Introductory
Mining Engineering

Joseph Howard

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PREFACE

This book has been written, keeping in view that students want more practical information. Thus, my aim has been to make it as comprehensive as possible for the readers. I would like to extend my thanks to my family and co-workers for their knowledge, support and encouragement all along.

The process which includes the extraction of valuable minerals and other geological materials from the Earth is known as mining. Minerals and other materials are usually extracted from an ore body, vein, seam, lode, and reef or placer deposit. Ores that are recovered through mining include coal, oil, metals, gemstones, dimension stone, potash, gravel, chalk and clay. Mining is an important activity as it is required to get any material that cannot be grown through agricultural processes or created artificially. It primarily includes the extraction of non-renewable resources such as petroleum, natural gas and water. Modern mining includes prospecting for ore bodies, extraction of the desired materials and reclamation of the land after the mine is closed. This textbook outlines the processes and applications of mining in detail. It elucidates new techniques and their applications in a multidisciplinary approach. This textbook is a complete source of knowledge on the present status of this important field.

A brief description of the chapters is provided below for further understanding:

Chapter – What is Mining?

Mining refers to the extraction of valuable minerals as well as other geological materials from the Earth. They are usually extracted from an ore body, reef, seam, lode and vein. Different types of mining are automated mining, atmospheric mining, biomining, uranium mining, coal mining and deep sea mining. All these types of mining have been carefully analyzed in this chapter.

Chapter – Mine Development and Life Cycle

Mine development is a process that deals with the construction of mining facility and the infrastructure to support the facility. It includes preparation of mine sites, construction of mine facilities and creation of infrastructure. This chapter closely examines these key concepts of mine development and life cycle to provide an extensive understanding of the subject.

Chapter – Mining Techniques

There are four main mining techniques used in the mining industry. These are underground mining, placer mining, in-situ mining and surface mining. These techniques are used depending on the type of mineral resources to be mined. The topics elaborated in this chapter will help in gaining a better perspective about these techniques of mining.

Chapter – Mining Equipments

Mining equipments are used to aid extraction of minerals through mining. Some of the common equipment used in mining are cone crusher, dragline excavator, load, haul, dump machine, haul truck and power shovel. This chapter closely examines these mining equipments to provide an extensive understanding of the subject.

Chapter – Impacts of Mining

Mining has severe impacts on the environment such as air pollution, water pollution, soil erosion and soil pollution, loss of biodiversity and formation of sink holes. This chapter has been carefully written to provide an easy understanding of these various environmental effects of mining.

Chapter – Mining: Hazard Prevention and Safety

Mining hazard can be defined as the dangers related to the working in mines. The most critical hazards that are linked to mining are gas or dust explosions, fire, flood, collapse and toxic atmospheric contaminants. All these mining hazards and their prevention and safety protocols have been carefully analyzed in this chapter.

Joseph Howard

What is Mining?

1 CHAPTER

Mining refers to the extraction of valuable minerals as well as other geological materials from the Earth. They are usually extracted from an ore body, reef, seam, lode and vein. Different types of mining are automated mining, atmospheric mining, biomining, uranium mining, coal mining and deep sea mining. All these types of mining have been carefully analyzed in this chapter.

Mining is the extraction of valuable minerals and other geological materials from the earth, usually from an ore body, vein, or (coal) seam. Materials recovered by mining include coal, diamonds, limestone, bauxite, phosphate, rock salt, precious metals, iron, nickel, lead, tin, uranium, and molybdenum. In a broader sense, the term “mining” may also be applied to the extraction of petroleum, natural gas, and even water. Thus, mining activities around the world have provided us with a wide range of raw materials that have helped us develop technologies to enhance our quality of life.

Mining has also been associated with problems related to miners’ health and safety, environmental pollution and degradation, and threats to public health. Today, many countries have strict regulations to prevent these problems and to reclaim the land after the mining project is completed. Consequently, mining practices have become significantly safer and healthier. Yet, these problems persist in regions of the world where regulations are lax and clean mining technologies are unavailable.

Chuquicamata, in Chile, is the largest open-pit copper mine in the world.

Planning a Mining Project

Several steps need to be taken before a mining project can begin:

- Prospecting, to discover the locations of ore.
- Exploration, to defining the extent and value of the ore that was located.

- Resource estimation, to mathematically estimate the extent and grade of the deposit.
- Mine planning, to evaluate the economically recoverable portion of the deposit.
- Conducting a feasibility study, to evaluate the total project and to decide whether or not to proceed with the project. It includes a cradle-to-grave analysis of the possible mine, from initial excavation all the way through land reclamation.

Once the decision has been made to start the project, an infrastructure has to be put in place to create access to the ore body. When that is completed, the land is excavated and the ore is extracted on a large scale. Finally, a well-planned mining project ends with reclamation efforts to make the land suitable for future use.

Mine Planning Software

One of the most dramatic changes in the mining industry has been the role of sophisticated, three-dimensional mine planning computer software packages. Once the decision has been taken to proceed with a mine, one needs to create detailed designs that take into account the area's topography and infrastructure, as well as the physical parameters of the ore body. Manual design and old-fashioned planning methods can be tedious and face many unique challenges that depend on the nature of the mine. Initially, the 3-D software was used for relatively simple tasks, such as rendering graphic images of drill holes, which made it easier for surveyors, geologists, mine planners, mining engineers, and other technical staff to manipulate and visualize data. In recent years, however, a wide range of integrated mine planning tools have been developed so that complex models can be built to optimize the extraction and processing of mineral resources.

Mining Industry

Miners today do more than just digging tunnels in the earth. The mining industry employs personnel ranging from engineers and lab technicians to geologists and environmental specialists. In addition, it uses the services of accountants, lawyers, sales representatives, and public relations specialists, as well as the people who manufacture the machines and equipment necessary for the project.

Mining, like other heavy industries, requires heavy machinery to break and remove rocks that range in their degree of hardness and toughness. Bulldozers, drills, explosives, and trucks are important for digging into the land, especially in surface mining. Underground mining today tends to be technologically more sophisticated, because of the dangers and expense of subsurface tunneling.

Although individual entrepreneurs and small businesses sometimes conduct exploration and mining, most modern-day mines are large-scale enterprises requiring huge amounts of capital. Consequently, giant companies that are often multinational and publicly owned dominate the industry.

In the United States, employment in the mining industry offers highly competitive wages and benefits, especially in rural or remote areas. Yet the industry is going to find it difficult to replace the generation of miners, mine engineers, senior managers, technical experts, and others who are set to retire between 2005 and 2015. Enrollment levels in mining education programs at American colleges appear too low to meet the anticipated demand.

Miners' Safety and Health Issues

Miners' safety and health have long been issues of concern associated with the mining business, especially subsurface mining. Problems include occasional collapse of a mine and explosions of flammable gas and dust, leading to injury and death of workers. Poor ventilation and exposure to harmful dust have been known to cause lung problems such as pneumoconiosis, also known as "black lung disease."

Recent regulations, proper planning, and technological improvements have made mining substantially safer today than it was in earlier decades. For instance, to deal with the ventilation problem in underground mines, fresh air is forced through the mine in a single direction using a large fan situated aboveground.

In the United States, mining is regulated under the federal Mine Safety and Health Act. The regulations are enforced by the Department of Labor's Mine Safety and Health Administration (MSHA), which employs nearly one safety inspector for every four coal mines. Underground coal mines are thoroughly inspected at least four times annually by MSHA inspectors. In addition, miners can report violations and request additional inspections, without fear of losing their jobs for doing so.

Immediately reportable accidents and injuries include:

1. The death of an individual at a mine.
2. An injury that has reasonable potential to cause death.
3. Entrapment of an individual for more than 30 minutes.
4. An unplanned inundation of a mine by a liquid or gas.
5. An unplanned ignition or explosion of gas or dust.
6. An unplanned fire not extinguished within 30 minutes of discovery.
7. An unplanned ignition or explosion of a blasting agent or explosive.
8. A roof or rib falls unexpectedly in active working areas, impairing ventilation or impeding passage.
9. A coal or rock outburst that causes withdrawal of miners or disrupts regular mining activity for more than one hour.
10. An unstable condition at an impoundment, refuse pile, or culm bank, requiring emergency action to prevent failure, or causing individuals to evacuate an area; or failure of an impoundment, refuse pile, or culm bank.
11. Damage to hoisting equipment in a shaft or slope, endangering an individual or interfering with use of the equipment for more than 30 minutes.

Statistical analyses by the MSHA show that between 1990 and 2004, the industry cut the rate of injuries (a measure comparing the rate of incidents to overall number of employees or hours worked) by more than half and fatalities by two-thirds, following three prior decades of steady improvement.

Environmental Impacts

Iron hydroxide precipitate stains a stream receiving acid drainage from surface coal mining.

Environmental problems associated with mining include erosion, formation of sinkholes, chemical contamination of surface waters and groundwater, and loss of biodiversity. For example, coal mining releases approximately 20 toxic chemicals, of which 85 percent are said to be managed on site. If even some of these chemicals leach out with water coursing through the mine, the contamination spreads.

Some specific examples of contaminated sites are as follows:

- Ashio Copper Mine in Ashio, Japan: It was the site of substantial pollution at end of the nineteenth century.
- Berkeley Lake: An abandoned pit mine in Butte, Montana, it became filled with water that turned acidic and poisonous. A water treatment plant installed in 2003 has been treating "new" water entering the pit and reducing the rate of rise of pit water. Eventually, water in the pit itself will be treated.
- Britannia Mines: This abandoned copper mine near Vancouver, British Columbia, has been releasing copper into Howe Sound, polluting the water and killing animal life. After the installation of a water treatment plant, fish have been returning to Britannia Bay—perhaps for the first time in recorded history.
- Scouriotissa: An abandoned copper mine in Cyprus, it is a source of contaminated dust.
- Tar Creek: An abandoned mining area in Picher, Oklahoma, it is now an EPA (Environmental Protection Agency) "superfund" site. Water has leaked out of the mine and into local groundwater, contaminating it with metals such as lead and cadmium.

In many countries today, mining companies are required to follow strict environmental and rehabilitation codes, to ensure that appropriate measures are taken to protect the environment during the mining process, and that, once the mining operation is completed, the area is returned to a state similar to or better than its condition before the project was begun. These regulations, along with the technologies used to implement them, have led to significantly healthier mining practices. Yet in parts of the world where environmental regulations are lax and clean mining technologies are not available, the environment and public health continue to suffer.

To protect surface waters and groundwater from contamination, including acid mine drainage (AMD), water quality is continuously monitored near the mines. The five principal technologies used to control water flow at mine sites are: diversion systems, containment ponds, groundwater pumping systems, subsurface drainage systems, and subsurface barriers. In the case of AMD, contaminated water is usually pumped to a treatment facility that neutralizes the contaminants.

In the United States, mining practices are subject to close scrutiny and have improved significantly. To ensure completion of land reclamation, the Office of Surface Mining requires that mining companies post a bond to be held in escrow until the productivity of reclaimed land has been demonstrated convincingly. Since 1978, the mining industry has reclaimed more than two million acres (8,000 square kilometers) of land. This reclaimed land has renewed vegetation and wildlife and can even be used for farming and ranching.

Abandoned Mines

This danger sign at an old Arizona mine warns, "Stay Out! Stay Alive!".

According to some estimates, there are between 700,000 and 800,000 abandoned mines in the United States. Many of them are in the vicinity of abandoned towns, often referred to as "ghost towns."

Experts strongly warn against entering or exploring old or abandoned mines. It is estimated that approximately 25 percent of the abandoned mine lands (AML sites) pose physical safety hazards, because they may harbor deadly gases, snakes, and other dangerous animals. The entrance to an old mine, in particular, can be very dangerous, as weather may have eroded the soil or rock surrounding the entrance.

Every year, dozens of people are injured or killed in recreational accidents at mine sites. In 1999, MSHA launched a national public awareness campaign called "Stay Out – Stay Alive." It is aimed at warning and educating children and adults about the dangers of exploring and playing on active and abandoned mine sites.

The Abandoned Mine Land Initiative, launched by the Western Governors Association and the National Mining Association, is an effort focusing on reporting the number of high-priority AML sites and to identify, measure, and report on the progress of current reclamation cleanup programs on an annual basis.

AUTOMATED MINING

Automation is becoming increasingly standard in mining operations around the planet, as operations embrace autonomous trucks, loaders, drills and other equipment. Automation is projected to make mines more productive and reduce costs, along with making them a great deal safer.

Benefits of Automation

Businesses that apply automation will swiftly realize a substantial boost in productivity and a reduction in costs. Some businesses have seen productivity climb by 15 to 20 percent after launching the technology.

Efficiency is also enhanced with automation. For instance, there is no time lost at shift changeovers. Automated robots also don’t need to adopt the same safety measures or personal protective equipment that humans must.

Because automated equipment can be moved into unsafe areas and challenging spaces, mining operations can send fewer workers underground, realize a greater output and reduce risk to their workers in the process.

Automation will also permit access to ore bodies that had been inaccessible, and this will have substantial market ramifications. For example, the gold price has played a role in the accessibility of ore bodies, but automation will increasingly lower that factor.

Opportunities to Make In-roads in Mining Operations

A major issue associated with automation is the potential elimination of jobs. This is significantly prevalent in regions that depend on mining as a crucial provider of jobs, often underdeveloped regions. Supporters of automation say it will not reduce employment, but rather allow for new kinds of technology-based jobs.

Increased automation will likely mean an initial skills gap, which will have an outsized impact on the areas immediately surrounding a mining operation. However, it will also offer opportunity as local workers become cross-trained and upskilled. Workers trained to work with automation will be able to use mining equipment in new ways, possibly creating more opportunity.

Also, mines have traditionally used expatriate managerial and technical labour, but innovative technologies could allow for local more talent to make in-roads in these areas.

The benefits of automating a mine are obvious: greater efficiency and safety.

In spite of the upfront cost of implementing state-of-the-art autonomous equipment, Resolute has said it will be able to cut mining costs by around 30 percent.

Connectivity issues are often mentioned concerning automation in challenging environments, but connectivity concerns are often related to factors associated with retrofitting. The Syama mine avoids connectivity and other issues through its purpose-built nature.

Machines

The Bagger 288 is a bucket-wheel excavator used in strip mining.
It is also one of the largest land vehicle of all time.

Heavy machinery is used in mining to explore and develop sites, to remove and stockpile overburden, to break and remove rocks of various hardness and toughness, to process the ore, and to carry out reclamation projects after the mine is closed. Bulldozers, drills, explosives and trucks are all necessary for excavating the land. In the case of placer mining, unconsolidated gravel, or alluvium, is fed into machinery consisting of a hopper and a shaking screen or trommel which frees the desired minerals from the waste gravel. The minerals are then concentrated using sluices or jigs.

A Bucyrus Erie 2570 dragline and CAT 797 haul truck at
the North Antelope Rochelle opencut coal mine.

Large drills are used to sink shafts, excavate stopes, and obtain samples for analysis. Trams are used to transport miners, minerals and waste. Lifts carry miners into and out of mines, and move rock and ore out, and machinery in and out, of underground mines. Huge trucks, shovels and cranes are employed in surface mining to move large quantities of overburden and ore. Processing plants utilize large crushers, mills, reactors, roasters and other equipment to consolidate the mineral-rich material and extract the desired compounds and metals from the ore.

ATMOSPHERIC MINING

Atmospheric mining is the process of extracting valuable materials or other non-renewable resources from the atmosphere. Due to the abundance of hydrogen and helium in the outer planets of the Solar System, atmospheric mining may be easier than mining terrestrial surfaces.

Atmospheric mining of outer planets has not yet begun. There is some consensus that gas should be mined from gas planets, but this would be difficult with current technology; however Uranus & Neptune would be the easiest planets to mine for gas. Jupiter & Saturn are closer, but Jupiter has a lot of gravity to contend with, and it could be difficult navigating through the rings of Saturn. Also, Earth's atmosphere can be mined for carbon dioxide to produce fuel and to reduce the levels of greenhouse gas in the atmosphere.

Types of Atmospheric Mining

- Hydrogen Mining: Hydrogen may fuel chemical and nuclear propulsion.
- Helium Mining: Helium-3 may fuel nuclear propulsion.
- Methane Mining: Methane may fuel chemical propulsion.
- Carbon Dioxide Mining: Carbon dioxide mining on earth will reduce the level of greenhouse gases & can also produce fuel.

Exploration for Atmospheric Mining

Hydrogen and helium are abundant in outer planets.

Atmospheric composition of outer planets				
Resource	Jupiter	Saturn	Uranus	Neptune
Hydrogen	89.8	96.3	82.5	80.0
Helium	10.2	3.3	15.2	19.0
Methane			2.3	1.0
Other		0.4	1.0	

Methods of Atmospheric Mining

- Aerostats: An aerostat would be a buoyant station in the atmosphere that gathers and stores gases. A vehicle would transfer the gases from the aerostat to an orbital station above the planet.
- Scoopers: A scooper would be a vehicle that gathers and transfers gases from the atmosphere to an orbital station.
- Skyhook: A Skyhook (structure) is similar to a space elevator, such a device would be used to pump gas to a orbital propellant depot.
- Cruisers: A cruiser would be a vehicle in the atmosphere that gathers and stores gases. A smaller vehicle would transfer the gases from the cruiser to an orbital station.

BIOMINING

Biomining is the process of using microorganisms (microbes) to extract metals of economic interest from rock ores or mine waste. Biomining techniques may also be used to clean up sites that have been polluted with metals.

Biomining is mineral processing with microbes.

Valuable metals are commonly bound up in solid minerals. Some microbes can oxidize those metals, allowing them to dissolve in water. This is the basic process behind most biomining, which is used for metals that can be more easily recovered when dissolved than from the solid rocks. A different biomining technique, for metals which are not dissolved by the microbes, uses microbes to break down the surrounding minerals, making it easier to recover the metal of interest directly from the remaining rock.

What Metals are Currently Biomined?

Most current biomining operations target valuable metals like copper, uranium, nickel, and gold that are commonly found in sulfidic (sulfur-bearing) minerals. Microbes are especially good at oxidizing sulfidic minerals, converting metals like iron and copper into forms that can dissolve more easily. Other metals, like gold, are not directly dissolved by this microbial process, but are made more accessible to traditional mining techniques because the minerals surrounding these metals are dissolved and removed by microbial processes. When the metal of interest is directly dissolved, the biomining process is called "bioleaching," and when the metal of interest is made more accessible or "enriched" in the material left behind, it is called "biooxidation." Both processes involve microbial reactions that can happen anywhere the microbes, rocks, and necessary nutrients, like oxygen, occur together.

What Processes are used to Biomine?

The most common processes used in biomining are:

- Heap leaching: Freshly mined material is moved directly into heaps that are then bioleached.
- Dump leaching: Low-value ore or waste rock is placed in a sealed pit and then bioleached to remove more of the valuable metals from the waste pile.

- Agitated leaching: Crushed rocks are placed into a large vat that is shaken to distribute the microbes and material evenly and speed up the bioleaching process.

Leaching times vary from days to months, making this process slower than conventional mineral extraction techniques. Dump and heap leaching are the oldest and most established biomining techniques, but the use of agitated leaching is becoming more common for minerals that are resistant to leaching, including some copper sulfides like chalcopyrite.

What are the Environmental Risks of Biomining?

Most current biomining operations use naturally occurring microbial communities. Because these types of organisms are already common in the environment, the risks from the release of the microbes themselves into the local environment are considered to be relatively small. The greatest environmental risks are related to leakage and treatment of the acidic, metal-rich solution created by the microbes, which is similar to the acid mine drainage from some abandoned mines. This risk can be managed by ensuring that biomining is conducted under controlled conditions with proper sealing and waste management protocols.

How Common is Biomining?

Biomining is currently a small part of the overall mining industry. It is used most frequently when the percentage of the desired metal in a rock is small, or to extract remaining metals from waste rock after conventional mining. In Chile, which currently produces one-third of the world's copper, many of the most copper-rich ores have already been mined. As a result, biomining is increasingly being used to mine deposits with low percentages of copper, and worldwide, 10-15% of copper is extracted using bioleaching. Biomining is also important in the gold industry, where roughly 5% of global gold is produced using biooxidation. As metal-rich ores are depleted worldwide, and with advances in microbial research and engineering, biomining may become more common in the future.

Other uses of Biomining

- New biomining techniques that do not involve oxidation are being tested, which would enable large-scale biomining for different types of minerals and metals.
- Some researchers and companies are testing the use of biomining for recycling, to recover valuable elements from wastewater and electronic waste.

- Several smaller operations recover metals from existing acid mine drainage. These operations recover economically valuable metals that would otherwise cause pollution.
- In Europe, the BIOMOre project is studying the feasibility of biomining deep underground to avoid having to excavate the rocks themselves.

URANIUM MINING

Uranium occurs naturally in rocks on the Earth's surface and can be extracted through uranium mining. Miners originally discovered uranium alongside radium, another element that was used as glowing, decorative paint (at least until people realized its harmful, radioactive effects). Uranium hit the market as a decorative glaze before its nuclear properties were discovered.

This heavy metal comes in several isotopes, or forms of the element with different numbers of neutrons. Depending on the stability of an isotope, some can be more radioactive (likely to give off energetic particles) and fissile (likely to produce nuclear fission) than others. Uranium-238 measures as the most abundant isotope of the element on Earth and can be found in rocks and seawater. But it's not as radioactive as uranium-235, the best-known form of uranium used to create nuclear reactions.

Most mining sites stem from larger deposits, which vary in size and depth. Australia's Olympic Dam, one of the largest sites in the world, has explored and mined roughly 6.5 million feet (2,000 kilometers) of land. In recent years, surveyors have established that 1.1 million acres of land near the Grand Canyon may be suitable for mining, although U.S. President Obama announced a 20-year ban on uranium mining on 1 million acres of land near the Grand Canyon in 2012.

This preliminary stage of the mining process is called exploration, where geoscience experts figure out which areas would be economically feasible to mine. Companies compare the estimated number of recoverable ore tons with the cost of extracting them. Because of financial constraints, landscape and access to a mining site dictate whether companies will invest in mining there. Even then, successes are rare. Among all minerals and metals, around one in every 1,000 exploration projects transitions into the mining stage.

But uranium's radioactivity makes finding it a bit easier. Geiger counters and scintillometers pick up on radiation and help survey uranium hot spots. Surveyors use hand-held Geiger counters to detect radioactivity closer to the ground, while larger devices called scintillometers can pick up gamma rays at greater distances. Geologists will also sample the soil and rock to find out the ratios of uranium hidden beneath the ground's surface. Several uranium isotopes occur together, including U-234, U-235 and U-238. Methods to detect them usually don't discriminate which is more abundant in a sample, but some devices that pick up U-235 may become more widely used.

Uranium's decay process also gives rise to byproducts called daughter elements such as radium and radon, which are both radioactive as well. Surveyors measure radiation carefully to make sure they're not mistaking other elements for uranium.

Once a company knows it wants to give uranium mining a shot, it must apply for permits from the local and federal government. The process differs by country, but most permits ensure that companies uphold standards that help protect the health of miners, nearby communities and the environment. In the United States, obtaining permits for mining, getting investors onboard and conducting resource assessments can take anywhere between three and 10 years.

Mining: Making the Most of Radioactive Caches

Pictured is an open-pit uranium mine in Gas Hills.

After locating uranium deposits and obtaining appropriate permits, a company will begin to mine. There are a few ways to extract uranium from the ground: open-pit mining, underground mining and in-situ recovery.

Mining methods depend on the type of deposit, whether it's suspended in water and the geography of the area. For instance, if miners find a deposit sandwiched between layers of rock and water, in-situ recovery will be a more cost-effective option. If experts deal with dry ore, they'll most likely stick with a type of open-pit or underground mining.

- Open-pit removal for uranium closely resembles what's done to mine other metal ore. Experts and miners will use machines and explosives to create a pit. Then, they'll remove the uranium ore in chunks to be transported for further processing. Miners are specially trained to separate ore from waste. Often, they keep this motto in mind: "A mine is a terrible thing to waste, and waste is a terrible thing to mine". Open-pit differs from other types of surface mining, which remove topsoil in strips throughout the mining process.

- Underground mining calls for venturing deeper into underground mine systems, where miners use shafts or adits (vertical and horizontal tunnels) to move equipment and position workers throughout the mine. Mining underground for uranium poses higher health risks than other methods.

- In-situ recovery (previously called in-situ leaching) remains a popular way to mine for uranium, especially in the United States, where uranium deposits often lie between rock and aquifers. Rather than removing chunks of ore for processing, in-situ recovery requires using chemistry to separate the uranium from ore in the ground. By injecting baking soda and club-soda-like solutions into the ore through pipes, miners separate uranium from the rock and pump the solution to the surface. In the United States, this is the most common form of uranium mining for sandstone deposits. Experts say in-situ recovery leaves a smaller footprint on the environment, as well as a smaller reclamation tab for mining companies.

- Some operations use heap leaching, a process by which companies extract ore, break it into smaller pieces above ground and leach the pile with chemicals to separate the uranium. As the chemicals soak in, the uranium leaches into underground pipes that gather the solution. American uranium mines do not practice this method, mostly because of the environmental impacts of using acidic chemicals.

Uranium mines might appear expansive, but a relatively small number of workers perform duties at each site. Roughly 35 people help drill and place steel reinforcements into the ground to secure shafts with machines, 35 miners specialize in removing the uranium ore (in open-pit operations; 20 for underground) and about 25 individuals assist with the reclamation process in efforts to restore land back to its natural state.

Milling and Processing

At the mill, uranium ore undergoes a variety of changes to turn it into a finished product: uranium powder, also known as yellowcake.

The milling process is so important that the U.S. Atomic Energy Commission has helped mines establish mills close by to make it easier to process uranium ore and quicken the production of yellowcake.

For dry uranium ore, the rocks are milled up into smaller pieces before being placed in tanks. In-situ recovery solutions are usually ready to be placed in tanks as well. Depending on how the uranium was mined, chemical solutions are applied to the ore to strip other substances away. One part of the process will separate sand and debris gathered with the ore through ion technology, while another will use a series of solvents to pick the uranium away from other parts of the ore. Throughout the milling process, remnants of other rocks and radioactive elements from the ore -also called tailings-are gathered to be stored away. The product will continue to undergo chemical separation until all that's left is the desired amount of uranium.

The goal is to isolate uranium oxide (U_3O_8) to sell to companies for further enrichment. Most milling operations employ between 20 and 50 people.

After milling, other companies will buy the uranium to enrich it, or increase the ratio of the isotope U-235 in a given sample. During enrichment, scientists convert the yellowcake (uranium oxide) to uranium hexafluoride gas, which is put in cylinders to become a solid when it cools. To enrich uranium enough to be used as nuclear fuel, workers will increase the concentration of U-235 in the sample to usually between 2 and 5 percent. Then, fuel fabricators will transform the substance into uranium oxide powder to be compressed into uranium fuel pellets. The enriching process is highly regulated and is often done by companies other than the ones that mined it.

Uranium's Health Concerns

Ever since the negative health effects surrounding uranium mining began to surface in the 1950s, public opinion about uranium mines has split into camps of support and opposition.

Both sides agree that uranium mining raises legitimate health concerns. The most dangerous aspects of uranium mining involve radon gas, radiation and toxicity hazards.

Radon gas, a direct product of radium-226, which stems from uranium-238 decay, is known to cause lung cancer. Although radon may frequent all types of mines, tobacco smokers have an increased risk of developing cancer About halfway through the 20th century, mining regulations tightened to make conditions safer. Mines now require complex ventilation systems and protective gear for miners working in conditions with radon, especially for underground mining projects. Work areas, including break rooms and small buildings on-site, are routinely tested for radon gas in the United States.

There's also the problem of ionizing radiation, which is caused more by the elements commonly found with uranium such as radium. Some radiation can travel through skin, but the type involved with extracting uranium causes the most problems when it's accidentally ingested or inhaled. Several studies have linked these radioactive elements to an increased risk of cancer.

Uranium itself poses more risk as a toxic substance than a radioactive element. Ingesting uranium can cause kidney problems. Its radioactive cousin, radium, often integrates itself into a person's bones, which can degrade a person's health and even cause death. Because of certain risks, physical demands and skills involved in all types of mining, individuals working in this industry make salaries that are usually higher than the national average. In 2010, U.S. miners, including those who mine for uranium, made $67,000 on average-more than $20,000 more than other U.S. workers.

For nearby communities, the largest health risk may be contaminated drinking water from mining, which can contain radioactive particles and heavy metals. One expert estimates that it normally takes around 40 years to remediate groundwater from mining sites back to safe levels.

Uranium Mining: Hazards for the Environment

The environmental effects of uranium mining remain a controversial talking point. Tailings, which are leftover pieces of ore and byproducts from mills, can contain radon, radium, thorium, polonium and sometimes arsenic.

Perhaps the most serious concern is water quality. U.S. mines abandoned before the mid-1970s are deemed the most dangerous because tailings were left on site and were never properly disposed of. There's also the risk of toxic and radioactive material being carried by rain and wind.

Both the mining process and abandoned mines have had negative effects on the health and land quality of nearby communities, particularly throughout Navajo lands in the United States.

Balancing human and environmental interests lies at the heart of the uranium mining debate. On average, uranium mining sites last roughly 30 years, providing locals with jobs and economic opportunity. Individual mines last approximately seven years before becoming depleted.

The short-term economic benefits of mining for small towns become apparent as well.

"It brings 35 and 40 people into town with above average salaries," said Rick Deery, a geologist and mining law leader at the U.S. Bureau of Land Management. "They're going to buy stuff they're going to support indirect jobs".

Other people don't think the long-term effects on the environment justify uranium mining, while supporters of the practice say uranium represents a cleaner form of energy than coal or oil.

Still, tighter regulations and Superfund projects have sought to clean up uranium mines. Companies usually commit to reclamation bonds, or a type of collateral that ensures enough money will be put toward to cleanup efforts after the mining process ends. Remediation typically involves cleaning up waste from a site, while reclamation seeks to restore the area back to its natural state.

COAL MINING

Coal mining is the extraction of coal deposits from the surface of Earth and from underground.

Coal is the most abundant fossil fuel on Earth. Its predominant use has always been for producing heat energy. It was the basic energy source that fueled the Industrial Revolution of the 18th and 19th centuries, and the industrial growth of that era in turn supported the large-scale exploitation of coal deposits. Since the mid-20th century, coal has yielded its place to petroleum and natural gas as the principal energy supplier of the world. The mining of coal from surface and underground deposits today is a highly productive, mechanized operation.

Developments in Mine Entry

Shafts

Except for the Chinese, who may have mined coal underground, all the early coal seams were worked from the surface, in fully exposed outcroppings. In the later Middle Ages, however, exhaustion of outcrop coal in many places forced a change from surface to underground, or shaft, mining. Early shaft mines were little more than wells widened as much as miners dared in the face of danger of collapse. Shafts were sunk on high ground, with adits—near-horizontal tunnels—for drainage driven into the side of the hill. In England some shallow mine shafts were exhausted as early as the 14th century, making it necessary to go deeper and expand mining at the shaft bottoms. These remained small operations; a record of 1684 shows 70 mines near Bristol, employing 123 workers. Greater depth created many problems. First, water could no longer simply be drained away. Crude methods were devised to lift it to the surface. A bucket-and-chain device was first powered by men and later by horses; a continuous belt of circular plates was drawn up through a pipe. Windmills were used for pumps. But shafts had to be restricted to depths of 90 to 105 metres (300 to 350 feet) and a mining radius of 180 metres. It was not until 1710 that the water problem was eased by Thomas Newcomen's steam atmospheric engine, which supplied a cheap and reliable power source for a vertical reciprocating lift pump.

Hoisting

Raising the coal itself was another problem. Manpower, operating a windlass, was replaced by horsepower; and, as the shafts went deeper, more horses were added. At Whitehaven in 1801, coal was hoisted 180 metres by four horses at the rate of 42–44 metric tons (46–48 tons) in nine hours. The introduction of the steam engine to hoist coal was a major turning point for the industry. Small steam-powered windlasses were successfully tried out about 1770. About 1840 the first cage was used to hoist the loaded car; and from 1840 onward advances in coal-mining techniques were rapid.

Ventilation

The presence of noxious and flammable gases caused miners to recognize the critical importance of ventilation in coal mines from the earliest days. Natural ventilation was afforded by level drainage tunnels driven from the sloping surface to connect with the shaft. Surface stacks above the shaft increased the efficiency of ventilation; their use continued in small mines until the early 20th century. The most reliable method, before the introduction of fans, was the use of a furnace at the shaft bottom or on the surface. Despite the hazard of fire and explosion, there were still a large number of furnaces operating, at least in nongassy mines, in the early 20th century.

Open-flame illumination, however, was a much more common cause of explosions until the introduction of the Davy safety lamp (about 1815), in which the flame is enclosed in a double layer of wire gauze that prevents ignition of flammable gases in the air of the mine. Presence of strong air currents, however, made even the Davy lamp unsafe.

Rotary ventilating fans were introduced in mines in the 18th century. Originally of wood and powered by steam, they were improved throughout the 19th and 20th centuries by the introduction of steel blades, electric power, and aerodynamically efficient shapes for the blades.

From Manual to Mechanized Extraction

Conventional Mining

Early European miners wedged coal out of the seam or broke it loose with a pick. After explosives were introduced, it was still necessary to undercut the coal seam with hand tools. The advent of steam, compressed air, and electricity brought relief from this hard, dangerous work. In 1868, after almost 100 years of trial and error, a commercially successful revolving-wheel cutter for undercutting the coal seam was introduced in England. This first powered cutting tool was soon improved by introduction of compressed air as a power source in place of steam. Later, electricity was used. The longwall cutter was introduced in 1891. Originally driven by compressed air and later electrified, it could begin at one end of a long face (the vertical, exposed cross section of a seam of coal) and cut continuously to the other.

Development of Continuous Mining

The conventional mining techniques made up of the cyclic operations of cutting, drilling, blasting, and loading, developed in association with room-and-pillar mining. The oldest of the basic underground methods, room-and-pillar mining grew naturally out of the need to recover more coal as mining operations became deeper and more expensive. During the late 1940s, conventional techniques began to be replaced by single machines, known as continuous miners, that broke off the coal from the seam and transferred it back to the haulage system. The Joy Ripper was the first continuous miner applicable to the room-and-pillar method.

Origins of Longwall Mining

The other principal method of modern mining, longwall mining, had been introduced as early as the 17th century and had found general use by the 19th century, but it had long been less productive than room-and-pillar mining. This began to change in the 1940s, when a continuous system involving the “plow” was developed by Wilhelm Loebbe of Germany. Pulled across the face of the coal and guided by a pipe on the face side of a segmented conveyor, the plow carved a gash off the bottom of the seam. The conveyor snaked against the face behind the advancing plow to catch the coal that chipped off from above the gash. Substantially reducing the labour required at the coal face, the Loebbe system quickly became popular in Germany, France, and the Low Countries.

The plow itself had limited application in British mines, but the power-advanced segmented conveyor became a fundamental part of equipment there, and in 1952 a simple continuous machine called the shearer was introduced. Pulled along the face astride the conveyor, the shearer bore a series of disks fitted with picks on their perimeters and mounted on a shaft perpendicular to the face. The revolving disks cut a slice from the coal face as the machine was pulled along, and a plow behind the machine cleaned up any coal that dropped between the face and the conveyor.

Roof Support

The technique of supporting the roof by rock bolting became common in the late 1940s and did much to provide an unobstructed working area for room-and-pillar mining, but it was a laborious and slow operation that prevented longwall mining from realizing its potential. In the late 1950s, however, powered, self-advancing roof supports were introduced by the British. Individually or in groups, these supports, attached to the conveyor, could be hydraulically lowered, advanced, and reset against the roof, thus providing a prop-free area for equipment (between the coal face and the first row of jacks) and a canopied pathway for miners (between the first and second rows of jacks).

Haulage

Manual Labour to Electric Power

In the first shaft mines, coal was loaded into baskets that were carried on the backs of men or women or loaded on wooden sledges or trams that were then pushed or hauled through the main haulage roadway to the shaft bottom to be hung on hoisting ropes or chains. In drift and slope mines, the coal was brought directly to the surface by these and similar methods. Sledges were pulled first by men and later by animals, including mules, horses, oxen, and even dogs and goats.

Steam locomotives designed by Richard Trevithick were used in the fields of South Wales and Tyne and later in Pennsylvania and West Virginia, but they created too much smoke. Compressed-air locomotives, which appeared in the 1880s, proved expensive to operate. Electric locomotives, introduced in 1887, rapidly became popular, but mules and horses were still working in some mines as late as the 1940s.

Mechanized Loading

The loading by hand of broken coal into railcars was made obsolete early in the 20th century by mobile loaders. The Stanley Header, the first coal-loading machine used in the United States, was developed in England and tested in Colorado in 1888. Others were developed, but few progressed beyond the prototype stage until the Joy machine was introduced in 1914. Employing the gathering-arm principle, the Joy machine provided the pattern for future successful mobile loaders. After the introduction in 1938 of electric-powered, rubber-tired shuttle cars designed to carry coal from the loading machine to the elevator, mobile loading and haulage rapidly supplanted track haulage at the face of room-and-pillar mines.

Conveyors

In 1924 a conveyor belt was successfully used in an anthracite mine in central Pennsylvania to carry coal from a group of room conveyors to a string of cars at the mine entry. By the 1960s belts had almost completely replaced railcars for intermediate haulage.

Preparation

The history of coal preparation begins in the 19th century, with the adaptation of mineral-processing methods used for enriching metallic ores from their associated impurities. In the early years, larger pieces of coal were simply handpicked from pieces composed predominantly of mineral matter. Washing with mechanical devices to separate the coal from associated rocks on the basis of their density differences began during the 1840s.

At first, coal preparation was necessitated by the demand for higher heating values; another demand was for such special purposes as metallurgical coke for steelmaking. In recent years, as concern has grown over the emission of sulfur dioxide in the flue gases of power plants, coal preparation has taken on greater importance as a measure to remove atmospheric pollutants.

Coal Deposits

Coalification

In geologic terms, coal is a sedimentary rock containing a mixture of constituents, mostly of vegetal origin. Vegetal matter is composed mainly of carbon, hydrogen, oxygen, nitrogen, sulfur, and some inorganic mineral elements. When this material decays under water, in the absence of oxygen, the carbon content increases. The initial product of this decomposition process is known as peat. Peat can be formed in bogs, marshes, or freshwater swamps, and in fact huge freshwater swamps of the geologic past provided favourable conditions for the formation of thick peat deposits that over time became coal deposits. The transformation of peat to lignite is the result of pressure exerted by sedimentary materials that accumulate over the peat deposits. Even greater pressures and heat from movements of the Earth’s crust (as occurs during mountain building), and occasionally from igneous intrusion, cause the transformation of lignite to bituminous and anthracite coal.

Major Coal Eras

Coal deposits are known to have formed more than 400 million years ago. Most anthracite and bituminous coals occur within the 299- to 359.2-million-year-old strata of the Carboniferous Period, the so-called first coal age. The formation of coal deposits continued through the Permian, Triassic, and Jurassic periods into the “second coal age,” which includes the Cretaceous, Paleogene, and Neogene periods. Coals of the Cretaceous Period (145.5 million to 65.5 million years ago) are generally in the high-volatile to medium-volatile bituminous ranks. Cenozoic coals, formed less than 65.5 million years ago, are predominantly of the subbituminous and lignitic ranks.

Rank and Grade

The rank of a coal indicates the progressive changes in carbon, volatile matter, and probably ash and sulfur that take place as coalification progresses from the lower-rank lignite through the higher ranks of subbituminous, high-volatile bituminous, low-volatile bituminous, and anthracite. The rank of a coal should not be confused with its grade. A high rank (e.g., anthracite) represents coal from a deposit that has undergone the greatest degree of devolatilization and contains very little mineral matter, ash, and moisture. On the other hand, any rank of coal, when cleaned of impurities through coal preparation, will be of a higher grade.

Resources and Reserves

Distribution Worldwide

Coal deposits are found in sedimentary rock basins, where they appear as successive layers, or seams, sandwiched between strata of sandstone and shale. There are more than 2,000 coal-bearing sedimentary basins distributed around the world. World coal resources—that is, the total amount of coal available in the world—are approximately 11 trillion tons. The distribution of the estimated coal resources of the world is approximately as follows: Europe (including Russia and the former Soviet republics) 49 percent; North America 29 percent; Asia 14 percent; Australia 6 percent; and Africa and South America 1 percent each. Distinct from coal resources are coal reserves, which are only those resources that are technically and economically minable at a particular time. The current recoverable coal reserves of the world are estimated at 760 billion tons. Their distribution by continent is: Europe 44 percent; North America 28 percent; Asia 17 percent; Australia 5 percent; Africa 5 percent; and South America 1 percent.

Economic Factors

Among the most important factors that influence the movement of a coal deposit from a resource to a reserve or vice versa are the price of coal in the energy market and the costs of producing the coal for that market. Currently, seams less than 30 centimetres (1 foot) in thickness are not considered economically recoverable. Furthermore, extraction from seams at great depth—i.e., over 1,000 metres (3,300 feet)—presents great difficulties. Other geologic features, such as excessively steep seams, extensive faulting and folding, washouts created by erosion and sedimentation, and burnout of the coal seams by igneous intrusion, all affect the amount and quality of coal that can be recovered from a seam.

Prospecting and Exploration

The fundamental objective of coal prospecting is to discover coal resources through a search. In areas where coal mining has not been previously practiced, the search process should result in obtaining coal samples that give reasonable evidence of the existence of a coal seam. Once a seam has been discovered, considerable further work is necessary in order to advance knowledge of the particular geologic aspects and the extent of the coal deposit. The term coal exploration is used to describe these activities. Coal exploration includes activities and evaluations necessary to gather data for making decisions on such issues as the desirability of further exploration, the technical feasibility of mining (including favourable and unfavourable factors), and economic feasibility (including size of mine, coal quality assessment, marketability, and preparation of mined coal for market requirements).

Mapping

Geologic mapping is an important task in exploration. Mapping involves compiling detailed field notes on coal seams, strata above and below the seam, rock types, geologic structures, stream data, and man-made structures. Good maps and mapping techniques provide a means for planning and accomplishing exploration, development, reclamation, day-to-day operations, and equipment moves. Calculation of material volumes, location of physical elements, and determination of mining conditions are expedited by the use of maps. Maps also provide a method for recording data so that they can be organized and analyzed for ready reference.

Aerial photography and mapping methods (photogrammetry) are increasing in usefulness, particularly in the exploration and mining of surface deposits. Photogrammetric methods are relatively easy and inexpensive, can be adjusted to any scale, and are highly accurate in any terrain. Aerial photography can be conducted at an altitude designed to produce maps that show drainage configuration, roads, buildings, lakes, streams, timber, power lines, railroads, and fences or other features that may be missed by a ground survey.

Drilling

Drilling is the most reliable method of gathering information about a coal deposit and the mining conditions. It provides physical samples of the coal and overlying strata for chemical and physical analysis.

Spatial Patterns

Numerous factors are associated with a drilling program. One is the spatial pattern of the holes in an exploration area. When very large areas are being studied, hole spacings vary greatly and generally are not in any set pattern. When the program is narrowed to a specific target area, a grid pattern is most common. In areas where coal is known to exist, closely spaced drill-hole patterns are required.

Core Drilling and Rotary Drilling

A second factor associated with a drilling program is the choice between core drilling and rotary drilling. In core drilling, a hollow drill bit is attached to a core barrel so that cylindrical samples of the strata can be obtained. (Since the drill bit is faceted with diamonds for cutting the strata, this method is also called diamond core drilling.) Photographing the cores as they come out of the hole can provide data of great reliability. In rotary drilling, the samples obtained are the chips and pulverized rock produced by the abrasive and chipping action of the drill bit. Rotary drilling is faster and comparatively less expensive than core drilling. In fact, it is not uncommon to drill down to the top of the coal seam by rotary drilling and then replace the drill tools for core drilling. In most programs, only 10 to 25 percent of the holes are actually cored for detailed information on overlying strata and coal. Coring of the coal seam itself, however, should closely approach 100 percent; if it does not, the analytical information obtained should be considered suspect.

Dozer Cutting

Exploration of coal outcrops may be accomplished with dozer cuts at regular intervals. Dozer cutting provides information on the attitude of the coal and on the nature of the overburden—important factors with regard to machine operation.

Geophysical Exploration

In geophysical exploration, the seismic, electric, magnetic, radiometric, and gravitational properties of earth materials are measured in order to detect anomalies that may be caused by the presence of mineral deposits. Their form of exploration may begin with airborne methods in regional and target-area investigations and continue with on-ground methods during detailed investigations. The most widely utilized airborne methods are, in increasing order of use, magnetic, magnetic plus radiometric, magnetic plus electromagnetic, and electromagnetic. These methods are almost always accompanied by aerial photography.

Ground geophysical methods have a major advantage over the airborne methods in that they are in direct contact with the earth. The principal methods are electrical, magnetic, electromagnetic, radiometric, gravimetric, and refraction-seismic. The drill-hole geophysical survey, called logging, is an important method of extending data acquisition beyond the drill hole. A combination of logging methods is advantageous: gamma-ray and density logging for identifying the type of coal present; gamma-ray (radiometric), resistivity (electric), and calliper logs for determining the thickness of the seam; and sonic and density logs for determining the condition of the roof and floor strata.

Choosing a Mining Method

The various methods of mining a coal seam can be classified under two headings, surface mining and underground mining. Surface and underground coal mining are broad activities that incorporate numerous variations in equipment and methods, and the choice of which method to use in extracting a coal seam depends on many technological, economic, and social factors. The technological factors include, at a minimum, the number of seams, the thickness and steepness of each seam, the nature and thickness of the strata overlying the seams, the quality of the coal seams, the surface topography, the surface features, and the transportation networks available. Economic factors include energy demand and its growth, the supply and cost of alternative sources of energy, coal quality and the cost of coal preparation, the selling price of coal, advancements in technology that affect costs of production, and environmental legislation. Social factors include prior history of mining in the area, ownership patterns, availability of labour, and local or regional government support.

It is a general rule that technological factors dictate a clear choice between surface and underground mining, whereas economic and social factors determine whether a coal reserve will be mined at all. Some coal reserves, however, are surface-mined first and then deep-mined when the coal seam extends to such great depths that it becomes uneconomical to continue with surface mining. The point where it becomes economically necessary to switch from one method to the other can be calculated with the aid of stripping ratios, which represent the amount of waste material that must be removed to extract a given amount of coal. Stripping ratios can also consider the selling price of coal, and a certain minimum profit can be added to the total cost of producing and marketing the coal for a more thorough cost-benefit analysis.

Analysis of world coal production indicates that contributions from surface and underground production are approximately equal. Anthracite seams (less than 10 percent of world coal production) are generally mined by underground methods, whereas lignite seams (25 percent) are most often surface-mined. Bituminous seams (approximately 65 percent) are mined in roughly equal proportions by both methods.

Surface Mining

Surface coal mining generally involves the following sequence of unit operations:

1. Clearing the land of trees and vegetation,
2. Removing and storing the top layers of the unconsolidated soil (topsoil),
3. Drilling the hard strata over the coal seam,
4. Fragmenting or blasting the hard strata with explosives,
5. Removing the blasted material, exposing the coal seam, and cleaning the top of the coal seam,
6. Fragmenting the coal seam, as required, by drilling and blasting,
7. Loading the loose coal onto haulage conveyances,
8. Transporting the coal from the mine to the plant, and
9. Reclaiming lands affected by the mining activity.

Mining Methods

Surface techniques can be broadly classified into:

1. Contour strip mining,
2. Area strip mining,
3. Open-pit mining, and
4. Auger mining.

Contour Strip Mining

Contour mining is commonly practiced where a coal seam outcrops in rolling or hilly terrain. Basically, the method consists of removing the overburden above the coal seam and then, starting at the outcrop and proceeding along the hillside, creating a bench around the hill. In the past, the blasted overburden spoil was simply shoved down the hill; currently, soil is either carried down the mountain to fill a chosen valley in horizontal layers or is replaced on the working bench itself in places where coal has been removed. If the break-even stripping ratio remains favourable, further cuts into the hillside will be made. Otherwise, if there are sufficient reserves under the knob of the hill, the coal may be recovered by underground mining or by augering.

Area Strip Mining

Area mining, applied where the terrain is flat, commences with a trench or “box cut” made through the overburden to expose a portion of the coal seam. This trench is extended to the limits of the property in the strike direction. After coal removal, a second cut is made parallel to the first one, and the overburden material from this cut is placed in the void of the first cut. The process is repeated in successive parallel cuts until the stripping ratio indicates that continued surface mining is uneconomical.

Open-pit Mining

In open-pit mining of the coal seam, several benches are established in both the overburden strata and the coal seam. The open-pit method is generally practiced where thick coal seams are overlain by thick or thin overburden; it is also used for mining steeply pitching coal seams. In the beginning stages of mining, considerable volumes of overburden materials must be accumulated in large dump areas outside the mine.

Auger Mining

Auger mining is usually associated with contour strip mining. With this method, the coal is removed by drilling auger holes from the last contour cut and extracting it in the same manner that shavings are produced by a carpenter's bit. Coal recovery rates approach 60 percent with this method. The cutting heads of some augers are as high as 2.5 metres. As each stem works its way into the coal seam, additional auger stems are added, so that hole depths of more than 60 to 100 metres are not uncommon. Problems of subsidence, water pollution, and potential fires are associated with augering.

Highwall mining is an adaptation of auger mining. Instead of an auger hole, an entry into the coal seam is made by a continuous miner, remotely operated from a cabin at the surface. The cut coal is transported by conveyors behind the miner to the outside. Using a television camera, the operator can see and control the miner's progress. The entry can be advanced 300 to 400 metres into the coal seam, after which the miner is retreated to the surface and repositioned to drive an entry adjacent to the previous one. Advantages over augering include higher productivity, greater safety, and lower cost.

Equipment

Dozers and Scrapers

A variety of equipment is used in a surface mining operation. In land clearing, topsoil removal, and preparation of the mining area for subsequent unit operations, bulldozers and scrapers have extensive applications. These pieces of equipment have grown bigger and better over the years. Currently, scrapers for rock have bucket capacities of 33 cubic metres (1,165 cubic feet; about 47 tons of material), and scrapers for coal have capacities of 43 cubic metres (37 tons). Bulldozers have blade capacities up to 30 cubic metres.

Drilling and Blasting

Where strata are hard, drilling and blasting are necessary. Blastholes are generally drilled from the surface, are vertical, and vary in diameter from 25 to 100 centimetres. In some mines, horizontal holes are drilled into the overburden with the drill sitting on the coal surface. The holes are charged with explosives that are based on a mix of ammonium nitrate and fuel oil (ANFO) in dry mix, slurry, or emulsion form. It is common to have a bulk-explosive truck drive into the area where holes have been drilled to fill holes with custom-designed explosive mixtures.

