an incline shaft direct to the surface. The ore is fed down ore passes, with mining equipment accessing the ore body via a decline from surface.

Deepest mines

- The deepest mines in the world are the TauTona (Western Deep Levels) and Savuka gold mines in the Witwatersrand region of South Africa, which are currently working at depths exceeding 3,900 m (12,800 ft). There are plans to extend Mponeng mine, a sister mine to TauTona, down to 4,500 m (14,800 ft) in the coming years.
- The deepest hard rock mine in North America is Agnico-Eagle's LaRonde mine, which mines gold, zinc, copper and silver ores roughly 45 km (28 mi) east of Rouyn-Noranda in Cadillac, Quebec. LaRonde's Penna shaft (#3 shaft) is believed to be the deepest single lift shaft in the Western Hemisphere. The new #4 shaft bottoms out at over 3,000 m (9,800 ft) down. Their LaRonde mine expansion sees open stopes down to a depth of over 3,000 m (9,800 ft), the deepest longhole open stopes in the world.
- The deepest hard rock mines in Australia are the copper and zinc lead mines in Mount Isa, Queensland at 1,800 m (5,900 ft).
- The deepest platinum-palladium mines in the world are on the Merensky Reef, in South Africa, with a resource of 203 million Troy ounces, currently worked to approximately 2,200 m (7,200 ft) depth.
- The harshest conditions for hard rock mining are in the Witwatersrand area of South Africa, where workers toil in temperatures of up to 45°C (113°F). However, massive refrigeration plants are used to bring the air temperature down to around 28°C (82°F).

Chapter- 7

Underground Mining (Soft Rock)

Underground mining (soft rock) refers to a group of underground mining techniques used to extract coal, oil shale and other minerals or geological materials from sedimentary ("soft") rocks. Because deposits in sedimentary rocks are commonly layered and relatively less hard, the mining methods used differ from those used to mine deposits in igneous or metamorphic rocks. Underground mining techniques also differ greatly from those of surface mining.

Methods

- **Longwall mining** - A set of longwall mining equipment consists of a coal shearer mounted on conveyor operating underneath a series of self-advancing hydraulic roof supports. Almost the entire process can be automated. Longwall mining machines are typically 150-250 metres in width and 1.5 to 3 metres high. Longwall miners extract "panels" - rectangular blocks of coal as wide as the face the equipment is installed in, and as long as several kilometres. Powerful mechanical coal cutters (shearers) cut coal from the face, which falls onto an armoured face conveyor for removal. Longwalls can advance into an area of coal, or more commonly, retreat back between development tunnels (called "gateroads") As a longwall miner retreats back along a panel, the roof behind the supports is allowed to collapse in a planned and controlled manner.
- **Room-and-pillar mining** or **continuous mining** - Room and pillar mining is commonly done in flat or gently dipping bedded ores. Pillars are left in place in a regular pattern while the rooms are mined out. In many room and pillar mines, the pillars are taken out, starting at the farthest point from the mine haulage exit, retreating, and letting the roof come down upon the floor. Room and pillar methods are well adapted to mechanization, and are used in deposits such as coal, potash, phosphate, salt, oil shale, and bedded uranium ores.
- **Blast mining** – An older practice of coal mining that uses explosives such as dynamite to break up the coal seam, after which the coal is gathered and loaded onto shuttle cars or conveyors for removal to a central loading area. This process consists of a series of operations that begins with "cutting" the coalbed so it will

break easily when blasted with explosives. This type of mining accounts for less than 5% of total underground production in the U.S. today.

- **Shortwall mining**– A coal mining method that accounts for less than 1% of deep coal production, shortwall involves the use of a continuous mining machine with moveable roof supports, similar to longwall. The continuous miner shears coal panels 150–200 feet wide and more than a half-mile long, depending on other things like the strata of the Earth and the transverse waves.

Mine Shorthand

The number sign, or hash sign (#) is often used as shorthand to denote shaft or seam, as in 4# (4 shaft or seam depending on context).

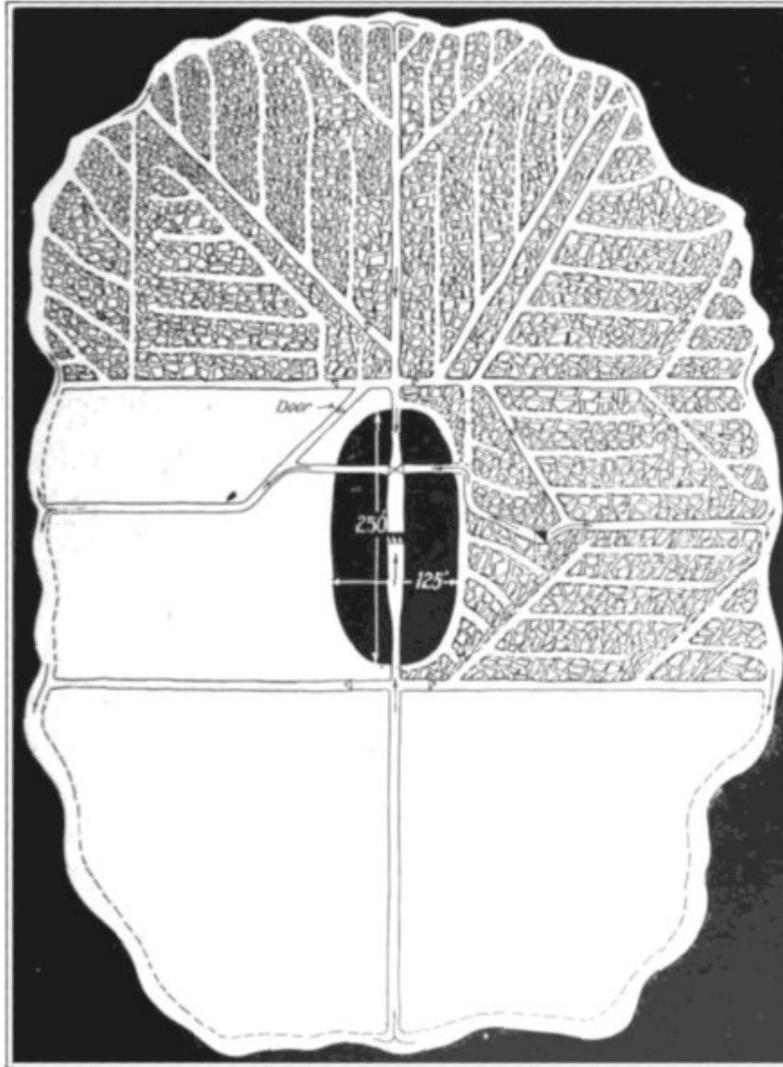
Longwall mining



Longwall mining

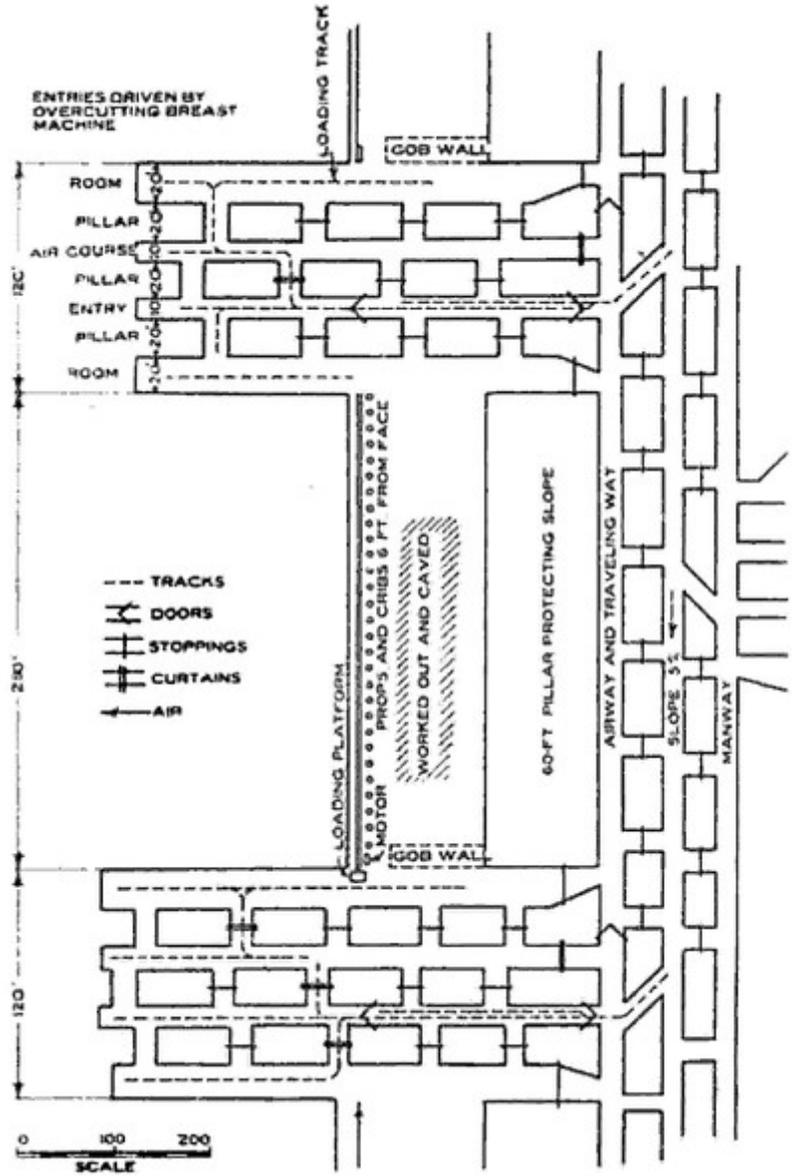
Longwall mining is a form of underground coal mining where a long wall of coal is mined in a single slice (typically 1–2 m thick). The longwall *panel* (the block of coal that is being mined) is typically 3–4 km long and 250–400 m wide.

History

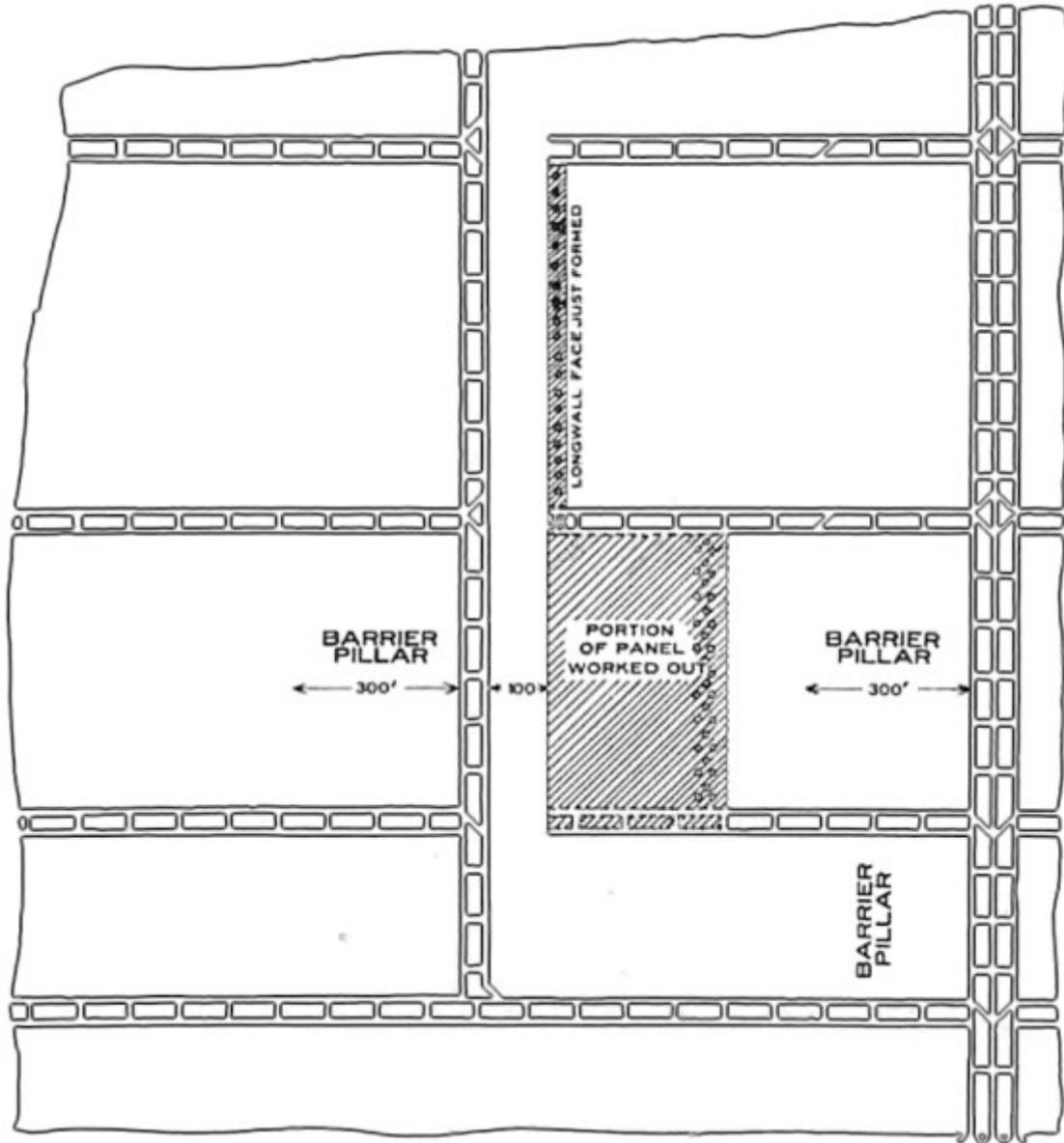


Plan of longwall mine before conveyors, hoist is at the center of the central pillar

The basic idea of longwall mining was developed in England in the late 17th century. Miners would undercut the coal along the width of the coal face, removing coal as it fell, and using wooden props to control the fall of the roof behind the face. This was known as the *Shropshire method* of mining. While the technology has changed considerably, the basic idea remains the same, to remove essentially all of the coal from a broad coal face and allow the roof and overlying rock to collapse into the void behind, while maintaining a safe working space along the face for the miners.



Oklahoma advancing longwall mine circa 1917, arrows show airflow



West Virginia retreating longwall mine circa 1917

Starting around 1900, mechanization was applied to this method. By 1940, some referred to longwall mining as "the conveyor method" of mining, after the most prominent piece of machinery involved. Unlike earlier longwall mining, the use of a conveyor belt parallel to the coal face forced the face to be developed along a straight line. The only other machinery used were an electric cutter to undercut the coal face and electric drills for blasting to drop the face. Once dropped, manual labor was used to load coal onto the conveyor parallel to the face and to place wooden roof props to control the fall of the roof.

Such low-technology longwall mines continued in operation into the 1970s. The best known example of this was the New Gladstone Mine near Centerville, Iowa "one of the

last advancing longwall mines in the United States." This longwall mine did not even use a conveyor belt, but relied on ponies to haul coal tubs from the face to the slope where a hoist hauled the tubs to the surface.

Longwall mining has been extensively used as the final stage in mining old room and pillar mines. In this context, Longwall mining can be classified as a form of retreat mining.

Layout

Gate roads are driven to the back of each panel before longwall mining begins. The gate road along one side of the block is called the *maingate* or *headgate*; the road on the other side is called the *tailgate*. Where the thickness of the coal allows, these gate roads have been previously developed by continuous miner units, as the longwall itself is not capable of the initial development. In thinner seams the advancing longwall mining method may be used. In this system the gate roads are formed as the coal face advances.

Only the maingate road is formed in advance of the face. The tailgate road is formed behind the coal face by removing the stone above coal height to form a roadway that is high enough to travel in. The end of the block that includes the longwall equipment is called the face. The other end of the block is usually one of the main travel roads of the mine. The cavity behind the longwall is called the *goaf*, *goff* or *gob*.

Ventilation

Fresh air travels up the main gate, across the face, and then down the tail gate. Once past the face the air is no longer fresh air, but return air carrying away coal dust and mine gases such as methane, carbon dioxide, depending on the geology of the coal. Return air is extracted by ventilation fans mounted on the surface. A series of seals are erected as mining progresses to maintain goaf gas levels.

Typically to avoid coal in the goaf spontaneously combusting, goaf gases are allowed to build up so as to exclude oxygen from the goafed area. This means that there is an explosive goaf fringe between the face and the goaf at all times requiring constant monitoring.

Equipment



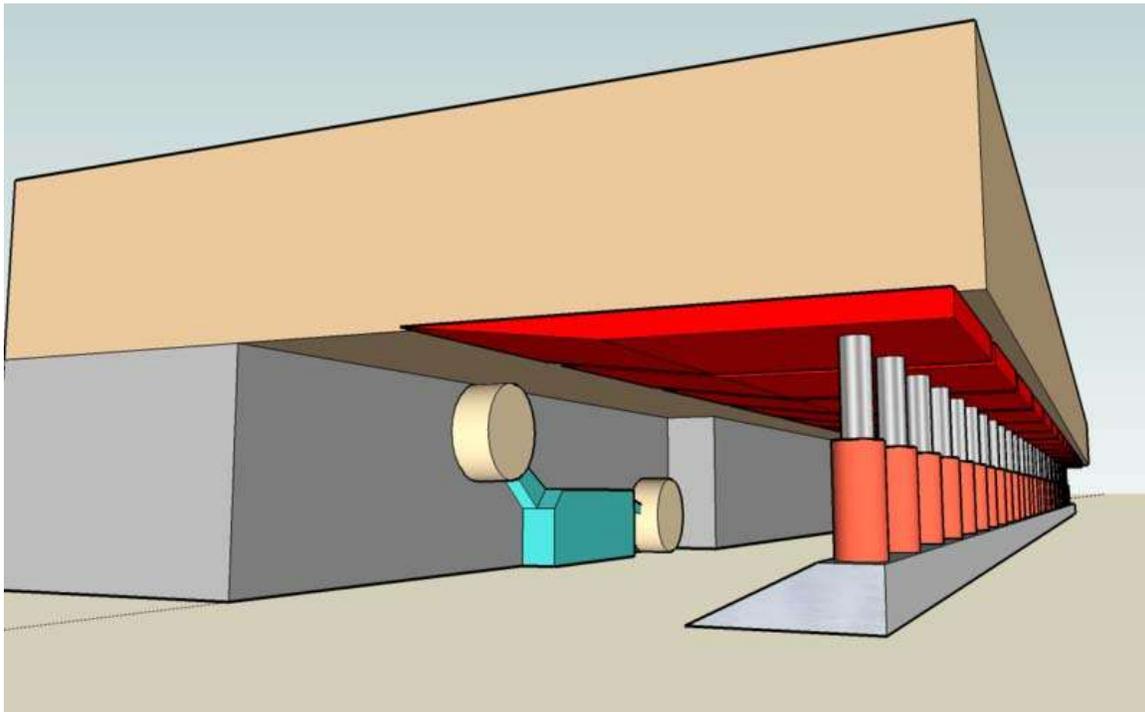
Hydraulic chocks

A number of hydraulic jacks, called *powered roof supports*, *chocks* or *shields*, which are typically 1.75 m wide and placed in a long line, side by side for up to 400 m in length in order to support the roof of the coalface. An individual chock can weigh 30–40 tonnes, extend to a maximum cutting height of up to 6 m and have yield rating of 1000–1250 tonnes each, and hydraulically advance itself 1 m at a time.



Hydraulic chocks, conveyor and shearer

The coal is cut from the coalface by a machine called the *shearer (power loader)*. This machine can weigh 75–120 tonnes typically and comprises a main body, housing the electrical functions, the tractive motive units to move the shearer along the coalface and pumping units (to power both hydraulic and water functions). At either end of the main body are fitted the ranging arms which can be ranged vertically up down by means of hydraulic rams, and onto which are mounted the shearer cutting drums which are fitted 40–60 cutting picks. Within the ranging arms are housed very powerful electric motors (typically up to 850 kW) which transfer their power through a series of lay gears within the body the arms to the drum mounting locations at the extreme ends of the ranging arms where the cutting drums are. The cutting drums are rotated at a speed of 20–50 revs/min to cut the mineral from coal seam.