Shovels and Trucks

Overburden removal is the most important operation in the system. When the haul distances are small (for example, 500 to 1,000 metres) and the overburden material soft, a fleet of scrapers can load, haul, and dump the overburden. Where distances are very small (for example, 30 to 40 metres), mobile front-end loaders, or wheel loaders, may be used to load, haul, and dump. At greater haul distances, a fleet of trucks may be necessary, the trucks being loaded by front-end loaders.

Three types of shovel are currently used in mines: the stripping shovel, the loading (or quarry-mine) shovel, and the hydraulic shovel. The hydraulic mining shovel has been widely used for coal and rock loading since the 1970s. The hydraulic system of power transmission greatly simplifies the power train, eliminates a number of mechanical components that are present in the loading shovel, and provides good crowding and breakout forces. Hydraulic and loading shovels are available with capacities up to and over 30 cubic metres. The capacity of the loading shovel is carefully matched with the haul unit into which the load will be dumped. In open-pit coal mines, the haul units for overburden material are usually large, off-highway, end-dumping trucks; their capacities range from 35 to 250 tons. The stripping shovel has a large bucket, usually sits in the pit on the top of the coal seam, digs into the overburden material, and deposits it in the adjacent mined-out area.

Draglines

Draglines are by far the most commonly used overburden-removal equipment in surface coal mining. A dragline sits on the top of the overburden, digs the overburden material directly in front of it, and disperses the material over greater distances than a shovel. Compared with shovels, draglines provide greater flexibility, work on higher benches, and move more material per hour. The largest dragline in operation has a bucket capacity of 170 cubic metres.

Wheel Excavators

The bucket-wheel excavator (BWE) is a continuous excavation machine capable of removing up to 12,000 cubic metres per hour. The most favourable soil and strata conditions for BWE operation are soft, unconsolidated overburden materials without large boulders. BWEs are widely employed in lignite mining in Europe, Australia, and India. In these mines, the wheel excavators deposit the overburden and coal materials onto high-speed, high-capacity belt conveyors for transport to the mined-out areas of the pit and the coal stockpile, respectively. In the United States, wheel excavators have been used in combination with shovels or draglines, with a wheel handling soft topsoil and clay layers and a shovel or dragline removing hard strata.

Coal Removal

Coal is usually loaded by front-end loaders, loading shovels, or wheel excavators into off-highway, bottom-dump trucks for transport to the stockpile. In small operations, it can be loaded into on-highway trucks for direct shipment to customers. In some open-pit operations with BWEs, rail haulage is practiced in the benches themselves, coal and overburden being loaded directly into railcars by the wheel excavator. Nevertheless, in BWE operations belt haulage is preferable, as it facilitates continuous mining.

Reclamation Equipment

Equipment used in reclaiming mined lands includes bulldozers, scrapers, graders, seeders, and other equipment used extensively in agriculture. Reclamation operations, which include backfilling the last cut after coal removal, regrading the final surface, and revegetating and restoring the land for future use, are integrated with the mining operation in a timely manner in order to reduce erosion and sediment discharge, slope instability, and water-quality problems.

A primary goal of reclamation is to restore or enhance the land-use capability of disturbed land. Various reclamation programs aim at restoring the ground for farming and livestock raising, reforestation, recreation, and housing and industrial sites. Even spoil banks that can be revegetated present only minor problems and have great potential for development. There are, however, marginal and problem spoils (such as those containing acids or toxic wastes) that require special attention and additional planning.

Underground Mining

In underground coal mining, the working environment is completely enclosed by the geologic medium, which consists of the coal seam and the overlying and underlying strata. Access to the coal seam is gained by suitable openings from the surface, and a network of roadways driven in the seam then facilitates the installation of service facilities for such essential activities as human and material transport, ventilation, water handling and drainage, and power. This phase of an underground mining operation is termed "mine development." Often the extraction of coal from the seam during mine development is called "first mining"; the extraction of the remaining seam is called "second mining."

Mining Methods

Modern underground coal-mining methods can be classified into four distinct categories: room-and-pillar, longwall, shortwall, and thick-seam.

Room-and-pillar Mining

In this method, a number of parallel entries are driven into the coal seam. The entries are connected at intervals by wider entries, called rooms, that are cut through the seam at right angles to the entries. The resulting grid formation creates thick pillars of coal that support the overhead strata of earth and rock. There are two main room-and-pillar systems, the conventional and the continuous. In the conventional system, the unit operations of undercutting, drilling, blasting, and loading are performed by separate machines and work crews. In a continuous operation, one machine—the continuous miner—rips coal from the face and loads it directly into a hauling unit. In both methods, the exposed roof is supported after loading, usually by rock bolts.

Under favourable conditions, between 30 and 50 percent of the coal in an area can be recovered during development of the pillars. For recovering coal from the pillars themselves, many methods are practiced, depending on the roof and floor conditions. The increased pressure created by pillar removal must be transferred in an orderly manner to the remaining pillars, so that there is no excessive accumulation of stress on them. Otherwise, the unrecovered pillars may start to fail, endangering the miners and mining equipment. The general procedure is to extract one row of pillars at a time, leaving the mined-out portion, or gob, free to subside. While extraction of all the coal in a pillar is a desirable objective, partial pillar extraction schemes are more common.

At depths greater than 400 to 500 metres, room-and-pillar methods become very difficult to practice, owing to excessive roof pressure and the larger pillar sizes that are required.

Longwall Mining

In the longwall mining method, mine development is carried out in such a manner that large blocks of coal, usually 100 to 300 metres wide and 1,000 to 3,000 metres long, are available for complete extraction. A block of coal is extracted in slices, the dimensions of which are fixed by the height of coal extracted, the width of the longwall face, and the thickness of the slice (ranging from 0.6 to 1.2 metres). In manual or semimechanized operations, the coal is undercut along the width of the panel to the depth of the intended slice. It is then drilled and blasted, and the broken coal is loaded onto a conveyor at the face. The sequence of operations continues with support of the roof at the face and shifting of the conveyor forward. The cycle of cutting, drilling, blasting, loading, roof supporting, and conveyor shifting is repeated until the entire block is mined out.

A longwall miner shearing coal at the face of a coal seam.

In modern mechanized longwall operations, the coal is cut and loaded onto a face conveyor by continuous longwall miners called shearers or plows. The roof is supported by mechanized, self-advancing supports called longwall shields, which form a protective steel canopy under which the face conveyor, workers, and shearer operate. In combination with shields and conveyors, longwall shearers or plows create a truly continuous mining system with a huge production capacity. Record productions exceeding 20,000 tons per day, 400,000 tons per month, and 3.5 million tons per year have been reported from a single U.S. longwall shearer face.

Two main longwall systems are widely practiced. In this method the block is developed to its boundary first, and then the block is mined back toward the main haulage tunnel. In the advancing longwall method, which is more common in Europe, development of the block takes place only 30 to 40 metres ahead of the mining of the block, and the two operations proceed together to the boundary.

In longwall mining, as in the room-and-pillar system, the safe transfer of roof pressures to the solid coal ahead of the face and to the caved roof behind the face is necessary. Caving of the overlying strata generally extends to the surface, causing surface subsidence. The subsidence over a longwall face is generally more uniform than it is over room-and-pillar workings. If conditions are such that the roof will not cave or subsidence to the surface is not allowable, it will be necessary to backfill the void with materials such as sand, waste from coal-preparation plants, or fly ash. Owing to technical and environmental reasons, backfilling is practiced in many mining countries (e.g., Poland, India), but the cost of production is much higher with backfilling than it is without.

Shortwall Mining

In the shortwall mining method, the layout is similar to the longwall method except that the block of coal is not more than 100 metres wide. Furthermore, the slices are as much as three metres thick and are taken by a continuous miner. The mined coal is dumped onto a face conveyor or other face haulage equipment. The roof is supported by specially designed shields, which operate in the same manner as longwall shields. Although a great future was envisioned for shortwall mining, it has not lived up to expectations.

Thick-seam Mining

Coal seams as much as five metres thick can be mined in a single "lift" by the longwall method, and seams up to seven metres thick have been extracted by conventional mining systems in one pass. However, when a seam exceeds these thicknesses, its extraction usually involves dividing the seam into a number of slices and mining each slice with longwall, continuous, or conventional mining methods. The thickness of each slice may vary from three to four metres. Many variations exist in the manner in which the complete seam is extracted. The slices may be taken in ascending or descending order. If the roof conditions or spontaneous-combustion liability of the seam requires that there be no caving, the void created by mining will be backfilled. The backfill material then acts as an artificial floor or roof for the next slice. Caving is the preferred practice, however.

Thick coal seams containing soft coal or friable bands and overlain by a medium-to-strong roof that parts easily from the coal can be fragmented by a high-pressure water jet. For successful operation, the floor must not deteriorate through contact with water, and the seam gradient must be steep enough to allow the water to flush the broken coal from the mined areas. Under favourable conditions, hydraulic mining of coal is productive, safe, and economical. It has been employed experimentally within the United States and Canada, but it is practiced extensively in the Kuznetsk Basin of Siberia for the extraction of multiseam, steeply pitching deposits. Here the water is also used to transport the coal from the working faces to a common point through open channels and from the common point to the surface through high-pressure hydraulic transportation systems.

Auxiliary and Unit Operations

Those activities which are essential to maintain safe and productive operating conditions both at the working faces and in all parts of the mine are known as auxiliary operations. These include ground control, ventilation, haulage, drainage, power supply, lighting, and communications. Those activities which are conducted sequentially in a production cycle—i.e., cutting and hauling the coal and supporting the immediate exposed roof after coal removal—are called unit operations. Unit operations are planned and conducted so as to use the auxiliary services most effectively for maintaining health and safety as well as productivity at the locations where coal is actually being mined.

Access

Accesses to a coal seam, called portals, are the first to be completed and generally the last to be sealed. A large coal mine will have several portals. Their locations and the types of facilities installed in them depend on their principal use, whether for worker and material transport, ventilation, drainage and power lines, or emergency services. In many cases, the surface facilities near a portal include bathhouses and a lamp room; coal handling, storage, preparation, and load-out facilities; a fan house; water- and waste-handling systems; maintenance warehouses; office buildings; and parking lots.

There are three types of portal: drift, slope, and shaft. Where a coal seam outcrops to the surface, it is common to drive horizontal entries, called drifts, into the coal seam from the outcrop. Where the coal seam does not outcrop but is not far below the surface, it is accessed by driving sloping tunnels through the intervening ground. Slopes are driven at as steep an angle as is practicable for transporting coal by belt. Commonly, a pair of slopes is driven (or a slope is divided into two separate airtight compartments) or ventilation and material transport. Where the minimum coal-seam depth exceeds 250 to 300 metres, it is common to drive vertical shafts. (Poor ground conditions are another factor in selecting a shaft over a slope.) Shafts, too, may be split into separate compartments for fresh air, return air, worker and supply transport, and coal haulage.

Capital and operating costs for coal haulage are lowest in a drift access. Capital investment for coal haulage in a shaft or a slope is somewhat similar, but operating costs are generally higher in a shaft, owing to the noncontinuous nature of shaft coal-handling facilities. It has been estimated that shafts and slopes, drifts, and permanent equipment in these access openings may account for more than 30 percent of the capital investment in a large mine.

Ground Control and Roof Support

Overall ground control—i.e., long-term stability of mine accesses and entries and subsidence control—can be regarded as an auxiliary operation, whereas supporting the roof at production faces (roof control) is a unit operation. Ground control is concerned with the design of underground entries, their widths, the distance between the entries, and the number of entries that can be driven as a set. A hierarchy of entries exists in underground coal mines. Main entries are driven so as to divide the property into major areas; they usually serve the life of the mine for ventilation and for worker and material transport. Submain entries can be regarded as feeders from the mains that subdivide each major area. From the submains, panel entries take off to subdivide further a block of coal into panels for orderly coal extraction.

In some cases, complete collapse of the overlying strata during extraction eventually travels to the surface, resulting in surface depressions. This effect is called subsidence. Clearly, the wider and more numerous the entries, the more effective they will be for ventilation, materials handling, and first-mining extraction percentage. However, with increased width may come problems in entry and pillar stability. Often, by limiting the first mining to a small fraction of the coal seam and by laying out large undisturbed blocks of coal, subsidence may be reduced. The science of rock mechanics is well advanced and is useful for understanding such stability problems and for the design of mine openings, pillar sizing, extraction techniques, and planned subsidence.

Roof support at the face (the area where coal is actively mined) is intended to hold the immediate roof above the coal face. In modern mechanized mines, roof bolting is the most common method employed. Steel bolts, usually 1.2 to 2 metres long and 15 to 25 millimetres in diameter, are inserted in holes drilled into the roof by an electric rotary drill and are secured by either friction or resin. The bolts are set in rows across the entry, 1.2 to 1.8 metres apart. Several theories explain how roof bolts hold the roof. These include the beam theory (roof bolts tie together several weak strata into one), the suspension theory (weak members of the strata are suspended from a strong anchor horizon), and the keying-effect theory (roof bolts act much like the keystone in an arch).

Inserting steel bolts to support the roof of an underground.

Additional supporting systems for entries (mains, submains, and panels) include temporary or permanent hydraulic or friction props, cribs (made of timber or reinforced concrete block), yieldable steel arches, and roof trusses.

Haulage

Coal haulage, the transport of mined coal from working faces to the surface, is a major factor in underground-mine efficiency. It can be considered in three stages: face or section haulage, which transfers the coal from the active working faces; intermediate or panel haulage, which transfers the coal onto the primary or main haulage; and the main haulage system, which removes the coal from the mine. The fundamental difference between face, intermediate, and main haulages is that the last two are essentially auxiliary operations in support of the first. Face haulage systems must be designed to handle large, instantaneous production from the cutting machines, whereas the outer haulage systems must be designed to accommodate such surges from several operating faces. Use of higher-capacity equipment in combination with bins or bunkers is common. In addition, face haulage systems generally discharge onto ratio-feeders or feeder-breakers in order to even out the flow of material onto the intermediate systems and to break very large lumps of coal or rock to below a maximum size.

In room-and-pillar systems, electric-powered, rubber-tired vehicles called shuttle cars haul coal from the face to the intermediate haulage system. In some semimechanized or manual longwall operations, chain haulage is used, while the face haulage equipment of choice in modern mechanized longwall systems is an armoured face conveyor (AFC). In addition to carrying coal from the face, the AFC serves as the guide for the longwall shearer, which rides on it.

Intermediate haulage in coal mines is provided by panel belts or by mine cars driven by locomotives. Panel belts have widths ranging from 90 to 150 centimetres, the wider belts being used with longwall panels. The use of mine cars and locomotives requires detailed considerations of shuttle-car dumping ramps, locomotive switching requirements, the inventory of mine cars, and track layout for empties and loads. Locomotives are electric- or diesel-powered. Mainline haulage is also provided by belt or railcar. The major differences are only in the size, scope, and permanence of installations. For example, mainline belts are laid for the life of the mine and are much wider and faster than intermediate belts. Mainline locomotives are also much larger than intermediate locomotives, and mainline tracks are built to more exacting standards of speed and reliability.

For the transport of maintenance and operating supplies to the working sections, advantage is taken of the mainline, intermediate, and face haulage systems. Monorail systems or endless-rope haulage systems, which are much like ski lifts, are commonly used in intermediate and face systems to transport supplies to the working faces. In all-belt mines, it is not unusual to have trolley rail haulage for carrying workers and materials to and from the working face. Other supply haulage equipment includes scoops and battery- or diesel-powered trucks.

Ventilation

The primary purpose of underground-mine ventilation is to provide oxygen to the miners and to dilute, render harmless, and carry away dangerous accumulations of gases and dust. In some of the gassiest mines, more than six tons of air are circulated through the mine for every ton of coal mined. Air circulation is achieved by creating a pressure difference between the mine workings and the surface through the use of fans. Fresh air is conducted through a set of mine entries (called intakes) to all places where miners may be working. After passing through the workings, this air (now termed return air) is conducted back to the surface through another set of entries (called returns). The intake and return airstreams are kept separate. Miners generally work in the intake airstream, although occasionally work must be done in the return airways.

The task of bringing fresh air near the production faces is an important auxiliary operation, while the task of carrying this air up to the working faces—the locations of which may change several times in a shift—is the unit operation known as face ventilation. The major difference between main ventilation and face ventilation is the number and nature of the ventilation control devices (fans, stoppings, doors, regulators, and air-crossings). In face ventilation, plastic or plastic-coated nylon cloth is generally used to construct stoppings and to divide the air along a face into the two streams of intake and return air. Furthermore, the stoppings, which are generally hung from the roof, are not secured at the bottom, in case machinery and coal must be transported from one side to the other. Main ventilation stoppings and air crossings, on the other hand, are constructed of brick or blocks and coated with mortar; the fans, regulators, and doors are also of substantial construction.

Monitoring and Control

Advancements in sensor technology and in computer hardware and software capabilities are finding increasing application in underground coal mines, especially in the monitoring and control of ventilation, haulage, and machine condition. Longwall shearers and shields can be remotely operated, and continuous miners have also been equipped with automatic controls. The atmospheric environment is remotely monitored for air velocity, concentrations of various gases, and airborne dust; fans and pumps are also monitored continuously for their operational status and characteristics.

Health, Safety and Environment

In coal mining—particularly underground coal mining—there are numerous conditions that can threaten the health and safety of the miners. For this reason, coal mining worldwide is heavily regulated through health and safety laws. Through the development of new equipment for personnel protection, new approaches to mine design, more effective emergency preparedness plans and procedures, and major changes in legislation, regulation, and enforcement, higher standards of health and safety are now achieved. For example, the self-contained self-rescuer (SCSR) represents a significant development in raising a miner's chances of survival and escape after an explosion, fire, or similar emergency contaminates the mine atmosphere with toxic gases. This lightweight, belt-wearable device is available worldwide and is mandated in several countries to be carried on the person whenever underground.

The effects of mining on the water, air, and land outside the mine are as important as those that occur in the mine. These effects may be felt both on- and off-site; in addition, they may vary in severity from simple annoyance and property damage to possibly tragic illness and death. Even abandoned lands from past mining activities present such problems as mine fires, precipitous slopes, waste piles, subsidence, water pollution, derelict land, and other hazards endangering general welfare and public health. Growing environmental consciousness has brought about a greater consideration of environmental factors in the planning, designing, and operating of mines.

Coal Preparation

During the formation of coal and subsequent geologic activities, a coal seam may acquire mineral matter, veins of clay, bands of rock, and igneous intrusions. In addition, during the process of mining, a portion of the roof and floor material may be taken along with the coal seam in order to create adequate working height for the equipment and miners. Therefore, run-of-mine (ROM) coal—the coal that comes directly from a mine—has impurities associated with it. The buyer, on the other hand, may demand certain specifications depending on the intended use of the coal, whether for utility combustion, carbonization, liquefaction, or gasification. In very simple terms, the process of converting ROM coal into marketable products is called coal preparation.

Levels of Cleaning

Coal preparation results in at least two product streams, the clean coal product and the reject. Generally, five levels of preparation can be identified, each being an incremental level of cleaning over the previous one:

Level 0:

At this level, no coal cleaning is done; ROM coal is shipped directly to the customer.

Level 1:

ROM coal is crushed to below a maximum size; undesirable constituents such as tramp iron, timber, and perhaps strong rocks are removed; the product is commonly called raw coal.

Level 2:

The product from level 1 is sized into two products: coarse coal (larger than 12.5 millimetres) and fine coal (less than 12.5 millimetres); the coarse coal is cleaned to remove impurities; the fine coal is added to the cleaned coarse coal or marketed as a separate product.

Level 3:

Raw coal of less than 12.5 millimetres is sized into two products: an intermediate product (larger than 0.5 millimetre) and a product smaller than 0.5 millimetre; the intermediate product is cleaned to remove impurities; the smaller product is added to the cleaned intermediate product or marketed separately.

Level 4:

Cleaning is extended to material less than 0.5 millimetre in size.

Preparation Steps

In the early days of coal preparation, the objective was to provide a product of uniform size and to reduce the content of inert rock materials in ROM coal. Reduction of impurities increased the heating value of the cleaned product, reduced deposits left on the furnace, reduced the load on the particle-removal system, and increased the overall operating performance of the furnace. Today, air-pollution regulations require that ROM coal be cleaned not only of ash and rocks but of sulfur as well. The processing of raw coals at levels 2, 3, and 4 therefore requires a maximized recovery of several characteristics (e.g., ash content, heating value, and sulfur content) in the respective product streams (i.e., clean coal and the reject). Four steps need to be considered: characterization, liberation, separation, and disposition.

Characterization

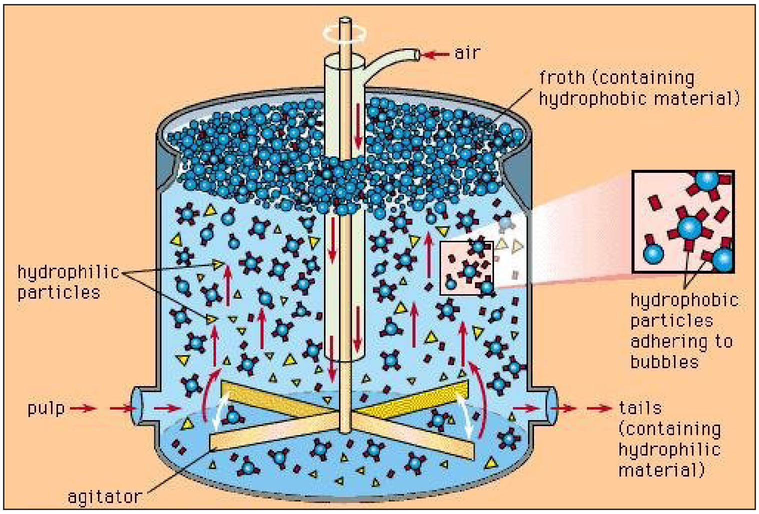
Characterization is the systematic examination of ROM coal in order to understand fully the characteristics of the feed to the preparation plant. Washability studies are performed to determine how much coal can be produced at a given size and specific gravity and at a particular level of cleaning. The studies provide a basis for selecting the washing equipment and preparation-plant circuitry.

Liberation

Liberation is the creation of individual particles that are more homogeneous in their composition as either coal or impurities. (In practice, middlings, or particles containing both coal and impurities, are also produced.) Liberation is achieved by size reduction of the ROM coal. It is a level-1 process, the product of which is the input to a level-2 plant. In general, the finer the ROM coal is crushed, the greater the liberation of impurities. However, the costs of preparation increase nonlinearly with decreasing desired size.

Separation

In the separation step, the liberated particles are classified into the appropriate groups of coal, impurities, and middlings. Since impurities are generally heavier than middlings and middlings heavier than coal, the methods most commonly used to separate the input stream into the three product streams are based on gravity concentration. Relying on differences in the two physical properties of size and specific gravity, equipment such as jigs, heavy-media baths, washing tables, spirals, and cyclones separate the heterogeneous feed into clean, homogeneous coal and waste products. For extremely fine coal, a process called flotation achieves this purpose. A schematic diagram of a flotation separation cell is shown in the figure.



Schematic diagram of a flotation separation cell.

Disposition

Disposition is the handling of the products of a preparation plant. The entire plant process includes ROM storage, raw coal storage, crusher house, screening plants, various slurries (coal-water mixtures), dewatering system, thickeners, thermal dryer, process-water systems, clean-coal storage, clean-coal load-out system, monitoring and process-control system, and refuse-disposal system. Occupational health and safety hazards as well as environmental problems are associated with each of these processes. Detailed planning and designing can eliminate the worst problems of noise, dust, and visual blight and can also significantly reduce adverse impacts on air, water, and land.

Coal Transportation

There are several methods for moving prepared coal from the mine to the markets. The cost of transport can be substantial and can account for a large fraction of the total cost to the consumer.

Railroads

Rail transportation is by far the most common mode of hauling coal over long distances. Roadbed and track requirements and large fixed investment in railcars make rail transport capital-intensive. However, the long life of the permanent assets, relatively trouble-free operation with minimum maintenance, the large-volume shipments that are possible, the high mechanical efficiencies that are obtained with low rolling resistances, and the dedicated nature of the origin and destination of the runs are some of the factors that make rail transport most attractive for long-term, long-distance, high-volume movements of coal.

In the United States, about half of the coal carried by rail is transported by unit trains, groupings of

100 or more cars of 100- to 110-ton capacity each. Unit trains generally carry 10,000 to 15,000 tons of coal in a single shipment. A “dedicated unit train” is made up especially for movement between one point of origin and one destination. In order to attain high efficiency, carefully matched loading and unloading terminals are necessary. In one example, a unit train transporting 17,400 tons per 1,200-kilometre round trip from mine to plant has a turnaround time of 72 hours—including a 4-hour loading and 10-hour unloading and servicing time per train.

On-highway Trucks

If haul distances and shipment sizes are small, it may be advantageous to transport coal by truck through a network of public roads. Whereas off-highway trucks have exceeded 250 tons in capacity, on-highway trucks are usually much smaller, not exceeding 25-ton payloads. Advantages over railroads are that trucks can negotiate more severe grades and curves, roads can be resurfaced or constructed more readily and with far lower capital investments than can railways, and the coal flow can be made continuous by adding new trucks and replacing failing trucks.

Barges

Rivers and lakes have long played a major role in the transport of bulk commodities like coal in Germany, The Netherlands, France, Belgium, Canada, and the United States. The costs of barge transport depend on the number of barges being towed by a single towboat; this in turn depends on the dimensions of the waterway. For example, the Cumberland, Ohio, Tennessee, and upper Mississippi rivers in the United States can take up to 20- to 25-barge tows, and the lower Mississippi can take 25- to 35-barge tows. Each barge has a capacity of up to 1,500 tons. Waterways are usually circuitous, resulting in slow delivery times. However, transport of coal on barges is highly cost-efficient.

Conveyors

While use of conveyors for carrying coal over long distances from producing to consuming centres is uncommon, it is not uncommon to find conveyors transporting coal from mines to barge-loading stations. In addition, where a power plant is in close proximity to a mine, conveyors are generally used to transport coal to the power plant stockpile. Conveyors can traverse difficult terrain with greater ease than trucks or rail systems, and they can also be extended easily and have the advantage of continuous transport. Conveyors with wide belts and high operating speeds can have enormous capacities, varying from 2,000 to 5,000 tons per hour.

Slurry Pipelines

Coal slurry is a mixture of crushed coal and a liquid such as water or oil. The traditional mixture, first patented in England in 1891, consists of 50 percent coal and 50 percent water by weight. So-called heavy coal slurries or slurry fuels consist of 65 to 75 percent coal, with the remainder being water, methanol, or oil. Unlike traditional slurry—which is transported by pipeline to the user, who separates the water from the coal before burning—slurry fuels can be fired directly into boilers.

Coal slurry pipelines currently in operation in the United States and Europe cover distances ranging from a few kilometres to several hundred kilometres. They have several advantages. A large portion—approximately 70 percent—of the costs involved in a slurry pipeline are invested in the initial construction of the line and pumping stations and are fixed for the life of the pipeline. Therefore, the total costs of moving slurry during the life of the line do not increase in proportion to inflation. The advantage over rail and truck transport is clear, as the costs of these latter modes escalate with inflation. Furthermore, pipelines require less right-of-way, much less labour, and about half of the steel and other supplies required for other transport methods.

On the other hand, slurry pipelines involve potential environmental problems. Water requirements are substantial: almost one ton of water is needed to move one ton of coal—an important issue in Australia and the western United States, where water supplies are scarce and its availability cannot be guaranteed. Other concerns focus on water pollution at the mouth of the pipeline as well as along its length. For this reason, efforts to obtain right-of-way to lay a pipeline have often faced legal and environmental challenges.

Electric Wire

In the early 1960s, dedication of large coal reserves to mine-mouth power plants resulted in the development of huge complexes involving mining, preparation, and utility plants. Transportation of electricity from coal-fired power plants to distant consuming centres is still attractive for several reasons. Coal is generally available in abundance and is the lowest-cost fuel in many instances. In addition, the search for inherently cleaner and more efficient ways to burn coal in electric utilities has intensified. The world's highest-voltage transmission line (1,150 kilovolts) transports electricity from Siberia to consumers in the western republics of the former Soviet Union—a distance of more than 3,000 kilometres. In the United States, coal-fired plants account for 50 percent of electricity generation. The U.S. electrical grid consists of three networks—one in the east, one in the west, and one in Texas. Although there are only small transfers between networks, the ability to transmit power from one network to another reveals the potential for greater use of electrical wire for coal power transport.

Ships

It is predicted that coal exports and, therefore, the importance of ocean transport will increase. Ocean transport of coal requires detailed considerations of:

1. Transportation from the mine to the port,
2. Coal-handling facilities at the export port,
3. Ocean carrier decisions such as number and size of ships, contractual obligations, management of the fleet, and route decisions,
4. Coal-handling facilities at the importing port, and
5. Transportation from the port to the customer.

Transportation costs have an important impact on coal exports. Mining, rail, port, and shipping costs may vary greatly for different overseas buyers, and the combined cost may represent more than one-half of the delivered price of coal to overseas ports. In addition, substantial capital costs are involved in developing the necessary facilities and in maintaining sizable stockpiles at the exporting ports. Since all these costs differ considerably among suppliers, they are important in determining the competitiveness of various coals in world markets.

DEEP SEA MINING

Deep sea mining is a mineral retrieval process that takes place on the ocean floor. Ocean mining sites are usually around large areas of polymetallic nodules or active and extinct hydrothermal vents at 1,400 to 3,700 metres (4,600 to 12,100 ft) below the ocean's surface. The vents create globular or massive sulfide deposits, which contain valuable metals such as silver, gold, copper, manganese, cobalt, and zinc. The deposits are mined using either hydraulic pumps or bucket systems that take ore to the surface to be processed. As with all mining operations, deep sea mining raises questions about its potential environmental impact. Environmental advocacy groups such as Greenpeace and the Deep sea Mining Campaign have argued that seabed mining should not be permitted in most of the world's oceans because of the potential for damage to deepsea ecosystems and pollution by heavy metal laden plumes.

Resources Mined

The deep sea contains many different resources available for extraction, including silver, gold, copper, manganese, cobalt, and zinc. These raw materials are found in various forms on the sea floor.

Minerals and Related Depths

Type of mineral deposit	Average Depth	Resources found
Polymetallic nodules	4,000 – 6,000 m	Nickel, copper, cobalt, and manganese
Manganese crusts	800 – 2,400 m	Mainly cobalt, some vanadium, molybdenum and platinum
Sulfide deposits	1,400 – 3,700 m	Copper, lead and zinc some gold and silver

Diamonds are also mined from the seabed by De Beers and others. Nautilus Minerals Inc and Neptune Minerals are planning to mine the offshore waters of Papua New Guinea and New Zealand.

Extraction Methods

Recent technological advancements have given rise to the use remotely operated vehicles (ROVs) to collect mineral samples from prospective mine sites. Using drills and other cutting tools, the ROVs obtain samples to be analyzed for precious materials. Once a site has been located, a mining ship or station is set up to mine the area.

There are two predominant forms of mineral extraction being considered for full-scale operations: continuous-line bucket system (CLB) and the hydraulic suction system. The CLB system is the preferred method of nodule collection. It operates much like a conveyor-belt, running from the sea floor to the surface of the ocean where a ship or mining platform extracts the desired minerals, and returns the tailings to the ocean. Hydraulic suction mining lowers a pipe to the seafloor which transfers nodules up to the mining ship. Another pipe from the ship to the seafloor returns the tailings to the area of the mining site.

In recent years, the most promising mining areas have been the Central and Eastern Manus Basin around Papua New Guinea and the crater of Conical Seamount to the east. These locations have shown promising amounts of gold in the area's sulfide deposits (an average of 26 parts per million). The relatively shallow water depth of 1050 m, along with the close proximity of a gold processing plant makes for an excellent mining site.

Deep sea mining project value chain can be differentiated using the criteria of the type of activities where the value is actually added. During prospecting, exploration and resource assessment phases the value is added to intangible assets, for the extraction, processing and distribution phases the value increases with relation to product processing. There is an intermediate phase – the pilot mining test which could be considered to be an inevitable step in the shift from “resources” to “reserves” classification, where the actual value starts.

Exploration phase involves such operations as locating, sea bottom scanning and sampling using technologies such as echo-sounders, side scan sonars, deep-towed photography, ROVs, AUVs. The resource valuation incorporates the examination of data in the context of potential mining feasibility.

Value chain based on product processing involves such operations as actual mining (or extraction), vertical transport, storing, offloading, transport, metallurgical processing for final products. Unlike the exploration phase, the value increases after each operation on processed material eventually delivered to the metal market. Logistics involves technologies analogous to those applied in land mines. This is also the case for the metallurgical processing, although rich and polymetallic mineral composition which distinguishes marine minerals from its land analogs requires special treatment of the deposit. Environmental monitoring and impact assessment analysis relate to the temporal and spatial discharges of the mining system if they occur, sediment plumes, disturbance to the benthic environment and the analysis of the regions affected by seafloor machines. The step involves an examination of disturbances near the seafloor, as well as disturbances near the surface. Observations include baseline comparisons for the sake of quantitative impact assessments for ensuring the sustainability of the mining process.

Environmental Impacts

Research shows that polymetallic nodule fields are hotspots of abundance and diversity for a highly vulnerable abyssal fauna. Because deep sea mining is a relatively new field, the complete consequences of full-scale mining operations on this ecosystem are unknown. However, some researchers have said they believe that removal of parts of the sea floor will result in disturbances to the benthic layer, increased toxicity of the water column and sediment plumes from tailings. Removing parts of the sea floor could disturb the habitat of benthic organisms, with unknown long-term effects. Aside from the direct impact of mining the area, some researchers and environmental activists have raised concerns about leakage, spills and corrosion that could alter the mining area’s chemical makeup.

Among the impacts of deep sea mining, sediment plumes could have the greatest impact. Plumes are caused when the tailings from mining (usually fine particles) are dumped back into the ocean, creating a cloud of particles floating in the water. Two types of plumes occur: near bottom plumes and surface plumes. Near bottom plumes occur when the tailings are pumped back down to the mining site. The floating particles increase the turbidity, or cloudiness, of the water, clogging filter-feeding apparatuses used by benthic organisms. Surface plumes cause a more serious problem. Depending on the size of the particles and water currents the plumes could spread over vast areas. The plumes could impact zooplankton and light penetration, in turn affecting the food web of the area.

Controversy

An article argued that "the 'new global gold rush' of deep sea mining shares many features with past resource scrambles – including a general disregard for environmental and social impacts, and the marginalisation of indigenous peoples and their rights". The Foreshore and Seabed Act (2004) ignited fierce indigenous opposition in New Zealand, as its claiming of the seabed for the Crown in order to open it up to mining conflicted with Māori claims to their customary lands, who protested the Act as a "sea grab." Later, this act was repealed after an investigation from the UN Commission on Human Rights upheld charges of discrimination. The Act was subsequently repealed and replaced with the Marine and Coastal Area Bill (2011). However, conflicts between indigenous sovereignty and seabed mining continue. Organizations like the Deep Sea Mining Campaign and Alliance of Solwara Warriors, comprising 20 communities in the Bismarck and Solomon Sea, are examples of organizations that are seeking to ban seabed mining in Papua New Guinea, where the Solwara 1 project is set to occur, and in the Pacific. They argue primarily that decision-making about deep sea mining has not adequately addressed Free Prior and Informed Consent from affected communities and have not adhered to the Precautionary Principle, a rule proposed by the 1982 UN World Charter for Nature which informs the ISA regulatory framework for mineral exploitation of the deep sea.

MINING ENGINEERING

Mining engineering is an engineering discipline that applies science and technology to the extraction of minerals from the earth. Mining engineering is associated with many other disciplines, such as mineral processing, Exploration, Excavation, geology, and metallurgy, geotechnical engineering and surveying. A mining engineer may manage any phase of mining operations – from exploration and discovery of the mineral resource, through feasibility study, mine design, development of plans, production and operations to mine closure.

With the process of Mineral extraction, some amount of waste and uneconomic material are generated which are the primary source of pollution in the vicinity of mines. Mining activities by their nature cause a disturbance of the natural environment in and around which the minerals are located. Mining engineers must therefore be concerned not only with the production and processing of mineral commodities, but also with the mitigation of damage to the environment both during and after mining as a result of the change in the mining area. Such Industries go through stringent laws to control the pollution and damage caused to the environment and are periodically governed by the concerned departments.

Pre-mining

Mineral exploration is the process of finding ores (commercially viable concentrations of minerals) to mine. Mineral exploration is a much more intensive, organized and professional form of mineral prospecting and, though it frequently uses the services of prospecting, the process of mineral exploration on the whole is much more involved.

The foremost stage of mining starts with the process of finding and exploration of the mineral deposit. In the initial process of mineral exploration, however, the role of geologists and surveyors is prominent in the pre-feasibility study of the future mining operation. Mineral exploration and estimation of reserve through various prospecting methods are done to determine the method and type of mining in addition to profitability condition.

Prospector.

Mineral Discovery

Once a mineral discovery has been made, and has been determined to be of sufficient economic quality to mine, mining engineers will then work on developing a plan to mine this effectively and efficiently.

The discovery can be made from research of mineral maps, academic geological reports or local, state, and national geological reports. Other sources of information include property assays, well drilling logs, and local word of mouth. Mineral research may also include satellite and airborne photographs. Unless the mineral exploration is done on public property, the owners of the property may play a significant role in the exploration process, and may be the original discoverer of the mineral deposit.

Mineral Determination

After a prospective mineral is located, the mining geologist and mining engineer then determines the ore properties. This may involve chemical analysis of the ore to determine the composition of the sample. Once the mineral properties are identified, the next step is determining the quantity of the ore. This involves determining the extent of the deposit as well as the purity of the ore. The geologist drills additional core samples to find the limits of the deposit or seam and calculates the quantity of valuable material present in the deposit.

Feasibility Study

Once the mineral identification and reserve amount is reasonably determined, the next step is to determine the feasibility of recovering the mineral deposit. A preliminary study shortly after the discovery of the deposit examines the market conditions such as the supply and demand of the mineral, the amount of ore needed to be moved to recover a certain quantity of that mineral as well as analysis of the cost associated with the operation. This pre-feasibility study determines whether the mining project is likely to be profitable; if it is then a more in-depth analysis of the deposit is undertaken. After the full extent of the ore body is known and has been examined by engineers, the feasibility study examines the cost of initial capital investment, methods of extraction, the cost of operation, an estimated length of time to payback, the gross revenue and net profit margin, any possible resale price of the land, the total life of the reserve, the total value of the reserve, investment in future projects, and the property owner or owners' contract. In addition, environmental impact, reclamation, possible legal ramifications and all government permitting are considered. These steps of analysis determine whether the mine company should proceed with the extraction of the minerals or whether the project should be abandoned. The mining company may decide to sell the rights to the reserve to a third party rather than develop it themselves, or the decision to proceed with extraction may be postponed indefinitely until market conditions become favorable.

Mining Operation

Mining engineers working in an established mine may work as an engineer for operations improvement, further mineral exploration, and operation capitalization by determining where in the mine to add equipment and personnel. The engineer may also work in supervision and management, or as an equipment and mineral salesperson. In addition to engineering and operations, the mining engineer may work as an environmental, health and safety manager or design engineer.

The act of mining required different methods of extraction depending on the mineralogy, geology, and location of the resources. Characteristics such as mineral hardness, the mineral stratification, and access to that mineral will determine the method of extraction.

Generally, mining is either done from the surface or underground. Mining can also occur with both surface and underground operations taking place on the same reserve. Mining activity varies as to what method is employed to remove the mineral.

Surface Mining

Surface mining comprises 90% of the world's mineral tonnage output. Also called open pit mining, surface mining is removing minerals in formations that are at or near the surface. Ore retrieval is done by material removal from the land in its natural state. Surface mining often alters the land characteristics, shape, topography, and geological make-up.

Surface mining involves quarrying which is excavating minerals by means of machinery such as cutting, cleaving, and breaking. Explosives are usually used to facilitate breakage. Hard rocks such as limestone, sand, gravel, and slate are generally quarried into a series of benches.

Strip mining is done on softer minerals such as clays and phosphate are removed through use of mechanical shovels, track dozers, and front end loaders. Softer Coal seams can also be extracted this way.

With placer mining, minerals can also be removed from the bottoms of lakes, rivers, streams, and even the ocean by dredge mining. In addition, in-situ mining can be done from the surface using dissolving agents on the ore body and retrieving the ore via pumping. The pumped material is then set to leach for further processing. Hydraulic mining is utilized in forms of water jets to wash away either overburden or the ore itself.

Mining Process

- Blasting: Explosives are used to break up a rock formation and aid in the collection of ore in a process called blasting. Blasting utilizes the heat and immense pressure of the detonated explosives to shatter and fracture a rock mass. The type of explosives used in mining are high explosives which vary in composition and performance properties. The mining engineer is responsible for the selection and proper placement of these explosives, in order to maximize efficiency and safety. Blasting occurs in many phases of the mining process, such as development of infrastructure as well as production of the ore.
- Leaching: Leaching is the loss or extraction of certain materials from a carrier into a liquid (usually, but not always a solvent). Mostly used in rare-earth metals extraction.
- Flotation: Flotation (also spelled floatation) involves phenomena related to the relative buoyancy of minerals. It is the most widely used metal separate method.
- Electrostatic separation: Separating minerals by electro-characteristic differences.
- Gravity separation: Gravity separation is an industrial method of separating two components, either a suspension, or dry granular mixture where separating the components with gravity is sufficiently practical.
- Magnetic separation: Magnetic separation is a process in which magnetically susceptible material is extracted from a mixture using a magnetic force.
- Hydraulic separation: Hydraulic separation is a process that using the density difference to separate minerals. Before hydraulic separation, minerals were crushed into uniform size; because minerals have uniform size and different density will have different settling velocities in water, and that can be used to separate target minerals.

Mining Health and Safety

Legal attention to Mining Health and Safety began in the late 19th century and in the subsequent 20th century progressed to a comprehensive and stringent codification of enforcement and mandatory health and safety regulation. A mining engineer in whatever role they occupy must follow all federal, state, and local mine safety laws.

The United States Congress, through the passage of the Federal Mine Safety and Health Act of 1977, known as the Miner's Act, created the Mine Safety and Health Administration (MSHA) under the US Department of Labor.

This comprehensive Act provides miners with rights against retaliation for reporting violations, consolidated regulation of coal mines with metallic and nonmetallic mines, and created the independent Federal Mine Safety and Health Review Commission to review MSHA's reported violations.

The Act as codified in Code of Federal Regulations 30 (CFR 30) covers all miners at an active mine.

When a mining engineer works at an active mine he or she is subject to the same rights, violations, mandatory health and safety regulations, and mandatory training as any other worker at the mine. The mining engineer can be legally identified as a "miner."

The Act establishes the rights of miners. The miner may report at any time a hazardous condition and request an inspection. The miners may elect a miners' representative to participate during an inspection, pre-inspection meeting, and post-inspection conference. The miners and miners' representative shall be paid for their time during all inspections and investigations.

Mining and the Environment

Land reclamation is regulated for surface and underground mines according to the Surface Mining Control and Reclamation Act of 1977. The law creates as a part of the Department of Interior, the Bureau of Surface Mining (OSM). OSM states on their website, "OSM is charged with balancing the nation's need for continued domestic coal production with protection of the environment."

The law requires that states set up their own Reclamation Departments and legislate laws related to reclamation for coal mining operations. The states may impose additional regulations and regulate other minerals in addition to coal for land reclamation.

TECHNOLOGIES IN MINING INDUSTRY

Automation

Automation is one of the hottest topics in every sector of industry. Whether it's the World Bank fearing for the future of low skilled workers or reasons to be optimistic.

Mining is no different – autonomous trucks are becoming an ever more frequent presence around mines, with market leaders Cat and Komatsu introducing their automated haulage systems in the last two years, and Hitachi announcing their offering.

The next step in mining automation could even be mines with no miners 'intelligent mine' packed with driverless trains, trucks and robotics. They're not necessarily just replacing jobs either – some automation in mining is allowing producers to drill deeper and with narrower shafts into conditions uninhabitable for humans.

Underground Excavators

In underground mining, safety is a top priority and a new line of Underground Mobile Miners has been released specifically for hard rock mines. This new technology circumvents the traditional, and more dangerous, drill and blast method and also means that mines wouldn't have to be evacuated in order to mine hard rock.

Electric Vehicles

Mining isn't necessarily seen as the most environmentally friendly industry, and with the Paris

Climate Agreement and a host of other factors urging the international community to do more to reduce emissions and tackle climate change, the use of electric vehicles is set to become more and more popular, replacing their diesel-powered alternatives.

No one company has monopolised the space and, whilst companies are developing products like their Underground Electric LHD, we're also seeing a host of smaller players moving into the area. ETF Manufacturing have recently introduced their all-electric surface haul truck and GHH have also introduced their own range of electric LHDs.

X-ray Diffraction

It's not all hardware that will be changing the game in 2018. Mining software has been making every mine 'smarter' for some time, and one of the most innovative examples of this is X-ray diffraction.

This is used to analyse samples to check their property densities which saves both time and money when targeting particularly rich materials. Companies have already enjoyed success through effectively utilising the technology.

There are a number of other players too though, with SGS, Bureau Veritas and Bruker all involved.

Sensor based Sorting

Innovation isn't just staying down the mine either. Companies have been investing heavily in new mineral processing technology, with sensor based sorting being a particular area of focus.

Sensor based sorting is designed to split commercially valuable minerals from ores as efficiently and cheaply as possible – leading to increased productivity. New technologies are incorporated such as mining magnets.

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Mine Development and Life Cycle

CHAPTER 2

Mine development is a process that deals with the construction of mining facility and the infrastructure to support the facility. It includes preparation of mine sites, construction of mine facilities and creation of infrastructure. This chapter closely examines these key concepts of mine development and life cycle to provide an extensive understanding of the subject.

The process of constructing a mining facility and the infrastructure to support the facility is known as mine development.

Mine development may involve many activities such as:

- The preparation of the mine site by clearing trees and blasting rock.
- The construction of mining facilities such as head frames, administration buildings or mechanical shops.
- The creation of infrastructure such as power lines and substations, roads or water lines.

Requirements

Before beginning development, certain requirements must be met. These requirements include:

- Submitting a Notice of Project Status to the Mineral Exploration and Development Section.
- Consulting with all required parties.
- Filing a closure plan with accompanying financial assurance and achieving certification.
- Acquire all required permits/approvals from ministries, agencies and government organizations.

Mineral Exploration and Development: Risk and Reward

Mineral exploration and development are investigative activities prior to mining. The rewards of successful exploration and development can be large, if a mineral deposit is discovered, evaluated, and developed into a mine. For a mining company, successful exploration and development lead to increased profits. For a local community or nation, successful mineral exploration and development can lead to jobs—often well paying— that otherwise would not exist; to new infrastructure, such as roads and electric power supplies, that are catalysts for broader, regional economic development; and to increased government revenues that, in turn, can be invested in social priorities such as education, health care, and poverty alleviation.

But mineral exploration and development carry with them risks, as well. For local communities and governments, the risks come from the possibility that there will be significant external (or spillover) effects from mining—for example, environmental degradation or strains on local communities and social services when there is an influx of new people into a booming mining town. These spillovers may outweigh the benefits from mining if most jobs go to outsiders, environmental degradation or community disruptions are large, tax revenues accrue to national governments and are not returned sufficiently to local communities, or governments spend mining revenues unwisely.

Characteristics of Mineral Exploration and Development

Mineral exploration and development are investments. As such, companies spend money today in the expectation that future revenues will be sufficient to cover all costs including a minimum acceptable profit. Possible investment projects in the mineral sector compete for funds with other investment opportunities, both within and outside the mining sector. The level and location of investment are determined by expected revenues and costs, adjusted for time and risk. The higher the expected revenues or the lower the expected costs, the more attractive an investment opportunity is. When comparing one investment opportunity with another, the longer an investor has to wait to receive revenues or the riskier the investment, the less attractive the investment is.

In the mineral sector, the factors that influence expected revenues, costs, and risks can be grouped into four categories:

- Geologic Factors: Does a mineral resource exist in a region, in what quantities, and of what quality? Geologic risk can be thought of as the likelihood and degree to which actual mineralization (its quantity and quality) differs from what is anticipated at the point a decision is made to undertake exploration or development. For example, what is the likelihood that a mineral deposit exists in a region undergoing initial geologic investigation? Or during mining, what is the likelihood that the grade and quality of ore differs from what was expected at the time the mine was initially developed?

- Technical Factors: Can a known resource be extracted and processed with existing or likely future technologies? Technical risk can be thought of as the likelihood and degree to which actual recovery of a mineral during mining and processing differs from what was anticipated. In other words, are there unanticipated technical problems or complications associated with mining, mineral processing, and extractive metallurgy?

- Environmental, Social, and Political Factors: Can a resource be extracted in ways that are consistent with a nation‟s preferences and policies for environmental protection? Can it be extracted in ways consistent with preferences and policies of local communities? Risks in this category can be thought of as the likelihood and degree to which actual environmental degradation or impacts on local communities differ from what was expected. Or the likelihood and degree to which public attitudes, public policies, and the overall business environment differ from what was expected at the time of initial investment.

- Economic Factors: Overall, can a mineral resource be extracted at a profit? Economic risk can be thought of as the likelihood and degree to which actual revenues and costs differ from what was anticipated at the time of investment? Economic risk is an overarching type of risk because it incorporates and reflects the three other categories of risk cited above.

It incorporates the purely economic risks that actual mineral prices and production costs are different than anticipated at the time of initial investment.

Two important implications of viewing mineral exploration and mine development as investments are (a) the mineral sector competes with other sectors for scarce investment resources, and (b) within the mineral sector, countries compete with one another for investment.

Mineral exploration and development are the first stage in the process of mineral supply. The stages of mineral supply are:

- Mineral exploration and development, in which mineral deposits are identified, evaluated, and prepared for mining. Exploration and development can be subdivided into four substages:
  - Grassroots exploration prior to detection of mineralization or identification of a geologic deposit.
  - Advanced-stage exploration evaluating a geologic discovery to determine whether it should proceed to development.
  - Deposit development, in which full technical and economic assessments are carried out, and a decision is made on whether to proceed to mining.
  - Mine development, in which a mine and all associated facilities and infrastructure are planned, designed, and constructed. Any precise boundaries between these substages of exploration and development are somewhat arbitrary. These substages perhaps most usefully are thought of as a continuum of activities.

A word on the distinction between mineral resources and mineral reserves: Resources are discovered during exploration but not sufficiently well characterized to determine their exact size and quality and whether they can be mined commercially. Reserves are developed (during development, of course); they are known to exist with a high degree of certainty and capable of being extracted and recovered with existing technologies for a profit. Reserves are a subset of mineral resources. Estimates of reserves change over time as a result of exploration, depletion of deposits at existing mines, and changes in technology, public policies influencing mining, and mineral prices and production costs.