Chocks providing support to allow shearer to work

The shearer is carried along the length of the face on the *armoured face conveyor (AFC)*; using a chain-less haulage system, which resembles a ruggedised rack and pinion system especially developed for mining. Before chainless haulage systems, a heavy duty chain was run the length of the coal face for the shearer to pull itself along. The shearer moves at a speed of 10–30 m/min depending on cutting conditions.

The AFC is placed in front of the powered roof supports, and the shearing action of the rotating drums cutting into the coal seam disintegrates the coal, this being loaded onto the AFC. The coal is removed from the coal face by a scraper chain conveyor to the main gate. Here it is loaded onto a network of conveyor belts for transport to the surface. At the main gate the coal is usually reduced in size in a crusher, and loaded onto the first conveyor belt by the *beam stage loader (BSL)*.

As the shearer removes the coal, the AFC is snaked over behind the shearer and the powered roof supports move forward into the newly created cavity. As mining progresses and the entire longwall progresses through the seam, the goaf increases. This goaf collapses under the weight of the overlying strata. The strata approximately 2.5 times the thickness of the coal seam removed collapses and the beds above settle onto the collapsed goaf. This collapsing can lower surface height, causing problems like changing the course of rivers and severely damage building foundations.

Comparison with room and pillar method

Longwall and room and pillar methods of mining can both be used for mining suitable underground coal seams. Longwall has better resource recovery (about 80% compared with about 60% for room and pillar method, fewer roof support consumables are needed, higher volume coal clearance systems, minimal manual handling and safety of the miners is enhanced by the fact that they are always under the hydraulic roof supports when they are extracting coal.

Subsidence

Subsidence is largely immediate, allowing for better planning and more accountability by the mining company. There have been cases of surface subsidence altering the landscape above the mines. At Newstan Colliery in New South Wales, Australia "the surface has dropped by as much as five metres in places" above a multi level mine. In some cases the subsidence causes damage to natural features such as drainage to water courses or man-made structures such as roads and buildings. "Douglas Park Drive was closed for four weeks because longwall panels... destabilised the road. In 2000, the State Government stopped mining when it came within 600 metres from the twin bridges. A year later there were reports of 40-centimetre gaps appearing in the road, and the bridge had to be jacked sideways to realign it." p. 2

A 2005 geotechnical report commissioned by the NSW RTA warns that "subsidence could happen suddenly and occur over many years."

Room and pillar

Room and pillar (also called bord and pillar) is a mining system in which the mined material is extracted across a horizontal plane while leaving "pillars" of untouched material to support the roof overburden leaving open areas or "rooms" underground. It is usually used for relatively flat-lying deposits, such as those that follow a particular stratum.

The room and pillar system is used in mining coal, iron and base metals ores particularly when found as manto or blanket deposits, stone and aggregates, talc, soda ash and potash.

The key to the successful room and pillar mining is selecting the optimum pillar size. If the pillars are too small the mine will collapse. If the pillars are too large then significant quantities of valuable material will be left behind reducing the profitability of the mine. The percentage of material mined varies depending on many factors, including the material mined, height of the pillar, and roof conditions; typical values are: stone and aggregates 75%, coal 60%, and potash 50%.

History

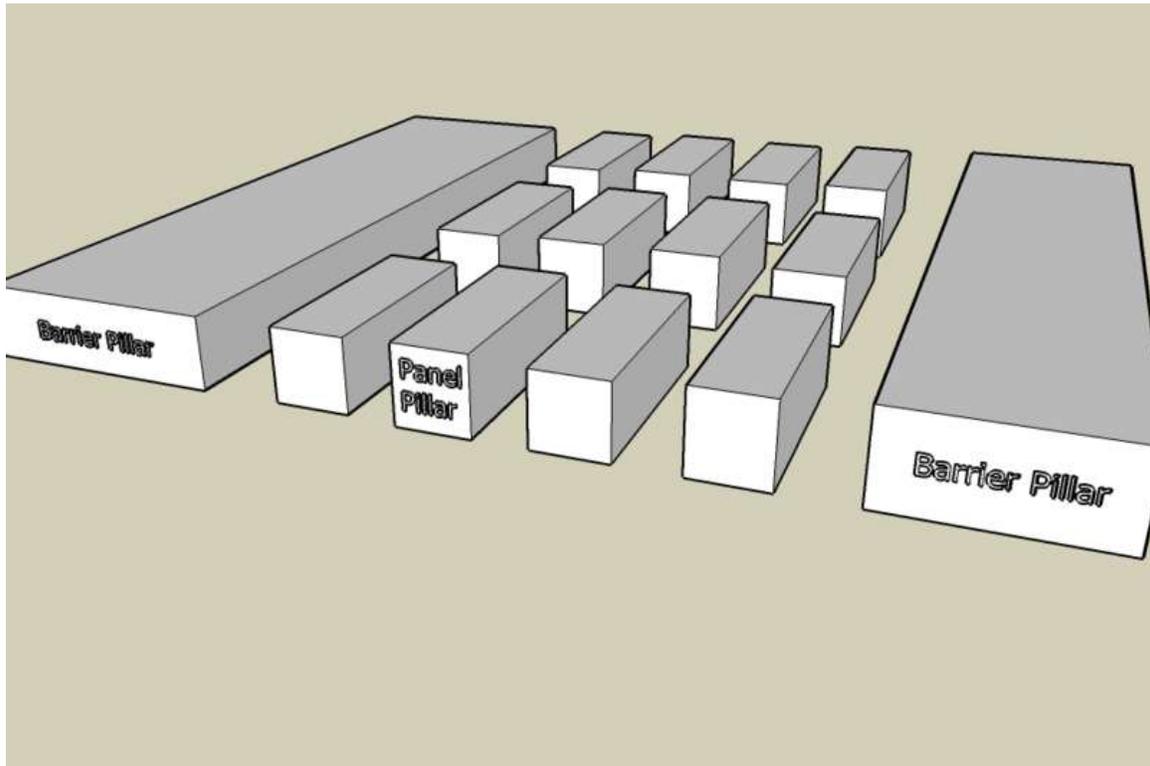


A Maryland coal mine from 1850

Room and pillar mining is one of the oldest mining methods. Early room and pillar mines were developed more or less at random, with pillar sizes determined empirically and headings driven in whatever direction was convenient.

Random mine layout makes ventilation planning difficult, and if the pillars are too small, there is the risk of pillar failure. In coal mines, pillar failures are known as squeezes because the roof squeezes down, crushing the pillars. Once one pillar fails, the weight on the adjacent pillars increases, and the result is a chain reaction of pillar failures. Once started, such chain reactions can be extremely difficult to stop, even if they spread slowly.

Mine Layout



Room and Pillar mines are developed on a grid basis except where geological features such as faults require the regular pattern to be modified. The size of the pillars is determined by calculation. The load bearing capacity of the material above and below the material being mined and the capacity of the mined material itself will determine the pillar size.

If one pillar fails and surrounding pillars are unable to support the area previously supported by the failed pillar they may in turn fail. This could lead to the collapse of the whole mine. To prevent this the mine is divided up into areas or panels. Pillars known as barrier pillars separate the panels. The barrier pillars are significantly larger than the "panel" pillars and are sized to allow them to support a significant part of the panel and prevent progressive collapse of the mine in the event of failure of the panel pillars.

Rock blasting

Rock blasting is the controlled use of explosives (or other methods such as gas pressure pyrotechnics or plasma processes) to excavate, break down or remove rock. It is practised most often in mining, quarrying and civil engineering such as dam construction.



Blast hole drilling with Tamrock Scout 700



Loading drilled holes with ANFO



Rock surface newly blasted



Sideling Hill road cut formed by rock blasting

The use of explosives in mining goes back to the year 1627, when gunpowder was first used in place of mechanical tools in the Hungarian (now Slovakian) town of Banská Štiavnica. The innovation spread quickly throughout Europe and the Americas.

In 1990, 2.1 million tonnes (2.32 million short tons) of commercial explosives were consumed in the USA, representing an estimated expenditure of 3.5 to 4 billion 1993 dollars on blasting. Australia had the highest explosives consumption that year at 500 million tonnes (551 million short tons), with Scandinavian countries another leader in rock blasting (Persson et al. 1994:1).

Chapter- 8

Underground Mining Techniques

Box cut

A **box cut** is a small open cut created to provide a secure and safe portal as access to a decline to an underground mine. Generally the box cut is sunk until sufficiently unweathered rock is found to permit the development of the decline. The portal is generally made safe with rock bolts, wire mesh, and shotcrete, which prevents accidental rock falls from closing access to the decline.

Adit



Gated entrance of an abandoned adit near Medford, Oregon, USA



Adit in the abandoned stibnite mine, Kuchyňa, Slovakia

An **adit** is an entrance to an underground mine which is horizontal or nearly horizontal, by which the mine can be entered, drained of water, and ventilated.

Construction

Adits are driven into the side of a hill or mountain, and are often used when an ore body is located inside the mountain but above the adjacent valley floor or coastal plain. In cases where the mineral vein outcrops at the surface, the adit may follow the lode or vein until it is worked out, in this case the adit is rarely straight. The use of adits for the extraction of ore is generally called drift mining.

Adits can only be driven into a mine where the local topography permits. There will be no opportunity to drive an adit to a mine situated on a large flat plain, for instance. Also if the ground is weak, the cost of shoring up a long adit may outweigh its possible advantages.

Access and ventilation

Access to a mine by adit has many advantages over the vertical access shafts used in shaft mining. Less energy is required to transport miners and heavy equipment into and out of the mine. It is also much easier to bring ore or coal out of the mine. Horizontal travel by

means of narrow gauge tramway or cable car is also much safer and can move more people and ore than vertical elevators.

In combination with shafts, adits form an important element in the ventilation of a mine: in simple terms, cool air will enter through an adit, be warmed by the higher temperature underground and will naturally exhaust from vertical shafts, some of which are sunk specifically for this purpose and are known as "ventilation shafts".