In addition, mine-site exploration takes place at or in the vicinity of operating mines with the goal of extending the lives of these operations:

- Mining, in which ore and concentrate (or other form of semiprocessed material) are produced. Ore is the rock from which an element ultimately will be extracted. The weight percent (or grade) of the desired element in the rock varies considerably from one mineral to another at operating mines—much less than 1% by weight for gold, more than 60% by weight for some iron-ore mines. Ore usually is transformed into concentrate at the mine site. Concentrate is an upgraded material. For example, copper ore often has a grade of about 1%. Copper concentrate typically contains 20-25% copper by weight.

- Metallurgical processing, in which ore or concentrate is transformed into a saleable product, usually refined metal that is essentially 100% metal by weight.

- Fabrication and manufacturing, in which refined metal or other similar product is transformed into a final product.

From the perspective a mineral deposit, it obviously must be the case that a deposit has to be discovered before it can be mined.

Perhaps just as important is to consider the perspective of a company at a point in time. In its quest for profits, a company can choose to enter the mineral supply chain at any stage of production. A company can emphasize grassroots exploration; should it discover a mineral deposit, it then chooses whether to continue with advanced exploration, take on a partner to jointly undertake further exploration, or sell its rights to further exploration to another company. Alternatively, company can eschew grassroots exploration altogether and enter the supply chain by participating in advanced exploration of a deposit discovered by someone else. Or a company can avoid exploration altogether and develop a known but undeveloped deposit. Or a company can purchase an existing mine from another company, or expand or refurbish an existing operation of its own. Or, finally, a company can choose to invest in technological research and development that creates the possibility of making activities at any stage of production more efficient. How a company allocates its financial resources among these alternative activities depends on its expectations about future revenues, costs, timing of these revenues and costs, and risks. These expectations, in turn, are influenced by how a company evaluates its own strengths and weaknesses. Some companies specialize in grassroots exploration, others in advanced exploration and deposit development, and still others in mining. Many companies have a portfolio of activities at multiple or even all stages of mineral supply.

Table summarizes the characteristics of grassroots exploration, advanced exploration and deposit development. These characteristics inform company decisions about where to enter the mineral supply chain. The typical lead time between grassroots exploration ranges between five and fifteen years. By entering the supply chain at a later point, a company reduces the time it takes to commence mining. Geologic risks are highest during grassroots exploration, lowest during mining. Think of geologic risk here as the probability that a specific exploration or development project leads to an operating mine. It sometimes is said that it takes 500-1,000 grassroots exploration projects to identify 100 targets for advanced exploration, which in turn lead to 10 development projects, 1 of which becomes a profitable mine. The land area involved gets smaller as activities get closer to mining. Costs and economic risks become larger the closer activities get to mining. Grassroots exploration is relatively inexpensive compared to deposit development and mining. Potential profit, however, arguably is higher for any particular grassroots project in the sense that the discovery of a large mineral deposit can literally re-make a mining company and be an essential source of its profitability for years or decades. The later a company enters the supply chain, the less likely it is to fully capture this profitability; when a company buys into a partially explored or developed deposit— or buys an operating mine—it almost certainly will have to share the expected future profitability with the seller, and this sharing of profits will be reflected in the transaction price.

Table: Company perspectives - where to enter the supply chain.

	Grassroots Exploration	Advanced Exploration	Deposit Development	Operating Mine
Lead time until mining	Longer → Shorter (5-15 years of continuous activity from start of grassroots exploration)			

Geologic risks	Higher → Lower
Land area	Larger → Smaller
Costs and economic risks	Lower → Higher
Profit potential	Higher → Lower
Political risks	Lower → Higher (bargaining power switches to government once mining begins; exploration is footloose)

As for political risks facing a company, the balance of negotiating power switches from mining company to government once mining begins. Mineral exploration is “footloose” in the sense that it can move easily and quickly to another location or country if public policies become less favorable. On the other hand, once a company has developed an operating mine, the company cannot easily, quickly, or cheaply redeploy these assets to another location or country.

Mineral exploration and development are information-gathering activities. In this sense, mineral exploration and development represent a variety of activities that collect information necessary to identify mineral deposits and then evaluate whether they should developed into mines.

Table focuses on information gathering in grassroots exploration. The important information-gathering activities are desk studies and reviews of existing information; acquisition of exploration rights for lands identified through desk studies; regional geological, geochemical, and geophysical examinations; and preliminary engagement with local communities. The land area involved is large, ranging typically from several tens to several millions of square kilometers. Costs are relatively low, up to several tens of millions of U.S. dollars. The desired outcome of grassroots exploration is the identification of promising mineralization or even a geologic deposit that will examined more closely and in greater detail in subsequent activities.

Table: Grassroots Exploration.

Activities	Desk studies, area selection, land acquisition, regional studies (geology, geochemistry, geophysics), preliminary community engagement.
Typical landarea	10,000s-1,000,000s of square kilometers.
Typicalexpenditures	Up to 10s (million US$).
Possible outcomes of studies	Target identification for subsequent detailed examination.

Table focuses on advanced exploration, sometimes called detailed target evaluation. Typical information-gathering activities include geological, geochemical, and geophysical studies at much closer scale or greater density than during grassroots exploration; drilling, trenching, and delineation of the mineral deposit; preliminary studies of the amenability of the rock to mineral recovery (extractive metallurgy); collection of environmental and social baseline data; and continued engagement with local communities. The typical land area is smaller than in grassroots exploration, one to several tens of thousands of square kilometers. Typical expenditures are larger, up to several hundreds of millions of U.S. dollars. Possible outcome of advanced exploration are two types of studies. A scoping study is an initial, order-of-magnitude evaluation of the deposit‟s commercial attractiveness. It typically includes a preliminary resource estimate and order-of-magnitude cost estimates. A scoping study may be prepared by only one or a small team of people. A preliminary feasibility study is more detailed and includes revised resource estimates, preliminary mine design and engineering (a mining concept), and associated preliminary cost estimates. If a scoping study and, then, a preliminary feasibility study continue to suggest that a mine might be commercially feasible, a deposit moves to the next stage, deposit development.

Table: Advanced Exploration.

Activities	Detailed target evaluation (geology, geochemistry, geophysics), drilling, trenching, deposit delineation, preliminary metallurgy, collection of environmental and social baseline data, community engagement.
Typical land area	1,000s-10,000s of square kilometers.
Typical expenditures	Up to 100s (million US$).
Possible outcomes or studies	• Scoping study: resource estimates, order-of-magnitude cost estimates, general idea of what a mine might look like. • Preliminary feasibility study: more detailed than scoping study and including revised resource estimates, preliminary mine design and engineering, and preliminary cost estimates.

Table summarizes key characteristics of deposit development. Typical informationgathering activities include detailed (close-spaced) drilling, mine planning, metallurgical testing, continued assessment of the likely environmental consequences of mine development, and continued community engagement. The land necessary becomes smaller, up to about 1,000 square kilometers. Typical expenditures vary, but can exceed US$1 billion. Should a deposit continue to be attractive, a company will begin to apply for the permits and other approvals necessary to proceed with mining. A company will prepare a feasibility study, a technical and economic assessment that serves as the basis for making a "go/no go" decision about whether to develop the mine. A feasibility study includes reserve estimates, mine and plant designs, detailed cost estimates, full technical and economic assessments, and details of possible financing arrangements. A so-called "bankable" feasibility study is a type of feasibility study that a company would take to a bank or other entity in its search for financing.

Table: Deposit Development.

Activities	Detailed drilling, mine planning, metallurgical testing, continued environmental assessment, continued community engagement.
Typical land area	Up to 1 (thousand square kilometers).
Typical expenditures	Varies, can be > US$1 billion.
Possible outcomes or studies	• Applications for required permits and approvals. • Feasibility study: reserve estimates, mine and plant design, detailed engineering and cost estimates, full technical and economic assessment, financing. • "Go/no go" decision on mine development.

In each stage of exploration and development, there are effects on the natural environment and on local communities. Table summarizes the important environmental and social impacts during grassroots exploration, advanced exploration, and development and mining, as well as their degree of typical severity. In grassroots exploration, effects typically are minimal. The number of people involved is small. Techniques for the most part are noninvasive. For example, airborne geophysical surveys are conducted from the air. Geological mapping involves people walking on the ground and collecting rock samples. In some cases, there may be road building to allow access or clearing of trees to permit collection of rock or soil samples.

Table: Environmental and Social Impacts.

Grassroots exploration	• Usually minimal effects from airborne geophysical surveys and regional reconnaissance on the ground.
Advanced exploration	• More significant but still moderate effects. • Road building, traffic, drilling, trenching, etc., can affect air, flora, fauna, land, water. • Most effects can be mitigated at a cost with helicopters, remediation after drilling, and other activities.
Deposit development and mining	• More significant effects. • Environmental: construction, mining, processing, waste disposal and tailings affect air, flora, fauna, land, water. • Social: potential influx of people and significant community change represent challenges. • Many effects can be minimized and controlled, but some change is inevitable and permanent.

During advanced exploration, environmental and social impacts are more significant but typically still moderate compared to those of mining. Road building, vehicle traffic, drilling and trenching, and other activities can affect air, water, land, flora, and fauna. Some of these impacts can be avoided or mitigated at a cost by using helicopters (rather than building new roads) and by remediating drill sites. There may be some impacts on local communities through the presence of non-local exploration geologists and other workers who often reside in an area for one or more years.

It is deposit development and mining that potentially have much more significant environmental and social effects. Construction, mining, mineral processing, disposal of waster rock, and tailings management1 can have significant effects on the natural environment. Local communities can be significantly affected by an influx of outsiders and other changes that mining brings to a community. An influx of outsiders may strain public infrastructure designed for a smaller population. Outsiders may be culturally different than local residents leading to a clash of lifestyles. Many of the social impacts of a new mine can be minimized or controlled through deliberate planning but some community change is inevitable and permanent.

The Geographic Location of Mineral Exploration and Mine Development

Where mineral exploration and development occur depends on:

- Perceptions of geologic potential.
- The investment climate.

Perceptions of geologic potential: These perceptions are based on at least two factors. First, perceptions reflect geologic knowledge obtained from previous activities, which include previous exploration and mining, as well as non-mining activities such as road building and assessment of geologic hazards. I include in this category the lemming or bandwagon effect that exploration success by one company has on geologic perceptions of others. In a relatively unexplored area, word of mineralized drill core from one company's activities often leads to a flurry of claim staking or purchase of exploration rights in the area by other companies.

Second, geoscientific research and information from public geological-survey organizations often play a critical role in attracting exploration to a relatively unexplored region. Precompetitive research and information can be thought of as examples of what economists call public goods—that is, goods that are likely to be undersupplied from society's perspective by the market acting alone because the benefits or rewards of these activities are difficult for those who fund these activities to fully capture. The benefits of precompetitive research and information usually come far in the future if they come at all. Imitators find it relatively easy to take advantage of research carried out and information gathered by others; some refer to this situation as "free riding" on the efforts of others.

Government can provide a catalyst for mineral exploration in unexplored areas by providing precompetitive (basic) geoscientific information. This information serves as advertising or as a new signal of geologic potential. Using an analogy from chemistry, basic geoscientific information can be thought of as a catalyst that speeds up the rate of chemical reaction. Important types of precompetitive information are geologic maps, regional geophysical surveys, and geochemical analyses of stream sediments (ideally in digital formats, capable of being downloaded from the Internet).

A final word about perceptions of geologic potential: Exploration of an area can never be done in a once-and-for-all manner. Different explorers view the same data and information differently. Many deposits have been discovered only after several companies, exploration programs, or drilling campaigns investigated the same area. Moreover, over time, conditions change, altering the attractiveness of the same piece of land. One company may discover promising mineralization but quit an area because economic conditions are not favorable or because extraction techniques do not permit recovery of a certain mineral type. Over time, economic conditions change and technological capabilities improve. Exploration techniques also improve, increasing the chances of detecting subsurface mineralization. Scientific advances in how mineral deposits are formed alter how geoscientists view the prospectivity of an area.

The investment climate: How attractive the investment climate is for private investment in mineral exploration and development depends on:

- General considerations such as macroeconomic and political stability, legal and banking systems, fiscal rules.
- Policies designed specifically for the mining sector.

These mineral policies include:

- The role of the state: Who owns subsurface minerals? Is the state an owneroperator of mines, or a lessor-regulator?
- Access to land and mineral resources: What areas are available or closed to mineral exploration and development? What are the processes and requirements for obtaining the right to explore or mine? Are the processes transparent and predictable?
- Exploration and mining rights and obligations: What are the time lengths for an exploration or mining right? What are the requirements for maintenance and renewal? Is a right transferable and, if so, how? How secure is a right? Are obligations of a right holder clearly

defined? Are cancellation criteria and procedures clear? Is the right to proceed from exploration virtually automatic, subject to meeting clear and objective requirements?

- Environmental and social issues: What are the requirements for environmental protection—before mining, during operations, and post-closure? What is the role of local communities and what are their rights?
- Mining taxation: What is the basis for taxation (revenues, profits, etc.)? At what rates? What are allowable costs in determining taxable income?
- Other commercial considerations: Are there requirements for downstream processing? Are there restrictions on marketing, foreign-exchange transactions, repatriation of profits, and transferability of rights? Are there special considerations for junior exploration companies?

Mining taxation: Much mineral exploration is carried out by junior exploration companies, which typically do not operate mines. These relatively small companies specialize in mineral exploration and aim to sell any partially explored deposits they discover to larger companies that will conduct subsequent activities to determine whether the mineral resources can be developed into reserves and, in turn, a mine. Some governments provide special tax incentives to encourage exploration by junior companies. The best known of these incentives is flow-through shares in Canada. For a junior company with no operating income, the tax deduction for exploration expenses is worthless because it has no operating revenue from which to deduct exploration expenses. Instead the tax deduction for exploration expenses "flows through" to the owners of shares of stock in the company. In some cases, when countries or regions want to provide an especially strong incentive for exploration, equity owners are allowed to deduct more than $1 for every $1 of actual exploration expenses.

More broadly and considering the mining tax system as a whole, both the rate and form of taxation affect the relative attractiveness of different countries or sub-national regions for investment in mineral exploration and development. The effect of tax rates is obvious; the higher the tax rate the lower the attractiveness of a region, other factors remaining the same. The influence of the tax form on the location of investment is more complicated.

Most fiscal systems take one of four forms:

- Units-of-production taxes, in which tax liability is based on the weight or tonnage of produced mineral (for example, dollars per tonne produced).
- Gross-value taxes, in which tax liability is a percentage of revenues (or revenues perhaps slightly adjusted for a few expenses or costs, such as net-smelterreturn royalties).
- Net-income or profits taxes, in which tax liability is a percentage of gross value less allowable costs.
- Upfront bonus payments, in which a company pays money up front to obtain the right to carry out mineral exploration or mine development.

These tax forms influence the attractiveness of investment in two ways:

- The degree to which they tax surpluses and, in turn, distort production and investment decisions. During production, a tax only on the surpluses (or profits) of mining will not influence the profit-maximizing level of output. Such taxes are based on a firm's ability to pay. Unit-of-production and gross-revenue taxes, in contrast, do not distinguish between highly profitable and marginally profitable mine. They will discourage production from marginal mines. Bonus payments made prior to mining, in effect, represent taxes on expected surpluses from mining. A company will bid—at most—an amount representing the present value of expected future net revenues. Another way of looking at bonus payments is that they will have no effect on the profit-maximizing level of output because they are sunk costs.

At the stage of mineral exploration, no tax is completely nondistortionary. Exploration is footloose in that explorers can redirect their activities to regions or countries with more favorable tax regimes.

How the tax form allocates risks between a company and government. A tax on net income splits financial risks between a company and government. Government does not receive any revenue until there are profits or surpluses to be shared. Gross-value and unit-of-production taxes shift financial risks toward companies. Government receives its revenues "off the top" before profits are determined. In this sense, gross-value taxes represent a cost rather than a sharing of surpluses. Finally, an upfront bonus payment shifts all financial risks to a company. Government receives its revenue before mining begins or even before a company determines whether mining is feasible.

From the perspective of governments, two other considerations are relevant:

- The timing, stability, and predictability of tax revenues: A single, upfront bonus payment obviously comes soonest, is most stable, and most predictable from a government's perspective from among the various tax forms. Comparing the other three forms, gross-value and unit-of-production taxes typically yield earlier, more stable, and more predictable tax streams than net-income taxes—earlier because a mine typically earns small or negative profits early in its life as its developer is ramping up production and repaying capital; more stable because levels of production and gross revenues tend to vary less from one year to the next than profits; and more predictable because government only needs estimates of production and prices to estimate tax revenues, whereas to estimate receipts from net-income taxes a government needs information about accounting costs.

- The ease and cost of implementation: Taxes based on gross revenues typically are easiest and cheapest to implement effectively. The only information needed to calculate tax liabilities are production levels and a market price. Net-income taxes require accounting rules defining, for example, which costs are deductible from gross income before calculating tax liabilities. Net-income taxes are more susceptible to abuse through creative company accounting. Systems based on bonus bids require a different administrative structure, including rules governing bidding procedures and determination of whether a bid is acceptable.

No system of mineral taxation is ideal from both government and company perspectives. Governments often prefer gross-revenue systems because more of the risks are shouldered by companies, tax revenues typically come sooner and are steadier, and this form of taxation is easier to implement and less prone to abuse through creative accounting. However, governments need to realize such tax systems will tend to discourage preproduction investment in mineral exploration than net-income taxes, other factors remaining the same, because mining companies shoulder relatively more risk and the level taxation is not based on ability to pay (profits).

Bonus payments are widely used in the oil and gas sector. In mining, they are almost never used as a basis for awarding rights for exploration, and rarely used for auctioning a partially developed mineral deposit. Occasionally they are used when selling an operating mine.

Nevertheless public policies importantly influence the risks and costs of mineral exploration and mine development. Penney, McCallum, Schultz, and Ball offer the following as best practices:

- Provision of basic up-to-date geoscientific information,
- Optimal allocation of land, incorporating economic, social, and environmental issues,
- Clear, efficient, and transparent licensing,
- Security of tenure,
- Internationally competitive tax regimes,
- Adequate supply of qualified professionals,
- Appropriate and consistent environmental rules,
- Effective stakeholder engagement, and
- Optimal distribution of benefits.

Financing Mineral Exploration and Mine Development

How mineral exploration and development are financed influences how the financial risks of these activities are allocated. There are three private sources of financing: internal funds, equity, and debt. Internal funds represent earnings retained by a company from its revenues after it pays all its costs and taxes and distributes any dividends to owners. Equity represents funds raised from investors in exchange for which they become partial owners of the company. In both cases, all risks are borne by the owners of the company (those who hold equity). Debt represents funds borrowed from another entity. Lenders (holders of debt) bear the risk that a borrower will be unable to repay a loan. But debt holders bear less risk than holders of equity because loans must be repaid before equity holders receive dividend or other payments. In other words, debt holders bear less risk than equity holders because debt repayment occurs before the sharing of profits to equity owners.

Most mineral exploration, as well as development prior to the decision to build a mine, is financed either through internal funds or equity. Internal funds typically are used by companies with operating mines. Equity is typically used by junior exploration companies with no operating mines. Debt financing for exploration is difficult to obtain because usually there is no asset (collateral) at the time of the loan for the lender to obtain should the borrower be unable to repay the loan.

Mineral exploration is funded with various types of equity financing. Some is raised on organized stock exchanges or markets in the form of initial public offerings (IPOs) or subsequent share issuances. Shares issued through organized stock exchanges are subject to significant reporting standards about, for example, resource and reserve estimates. Such shares also are "liquid" in that owners can sell their equity any time the exchange is open for business, assuming there is a buyer. Significant amounts of equity for mineral exploration, however, are raised "off exchange"—through activities and transactions that are not conducted through organized stock exchanges. Procedures are less standardized, structured, and regulated. Such off-exchange equity typically is less liquid in that a ready buyer usually is more difficulty, costly, and time consuming to find because the equity is not traded on a stock exchange. Examples of off-exchange equity include joint ventures, royalty-based financing, private placements, and venture capital. A joint venture occurs when a mining company funds activities of a junior exploration company, usually advanced exploration of a partially explored deposit, in exchange for partial ownership of the project. Royalty-based financing represents cash in exchange for the right to ongoing royalty payments if and when mining occurs. Private placements are like IPOs except that they are not "public"—they represent shares issued to a small group of individuals or institutions in exchange for cash. Finally, venture capital also is cash in exchange for shares, with the funds provided by institutional investors, such as pension funds, and wealthy investors, who fund entrepreneurial activities and typically plan to get their reward by selling their shares during a later IPO.

Most mine development, activities once a decision has been made to build a mine, is financed with debt. Some debt represents loans to a parent company, known as corporate debt. If mine development is not successful, a lender has recourse to the assets of the parent company in being repaid for the loan. Another form of debt often used in mineral development is project (or nonrecourse) financing—loans to a project rather than the project's parent company. If mine development is not successful, the lender cannot compel the project's parent company to repay the loan from other company assets. Project financing is more expensive (involves a higher interest rate) than corporate debt because the lender assumes greater risk (unless a lender views a single project as less risky than the company‟s entire portfolio of assets including the project).

LIFECYCLE OF A MINE

Setting up a new mine is a long and complex process that offers traders plenty of opportunity. The share prices of mining companies are highly sensitive to new barriers that appear and each hurdle that is cleared. So how is a new mine set up and what opportunity is there for traders?

'Mining is the art of exploiting mineral deposits at a profit. An unprofitable mine is fit only for the sepulchre of a dead mule,' – renowned mining engineer Thomas Arthur Rickard.

Setting up a new mining project is no small feat. Discovering, developing and constructing a new mine takes years to complete and it is not uncommon for work to span over a decade before any serious levels of production are seen.

A lot can change in a matter of years, and the journey from discovery to production can be a tumultuous one for mining companies. Commodity prices can change drastically and affect the economics of the project, governments and legislation can be overhauled, and the supply and demand for any given commodity can change for a whole host of reasons – to name but a few potentials.

It is for this reason, coupled with the sheer amount of barriers they must clear and the substantial financial requirement to build a new mine, that share prices of mining companies are highly sensitive while projects are developed, particularly for junior mining companies that can often throw all their energy behind a couple or even just one project – making them all the more important for the future of the business.

There are many variables that make each mine unique, including what commodity is being mined. Projects can range from small operations often developed by junior mining firms to gigantic projects like the Bingham Canyon copper mine in the US (also known as Kennecott), thought to be one of the largest mines in the world. Some mines are on the surface, some underground, projects can be low-grade or high-grade, and different processes of extraction can be used.

While every new mining project has its own requirements and needs an individual plan to take it from discovery into production, virtually all miners follow the same general process that forms the backbone of mine development. With so much work to complete and so many milestones to meet, investors react to every barrier that emerges and every hurdle that is cleared – providing numerous windows of opportunity for traders.

Location and Commodity of a Mine

As a miner looks to set up a new mining project the first two questions that it must answer are simple: what commodity will it mine and where could the new mine be located? Mining companies often focus on either one or a select group of metals that it wants to extract, like gold (which often comes with silver and other metals), platinum group metals, or base metals like copper, tin and zinc.

For example, the rising demand for batteries (for the likes of electric cars and energy storage being developed by firms such as Tesla) has swayed many miners to develop lithium mines as they attempt to plug forecasted supply gaps and capitalise on more favourable prices. Bacanora Lithium (previously Bacanora Minerals) is one of the most advanced lithium miners listed on AIM and is developing the Sonora project in Mexico, regarded as one of the largest known clay lithium deposits in the world.

The location of a mine is also extremely important. Some commodities are concentrated in certain regions or countries. Metal-rich South Africa is thought to produce around two-thirds of global platinum and hold the vast majority of the world's reserves, while iron ore and copper are particularly prominent in Latin America and Australia, although also found elsewhere.

Companies will look for opportunities in countries with stable governments and a favourable business environment, which can be harder if their chosen commodity is only found in certain areas. Geopolitical activities also play their part. Western sanctions against the likes of Russia and Iran made both countries less attractive for natural resource firms. Location is also important for supply routes

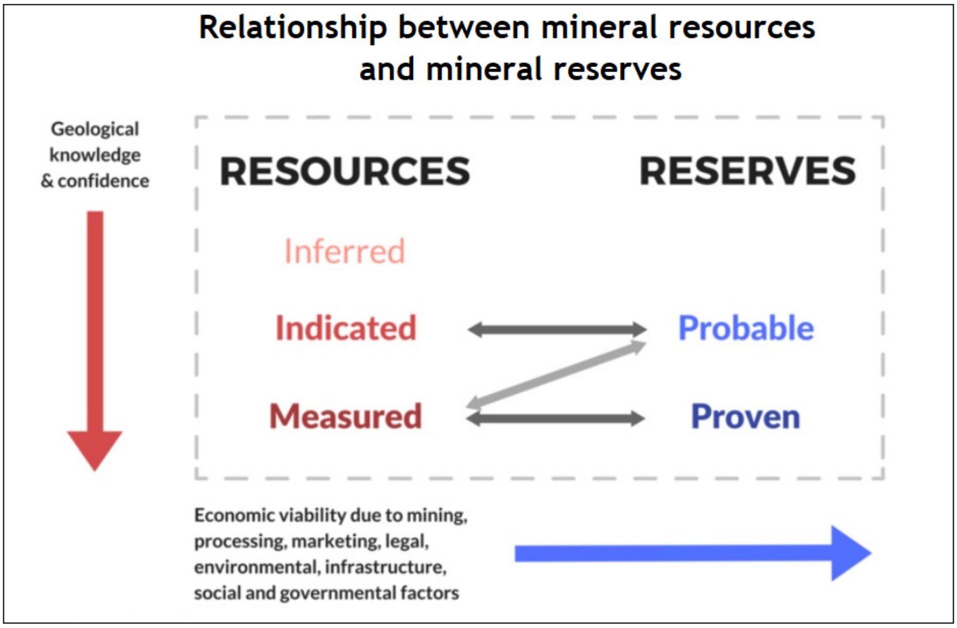
'New' mines are not always necessarily that new. Miners are increasingly re-exploring old mines as updated technology means metals that could not previously be extracted now can be extracted. Some even target old tailings dumps (essentially the waste that builds up from a mining operation) with the hope of squeezing out whatever mineral is left inside.

Before we go through the lifecycle of a mine it is important to understand two other core elements that feature throughout the process and form the foundations of taking a mine from the exploratory stage to one that is in full production.

Mineral Resources vs Mineral Reserves

The backbone of any mining company is its mineral resources and reserves that categorise the quality and accuracy of the estimates of what minerals lie in the ground. While there are various models used to categorise these, the main model used by the vast majority of the international community is set by the Joint Ore Reserves Committee (JORC), aligning standards across the world. Countries like Russia and China however, can often use their own system.

There is a relationship between mineral resources and mineral reserves, demonstrated by the chart below. Miners prove up their deposits with the hope of gathering proven reserves which can be produced, primarily done through drilling and technical work, although the economic viability of the project is constantly being tested. The data used to estimate how much metal is in the ground forms the basis of what category the deposit falls into and the confidence behind those estimates.



For example, the data used to calculate probable reserves is not too different to that used to determine proven reserves. However, proven reserves are estimated using detailed data over one entire area where the boundaries of deposits are fully understood, whereas the measurements and samples used to calculate probable reserves can be more spaced out, leaving blackspots which need to be drilled (called infill drilling) to fully understand the entire area, not just sections of it.

Resources and reserves are extremely important to natural resource companies, including oil firms. One of the reasons the share prices of natural resource companies are so sensitive is because the value of their resources and reserves – their biggest and most important asset – fluctuates in line with commodity prices.

Reserves and resources also play an integral role when it comes to the finances of natural resource firms. Many banks lend to natural resource companies depending on their resources or reserves, known as reserve-based lending, although this is more common in the oil sector. Importantly, lending is based on the value of the resources and reserves, not the size or volume. When determining the price of resources and reserves, certain discounts are applied to each category of mineral to reflect the level of confidence behind the estimates.

As miners produce proven reserves they attempt to replace them by proving up other minerals so they too can be produced. This is why many firms will often continue exploring even after they have set up a producing mine, as they need to ensure they have adequate time to replenish their production, and have many batches of minerals at different stages of the proving process.

Studies Undertaken for a New Mining Project

There are a number of studies that miners must complete before they can get their project off the ground and these can be considered as the major milestones that companies need to achieve to demonstrate the progress being made. Share prices are particularly sensitive to these studies as each one de-risks the project. Here are some of the major studies (not necessarily in order) that miners must complete to progress their project to the construction stage:

- Desktop or conceptual studies: This is one of the first studies undertaken. These studies are based around benchmark and industry data, as well as any historic information that has been collected about the site.
- Environmental and social impact assessments: These are used to outline how a project would impact the local community and the environment, including items like the effect on local employment and how the area will be reclaimed once the mine has been exhausted. These are integral to gaining government and community support for a mine.
- Scoping studies: These studies outline the different options (usually three or four) that could be considered for the project to try and identify the optimum operational plan to get the most out of the mine and the chances of success. Ultimately, these studies must prove that further work on the site is warranted.
- Preliminary economic assessment: This is the first snapshot of the economic potential of a project, estimating the financial outcome for the different operational plans that are being considered and proving there is a profitable and viable option among them.
- Pre-feasibility study: The pre-feasibility study is one of three studies that can be considered the most important for a company looking to open a new mine. The pre-feasibility study

will only use measured or indicated mineral resources and collects all of the work done so far to outline all the elements for each proposed plan. These include how the mine and plants will be designed, the rate of production, recovery rates, what labour is needed as well as operational and capital expenditure projections.

- Feasibility study: This is a more detailed and accurate version of the pre-feasibility study, which narrows the options being considered into the proposal that the company will take forward, defining the route that the company has opted for. Miners start to seriously consider the financial requirements for the project and start preparing where it will source the necessary funding before moving on to the next and most important study.
- Definitive/bankable feasibility study: This is what all the previous studies build up to. This is the final and most detailed version of the feasibility studies and is regarded as accurate enough to take forward. This is the key document for any miner that does not already have the funds needed to develop the project, as lenders base their decisions on this study more than anything else. This will also include other elements such as any commercial agreements (like offtakes) that have been signed.

Lifecycle of a Mine

Once a mining company has identified a site to set up an operation, the lifecycle of the mine begins. As a broad guideline, the lifecycle of a mine consists of the following stages.

Mineral Exploration and Prospecting

The initial aim of exploration is to understand the characteristics of the land. Water, oil and soil is tested and firms starts to consider the socio-economic effects that a new mine would have on the local area.

This is followed by prospecting, which includes more detailed surveys being carried out including airborne or ground geophysical surveys that read the Earth's magnetic field, radiation and electrical conductivity underground. Airborne surveys allow larger areas to be covered, while ground surveys can provide more detailed data deeper underground. Some companies use one method, some use both.

These surveys help identify possible targets and allow a company to start drilling to find out more about what lies underneath. Drilling and sampling work will provide the first glimpse of the type of ore (the rock containing minerals) being mined and the grade it could yield. The surveys, drilling and sampling work allow a miner to draw up a 2D or 3D model of the geological ore, which is essentially a virtual underground map showing where the minerals lie. This is a very preliminary outline of the potential size of the deposits or veins found.

Mine Design and Project Development

Once confident that there is an opportunity lying in the ground, miners can now start to design the project and begin early stage development. Companies will evaluate the various options it has and will draw up multiple plans that could be used in order to identify the best available one. For example, a company may draw up one plan proposing to mine all the estimated material in the ground over 20 years and one plan over ten years to estimate the different financial implications, or numerous plans that consider using different types of equipment. This is when the miner will start to outline the possible profitability of its future project.

More detailed technical work is completed and drilling often continues to test the flow of information coming out of the ground. Understanding the ore and minerals will allow firms to consider what metallurgical process will be used to extract the commodity from the rock.

The multiple mine designs and development plans that are drawn up ultimately test the viability of the proposed project and, if viable, prepare everything for the construction phase.

Major Contracts and Financing

Once all of the studies have been completed the company will know exactly what it needs to create the project and how much it will cost. A new mine does not come cheap and the bankable feasibility study will propose where the funding will come from. Funding can come in a variety of forms and smaller firms tend to blend a mixture of debt and equity, but other options such as vendor financing can also be considered.

Running parallel with the financing, companies will start to tender work to attract bids from different providers, with the aim of driving down the cost of the operation and, once awarded, clarify the exact costs of some of the major elements of development. Some mining companies choose to operate their own mine, some hire contractors. Some will outsource only one element of the operation, such as processing.

The front-end engineering and design (FEED) contract covers the basic engineering work and is usually awarded around the conceptual or feasibility study stage. This forms the basis of later contracts like engineering, procurement and construction (EPC), which tasks a contractor with executing and delivering the project within an agreed time and budget.

Underground Mines vs Open Pits

Once the miner has addressed all the regulatory, funding and technical aspects of the project it can finally start construction. The construction process can be very different depending on the mineral being mined and the size of the project, and will often take considerably longer than exploratory and design stages.

Although this kickstarts tangible progress on the ground, it is also when the company is likely to suffer the most hiccups, particularly for smaller miners that don’t boast the same track record as more experienced players. With so many moving parts it is almost impossible for a company not to be hit by some issue or delay during this stage.

There are two predominant types of mines that can be built: underground mines and surface mines (an open pit).

Underground mines are built to access ore and minerals that lie deeper underground and their construction is highly complex, involving tunnels and shafts that can sometimes be big enough to drive a haulage truck down it. Safety, while always a concern, is even more important for underground mines.

Surface mining, or open pits, are for shallower minerals. Visually, these look like quarries and therefore have a bigger visual impact that underground mines. However, they are usually a lot cheaper to develop than an underground operation.

Mine Production and a Gradual Ramp up to Full-scale Output

Eventually, the project is constructed and ready to begin producing. However, output tends not to go full throttle from day one. It can often take years to ramp up to peak production as everything comes together.

Having said that, some choose to produce more in the initial years to help pay the high costs of building the operation, before lowering output later on. Equally, some miners take a phased approach in order to reduce the capital intensity, building a smaller operation in order to generate cash flow to fund the main project for example.

The amount to be produced each year dictates the life-of-mine (LOM), which estimates how many years it can economically produce for. However, many companies have shut mines earlier than planned because the economics became unfavourable, or extended the LOM at some point as new resources and reserves are found, such as a nearby satellite deposit that supplements the main deposit.

Mine Closure and Land Reclamation

Many mines may be capable of producing economically for decades, but mining is still a temporary activity. The vast majority of companies now have to formulate their plan on how to close their operation before they have even built it, as governments require assurances that firms have a plan and the funds needed to close the mine before they are willing to issue permits. The detailed environmental and social studies that are conducted during the process form a major part of the plan on how the mining operation will be closed.

While some mines are closed because the resources and reserves have been exhausted, many are shut down because they are no longer economical. The latter means the mine is closed with minerals left in the ground. This may encourage another company to open the mine again in the future, when the economics become more favourable or because technology has developed and allowed new and possibly cheaper ways of extracting the minerals that were left.

Depending on the size of the operation it can take up to a decade to fully shut down a mining operation, and potentially longer if water in the area needs to be retreated or monitored for a prolonged period of time.

Mine closure plans can aim to renovate the site to varying degrees:

- Remediation: Cleaning up the contaminated area, including water.
- Reclamation: Stabilising the terrain, landscaping and topsoil replacement to make the land useful once again.
- Restoration: Rebuilding any part of the ecosystem that was disturbed as a result of the mine such as flora and fauna.

- Rehabilitation: Rehabilitating the site to a stable and self-rejuvenating state, either as it was before the mine was built or as a new equivalent ecosystem.

Some of the major steps that are common for companies to follow when shutting a mine are as follows:

- Mine shutdown: Production is halted, equipment is taken offline and the workforce is scaled back.
- Decommissioning: The operation and equipment is taken apart, waste is disposed of, buildings are demolished or repurposed and the site is cleaned.
- Remediation or reclamation: Returning the land, trees, topsoil, water and wider ecosystem to a satisfactory state while removing contaminants or hazardous materials.
- Post-closure: Monitoring programmes initiated to ensure shut down is effective and highlight any further work that needs to be completed.

TECHNOLOGIES IN EXPLORATION, MINING AND PROCESSING

The life cycle of mining begins with exploration, continues through production, and ends with closure and postmining land use. New technologies can benefit the mining industry and consumers in all stages of this life cycle. This report does not include downstream processing, such as smelting of mineral concentrates or refining of metals. The discussion is limited to the technologies that affect steps leading to the sale of the first commercial product after extraction.

The three major components of mining (exploration, mining, and processing) overlap somewhat. After a mineral deposit has been identified through exploration, the industry must make a considerable investment in mine development before production begins. Further exploration near the deposit and further development drilling within the deposit are done while the mining is ongoing. Comminution (i.e., the breaking of rock to facilitate the separation of ore minerals from waste) combines blasting (a unit process of mining) with crushing and grinding (processing steps). In-situ mining is a special case that combines aspects of mining and processing but does not require the excavation, comminution, and waste disposal steps. The major components can also be combined innovatively, such as when in-situ leaching of copper is undertaken after conventional mining has rubblized ore in underground block-caving operations.

Exploration

Modern mineral exploration has been driven largely by technology. Many mineral discoveries since the 1950s can be attributed to geophysical and geochemical technologies developed by both industry and government. Even though industrial investment in in-house exploration research and development in the United States decreased during the 1990s, new technologies, such as tomographic imaging (developed by the medical community) and GPS (developed by the defense community), were newly applied to mineral exploration. Research in basic geological sciences, geophysical and geochemical methods, and drilling technologies could improve the effectiveness and productivity of mineral exploration. These fields sometimes overlap, and developments in one area are likely to cross-fertilize research and development in other areas.

Geological Methods

Underlying physical and chemical processes of formation are common to many metallic and nonmetallic ore deposits. A good deal of data is lacking about the processes of ore formation, ranging from how metals are released from source rocks through transport to deposition and post-deposition alteration. Modeling of these processes has been limited by significant gaps in thermodynamic and kinetic data on ore and gangue (waste) minerals, wall-rock minerals, and alteration products. With the exception of proprietary data held by companies, detailed geologic maps and geochronological and petrogenetic data for interpreting geologic structures in and around mining districts and in frontier areas that might have significant mineral deposits are not available. These data are critical to an understanding of the geological history of ore formation. A geologic database would be beneficial not only to the mining industry but also to land-use planners and environmental scientists. In many instances, particularly in arid environments where rocks are exposed, detailed geologic and alteration mapping has been the key factor in the discovery of major copper and gold deposits.

Most metallic ore deposits are formed through the interaction of an aqueous fluid and host rocks. At some point along the fluid flow pathway through the Earth's crust, the fluids encounter changes in physical or chemical conditions that cause the dissolved metals to precipitate. In research on ore deposits, the focus has traditionally been on the location of metal depositions, that is, the ore deposit itself. However, the fluids responsible for the deposit must continue through the crust or into another medium, such as seawater, to maintain a high fluid flux. After formation of a metallic ore deposit, oxidation by meteoric water commonly remobilizes and disperses metals and associated elements, thereby creating geochemical and mineralogical haloes that are used in exploration. In addition, the process of mining commonly exposes ore to more rapid oxidation by meteoric water, which naturally affects the environment. Therefore, understanding the movement of fluids through the Earth, for example, through enhanced hydrologic models, will be critical for future mineral exploration, as well as for effectively closing mines that have completed their life cycle.

The focus of research on geological ore deposits has changed with new mineral discoveries and with swings in commodity prices. Geoscientists have developed numerous models of ore deposits. Models for ore deposits that, when mined, have minimal impacts on the environment (such as deposits with no acid-generating capacity) and for deposits that may be amenable to innovative in-situ extraction will be important for the future. Because the costs of reclamation, closure, post-mining land use, and long-term environmental monitoring must be integrated into mine feasibility studies, the health and environmental aspects of an orebody must be well understood during the exploration stage. The need for characterizations of potential waste rock and surrounding wall rocks, which may either serve as chemical buffers or provide fluid pathways for escape to the broader environment. Baseline studies to determine hydrologic conditions and natural occurrences of potentially toxic elements in rocks, soils, and waters are also becoming critical. The baseline data will be vital to determining how mining may change hydrologic and geochemical conditions. Baseline climatological, hydrological, and mineralogical data are vital; for example, acid-rock drainage will be greatly minimized in arid climates where natural oxidation has already destroyed acid-generating sulfide minerals or where water flows are negligible.

A wealth of geologic data has been collected for some mining districts, but the data are not currently being used because much of the data is on paper and would be costly to convert to digital format. Individual companies have large databases, but these are not available to the research community or industrial competitors. Ideally, geological research on ore deposits should be carried out by teams of geoscientists from industry, government, and academia. Industry geoscientists have access to confidential company databases and a focus on solving industrial problems; government and academic geoscientists have access to state-of-the-art analytical tools and a focus on tackling research issues. Currently, geological research activities in the United States are not well coordinated and are limited primarily to studies of individual deposits by university groups and, to a much lesser extent, by the USGS. More effective research is being carried out in Australia and Canada by industry consortia working with government and academia to identify research problems, develop teams with the skills appropriate to addressing those problems, and pool available funding. Both Canada and Australia have resolved issues of intellectual property rights in the industry-university programs, but these issues have yet to be resolved in the United States.

Geochemical and Geophysical Methods

Surface geochemical prospecting involves analyzing soil, rock, water, vegetation, and vapor (e.g., mercury and hydrocarbons in soil gas) for trace amounts of metals or other elements that may indicate the presence of a buried ore deposit. Geochemical techniques have played a key role in the discovery of numerous mineral deposits, and they continue to be a standard method of exploration.

With examples of environmental and health concerns that should be identified during exploration:

- Groundwater and surface water quality.
- Trace elements in existing soils.
- Trace elements in ores, particularly elements of concern, such as mercury and arsenic.
- The presence of asbestiform minerals associated with industrial-minerals operations.
- The potential for acid-rock drainage (amounts of sulfide minerals and buffering minerals, climate, and hydrology).
- Location of aquifers in relation to ore bodies.
- Existence and location of sensitive biological communities.
- Climatological impacts on mining operations, including precipitation and prevailing winds.
- Socioeconomic and cultural issues, including sustainable development.

Drilling Technologies

Almost all mineral exploration involves drilling to discover what is below the surface. No significant changes in mineral drilling technology or techniques have been made for more than three decades.

This contrasts sharply with spectacular advances in drilling technologies, including highly directional drilling, horizontal drilling, and a wide range of drilling tools for the in-situ measurement of rock properties, for the petroleum and geothermal sectors. Mineral exploration involves both percussion and rotary drilling that produce rock chips and intact samples of core. The diameter of mineral exploration drill holes (called slimholes) is generally much smaller than the diameter of either petroleum or geothermal wells. Therefore, many of the down-hole tools used for drilling in the petroleum and geothermal fields are too large to be used in the mineral exploration slimholes. The need for miniaturization of existing drilling equipment is growing not only in the mineral industry but also for NASA to investigate drilling on Mars. The development of guided microdrill systems for the shallow depths of many mineral exploration projects will be challenging.

Drilling generally represents the largest single cost associated with mineral exploration and the delineation of an ore deposit once it has been discovered. Hundreds of drill holes may be required to define the boundaries and evaluate the quality of an orebody. Decreasing the number of drill holes, increasing the drilling rate, or reducing the energy requirements for drilling would have a substantial impact on mineral exploration and development costs. In many situations directional drilling could significantly reduce the number of drill holes required to discover a resource in the ground. Novel drilling technologies, such as down-hole hammers, turbodrills, in-hole drilling motors, and jet drilling systems, have the potential to increase the drilling rate. Novel technologies, together with more efficient rock bits, could also reduce energy requirements for drilling.

Down-hole logging is a standard technique in petroleum exploration. However, it is rarely used in mineral exploration. Standard petroleum well-logging techniques include gamma-ray surveys (to distinguish different rock types based on natural radioactivity), spontaneous potential (to determine the location of shales and zones with saline groundwater), mechanical caliper and dipmeter test (to determine dip and structure of the rock mass penetrated), and a variety of other geophysical tests (resistivity, induction, density, and neutron activation). These tests determine the physical properties of the drilled rock mass and differentiate rock types. Typically, the minerals industry has obtained some of this information by taking samples of rock (either drill chips or drill cores) for analysis. The development of down-hole analytical devices, such as spectrometers, would make it possible to conduct in-situ, real-time analyses of trace elements in the rock mass that could dramatically shorten the time required to determine if a drill hole had “hit” or not. Miniaturization will be necessary for existing down-hole technologies to be used in slimholes.

Drilling and access for drilling generally represent the most invasive aspect of mineral exploration. The environmental impacts of exploration activities could be significantly reduced by the development of drilling technologies that would minimize the footprint of these activities on the ground, such as the miniturization of drilling rigs, the ability to test larger areas from each drill site, and better initial targeting to minimize the number of holes.

Recommendations for Research on Exploration Technologies

Numerous opportunities exist for research and development that would significantly benefit exploration, many of which involve the application of existing technologies from other fields. Support for technological development, primarily the miniaturization of drilling technologies and analytical tools, could dramatically improve the efficiency of exploration and improve the mining process.

Although industry currently supports the development of most new geochemical and geophysical technologies, basic research on the chemistry, biology, and spectral characterization of soils could significantly benefit the mineral industry. Continued government support for spaceborne remote sensing, particularly hyperspectral systems, will be necessary to ensure that this technology reaches a stage at which it could be commercialized. In the field of geological sciences more support for basic science, including geological mapping and geochemical research, would provide significant though gradual improvements in mineral exploration. Filling gaps in fundamental knowledge, including thermodynamic-kinetic data and detailed four-dimensional geological frameworks of ore systems, would provide benefits not only for mineral exploration and development but also for mining and mineral processing. The thermodynamic-kinetic data would lead to a better understanding of how the ore systems evolved through time, how the minerals in the ores and waste rocks will react after exposure to postmining changes in hydrology, and how new processing technologies should be developed. The geological framework of an ore system includes the three-dimensional distribution of rock types and structure, such as faults and fractures, as well as the fourth dimension of time—how the rocks and structures formed. This framework is important to successful exploration, efficient mining, and later reclamation. Focused research on the development of exploration models for "environmentally friendly" ore deposits might yield important results in the short term. A mechanism for focusing research on the most important issues, as identified by industry, would help focus industrial, governmental, and academic resources on these problems.

Opportunities for research and technology development in exploration:

- Geological Methods:
  - More robust thermodynamic and kinetic geochemical data.
  - New ore-deposit models, particularly for deposits with less environmental impact when mined.
  - Better geohydrological models.
  - Geological maps of more mineralized areas.
  - Databases for mineralized areas.
- Geochemical/Geophysical Methods:
  - Hand-held and down-hole analytical instruments.
  - Cross-bore-hole characterization.
  - Better understanding of element mobility in soils.
  - Drones for airborne geophysics.
  - Low-cost, shallow seismic methods.
  - Better intrepretation of hyperspectral data.
- Drilling Technology:
  - Application of existing petroleum and geothermal drilling technologies to minerals sector (directional drilling, better bits, down-hole logging).

- Novel drilling techniques (e.g., improvements in slimhole drilling and in-situ measurements).

Technology Needs

In simple terms mining involves breaking in-situ materials and hauling the broken materials out of the mine, while ensuring the health and safety of miners and the economic viability of the operation. Since the early 1900s, a relentless search has been under way for new and innovative mining technologies that can improve health, safety, and productivity. In recent decades another driver has been a growing awareness of the adverse environmental and ecological impacts of mining. Markers along the trail of mining extraction technology include the invention of the safety lamp, and safe use of dynamite for fragmentation, the safe use of electricity, the development of continuous miners for cutting coal, the invention of rock bolts for ground support, open-pit mining technology for mining massive low-grade deposits, the introduction of longwall coal mining, and recently in-situ mining and automated mining.

At the turn of the twenty-first century, even as the U.S. mining industry is setting impressive records in underground and surface mine production, productivity, and health and safety in all sectors of the industry (metal, industrial minerals, and coal), the industry still needs more effective and efficient mining technologies. For example, the inability to ascertain the conditions ahead in the mining face impedes rapid advance and creates health and safety hazards. As mining progresses to greater depths the increase in rock stress requires innovative designs for ensuring the short-term and long-term stability of the mine structure. Truly continuous mining will require innovative fragmentation and material-handling systems. In addition, sensing, analyzing, and communicating data and information will become increasingly important. Mining environments also present unique challenges to the design and operation of equipment. Composed of a large number of complex components, mining systems must be extremely reliable. Therefore, innovative maintenance strategies, supported by modern monitoring technologies, will be necessary for increasing the productive operational time of equipment and the mining system as a whole.

Look-ahead Technologies

Unexpected geological conditions during the mining process can threaten worker safety and may decrease productivity. Geological problems encountered in mining can include local thinning or thickening of the deposit, the loss of the deposit itself, unexpected dikes and faults, and intersections of gas and water reservoirs. Even with detailed advanced exploration at closely spaced intervals, mining operations have been affected by many problems, such as gas outbursts, water inundations, dangerous strata conditions, and severe operational problems, that can result in injuries to personnel, as well as major losses of equipment and decreases in production. Advances in in-ground geophysics could lead to the development of new technologies for predicting geological conditions in advance of the mining face. Three major technology areas are involved in systems that can interrogate the rock mass ahead of a working face: sensor systems, data processing, and visualization. All three areas should be pursued in parallel to effect progress in the development of a usable system.

Research on the development of specific sensors and sensor systems has focused on seismic methods. In underground mining the mining machine (if mining is continuous) can be used as a sound source, and receivers can be placed in arrays just behind the working face. For drilling and blasting operations, either on the surface or underground, blast pulses can be used to interrogate rock adjacent to the rock being moved. However, numerous difficulties have been encountered, even with this relatively straightforward approach. Current seismic systems are not designed to receive and process multiple signals or continuous-wave sources, such as those from the mining machine.

Some projects sponsored by DOE's Office of Non-Proliferation and National Security have focused on the nature of seismic signals from mining operations to determine whether these signals would interfere with the monitoring of and compliance with the Comprehensive Test Ban Treaty. In another study an NRC panel concluded that controlled blasting methods could generate strong enough signals for analysis and suitable for geotechnical investigations. Other sensing methods that could be explored include electromagnetics and ground-penetrating radar. Combinations of sensing methods should also be explored to maximize the overlaying of multiple data sets.

The second major area that requires additional research is data processing methods for interpreting sensor data. The mining industry has a critical need for processing algorithms that can take advantage of current parallel-processing technologies. Currently, the processing of seismic data can take many hours or days. Real-time turnaround (in minutes) in processing will be necessary for the data to be useful for continuous mining.

The third area of need is data display and visualization, which are closely related to the processing and interpretation of data. The data cannot be quickly assessed unless they are in a form that can be readily reviewed. The need for visualizing data, especially in three dimensions, is not unique to the mining industry. In fact, it is being addressed by many technical communities, especially in numerical analysis and simulation. Ongoing work could be leveraged and extended to meet the needs of the mining industry.

With look-ahead technology unexpected features and events could be detected and avoided or additional engineering measures put in place to prevent injuries and damage to equipment. The economic benefits of anticipating the narrowing or widening of the mined strata or other changes in the geologic nature of the orebody would also be substantial.