Drainage



A small, almost hidden adit entrance at Eylesbarrow mine, Dartmoor, Devon

Most adits are designed to slope slightly upwards from the entrance so that water will flow freely out of the mine. Mines that have adits can be at least partly drained of water by gravity alone or power-assisted gravity. The depth to which a mine can be drained by gravity alone is defined by the deepest open adit which is known as the "drainage adit". Workings above this level (known as "above adit") will remain unflooded as long as the adit does not become blocked. All mine workings below both the drainage adit ("below adit") and the water table will flood unless mechanical means are used for drainage. Until the invention of the steam engine this was the main restriction on deep mining. Of course, adits are still useful for deeper mines because the water only needs to be raised to the drainage adit rather than to the surface.

Because of the great reduction in ongoing costs that a drainage adit can provide, they have sometimes been driven for great distances just for this purpose, one such being the Milwr tunnel in North Wales, which is about ten miles long. Another example is the Great County Adit in Cornwall, a 40-mile-long network of adits that used to drain the whole Gwennap mining area. A side benefit of driving such extensive adits is that previously unknown ore-bodies can be discovered, helping finance the enormous cost.

Adits were in use in Cornwall well before 1500 and were particularly important to the tin and copper mines in Cornwall and Devon because the ore-bearing veins here are near-vertical and act as channels through which water can easily seep. There are many reports of torrents of warm or hot water continuously pouring into the lower levels of Cornish mines.

Notable examples

- Great County Adit, a system of nearly 40 miles of adits used for dewatering the mines in the Gwennap area of Cornwall in the 18th and early 19th centuries.
- Milwr tunnel, a ten-mile-long drainage adit in North Wales. Started in 1897, it still discharges an average of 23 million gallons of water per day from the disused Halkyn District United Mines.
- The Snowy Hydro scheme in the Australian Snowy Mountains created during its construction. These adits are very large and used to access the central point from which the hydro tunnels were constructed.
- Black Trout Adit in Tarnowskie Góry, Poland. It is a part of former silver mine, the adit was used for removing the water out of the mine. It still carries water from old galleries to the nearest river, a part of it is open for tourists, who go 20m down the steps in one shaft, have a ride in a boat and go up the stairs in another shaft.
- Blue Hawk Mine near Kelowna, BC, Canada

Similar terms

- A "drift" is a more general term for any near-horizontal underground passage in a mine. Unlike an adit, a drift need not break out to the surface. Drift mining is the use of drifts to extract ore - in this case the drifts follow the vein.
- A "level" is a horizontal passage that branches off from a shaft and is used for access to the parts of the mine where the ore is being removed. In mines where the lodes have significant vertical extent there can be many numbered levels, one below the other. They can be connected by short vertical shafts known as "winzes". A level that reaches the surface, on a hillside or in a valley, for instance, is called an "adit level".
- "Sough" is a term mainly used in the lead mining areas of Derbyshire. The main purpose of a sough is to drain water from the mine.

Cross brace

Cross brace is the cross-beam connecting the next arches for giving of rigidity at construction of minings and tunnels, more often tubular round diameter (as a rule, it is made of scraps of pipes), on the ends with clips or apertures for screw fastening; serves as an element stiffening and stability of a design. There are also other forms; at times, this word name ordinary cross-section wooden cross-beam, or even a board.

Drift mining

Drift mining is either the mining of a placer deposit by underground methods, or the working of coal seams accessed by adits driven into the surface outcrop of the coal bed. **Drift** is a more general mining term, meaning a near-horizontal passageway in a mine, following the bed (of coal, for instance) or vein of ore. A drift may or may not intersect the ground surface. This kind of mining is done when the rock or mineral is on the side of a hill.



Drift mine entry in West Virginia, 1908. Photo by Lewis Hine.

Nome, Alaska

Drift mining methods were used extensively to mine placer deposits during the early years of the Nome mining district. During summer, surface deposits could be worked, but some placer deposits were buried too deeply for surface placering. In addition, water to wash the gold from the placers was not available in the winter. Many miners tunnelled into deep placer deposits, bringing out the high-grade gravels to be washed at the spring thaw. Most of the ground in Nome is permafrost. By drift mining, miners were able to recover much of the gold buried under the permafrost.

Gold at Nome was concentrated in three ancient beach lines, now inshore, above sea level, and buried under roughly fifty feet of permafrost overlain by two feet of tundra. Gold was usually found on top of either bedrock or "false bedrock," a layer of clay that occurred at the base of the beach or stream deposit.

The miners initially sank shafts to prospect for the pay streaks. This was done by building a fire atop the permafrost, and, each day as it melted, shoveling away the mud. The process would be continued down to either a pay streak or bedrock. When the gold was found, the drift mining began.

Once they had found a pay streak, miners would tunnel horizontally from the bottom of their prospect shaft, and follow the gold along the surface of the bedrock. The tunnels, because the ground was frozen, would not cave in. Miners discovered old underground beach and river gravels rich with gold. Around 1900 the population of Nome was more than twenty thousand, many of them drift miners. Nome's gold fields, appearing untouched from the surface, are honeycombed with tunnels left by the gold rush drift miners. Today's miners, prospecting with modern drilling equipment, sometimes hit old drifts.

Headframe



The Kintore Headframe and winding drums in Broken Hill, NSW



Steely headframe of Otiliae shaft (1876) in Clausthal-Zellerfeld. It is the oldest existing headframe in Germany.

A **headframe** (also known as a **gallows frame**, **winding tower**, **hoist frame**, **pit frame**, **shafthead frame**, or **headgear**) is the structural frame above an underground mine shaft. Modern headframes are built out of steel, concrete or a combination of both. Timber headframes are no longer used in industrialized countries, but are still used in developing nations. Traditionally steel headframes are used when a drum hoist is employed, and concrete headframes are built for friction hoists, however a steel headframe can be used with a friction hoist for shafts with a smaller capacity and depth.

Benefits of steel headframes



Headframe of the #1 Shaft at Oyuu Tolgoi

A steel headframe is less expensive than a concrete headframe providing the height (defined as the vertical distance from the collar elevation to the center-line of the highest head sheave) does not exceed 50m. Steel headframes are more adaptable to modifications (making any construction errors easier to remedy), and are considerably lighter, requiring less substantial foundations. As steel headframes are easier to design, they have the potential to utilize "off the shelf" design tools. Construction of a steel headframe can be easily interrupted and restarted if necessary for statutory holidays or bad weather, where slip forming concrete is not. Upon mine closure and mine reclamation a steel headframe is easier to demolish and may have value as scrap metal.

A recently erected steel headgear in the Zamabian copper belt town of Chililemombwe at the Konkola number 4 shaft, has total height of 81 metres to the top of the maintenance crane rail, with the centre-line of the head sheaves at 71 metres above collar, making it highest steel headgear in Africa.

Benefits of concrete headframes



The enclosed #2 Headframe (left) and the Hoist House (right) of the Quincy Mine

Concrete headframes require less maintenance and are less susceptible to corrosion than steel headframes. There is much less waste of concrete during construction of a concrete headframe than there is of steel in construction of a steel headframe. Concrete headframes provide an enclosure upon construction, where steel headframes require cladding and insulation to protect from weather. Concrete headframes are less susceptible to vibrations, and sway less during high winds. Concrete is usually more readily available than steel (except in remote locations), and the price is predictable, where fabricated steel prices can be volatile.

Symbolism

Headframes have become prominent features in historic mining regions. The Ruhr district of Germany and the South Wales Valleys in Britain are both examples of areas which are now associated with headframes due to the large number constructed to mine coal during the Industrial Revolution. Most of these headframes have now been removed although both regions have turned non-operating mines with headframes into national museums; the German Mining Museum in Bochum and Big Pit National Coal Museum in Blaenavon. Sporting teams from former coal mining regions such as Llanharan RFC and Cilfynydd RFC have headframes included in their club badges.

Hoist



A drum hoist (cables visible) and motor

In underground mining a **hoist** or **winder** is used to raise and lower conveyances within the mine shaft. Modern hoists are normally powered using electric motors, historically with direct current drives utilizing solid-state converters (thyristors), however modern large hoists utilize alternating current drives that are variable frequency controlled. There are three principal types of hoists used in mining applications:

Drum hoist



A drum hoist and motor

Drum hoists are the most common type of hoist used in North America, South Africa and South America. When using a drum hoist the hoisting cable is wound around the drum when the conveyance is lifted. Single-drum hoists can be used in smaller applications, however double-drum hoists easily allow the hoisting of two conveyances in balance (i.e. one skip being lifted while a second skip is being lowered). Drum hoists are mounted on concrete within a hoistroom, the hoisting ropes run from the drum, up to the top of the headframe, over a sheave wheel and down where they connect to the conveyance (cage or skip).

Advantages

Drum hoists require less routine maintenance than a friction hoist, because the haulage cable is fixed to the drum, and therefore have less downtime, and the maintenance regime is less sophisticated. Drum hoists can continue to operate if the shaft bottom gets flooded and less shaft depth is required below the loading pocket, unlike friction hoists where such flooding could cover the tail ropes etc. Because drum hoists do not have tail ropes, the hoisting system is more suited to slinging beneath a conveyance.

Disadvantages

Drum hoists take up more space than a friction hoist for the same service as all of the haulage cable must be accommodated on the drum when the hoist is fully raised. Drum hoists require rapid fluctuations in power demand, which can pose a problem if power is generated on site rather than provided through the main power grid.

Friction hoist



A headframe housing a friction hoist

Friction (or Koepe) hoists are the most common type of hoist used in Europe, Asia and Australia. The friction hoist was invented in 1877 by Frederick Koepe. Friction hoists are mounted on the ground above the mine shaft, or at the top of the headframe. Friction hoists utilize tail ropes and counterweights and do not have the haulage rope fixed to the wheel, but instead passed around it. The tailropes and weights offset the need for the motor to overcome the weight of the conveyance and hoisting rope, thereby reducing the required horsepower of the hoisting motor by up to 30%, with the overall power consumption remaining the same. Friction hoists, unlike drum hoists, can and normally do use multiple ropes giving them a larger payload capacity, however since they require a larger safety factor, they are impractical for very deep shafts.