Cutting and Fragmentation

Mechanized cutting of rock for underground construction and mining has long been a focus area of technology development. For coal and soft rock, high-production cutting tools and machines have been available for some time and continue to be improved, especially in cutter designs that minimize dust and optimize fragment size for downstream moving and processing. Hardrock presents much more difficult problems. Tunnel-boring machines can cut hardrock at reasonable rates, but the cutters are expensive and wear out rapidly, and the machines require very high thust and specific energy (the quantity of energy required to excavate a unit of volume). In addition, tunnel-boring machines are not mobile enough to follow sharply changing or dipping ore bodies.

Drilling and blasting methods are commonly used to excavate hardrock in both surface and underground mining. Blasting is also used to move large amounts of overburden (blast casting) in some surface mining operations. Improved blasting methods for more precise rock movement and better control of the fragment sizes would reduce the cost of overbreak removal, as well as the cost of downstream processing.

Recommended areas for research and development in cutting and fragmentation are the development of hardrock cutting methods and tools and improved blast designs. Research on the design of more mobile, rapid, and reliable hardrock excavation would benefit both the mining and underground construction industries. Early focus of this research should be on a better understanding of fracture mechanisms in rock so that better cutters can be designed. In addition, preconditioning the rock with water jets, thermal impulses, explosive impulses, or other techniques are promising technologies for weakening rock, which would make subsequent mechanical cutting easier. Novel combinations of preconditioning and cutting should also be investigated. Numerous ideas for the rapid excavation of hard rock were explored in the early 1970s, motivated by the defense community. These concepts should be re-examined in light of technological improvements in the last 20 years that could make some of the concepts more feasible.

Improvements in blast design (e.g., computer-simulation-assisted design) would improve perimeter control, casting, and control of fragment size and would result in large energy savings by decreasing the need for downstream crushing and grinding. New methods of explosive tailoring and timing would also have significant benefits. Research into novel applications of blasting technology for the preparation of in-situ rubble beds for processing would help overcome some of the major barriers to the development of large-scale, in-situ processing methods. New developments in micro-explosives that could be pumped into thin fractures and detonated should be explored for their applications to in-situ fracturing and increasing permeability for processing. These methods would also have applications for coal gasification and in-situ leaching.

The development of better and faster rock-cutting and fragmentation methods, especially for applications to hard rock and in-situ mining, would result in dramatic improvements in productivity and would have some ancillary health and environmental risks and benefits. Mechanized, continuous mining operations are recognized as inherently safer than conventional drill-and-blast mining because it requires fewer unit operations, enables faster installation of ground support, and exposes fewer personnel to hazards. Continuous mining methods for underground hard-rock mining would also raise the level of productivity considerably. The environmental risks associated with in-situ mine-bed preparation by injection of explosives or other means of creating permeability will have to be evaluated. This evaluation should include the hazardous effects of unexploded materials or poisonous by-products in the case of chemical generation of permeability. Current thinking is that these risks would not be high relative to the risks of the processing operations used in in-situ mineral extraction (e.g., retorting and leaching).

Ground Control

The planning and design of virtually all elements of a mining system—openings, roadways, pillars, supports, mining method, sequence of extraction, and equipment—are dictated by the geological and geotechnical characterization of the mine site. The objective of ground control is to use site information and the principles of rock mechanics to engineer mine structures for designed purposes. Massive failures of pillars in underground mines, severe coal and rock bursts, open-pit slope failures, and roof and side falls all represent unexpected failures of the system to meet its design standard. These failures often result in loss of lives, equipment, and in some cases large portions of the reserves. Mining-related environmental problems, such as subsidence, slope instability, and impoundment failures, also reflect the need for more attention to the long-term effects of ground control on mine closures and facility construction.

Advances in numerical modeling, seismic monitoring, acoustic tomography, and rock-mass characterization have contributed immensely to the evolution of modern, ground-control design practices. Problems in mine design and rock engineering are complicated by the difficulties of characterizing rock and rock-mass behavior, inhomogenity and anisotropy, fractures, in-situ stresses, induced stress, and groundwater. The increasing scale of mining operations and equipment, coupled with the greater depths of mining and higher extraction rates, will require improved procedures for ground-control design and monitoring and improved prediction systems for operational ground control.

Site-characterization methods for determining the distributions of intact rock properties and the collective properties of the rock mass will require further development of geostatistical methods and their incorporation into design methodologies for ground support. So far, automated monitoring data, such as data from seismic and/or other geophysical monitoring networks, have not been successfully integrated into the design of mine structures. In addition, ground-support elements, such as rock bolts, could be installed at selected locations and instrumented to monitor stress, support loads, and conditions (to determine maintenance intervals) to validate ground-support designs. With rapid advances in mathematics and numerical modeling, research should focus on approaches, such as real-time analysis and interrogation of data with three-dimensional models. In addition, the heterogeneity of rock strata and the diverse processes acting on the mine system (e.g., geologic, hydrologic, mechanical, and engineering processes) should be considered through stochastic and coupled-system modeling. The technology development advocated for look-ahead technologies should also be beneficial for assessing stability in the immediate vicinity of mining.

The failure of ground control has been a perpetual source of safety and environmental concern. Establishing and adopting better engineering approaches, analytical methods, and design methodologies, along with the other characterization technologies described above, would considerably reduce risks from ground-control failures and provide a safer working environment.

Materials Handling

The design and proper operation of clearance systems for transporting mined materials from the point of mining to processing locations are critical for enhancing production. In many cases the system for loading and hauling the mineral is not truly continuous. Belt and slurry transportation systems have provided continuous haulage in some mining systems. Longwall systems in underground mines, bucket-wheel excavator systems in surface mines, and mobile crushers hooked to conveyor belts in crushed-stone quarries are successful steps in the development of a continuous materials-handling system. Even in these systems haulage is regarded as one of the weakest components. In most cases, both in underground and surface mining, the loading and hauling functions are performed cyclically with loaders and haulers.

The major problem in the development of continuous haulage for underground mining is maneuvering around corners. To increase productivity a truly continuous haulage system will have to advance with the advancing cutter-loader. If the strata conditions require regular support of the roof as mining advances, the support function must also be addressed simultaneously. Therefore, research should also focus on automated roof bolting and integration with the cutting and hauling functions.

The increasing size of loaders and haulers in both surface and underground mines has increased productivity. However, larger equipment is associated with several health and safety hazards from reduced operator visibility.

Reducing the amount of material hauled from underground mines by clearly identifying the waste and ore components at the mine face would result in both energy and cost savings, as well as a reduction in the amount of waste generated. It might even lead to leaving the subgrade material in place through selective mining. For this purpose the development of ore-grade analyzers to quantify the metal and mineral contents in the rock faces would be extremely useful. The ore-grade analyzer must have both real-time analysis and communication capability so operations could be adjusted. Similarly, in surface mines the down-hole analysis of ore in blast holes could lead to more efficient materials handling by identifying ore and waste constituents.

Equally important to improving the performance of materials-handling machinery will be the development of new technologies for monitoring equipment status and for specific automation needs. In addition, for underground applications the interruption of the line of sight with satellites and thus the impossibility of using the GPS means a totally new technology will have to be developed for machine positioning.

Transporting ore for processing can take considerable time and energy and can contribute significantly to the overall cost of production in both surface and underground mining operations. An area for exploratory research should be downstream processing while the ore is being transported. For certain processes transport by conveyer-belt systems and hydraulic transport through pipelines would allow for some processing before the ore reaches the final process mills. Physical separation processes, such as those outlined later in this report, and leaching with certain chemical agents are the most likely processes that could be integrated with transport.

The initial transport of materials is currently done by powered vehicles. In underground mining the use of diesel-powered loading and hauling equipment presents both safety and health challenges. Electric equipment has similar disadvantages, even though it is cleaner and requires less ventilation, because power transmission and cabling for highly mobile equipment complicates operations. Equipment powered from clean, onboard energy sources would alleviate many of these health and safety problems. Research could focus on powering heavy equipment with alternative energy sources, such as new-generation battery technology, compressed air, or novel fuel-cell technology. The development of such technologies may have mixed results from an environmental standpoint. On the one hand, a reduction in the use of fossil fuels would have obvious benefits in terms of reduced atmospheric emissions. On the other hand, the manufacturing and eventual disposal of new types of batteries or fuel could have environmental impacts.

Improved Machine Performance

Mining depends heavily on mechanical, motor-driven machinery for almost every aspect of the process, from initial extraction to transport to processing. Improving the performance of machinery (thus reducing down time), increasing the efficiency of operation, and lowering maintenance costs would greatly increase productivity. The development and application of better maintenance strategies and more advanced automation methods are two means of improving machine performance.

In recent years new concepts of providing maintenance for large fleets of vehicles, especially vehicles in remote or difficult-to-access areas, have emerged primarily as a result of research sponsored by the U.S. Department of Defense (DOD) and equipment manufacturers. Mining operations are also often conducted in remote locations where access to spare parts and large maintenance facilities may be difficult. Current research has focused on the development of sensor systems that can be incorporated into large vehicles and heavy machinery to monitor continuously the “state of the health” of the vehicle. When problems are detected, the vehicle monitoring system can transmit data directly to a monitoring station at a large repair facility where the problem can be diagnosed, and repair packages can be prepared and shipped to the field before the equipment actually fails. Additional research into sensors, software, and communications could focus on adapting this concept to a variety of mining situations. Leveraging ongoing DOD programs could have substantial payoffs in terms of reduced down time, reduced volume of spare parts stored on site, and lower repair costs.

Better automation and control systems for mining equipment could also lead to large gains in productivity. Some equipment manufacturers are already incorporating human-assisted control systems in newer equipment, and improvements in man-machine interfaces are being made. Additional research should focus on alternatives, however, such as more autonomous vehicles that have both sensor capability and sufficient processing power to accomplish fairly complex tasks without human intervention. Tasks include haulage and mining in areas that are too dangerous for human miners. Semiautonomous control methods should also be explored, such as “fly-by-wire” systems in which the operator’s actions do not directly control the vehicle but give directions to a computer, which then decides how to accomplish the action. A good example of this technology is currently being used in large construction cranes; the motion of the crane to move a load from one location to another is controlled by the operator through a computer, which controls the rate of movement of the crane in such a way as to minimize the swing of the load. This technology has considerably improved safety, speeded up cycle time, and enhanced energy conservation in the motion of the crane.

Substantial research and development opportunities could be explored in support of both surface and underground mining. The entire mining system, including rock fracturing, material handling, ground support, equipment utilization, and maintenance, would benefit from research and development in four key areas:

- Fracture, fragmentation, and cutting, with the goal of achieving truly continuous mining in hardrock as is done with coal.
- Small, inexpensive sensors and sensor systems for mechanical, chemical, and hydrological applications.
- Data processing and visualization methods (especially taking advantage of advanced, parallel-computing architecture and methods) that would provide real-time feedback.
- Automation and control systems (especially for mining equipment used in hazardous areas).

The above four areas represent a very broad summary of technology advances that would greatly enhance productivity and safety in mining. A more detailed breakdown is provided.

In-situ Mining Technologies

Many areas offer opportunities for research and technology development in in-situ mining and related approaches to direct extraction. The chief hurdle to using in-situ leaching for mining more types of mineral deposits is permeability of the ore. The uranium deposits for which in-situ leaching has been successful were located in exceptionally permeable sandstones. However, ore minerals in the most permeable parts of rock formations are unusual; many metallic ores and industrial-mineral deposits are not highly permeable. Technologies that could fracture and rubblize ore in such a way that fluids would preferentially flow through the orebody and dissolve ore-bearing minerals (although this would be difficult in competent rocks with high compressive strengths) are, therefore, a high priority need for in-situ mining.

Opportunities for research and technology development in in-situ mining:

- In-situ well-field operations:
    - Rock-fracturing and rubblization techniques.
    - Directional drilling.
    - More efficient drilling.
    - Casing for depths below 270 meters.
    - Hydrogeologic modeling.
    - Tomography between bore holes.
    - Sensors for monitoring groundwater and operational controls.
    - New mining technologies for increasing permeability for in-situ leaching, particularly of base metals.
- Bore-hole excavation:
    - Extending of rock fracturing or cutting to tens of meters beyond well bores.
    - Sensors for assaying samples without removing them.
- Hydrometallurgical advances:
    - Development of lixiviants and microbiological agents.
    - Suppression of undesirable elements in solution.
    - Additives that precipitate or enhance adsorption of elements of concern during restoration of groundwater quality.
    - Thermodynamic and kinetic data.

For some commodities, such as phosphate rock and coal, removal through bore-hole mining of the entire rock mass without dissolving specific minerals may be an alternate approach. New technologies that would extend rock fracturing and cutting to tens of meters beyond well bores, while maintaining control of the direction of cutting to stay within the orebody or coal seam and avoid removing waste rock, would make bore-hole mining more attractive.

Key environmental and health concerns raised by in-situ leaching are the possibility of potentially toxic elements being brought to the surface or mobilized into groundwater. For example, selenium, arsenic, molybdenum, and radioactive daughter products of uranium are concerns in mining sandstone-type uranium deposits. Therefore, the committee also rates as a high priority development of lixiviants and microbiological agents that can selectively dissolve the desired elements and leave the undesired elements in the rock.

The closure of in-situ leaching facilities raises an additional environmental concern, especially in the copper industry where large-scale in-situ leaching of oxide ore bodies above underground sulfide workings and leaching of sulfide (particularly chalcocite) ores have been conducted. During operations the maintenance of a cone of depression around these ore bodies and the continuous extraction of product solution limits the release of lixiviants and mobilized metals to the surrounding aquifer. However, once mine dewatering and solution recovery are completed, there may be a significant potential for the transport of metals and residual leaching solution. To the extent that the orebody is again totally immersed in the water zone, metals will be in a reduced state, and their mobility will be limited. However, if leaching has taken place above the water table, metals may continue to leach if meteoric water penetration and bacterial activity are sufficient to produce acid conditions. Research should, therefore, also include the evaluation of how these facilities can be closed without long-term adverse impacts to ground-water quality.

Processing

Mineral and coal processing encompasses unit processes required to size, separate, and process minerals for eventual use. Unit processes include comminution (crushing and grinding), sizing (screening or classifying), separation (physical or chemical), dewatering (thickening, filtration, or drying), and hydrometallurgical or chemical processing.

Coal processing, mainly for reducing ash and sulfur contents in the mined raw coal, requires a subset of processing technologies. Some problems in coal processing arise from the way the sulfur and ash are bonded and the need to keep the water content in the cleaned coal low.

Different unit processes are required in specific cases; some processes are designed especially for the treatment of a particular mineral commodity. Therefore, the committee established a technical framework and broad economic principles as a basis for recommending categories of research and development. The key environmental, health, and safety risks and benefits of these technologies are also highlighted.

Comminution

Comminution, an energy-intensive process, usually begins with blasting of rock in the mining operation followed by crushing in large, heavy machines, often used in stages and in combination with screens to minimize production of particles too fine for subsequent treatment. Grinding is usually done in tumbling mills, wet or dry, with as little production of fine particles as possible. Comminution is a mature process for which few changes have been made in the past decade. Dry grinding, a higher cost process than wet grinding, is used mainly for downstream processing that requires a dry ground material or for producing a special dry product.

The manner in which rock is blasted in mining operations subjects the rock mass to stress resulting in breakage. Different blasting methods result in different stress distributions in the rock and may have a significant effect on subsequent comminution operations. The effects of blasting on crushing and grinding are poorly understood. Comminution may take advantage of internal cracking and weakness in the rock caused by an explosive shock from blasting. However, quantifying this phenomenon will require a multidisciplinary investigation involving the physics of rock breakage, mining and mineral processing, and the optimization of energy requirements between blasting and crushing for size reduction.

In the metals and coal industries comminution is generally done to liberate the mineral. In the industrial-mineral sector grinding is more commonly used to meet product specifications or for economic reasons. For example, wet-ground mica commands a much higher price than dry-ground mica of the same quality and size. The grinding method after mineral separation must ensure that the final products.

Need for Research on Fine Particles and Dust

As processing technologies move toward finer and finer particle sizes, dust and fine particles produced in the mineral industry are becoming an important consideration. Dust is considered dry material; fine particles are suspended in water. The particle sizes of dust and fine particles are defined differently for various sectors of the mineral industry. Unwanted fine particles in the coal industry may be less than 0.147 millimeters (minus 100 mesh particles), while unwanted fine particles for many industrial minerals are less than 10 microns.

Fine particles and dust can represent a health hazard, an environmental concern, and an economic loss. Processes for capturing dust and removing it from the atmosphere, either dry (e.g., in bag houses) or wet (e.g., in scrubbers), are highly efficient. Fine particles are most often disposed of in waste ponds.

The amount of waste dust and fine particles is increasing significantly as more rock is mined and processed. Research should be focused on minimizing the generation of unwanted fine particles and dust or on using these materials as viable by-products meet chemical specifications (e.g., iron contamination) or physical/chemical specifications (e.g., particle size or shape).

Energy consumption is a major capital and operating cost of mineral beneficiation, and approximately two-thirds of energy processing costs can be attributed to size reduction. Therefore, comminution is often a significant factor in determining economic viability. A savings of a few percent in comminution efficiency may represent a large dollar savings for the overall mining operation.

High-pressure rolls, recently developed in Germany, can significantly reduce specific energy requirements for size reduction. This technology also has downstream processing advantages because it causes microfractures that increase leaching efficiency. High-pressure rolls are currently being used successfully to comminute cement clinker and limestone. The use of high-pressure rolls in the mining industry has been slow, however, because of the high capital cost of the units and because the process has to be dry. Nevertheless, it is evident that mineral liberation could be improved with these devices, and with more experience and research, this technology is expected to gain greater acceptance in metal-processing plants.

About 10 years ago the water-flush crusher attracted renewed interest, and units have been installed in various operating plants in several countries. These crushers operate on a wet slurry-type feed to improve crushing performance and possibly reduce metal wear. The improved water-flush crusher is an example of an incremental improvement of an existing process.

Energy efficiency in size reduction by grinding is typically less than 20 percent, indicating an enormous potential for improvement. Autogenous and semiautogenous mills, which offer economic benefits because of their relatively large scale and simplicity, quickly gained acceptance. These mills are well suited to continuous, high throughput and can be moderately controlled to produce the required distribution of particle size. However, autogenous grinding is only one step in the total comminution process, which includes sizing, pumping, and often crushing. When evaluating a comminution circuit, energy consumption of all aspects of the system should be considered.

The current comminution technology to reduce material to less than 52 microns is inefficient and limited. Relatively few attempts have been made to develop true alternatives to conventional grinding. This represents an excellent opportunity for innovative research that could lead to revolutionary developments that could have dramatic energy savings.

The processing of ultra-fine particles, either occurring naturally in the ore or produced during comminution, is one of the biggest problems facing the mineral industry. Ultra-fine grinding is becoming common for regrinding flotation concentrates and preparing feed for hydrometallurgical processes. Ultra-fine grinding is mandatory in some industries (e.g., mica produced for the paint industry must be gorund to below 10 microns). Current ultra-fine grinding by vertical stirred mills has very high energy requirements. Energy-efficient ultra-fine grinding devices would be an important contribution for the future of the mineral industry. Some recent grinding installations in Australia have demonstrated potential for ultra-fine grinding with acceptable power consumption. A combination of high-pressure rolls and ultra-fine grinding devices could potentially save energy in the production of ultra-fine particles because they create micro-cracks during the crushing step.

Another emerging technology is optimization and control of component processes of a system that can optimize the energy efficiency of entire operations. Many aspects of optimization and control are mature technologies that are routinely used and are gradually evolving as better sensors and controls become available. Because of the diversity and variability of mineral deposits, process modeling and simulation of total systems in the mining industry is complex and extremely difficult for dynamic in-plant applications. With the advent of high-speed, large-capacity computers, modeling and simulation of individual unit operations have advanced the basic understanding of processes for the industry. Research in this area will be fruitful and should be continued.

The most important objective in comminution is the liberation or breaking apart of desired mineral crystals from unwanted gangue mineral crystals. Effective, reliable analysis of the liberation phenomenon has recently been achieved through imaging analysis and mathematics. Technology has progressed to a point where it is now possible to predict three-dimensional images from two-dimensional analyses in some mineral systems. Refinements in this technology could lead to defining liberation in an ore, thus eliminating overgrinding and reducing both energy usage and excessive loss of fine-grained particles.

The mineral industry needs innovations in instrumentation for size measurements, chemical analysis, and physical characterizations. Instrumentation to measure the physical and chemical properties in core samples, down the bore hole, or in sections of ore at the mine face would enhance subsequent operations by determining the liberation and separation characteristics of minerals before they were processed. With advancing laser technology new instruments may be able to determine the particle-size distribution of fine particles in both aqueous and gaseous suspensions. Flotation is the major concentration process used in the mineral industry, yet there is no good method of characterizing froth quality. Often the instruments are too costly for small and medium-sized operating plants. Although technology in process instrumentation and sensors has significantly advanced in recent years, much still needs to be accomplished.

The end use of most industrial minerals dictates the particle size. Clays, including the important mineral kaolin, occur naturally in fine and ultra-fine sizes, and usually not requiring crushing or, at times, even grinding. After grinding to liberate the minerals quartz, feldspar, and mica for concentration each of the minerals is subjected to another stage of grinding to meet ultra-fine-size specifications for the commercial market, especially as a filler material. No crushing or grinding is required on the ore matrix in Florida phosphates before flotation, but after removal of contaminants the concentrate is ground prior to the production of phosphoric acid. In the aggregate and sand industries a multitude of sized products with different values are routinely produced.

Reducing the cost of energy is one of several factors of interest in the processing of industrial minerals. For fine and ultra-fine grinding, the industry needs better construction materials for equipment because many minerals, such as quartz, are highly abrasive. In recent years some interest has been shown in the development of chemicals called "grinding aids." The results of tests have been mixed, however, and the economic benefits uncertain. Further research on using chemicals to reduce the cost of fine and ultra-fine grinding appears to be warranted.

Coal processors have an urgent need for a comminution system that minimizes the production of fine particles. The treatment of fine coal particles (less than 0.5 millimeter) costs three to four times that of the treatment of coarse coal particles (more than 0.5 millimeter). In addition, the moisture content of fine particles is usually more than four times that of coarse particles, representing an added penalty.

Physical Separation

Physical separation involves (1) the separation of various minerals from one another and (2) the separation of solids (minerals) from liquid (water). The brief discussion that follows includes only the primary processes for mineral separation. Flotation is unquestionably the most important and widely used process to separate minerals, including metals, industrial minerals, and coal.

Almost all separation processes are conducted in a slurry of water. The vast majority of minerals are concentrated by wet processes, but all mineral products are marketed as low-moisture materials. These processes include gravity separation techniques and flotation. Water is one of the most important parameters in wet-separation techniques. Most mineral plants operate in a closed water cycle by regulation because process water often raises environmental concerns. Therefore, dewatering is considered an important step in most processes.

Most physical separation processes are conducted wet, but the availability and cost of water are becoming concerns for most mineral-processing operations. A number of physical separations are conducted on dry feeds, often for reasons having to do with the separation process itself. Dry processes include electrostatic and electrodynamic separation, dry magnetic separation, air tabling, air elutriation, dry cycloning, and mechanized sorting. Many industrial-mineral separations are also dry processes. For example, beach-sand processing for titanium, zirconium, rare Earths, and some radioactive minerals depends on dry-separation methods. Dry-feed separation processes are usually developed or improved by vendors and users, but additional research would be justified.

Gravity Separation

Gravity separation (including processes that use other forces as adjuncts) is not used much in processes for metal ores because sources of ores amenable to gravity separation are now rare. Exceptions include free gold particles, because of the great disparity in density between gold and the common gangue minerals, and tin, titanium, zirconium, and certain rare-Earth minerals, which can be efficiently concentrated by combinations of gravity, magnetic, and electrical processes. Innovations continue to be made in gravity separation techniques for metallic minerals, as well as for certain industrial-mineral processes, but mature technologies and machine designs are adequate for metal ores and coarse coal. Innovations could be made, however, with the development of inexpensive gravity separation methods that could be used to recover small quantities of heavy minerals from metal-mining flotation tailings. The use of multiforce fields in the separation of particles could improve gravity separation in combination with other processes.

Some gravity separation methods can be used to treat fine particles if there are large density differences between the desired and undesired minerals. In gold plants, for example, a number of gravity devices, old and new, are being used to recover relatively coarse gold. Over the past few years gravity separators that take advantage of differential specific gravities in a high-gradient centrifugal force field (e.g., Knelson and Falcon separators) have been used successfully for gold. Older devices (such as spirals on which the centrifugal forces are lower, pinched sluices, and Reichert cones) have been adapted for other heavy minerals.

Heavy-media or dense-media separation uses a suspension of fine, heavy minerals (magnetite or ferrosilicon) to ensure that the apparent density of the slurry is intermediate between the density of the heavy and light particles. The light particles float to the surface and are separated. Commonly, separation occurs in the settling tank vessel. In some cases a cyclone is used to provide centrifugal force to assist in the mineral separation. The mineral used as media is recycled magnetically. This method is widely used for coal and to remove shale from construction aggregates. Early work has been done to develop a low-cost, effective, safe, and environmentally acceptable “true” heavy fluid but has not led to a commercial success. Research is still needed on metallurgically efficient, cost-effective technologies for the metal and non-metal industries.

Most gravity concentrators operate in dilute pulp systems allowing minerals to separate, in part, according to their specific gravity, usually in conjunction with other forces, such as those imparted by flowing water films and centrifugal force. These processes can be used on finer solids if the differences in specific gravity are sufficiently large or if there are marked differences in shape. The natural viscosity of water and the apparent viscosity of the pulp are the dominant process factors. Low pulp-density feed limits the throughput capacity of the machines and results in high water requirements for the system. Improving gravity separation in dense pulps could increase the number of applications for this technology. Research could make a significant and revolutionary change in the use of gravity concentration for fine and ultra-fine mineral separations. At the present time the only large-scale ultra-fine mineral separation process is the degritting of clay using centrifuges.

Magnetic and Electrical Separation

Magnetic separation, which can be either a dry or a wet process, exploits the differences in magnetic susceptibility of minerals. Electrostatic separation is a dry process in which particles falling through a high-voltage static field are diverted according to their natural charges. Electrostatic separation is not suited to extremely fine particles or to large particles whose masses overcome the electrical effect. Electrodynamic separation (high tension) applies a surface charge to fine particles that then contact a grounded roll. Particles that lose their charges are quickly repelled from the roll; others cling to the roll and fall or are brushed off. Eddycurrent separators can treat nonmagnetic conductors that, when exposed to an electrical field, experience a force caused by internal eddy currents and are diverted.

Conventional, low-intensity magnetic separators are widely used on ferromagnetic minerals. Electromagnets are being replaced by stronger, more efficient permanent magnets that can be operated wet or dry. At the next level of magnetic intensity, dry separators are common, and wet high-intensity separators are in everyday use on hematite, a paramagnetic mineral. Many attempts have been made to develop continuously operating magnetic separators with superconducting coils, but batch-type separators for removing fine impurities in the production of high-grade kaolin are the only units that have been successfully commercialized.

Sorting

Various sorting systems are used in other industries to separate materials, but few mining companies use them. Ore sorting in mining is usually considered a preconcentration method of upgrading run-of-mine ore before another beneficiation process. Ore sorting is a dry process primarily used for very coarse particles. Minerals in ore can be separated by color, particle shape, particle size, or some other physical characteristic, most commonly optical properties.

A workable ore-sorting system located at the mine could significantly reduce transportation costs, provide a method of maintaining a constant grade of feed to the process plant, and reduce operating costs by preventing uneconomical material from being processed. With technology advancing so rapidly in the instrumentation and electronics industries, sorting methods may improve sufficiently to be useful in mining.

Flotation

Flotation is both a revolutionary unit process and a mature technology that has been used for approximately 100 years for mineral separation throughout the world. The flotation process, which is versatile, can separate minerals as large as 3.3 millimeters (6 mesh) and as small as 5 microns and can handle minerals with a specific gravity as high as 19 (gold) and as low as 1.5 (vermiculite). The process can be used in a medium of almost pure water, seawater or saturated brines. Mineral separations have been made in water near freezing temperature, as well as in water near 38°C (100°F). Operating flotation plants process as little as 100 tons per day to more than 100,000 tons per day. Flotation is a major separation method for metals, coal, and industrial minerals. Most sulfides can be economically recovered by the flotation process.

Parameters that influence flotation can be divided into two general categories: (1) the surface characteristics of the minerals and (2) the design of the flotation equipment. Surface chemistry is by far the dominant factor in flotation. Mineral separation is dependent on both reagent chemistry and water chemistry. Flotation equipment (cells) provides the mechanism for air (as bubbles) to come into contact with mineral surfaces so chemical attachment can take place for separation of the selected mineral species. Two types of flotation cells are used in industry today: (1) mechanical flotation cells and (2) column flotation cells. Mechanical cells are by far the predominant type, and except for increasing the size of the process units this fundamental design has not changed significantly for several decades. The design parameters of mechanical cells are fairly well understood, but much is still not known about the design and operation of column cells.

Mineral separation in flotation requires surface modification for attachment between the mineral and the air bubbles. This system requires a careful balance between activators and depressants. Selective flotation is often effected using modifiers to separate gangue minerals from useful minerals. Separation of various sulfides is usually carried out by adjusting the pH of the solution and adding activators and depressants. Pyrite in sulfide deposits is sometimes depressed using cyanide. The introduction of inexpensive, effective, environmentally benign chemical agents would undoubtedly improve mineral separations.

Air is normally used for flotation, but recently nitrogen has been successfully used in flotation for chalcopyrite, molybdenite, and gold. Further research will be necessary to determine the potential of this innovation. Unfortunately, the advancement of flotation reagents has been slow. In the past, U.S. chemical manufacturers supported research on less costly, more effective reagents, but in the past 50 years very few flotation reagents have been introduced.

Most flotation is conducted in a water pulp, and yet water, a major component of the system, is probably the least understood aspect of the process. Little attention has been paid to the water used in tests, in spite of the fact that water quality and the ions contained in the water can alter the surface characteristics of minerals, thus having an effect on the separation process. The key to the effective separation of fine and ultra-fine minerals may be related to water quality.

During the past decade significant efforts have been made to develop and improve flotation equipment. Large-scale systems and the utility of column flotation cells have been established. Manufacturers' improvements in flotation equipment have been focused on larger units (on the order of 140 cubic meters), but markets for large flotation cells may be limited because of short-circuiting problems and because many operations are small (less that 1,000 tons per day), and the volume of the flotation cell may not be the dominant factor.

In the past 10 to 15 years column cells have been introduced into various flotation circuits, but the use, understanding, and acceptance of these units remain limited. The full potential and understanding of column cells have not been determined. In general, laboratory testing on column cells has not been a reliable method of predicting full-scale plant operation. The scale-up of column cells from laboratory and pilot-plant studies has been problematic and has resulted in plant failures, indicating that not enough is known about how the flotation process interacts with the column-cell dynamics. More developmental research will be necessary on the use of column-cells in operating plants.

New instrumentation has advanced the understanding of flotation fundamentals. Recent research using three-dimensional analysis to examine mineral liberation directly has shown promising results. Research on state-of-the-art instrumentation will require more support to ensure its development and application. Other advances related to flotation chemistry include improved surface spectroscopy, electrochemistry instrumentation, Fourier infrared spectroscopy, and atomic-force microscopy, all of which have improved our understanding of surface-reaction phenomena. Consequently, some improvements in flotation systems have been made, but research is still needed to develop more efficient cell designs and new economical reagents.

Most applications of flotation of industrial minerals are unique in that a large quantity of the incoming material feed to the plant reports to the froth. The separation process is often complex because the minerals in the ore are very similar in composition and crystal structure, such as halite ($NaCl$) and sylvite (KCl). Therefore, the process requires maximum use of flotation reagents and modifying agents to separate minerals that are similar. Many of the flotation plants in the industrial-minerals industry have multiple circuits with both cleaner and scavenger cells to maximize recovery and produce high-purity concentrates that meet strict market specifications. Beneficial new technologies for the industrial-minerals industry would be: (1) control mechanisms for process parameters; (2) on-stream analysis of mineralogy (not chemical composition); (3) on-stream particle-size or particle-distribution analysis; (4) automation to ensure constant concentrations; and (5) the integration of grinding, classification, conditioning, and flotation unit operations into an understandable model that could be used to operate the process as a single system.

Selective Flocculation

Selective flocculation technology used for industrial minerals is based on the surface chemistry of minerals. In this process chemicals are added to a fine-particle mineral mix resulting in one mineral being flocculated and the remaining minerals being dispersed in a water slurry. Flocculation technologies are used in the iron-ore industry to flocculate and recover iron oxide and in the clay industry to flocculate the quartz and reject grit.

Dewatering

One of the most important aspects of physical separation is dewatering. Once a physical separation is effected in water, the solids and liquids must be separated so unwanted solids can be disposed of. Thickeners, filters, or centrifuges can be used for dewatering, but final waste products are usually sent to tailings ponds after thickening only. The most desirable final solid products settle quickly and contain minimum amounts of water. Various chemicals are used to achieve this.

Hydrometallurgy and Chemical Processing

Hydrometallurgy encompasses leaching in water with various chemicals, assisted by oxidizing agents, elevated oxygen partial pressure, or bio-oxidation; dissolved species are removed by precipitation, solvent extraction, electrowinning, or adsorption. Leaching may be carried out in vessels, heaps, or dumps. Unlike physical separations, hydrometallurgy is capable of yielding solutions of relatively pure metal ions, which usually can be recovered directly. Hydrometallurgy has become increasingly important over the years and is now a major aspect of extractive metallurgy.

Heap Leaching and Dump Leaching

The development of heap-leaching and dump-leaching technologies for low-grade ore has extended the world's ore resource base considerably. The processes were developed by the copper industry and the USBM and have been extended to uranium and gold. The gold industry adopted innovations, such as feed preparation (agglomeration), perfected heap design and construction, and solution distribution. Bioleaching for heaps and dumps was developed by the copper mining industry and adapted to treat refractory gold. To speed up leaching rates and improve recovery rates, successful heap-leaching and dump-leaching operations require a combination of geology, mineralogy, hydrometallurgy, hydrology, and modeling, and sometimes biology (when bioleaching is used). Understanding the characteristics of the ore to be leached and solution management are key elements of heap-leaching and dump-leaching operations.

Mathematical modeling to profile metals and predict optimum performance would improve the overall rate of metals recovery. Recently, encouraging results have been obtained using a high-resolution resistivity technique to survey poorly wetted (nonpenetrated) areas in the heap. Selective releaching of the resistive zones has increased the recovery rate. In-situ mining aids, such as catalysts, surfactants, and wetting agents, may accelerate leach kinetics and increase the permeability of rock surfaces. An important advance in heap leaching and dump leaching would be the development of new lixiviants that could effectively extract metals directly in an environmentally friendly manner, especially metals from refractory sulfide minerals (Sparrow and Woodcock, 1995). New lixiviants would be particularly beneficial for maximizing metals extraction from near-surface deposits using in-situ techniques.

High-pressure Technology

The use of high-pressure technology has been demonstrated for a variety of commodities in acidic and basic solutions under oxidizing and reducing conditions. Because of increased reaction rates for both oxidative and reductive processes, pressure hydrometallurgy would be a suitable technology for the future. Large-scale autoclaves are used for production of zinc and nickel and to treat refractory gold ores. New developments in autoclave technology for pressure leaching a copper concentrate may also be useful for other mineral systems.

Recently developed processes include pressure leaching with ultra-fine grinding, which increases leaching kinetics and metal recovery, thus making pressure hydrometallurgy more attractive. Selective leaching and precipitation capabilities are available at elevated temperatures, which may be achieved at elevated pressures. Improved gas/solid/liquid mixing in the autoclave and development of catalysts and other chemical aids are becoming increasingly important to accelerating reaction kinetics.

Bioprocessing

Bioprocessing, the application of biotechnology to the extraction and recovery of metals, is becoming an increasingly important hydrometallurgical processing tool. Bioprocessing is divided into bioleaching/mineral bio-oxidation technology and biotechnology for the recovery and concentration of metals from aqueous solutions. Bioleaching uses the catalytic properties of micro-organisms to dissolve metals into an aqueous solution. An example of bioleaching is the microbially catalyzed oxidation of chalcocite to solubilize copper in acidic water. Mineral bio-oxidation is a pretreatment process that uses microorganisms to catalyze the oxidation of a sulfide mineral, such as pyrite, exposing precious metals for subsequent dissolution by another reagent, such as cyanide. Another aspect of bioprocessing involves the removal of metals from a solution, using micro-organisms themselves or products of micro-organisms to concentrate or immobilize them.

Bioleaching and mineral bio-oxidation are in commercial use today (1) in dumps to scavenge copper from run-of-mine rock; (2) in heaps to leach copper from secondary copper ores and to pretreat precious-metal ores in which the gold and silver are locked in a sulfide-mineral matrix; and (3) in aerated, stirred-tank reactors to pretreat precious-metal concentrates and bioleach base-metal concentrates. Bioleaching/mineral bio-oxidation employs a variety of different microorganisms that function under acidic conditions and a range of temperatures. Despite its commercial uses little is known about the microbial ecology of the heaps, dumps, aerated reactors, or the microbial/mineral interactions that occur in these systems.

The principal drivers of the development and commercial application of bioprocessing are (1) decreased production costs through lower energy requirements, lower reagent usage, and lower labor requirements; (2) lower capital costs because of simpler equipment and faster construction; (3) an increased reserve base because lower grade ores can be economically processed and more diverse mineral types can be processed; and (4) improved environmental conditions and worker safety because there are no gaseous emissions and, in some cases, no aqueous discharges.

Genetic modification, using standard "adaptation and selection" techniques, is usually used for microorganisms employed in aerated, stirred-tank reactors to ensure that microbial cultures can tolerate high metal concentrations. Modern molecular-biology techniques have not been used to genetically modify microorganisms used in commercial practice but have been used to identify and enumerate microorganisms in heaps and stirred-tank reactors. The use of modern molecular biology to modify microorganisms genetically for processing applications should be pursued as "blue-sky" research. Because mineral processing applications release organisms into the environment, researchers will have to be mindful of regulations governing the release of genetically engineered organisms into the environment.

The solubilization of metals from mineral matrices can also be accomplished with a large number of micro-organisms other than the acid-loving ones currently used commercially. Bioleaching under neutral or slightly alkaline conditions has been carried out by bacteria, fungi, yeast, and algae through several metabolic means. Most studies on nonacidic bioleaching have focused on understanding microbial processes as they relate to subsurface microbiology, rock weathering, and mineral deposition, as apposed to hydrometallurgical processing. Research on the most promising nonacidophilic microbial processes for metals mobilization coupled with careful process-engineering design and rigorous economic assessments of the proposed processes could result in commercially usable technologies that are more energy efficient and less polluting than the technologies used today.

Bacteria, fungi, yeast, and algae recover and concentrate metals from solutions using a variety of metabolic strategies. Most research in this area is focused on using microbial mechanisms for environmental management as opposed to hydrometallurgical processing. Considerably more research and development will be necessary before this area of bioprocessing delivers commercially viable products and processes. A more fruitful approach might be to focus on developing these technologies for environmental control in mining and, when demonstrated effective for that use, modifying the technology for metallurgical processes.

Solution Purification and Concentration

The vitally important hydrometallurgical processes of solution purification and concentration not only concentrate metal ions from dilute leaching solutions to levels suitable for metals recovery but also selectively reject other impurities. Over many years chemists learned how to precipitate dissolved metals from solution by a number of techniques, and by the early 1800s they suspected that some sort of electrical phenomenon might be involved. Miners knew, well before that time, that strong acids could dissolve some of the metals in an ore and that copper could be collected in solid form by “cementation.” This technique survived until the 1950s, although “cement” copper was not pure enough for electrical uses. Since then, the cementation process has been superceded by solvent extraction and electrowinning (SXEW).

Technologies used for solution purification and concentration include precipitation, ion exchange, solvent extraction, membrane transfer, and electrowinning. An excellent discussion of these methods and others can be found in Separation Technologies for the Industries of the Future. All of them have been used for nonmining chemical separations, and precipitation has been used in the leachprecipitation-flotation process for copper.

Solvent extraction is a phase-transfer process between organic and aqueous phases. The process, which was well known to analytical chemists, became an industrial process during World War II, when it was used for such separations as zirconium/hafnium, uranium/vanadium, and plutonium purification. The first commercial solvent-extraction process for uranium was installed in 1955 at the Kerr-McGee plant in New Mexico. In 1963 General Mills succeeded in producing a copper reagent, LIX 63, which in combination with electrowinning led to the first small copper SXEW plant in Arizona. The development of solvent extraction made copper hydrometallurgy the successful process it is today. The use of solvent extraction has been extended considerably to the production of nickel, cobalt, and rare-earth elements.

Stable emulsions and the eventual formation of “crud” are problems common to most solvent-extraction operations in the mining industry. Crud can constitute a major solvent, uranium, and copper loss to a circuit and therefore adversely affect the operating cost. Overcoming solvent loss and improving the rate of metal recovery will depend on the development of new extractants, modifiers, and diluents. Solvent-extraction methods could be extended to other applications with the development of a larger suite of selective reagents. The design and operation of mixer-settlers for optimization of solvent-extraction performance and entrainment minimization could also be improved.

Ion exchange is a mature technology used in many industries. The application of ion-exchange technology to hydrometallurgy began with uranium extraction. The technology is based on resin beads containing exchangeable ions or groups and is employed in columns (for clear solutions) or directly in the pulp (resin-in-pulp). Ion exchange is uniquely suited to extraction from very low-grade (ppm) solutions where losses using solvent extraction would be excessive. Ion exchange also eliminates transport of flammable diluents. Challenges and great opportunities occur in the development of selective resins strong enough to withstand rough handling. Currently, considerable attention is being focused on increasing selectivity by introducing chelating functional groups into the resin.

Membrane technology and extractant-impregnated membranes/porous particulates are also important phase-transfer processes for the future. Thin-film, polymeric membranes with separation characteristics between reverse osmosis and ultra-filtration became available in the mid-1980s. In the past five years membrane-separation technology for concentrating ions from very dilute solutions has been developed for wastewater-treatment applications. Certain types of multilayer, thin-layer, polymer composite membranes that are stable in strongly acidic environments are capable of making separations among monovalent, divalent, and trivalent ions. However, like most technology developments, there are gaps between research, technology transfer, and implementation of the new process.

Solid-liquid separation is an important part of nearly all hydrometallurgical operations. Large amounts of gangue solids must be separated from the pregnant solution after leaching, and a clarified solution is required for downstream metal recovery. The economics of a hydrometallurgical plant are often influenced by the cost of solid-liquid separation.

Iron precipitation has played an important role in many chemical reactions. The formation of jarosite-type compounds, which are complex alkali iron sulfates, provides a ready avenue for the precipitation and elimination of alkalis, iron, sulfate, and other impurities from chemical processing solutions. One major advantage of precipitating jarosite-type compounds is the comparative ease of settling, filtration, and washing of the resulting solids.

One of the oldest and cleanest metal-separation technologies used in hydrometallurgy is electrowinning, an energy-intensive technology. Major advances in electrowinning have been made, but further improvements can be expected if overpotentials can be reduced, current densities increased, and at the same time morphology and purity of depositing phases controlled. Improvements in anodic and cathodic process controls, as well as minimization of acidic or toxic mist in the tank house, are important goals for the future.

Hydrometallurgical process streams are by nature very complex. The complexity and harsh environments characteristic of process streams make online instrumentation difficult. Sophisticated online sensors and instrumentation should be based on the chemistry and operating parameters of the individual operating unit. The main requirements of sensors are robustness, reliability, and operability in the process environment. Sophisticated online sensors for critical variables of some hydrometallurgical processes could be optimized. The research challenges are the complexities of structuring a well coordinated control and optimization scheme. Although control mechanisms, mostly implemented with computers, have improved rapidly in recent years, the industry could benefit from accelerated research on sensors. Progress on sensors and controls could increase the efficiency and productivity of existing processing facilities.

All mineral processing technologies have an effect on the environment. When valuable metals are dissolved in aqueous media, other metals may dissolve as well. Some of these metals are regarded as toxic and hazardous and must be removed before effluents can be discharged to the environment. Therefore, the development of innovative, environmentally friendly technologies will be extremely important. Minimizing waste generation and using wastes to produce useful by-products while maintaining economic viability must be a goal for new technologies. Hydrometallurgy uses the most sophisticated aspects of kinetics, solution chemistry, and electrochemistry to realize its full value. Major advances in understanding fundamental chemistry and physical phenomena in processing will contribute to improved extraction and separation efficiencies, as well as minimize environmental impact.

Hydrometallurgy technology is not used extensively in the processing of industrial minerals, almost all of which are insoluble in normal, low-cost acidic and basic lixiviants. Leaching or other hydrometallurgical techniques are used only for industrial minerals to remove minor contaminants of a product or to prepare the mineral surface to meet market specifications.

A few industrial minerals are "surface treated" for special industry applications. To meet market specifications in the kaolin and clay industries products are often bleached with a sodium hydrosulfite or similar compound to improve whiteness or brightness, or ozone is added to oxidize organic substances. Other minerals, such as mica, are surface treated with organic compounds to achieve selected coatings on the mineral. Hydrometallurgical techniques are also used in the production of lithium, boron, soda ash, sulfur, and other unique minerals. However, these minerals require specialized chemical processes. In general, the industrial-minerals industry has very limited interest in hydrometallurgical research; its research needs are either specific to a single mineral or are required to minimize adverse environmental impacts. The application of hydrometallurgical techniques in the coal industry is even more limited. The coal industry may, however, be interested in the chemical removal of mercury or sulfur, or both.

Processing Technologies

Research and development would benefit mineral processing in the metal, coal, and industrial-mineral sectors in many ways. Every unit process—comminution, physical separation, and hydrometallurgy/chemical processing— could be improved by technical input ranging from a better understanding of fundamental principles to the development of new devices and the integration of entire systems.

Because comminution is so energy intensive, the industry would significantly benefit from technologies that improve the efficiency of comminution (e.g., new blasting and ore-handling schemes) and selectively liberate and size minerals. Fine-particle technologies, from improving production methods for the ultra-fine grinding of metals to minimizing the production of fine particles in coal preparation and measuring and controlling the properties of industrial mineral fine particles would be useful.

Technology needs in physical-separation processes are focused mainly on minimizing entrained water in disposable solids, devising improved magnetic and electrostatic separators, developing better ore-sorting methods, and investigating selective flocculation applications. Although flotation is a well developed technology, the mining industry would benefit from the availability of more versatile and economic flotation reagents, on-stream analyses, and new cell configurations.

The most important change in the mineral industry in the next 20 years could be the complete replacement of smelting by the hydrometallurgical processing of base metals. This development could be the continuation of a trend that began with dump leaching and heap leaching, solvent extraction/electrowinning, followed by bioleaching and pressure oxidation. Future research and development focused on innovative reactor designs and materials, sensors, modeling and simulation, high-pressure and biological basics, leaching, and separation reagents are likely to continue this trend. Like other components of mining, mineral processing could also benefit from the integration of unit processes for optimal performance, economic benefits, and environmental benefits.

Mining Techniques

CHAPTER 3

There are four main mining techniques used in the mining industry. These are underground mining, placer mining, in-situ mining and surface mining. These techniques are used depending on the type of mineral resources to be mined. The topics elaborated in this chapter will help in gaining a better perspective about these techniques of mining.

UNDERGROUND MINING

Underground mines are the alternative to surface mines. Surface mines excavate from the top down, a method that can become inefficient at depths greater than about 200 feet (60 meters). Undergrounds coal mines can drive 2,500 feet (750 meters) into the Earth and other types even deeper-uranium mines can reach 6,500 feet, or 2 kilometers. But those depths are extreme; most top (or bottom) out at about 1,000 feet (300 meters).

Mining has changed a lot from the images we have of the 19th century when men with shovels toted canaries to make sure the air underground was not toxic. Modern mines feature extensive ventilation and water-drainage systems, high-tech communication networks and increasingly computerized machines that reduce the number of humans required underground.

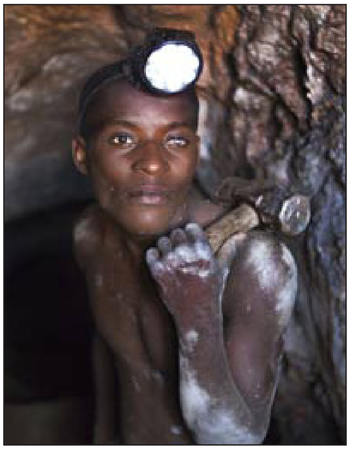
All underground mines have some crucial components in common: ventilation shafts to clear toxic fumes from drilling and blasting; escape routes; access shafts to lower workers and equipment; ore-transport tunnels; recovery shafts to carry excavated ore to the surface; and communication systems to send information back and forth between the surface and the depths.

No two mines are alike, though. Technology applications and basic decisions about design and mining method rest on considerations like the type of ore being mined, composition of surrounding rock, shape and orientation of the ore deposit, geologic features underground, and simple economics. And very early in the process, the determination of hard or soft.

Dangers in Underground Mining

The environmental toll of underground mining is significant. It includes air pollution, changes in water-flow patterns, chemical and gas seepage into water supplies and soil, inaccessible fires in abandoned mines, and dramatic changes in land composition that can make the area unusable after the mining operation is done.

Then there is the human toll. Most mining accidents gain little media attention, especially those involving few casualties or taking place in developing nations. In 2010, almost 2,500 Chinese miners died on the job, none of those attributed to "major accidents".



While mining has become much safer in developed countries, it is still very risky in parts of the third world. In Congo, Nsinku Zihindula works 24 hour shifts hammering at solid rock to find cassiterite ore. He was blinded in his left eye by flying rock.

That year was a terrible one for mining in general. In the United States, a mining catastrophe in West Virginia left 29 dead, the same number that died in an accident in New Zealand. In Chile, 33 miners were rescued in the dramatic incident recounted earlier, but another 45 died in other accidents that same year.

Many accidents occur when the mine props collapse due to earth tremors. Explosions, too, trigger casualties when ventilation systems fail to effectively remove exhaust from mining equipment, coal dust and natural underground gas leaks. Blasting can ignite those gases, leading to deaths from both the explosions themselves and the subsequent collapse of mine structures; a methane-gas explosion killed those 29 miners in West Virginia.

Long-term health problems are a serious job risk, as well. Continually breathing in mineral dust can cause lung diseases like pneumoconiosis or the dreaded black lung. Breathing in welding fumes, radon or mercury (often found in mines) also causes respiratory diseases. Hearing loss from noisy equipment and back injuries from lifting heavy loads are also common.

Most countries now have laws and regulations designed to address safety and environmental issues. Some require the mining company to return the mined area close to its original state. Others require mines to be inspected regularly to ensure they are safe. And new mining techniques have also decreased the death toll. In the U.S., the mining industry saw thousands of deaths from accidents each year in the early 1900s. This dropped to about a hundred per year in the 1990s, and just 35 in 2012. China had 7,000 mining deaths in 2002 but 2,500 in 2010.