Advantages

New friction hoists are less expensive than new drum hoists, and the lead time for delivery may be shorter as there is more competition for manufacturing. Multi-rope friction hoists have a larger lift capacity than a drum hoist. A friction hoist is smaller in diameter than a drum hoist for the same service, making it easier to ship and install than a drum hoist.

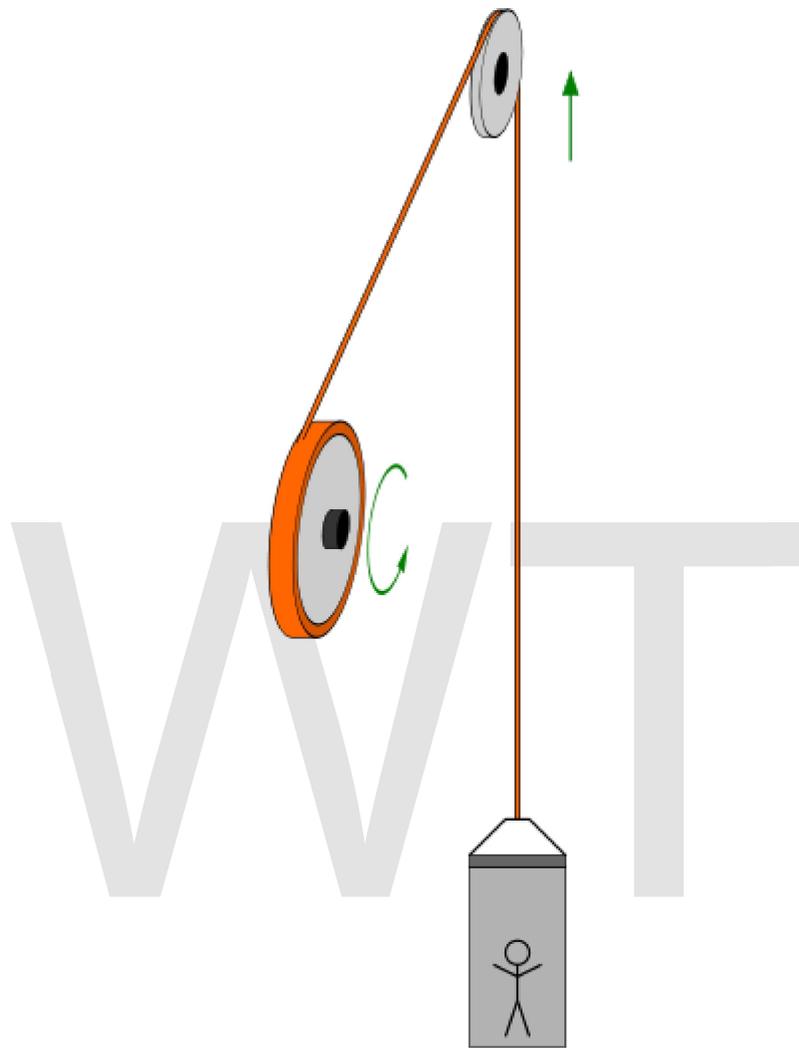
Disadvantages

Balanced friction hoists are not suitable for hoisting from multiple loading pockets on different horizons within a shaft, and are generally not suitable for deep shafts. Friction hoists can not operate at normal speeds if the shaft bottom is flooded and water reaches the tail ropes.

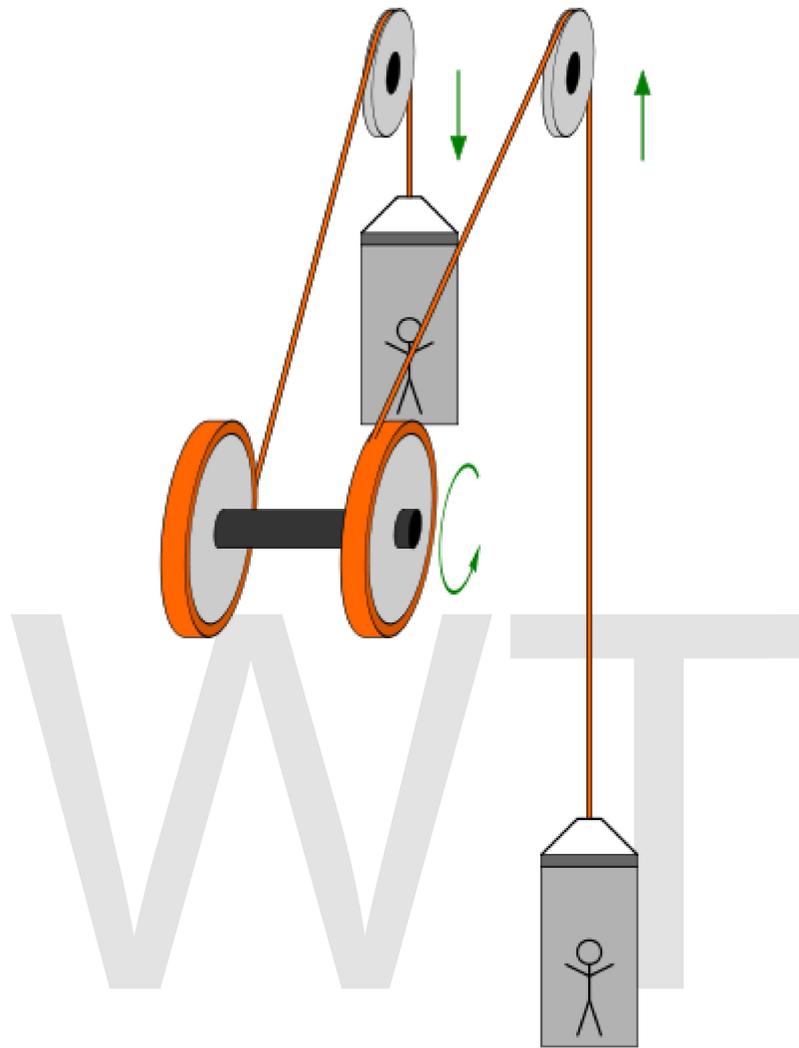
Blair multi-rope hoist

The Blair multi-rope hoist is a variation of the double-drum hoist. It is used in extremely deep shafts as the second drums cable are used to balance the primary load.

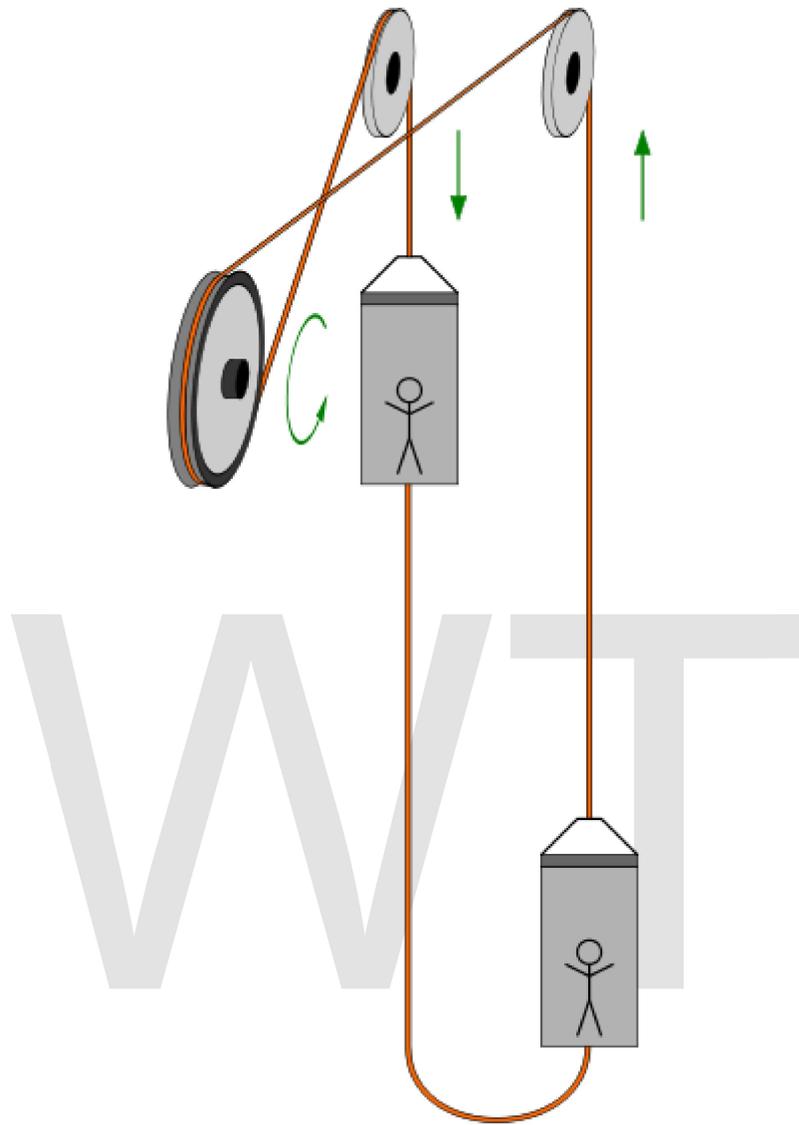
Examples of hoists



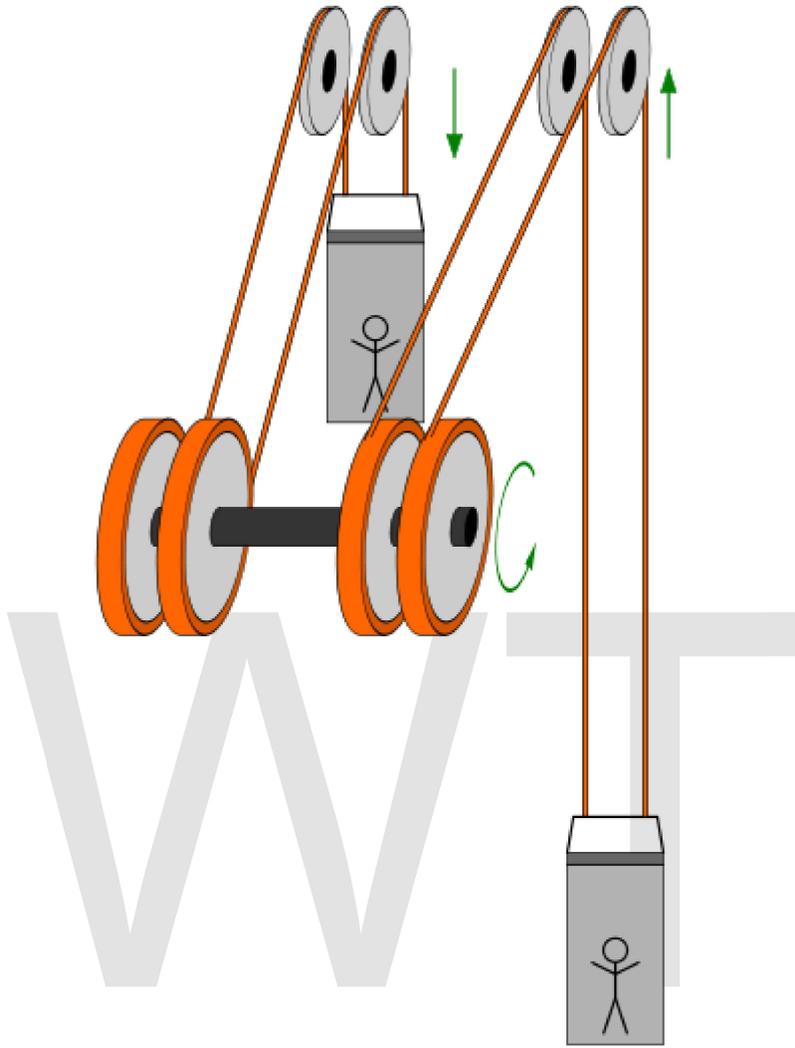
Single-drum hoist



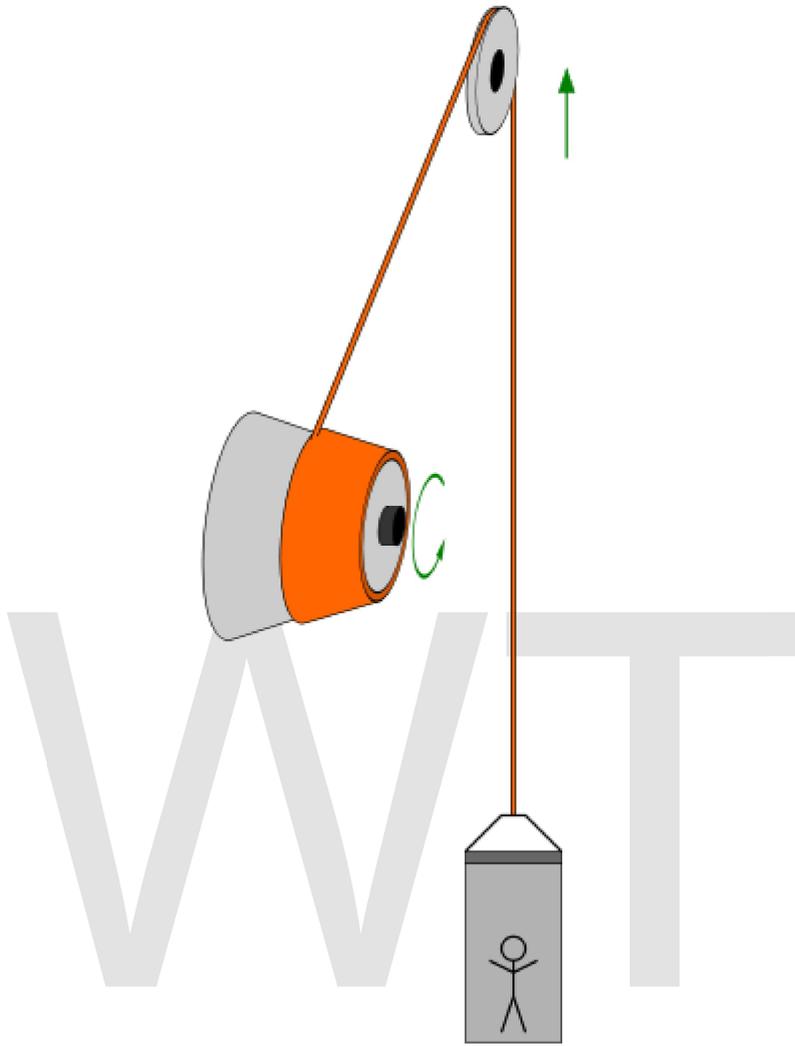
Double-drum hoist



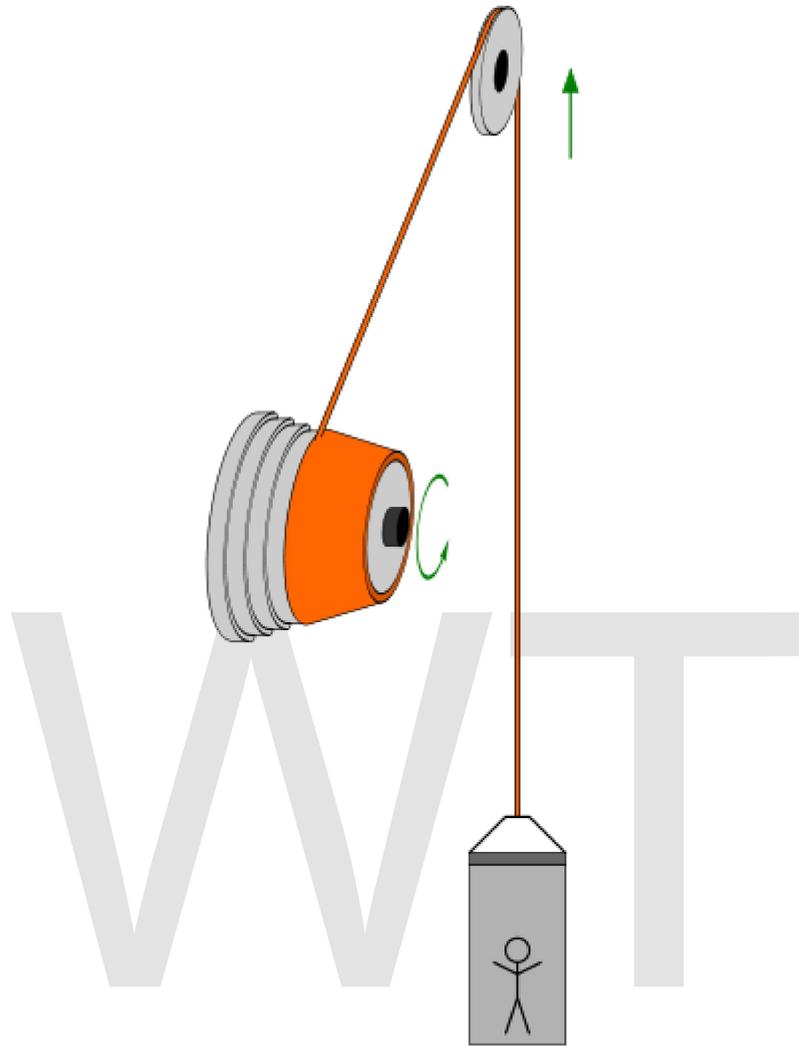
Friction (Koepe) hoist



Blair-multi rope hoist



Conical drum



Spiral drum

Raise



An emergency escape raise

In underground mining a **raise** refers to a vertical or inclined excavation that leads from one level, or drift, to another. A raise may also extend to surface. There are four excavation methods for raises:

1. Conventional or open raise
2. Long-hole or drop raise
3. Alimak
4. Raise boring

Raises serve a number of purposes including:

1. Transportation of ore and waste rock
2. Ventilation
3. Creating a free face for mining
4. Movement of workers via manway ladders

Raise borer

A **raise borer** is a machine used in underground mining, to excavate a circular hole between two levels of a mine without the use of explosives.

The raise borer is set up on the upper level of the two levels to be connected, on an evenly laid platform (typically a concrete pad). A small-diameter hole (pilot hole) is drilled to the level required; the diameter of this hole is typically 230mm - 350mm (9" - 15"), large enough to accommodate the drill string. Once the drill has broken into the opening on the target level, the bit is removed and a reamer head, of the required diameter of the excavation, is attached to the drill string and raised back towards the machine. The drill cuttings from the reamer head fall to the floor of the lower level. The finished raise has smooth walls and may not require rock bolting or other forms of ground support.

The *boxhole borer* (or machine roger) is a variant of a raise borer that is used when there is not enough space on the higher of the two levels to be connected. The boxhole borer is set up on the lower level, drills a pilot hole as a guide, then drives the reamer bit along the pilot hole from the lower level to the upper. Precautions have to be taken to redirect falling drill cuttings away from the machine, and to reinforce the drill string.

Stoping (mining method)



Bundesarchiv, B 145 Bild-F013068-0049
Foto: Wegmann, Ludwig | 28. Mai 1962

Stoping in a German coal mine in the 1960s

Stoping is the removal of the wanted ore from an underground mine leaving behind an open space known as a **stope**. Stoping is used when the country rock is sufficiently strong not to cave into the stope, although in most cases artificial support is also provided. As mining progresses the stope is often backfilled with tailings, or when needed for strength, a mixture of tailings and cement.