While safety has definitely increased in developed countries, it still has a long way to go in some developing countries. But we may see a day when underground mines aren't some of the most frightening factories on Earth.

Underground Mining

Underground hard rock mining refers to various underground mining techniques used to excavate *hard* minerals, usually those containing metals such as ore containing gold, silver, iron, copper, zinc, nickel, tin and lead, but also involves using the same techniques for excavating ores of gems such as diamonds or rubies. 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.

- 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. Adits 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), installing support or/and reinforcement using shotcrete etceteras, drill face rock, load explosives, and blast explosives. To start the mining, the first step is to make the path to go down. Before the start of Decline all preplanning of Power facility, drilling arrangement, dewatering, ventilation and, muck withdrawal facilities are required.

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 the primary method of clearing hazardous gases and dust which are created from drilling and blasting activity (e.g., silica dust, NOx), diesel equipment (e.g., diesel particulate, carbon monoxide), or to protect against gases that are naturally emanating from the rock (e.g., radon gas). Ventilation is also used to manage underground temperatures for the workers. In deep, hot mines ventilation is used to cool the workplace; however, in very cold locations the air is heated to just above freezing before it enters the mine. Ventilation raises are typically used to transfer ventilation from surface to 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 polyester 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.

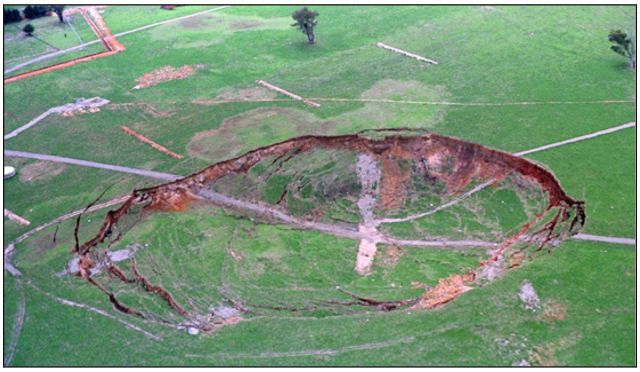
Local Ground Support

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

- Welded Wire Mesh is a metal screen with 10 cm × 10 cm (4 inch) openings. The mesh is held to the back using point anchor bolts or resin grouted rebar.
- Shotcrete is fibre reinforced spray on concrete which coats the back and ribs preventing smaller rocks from falling. Shotcrete thickness can be between 50 mm – 100 mm.
- Latex Membranes can be sprayed on the backs and ribs 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.

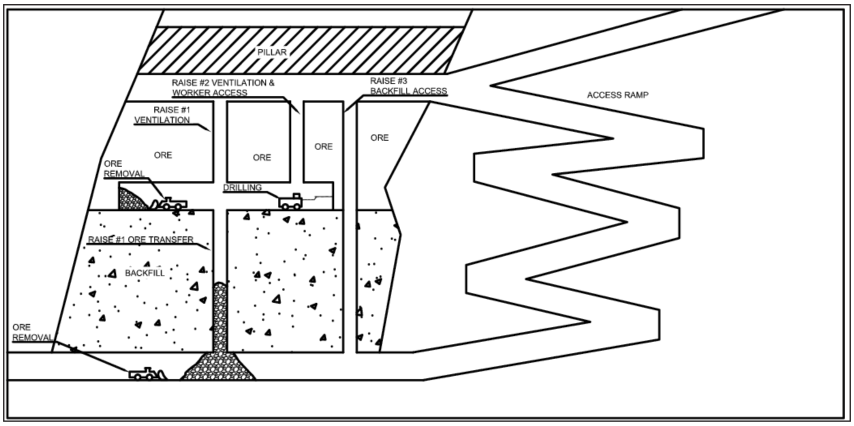
Using this method, mining is planned to extract rock from the stopes without filling the voids; this allows the wall rocks to cave in to the extracted stope after all the ore has been removed. The stope is then sealed to prevent access.

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

The mining method selected is determined by the size, shape, orientation and type of orebody to be mined. The orebody can be narrow vein such as a gold mine in the Witwatersrand, the orebody can be massive similar to the Olympic Dam mine, South Australia, or Cadia-Ridgeway Mine, New South Wales. The width or size of the orebody is determined by the grade as well as the distribution of the ore. The dip of the orebody also has an influence on the mining method for example a narrow horizontal vein orebody will be mined by room and pillar or a longwall method whereas a vertical narrow vein orebody will be mined by an open stoping or cut and fill method. Further consideration is needed for the strength of the ore as well as the surrounding rock. An orebody hosted in strong self-supporting rock may be mined by an open stoping method and an orebody hosted in poor rock may need to be mined by a cut and fill method where the void is continuously filled as the ore is removed.



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 the advantages of low ore loss and dilution.
- Drift and fill is similar to cut and fill, except that 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 stoping is a short-hole mining method which is suitable for steeply dipping ore-bodies. This 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 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.
- VRM/ VCR: Vertical retreat mining (VRM) also known as Vertical crater retreat (VCR) is a method where mine is divided in vertical zones with depth of about 50 meters using open stoping, bottom-up mining. Long-hole large-diameter holes are drilled vertically into the ore body from the top using in-the-hole (ITH) drills, and then blasting horizontal slices

of the ore body into an undercut. Ore blasted in retrieval taken in phase. This retrieval is done from bottom of the section developed. Last cleaning of ore is done through remote controlled LHD machines. A system of primary and secondary stopes is often used in VCR mining, where primary stopes are mined in the first stage and then backfilled with cemented fill to provide wall support for the blasting of successive stopes. Side chambers will be mined in pre-planned sequence after the fill has solidified.

Block 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 between the top of the haulage level and the bottom of 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.Where caving does continue, the ground surface may collapse into a surface depression such as those at the Climax and Henderson molybdenum mines in Colorado. Such a configuration is one of several to which miners apply the term "glory hole".

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 (or "muck") is removed from the stope (referred to as "mucked out" or "bogged") using center articulated vehicles (referred to as boggers or LHD (Load, Haul, Dump machine)). These pieces of equipment may operate using diesel engines or electric motors, and resemble a low-profile front end loader. LHD operated through electricity utilize trailing cables which are flexible and can be extended or retracted on a reel.

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, or via a rockbreaker. 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.

Underground Mining: Soft Rock

Underground soft rock mining is a group of underground mining techniques used to extract coal, oil shale, potash 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 of Underground Soft Rock Mining

- 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.
- Coal skimming – While no longer in general use, because of the massive amount of water needed and also as a result of the environmental damage caused by coal skimming, in the late 1930s DuPont developed a method that was much faster and less labour-intensive than previous methods to separate the lighter coal from the mining refuse (e.g. slate) called "coal skimming" or the "sink and float method".

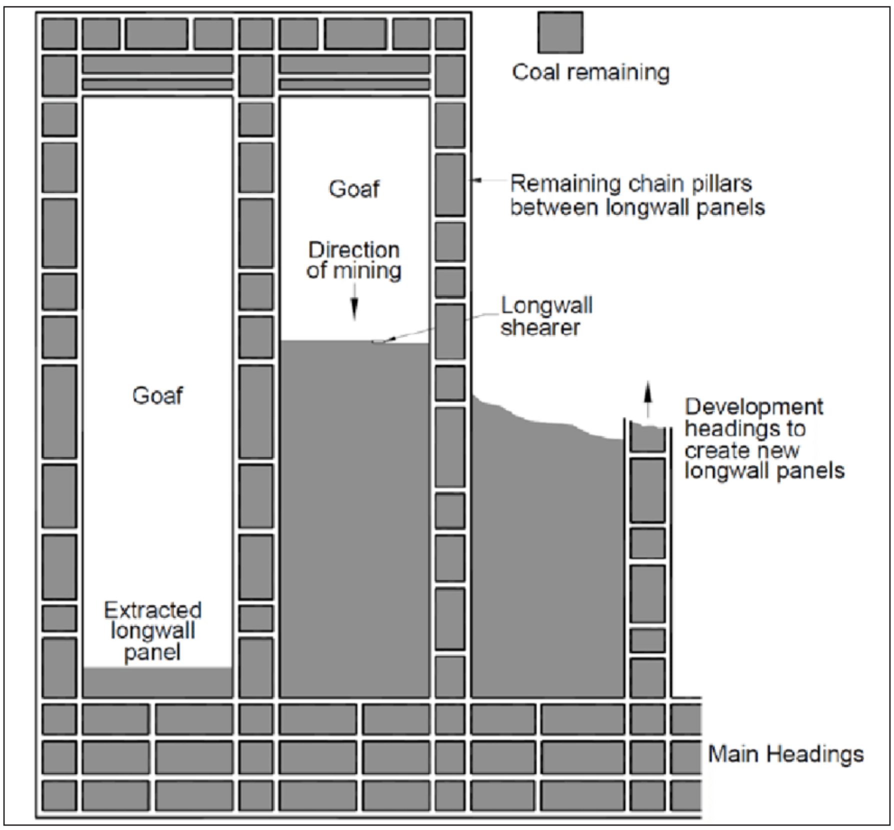
Mine Shorthand

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).

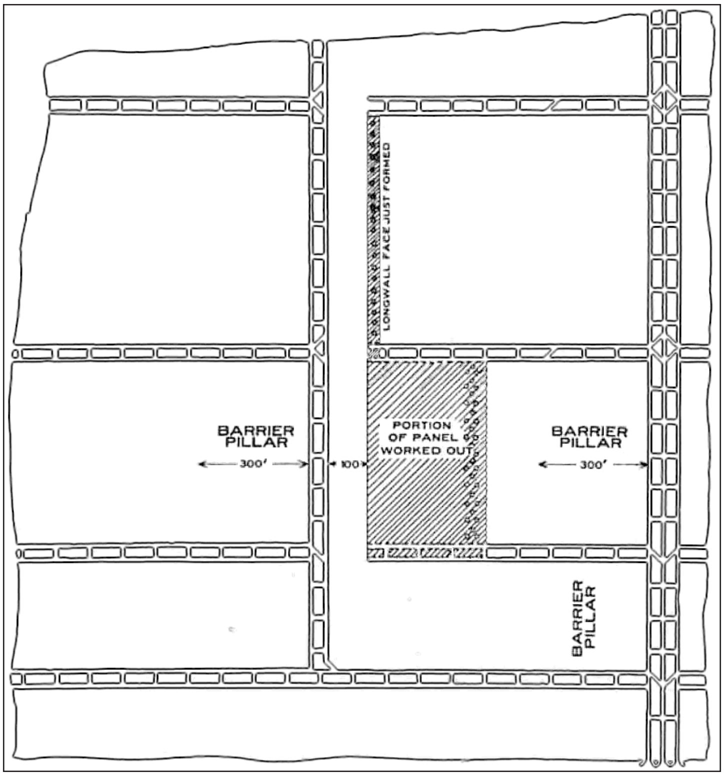
Longwall Mining

Longwall mining is a form of underground coal mining where a long wall of coal is mined in a single slice (typically 0.6–1.0 m thick). The longwall panel (the block of coal that is being mined) is typically 3–4 km long and 250–400 m wide.

The basic idea of longwall mining was developed in England in the late 17th century. Miners undercut the coal along the width of the coal face, removing coal as it fell, and used 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.



Plan of longwall.



West Virginia retreating longwall

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 was 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 on to 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 was the New Gladstone Mine near Centerville, Iowa, "one of the last advancing longwall mines in the United States". This longwall mine did not use a conveyor belt, instead relying 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

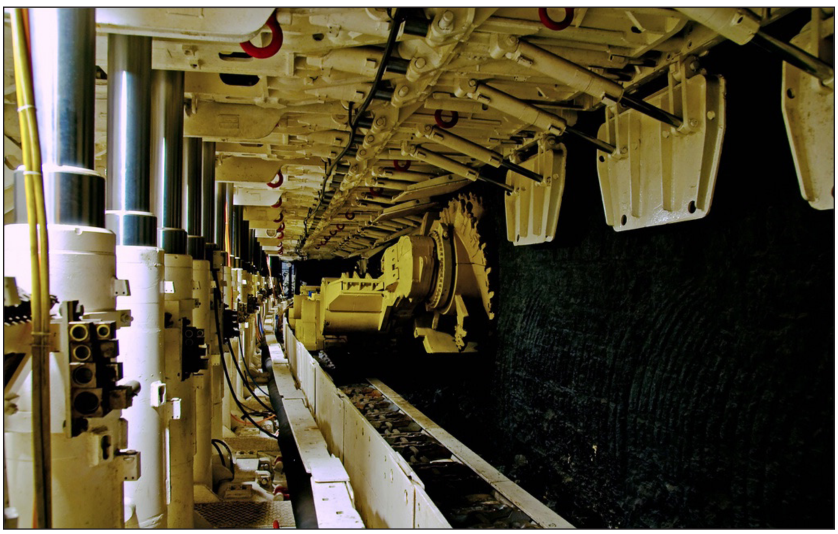
Gate roads are driven to the back of each panel before longwall mining begins. The gate road along one side of the block is called the maingate or headgate; the road on the other side is called the tailgate. Where the thickness of the coal allows, these gate roads have been previously developed by continuous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

Typically, intake (fresh) air travels up the main gate, across the face, and then down the tail gate, known as 'U' type ventilation. 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. Other ventilation methods can be used where intake air also passes the main gate and into a bleeder or back return road reducing gas emissions from the goaf on to the face, or intake air travels up the tail gate and across the face in the same direction as the face chain in a homotropal system.

To avoid spontaneous combustion of coal in the goaf area, gases may be allowed to build up behind seals so as to exclude oxygen from the sealed goaf area. Where a goaf may contain an explosive mixture of methane and oxygen, nitrogen injection/inertisation may be used to exclude oxygen or push the explosive mixture deep into the goaf where there are no probable ignition sources. Seals are required to be monitored each shift by a certified mine supervisor for damage and leaks of harmful gases.

Equipment

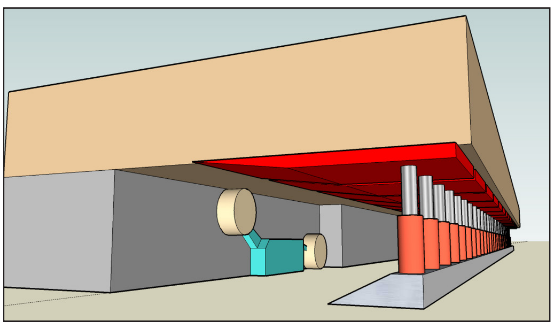


Hydraulic chocks.

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 on to which are mounted the shearer cutting drums which are fitted with 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 and through 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 specially developed for mining. Prior to the chainless haulage systems, haulage systems with chain were popular, where a heavy duty chain was run along 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 on to the AFC. The coal is removed from the coal face by a scraper chain conveyor to the main gate. Here it is loaded on to 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 on to 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 on to the collapsed goaf. This collapsing can lower surface height, causing problems such as changing the course of rivers and severely damaging 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.

Automation

Longwall mining has traditionally been a manual process in which alignment of the face equipment was done with string lines. Technologies have been developed which automates several aspects of the longwall mining operation, including a system that aligns the face of the retreating longwall panel perpendicularly to the gate-roads.

Briefly, Inertial navigation system outputs are used in a dead reckoning calculation to estimate the shearer positions. Optimal Kalman filters and smoothers can be applied to improve the dead reckoning estimates prior to repositioning the longwall equipment at the completion of each shear. Expectation-maximization algorithms can be used to estimate the unknown filter and smoother parameters for tracking the longwall shearer positions.

Compared to manual control of the mine equipment, the automated system yields improved production rates. In addition to productivity gains, automating longwall equipment leads to safety benefits. The coalface is a hazardous area because methane and carbon monoxide are present, while the area is hot and humid since water is sprayed over the face to minimize the likelihood of sparks occurring when the shearer picks strike rock. By automating manual processes, face workers can be removed from these hazardous areas.

Environmental Impacts

As with many mining techniques, it is important to consider the local and regional environmental impacts from longwall mining.

Subsidence

Longwall Mine Subsidence (LWMS) is an anthropogenic process that has many ecological and environmental impacts, particularly on soil health and water movement in a region where LWMS is heavily done. This is important to consider as some longwall mine sites can span lengths of several kilometers. That being said, hydrological flow systems, root systems from trees, and vegetative species can suffer from the amounts of soil being removed beneath them, and these stresses lead to surface erosion.

Abandoned mines are also an issue with regards to areas where residential development has moved in. Houses erected near to abandoned longwall mines face the threat of future damage from sinkholes and poor soil quality, even up to thirty years after mine abandonment.

Since longwall mining is namely, very long, it can effect areas of over 200 acres. Over these largest spans, it has been observed that longwall mines underlying mountain sides demonstrate more visible subsidence in mountain landscapes than it does for valley landscapes.

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”.

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

However, there are several mines, which were successfully mined with little to no measurable surface subsidence including mines under lakes, oceans, important water catchments and environmentally sensitive areas. Subsidence is minimised by increasing the block’s adjacent chain pillar widths, decreasing extracted block widths and heights, and by giving consideration to the depth of cover as well as competency and thickness of overlying strata.

Fracturing and Water Quality

Longwall mining can result in geological disruptions in the rockbed, and can in turn effect water movement and result in water moving away from the surface, through the mined area, and into the aquifer. A resulting loss in surface water can negatively impact riparian ecosystems.

On top of this, if there are present dams near to the longwall mining site, this could doubly impact the riparian ecosystems as it would have a reduced inflow rate as well as the loss to the underlying rock fracturing.

As of 2014, measures were taken by the Australian government to mitigate water impacts from longwall mining. Legislative assemblies have called for action to improve mine infrastructure to minimize disturbances.

As a result of bedrock cracking from mining beneath waters such as lakes or rivers, there have been groundwater losses of varying extents. Mines within a few hundred meters of the surface are susceptible to receiving great inputs of water from these bodies. Moreover, after mining interference disturbing the natural landscape near the mines, the natural water flow paths can be redirected which results in additional erosion across a stream or river bank. Additional mining in concentrated areas continuously move these water flow paths, which take years to return to their original states.

Ecosystem Impacts

Many ecosystems rely on the annual consistency of water inputs and outputs, and disturbing these patterns can result in unsustainable conditions for species reliant on water for species reproduction. Longwall mining can also result in localized water temperature change, stimulating algal bloom which can use up available oxygen required for other species health.

Longwall mining has limited available research on the impacts of nearby forests, however emerging satellite imagery studies have shown possible relations to drier surface soil near regions where longwall mining has recently occurred. In addition to drier soils, forest canopy moisture has been observed to be reduced.

Gas Emissions

Longwall mines have been observed to release methane gas, a common greenhouse gas into the environment, however the increase of a typical longwall mine face from 200 meters to 300 meters was not found to release significantly more methane. Methane emissions from closed longwall mines can continue for up to fifteen years, however it is possible to measure the volume of potential methane emissions based on water flow in the closed mines.

Room and Pillar Mining

Room and pillar mining is a mining system in which the mined material is extracted across a horizontal plane, creating horizontal arrays of rooms and pillars. To do this, "rooms" of ore are dug out while "pillars" of untouched material are left to support the roof overburden. Calculating the size, shape, and position of pillars is a complicated procedure, and is an area of active research. The technique is usually used for relatively flat-lying deposits, such as those that follow a particular stratum. Room and pillar mining can be advantageous because it reduces the risk of surface subsidence compared to other underground mining techniques. It is also advantageous because it can be mechanized, and is relatively simple. However, because significant portions of ore may have to be left behind, recovery and profits can be low. Room and pillar mining was one of the earliest methods used, although with significantly more man-power.

The room and pillar system is used in mining coal, gypsum, iron, and uranium ores, particularly when found as manto or blanket deposits, stone and aggregates, talc, soda ash and potash. It has been used worldwide from the Czech Republic to China to the US.

Process

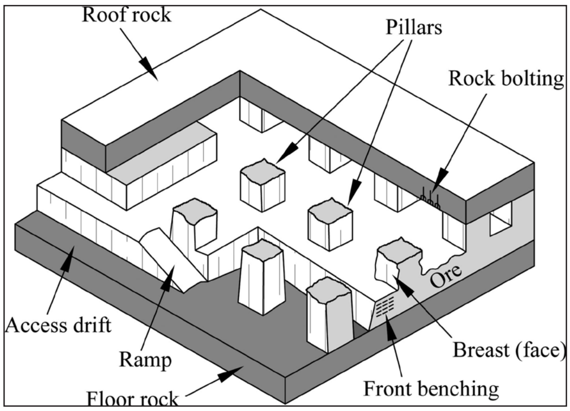
Stage 1—Exploration and Development

Planning for the development of room and pillar mines operates in much the same way as other mining methods, and begins with establishing ownership of the mine. Following this, the geology of the mine must be analysed, as this will determine factors like the lifespan of the mine, the production requirements, and the cost to develop and maintain.

Next, mine layout should be determined, as factors like ventilation, electrical power, and haulage of the ore must be considered in cost analysis. Due to the non-homogeneous nature of mineral deposits typically mined by room and pillar, mine layout must be mapped very carefully. It is desirable to keep the size and shape of rooms and pillars consistent, but some mines strayed from this formula due to lack of planning and deposit characteristics. Mine layout includes the size of rooms and pillars in the mines, but also includes factors like the number and type of entries, roof height, ventilation, and cut sequence.

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 will determine the pillar size.



General Layout or room and pillar mine.

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. To prevent this from happening, 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.

Stage 2—Mining

Traditionally, the act of mining consists of three steps. First, the deposit is "undercut", where a slot is cut as deep as possible along the bottom of a section of ore. This undercut allows for a manageable pile of rock in later stages. The second step was the drilling and blasting of the section. This creates a pile of ore that is loaded and hauled out of the mine—the final step of the mining process. More modern room and pillar mines use a more "continuous" method, that uses machinery to simultaneously grind off rock and move it to the surface.

Other processes, such as backfill, where discarded tailings are unloaded into mined-out areas, can be used, but are not required. Retreat mining (below) is an example of a process like this.

Retreat Mining

Retreat mining is often the final stage of room and pillar mining. Once a deposit has been exhausted using this method, the pillars that were left behind initially are removed, or "pulled", retreating back towards the mine's entrance. After the pillars are removed, the roof (or back) is allowed to collapse behind the mining area. Pillar removal must occur in a very precise order to reduce the risks to workers, owing to the high stresses placed on the remaining pillars by the abutment stresses of the caving ground.

Retreat mining is a particularly dangerous form of mining. According to the Mine Safety and Health Administration (MSHA), pillar recovery mining has been historically responsible for 25% of American coal mining deaths caused by failures of the roof or walls, even though it represents only 10% of the coal mining industry. Retreat mining cannot be used in areas where subsidence is not acceptable, reducing profitability.

Sometimes retreat mining is not used and the underground space is repurposed as climate controlled storage or office space instead.

Stage 3—Maintenance and Remediation

Many room and pillar mines have been abandoned for as long as 100 years. This drastically increases the risk of subsidence unless properly maintained, however, maintenance does not often occur.

Mention of "environmental stewardship" is often mentioned by mining companies, but no examples of how this is being done can be found.

Modern Use

Modern room and pillar mines can be few and far between. This is due to many factors, including the dangers to miners associated with subsidence, increasing use of other methods with more mechanization, and the decreasing cost of surface mining.

Advantages

Room and pillar mining is not particularly dependent on the depth of the deposit. At particularly deep depths, room and pillar mining can be more cost effective compared to strip mining due to the fact that significantly less overburden needs to be removed. This means that today, room and pillar mining is mostly used for high grade, but small, deep deposits.

Disadvantages

Due to a recovery rate as low as 40% in some cases, room and pillar mining cannot compete in terms of profitability with many modern, more mechanized types of mining such as Longwall or surface.

Abandoned mines have a tendency to collapse. In remote areas, collapses can be dangerous to wildlife, but subsidence of abandoned mines can be hazardous to infrastructure above and nearby.

Dredging

Underwater excavation is called dredging. Dredging is the process by which a water body is deepened. In simple terms, dredging means removal of material from the bottom of a water body.

Removal of sediment or other material from an aquatic area for the purpose of deepening the area, obtaining fill material, or maintaining existing structure is known as dredging. Dredging takes place to maintain the depth in existing ports, harbors and channels to provide ready and safe passage for commercial and recreational vessels. Dredging is done to create new or deeper access or berths for vessels. This means deepening and widening of channels and anchorages as well as the excavation of basins and marinas from areas of previously dry land.

Types of Dredging Vessel

- Suction: Suction dredges are essentially underwater vacuum cleaners. They are commonly used to pull material up from a stream bottom, run through a separation system to recover valuable minerals, and then redeposit the stream material back onto the bottom of the stream. Suction dredging is mostly done in a very dynamic environment, a natural stream or river.
- Trailer suction: A trailing suction hopper dredger is a large ocean going vessel. When the vessel starts dredging, the ship reduces its speed to some 1 to 2 knots and then lowers the suction pipes on both sides of the ship all the way to the seabed. Sand pumps transfer the sand dredged up by the suction head into the hold or hopper. The excess water is drained of via the overflow pipes. When the hopper is full, the ship sails to its destination, the reclamation area.
- Cutter suction: Cutter suction has to be towed to their work site by tugboats. Cutter suction dredgers are suitable to dredge hard soil or to pump o\up large amounts of sand in shallow water.
- Auger suction: Auger suction operates in the same manner as the cutter suction, except that the mechanical cutting tool is a rotating Archimedean screw placed at right angles to the suction pipe.
- Pneumatic dredge: Pneumatic dredgers work on the evacutor principle. A chamber with inlets for bed material is pumped out with the inlets closed. The inlets are then opened and water and material drawn in. The mixture is then pumped out and the cycle repeated. The unit is generally suspended from a crane on land or from a small pontoon or barge. The dredging action is intermittent and suitable only for easily flowing material.
- Air lift dredger: Air lift dredgers are very similar to the jet-lift dredgers but the medium for inducing water and material flow is high pressure air injected at the month of the suction pipe. As with jet-lift dredgers there are no moving parts in the flow system. Hard or other difficult to loosen materials cannot be dredged.

- Amphibious dredgers: Amphibious dredgers have the unusual feature of being able to work afloat or elevated clear of the water surface on legs. They can be equipped with grabs, buckets or a shovel installation.

Stoping

Stoping is the opening of large underground rooms, or stopes, by the excavation of ore.

Ore deposits vary greatly in their physical characteristics and with respect to the economic problems involved in their exploitation. Various methods of stoping have been devised for extracting the ore safely and economically from deposits of different types, and a nomenclature has been developed for use in referring to the various methods. Some of the terms are descriptive and require no interpretation, whereas others, particularly those applied to variations of the principal methods, are not. Among the variations are those bearing the names of mines at which they were devised or the names of the originators.

Basically, the stoping method or methods that can be applied to a given ore body depend on the requirements for support of the stope—the maximum area or span of back and walls that will be self-supporting during the removal of the ore; the nature, size, and interval between supports required to maintain the backs and the walls of the excavations; and the requirements for permanently supporting the overlying and surrounding country rocks and overburden to prevent their movement and subsidence. Variations of the principal methods of stoping may be based upon the direction or angle of working, sequence of operations, or methods of handling the broken ore.

Stoping Methods

A classification of stoping methods based upon method of support was adopted by the Mining Division of the Bureau of Mines in 1928. This classification has been used ever since as a basis for describing methods in its publications dealing with mining methods and costs and is as follows:

Classification of Stoping Methods

Stopes Naturally Supported

- Open stoping:
    - Open stopes in small ore bodies.
    - Sublevel stoping.
- Open stopes with pillar supports:
    - Casual pillars.
    - Room (or stope) and pillar (regular arrangement).

Stopes Artificially Supported

- Shrinkage stoping:
    - With pillars.

  - Without pillars.
  - With subsequent waste filling.
- Cut-and-fill stoping.
- Stulled stopes in narrow veins.
- Square-set stoping.

Caved Stopes

- Caving (ore broken by induced caving):
  - Block caving; including caving to main levels and caving to chutes or branched raises.
  - Sublevel caving.
- Top slicing (mining under a mat that, together with caved capping, follows the mining downward in successive stages).

Combinations of Supported and Caved Stopes

As shrinkage stoping with pillar caving, cut-and-fill stoping with top slicing of pillars, etc.

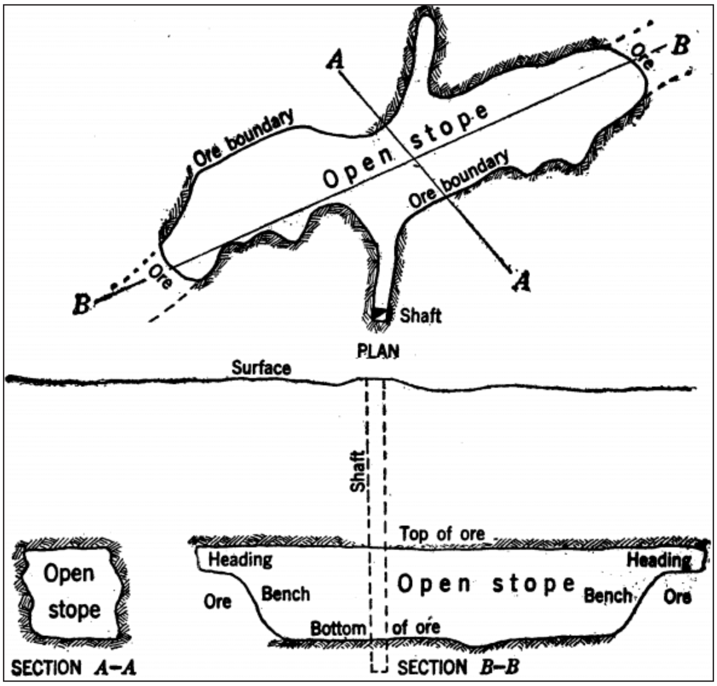
Forced caving (a method employed at several very large mines and therefore important) has heretofore been classed by the Bureau as a variation of shrinkage stoping. In reality it is intermediate between shrinkage (supported) stopes and caved stopes, as far as support is concerned. The ore is broken by large blasts, and considerable caving often follows the blasts, yet the operation is fundamentally quite different from natural caving induced by undercutting, as in block-caving or sublevel-caving systems.

Stopes Naturally Supported Open Stopes

Stopes naturally supported are those in which no regular artificial method of support is employed, although occasional props, cribs, or stulls may be used to hold local patches of insecure ground. The walls and roof are self-supporting. The simplest form of open stope is that in which the entire ore body is removed from wall to wall without leaving any pillars. It is applicable to relatively small ore bodies, as there is a limit to the length of unsupported span that will stand without support even in the firmest and strongest rocks. In sublevel stoping the ore is excavated in open stopes, retreating from one end of the stope toward an entrance at the other end on each of a series of sub-levels that are usually 20 to 25 feet apart vertically but may be 40 feet or more apart.

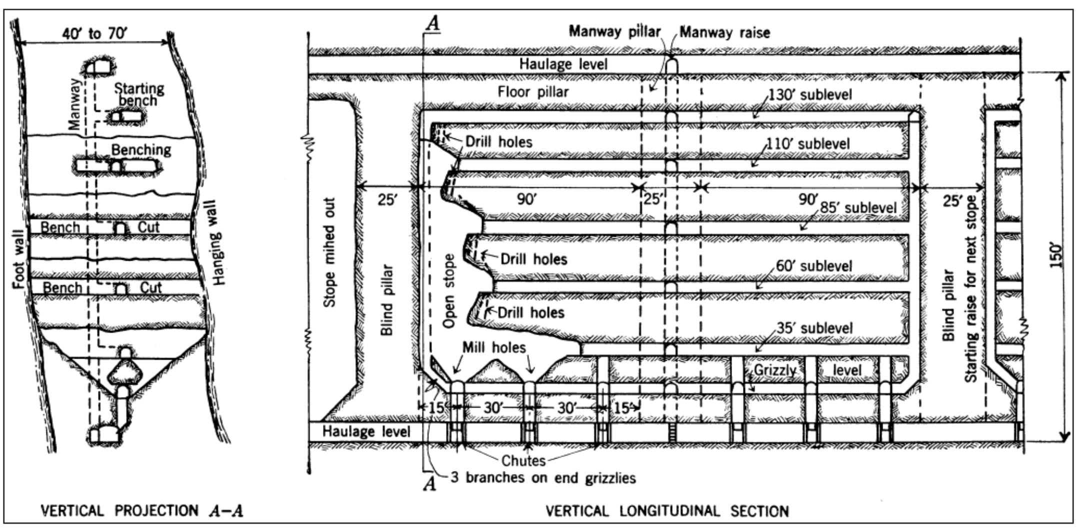
In open stopes with pillar support, the length of unsupported span is reduced by leaving pillars of ore. These pillars may be of the irregular or “casual” type, their position and size being determined by localized ground conditions, or may be regular in size and arrangement, conforming to a pre-determined pattern.

Open stoping is applicable to deposits of strong, firm ore having strong, firm walls. In the narrower deposits (30 to 50 feet wide) the ore often can be mined the full width in one operation without the use of pillars. In wide deposits it usually becomes necessary to leave solid pillars to reduce the length of unsupported span and thus prevent the failure of back or walls. When "casual" pillars are used, it frequently is possible to leave low-grade ore within the ore body as pillars, at least in part, and thus make possible more complete recovery of the higher-grade ore. In general, casual pillars are used in the firmest type of ground and in deposits of variable thickness where their size and spacing can be proportioned to suit the conditions of the back and the height of the ore. Often a somewhat higher percentage of the ore is recovered than where a regular room-and-pillar system is employed.



Open stoping without pillars In small ore bodies.

A regular room-and-pillar pattern is applied chiefly to relatively thin, regular, flat-lying beds, where the roof must be definitely and permanently supported, in other words, where it is not safe to rely on personal judgment of the foreman or boss as to the amount of pillar support required at individual local points.



Typical sublevel stoping.

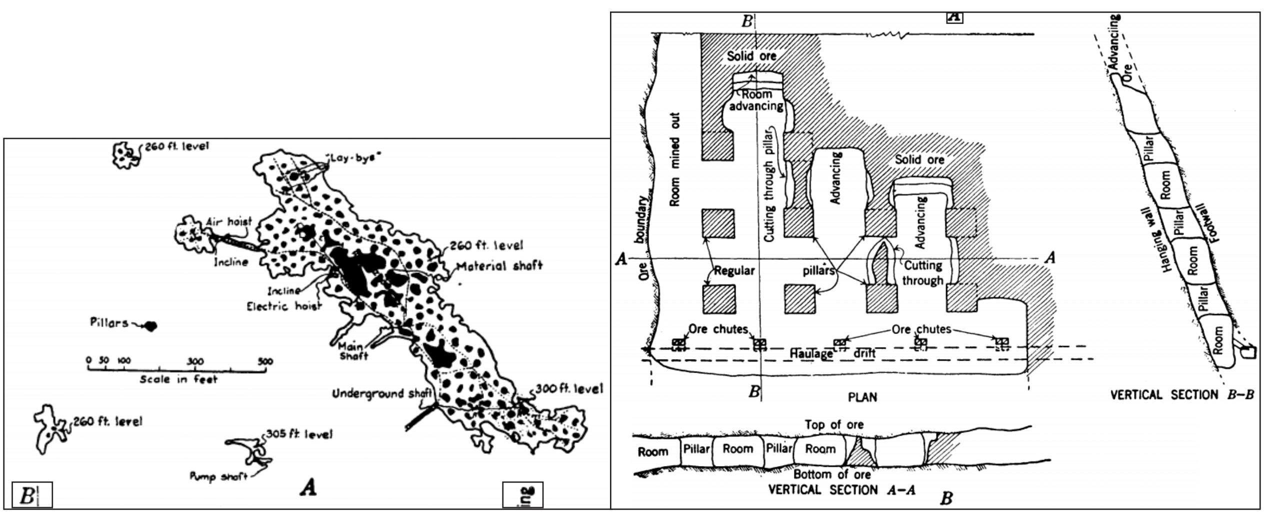
In the sublevel variation of open stoping, the stope faces retreat from the end of the ore body or stope limit longitudinally or (where the stopes are run across the lode) from one of its walls. The miners are always working under solid backs and have a safe avenue of retreat through the subdrifts to the manway raises. Slabbing of roof or walls at the worked-out end of the stope does not endanger the miners and, if the stope is worked back rapidly, usually will not cause serious dilution of the broken ore with waste. This system is applicable to wide, thick, irregular masses of ore that stand well without artificial support and that have firm walls and to thick, tabular ore deposits that dip 50° or more (and, by using scrapers for removing broken ore, to flatter deposits). It may be used successfully in weaker ground than could be worked safely by other open-stope systems, as the miners are always protected by solid ground overhead. Large open stopes are mined by this method where the ore is so soft that it can be drilled with auger steel, and the method can be applied where the ore is too weak to be safely minable by shrinkage stoping.

Stopes Artificially Supported

Shrinkage Stoping

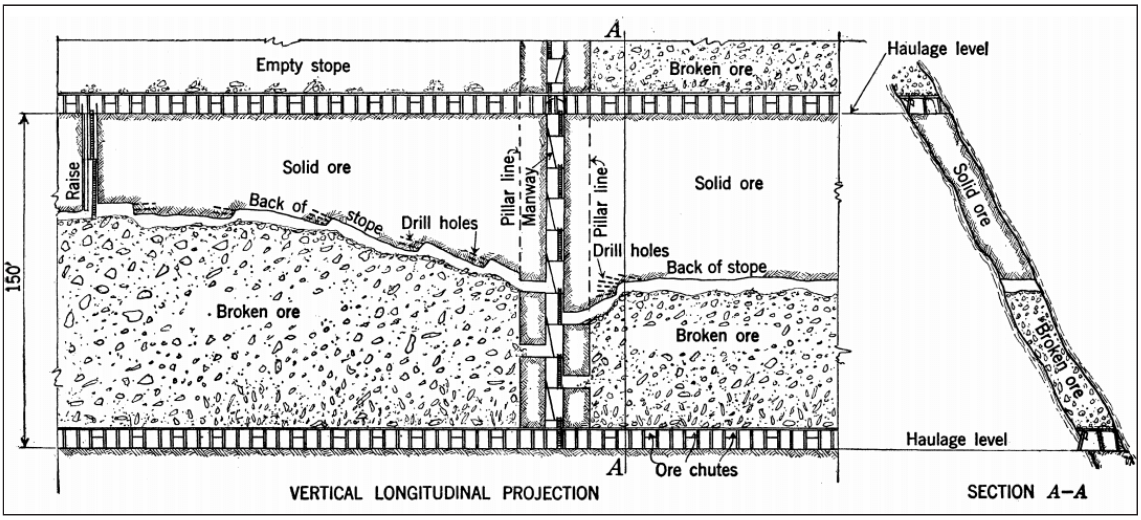
In shrinkage stoping the ore is mined in successive flat or inclined slices, working upward from the level or the bottom of the block of ore. After each slice or cut, enough broken ore is drawn off from below to provide a working space between the top of the pile of broken ore and the back of the stope. Usually about 35 to 40 percent of the ore will be drawn off during active mining in the stope. The remaining ore serves as a floor upon which to work in drilling the back for the succeeding cuts and also provides some support of a temporary nature to the stope walls. For this reason shrinkage stopes are considered to be a form of artificially supported stope, although undoubtedly there are good reasons why some consider them to be open stopes.

In narrow veins or lodes and those of moderate width, the stopes usually are run longitudinally and are mined from wall to wall without leaving pillars, except locally, to support bad ground or where the ore is too low-grade to be mined profitably. In wide ore, to reduce the unsupported span of the stope back, it may be necessary to mine the ore in a series of transverse stopes between intervening pillars of ore. The stopes then end against the walls of the vein and the sides are vertical pillars of ore.

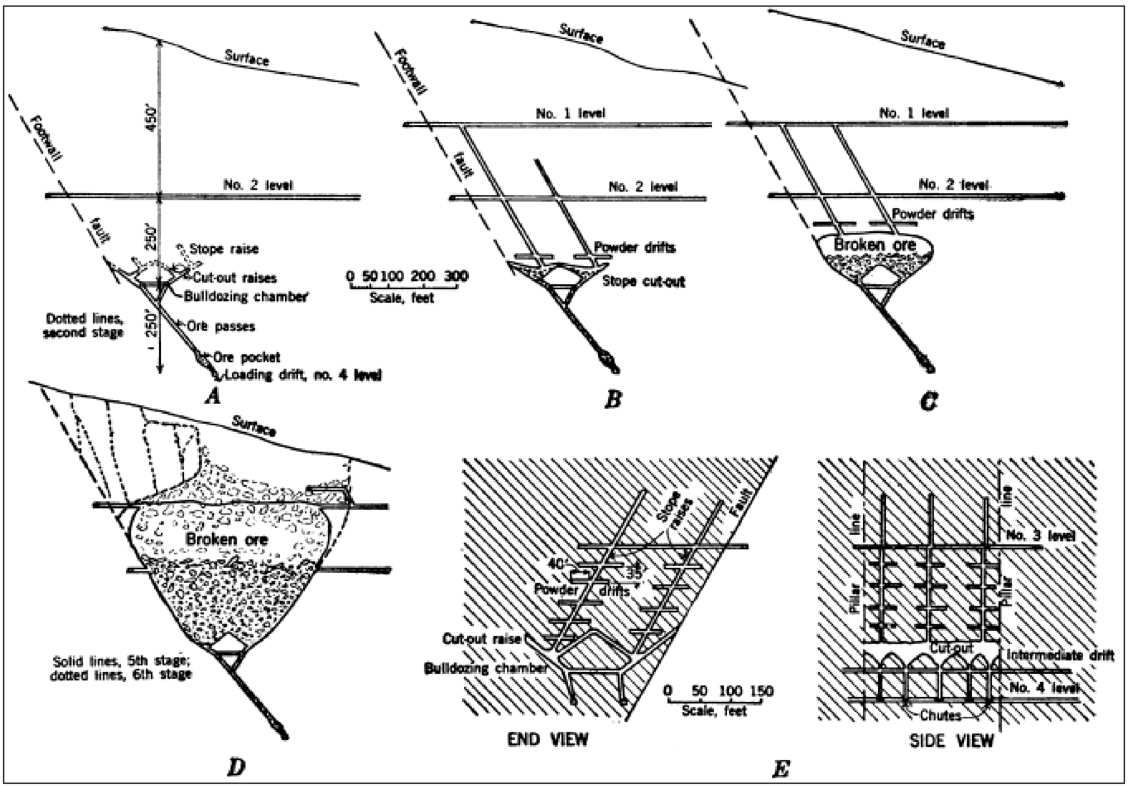


A. Open stoping with casual pillars, B. Open stoping with regular pillars.

After active mining has been completed to the level above or to the floor pillar, the rest of the broken ore is drawn off from below, leaving the stope empty. It may be filled with waste later to prevent general movement and subsidence or to permit mining of pillars left between stopes during the first mining.



Example of shrinkage stoping on drift sets.



Sequence of stope development and stoping operation, Alaska –juneau mine, Alaska. A. First and Second Stages, B. Third stage, C. Fourth stage, D. Fifth and sixth stages, E. Fully development stope, north ore body, ready for powder–drift blasting.

Stulls may be employed during active mining to support local patches of insecure ground. Where the width is not too great, they often are employed when the stope is being emptied to protect the miners from falls of loose ground while cleaning down broken ore that has hung on the footwall and recovering ore that was left in the walls during stoping. Stulls 30 to 40 feet long have been used for this purpose, but the safety and adequacy of this type of support are questionable for widths as great as this. While stuffing from the top down during drawing of the stope, the miners stand on the top of broken ore while placing the timbers to support patches of insecure wall rock. After the ground has been secured thus, drawing and cleaning down are resumed.

Shrinkage stoping is applicable to bodies of strong, firm ore enclosed between firm walls that will not slab or slough off to any great extent after standing for a considerable time. The method is applied most frequently to relatively thin, tabular deposits dipping at angles greater than 50°, in which few waste inclusions occur and which have fairly regular walls. By carrying transverse stopes separated by pillars, it may also be applied to wide, tabular deposits.

The "forced-caving system" may be considered a variation of this method and is employed for the non-selective mining of large, thick masses of ore at the Alaska-Juneau, Beatson, Climax Molybdenum, Britannia, and other mines. Figure depicts the mining cycle used at Alaska-Juneau and figure that at Beatson. In both cases the ore is broken down by large blasts into stopes that are kept partly full of broken ore (as in shrinkage stoping). The large blasts break ore directly into the stopes and have the further effect of shattering additional ore, part of which then caves. At both mines the miners come down through raises from the level above. At Juneau, small powder drifts (sometimes termed "coyote" drifts) are driven from the raises. Charges averaging 4,000 pounds of 40-percent dynamite are placed in the powder drifts segregated in two piles 35 or 40 feet apart. Three to five such piles make up the usual blast. At Beatson, however, a similar result is accomplished by drilling, from enlargements in the raises, a large number of long holes, which are loaded and fired in one blast.

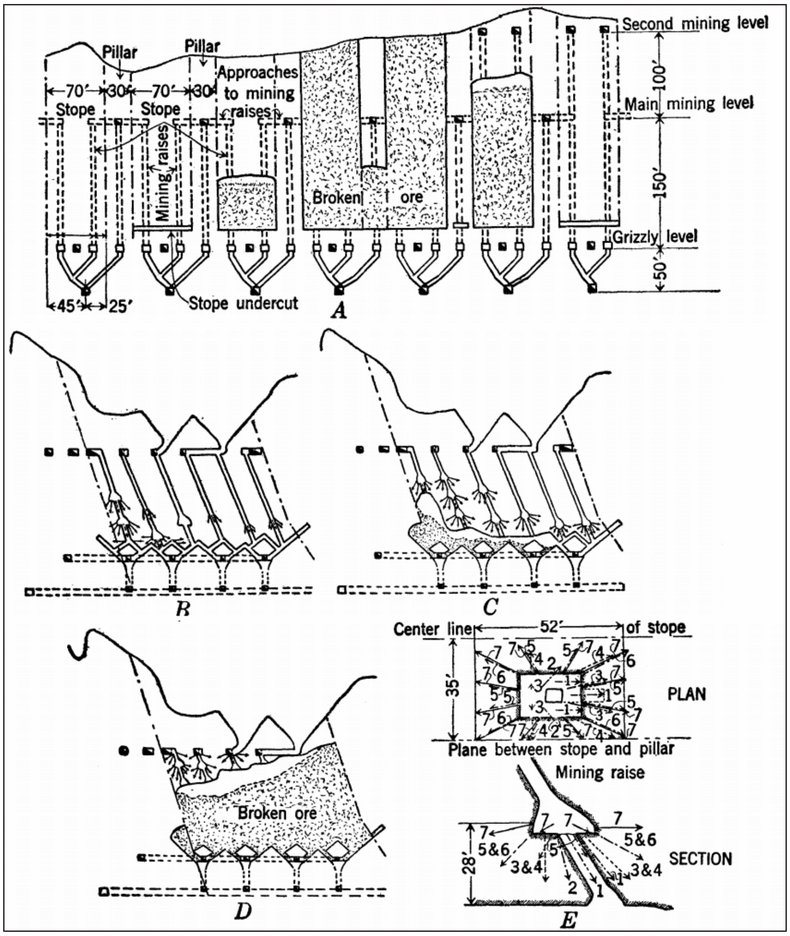
For the successful use of the ordinary shrinkage-stoping method the ore must be strong and stand well, as the back of the stope under which the men must work is unsupported except for occasional props or stulls that may be set to hold local patches of loose ground. Although the broken ore left in the stope affords support to the walls until drawing begins, unless the walls are firm they may slough or even collapse during and after drawing and cause serious dilution of the ore.

Cut and Fill Stoping

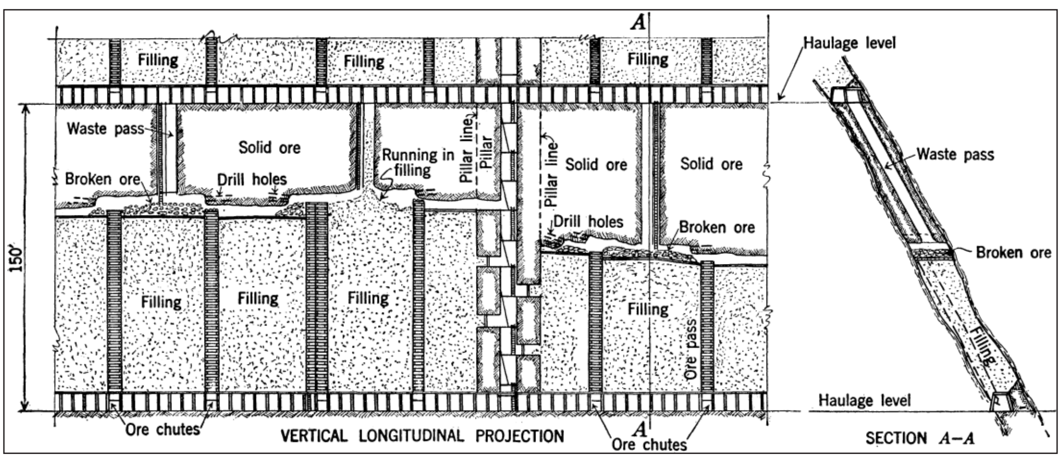
In cut-and-fill stoping the ore is excavated by successive flat or inclined cuts or slices, working upward from the level as in shrinkage stoping; but after each cut, all the broken-ore is removed and waste rock, sand, or other filling material is run in and the excavation filled to within a few feet of the back, thus providing permanent support to the walls and a working floor for the next cut. The term "cut-and-fill" implies a definite and characteristic sequence of operations:

- Breaking a slice of ore from the stope back,
- Removing the broken ore,
- Introducing filling; then breaking again, and so on.

Mining system employed at Beatson mine, Latouche, Alaska. A. Ideal vertical section parallet to strike showing levels, branch raises, stopes, and and pillars, B. Section of 202 stope, preparation completed and stope undercut, C. Section of 202 stope after 2 months' mining, D. Same stope after 6 months'mining, E. Plan and section of typical long round in raise bench in hard ground.

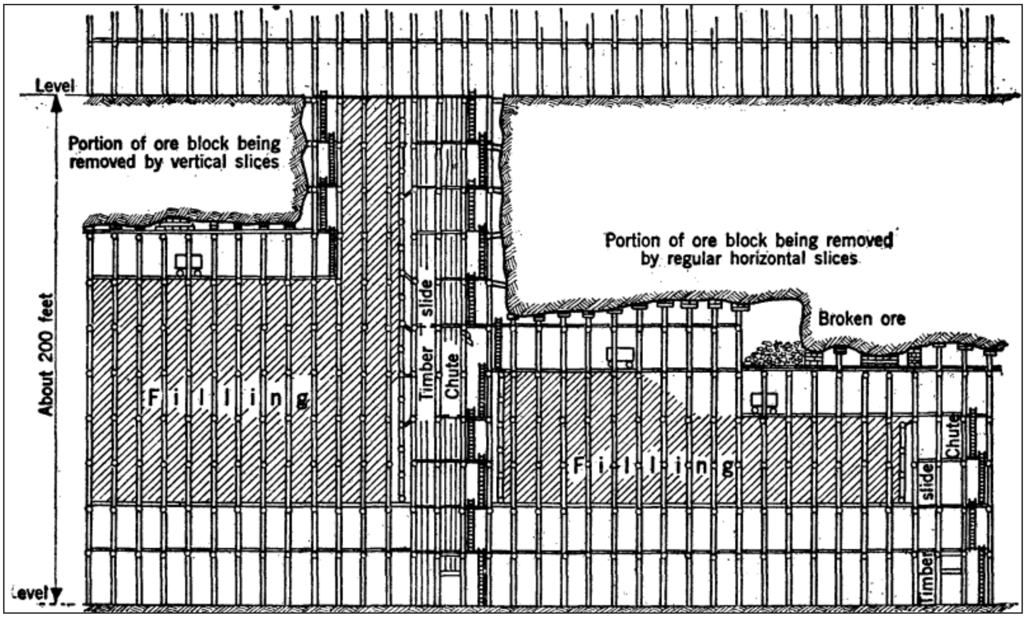


The filling is employed primarily to support the walls of the stope and may consist of waste sorted from the ore in the stope, waste blasted from the walls of the lode adjacent to the stope, waste rock from development work or special waste stopes, rock from surface quarries or glory holes, sand and gravel, mill tailings, or slag. Stulls, props, and cribs may be erected on top of the fill to support local patches of loose or insecure ground.



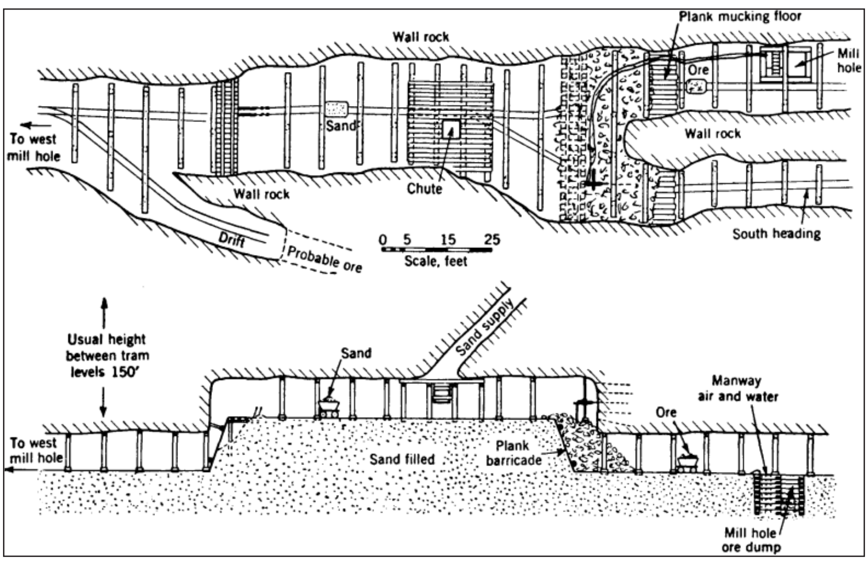
Example of horizontal cut and fill stoping.

Cut-and-fill stoping is applicable to the mining of firm ore enclosed within walls, one or both of which are weak and heavy. The deposits may be tabular in form, dipping at angles steeper than the angle of repose of the broken ore (or flatter, if scrapers are employed for moving the ore in the ore passes), or to wide, thick ore bodies or masses. Generally speaking, it is suitable for mining deposits too irregular for shrinkage stoping and deposits in which shrinkage could be employed were it not for the fact that the walls are too weak.



Stringer set cut and fill stoping.

The method is also used for mining high-grade veins that are less than minimum practicable stoping width and therefore require the breaking of wall rock to provide working room. When the ore and walls are broken separately, the method is termed "resuing" or "stripping." In resuing, one wall may be drilled and shot down first and the rock left in the stope for fill, after which the vein is "stripped" from the side of the resulting excavation; or the vein may be shot down first, the broken ore removed, and the wall then stripped to provide working room and filling for the stope.

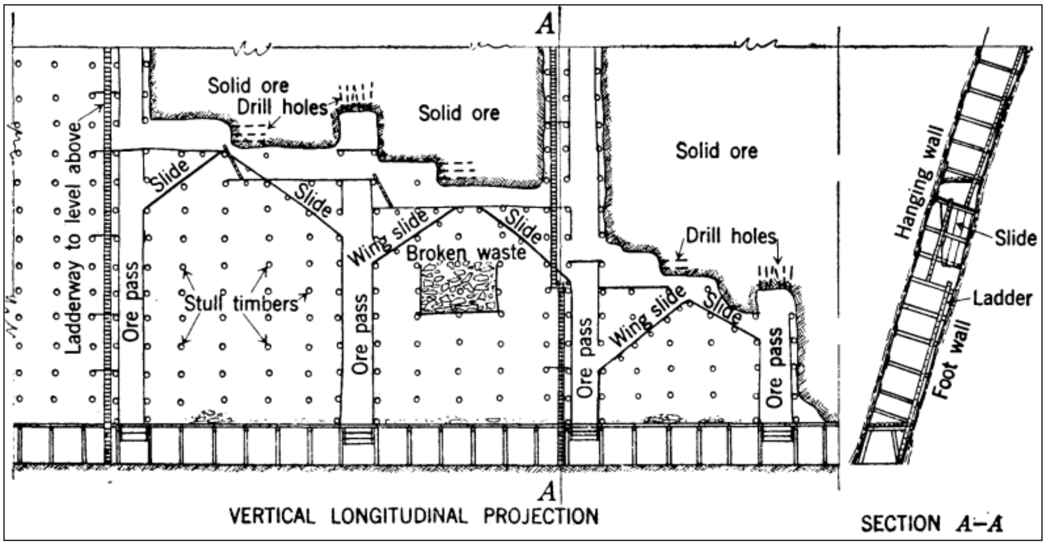


Horizontal cut and fill stoping with temporary timber support for back.

Since the filling material does not directly support the stope back, but only the walls, the ore itself must stand well for a short time, at least so as to apply this method without the use of timber for auxiliary support. In veins of moderate width a stringer-set cut-and-fill variation of the general method is employed sometimes where the walls are heavy; the ore itself is fairly strong, but the ground is not so heavy as to require the use of square-set-and-fill stoping.

In fairly wide ore the back may tend to slab off, and temporary stringers supported by posts resting on the fill may be employed to afford back and wall support above the filling.

If both the walls and the ore itself are heavy and weak, square-set stoping or a caved-stope method would be indicated rather than cut-and-fill stoping.



Example of stull stoping in narrow vein.

Stulled Stopes in Narrow Veins

Casual stubs may be used locally in open stopes or in other forms of supported stopes, as already indicated, and in such instances are only incidental to the mining method. In some narrow or moderately wide lodes, however, a regular arrangement of stub timbers is employed to support the immediate hanging wall and constitutes a rather distinct method of mining. It is especially applicable where the ore is separated from the solid or true wall (or walls) by one to a few feet of barren rock that loosens and slabs off after being exposed for a short time unless held in place by stulls—in other words, where only nominal rather than great weight develops. Where a weak hanging wall extends back a considerable distance from the vein, the weight usually will be too great to be held in this manner and cut-and-fill or square-set stoping must be employed. Figure shows a stull-supported stope.

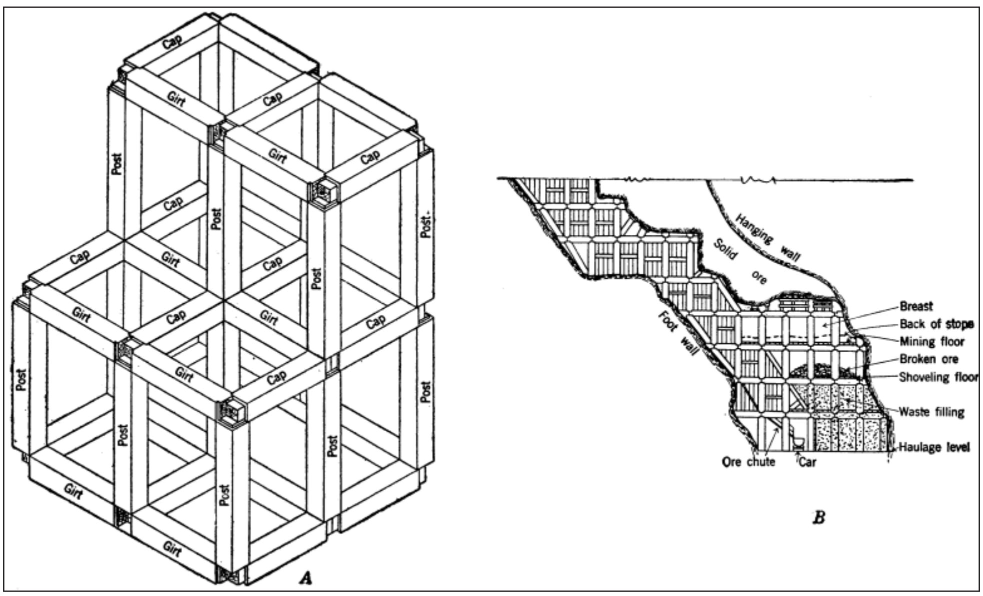
Square-set Stoping

In square-set stopes the walls and back of the excavation are supported by regular framed timbers forming a skeleton enclosing a series of contiguous, hollow, rectangular prisms in the space previously occupied by the ore and providing continuous lines of support in three directions at right angles to each other.

The ore is excavated in small rectangular blocks just large enough to provide room for standing a set of timber. The essential timbers comprising a standard square set are termed, respectively, "posts," "caps," and "girts" (or "ties"). The posts are the upright members and caps and girts are horizontal members. The ends of each member are framed to give each a bearing against the other two members at the corners where they meet.

Ordinarily the stopes are mined in floors or horizontal panels, one above the other, and the sets of each floor are framed into the sets of the preceding floor. Sometimes, however, the sets are mined in a series of vertical or inclined panels. Square-set stoping usually is accompanied by filling, and often in heavy ground the sets are filled with waste promptly after they are installed, leaving only a small volume of unfilled stope at any time. It has come to be accepted quite generally that unless the ground is heavy enough to require filling for permanent support, the expense of square-setting is not warranted and some other method should be employed.

Square-setting is adapted to mining regular or irregular ore bodies, commonly on dips steeper than about 45°, where the ore and walls are too weak to stand even over short spans for more than a brief time, and where caving and subsidence of overlying rocks must be prevented. From the viewpoint of support alone, both temporary and permanent, the method is applicable to conditions no other method has yet been devised to meet. Where the overlying strata may be allowed to cave, and where the loss of some ore or some dilution with waste would not be a serious drawback, caved-stope methods are adaptable to as bad or worse ground conditions and cost less.



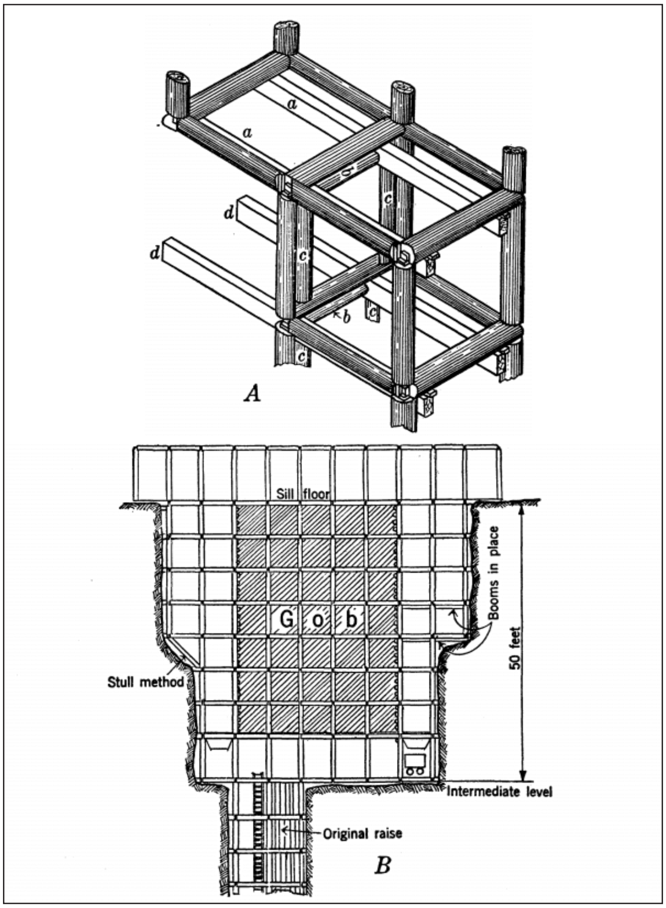
Square set stoping. A. Square set timbering, B. Vertical transverse section through typical square set stope.

Square-set stoping often is used in combination with other methods for extracting pillars between or over filled stopes. It is also employed as an auxiliary method, as for supporting the sill and first floors of some cut-and-fill or shrinkage stopes.

The stopes usually are worked upward from the level either in horizontal or inclined floors or in successive vertical panels, one along-side the other, but in some instances, especially in loose, running ground, may be worked from the top downward.

Caved Stopes Mining Method

When caved stope methods are employed, breaks to and subsidence of the surface will occur ultimately if caving is continued over an area wide and thick enough in relation to the depth of cover. Hence, caved-stope methods are applicable only where there is no objection to caving the overlying strata or to surface subsidence.

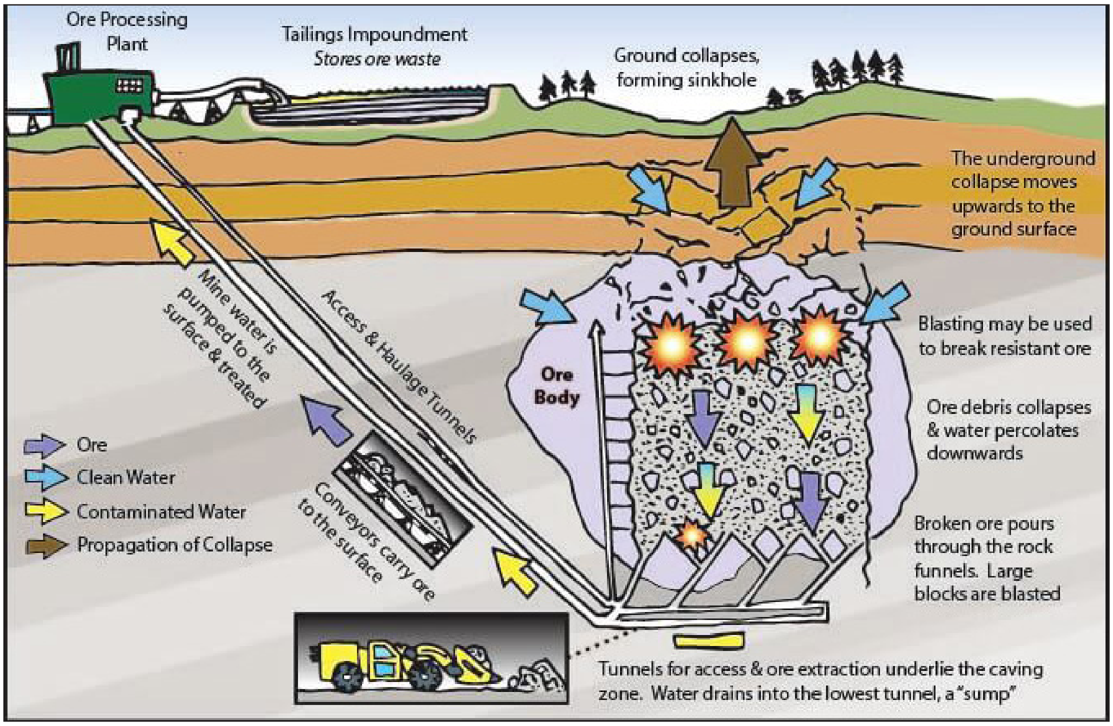


Understand square set stoping, Black Rock mine, Mont. A,Method of using booms.
B, General section through stope.

Caved stopes are of two distinct types: In the first, the ore is broken by caving induced by undercutting a block of the ore and isolating it from or weakening its connection to the surrounding ore or walls; in the second, the ore itself is broken by conventional drilling and blasting methods in a series of horizontal or inclined slices, and the capping is allowed to cave into and fill the space occupied previously by the ore. The first type embraces the caving methods of mining, whereas the second comprises the top-slicing method.

Mining by Block Caving Mining

In block caving a thick block of ore is partly cut off from surrounding blocks or the walls of the ore body by a series of drifts, one above the other, or by boundary shrinkage stopes; it is then undercut by removing a slice of ore or a series of slices separated by small pillars underneath the block. The isolated, unsupported block of ore breaks and caves under its own weight. The ore so broken is drawn off from below; and, as the caved mass moves downward owing to continued drawing from below, it is broken further by pressure and attrition. The capping finally caves also and follows the column of broken ore downward.



In the earliest applications of this method the block was undercut on or immediately above the haulage level, and the caved ore was shoveled into cars in drifts driven under or spiled through the cave. This system entailed the driving and maintenance of a large number of drifts to recover the ore and has been superseded by caving to a system of chutes or branched raises extending from haulage drifts at some distance below the bottom of the undercut and with an intermediate grizzly level on which chunks of ore too large to pass through the grizzlies are broken by sledging and bulldozing. With this system, hand shoveling is virtually eliminated.

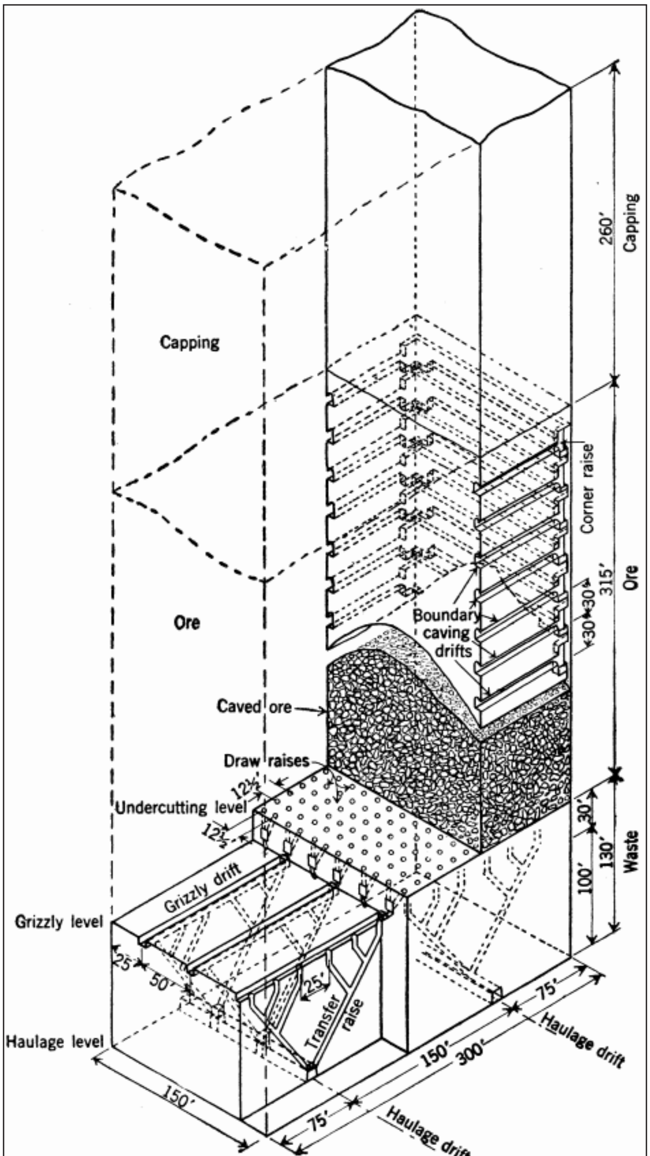
Natural forces are utilized to the highest degree possible for breaking the ore, transferring the broken ore to the haulage levels, and filling the mined-out areas.

The method is a nonselective one, and lean sections of the ore body and even barren horses of waste are broken up and drawn with the ore. It is applicable to the wholesale mining of masses of ore large in three dimensions that will cave readily when support is removed by under-cutting, and which, after caving, will break up fine enough to pass through the extraction raises as the caved mass is drawn downward. This condition occurs when the ore is friable enough to break up readily or the ore body is traversed by a multiplicity of closely spaced seams, fracture and joint planes, or invisible planes of weakness that strike and dip in various directions.

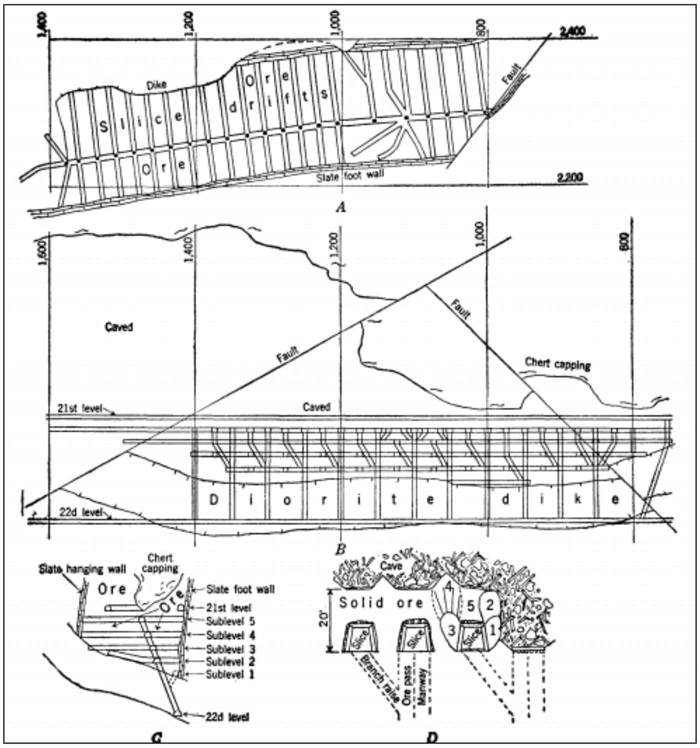
Block caving is employed principally for mining low-grade ores where the inevitable loss of some ore and some dilution with capping and wall rock are permissible and where mining must be done on a large scale and at a lower cost than can be obtained by the use of supported-stope or other selective mining methods.

Mining by Sublevel Caving

In sublevel caving, relatively thin blocks of ore are caused to cave by successively undermining small panels. The ore body is developed by a series of sublevels usually spaced at vertical intervals of 18 to 25 or 30 feet (more recently, intervals of 50 feet or more have been used). Figures shows complete development of a block or panel. Customarily all of this work is not done before stoping begins, but usually only one or, at most, two sublevels are opened at a time, beginning at the top of the ore. Sublevels are developed by first connecting the tops of the raises with a longitudinal drift from which timbered slice drifts are driven right and left to the ore boundaries or to the limits of the panel. Usually, alternate drifts are driven first, and caving back from them is begun and continued toward the raises while the intermediate slices are being driven. The bottoms of the slices or crossdrifts are covered with poles or plank, laid on cross timbers to form a good floor over which to scrape and to hold back the gob when caving the next sublevel below:

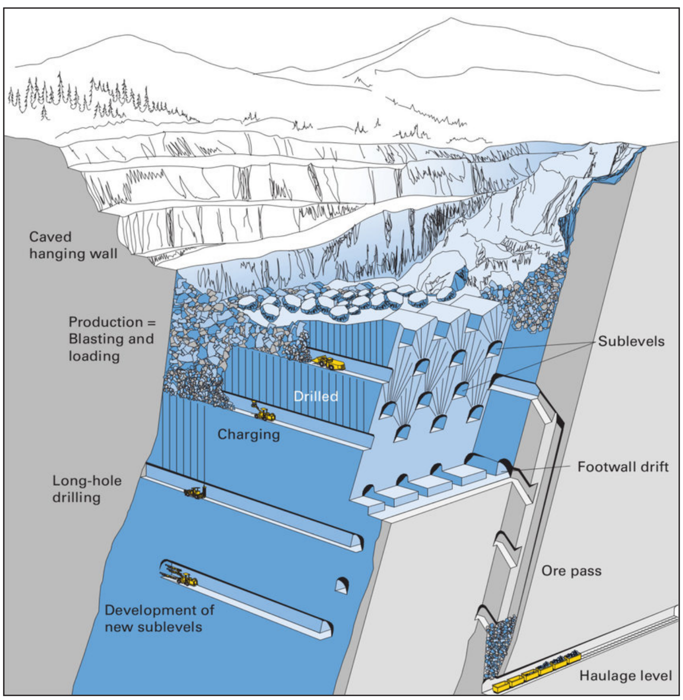


Example of block caving.



Example of sublevel caving. A. B. and C. Development of ore body for caving, D. Cross section showing details of caving back, cuts blasted in order shown.

Caving is begun at the ends of the slices by blasting cuts, as shown in figure and is continued in successive stages, working out toward the raises. The broken ore is dragged by power scrapers into the raises.



Sublevel caving, large pillar method.

More recent practice in at least one mine is to cave back two adjacent slices at a time, using a 50-foot instead of a 25-foot sublevel interval and an entrance manway to the cave, as shown in figure. When the top sublevel or a section of it has been mined out work is begun on the next sublevel below:

Sublevel caving may be employed for mining smaller deposits than would be suited to block caving, but is also applicable to large ore bodies and to soft ores, which will stand fairly well for a brief time over short spans but will cave over wider openings. The capping (and later the gob) must be of such character that it will hang up long enough to permit removal of the caved ore from beneath it in safety and without serious attendant dilution with waste. Schaus has summarized the conditions necessary for successful sublevel caving in the iron mines of the Gogebic range, as follows:

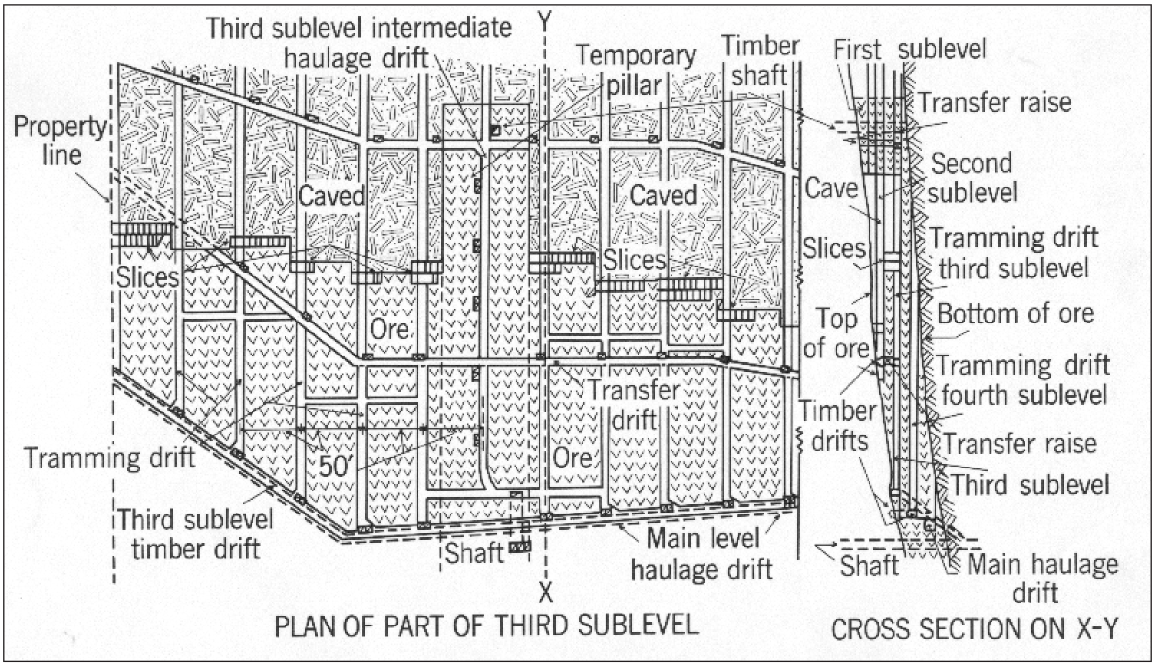
The determining conditions to which this method is adapted are (a) a dipping and pitching irregular ore body, which does not lend itself to top slicing; (b) a medium-soft ore which breaks fine yet stands well and is not free-caving; (c) a hard capping which caves in medium-sized blocks without much fines and which is easily controlled.

The method is also employed successfully in hard ores and may be used under conditions where top slicing would be dangerous because of the hanging up of the gob. For successful block caving the ore should be free-running; that is, it must be of such a nature that it will not pack and form a semisolid mass that cannot be drawn off through the draw raises. Due to the relative thinness of the slices and the small size of the units caved in sublevel caving, packing is not so serious an obstacle and the method can be used for mining softer and somewhat stickier ores than can block caving.

Top Slicing Mining Method

The term "top slicing" is applied to the method of mining whereby the ore is extracted by excavating a series of horizontal (sometimes inclined) timbered slices alongside each other, beginning at the top of the ore body and working progressively downward; the slices are caved by blasting out the supporting timbers or allowing them to crush, bringing the capping or overburden down upon the bottoms of the slices, which have previously been covered with a floor or timber mat to separate the cave from the solid ore beneath and prevent admixture of waste with the ore. Successive slices are mined in a similar manner up to the overlying gob or mat, which consists of an accumulation of broken timbers, flooring, and lagging used in the overlying slices and of caved capping or overburden. As the slices are mined and caved, this mat follows the mining downward, filling the space formerly occupied by the ore. The mat also serves to control the movement of the caved overburden and to prevent dilution of the ore with barren capping.

Top slicing is applicable to the mining of soft, weak ore that will stand unsupported for only a very short time, even over narrow spans, and that is overlain by an unconsolidated overburden or a weak capping that will break up and cave promptly after removal of support, tightly filling the space formerly occupied by the slice and leaving no open holes. It may be applied in tabular deposits lying at all angles of dip, from flat to vertical, or in wide, thick ore bodies. It is used successfully in deposits of very irregular outline and is employed for recovering pillars of ore from between filled or caved stopes and for mining broken ore or old caves that could not be worked safely from the bottom upward. The method is similar in some respects to sublevel caving—the ore is mined from the top downward by a series of slices, and the overlying strata cave and follow the mining downward with a mat intervening between the caved overburden and the ore beneath. The methods differ, however, in that in top slicing the slice is mined right up to the floor of the caved slice above, whereas in sublevel caving the sublevel interval is greater (usually about twice), and in driving the slice drifts a back of ore is left over the tops of the drifts and below the mat of the slice above, which is extracted later by caving on the retreat. In sublevel caving the slice drifts are separated by intervening pillars, which are also mined on the retreat, whereas in top slicing they are driven immediately alongside each other.

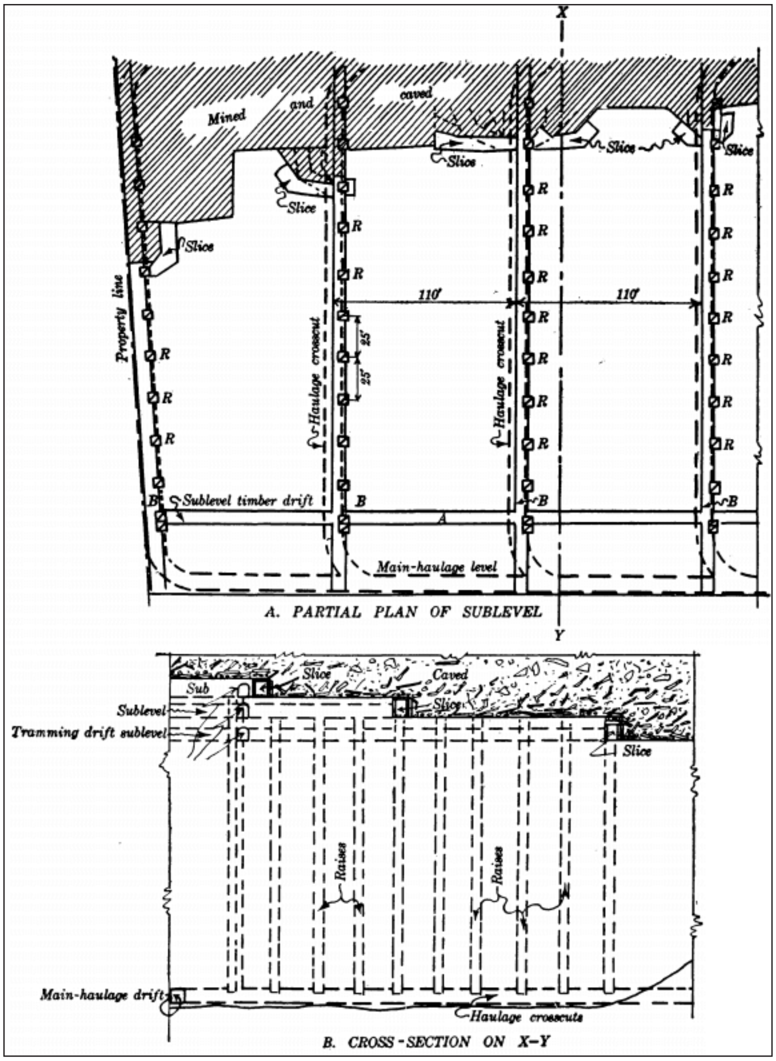


Example of parallel top slicing, scraping to cars: Flat dipping ore body, 2 to 4 subs thick.
Figure shows the method of parallel top slicing in a relatively.

The method has been applied most commonly in the mining of wide deposits of soft or weak ore overlain by a friable capping or unconsolidated overburden. A capping that breaks in large blocks that will wedge and arch over, leaving open holes in the gob, would be dangerous for top slicing. Hence, top-weight or vertical pressure is an essential condition for successful top slicing. The side walls may be either weak or strong.

Since top slicing requires the use of considerable timber and lagging, it is essential that there be a plentiful and cheap source of suitable timber available. Slice timber is required to stand for only a short time and is then blasted down or allowed to crush; a poorer grade is acceptable than would be required for more permanent supports, such as for drift timber. However, the timber should be tough and capable of standing considerable crushing before breaking.

A special application of the top-slicing method has been used for mining pillars between filled stopes under a capping that will not cave readily, even over large spans. In this instance, sand or waste filling is run in on top of the subsiding gob, keeping the hole filled. The filling will then act as a cushion to take the impact of any possible sudden collapse of the capping.



Radial top slicing to chutes; thick ore body.

Combinations of Supported and Caved Stopes

The use of two or more stoping methods independently of each other in the same mine, or even in different parts of the same ore body because of differences in the physical characteristics governing the requirements for support, does not constitute a combination method.

A combination method does exist, however, when a stoping system is laid out in advance of operations wherein two different methods are employed as essential complements, one to the other. An example is furnished where a series of alternating stopes and pillars is laid out, the stopes to be mined by shrinkage and then filled, or by cut-and-fill stoping, and the pillars to be mined by top-slicing between the filled stopes. Each method, one a supported-stope method and the other a caved-stope method, is essential to the complete extraction of the block of ore. Again, a block-caving system in which a considerable part of the ore is mined by shrinkage in undercutting stopes and boundary cut-offs and the balance by caving in reality constitutes a combination method. (It should be noted, however, that in modern block-caving practice only a small percentage, perhaps 2 to 5 percent of the ore, is customarily mined by shrinkage stoping).

DRILLING METHODS

Percussive Drilling

In this method which is the oldest one of drilling, the hole is drilled by striking a number at short in intervals on the rock by a chisel-type tool and between the blows the tool is rotated slightly. The rock is chipped away with each blow and a circular hole is formed. During drilling the chisel is suspended from the surface by rods or wire rope and the weight of the chisel, rods, etc., is utilised to give the striking force.

Drilling with Rods

The rods are Ni-Cr or carbon steel. Each rod has a male screw at one end and a female screw (screwed socket) at the other. Steel rods are usually in lengths of 3 m with nearly 38 mm x 38 mm square cross-section. For rotary drilling, the rods are hollow, circular in cross section, have flush joints, and the length varies from 0.5 to 3 m.

The drilling tool used varies greatly in shape and cutting edge according to the type of ground to penetrate. For soft surface deposits which consist of alluvium, clay auger and worm auger may be used. These are given a rotary rather than a percussive motion. The straight chisel is commonly used for hard strata and the V chisel and T chisel, for very hard strata.

Manual Drilling

The general arrangement for manual drilling is nearly like that water is not supplied through hose pipes under pressure and the cranck operated beam is replaced by a rocking lever connected to the drill rods. The drilling rods are given a percussive motion with the help of a corking level to which they are attached through a stirrup and a brace-head.

A brace-head is simply a pair of crossed handles fixed to the end of a short top rod which is screwed to the column of the rods. Two or three men press down the free end of the rocking level, thereby lifting the rods while one man turns them slightly by means of the brace-head.

The men then let go the free end so that the rods fall and the drilling tool gives a blow on the rock. Water is poured in the hole at intervals and the process is repeated. As the hole gets deeper, the rods are lowered in the stirrup by a screw, and when this can no longer provide for the increasing depth, a short rod is added to the column of rods and the screw runs back to repeat the same process of drilling.

Instead of the stirrup, Dlinks may be used. Short rods are added till the depth drilled by such small rods is slightly more than the length of full-length rod and the short rods are then replaced by a full-length rod. A device known as retaining key is used at the time of raising or lowering the rods of square cross-section. The same purpose is served in the case of rods of circular cross section with flush joints, by a device known as “bulldog safety clamp”.

During drilling the bottom of the hole soon gets filled with cuttings and has to be cleaned out frequently. This is done with the help of a sludger which consists of a long cylinder or pipe, open at the top and with a flap valve at its lower end. The flap valve opens upwards. When attached to the end of the rods and worked up and down the sludger gets filled with the sludge.

It is then withdrawn to the surface and the process repeated till the hole is cleaned. The cuttings brought to the surface in the sludger give an indication of the rock being drilled. The bottom of the drill hole is always kept full with water during drilling.

Sometimes a rod or chisel breaks in the drill hole during drilling. Devices like the crow's-foot and the spiral worm may be used to catch the broken rod under a joint in the borehole. Broken pieces of chisel are sometimes raised with the help of powerful magnets.

In diamonds drilling, the diamonds sometimes become loose and fall in the hole. The operation of tracing the broken and lost parts in the hole and withdrawing them to the surface is known as fishing the borehole.

Lining a Drill Hole

During drilling a steel pipe is used for lining the drill hole from surface upto the hard rock, and the drilling tool and rods pass through the pipe. Obviously, the length of the drill-hole upto which the lining pipe has to be fitted should be of a larger diameter. The lining pipe is generally withdrawn after the hole is completed though it may sometimes be necessary to leave it in its position to prevent caving of sides, e.g., drill hole for stowing, water pipes, etc.

The lining is done by hammering first a special steel pipe with a cutting edge. Pipes of 6 m lengths and having screwed joints are added to that pipe.

Power Drilling with Rods

Drilling with manual labour without the help of power is suitable for holes upto 150 mm in diameter and upto a depth of 30 m or so. Beyond that depth, it is impossible to drill without the use of power from a diesel or petrol engine, the common source of power in isolated drilling sites. Vertical boilers have sometimes been used to avail of steam power, specially where drilling had to be done in a colliery area where coal is easily available.

Figure shows the general arrangement where power is available for drilling with hollow rods. A power operated winch is used to raise and lower and the rods. The walking beam is operated by a crank through gearing from an engine to give the drilling tool 25 to 30 blows per minute and a stroke of nearly 225 mm.

The beam is mounted on steel springs which give elasticity and cause sudden recoil of the frilling bit thereby preventing jamming. The rods are attached to the rope with a swivel attachment and brace head. The rope of power-operated beam is slackened from time to time to keep the drilling tool in contact with the rock.

Water is forced down the hole of the hollow drill rods by a pump to keep the cutting tool cool. Such water returns to the surface from the outside of the rods with the sludge. With this arrangement it is possible to drill a depth equal to the length of one full rod at a time. Water flushing practically eliminates the use of a sludger.

Power drilling with road. Arrows indicate water course.

Rope Drilling or Cable Drilling

Where the percussive method of drilling is employed cable drilling is commonly adopted for holes deeper than 30 m. In this system the rigid rods are replaced by a steel wire rope to which the drilling tool is attached. The surface arrangement is practically the same as for drilling with rods, but the end of the walking beam is attached to a temperature screw. The rope from a winch is taken to the clamps of the temper screw across the pulley of the derrick.

Feed of upto 1.2 m is possible with the use of the temper screw. When no more feed is possible the temper screw is run back and the rope reclamped 1.2 m higher up.

During rope drilling no device is necessary to give a twist to the drilling tool between successive blows as the lay of the stranded rope causes the tool to twist slightly. The steel rope may be 18 mm diameter for a depth of 300 metres. The ropes have always a left hand lay, so that the spin of the rope which tends to rotate the drilling tool also tends to tighten the joints between them. Cable drilling is also known as churn drilling.

Rotary Drilling

For rotary drilling, hollow drill rods of steel or aluminium are used. These are thread- connected and transmit torque and feed pressure to the drilling bit or drilling tool which is attached at the end of a column of the drill rods. Rotation of the drill rods is through gearing driven by a prime mover at the surface.

As the rods rotate, the drilling tool abrades the rock and the cuttings are cleared by pumping water under pressure or compressed air down the hole through the hollow drill rods. The water or air, along with the cuttings, comes to the surface through the space between the drill rods and the sides of the drill hole.

In some drillings, specially those for oil exploration, mud which is not very viscous, is circulated instead of water. The mud which keeps back any water, gas or oil pressure encountered during drilling is known by various trade names such as bentonite, aqua gel, etc. and there muds serve different in the mining areas it may be necessary to resort to mud flushing when passing through a fractured or friable zone.

Aluminium rods weight only half as much as steel rods, but owing to their bigger gauge they possess 90% of the mechanical strength of the latter. The couplings, which are the parts most exposed to wear, are made of chromium-nickel steel.

Aluminium rods offer numerous advantages, such as increased machine capacity, easier handling, more rapid and simple recovery of the drill string and faster rotation, all of which contribution to simplifying drilling and reducing costs.

The various methods of rotary drilling are known by the type of drilling tool used but the diamond drilling method is quite common.

Diamond Drilling

This method is commonly adopted where cores of rocks passed through are desired for accurate records of the strata or for testing the rocks for their strength, composition, porosity, etc., the common type of drill bit which consists of a cylindrical cast steel shell having in its lower face a number of small sockets in which pieces of black diamonds are set.

These diamonds are not useful as jewelry but are used in the drill bits for their hardness and the bit is suitable for the hardest rocks. The hole sizes in diamond drilling are designated as NX, BX, AX, and EX. The drill rods and the drill bits are specified under two main groups, X series and W series.

The drill hole diameters and core sizes (in mm) available are given below:

Standard	Drill rod outside dia.		Hole dia. mm	Core dia. mm.
	X series in inches	W series in mm.		
NX....	2.3/8	NW-67	75	54
BX....	1.29/32	BW-54	60	40
AX....	1.5/8	AW-44	47	28
EX.....	1.5/16	EW-35	38	21

NW series rods are of W and conform to international standards for conventional drilling. NQ series drill rods are manufactured by Long year for wire line drilling technique. There are Q series standards for wire line drilling rods but some manufacturers have their own sizes.

The core sizes where wire line drilling technique is adopted are- NX holes – 44 mm; BX holes – 25 mm.

The surface arrangements for diamond drilling include:

1. A derrick,
2. An engine for supplying power,
3. An winch,
4. A pump for supplying water under pressure for flushing,
5. A setting tank,

6. A platform for keeping the drilling rods lifted for removal of core or changing the bit,
7. Core boxes for keeping the cores, and
8. A driving and feed mechanism for the drill rods.

The diamond drill bit is rotated at a speed of nearly 300 r.p.m. and the pressure on the diamonds is between 1.5 and 2 kgf/cm^2. The pressure acting upon the diamonds of the drill bit and the rate of advance of the drill bit into the rock are controlled by an arrangement known as “feed mechanism”.

The feed mechanism is hydraulic for deep holes, but may be replaced by screw feed for shallow holes. Beyond a depth of nearly 60 m, the weight of the rods keeps the bit pressed against the rocks and the feed mechanism may not be necessary. At greater depth the feed mechanism is operated in such a way that the weight on the drill bit is not excessive.

Screw Feed

On smaller machines, driven either by hand-power or mechanically, the feed is by a screw feed arrangement comprising a series of differential gears.

In this arrangement the drill rods pass through a hollow screw shaft, threaded on the outside, and provide with a long keyway. A bevel pinion, rotated by the bevel gear of the main driving shaft, has feathers engaging the keyway on the screw shaft, to which it imparts rotation. It also drives gear wheel a, engaging with gear wheel B on a rotation.

It also drives gear wheel A, engaging with gear wheel B on a countershaft. Usually three different combinations of gear are provided here, any of which can be utilised to vary the rate of advance to suit the type of rock.

Gear B, through the counter-shaft, drives C, which engages a fourth wheel D, threaded internally to fit the threads of the screw shaft. If, for example, the number of teeth on gears A, B, C and D are as shown in the diagram, viz. 38, 36, 24 and 25, one revolution of A = 38/36 revolution of B and C, = 3/836 x 24/25, revolutions of D.

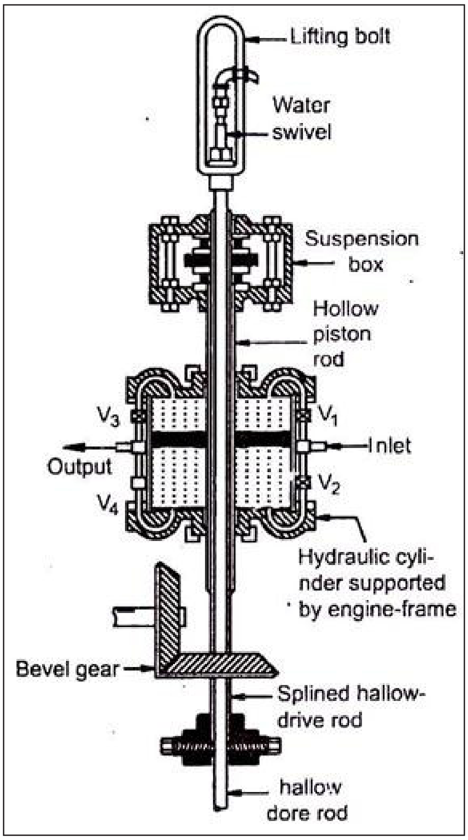
Therefore 75 revolutions of A will cause D to rotate 75 x 38/36 x 24/25 = 76 times. Consequently for every 75 revolutions of A, D revolves 76 times, and the screw shaft moves forward by a distance equal to the pitch of its thread. If this is 6 mm, then the rods advance 24 mm for every 300 revolutions. The movement of the screw shaft is imparted to the rods by the chuck.

A pressure gauge attached to the roller friction collar records the varying pressure on the bit. The setting of the feed decided upon is- obtained by sliding a lever to the desired position for locking the appropriate, loose gear, giving the speed required for the ground being bored.

The feed ratio may be changed while the drill is operating; but if any necessary change is neglected, so causing the drill rods to advance too rapidly (e.g., when a sofer stratum is suddenly encountered) the rate of advance is automatically checked by the slipping of a spring- loaded friction cone-clutch on the bottom of the countershaft.

Hydraulic Feed Mechanism

Figure shows the general principle of a typical hydraulic feed mechanism (excluding the engine and frame) for a deep boring, the main features, starting from the bottom, being the chuck, the bevel driving gears, the hydraulic cylinder and the ball-bearing suspension box. At the top is seen a lifting bail and water-swivel whose functions are self-evident.



Hydraulic feed mechanism.

There are three hollow rods, one within the other, namely, the inner bore rod, the middle drive rod and the outer piston rod. The hollow bore-rod is clamped to the drive-rod by the chuck. The drive rod is secured to and supported by the collar-plate in the suspension box, the latter remaining supported by being fixed to the hollow piston rod which carries the piston in the hydraulic cylinder. This cylinder is firmly fixed to the engine frame work.

The rate of feed of the bore-rods is governed by the rate at which the piston descends, for this governs the descent of the suspension box and therefore, of the collar plate and drive-rod to which the uppermost bore- rod is clamped. It will be seen that the drive rod is free to rotate within the suspensions box and within the hollows piston rod.

The drive-rod had on its outer surface ribs or splines which pass through slots or grooves in the box of the horizontal bevel drive-wheel. It can thus be rotated by the gear wheels (whose position is fixed) but it is free to descend through the horizontal wheel, carrying with it the bore-rods and boring tools at their lower end.

The piston in the hydraulic cylinder may be moved either up or down by admitting water under pressure to the appropriate side of the piston through the inlet pipe and one of the controlling valves, V_1 or V_2 and by simultaneously releasing an equal amount of water from the other side of the piston through one of the valves V_3 or V_4 and the outlet.

A single lever operates the four valves simultaneously to produce any desired pressure, either downward or upward, on the piston. Thus the weight of the rods may be partly taken off the boring tools by upward pressure; or the whole weight of the rods can rest on the boring tools and additional downward pressure can be applied. In this way complete control may be obtained over the pressure on the boring tool and over the rate of forward feed of the rods.

The cuttings are cleared from the drill hole by circulating water under pressure which is forced down the drill rods by a pump through a flexible hose pipe and water swivel connection. The return water from the hole goes to a settling tank and it is used over and over again.

Core Recovery

To collect the core of the rock drilled, a device known as the core barrel is used. It is length varies from 0.5 to 3 m.

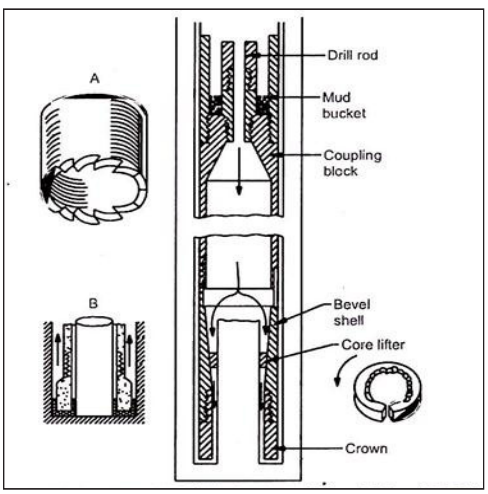
There are two types of this:

1. The single tube core barrel, and
2. Double tube core barrel.

Single Tube Core Barrel

A single tube core barrel is suitable for homogeneous formations where the core is not eroded by flushing water and a solid core can be taken without risk of blockage in the barrel.

The connection of the diamond crown, the single-tube core barrel and the mud bucket (also called calyx) are shown in figure. The core lifter is placed within the bevel shell which has its inside conically shaped to receive the former. The core lifter is corrugated on the inner face and is a split ring. It occupies the wider portion of the bevel shell when drilling takes place so that it has little or no tendency to grip the core.



(Left)A. Saw toothed crown; B. Chilled, shots during drilling (Middle) Single tube core barrel.

After certain progress in drilling when the rods are lifted to take out the core, the split ring descends inside the bevel shell and grips the core. The latter may now be broken off by a twist and raised to the surface. The core is replaced after about 250 m of drilling.