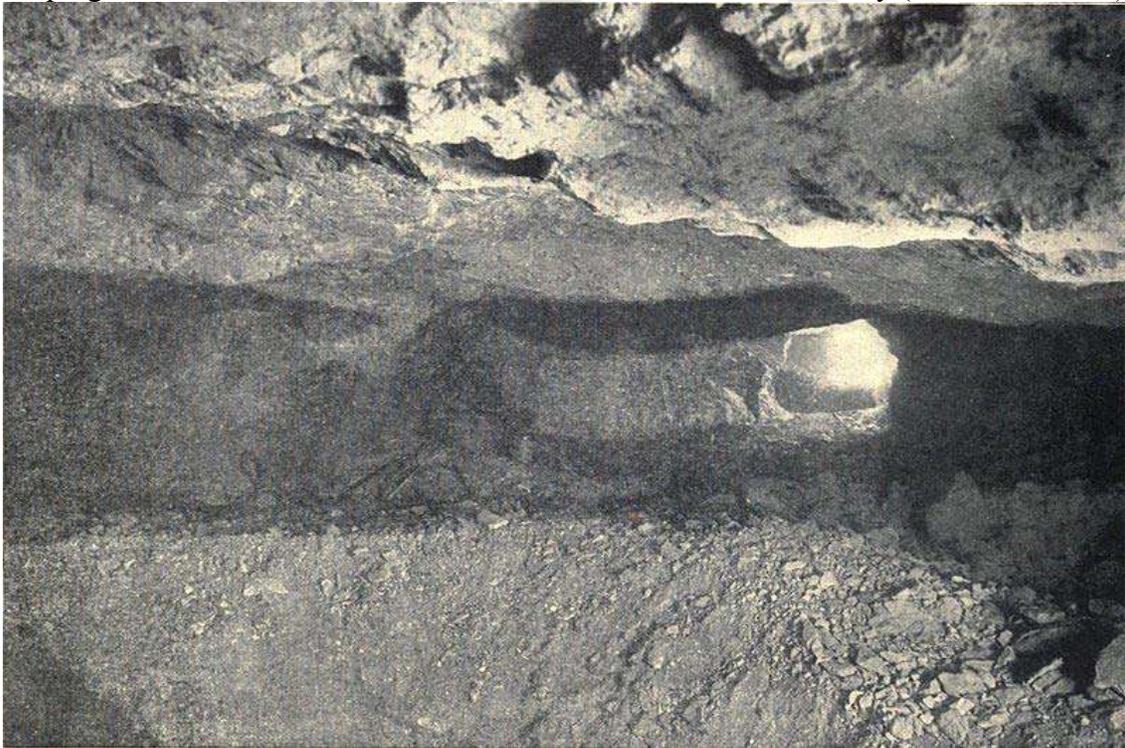
In the past stoping took place with manual tools or by fire-setting; later gunpowder was used, and from the 19th century various other explosives and power-tools came into use.

In old mines, stopes frequently collapse at a later time, leaving craters at the surface. They are an unexpected danger when records of underground mining have been lost with the passage of time.

Types of stoping



Stoping with an air drill in an American iron mine in the 20th century (museum exhibit)



A large stope in the Treadwell gold mine, Alaska, USA 1908; an example of shrinkage stoping

A stope can be created in a variety of ways, depending on the geology of the ore body being mined. It is common to dig shafts vertically downwards to reach the ore body and then drive horizontal levels through it. Stopping then takes place from these levels, in its simplest form as overhand and underhand stopping, which refer to the removal of ore from above or below the level, respectively. In steeply-dipping ore bodies, such as lodes of tin, the stopes become long narrow near-vertical spaces, which, if one reaches the surface is known as a gunnis or coffen. A common method of mining such vertical ore bodies is stull stopping.

When the ore body is more or less horizontal, various forms of room and pillar stopping, cut and fill, or longwall mining can take place.

Stull stopping

Stull stopping is a form of stopping used in hardrock mining that uses systematic or random timbering ("stulls") placed between the foot and hanging wall of the vein. The method requires that the hanging wall and often the footwall be of competent rock as the stulls provide the only artificial support. This type of stope has been used up to a depth of 3,500 feet (1,077 m) and at intervals up to 12 feet (3.7 m) wide. The 1893 mining disaster at Dolcoath mine in Cornwall was caused by failure of the stulls holding up a huge weight of waste rock.

Shrinkage stopping

Shrinkage stope mining, or shrinkage stopping, is most suitable for steeply dipping ore bodies (70°—90°). In shrinkage stopping, mining proceeds from the bottom upwards, in horizontal slices (similar to cut and fill mining), with the broken ore being left in place for miners to work from. Because blasted rock takes up a greater volume than in situ rock (due to swell factor), some of the blasted ore (approximately 40%) must be removed to provide working space for the next ore slice. Once the top of the stope is reached all the ore is removed from the stope. The stope may be backfilled or left empty depending on the rock conditions.

Long hole stoping



A large stope in a salt mine in Poland - now converted into a tourist attraction

Long hole stoping can be the lowest cost method when large ore bodies are located in strong country rock. In operation, it is similar to an underground version of quarrying.

Whim (mining)

A **whim**, also called a **whim gin** or a **horse capstan**, is a device similar to a windlass used in mining for hauling materials to the surface. It comprises a capstan or a wide drum with a vertical axle. A rope is wound around the drum, with both ends traversing several pulleys and hanging down the mine shaft. As the drum is turned around, one end of the rope is lowered, carrying an empty bucket, while the other one is raised, carrying a full load. The major benefit from using a whim is that the whim's operation can be performed at a distance from the shaft, thus resolving some of the congestion. Early whims were horse-powered, but later they were powered by waterwheels or steam engines, including the most advanced Cornish engines. Whims were used in coal mines until the end of the nineteenth century.

Chapter- 9

Copper Extraction Techniques



The Chino open-pit copper mine in New Mexico.



Chalcopyrite

Copper extraction from its ores involves a series of processes. First the ore must usually be concentrated. Then it must be roasted to convert sulfides to oxides, which are smelted to produce matte. Finally, it undergoes various refining processes, the final one being electrolytic. The main ore in use today is chalcopyrite (CuFeS_2), which accounts for about 50% of copper production.

For economic and environmental reasons, many of the byproducts of extraction are reclaimed. Sulfur dioxide gas, for example, is captured and turned into sulfuric acid — which is then used in the extraction process.

Concentration

Most copper ores contain only a small percentage of copper metal bound up within valuable ore minerals, with the remainder of the ore being unwanted rock or gangue minerals, typically silicate minerals or oxide minerals for which there is often no value. The average grade of copper ores in the 21st century is below 0.6% Cu, with a proportion of ore minerals being less than 2% of the total volume of the ore rock. A key objective in the metallurgical treatment of any ore is the separation of ore minerals from gangue minerals within the rock.

The first stage of any process within a metallurgical treatment circuit is comminution, where the rock particles are reduced in size such that ore particles can be efficiently separated from gangue particles, thereafter followed by a process of physical liberation of the ore minerals from the rock. The process of liberation of copper ores depends upon whether they are oxide or sulfide ores.

For oxide ores, a hydrometallurgical liberation process is normally undertaken, which uses the soluble nature of the ore minerals to the advantage of the metallurgical treatment plant. For sulfide ores, both secondary (supergene) and primary (unweathered), froth flotation is utilised to physically separate ore from gangue. For special native copper bearing ore bodies or sections of ore bodies rich in supergen native copper, this mineral can be recovered by a simple gravity circuit.

Hydrometallurgical extraction

Oxide ores

Oxidised copper ore bodies may be treated via several processes, with hydrometallurgical processes used to treat oxide ores dominated by copper carbonate minerals such as azurite and malachite, and other soluble minerals such as silicates like chrysocolla, or sulfates such as atacamite and so on.

Such oxide ores are usually leached by sulfuric acid, usually using a heap leach or dump leach process to liberate the copper minerals into a solution of sulfuric acid laden with copper sulfate in solution. The copper sulfate solution (the pregnant leach solution) is then stripped of copper via a solvent extraction and electrowinning (SX-EW) plant, with the barred sulfuric acid recycled back on to the heaps. Alternatively, the copper can be precipitated out of the pregnant solution by contacting it with scrap iron; a process called cementation. Cement copper is normally less pure than SX_EW copper. Commonly sulfuric acid is used as a leachant for copper oxide, although it is possible to use water, particularly for ores rich in ultra-soluble sulfate minerals.

In general froth flotation is not used to concentrate copper oxide ores, as oxide minerals are not responsive to the froth flotation chemicals or process (i.e.; they do not bind to the kerosene-based chemicals). Copper oxide ores have occasionally been treated via froth floatation via sulfidation of the oxide minerals with certain chemicals which react with the oxide mineral particles to produce a thin rime of sulfide (usually chalcocite), which can then be activated by the froth floatation plant.

Name	Formula	% Copper when pure
 <i>Chalcopyrite</i>	CuFeS_2	34.5
	Cu_2S	79.8

<i>Chalcocite</i>		CuS	66.5
<i>Covellite</i>		2Cu ₂ S•CuS•FeS	63.3
<i>Bornite</i>		Cu ₃ SbS ₃ + x(Fe,Zn) ₆ Sb ₂ S ₉	32-45
<i>Tetrahedrite</i>		CuCO ₃ •Cu(OH) ₂	57.3
<i>Malachite</i>		2CuCO ₃ •Cu(OH) ₂	55.1
<i>Azurite</i>		Cu ₂ O	88.8
<i>Cuprite</i>		CuO•SiO ₂ •2H ₂ O	37.9
<i>Chrysocolla</i>			

Copper-bearing Minerals

Secondary ores

Secondary sulfides - those formed by supergene secondary enrichment - are resistant (*refractory*) to sulfuric leaching. These ores are a mixture of copper carbonate, sulfate, phosphate, and oxide minerals and secondary sulfide minerals, dominantly chalcocite but other minerals such as digenite can be important in some deposits..

Supergene ores rich in sulfides may be concentrated using froth flotation. A typical concentrate of chalcocite can grade between 37% Cu to 40% Cu in sulfide, making them relatively cheap to smelt compared to chalcopyrite concentrates.

Some supergene sulfide deposits can be leached using a bacterial oxidation heap leach process to oxidize the sulfides to sulfuric acid, which also allows for simultaneous leaching with sulfuric acid to produce a copper sulfate solution. As with oxide ores, solvent extraction and electrowinning technologies are used to recover the copper from the pregnant leach solution.

Supergene sulfide ores rich in native copper minerals are refractory to treatment with sulfuric acid leaching on all practicable time scales, and the dense metal particles do not react with froth flotation media. Typically, if native copper is a minor part of a supergene profile it will not be recovered and will report to the tailings. When rich enough, native copper ore bodies may be treated to recover the contained copper via a gravity separation circuit where the density of the metal is used to liberate it from the lighter silicate minerals. Often, the nature of the gangue is important, as clay-rich native copper ores prove difficult to liberate.

Froth flotation



Froth flotation cells to concentrate copper and nickel sulfide minerals, Falconbridge, Ontario.

The modern froth flotation process was independently invented the early 1900s in Australia by C.V Potter and around the same time by G. D. Delprat.



Copper sulphide loaded air bubbles on a Jameson cell at the flotation plant of the Prominent Hill mine in South Australia

At the current level of technology all primary sulfide ores of copper sulfides, and most concentrates of secondary copper sulfides (being chalcocite), require smelting to produce copper from the sulfide minerals. Some experimental hydrometallurgical techniques to process chalcopyrite are being investigated but as of 2009 are unproven outside of laboratories. Some vat leach or pressure leach processes exist to solubilise chalcocite concentrates and produce copper cathode from the resulting leachate solution, but this is a minor part of the market.

Carbonate concentrates are a relatively minor product produced from copper cementation plants, typically as the end-stage of a heap-leach operation. Such carbonate concentrates can be treated by a SX-EW plant or smelted.

The copper ore is crushed and ground to a size such that an acceptably high degree of liberation has occurred between the copper sulfide ore minerals and the gangue minerals. The ore is then wet, suspended in a slurry, and mixed with xanthate reagents (or other reagents of the thiol class), which react with the copper sulfide mineral particle to make it hydrophobic on its surface. (Besides xanthates, dithiophosphates and thionocarbamates are commonly used).

The treated ore is introduced to a water-filled aeration tank containing surfactant such as methylisobutyl carbinol (MIBC) which is an alcohol. Air is constantly forced through the slurry and the air bubbles attach to the hydrophobic copper sulfide particles, which are conducted to the surface, where they form a froth and are skimmed off. These skimmings are generally subjected to a cleaner-scavenger cell to remove excess silicates and to remove other sulfide minerals which can deleteriously impact the concentrate quality (typically, galena), and the final concentrate sent for smelting.

The rock which has not floated off in the floatation cell is either discarded as tailings, or processed to extract other elements or other ore minerals such as galena, sphalerite if they exist.

To improve the process efficiency, lime is used to raise the pH of the water bath, causing the collector to ionize more and to preferentially bond to chalcopyrite (CuFeS_2) and avoid the pyrite (FeS_2). Iron exists in both primary zone minerals.

Copper ores containing chalcopyrite can be concentrated to produce a concentrate with between 20% and 30% copper-in-concentrate (usually 27-29% Cu); the remainder of the concentrate is iron and sulfur in the chalcopyrite, and unwanted impurities such as silicate gangue minerals or other sulfide minerals, typically minor amounts of pyrite, sphalerite or galena.

Chalcocite concentrates typically grade between 37% and 40% copper-in-concentrate, as chalcocite has no iron within the mineral.

Roasting

In the roaster, the copper concentrate is partially oxidised to produce calcine and sulfur dioxide gas. The stoichiometry of the reaction which takes place is:



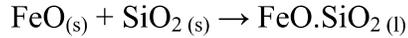
As of 2005, roasting is no longer common in copper concentrate treatment. Direct smelting using the following smelting technologies; flash smelting, Noranda, ISASmelt, Mitsubishi or El Teniente furnace are now used.

Smelting

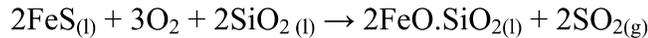
The calcine is then mixed with silica and coke and smelted at 1200 °C (in an exothermic reaction) to form a liquid called *copper matte*. This temperature allows reactions to proceed rapidly, and allow the matte and slag to melt, so they can be tapped out of the furnace. In copper recycling, this is the point where scrap copper is introduced.

Several reactions occur.

For example iron oxides and sulfides are converted to slag which is floated off the matte. The reactions for this are:



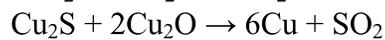
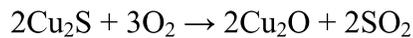
In a parallel reaction the iron sulfide is converted to slag:



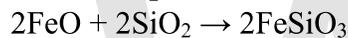
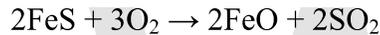
The slag is discarded or reprocessed to recover any remaining copper.

Conversion to blister

The matte, which is produced in the smelter, contains around 70% copper primarily as copper sulfide as well as iron sulfide. The sulfur is removed at high temperature as sulfur dioxide by blowing air through molten matte:



In a parallel reaction the iron sulfide is converted to slag:

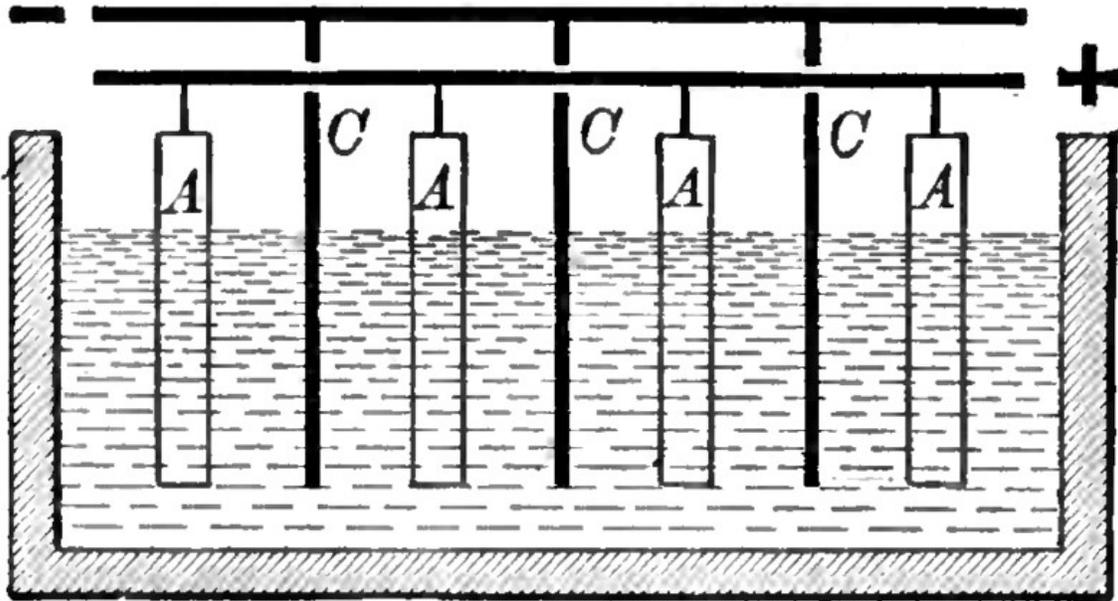


The end product is (about) 98% pure copper known as *blister* because of the broken surface created by the escape of sulfur dioxide gas as the copper ingots are cast. By-products generated in the process are sulfur dioxide and slag.

Reduction

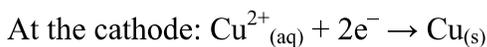
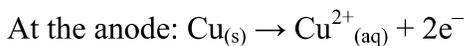
The blistered copper is put into an anode furnace (a furnace that uses the blister copper as anode) to get rid of most of the remaining oxygen. This is done by blowing natural gas through the molten copper oxide. When this flame burns green, indicating the copper oxidation spectrum, the oxygen has mostly been burned off. This creates copper at about 99% pure. The anodes produced from this are fed to the electrorefinery.

Electrorefining



Apparatus for electrolytic refining of copper

The copper is refined by electrolysis. The anodes cast from processed blister copper are placed into an aqueous solution of 3-4% copper sulfate and 10-16% sulfuric acid. Cathodes are thin rolled sheets of highly pure copper. A potential of only 0.2-0.4 volts is required for the process to commence. At the anode, copper and less noble metals dissolve. More noble metals such as silver and gold as well as selenium and tellurium settle to the bottom of the cell as anode slime, which forms a saleable byproduct. Copper(II) ions migrate through the electrolyte to the cathode. At the cathode, copper metal plates out but less noble constituents such as arsenic and zinc remain in solution. The reactions are:



Concentrate and copper marketing

Copper concentrates produced by mines are sold to smelters and refiners who treat the ore and refine the copper and charge for this service via treatment charges (TC's) and refining charges (RC's). The TC's are charged in US\$ per tonne of concentrate treated and RC's are charged in cents per pound treated, denominated in US dollars, with benchmark prices set annually by major Japanese smelters. The customer in this case can be a smelter, who on-sells blister copper ingots to a refiner, or a smelter-refiner which is vertically integrated.

The typical contract for a miner is denominated against the London Metal Exchange price, minus the TC-RCs and any applicable penalties or credits. Penalties may be assessed against copper concentrates according to the level of deleterious elements such as arsenic, bismuth, lead or tungsten. Because a large portion of copper sulfide ore bodies contain silver or gold in appreciable amounts, a **credit** can be paid to the miner for these metals if their concentration *within the concentrate* is above a certain amount. Usually the refiner or smelter charges the miner a fee based on the concentration; a typical contract will say a credit is due for every ounce of the metal in concentrate above a certain concentration; below that if it is recovered the smelter will keep the metal and sell it to defray costs.

Copper concentrate is traded either via spot contracts or under long term contracts as an intermediate product in its own right. Often the smelter sells the copper metal itself on behalf of the miner. The miner is paid the price at the time that the smelter-refiner makes the sale, not at the price on the date of delivery of the concentrate. Under a Quotational Pricing system, the price is agreed to be at a fixed date in the future, typically 90 days from time of delivery to the smelter.

A-grade copper cathode is of 99.999% copper in sheets that are 1 cm thick, and approximately 1 meter square weighing approximately 200 pounds. It is a true commodity, deliverable to and tradeable upon the metal exchanges in New York (COMEX), London (London Metals Exchange) and Shanghai (Shanghai Futures Exchange). Often copper cathode is traded upon the exchanges indirectly via warrants, options, or swap contracts such that the majority of copper is traded upon the LME/COMEX/SFE but delivery is achieved indirectly and at remove from the physical warehouses themselves.

The chemical specification for electrolytic grade copper is ASTM B 115-00 (a standard that specifies the purity and maximum electrical resistivity of the product).