The larger particles of drill cuttings which the circulating water fails to carry upto the surface settle down in the mud bucket. Where supply of flushing water is plentiful, calyx is not necessary. The water under circulation is nearly 900 litres per minute.

In soft and friable rocks, the core is partially washed away due to the circulating water flowing past it. The rotation of the barrel greatly assists in grinding the core so that its recovery in a single tube core barrel is poor. To avoid these difficulties a double tube core barrel is used, specially where good core of soft rock is desired.

Double Tube Core Barrel

In a double tube core barrel in inner tube with holds the core does not rotate during drilling as it is suspended on ball bearings mounted in the block at the top of the barrel permitting the inner core barrel to remain stationary. Moreover, water does not flow past the core but in the annual space between the inner tube and the outer barrel and through channels near the bottom of the hole.

A double tube core barrel improves drill bit economy and overall drilling performance. Core recovery is good in hard uniform rocks, but poor in loose, soft, friable or weathered rocks. Vibrations of drill rods result in poor recovery. In hard rocks, to achieve good core recovery the drill should be run at low speed and heavy pressure; in soft rocks, reverse procedure should be adopted. The combination of pressure on drill bit and its rotational speed should be such as to give vibration-free drill string during drilling.

Wire Line Drilling

Normally core barrels of 0.5 m to 3 m length are employed. For removal of core during the conventional method of drilling, all the drill rods have to be withdrawn to the surface, after drilling a length equal to length of core barrel. The withdrawal of the rods and their re-introduction into the borehole with the additional drill rod, after removal of core, takes a considerable time, nearly 75 to 90% of the total time spent on drilling.

A wire line drilling technique is an improvement to reduce this time. The rods are not taken out to remove the core which is collected in the core barrel tube during drilling. The tube is pulled out the surface through the drill rods with the help of a catcher which is lowered through the rods by a 5 mm dia. wire rope. The catcher grips the tube containing the core.

Core size less than BX is not possible with wire line coring equipment which is therefore used for drilling holes of NX and BX size only. The speed of drilling with this equipment is nearly 18 m per shift (8 hours) in the types of rocks met with in the coalfields. All the drill rods need to be withdrawn to the surface only when the bit has to be changed.

Wire line drilling is possible upto a depth of 1000 m. The rods used for wire line drilling have specifications as laid down in “Q” series decided by DCDMA. Ordinary drilling equipment can be adopted to wire-line drilling and hoisting equipment with suitable modifications.

Some of the recent drills in the market are equipped with hydrostatic drive. In such drive and electric motor or a diesel engine drive a water pump. Its pressure is used for rotation of drill rods through a hydraulic motor and also for hydraulic feed. Its main advantage is that speed can be varied from zero to a certain limit without any fixed ratios that are possible in a geared drive.

Water Loss during Drilling

When drilling in fractured zone or strata with cavities the circulating water is lost in such zone and fails to appear at the surface. This is known as water loss. To seal up the cavities or fractures around the hole, saw dust, husk, etc., are mixed in circulating water.

If this is ineffective, it may be necessary to ream the bore hole and fix a casing pipe to cover the fractured zone. The casing pipe can be removed after completion of drilling. At depth, instead of resorting to a casing pipe a special type of mud like bentonite or kaolinite may be used to overcome the water loss.

Drilling mud is a suspension mixture of certain types of colloidal clay in water and oil and used as drilling mud. The mud most commonly used in diamond drilling is slurry of clay and water, properly controlled drilling mud slurries can prevent caving or collapse of borehole sides by building thin, impermeable protective coatings of clay particles to the walls of the hole. The mud is generally used as a final resort and the water circulation pump has to be replaced by a suitable mud circulation pump for this purpose.

Diamond drilling method is suitable for drilling at any angle to obtain cores of friable strata as well as the hardest rock. It has been adopted for drilling upto a depth of 3000 m and hole diameter upto 200 mm. Drilling upto such large depths is not required in coal mining areas where the maximum drilling depth is upto 1000 m, as coal mines are rarely deeper than that. Other methods of rotary drilling differ from the diamond drilling method essentially in the type of drilling bit used.

The Drill Bits used are as follows:

The Saw-toothed Crown

The drilling tool is a saw-toothed steel crown or cutter. The teeth are set alternately inward and outward to give the necessary clearance. The speed of rotation is only 5 to 10 r.p.m. and the drill bits are suitable only for drilling through rocks of medium hardness; only holes of diameter not less than 150 mm are possible.

Rock Roller Bits

These are suitable for hole diameter between 75 mm and 300 mm. In mining areas these are commonly used for drilling large diameter holes in mechanised quarries. Flushing of the hole with compressed air instead of by water under pressure is the common practice with this type of bit. Rock roller bits can be used for deep hole drilling with speed and are suitable for mostly vertical downward holes.

Chilled Steel Shots

These shots are prepared by heating very finely divided steel particles to a very high temperature and then suddenly cooling them in ice cold water. Chilled shots are used in conjunction with a plain steel shell or cylinder with a diagonal slot near the bottom.

They are fed through the hollow drill rods and pass to the bottom of the hole where they get caught between the bottom end of the cutting shell and the rock. As the shell and the drill rods rotate, the chilled steel shots cut the rock by a milling action.

The method is suitable for vertical and large diameter holes of 100 mm to 750 mm. It is also called calyx drilling, but is not much favoured these days as diamond drill bits have gained wide popularity and are available in large diameters upto 250 mm.

Calyx drilling proved to be a significant step during the development of drilling techniques. Except the rock roller bits, all the other drilling tools used for rotary drilling provide cores of the strata passed through.

Underground Drilling

To drill a hole from underground workings for purposes of prospecting, stowing, tapping water or gas or any other object, the drill equipment has necessarily to be of smaller dimensions. This restricts the size and weight of the machine and therefore puts limitations on the size of the bore hole and its length (or depth).

The power available underground may be electricity at 440/550 volts, or compressed air (in most of the metalliferous mines). Flame proof diesel engines are rarely employed as power sources. At some underground working places the water supply for drilling may be on a very limited scale and not as plentiful as on the surface.

Underground drills for exploration have often to be shifted to blind ends of roadways with narrow dimensions. They are, therefore, usually with skid plates. Components of aluminium alloy are nowadays increasingly used for such drills to reduce weight.

IN-SITU LEACH

In-situ leaching (ISL), also called in-situ recovery (ISR) or solution mining, is a mining process used to recover minerals such as copper and uranium through boreholes drilled into a deposit, *in situ*. In situ leach works by artificially dissolving minerals occurring naturally in a solid state.

The process initially involves the drilling of holes into the ore deposit. Explosive or hydraulic fracturing may be used to create open pathways in the deposit for solution to penetrate. Leaching solution is pumped into the deposit where it makes contact with the ore. The solution bearing the dissolved ore content is then pumped to the surface and processed. This process allows the extraction of metals and salts from an ore body without the need for conventional mining involving drill-and-blast, open-cut or underground mining.

Process

In-situ leach mining involves pumping of a lixiviant into the ore body via a borehole, which circulates through the porous rock dissolving the ore and is extracted via a second borehole.

The lixiviant varies according to the ore deposit: for salt deposits the leachate can be fresh water into which salts can readily dissolve. For copper, acids are generally needed to enhance solubility of the ore minerals within the solution. For uranium ores, the lixiviant may be acid or sodium bicarbonate.

Minerals

Potash and Soluble Salts

In-situ leach is widely used to extract deposits of water-soluble salts such as potash (sylvite and carnallite), rock salt (halite), sodium chloride, and sodium sulfate. It has been used in the US state of Colorado to extract nahcolite (sodium bicarbonate). In-situ leaching is often used for deposits that are too deep, or beds that are too thin, for conventional underground mining.

Uranium

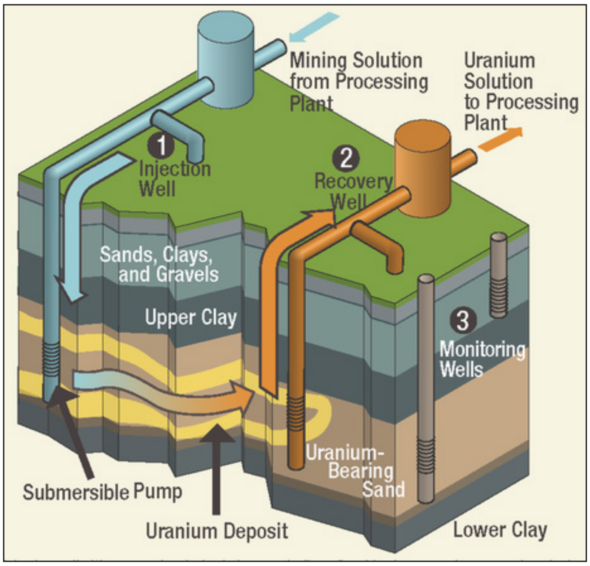


Diagram of in-situ leaching for uranium.

In-situ leach for uranium has expanded rapidly since the 1990s, and is now the predominant method for mining uranium, accounting for 45 percent of the uranium mined worldwide in 2012.

Solutions used to dissolve uranium ore are either acid (sulfuric acid or less commonly nitric acid) or carbonate (sodium bicarbonate, ammonium carbonate, or dissolved carbon dioxide). Dissolved oxygen is sometimes added to the water to mobilize the uranium. ISL of uranium ores started in the United States and the Soviet Union in the early 1960s. The first uranium ISL in the US was in the Shirley Basin in the state of Wyoming, which operated from 1961-1970 using sulfuric acid. Since 1970, all commercial-scale ISL mines in the US have used carbonate solutions. ISL mining in Australia uses acid solutions.

Ion exchange resin beads.

In-situ recovery involves the extraction of uranium-bearing water (grading as low as .05% U_3O_8). The extracted uranium solution is then filtered through resin beads. Through an ion exchange process, the resin beads attract uranium from the solution. Uranium loaded resins are then transported to a processing plant, where U_3O_8 is separated from the resin beads and yellowcake is produced. The resin beads can then be returned to the ion exchange facility where they are reused.

At the end of 2008 there were four in-situ leaching uranium mines operating in the United States, operated by Cameco, Mestena and Uranium Resources, Inc., all using sodium bicarbonate. ISL produces 90% of the uranium mined in the US. In 2010, Uranium Energy Corporation began in-situ leach operations at their Palangana project in Duval County, Texas. In July 2012 Cameco delayed development of their Kintyre project, due to challenging project economics based on $45.00 U_3O_8. One ISR reclamation project was also in operation as of 2009.

Significant ISL mines are operating in Kazakhstan and Australia. The Beverley uranium mine in Australia uses in-situ leaching. ISL mining accounted for 41% of the world's uranium production in 2010.

A drum of yellowcake.

Examples of in-situ uranium mines include:

- The Beverley Uranium Mine, South Australia, is an operating ISL uranium mine and Australia's first such mine.

- The Honeymoon Uranium Mine, South Australia, opened in 2011 and is Australia's second ISL uranium mine.
- Crow Butte (operating), Smith Ranch-Highland (operating), Christensen Ranch (reclamation), Irigaray (reclamation), Churchrock (proposed), Crownpoint (proposed), Alta Mesa (operating), Hobson (standby), La Palangana (operating), Kingsville Dome (operating), Rosita (standby) and Vasquez (restoration) are ISL uranium operations in the United States.
- In 2010 Uranium Energy Corp. began an ISL mining operation in the Palangana deposit in Duval County, Texas. The ion exchange facility at Palangana trucks uranium-loaded resin beads to the company's Hobson processing plant, where yellowcake is produced. Uranium Energy Corp. has three additional South Texas deposits permitted or in development.

Copper

In-situ leaching of copper was done by the Chinese by 977 AD, and perhaps as early as 177 BC. Copper is usually leached using acid (sulfuric acid or hydrochloric acid), then recovered from solution by solvent extraction electrowinning (SX-EW) or by chemical precipitation.

Ores most amenable to leaching include the copper carbonates malachite and azurite, the oxide tenorite, and the silicate chrysocolla. Other copper minerals, such as the oxide cuprite and the sulfide chalcocite may require addition of oxidizing agents such as ferric sulfate and oxygen to the leachate before the minerals are dissolved. The ores with the highest sulfide contents, such as bornite and chalcopyrite will require more oxidants and will dissolve more slowly. Sometimes oxidation is speeded by the bacteria *Thiobacillus ferrooxidans*, which feeds on sulfide compounds.

Recovery well at former San Manuel operation.

Copper ISL is often done by *stope leaching*, in which broken low-grade ore is leached in a current or former conventional underground mine. The leaching may take place in backfilled stopes or caved areas. In 1994, stope leaching of copper was reported at 16 mines in the US.

At the San Manuel mine in the US state of Arizona, ISL was initially used by collecting the resultant solution underground but in 1995 this was converted to a well-to-well recovery method which was the first large scale implementation of that method. This well-to-well method has been proposed for other copper deposits in Arizona.

Gold

In-situ leaching has not been used on a commercial scale for gold mining. A three-year pilot program was undertaken in the 1970s to in-situ leach gold ore at the Ajax mine in the Cripple Creek district in the US, using a chloride and iodide solution. After obtaining poor results, perhaps because of the complex telluride ore, the test was halted.

Environmental Concerns

According to the World Nuclear Organization in the USA legislation requires that the water quality in the affected aquifer be restored so as to enable its pre-mining use. Usually this is potable water or stock water (usually less than 500 ppm total dissolved solids), and while not all chemical characteristics can be returned to those pre-mining, the water must be usable for the same purposes as before. Often it needs to be treated by reverse osmosis, giving rise to a problem in disposing of the concentrated brine stream from this.

The usual radiation safeguards are applied at an ISL Uranium mining operation, despite the fact that most of the orebody's radioactivity remains well underground and there is hence minimal increase in radon release and no ore dust. Employees are monitored for alpha radiation contamination and personal dosimeters are worn to measure exposure to gamma radiation. Routine monitoring of air, dust and surface contamination are undertaken.

The advantages of this technology are:

- Reduced hazards for the employees from accidents, dust, and radiation.
- Low cost, no need for large uranium mill tailings deposits.

After termination of an in-situ leaching operation, the waste slurries produced must be safely disposed, and the aquifer, contaminated from the leaching activities, must be restored. Groundwater restoration is a very tedious process that is not yet fully understood.

The best results have been obtained with the following treatment scheme, consisting of a series of different steps:

- Phase 1: Pumping of contaminated water: the injection of the leaching solution is stopped and the contaminated liquid is pumped from the leaching zone. Subsequently, clean groundwater flows in from outside of the leaching zone.
- Phase 2: As 1, but with treatment of the pumped liquid (by reverse osmosis) and re-injection into the former leaching zone. This scheme results in circulation of the liquid.
- Phase 3: As 2, with the addition of a reducing chemical (for example hydrogen sulfide (H_2S) or sodium sulfide (Na_2S). This causes the chemical precipitation and thus immobilization of major contaminants.
- Phase 4: Circulation of the liquid by pumping and re- injection, to obtain uniform conditions in the whole former leaching zone.

But, even with this treatment scheme, various problems remain unresolved:

- Contaminants that are mobile under chemically reducing conditions, such as radium, cannot be controlled.
- If chemically reducing conditions are later disturbed for any reasons, the precipitated contaminants are re-mobilized.
- The restoration process takes very long periods of time, not all parameters can be lowered appropriately.

Most restoration experiments reported refer to the alkaline leaching scheme, since this scheme is the only one used in Western world commercial in-situ operations. Therefore, nearly no experience exists with groundwater restoration after acid in- situ leaching, the scheme that was applied in most instances in Eastern Europe. The only Western in-situ leaching site restored after sulfuric acid leaching so far, is the small pilot scale facility Nine Mile Lake near Casper, Wyoming (USA). The results can therefore not simply be transferred to production scale facilities. The restoration scheme applied included the first two steps mentioned above. It turned out that a water volume of more than 20 times the pore volume of the leaching zone had to be pumped, and still several parameters did not reach background levels. Moreover, the restoration required about the same time as used for the leaching period.

In USA, the Pawnee, Lamprecht, and Zamzow ISL Sites in Texas were restored using steps 1 and 2 of the above listed treatment scheme. Relaxed groundwater restoration standards have been granted at these and other sites, since the restoration criteria could not be met.

A study published by the U.S. Geological Survey in 2009 found that "To date, no remediation of an ISR operation in the United States has successfully returned the aquifer to baseline conditions."

Baseline conditions include commercial quantities of radioactive U_3O_8. Efficient in-situ recovery reduces U_3O_8 values of the aquifer. Speaking at an EPA Region 8 workshop, on September 29, 2010, Ardyth Simmons, PhD, Los Alamos National Laboratory (Los Alamos, NM) on the subject "Establishing Baseline and Comparison to Restoration Values at Uranium In-Situ Recovery Sites" stated "These results indicated that it may be unrealistic for ISR operations to restore aquifers to the mean, because in some cases, this means that there would have to be less uranium present than there was pre-mining. Pursuing more conservative concentrations results in a considerable amount of water usage, and many of these aquifers were not suitable for drinking water before mining initiated."

The EPA is considering the need to update the environmental protection standards for uranium mining because current regulations, promulgated in response to the Uranium Mill Tailings Radiation Control Act of 1978, do not address the relatively recent process of in-situ leaching (ISL) of uranium from underground ore bodies. In a February, 2012 letter the EPA states, "Because the ISL process affects groundwater quality, the EPA's Office of Radiation and Indoor Air requested advice from the Science Advisory Board (SAB) on issues related to design and implementation of groundwater monitoring at ISL mining sites."

The SAB makes recommendations concerning monitoring to characterize baseline groundwater quality prior to the start of mining operations, monitoring to detect any leachate excursions during mining, and monitoring to determine when groundwater quality has stabilized after mining operations have been completed. The SAB also reviews the advantages and disadvantages of alternative statistical techniques to determine whether post-operational groundwater quality has returned to near pre-mining conditions and whether mine operation can be predicted not to adversely impact groundwater quality after site closure acceptance.

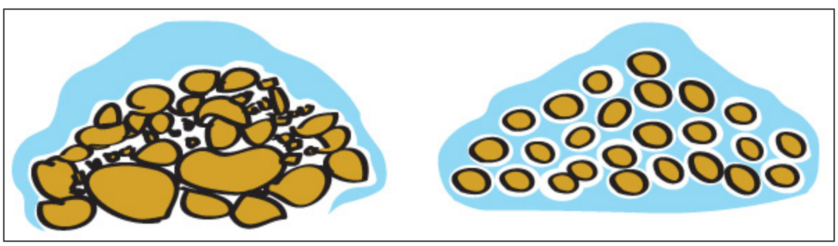
HEAP LEACHING

Heap leaching is an industrial mining process used to extract precious metals, copper, uranium, and other compounds from ore using a series of chemical reactions that absorb specific minerals and re-separate them after their division from other earth materials. Similar to *in situ* mining, heap leach mining differs in that it places ore on a liner, then adds the chemicals via drip systems to the ore, whereas *in situ* mining lacks these liners and pulls pregnant solution up to obtain the minerals. Most mining companies favor the economic feasibility of heap leaching, considering that heap leaching is a better alternative to conventional processing methods such as such as flotation, agitation, and vat leaching.

Additionally, dump leaching is an essential part of most copper mining operations and determines the quality grade of the produced material along with other factors. Due to the profitability that the dump leaching has on the mining process, i.e. it can contribute substantially to the economic viability of the mining process, it is advantageous to include the results of the leaching operation in the economic overall project evaluation. This, in effect, requires that the key controllable variables, which have an effect on the recovery of the metal and the quality of solution coming from a dump leaching process.

The process has ancient origins; one of the classical methods for the manufacture of copperas (iron sulfate) was to heap up iron pyrite and collect the leachate from the heap, which was then boiled with iron to produce iron(II) sulfate.

Process



Left: Ore fines without agglomeration. Right: Ore fines after agglomeration - Improved percolation as a result of agglomeration.

The mined ore is usually crushed into small chunks and heaped on an impermeable plastic or clay lined leach pad where it can be irrigated with a leach solution to dissolve the valuable metals. While sprinklers are occasionally used for irrigation, more often operations use drip irrigation to minimize evaporation, provide more uniform distribution of the leach solution, and avoid damaging the exposed mineral. The solution then percolates through the heap and leaches both the target and other minerals. This process, called the "leach cycle," generally takes from one or two months for simple oxide ores (e.g. most gold ores) to two years for nickel laterite ores. The leach solution containing the dissolved minerals is then collected, treated in a process plant to recover the target mineral and in some cases precipitate other minerals, and recycled to the heap after reagent levels are adjusted. Ultimate recovery of the target mineral can range from 30% of contained run-of-mine dump leaching sulfide copper ores to over 90% for the ores that are easiest to leach, some oxide gold ores.

The essential questions to address during the process of the heap leaching are as following:

- Can the investment of crushing the ore be justified by the potential increase in recovery and rate of recovery?
- How should the concentration of acid be altered over time in order to produce a solution that can be economically treated?
- How does the form of a heap affect the recovery and solution grade?
- Under any given set of circumstances, what type of recovery can be expected before the leach solution quality drops below a critical limit?
- What recovery (quantifiable measure) can be expected?

In recent years, the addition of an agglomeration drum has improved on the heap leaching process by allowing for a more efficient leach. The rotary drum agglomerator, such as the tyre driven Sepro Agglomeration Drum works by taking the crushed ore fines and agglomerating them into more uniform particles. This makes it much easier for the leaching solution to percolate through the pile, making its way through the channels between particles.

The addition of an agglomeration drum also has the added benefit of being able to pre-mix the leaching solution with the ore fines to achieve a more concentrated, homogeneous mixture and allow the leach to begin prior to the heap.

Although heap leach design has made significant progress over the last few years through the use of new materials and improved analytical tools, industrial experience shows that there are significant benefits from extending the design process beyond the liner and into the rock pile itself. Characterization of the physical and hydraulic (hydrodynamic) properties of ore-for-leach focuses on the direct measurement of the key properties of the ore, namely:

- The relationship between heap height and ore bulk density (density profile).
- The relationship between bulk density and percolation capacity (conductivity profile).
- The relationship between the bulk density, porosity and its components (micro and macro).
- The relationship between the moisture content and percolation capacity (conductivity curve).
- The relationship between the aforementioned parameters and the ore preparation practices (mining, crushing, agglomeration, curing, and method of placement).

Theoretical and numerical analysis, and operational data show that these fundamental mechanisms are controlled by scale, dimensionality, and heterogeneity, all of which adversely affect the scalability of metallurgical and hydrodynamic properties from the lab to the field. The dismissal of these mechanisms can result in a number of practical and financial problems that will resonate throughout the life of the heap impacting the financial return of the operation. Through procedures that go beyond the commonly employed metallurgical testing and the integration of data gleaned through real time 3D monitoring, a more complete representative characterization of the physicochemical properties of the heap environment is obtained. This improved understanding results in a significantly higher degree of accuracy in terms of creating a truly representative sample of the environment within the heap.

By adhering to the characterization identified above, a more comprehensive view of heap leach environments can be realized, allowing the industry to move away from the *de facto* black-box approach to a physicochemically inclusive industrial reactor model.

Precious Metals

The crushed ore is irrigated with a dilute alkaline cyanide solution. The solution containing the dissolved precious metals in a pregnant solution continues percolating through the crushed ore until it reaches the liner at the bottom of the heap where it drains into a storage (pregnant solution) pond. After separating the precious metals from the pregnant solution, the dilute cyanide solution (now called "barren solution") is normally re-used in the heap-leach-process or occasionally sent to an industrial water treatment facility where the residual cyanide is treated and residual metals are removed. In very high rainfall areas, such as the tropics, in some cases there is surplus water that is then discharged to the environment, after treatment, posing possible water pollution if treatment is not properly carried out.

The production of one gold ring through this method, can generate 20 tons of waste material.

During the extraction phase, the gold ions form complex ions with the cyanide:

$$Au^{+}(s) + 2CN^{-}(aq) \rightarrow Au(CN)_2^{-}(aq)$$

Recuperation of the gold is readily achieved with a redox-reaction:

$$2Au(CN)_2^{-}(aq) + Zn(s) \rightarrow Zn(CN)_4^{-}(aq) + 2Au(s)$$

The most common methods to remove the gold from solution are either using activated carbon to selectively absorb it, or the Merrill-Crowe process where zinc powder is added to cause a precipitation of gold and zinc. The fine product can be either doré (gold-silver bars) or zinc-gold sludge that is then refined elsewhere.

Copper Ores

The method is similar to the cyanide method above, except sulfuric acid is used to dissolve copper from its ores. The acid is recycled from the solvent extraction circuit and reused on the leach pad. A byproduct is iron(II) sulfate, jarosite, which is produced as a byproduct of leaching pyrite, and sometimes even the same sulfuric acid that is needed for the process. Both oxide and sulfide ores can be leached, though the leach cycles are much different and sulfide leaching requires a bacterial, or bio-leach, component.

In 2011 leaching, both heap leaching and in-situ leaching, produced 3.4 million metric tons of copper, 22 percent of world production. The largest copper heap leach operations are in Chile, Peru, and the southwestern United States.

Although heap leaching is a low cost-process, it normally has recovery rates of 60-70%. It is normally most profitable with low-grade ores. Higher-grade ores are usually put through more complex milling processes where higher recoveries justify the extra cost. The process chosen depends on the properties of the ore.

The final product is cathode copper.

Nickel Ores

This method is an acid heap leaching method like that of the copper method in that it utilises sulfuric acid instead of cyanide solution to dissolve the target minerals from crushed ore. The amount of sulfuric acid required is much higher than for copper ores, as high as 1,000 kg of acid per tonne of ore, but 500 kg is more common. The method was originally patented by Australian miner BHP Billiton and is being commercialized by Cerro Matoso S.A. in Colombia, a wholly owned subsidiary of BHP Billiton; Vale in Brazil; and European Nickel PLC for the rock laterite deposits of Turkey, Talvivaara mine in Finland, the Balkans, and the Philippines. There currently are no operating commercial scale nickel laterite heap leach operations, but there is a sulphide HL operating in Finland.

Nickel recovery from the leach solutions is much more complex than for copper and requires various stages of iron and magnesium removal, and the process produces both leached ore residue (“ripios”) and chemical precipitates from the recovery plant (principally iron oxide residues, magnesium sulfate and calcium sulfate) in roughly equal proportions. Thus, a unique feature of nickel heap leaching is the need for a tailings disposal area.

The final product can be nickel hydroxide precipitates (NHP) or mixed metal hydroxide precipitates (MHP), which are then subject to conventional smelting to produce metallic nickel.

Uranium Ores

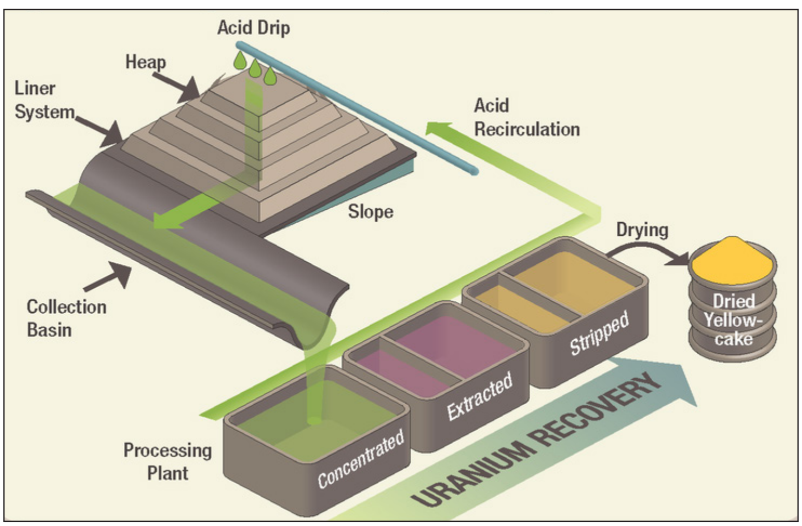


Diagram of heap leach recovery for uranium.

Similar to copper oxide heap leaching, also using dilute sulfuric acid. Rio Tinto is commercializing this technology in Namibia and Australia; the French nuclear power company Areva, in Niger with two mines and Namibia; and several other companies are studying its feasibility.

The final product is yellowcake and requires significant further processing to produce fuel-grade feed.

Apparatus

While most mining companies have shifted from a previously accepted sprinkler method to the percolation of slowly dripping choice chemicals including cyanide or sulfuric acid closer to the actual ore bed, heap leach pads have not changed too much throughout the years. There are still four main categories of pads: conventional, dump leach, Valley Fills, and on/off pads. Typically, each pad only has a single, geomembrane liner for each pad, with a minimum thickness of 1.5mm, usually thicker.

The conventional pads simplest in design are used for mostly flat or gentle areas and hold thinner layers of crushed ore. Dump leach pads hold more ore and can usually handle a less flat terrain. Valley Fills are pads situated at valley bottoms or levels that can hold everything falling into it. On/off pads involve the use of putting significantly larger loads on the pads and removing and reloading it after every cycle.

Many of these mines which previously had digging depths of about 15 meters are digging deeper than ever before to mine materials, approximately 50 meters, sometimes more, which means that, in order to accommodate all of the ground being displaced, pads will have to hold higher weights from more crushed ore being contained in a smaller area. With that increase in build up comes in potential for decrease in yield or ore quality, as well as potential either weak spots in the lining or areas of increased pressure buildup. This build up still has the potential to lead to punctures in the liner. As of 2004 cushion fabrics, which could reduce potential punctures and their leaking, were still being debated due to their tendency to increase risks if too much weight on too large a surface was placed on the cushioning. In addition, some liners, depending on their composition, may react with salts in the soil as well as acid from the chemical leaching to affect the successfulness of the liner. This can be amplified over time.

Environmental Concerns

Effectiveness

Heap leach mining works well for large volumes of low grade ores, as reduced metallurgical treatment (comminution) of the ore is required in order to extract an equivalent amount of minerals when compared to milling. The significantly reduced processing costs are offset by the reduced yield of usually approximately 60-70%. The amount of overall environmental impact caused by heap leaching is often lower than more traditional techniques. It also requires less energy consumption to use this method, which many consider to be an environmental alternative.

Government Regulation

In the United States, the General Mining Law of 1872 gave rights to explore and mine on public domain land; the original law did not require post-mining reclamation. Mined land reclamation requirements on federal land depended on state requirements until the passage of the Federal Land Policy and Management Act in 1976. Currently, mining on federal land must have a government-approved mining and reclamation plan before mining can start. Reclamation bonds are required. Mining on either federal, state, or private land is subject to the requirements of the Clean Air Act and the Clean Water Act.

One solution proposed to reclamation problems is the privatization of the land to be mined.

Cultural and Social Concerns

With the rise of the environmentalist movement has also come an increased appreciation for social justice, and mining has showed similar trends lately. Societies located near potential mining sites are at increased risk to be subjected to injustices as their environment is affected by the changes made to mined lands—either public or private—that could eventually lead to problems in social structure, identity, and physical health. Many have argued that by cycling mine power through local citizens, this disagreement can be alleviated, since both interest groups would have shared and equal voice and understanding in future goals. However, it is often difficult to match corporate mining interests with local social interests, and money is often a deciding factor in the successes of any disagreements. If communities are able to feel like they have a valid understanding and power in issues concerning their local environment and society, they are more likely to tolerate and encourage the positive benefits that come with mining, as well as more effectively promote alternative methods to heap leach mining using their intimate knowledge of the local geography.

PLACER MINING

Placer Mining is the mining of stream bed (alluvial) deposits for minerals. This may be done by open-pit (also called open-cast mining) or by various surface excavating equipment or tunnelling equipment.

Placer mining is frequently used for precious metal deposits (particularly gold) and gemstones, both of which are often found in alluvial deposits—deposits of sand and gravel in modern or ancient stream beds, or occasionally glacial deposits. The metal or gemstones, having been moved by stream flow from an original source such as a vein, are typically only a minuscule portion of the total deposit. Since gems and heavy metals like gold are considerably denser than sand, they tend to accumulate at the base of placer deposits.

It is important to note that placer deposits can be as young as a few years old, such as the Canadian Queen Charlotte beach gold placer deposits, or billions of years old like the Elliott Lake uranium paleoplacer within the Huronian Supergroup in Canada.

The containing material in an alluvial placer mine may be too loose to safely mine by tunnelling, though it is possible where the ground is permanently frozen. 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.

Deposits

An area well protected from the flow of water is a great location to find gold. Gold is very dense and is often found in a stream bed. Many different gold deposits are dealt with in different ways. Placer deposits attract many prospectors because their costs are very low. There are many different places gold could be placed, such as a residual, alluvial, and a bench deposit.

Residual

Residual deposits are more common where there has been weathering on rocks and where there hasn't been water. They are deposits which have not been washed away yet or been moved. The residual usually lies at the site of the lode. This type of deposit undergoes rock weathering.

Alluvial

Alluvial or eluvial deposits sometimes have the largest gold deposit and are very common. This deposit is created when a force of nature moves or washes the gold away, but it doesn't go into a stream bed. It contains pieces of ore that have been washed away from the lode. Alluvial deposits are the most common type of placer gold. This type of deposit occurs mostly in valleys.

Bench

Bench deposits are created when gold reaches a stream bed. Gold accumulations in an old stream bed that are high are called bench deposits. They can be found on higher slopes that drain into valleys. Dry stream beds (benches) can be situated far from other water sources and can sometimes be found on mountain tops. Today, many miners focus their activities on bench deposits.

Methods

A number of methods are used to mine placer gold and gems, both in terms of extracting the minerals from the ground, and separating it from the non-gold or non-gems.

Panning

Panning for gold.

The simplest technique to extract gold from placer ore is panning. This technique has been dated back to at least the Roman Empire. 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 gangue 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. Gold panning was commonly used on its own during the California gold rush, however it is now rarely used for profit since even an expert gold prospector can only process approximately one cubic yard of material for every 10 hours of work.

Rocker

A rocker box (or "cradle") is capable of greater volume than a gold pan, however its production is still limited when compared to other methods of placer mining. It is only capable of processing about 3 or 4 yards of gravel a day. It is more portable and requires less infrastructure than a sluice box, being fed not by a sluice but by hand. The box sits on rockers, which when rocked separates out the gold, and the practice was referred to as "rocking the golden baby". A typical rocker box is approximately 42 inches long, 16 inches wide and 12 inches long with a removable tray towards the top, where gold is placed. The rocker was commonly used throughout North America during the early gold rush, but its popularity diminished as other methods that could handle a larger volume became more common.

Sluice Box

Riffles in a sluice box. The small specks are gold, the larger ones are merely pebbles.

A modern sluice box made of metal; in its base are the riffles used to catch gold settling to the bottom.

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”). While they are capable of handling a larger volume of material than simpler methods such as the rocker box or gold panning, this can come at the cost of efficiency, since conventional sluice boxes have been found to recover only about 40% of the gold that they process.

The sluice box was used extensively during the California gold rush for larger scale operations. When streams became increasingly depleted, the grizzly and undercurrent variants of the sluice box were developed. The grizzly is a set of parallel bars placed at a 45 degree angle over the main sluice box, which filter out larger material. The undercurrent variety includes additional, auxiliary sluice boxes where material is initially filtered. It then travels through a trough into the primary sluice box where it is filtered again. Both the grizzly and undercurrent are designed to increase efficiency, and were often used in combination.

Dry Washing

Sluicing is only effective in areas where there is a sufficient water supply, and is impractical in arid areas. Alternative methods developed that used the blowing of air to separate out gold from sand. One of the more common methods of dry washing is the Mexican dry wash. This method involves placing gravel on a riffle board with a bellows placed underneath it. The bellows is then used to blow air through the board in order to remove the lighter material from the heavier gold. The amount of gravel that can be processed using the Mexican dry wash technique varies from 1 1/2 to 4 cubic yards per day, and can be processed at a maximum efficiency of 80%. Another form of dry washing is “winnowing”. This method was most commonly used by Spanish miner in America, and only requires a blanket and a box with a screen on the bottom. The material is first filtered through the box so only the finer material is placed onto the blanket. The material on the blanket is then flung into the air so that any breeze can blow away the lighter material and leave the gold behind. While this method is extremely simple and requires very few materials, it is also slow and inefficient.

Trommel

Trommel at the Potato Patch, Blue Ribbon Mine, Alaska.

A trommel is composed of a slightly-inclined rotating metal tube 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.

Gold Dredge

The Natomas No. 6 gold dredge in operation.

Large-scale sifting of placer gold from large volumes of alluvial deposits can be done by use of mechanical dredges.These dredges were originally very large boats capable of processing massive amounts of material, however as the gold has become increasingly depleted in the most easily accessible areas, smaller and more maneuverable dredges have become much more common. These smaller dredges commonly operate by sucking water and gravel up through long hoses using a pump, where the gold can then be separated using more traditional methods such as a sluice box.

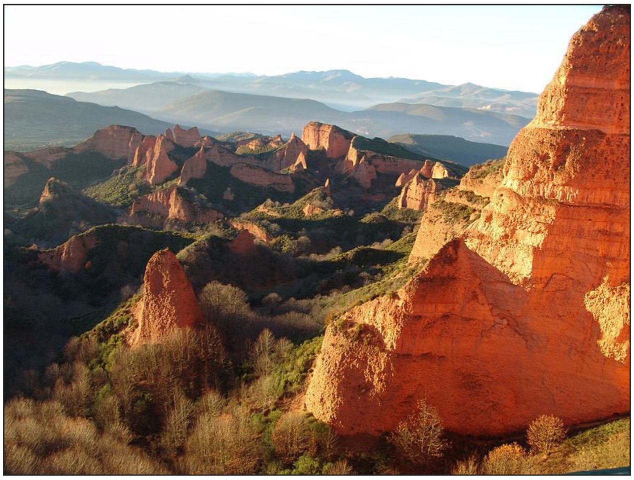
Underground Mining

Miners using jets of steam to melt the permafrost in an underground gold mine.

In areas where the ground is permanently frozen, such as in Siberia, Alaska, and the Yukon, placer deposits may be mined underground. As the frozen ground is otherwise too hard and firm to mine by hand, historically fires were built so as to thaw the ground before digging it. Later methods involve blasting jets of steam ("points") into the frozen deposits.

Environmental Effects

Although this procedure is 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.



View of Las Médulas.

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 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 "Dahlonega Method"). Most placer mines today use settling ponds, if only to ensure that they have sufficient water to run their sluicing operations.

In California, from 1853 to 1884, "hydraulicking" of placers removed an enormous amount of material from the gold fields, material that was carried downstream and raised the level of portions of the Central Valley by some seven feet in affected 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, the North Bloomfield Mining and Gravel Company case banned the flushing of debris into streams, and the hydraulic mining mania in California's gold country came to an end.

Examples:

- The Witwatersrand Basin in South Africa is an example of a placer deposit, as it is a 3 billion-year-old, alluvial sedimentary basin containing at least 70 ore minerals.
- The Klondike Gold Rush began in 1896 when nuggets of gold were found in the Klondike region of Alaska and the Canadian Yukon. The nuggets were found in running water, making the Klondike Gold deposit an alluvial placer mining deposit, which it soon became when 30,000 gold-seekers trekked the region.

SURFACE MINING

Surface mining is a form of mining in which the soil and the rock covering the mineral deposits are removed. It is the other way of underground mining, in which the overlying rock is left behind, and the required mineral deposits are removed through shafts or tunnels.

There are two basic classes of mining: mining at the Earth's surface and mining underground. Surface mining accounts for two thirds of the world's solid minerals, and is predominantly used in obtaining sand, gravel, crushed stone, phosphates, coal, copper, iron and aluminum.

There are 5 main types of surface mining, which are used in various degrees and for different resources. These mining categories are: strip mining, open-pit mining, mountaintop removal, dredging and high wall mining. All methods of surface mining will remove the waste material, or overburden, above the desired resource.

Surface mining is often preferred to sub-surface (underground mining) by mining companies for several reasons. It is less expensive, there are fewer complications in terms of electricity and water and it is safer.

Open-pit Mining

Open-pit mining is the most common type of surface mining. An open-pit mine is exactly what the name implies: a big hole (or pit) in the ground.

The pit in an open-pit mine is created by blasting with explosives and drilling. This type of mining is typically used to mine gravel and sand and even rock (when open-pit mining is used to extract rock from the earth, the pit is often called a "quarry").

High Wall Mining

High wall mining is a combination of surface mining techniques and sub-surface techniques. The basic idea is you start with an open-pit mine, and then drill or bore into those walls to extract more resources.

High Wall mining is performed remotely by a person in a cabin at the surface who uses a television camera to monitor and control the continuous miner machine.

Dredging

Dredging is the process of mining materials from the bottom of a body of water, including rivers, lakes, and oceans.

Strip Mining

Strip mining is the process of removing a thin strip of overburden (earth or soil) above a desired deposit, dumping the removed overburden behind the deposit, extracting the desired deposit, creating a second, parallel strip in the same manner, and depositing the waste materials from that second (new) strip onto the first strip. And so on.

Strip mining is using a lot for coal, phosphates, clays, and tar mining.

Mountaintop Removal

This is an alternative, and more recent, version of strip mining.

As the main suggests, mountaintop removal mining involves removing the top of steep mountains to expose desired deposits below. The excavated overburden from the mountaintop is deposited in nearby low valley areas known as "valley fills".

This method is for the most part confined to coal mining in the Appalachian region of the United States.

Common Physical Characteristics of Surface Mines

Surface mines have a unique physical terrain, and the specialized terms are used to describe the features of the surface mining environment.

Those terms include:

- Angle of repose
- Bench
- Berm
- Haul road
- Highwall
- Pit
- Settling pond/tank
- Stockpile
- Wastepile

Common Equipment used in Surface Mining

There's a specialized and diverse set of equipment commonly used during the surface mining process.

Equipment at a surface mine includes:

- Backhoes
- Bins
- Classifiers
- Cone crushers
- Cranes
- Dozers

- Draglines
- Dredges
- Feeders
- Front-end loaders
- Fuel tanks
- Generators
- Haul trucks
- Hoppers
- Human transport
- In-pit conveyor systems
- Jaw crushers
- Maintenance and repair shops
- Overland conveyor systems
- Scrapers
- Screw conveyors
- Shovels
- Skid steers
- Track haulage
- Truck and wheel washes
- Truck scales
- Water reclamation systems

Open-pit Mining

Open cut mining is a surface mining technique of extracting rock or minerals from the earth by their removal from an open pit or borrow.

This form of mining differs from extractive methods that require tunnelling into the earth, such as long wall mining. Open-pit mines are used when deposits of commercially useful ore or rocks are found near the surface. It is applied to ore or rocks found at the surface because the overburden is relatively thin or the material of interest is structurally unsuitable for tunnelling (as would be the case for sand, cinder, and gravel). In contrast, minerals that have been found underground but are difficult to retrieve due to hard rock, can be reached using a form of underground mining.

To create an open-pit mine, the miners must determine the information of the ore that is underground. This is done through drilling of probe holes in the ground, then plotting each hole location on a map. The information gained through the holes with provide an idea of the vertical extent of the ore's body. This vertical information is then used to pit tentative locations of the benches that will occur in the mine. It is important to consider the grade and economic value of the ore in the potential pit. Open-pit mines that produce building materials and dimension stone are commonly referred to as "quarries."

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, if the mine is situated in a climate of considerable precipitation or if any layers of the pit forming the mine border productive aquifers.

Open-pit mining is to be considered one of the most dangerous sectors in the industrial world. It causes significant effects to miners health, as well as damage to the ecological land. Open-pit mining causes changes to vegetation, soil, and bedrock, which ultimately contributes to changes in surface hydrology, groundwater levels, and flow paths. Additionally, open-pit produces harmful pollutants depending on the type of mineral being mined, and the type of mining process being used.

Extraction

Note the angled and stepped sides of the Sunrise Dam Gold Mine, Australia.

Open-cast mines are dug on benches, which describe vertical levels of the hole. The interval of the benches depends on the deposit being mined, the mineral being mined, and the size of the machinery that is being used. Generally, large mine benches are 12 to 15 metres thick. In contrast, many quarries do not use benches, as they are usually shallow. Mining can be conducted on more than one bench at a time, and access to different benches is done with a system of ramps. The width of each bench is determined by the size of the equipment being used, generally 20-40 metres wide. Downward ramps are created to allow mining on a new level to begin. This new level will become progressively wider to form the new pit bottom.

Most walls of the pit are generally mined on an angle less than vertical. Waste rock is stripped when the pit becomes deeper, therefore this angle is a safety precaution to prevent and minimize damage and danger from rock falls. However, this depends on how weathered and eroded the rocks are, and the type of rocks involved. It also depends on the amount of structural weaknesses occur within the rocks, such as a faults, shears, joints or foliations.

Heavy machinery extracting lignite from Garzweiler surface mine in Germany during 2008.

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

Waste

Open-pit mines create a significant amount of waste. Almost one million tons of ore and waste rock can move from the largest mines per day, and a couple thousand tons moved from small mines per day. There is generally four main operations in a mine that contribute to this load: drilling, blasting, loading and hauling.

Waste rock is hauled to a waste dump. Waste dumps can be piled at the surface of the active pit, or in previously mined pits.

Leftover waste from processing the ore is called tailings, and is generally in the form of a slurry. This is pumped to a tailings dam or settling pond, where the water is reused or evaporated. Tailings dams can 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. If proper environmental protections are not in place, this toxicity can harm the surrounding environment.

Pollutants

Open-pit mining involves the process of disrupting the ground, which leads to the creation of air pollutants. The main source of air pollutants comes from the transportation of minerals, but there are various other factors including drilling, blasting and the loading and unloading of overburden. These type of pollutants cause significant damage to public health and safety in addition to damaging the air quality. The inhalation of these pollutants can cause issues to the lungs and ultimately increase mortality. Furthermore, the pollutants affect flora and fauna in the areas surrounding open-pit mines.

Open-pit gold mining is one of the highest potential mining threats on the environment as it affects the air and water chemistry. The exposed dust may be toxic or radioactive, making it a health concern for the workers and the surrounding communities.

Untopping

A form of open-cast quarrying may be carried out as 'untopping'. This is done where a previous underground mine is becoming uneconomic or worked-out, but still leaves valuable rock in place, often as a result of room and pillar mining. Untopping removes the overburden from above this, opens up the mine from above, and then allows the previously 'trapped' minerals to be won.

Untopping was a feature of Welsh slate workings in the 1930s and 2000s, where Martyn Williams-Ellis, manager at Llechwedd found that earlier Victorian workings could be kept profitable with the newly mechanised techniques for bulk excavation to extract their pillars, and more recently across a number of worked-out mines.

Rehabilitation

Opencut coal mine loadout station and reclaimed land at the North Antelope Rochelle coal mine in Wyoming, United States.

After mining finishes, the mine area may undergo land rehabilitation. Waste dumps are contoured to flatten them out, to further stabilize 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 oxidize 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. Instead of returning the land to its former natural state, it may also be reused, converting it into recreational parks or even residential/mixed communities.

An open-pit sulfur mine at Tarnobrzeg, Poland undergoing land rehabilitation.

Mountaintop Removal Mining

Mountaintop removal mining (MTR), also known as mountaintop mining (MTM), is a form of surface mining at the summit or summit ridge of a mountain. Coal seams are extracted from a mountain by removing the land, or overburden, above the seams. This method of coal mining is conducted in the Appalachian Mountains in the eastern United States. Explosives are used to remove up to 400 vertical feet (120 m) of mountain to expose underlying coal seams. Excess rock and soil is dumped into nearby valleys, in what are called "holler fills" or "valley fills". Less expensive to execute and requiring fewer employees, mountaintop removal mining began in Appalachia in the 1970s as an extension of conventional strip mining techniques. It is primarily occurring in Kentucky, West Virginia, Virginia, and Tennessee.

The practice of mountaintop removal mining has been controversial. The coal industry cites economic benefits and asserts that mountaintop removal is safer than underground mining. Published scientific studies have found that mountaintop mining has serious environmental impacts that mitigation practices cannot successfully address. A high potential for human health impacts has also been reported.

Mountaintop removal mining (MTR), also known as mountaintop mining (MTM), is a form of surface mining that involves the topographical alteration and/or removal of a summit, hill, or ridge to access buried coal seams.

The MTR process involves the removal of coal seams by first fully removing the overburden lying atop them, exposing the seams from above. This method differs from more traditional underground mining, where typically a narrow shaft is dug which allows miners to collect seams using various underground methods, while leaving the vast majority of the overburden undisturbed. The overburden from MTR is either placed back on the ridge, attempting to reflect the approximate original contour of the mountain, and it is moved into neighboring valleys.

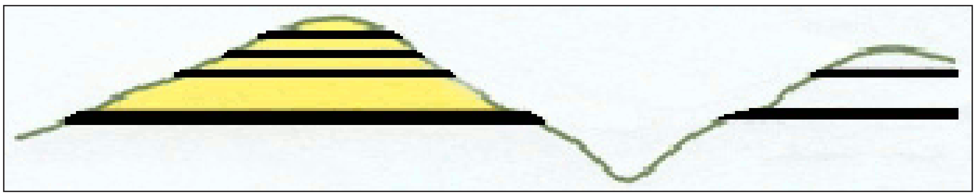
Excess rock and soil containing mining byproducts are disposed into nearby valleys, in what are called "holler fills" or "valley fills".

MTR in the United States is most often associated with the extraction of coal in the Appalachian Mountains, where the United States Environmental Protection Agency (EPA) estimates that 2,200 square miles (5,700 km^2) of Appalachian forests will be cleared for MTR sites by the year

2012. Sites range from Ohio to Virginia. It occurs most commonly in West Virginia and Eastern Kentucky, the top two coal-producing states in Appalachia, with each state using approximately 1,000 tonnes of explosives per day for surface mining. At current rates, MTR in the U.S. will mine over 1.4 million acres (5,700 km^2) by 2010, an amount of land area that exceeds that of the state of Delaware.

Mountaintop removal has been practiced since the 1960s. Increased demand for coal in the United States, sparked by the 1973 and 1979 petroleum crises, created incentives for a more economical form of coal mining than the traditional underground mining methods involving hundreds of workers, triggering the first widespread use of MTR. Its prevalence expanded further in the 1990s to retrieve relatively low-sulfur coal, a cleaner-burning form, which became desirable as a result of amendments to the U.S. Clean Air Act that tightened emissions limits on high-sulfur coal processing.

Process



US EPA diagram of mountaintop mining: "Step 1. Layers of rock and dirt above the coal (called overburden) are removed". "Step 2. The upper seams of coal are removed with spoils placed in an adjacent valley". "Step 3. Draglines excavate lower layers of coal with spoils placed in spoil piles". "Step 4. Regrading begins as coal excavation continues". "Step 5. Once coal removal is completed, final regrading takes place and the area is revegetated".

Land is deforested prior to mining operations and the resultant lumber is either sold or burned. According to the Surface Mining Control and Reclamation Act of 1977 (SMCRA), the topsoil is supposed to be removed and set aside for later reclamation. However, coal companies are often granted waivers and instead reclaim the mountain with "topsoil substitute". The waivers are granted if adequate amounts of topsoil are not naturally present on the rocky ridge top. Once the area is cleared, miners use explosives to blast away the overburden, the rock and subsoil, to expose coal seams beneath. The overburden is then moved by various mechanical means to areas of the ridge previously mined. These areas are the most economical area of storage as they are located close to the active pit of exposed coal. If the ridge topography is too steep to adequately handle the amount of spoil produced then additional storage is used in a nearby valley or hollow, creating what is known as a *valley fill* or *hollow fill*. Any streams in a valley are buried by the overburden.

A front-end loader or excavator then removes the coal, where it is transported to a processing plant. Once coal removal is completed, the mining operators back stack overburden from the next area to be mined into the now empty pit. After backstacking and grading of overburden has been completed, topsoil (or a topsoil substitute) is layered over the overburden layer. Next, grass seed is spread in a mixture of seed, fertilizer, and mulch made from recycled newspaper. Depending on surface land owner wishes the land will then be further reclaimed by adding trees if the pre-approved post-mining land use is forest land or wildlife habitat. If the land owner has requested other post-mining land uses the land can be reclaimed to be used as pasture land, economic development or other uses specified in SMCRA.

Because coal usually exists in multiple geologically stratified seams, miners can often repeat the blasting process to mine over a dozen seams on a single mountain, increasing the mine depth each time. This can result in a vertical descent of hundreds of extra feet into the earth.

Economics and Legislation

As of 2015, approximately one third of the electricity generated in the United States is produced by coal-fired power plants. MTR accounted for less than 5% of U.S. coal production as of 2001. In some regions, however, the percentage is higher, for example, MTR provided 30% of the coal mined in West Virginia in 2006.

Historically in the U.S. the prevalent method of coal acquisition was underground mining which is very labor-intensive. In MTR, through the use of explosives and large machinery, more than two and a half times as much coal can be extracted per worker per hour than in traditional underground mines, thus greatly reducing the need for workers. In Kentucky, for example, the number of workers has declined over 60% from 1979 to 2006 (from 47,190 to 17,959 workers). The industry overall lost approximately 10,000 jobs from 1990 to 1997, as MTR and other more mechanized underground mining methods became more widely used. The coal industry asserts that surface mining techniques, such as mountaintop removal, are safer for miners than sending miners underground.

Proponents argue that in certain geologic areas, MTR and similar forms of surface mining allow the only access to thin seams of coal that traditional underground mining would not be able to mine. MTR is sometimes the most cost-effective method of extracting coal.

Several studies of the impact of restrictions to mountaintop removal were authored in 2000 through 2005. Studies by Mark L. Burton, Michael J. Hicks and Cal Kent identified significant state-level tax losses attributable to lower levels of mining (notably the studies did not examine potential environmental costs, which the authors acknowledge may outweigh commercial benefits). Mountaintop removal sites are normally restored after the mining operation is complete, but "reclaimed soils characteristically have higher bulk density, lower organic content, low water-infiltration rates, and low nutrient content".

In the United States, MTR is allowed by section 515(c)(1) of the Surface Mining Control and Reclamation Act of 1977. Although most coal mining sites must be reclaimed to the land's pre-mining contour and use, regulatory agencies can issue waivers to allow MTR. In such cases, SMCRA dictates that reclamation must create "a level plateau or a gently rolling contour with no highwalls remaining".

Different organizations have tried to revise a stream buffer rule placed in 1977. The rule states that certain conditions must be met, or the mining operation must take place "within 100 feet of a stream". The Obama Administration, in July 2015, wrote up a draft "Stream Protection Rule". This draft adds "more protections to downstream waters", but it will also debilitate the current buffer requirements.

In February 2017, President Trump signed a bill that did away with the stream protection rule previously administered by the Obama Administration.

Permits must be obtained to deposit valley fill into streams. On four occasions, federal courts have ruled that the US Army Corps of Engineers violated the Clean Water Act by issuing such permits. Massey Energy Company is currently appealing a 2007 ruling, but has been allowed to continue mining in the meantime because "most of the substantial harm has already occurred," according to the judge.

The Bush administration appealed one of these rulings in 2001 because the Act had not explicitly defined "fill material" that could legally be placed in a waterway. The EPA and Army Corps of Engineers changed a rule to include mining debris in the definition of fill material, and the ruling was overturned.

On December 2, 2008, the Bush Administration made a rule change to remove the Stream Buffer Zone protection provision from SMCRA allowing coal companies to place mining waste rock and dirt directly into headwater waterways.

A federal judge has also ruled that using settling ponds to remove mining waste from streams violates the Clean Water Act. He also declared that the Army Corps of Engineers has no authority to issue permits allowing discharge of pollutants into such in-stream settling ponds, which are often built just below valley fills.

On January 15, 2008, the environmental advocacy group Center for Biological Diversity petitioned the United States Fish and Wildlife Service (FWS) to end a policy that waives detailed federal Endangered Species Act reviews for new mining permits. Under current policy, as long as a given MTR mining operation complies with federal surface mining law, the agency presumes conclusively, despite the complexities of intra- and inter-species relationships, that the instance of MTR in question is not damaging to endangered species or their habitat. Since 1996, this policy has exempted many strip mines from being subject to permit-specific reviews of impact on individual endangered species. Because of the 1996 Biological Opinion by FWS making case-by-case formal reviews unnecessary, the Interior's Office of Surface Mining and state regulators require mining companies to hire a government-approved contractor to conduct their own surveys for any potential endangered species. The surveys require approval from state and federal biologists, who provide informal guidance on how to minimize mines' potential effects to species. While the agencies have the option to ask for formal endangered species consultations during that process, they do so very rarely.

On May 25, 2008, North Carolina State Representative Pricey Harrison introduced a bill to ban the use of mountaintop removal coal from coal-fired power plants within North Carolina. This proposed legislation would have been the only legislation of its kind in the United States; however, the bill was defeated.

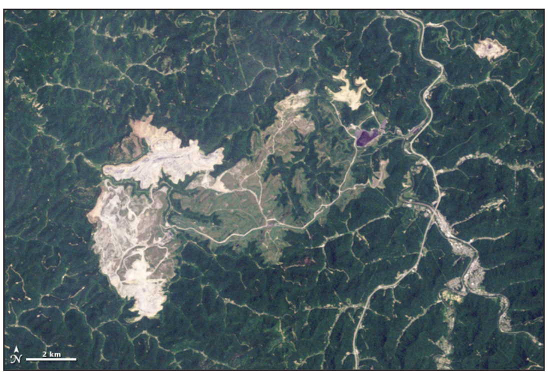
A Memorandum of Understanding (MOU) and Interagency Action Plan (IAP) were signed by officials of EPA, the Corps, and the Department of the Interior on June 11, 2009. The MOU and IAP outlined different administrative actions that would help decrease "the harmful environmental impacts of mountaintop mining". The plan also includes near and long-term actions that highlight "specific steps, improved coordination, and greater transparency of decisions".

The U.S. Energy Information Administration (EIA) stated that the Clean Water Rule was completed on May 27, 2015 by the U.S. Environmental Protection Agency (EPA) and the U.S. Army. The Clean Water Rule "more precisely defines waters protected under the Clean Water Act". The EIA also stated that the Office of Surface Mining Reclamation and Enforcement (OSMRE), the EPA and the U. S. Army Corps of Engineers are collaborating with each other to make an environmental impact statement (EIS) "analyzing environmental impacts of coal surface mining in the Appalachian region".

On Tuesday, April 9, 2019, the Subcommittee on Energy and Mineral Resources held a legislative hearing, "*Health and Environmental Impacts of Mountaintop Removal Mining"*. This hearing involved the H.R. 2050 bill. This bill stated that "until health studies are conducted by the Department of Health and Human Services", there will be a suspension on permitting for mountaintop removal coal mining.

Environmental and Health Impacts

The Hobet mine in West Virginia in 1984.



The Hobet mine in West Virginia in 2009.

Critics

Critics contend that MTR is a destructive and unsustainable practice that benefits a small number of corporations at the expense of local communities and the environment. Though the main issue has been over the physical alteration of the landscape, opponents to the practice have also criticized MTR for the damage done to the environment by massive transport trucks, and the environmental damage done by the burning of coal for power.

Blasting at MTR sites also expels dust and fly-rock into the air, which can disturb or settle onto private property nearby. This dust may contain sulfur compounds, which corrodes structures and is a health hazard.

A January 2010 report in the journal *Science* reviews current peer-reviewed studies and water quality data and explores the consequences of mountaintop mining. It concludes that mountaintop mining has serious environmental impacts that mitigation practices cannot successfully address. For example, the extensive tracts of deciduous forests destroyed by mountaintop mining support several endangered species and some of the highest biodiversity in North America. There is a particular problem with burial of headwater streams by valley fills which causes permanent loss of ecosystems that play critical roles in ecological processes.

In addition, increases in metal ions, pH, electrical conductivity, total dissolved solids due to elevated concentrations of sulfate are closely linked to the extent of mining in West Virginia watersheds. Declines in stream biodiversity have been linked to the level of mining disturbance in West Virginia watersheds.

Published studies also show a high potential for human health impacts. These may result from contact with streams or exposure to airborne toxins and dust. Adult hospitalization for chronic pulmonary disorders and hypertension are elevated as a result of county-level coal production. Rates of mortality, lung cancer, as well as chronic heart, lung and kidney disease are also increased. A 2011 study found that counties in and near mountaintop mining areas had higher rates of birth defects for five out of six types of birth defects, including circulatory/respiratory, musculoskeletal, central nervous system, gastrointestinal, and urogenital defects.

These defect rates were more pronounced in the most recent period studied, suggesting the health effects of mountaintop mining-related air and water contamination may be cumulative. Another 2011 study found "the odds for reporting cancer were twice as high in the mountaintop mining environment compared to the non mining environment in ways not explained by age, sex, smoking, occupational exposure, or family cancer history".

Impact Statement

A United States Environmental Protection Agency (EPA) environmental impact statement finds that streams near some valley fills from mountaintop removal contain higher levels of minerals in the water and decreased aquatic biodiversity. Mine-affected streams also have high selenium concentrations, which can bioaccumulate and produce toxic effects (e.g., reproductive failure, physical deformity, mortality), and these effects have been documented in reservoirs below streams. Because of higher pH balances in mine-affected streams, metals such as selenium and iron hydroxide are rendered insoluble, bringing attendant chemical changes to the stream.

The statement also estimates that 724 miles (1,165 km) of Appalachian streams were buried by valley fills between 1985 and 2001. On September 28, 2010, the U.S. Environmental Protection Agency's (EPA) independent Science Advisory Board (SAB) released their first draft review of EPA's research into the water quality impacts of valley fills associated with mountaintop mining, agreeing with EPA's conclusion that valley fills are associated with increased levels of conductivity threatening aquatic life in surface waters.

Reclamation

Established in 1977, the Surface Mining Control and Reclamation Act set up a program "for the regulation of surface mining activities and the reclamation of coal-mined lands". Although U.S. mountaintop removal sites by law must be reclaimed after mining is complete, reclamation has traditionally focused on stabilizing rock formations and controlling for erosion, and not on the reforestation of the affected area. However, the Surface Mining Control and Reclamation Act of 1977 list "the restoration of land and water resources" as a priority. Fast-growing, non-native flora such as *Lespedeza cuneata*, 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. In addition, reintroduced elk (*Cervus canadensis*) on mountaintop removal sites in Kentucky are eating tree seedlings.

Advocates

Advocates of MTR claim that once the areas are reclaimed as mandated by law, the area can provide 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 suited to support populations of game animals.

While some of the land is able to be turned into grassland which game animals can live in, the amount of grassland is minimal. The land does not retake the form it had before the MTR. As stated in the book *Bringing Down the Mountains*: "Some of the main problems associated with MTR include soil depletion, sedimentation, low success rate of tree regrowth, lack of successful revegetation, displacement of native wildlife, and burial of streams." The ecological benefits after MTR are far below the level of the original land.

Strip Mining

Strip Mining is the removal of soil and rock (overburden) above a layer or seam (particularly coal), followed by the removal of the exposed mineral.

The common strip-mining techniques are classified as area mining or contour mining on the basis of the deposit geometry and type. The cycle of operations for both techniques consists of vegetation clearing, soil removal, drilling and blasting of overburden, stripping, removal of the coal or other mineral commodity, and reclamation.

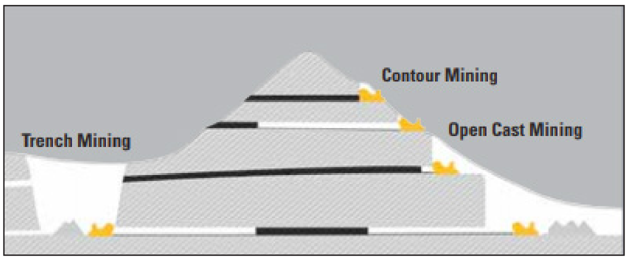
Area mining is appropriate for the extraction of near-surface, relatively flat-lying, and thin deposits of coal, phosphate, and similar minerals. Area mining usually progresses in a series of parallel deep trenches referred to as furrows or strips. The length of these strips may be hundreds of metres. Contour mining progresses in a narrow zone following the outcrop of a mineral seam in mountainous terrain.

In the past, strip-mined mineral deposits that became exhausted or uneconomical to mine often were simply abandoned. The result was a barren sawtooth, lunarlike landscape of spoil piles hostile to natural vegetation and generally unsuitable for any immediate land use. Such spoil areas are now routinely reclaimed and permanent vegetation reestablished as an integral part of surface-mining operations. Generally, reclamation is performed concurrently with mining.

High Wall Mining

Highwall mining is a proven primary method for mining coal from outcropping horizontal seams. In this method of mining, an unmanned continuous miner is driven underground and operated in front of the highwall. The highwall mining machine stands on the pit floor or on a bench, directly in front of the exposed seam and makes long parallel rectangular drives into the coal seam. A remote-operated cutter module is pushed into the seam by a string of push beams (unmanned coal-conveying elements) that transport the mined coal back to the entry of the drive onto a stockpile. The whole mining cycle is completed by a three- or four-man crew, with no personnel going underground at any time.

The self-contained Cat highwall mining system offers an innovative method for extracting coal from outcropping seams in a multitude of applications.



Whether you're operating a trench, open cast or contour mine, the Cat highwall mining system can extract coal affordably and safely:

- Open cast: Highwall mining is used to mine coal from underneath the final highwall, when the strip limit is reached due to economic reasons or surface conditions.
- Contour mining: In a mountainous area, the Cat highwall mining system can follow a coal seam along the side of the hill.
- Trench mining: The unit mines coal from both sides of a purpose-prepared trench; this mining method is used when an open pit is not an option.

Our highly skilled team is eager to assist you to determine the feasibility of your highwall mining project. The Caterpillar team uses an evaluation of your geological data and site plan to determine how best to use a Cat highwall mining system. We can even assist you to develop a mine plan if you don't already have one.

Cat Highwall Mining System

The industry-leading Cat highwall mining system is a new, low-cost addition to traditional mining methods. The system can produce 40,000-110,000 tonnes (44,000 to 121,000 tons) of coal per month, depending on seam height. Capable of full operation with a threeto four-man crew, the Cat highwall mining system averages 27 to 36 tonnes (30 to 40 tons) per man-hour. Innovative technologies, such as an effective cutter module and powerhead assembly, contribute to the system's outstanding productivity.

The Cat highwall mining system is designed for easy maintenance with a reliable, straightforward design and a comprehensive diagnostic system with troubleshooting capabilities to enhance uptime. Able to be disassembled in modules, the system can be transported over long distances. Everything about this highly efficient highwall mining system is engineered to provide excellent return on investment.

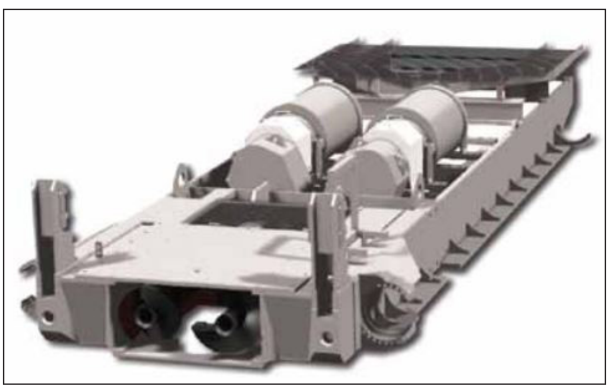
Machine Service and Support

Every Cat highwall mining system is backed by 24/7 support from our highly skilled and experienced staff. Our large warehouse is fully stocked with spare parts to ensure the highest levels of machine uptime. Service and parts back-up can be tailored to your needs.

Proven Cutter Module

Caterpillar offers two electric cutter modules: a low-seam cutter for seams 0.76 – 1.62 m (2.5 – 5.3 ft) in height and a high-seam cutter module to mine 1.3 – 3.05 m (4.3 – 10 ft) seams. The cutter modules are interchangeable and quickly attached to the powerhead assembly. The cutting cycle is fully automated, yet allows the operator to manually adjust the machine function using an ampere reading as the coal seam varies. This proven technology allows the cutter module to accurately follow the coal seam and produce a clean product.

Heavy-duty Powerhead Assembly



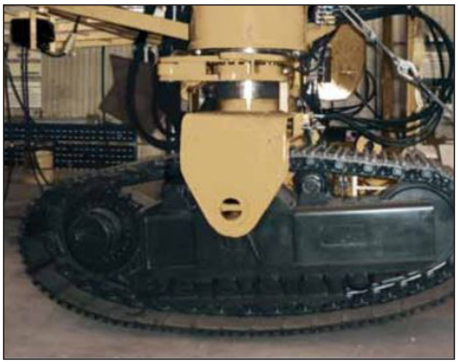
Heavy-duty powerhead assembly.

The powerhead drives the cutter module and push beam string forward using two hydraulically-powered sump cylinders with a 6.85 m (22.47 ft) stroke. At 276 bars of hydraulic pressure, a pushing force of 136/276 tonnes (150/304 tons) pulling force propels the cutter module to depths of more than 300 m (1,000 ft).

Advanced Technology

An optional Gamma Ray Detection system can be used to guide the cutter module through the coal seam, leaving predetermined amounts of coal in the roof and floor, if required. This system also allows the mining of coal in soft roof and soft floor situations.

For even more accurate directional mining operation, Caterpillar offers an optional solid-state, fiber-optic, gyro-based navigation and steering system. This provides operators with very precise cutter module location data in real time for enhanced cutter module steering and pillar width control.



Tram mode.

Excellent Mobility

The Cat highwall mining system is an agile, self-propelled machine that operates on contour benches as narrow as 18 m (59 ft). It trams easily from entry to entry and discharges coal in tight spaces.

An optional right-angle conveyor system discharges coal on the right or left side on narrow benches. It can also discharge onto a stacking conveyor system, where coal is moved to the center of the bench for stockpiling large volumes.

Mine mode.

Four heavy-duty, hydraulically-powered tracks articulate independently in two operating modes – mine mode and tram mode – and can rotate the machine 360°, which improves maneuverability in congested areas. Mine mode is used for moving parallel to the highwall, while tram mode is used when moving from pit to pit.

Operator Comfort

The Cat highwall mining system is equipped with a comfortable, air-conditioned cab that offers a full view of the mining operation and the highwall. The fullsuspension operator seat and the two user-friendly touchscreens create an ergonomic workplace, placing controls and system information at the operator's fingertips.

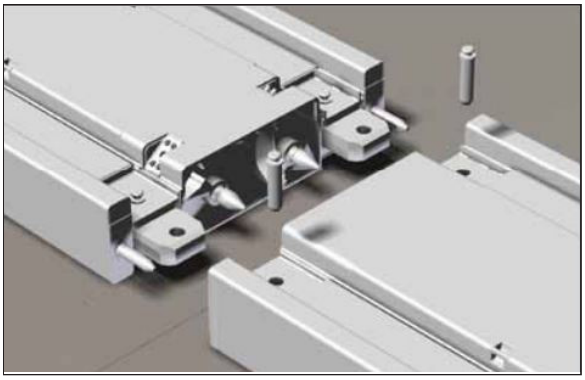
User-friendly touch screens.

Dependable Push Beams

Cat push beams are 6 m long (20 ft), rectangular, reinforced steel box structures joined together to form a string, which connects the highwall mining system to the cutter assembly. The push beam string is the backbone of the machine; pushing and pulling the cutter module in and out of the highwall with retract forces up to 363 tonnes (400 tons) at 345 bars. The push beams also transport mined coal and support the hose chain that supplies control and power to the cutter.

Moving coal inside the push beam (via a pair of screw conveyors) protects the coal from contamination and the moving mechanical parts from rock debris, resulting in higher availability. Other Cat push beam advantages include:

- A strong method of attachment that is secured and disengaged quickly.
- A horizontal hinge design that allows the string and cutter to navigate through coal seam rolls and undulations.
- Structural rigidity that ensures mining in parallel drives.
- A simple design free of electrical and hydraulic connections.
- Push beams that can be stacked six high for storage in narrow worksites, even under tough pushing and pulling conditions.



Push beams.

Robust Reel and Chain

A steel-armored hose chain stores and protects all electric power cables, hydraulic and water lines, and the control cable to the cutter module. The hose chain is automatically unrolled and retracted on a reel during mining.

Reel and chain.

Control System with Diagnostics

The Cat highwall mining system's operation is controlled by a Programmable Logic Controller, which provides reliable performance for greater uptime. A comprehensive diagnostics system, including troubleshooting assistance, streamlines maintenance procedures.

Anchoring System

Two drills mounted on the front of the machine are used to drill into the pit floor up to 2.5 m (8.2 ft). High-strength pins are then inserted through the base frame into the pit floor to help stabilize the machine and to maintain its accurate position, even under tough pushing and pulling conditions.

Easy Equipment Relocation

For quick relocation over long distances, the Cat highwall mining system can be taken apart in modules. Rapid disassembly and reassembly is facilitated by convenient hydraulic and electrical connectors, and all modules are sized for transport using regular public roads. Depending on local conditions, the system can also be transported between sites and without disassembly by heavy haul trucks.


Remote operation.

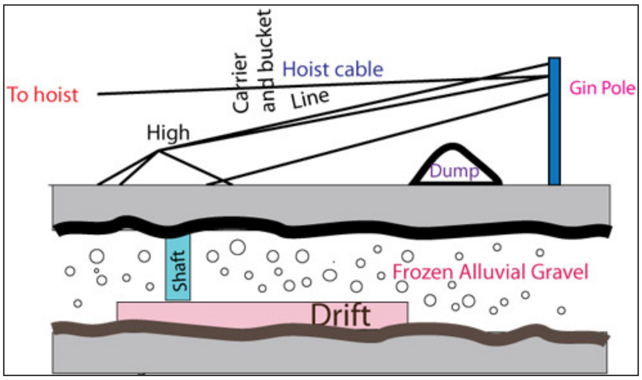
Specialized Training

Our operational and technical training covers every aspect of the Cat highwall mining system. We offer a two-week training program from our Beckley, West Virginia, USA, facility to new customers and to existing customers as a refresher. We can also offer a tailored program at your location.

- Push Beam String Holding System: When mining on a dipping seam, this option prevents the push beam string and cutter module from sliding back down into the mined entry when disconnected from the power head.
- Gamma Ray Sensors: A direct-ship product is produced with rock and debris left underground when gamma sensors are used in either a top and floor application.
- Tropical Package: For hot-climate applications, this package extends the operating temperature of the equipment up to 55° C (131° F).
- Arctic Package: For extreme-cold climates, this package extends the operating temperature to -40° C (-40° F). Infrared or electrical heaters are equipped for the cab, BPM, generating set and working platforms. Hydraulic oil is circulated, cylinders are insulated and heat-tracing cables are added.
- Right-Angle Discharge: This feature discharges coal to the right or left of the machine.
- Stacker Belt: This is a heavy-duty conveyor that moves coal from the right angle conveyor to produce a surge pile for loading coal into trucks.
- Push Beam Grapple: This tool is mounted to the front of a wheel loader to provide safe and efficient transportation of push beams to and from the highwall mining system.
- Generator Set: A self-contained, trailer-mounted generator system provides electrical power to the highwall mining system in remote locations where connection to a utility grid is not practical. It includes a 16-cylinder Cummins diesel engine with a 4,160 V, 1,500 kW alternator, a fuel supply tank and all required electrical switch gear, packaged in a silenced container.

SHAFT MINING

Shaft mining is a form of underground mining where shafts are pushed vertically from top to bottom to excavate the ores and minerals. It is also called shaft sinking. It is best suited for concentrated minerals such as iron, coal, etc. which can be found at the depth of the earth's surface. It is found mostly all over the world. Shaft sinking refers to shallow shafts and it is different from a deep shaft. The former is sunk for the civil engineering projects and the latter is sunk for the mining projects. When the excavation is done on the ground surface, it is called a shaft and if it is on the underground it is called a sub-shaft. This is also known by the name Winze.



This mine is allotted with different compartments. The main compartment which is called a central compartment is used as a lift or an elevator for the workers and the equipments to be transported in and out of the mine. A secondary compartment is used to transport the extracted ores and other materials out of the mines. Last but not the least a third shaft is reserved as an emergency exit. It is also used to transport all kinds of pipes, water, fuels etc.

The shaft is either inclined or vertical. However, most modern shafts are vertical .To excavate the ore from the depths and with ground conditions favorable shafts are raised from the bottom to the top. This is called borehole shafts. Raise boring is a method by which small shafts are taken out of an existing mine as long as there is access at the bottom. Shaft sinking is one of the dangerous forms of mining and involves a lot of risk. This method is now mainly carried out in Canada and South Africa.

Off-shaft Access

It is necessary to take into consideration the capability of the mine shaft to penetrate deep into underground mining. The process by which the horizontal working off the shaft is referred to as drifts, galleries or levels. It spreads from the central shaft towards the place where the ore is available in abundance. The exact place where the shaft and these levels meet is called the inset, shaft station or plat.

Surface facilities

The surface over the shaft is occupied by a building called the head frame. Depending upon the capacity of the device used the top of the frame will have to either a hoist motor or a sheave wheel. The ore extracted is stored in a bin provided in the head frame and this ore is moved to the dealing out facility. The shaft is used for many purposes. If it is used for ventilation of the mine a plenum or casing is combined with the head frame to allow the proper flow of air in and out of the mine.

Shaft Lining

Several important functions are performed by shaft lining. This lining acts as a safety layer preventing the fall of loose or unstable rocks into the shaft. It is also a place for shaft sets to be bolted into and it is a smooth surface to allow free flow of air for ventilation. Shaft lining is almost always dependent on the geology of the rock. In rocks where no support is needed for opening, shaft lining has no role to play.

In North America and South America smaller shafts are used which is rectangular in shape and larger ones are round with concrete lining. Several materials are used to line the shaft like shotcrete, fibrecrete, brick, cast iron tubing and concrete segments. Under specific circumstances materials like bitumen and squash balls are also used. When circumstances are extreme, liners consisting of two or more materials are required. The shaft liner during sinking does not reach the bottom of the shaft and stays away at a distance before reaching the spot. The distance to be covered is determined by the methodology of excavation. The safety of the workers is also taken care by installing temporary ground support consisting of welded mesh and rock bolts. The most challenging part is the installation of temporary ground support. This is done by pneumatic powered rock drills. Due to this number of workers working on the shaft bottom is minimized. As a result many projects are depending on shotcrete for this temporary lining. Even robotic application of shotcrete is being considered.

Shaft Compartments

Shafts are usually split into compartments when it is used for hoisting. They are divided into multiple compartments that are made either of timber or steel. Shaft sets are either vertical or horizontal. Vertical members are called Guides or horizontal members are called Buntons. Hollow structural sections and top hat sections are the two main options for steel shaft guides. Top hat sections have more advantages than hollow structural sections. It includes simpler installation, increased stiffness and it is also more resistant to corrosion. Wire ropes also referred to as Guide ropes are used instead of guide beams as they are easy to replace and also to maintain.

The largest compartment is used for moving workers and the minerals extracted from the mines. They bear a close resemblance to the elevators. In order to avoid any emergency the cages may be single, double or even triple deck. In case of unexpected failure, they can make use of this safety system. The second compartment is used to hoist the ores to the surface. The third one is used for an emergency exit .This may have an additional cage or ladders .This is used for moving pipes, cable, transfer of water, compressed air, diesel fuel, etc.

Ventilation is very necessary during the entire mining process and this is why the shafts are divided into compartments. These compartments are also used for the intake of air and also it may be used for the air to be exhausted. Even though many safety measures are taken to avoid all risk factors, it is advisable to have an alternate route to exit the mines. The shaft and the compartments are so closely connected and any problem in the shaft may affect the compartment.

CONTOUR MINING

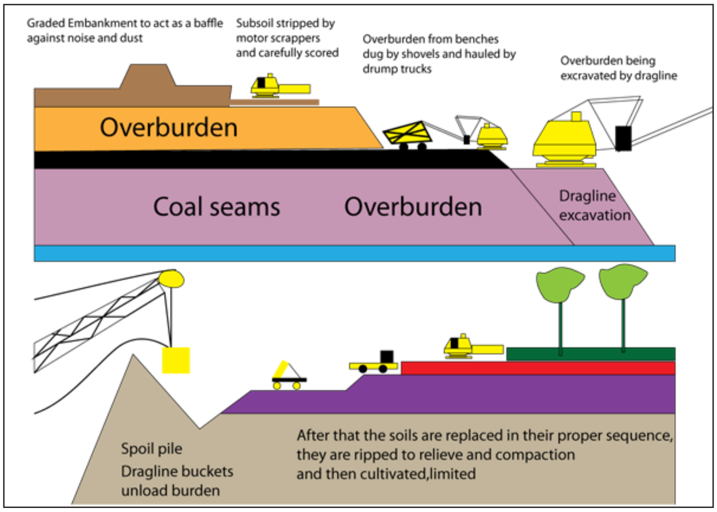
Coal is one of the most important mineral has been valued for many purposes since 1880's and it has been used to generate electricity and utilized for multipurpose operations. The process of Coal mining has developed over the years and different methods have been evolved to extract the mineral which is available in different terrains across the world. The most economical method of extracting coal depends upon the depth and the quality of the coal seams. Coals are mined both from surface and underground.

Contour mining is associated with coal. This bed of coal is located at an elevation in a mountain range or any other hilly area. It is a method of strip or surface mining. It is also referred to as Bench mining. The coal is extracted from a mountainous area where it is not possible to extract the entire seam using mountain top removal mining. Only partial coal removal is done by this method of mining. Most of the time it can be noticed that this kind of mining happens in many locations on the same mountain. It is a method by which the overburden is removed from the coal seam following the contours around a mountain or any hilly area.

The process of mining begins with the construction of road to reach the coal seam located at the mountain top. The excavations of bench in the mountain are first done by placing the mining equipments and then preparing a store for other facilities. Drills are placed from the top of the mountain so as to drill out all the overburdens and to place the explosives in the holes. They are then systematically exploded and thereby the rocks are blasted and carried and shifted to into large haul trucks and finally moved to a fill area. These unused rocks will later be used to refill the mining area. It is then restored back to its original position, the mountainous core. When the rock covering the coal seam is removed the mining of the coal is done and it is crushed and made into the appropriate size .It is finally sent to a preparation plant where the non –coal materials are removed. As far as this method of mining is concerned, it looks into various aspects when the planning of the mine is done in the initial stage.The first step taken is to minimize the surface disturbance .Then efforts are taken to control the effects after the mining process like dust, vibration of the blast, water runoff, and many other causes that can bring negative effect to the environment. To extract more coal, augering method is used to bore holes into the outcrop of the coal seam. Later on, these holes are filled and the contour bench is retrieved according to the state and federal laws. Steps are also taken to plant shrubs and trees in the center of the surface to improve the wildlife habitat.

The limitations of this method of mining are both economical and technical .When the burden undertaken exceeds the coal obtained, the result would be a financial loss. The equipment available may not be able to increase a certain height of the wall, and then it is advisable to shift to augering method.

This method of mining is more prevalent in the steep Appalachian region of the United States. This method first makes a cut on the slope after they find that there is deposit of coal in that particular area. First the overburden is removed and then the coal. This process continues till the proportion of overburden to coal becomes uneconomical. When the resources are exhausted completely the process comes to an end. Coal resources and the operator resources contribute equally to the completion of this process.



The most important equipments which are required for this method of mining are backhoes, shovels, and bulldozers which are all earth moving equipments. These equipments are generally used for many construction activities. The people who are involved in this business can opt out and re enter according to the change in the market condition.

The amount of waste accumulated after this method of mining is comparatively very high to open pit mining. During the process of removal of overburdens some of the compaction is lost. Even after the replacement the volume again increases. The pits are also not large enough to hold this material. As a result the contour miners must find places to dispose this waste in another fill or disposal area.

Economical aspects have to be taken into consideration when the area for mining is fixed. It can be practiced only in areas where it is uneconomical to remove the overburden from the coal seams. The excavation of the coal starts by first removing the overburden and then recovering the coal seams. Excavation helps to understand the depth of the mountain.

In the nineteenth and early twentieth century the coal mines were not that deep. Almost everywhere there were surface mines. Surface coal mining in the early twentieth century included contour mining, which removed the top layer of soil to get a coal seam. But after World War II surface coal mining was enveloped by auger mining, which is a normal part of contour operations. Surface mining was referred to as strip mining or stripping or sometimes as surface mining itself. They often failed to differentiate these different methods of mining. Sometimes it was also called contour mining as it was the closest form of surface mining in Appalachia.

In West Virginia this method of mining was introduced in the 1916 and it was supported by steam technology. In Tennessee this method started slowly but the production like any other mountain states eventually shot up. After the recession period in 1956 we can see that the number of contour operations doubled. However, this method of mining could benefit the states only with mountain ranges. In places where accessibility is not very easy and where no other method of mining can be done, contour mining still prevails as one of the most important methods to excavate coal.

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Mining Equipments

CHAPTER 4

Mining equipments are used to aid extraction of minerals through mining. Some of the common equipment used in mining are cone crusher, dragline excavator, load, haul, dump machine, haul truck and power shovel. This chapter closely examines these mining equipments to provide an extensive understanding of the subject.

CONE CRUSHER

The cone crusher, was designed primarily with a view to achieving top performance in the field of ne-reduction crushing. It has also been adapted to what is designated simply as “ne-crushing,” which extends into a range below that ordinarily defined by the term “ne-reduction.” Although the eccentric speeds of the various sizes of this type are not quite so high as the speeds used for the Newhouse crusher, the Hydro-cone crusher definitely rates as a high speed machine, its product comparing quite closely to that of the former type, for equal close-side settings. Probably the outstanding feature of the. Hydrocone crusher is the hydraulic support. This device makes it possible to adjust the crusher to any desired setting within its range in a matter of seconds; adjustments may be made while the crusher is running, although the feed must be shut off before operating the adjusting pump. An accumulator in the hydraulic system provides protection against tramp iron or packing.

Cone crushers are used in AG and SAG grinding circuits to increase tonnage by effectively dealing with any pebble (critical size) build-up problem. Normally, heavy duty short head crushers are employed to crush pebbles. Power and crusher cavity level are the key variables for monitoring and controlling the crusher operation. Crusher product size is adjusted by changing the closed side setting.

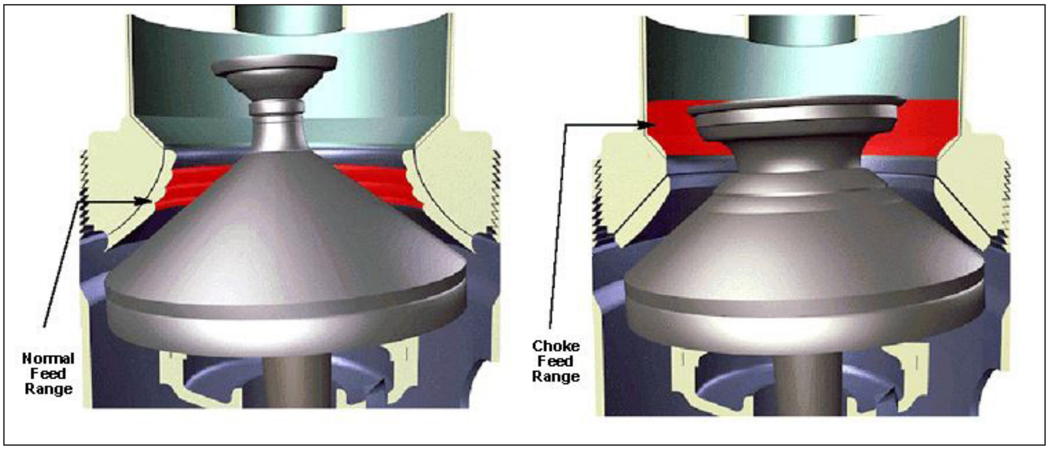
On the left is a diagram of the Hydro-cone crushing chamber. It will be noted that the choke-point has been raised far above the discharge level, in fact, to a point not far below the nip- point for the recommended maximum one-way feed dimension. By virtue of the decided are of the head, and the corresponding are of the top shell bore, the line-of-mean diameters slopes sharply away from the crusher centerline. For some, distance above the discharge point the angle between head and concave is very acute; in fact, at the open-side position of the head this zone is almost parallel.

For recommended operating conditions, i.e., for safe combinations of throw and setting, and with screened feed, this type of crushing chamber does not approach anything like a choke or near-choke condition. For the combination shown in the diagram the ratio of volume reduction is almost

1:1 from zone 0-1 to zone 2-3 at the choke-point; consequently, if the crusher is given a screened feed (as all ne-reduction crushers should be) the reduction in voids by the time the choke-point is reached cannot very well reach serious proportions. The diagram shows the standard chamber. With screened feed these crushers will operate at close-side discharge settings equal to the throw of the head at the discharge point (usually spoken of as "eccentric-throw").

The level in the crusher feed pocket is an important variable, since it can indicate whether the feed is building up. A build-up could lead to a plug in the feed chute, a spill through the skirting on the crusher feed, or a crusher plug. None of these are desirable.

In a normal feed situation the level in the crusher cavity is kept fairly low, just enough to ensure that there is sufficient feed to keep the crusher working, but if the feed has to be suspended suddenly because of impending plugging, the crush-out won't take too long (10 seconds or less). Normal feed is usually used in standard crushers where the feed particle size is quite large, say greater than 65 mm.

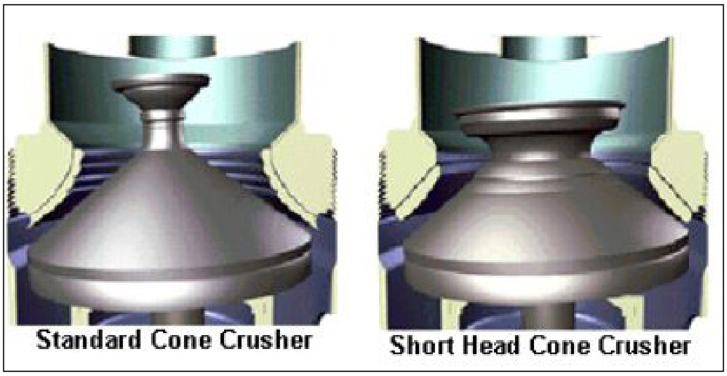


Choke feed is when the crusher cavity is kept full, without spilling out through the skirting. Choke feeding is usually used in short-head crushers where the feed particle is smaller than that for a standard crusher.

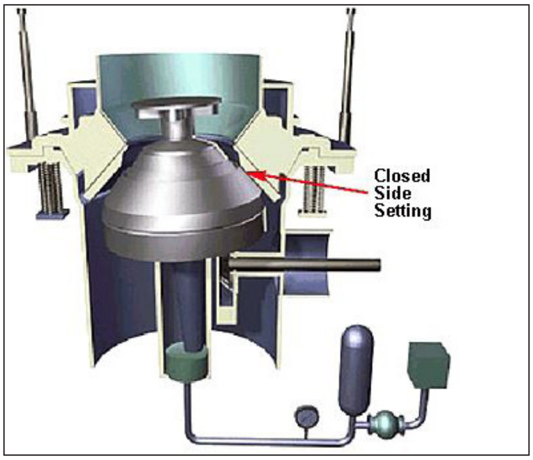
Medium and Fine Crushing Chamber

This crusher is a modification of the standard machine, developed for ne-crushing duty. Mechanically, the machine is the same in every respect as the standard crusher of the same type, but for each developed size of machine a special top shell and concave ring has been designed, with reduced receiving opening, reduced angularity between head and concave, and, consequently, superior characteristics at the finer settings. Medium crushing chambers may be operated at close side settings of one-half the eccentric-throw, on screened feed; hence capacities at the finer settings are better than those of the standard type. Fine crushing chambers operate at one-fourth the eccentric throw. Inasmuch as the maximum feed-size is smaller in the case of the ne chamber, the ratios of reduction are approximately the same for both machines.

There are two main types of cone crushers: standard and shorthead. They differ by the shape of the cavity. The standard crusher cavity is wider to accommodate larger feed size material. The short head crusher is designed to crush finer material and to produce a finer product.



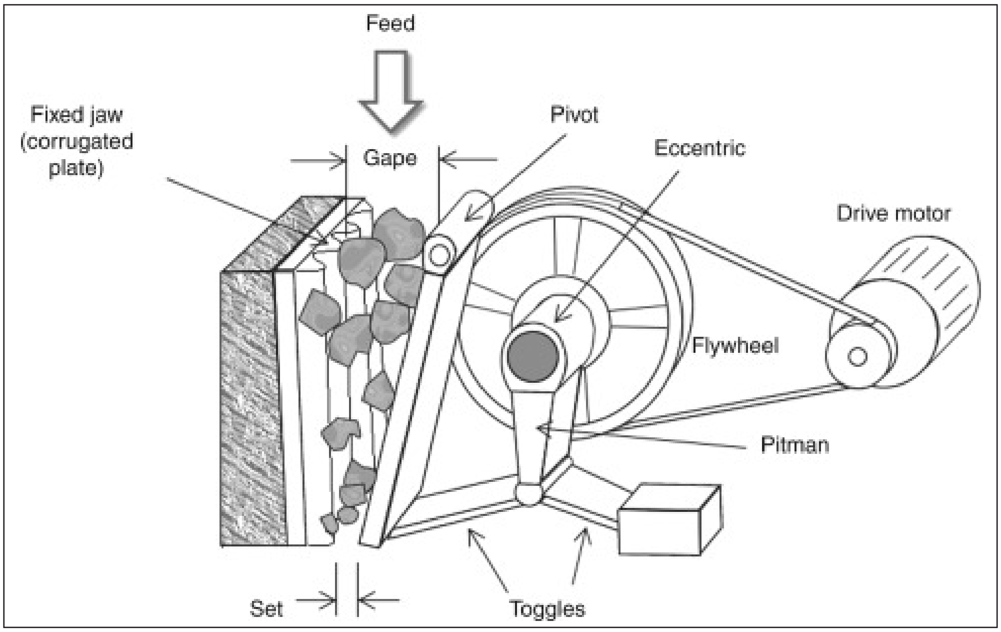
The closest approach between the mantle and the bowl liner is called the closed side setting. This is usually specified by the metallurgist to give the desired crusher product discharge size. It can be checked by running the crusher empty, hanging a lead plug into the crusher bowl, and then removing it to measure the "gap". The gap is adjusted by rotating the bowl. Some crushers are equipped with an hydraulic jack mechanism on the crushing head assembly instead of having a bowl adjustment ring. The head can be raised or lowered to meet the operator's needs. It can be very helpful in operation and process control.



An important variable is crusher cone rotational speed, which is usually measured on the motor drive pulleys. If the pulleys begin to slow down, this means that the drive belts are slipping or that the crusher may be beginning to plug. In either case, the operator should reduce tonnage and investigate the problem.

Cone Crushers

The Symons Cone Crusher has come into almost universal use during the last few years for the final stage of crushing. It is a development of the secondary gyratory crusher, which is merely a small gyratory crusher designed to break the product of the primary machine down to about 1½-in. size ; but the main shaft of a cone crusher instead of being suspended from a spider is supported on a large socket bearing situated immediately under the crushing head and protected from grit and dust by a sealing assembly, this bearing taking the whole of the crushing load.



Cone Crushers Overview.

It will be seen that the head and the bowl are parallel at the lower part of the crushing zone. The parallel space is deep enough, in conjunction with the speed of gyration, to ensure that no piece of ore can pass through it without being struck two or three times by the head before it falls clear. It follows that, unlike the jaw and gyratory crushers, the size of the product is determined by the distance apart of the bottom edges of the head and bowl in the position when they are closest together.

Coarse buttress threads on the outer circumference of the bowl t into corresponding threads on the inner side of the adjusting ring, which is held down to the main frame by a circle of long heavy springs, flexible enough to allow the whole assembly to rise should " tramp " iron or other uncrushable material enter the crushing zone. By means of a windlass and chain the bowl can be rotated in the threads that support it in the adjusting ring while the machine is running, thus enabling the bowl liner to be adjusted for wear or the size of the product to be changed without stopping. The cone crusher is usually set to give a 3/8-in. or ½-in. product when discharging to ball mills.

Symons Cone Crusher.

Figure gives a sectional view of the machine. The main shaft is carried in a long gear-driven eccentric, the rotation of which causes the gyration of the head in the usual way, but the centre of gyration is at the apex of the crushing head instead of in the spider. At the top of the bowl, therefore, the lumps of ore entering the crushing zone are cracked by short powerful strokes ; but at the bottom the head has a much longer but less powerful stroke, enabling the ore in the finishing stages to be rapidly crushed and quickly discharged without any tendency to choke, a condition which reduces over crushing to a minimum. This, together with the curved shape of the bowl, accounts for the large reduction ratio possible with this type of machine and makes it superior to other secondary crushers and coarse rolls.

A possible disadvantage of the cone crusher is that as a rule it cannot be choke-fed, but must be given an even feed of ore if it is to do efficient work. Should circumstances call for the installation of a machine which can be run if necessary with the ore piled up over the top of the head, a secondary gyratory crusher of the suspended shaft type will be required. The Traylor Reduction Crusher Type TZ, which is constructed on the principles of an ordinary gyratory crusher, but is fitted with a curved bowl liner similar to that of the Symons Cone Crusher, is designed to meet the case. Although the suspension of the shaft restricts the movement of the head to a smaller circle of gyration than that of the cone crusher, the ratio of reduction is still large enough to enable it to crush the product of the primary breaker to ½-in. size (¾-in. for the large machines), and it fulfils the condition that it can be choke-fed. Owing to the smaller movement of the head, however, the capacity for a given range is much less than that of the equivalent size of cone crusher and the latter is therefore preferred when choke-feeding can be avoided.

Symons Cone Crusher

The Symons Shorthead Cone Crusher, which is constructed on the same general principles as the larger machine, is designed to follow the latter, taking its product at 1-in. and reducing it to about ¼-in. size. The strains imposed on the crushing members, however, would be very heavy if the machine were run with the discharge opening set to ¼-in. or less. It is usual, therefore, to crush in closed circuit with a screen, the discharge opening of the bowl being set to 5/8 or ½ in. Thus a circulating load is built up and a certain amount of choke-crushing takes place, but the method actually gives greater efficiency with a finer product than can be obtained in an open circuit, whatever the discharge setting of the bowl in the latter case.

Cone crusher and jaw crusher process diagram.

In ordinary crushing practice the grinding section is supplied with ½-in. or 3/8-in. material direct from Symons Cone Crushers. But the demand is for a finer feed and it seems likely that the Short-head Cone Crusher will satisfy this demand to the exclusion of ne crushing rolls.

Symons Cone Crushers have been used extensively for secondary crushing in metallic, non-metallic, rock products and industrial operations. The Symons Cone was developed to give large capacity, ne crushing. The combination of high speed and wide travel of the cone results in a series of rapid, hammer-like blows on the material as it passes through the crushing cavity and permits free flow of material through the cavity.

Reduction in size of any particle, with each impact of the head, is regulated by the opening between the head and bowl at that point. A threaded arrangement of the bowl affords a quick and easy method for changing the size of product or to compensate for wear. This adjustment can be made while crusher is operating. A parallel zone between the lower portion of the crushing members assures uniform sizing.

Frame, adjustment ring and cone are made of cast steel; gears are made of special treated steel and have cut teeth; all bearings are bronze; mantle and bowl liners are manganese steel. The head and shaft can be removed as a unit, and other parts such as the eccentric and thrust bearings can easily be a complete unit.

The circle of heavy coil springs, which holds the bowl and adjustment ring down firmly onto the frame, provides automatic protection against damage due to tramp iron. These springs compress, allowing the bowl to rise the full movement of the head until non crushable material passes through. The springs then automatically return to their normal position.

Symons Cone Crushers are made in Standard and Short Head types. They are of the same general construction but differ in shape of the crushing cavity. The Standard cone is used for intermediate crushing. The Short Head cone is used for finer crushing. It has a steeper angle of the head, a shorter crushing cavity and greater movement of the head at the top of the crushing cavity.

Standard Cone Crusher Capacity

Table: Standard Cone Crushers.

Size	Dimensions			H.P	Full Load R.P.M.	Approx. Ship. Wt. Lbs.
	L	W	H			
20 In.	5.9 3″/16	4′2 1/2″	4′10 1/4″	20 to 25	650	7,700
2 Ft.	7′2 5/8″	4′5 1/8″	5′5 3/8″	25 to 30	575	10,000
3 Ft.	9′1 5/8″	6′2 1/2″	6′6 1/2″	50 to 60	580	21,000
4 Ft.	10′4 3/8″	7′6 1/4″	8′3 3/8″	75 to 100	485	35,000
4 1/4 Ft.	10′6″	7′6 1/2″	9′ 7/8″	125 to 150	485	45,000
5 1/2 Ft.	12′6 5/16″	8′10 9/16″	11′ 1/4″	150 to 200	485	83,000
7 Ft.	13′10 5/16″	10′5 3/8″	13′1 5/8″	250 to 300	435	140,000
7 Ft.	13′10 5/16″	10′5 3/8″	13′3″	250 to 300	435	145,000

Table: Short Head Cone Crushers:

Size	Dimensions			H.P	Full Load R.P.M.	Approx. Ship. Wt. Lbs.
	L	W	H			
2 Ft.	$7'2\frac{5}{8}''$	$4'5\frac{1}{8}''$	$5'5\frac{3}{8}''$	25 to 30	575	10,000
3 Ft.	$9'1\frac{5}{8}''$	$6'2\frac{1}{2}''$	$6'6\frac{1}{2}''$	60 to 75	580	21,500
4 Ft.	$10'6''$	$7'6\frac{1}{2}''$	$8'5\frac{3}{8}''$	100 to 150	485	44,000
$5\frac{1}{2}$ Ft.	$12'6\frac{5}{16''}$	$8'10\frac{9}{16''}$	$11'\frac{1}{4}''$	150 to 200	485	86,000
7 Ft.	$13'10\frac{5}{16''}$	$10'5\frac{3}{8}''$	$12'10''$	250 to 300	435	150,000

Cone Crusher Components and Operating Principle

Table: Standard Cones:

Size of crusher	Type of bowl	Recommended minimum discharge setting A	Feed opening B
20 Inch	Fine Coarse	$\frac{5}{16''}$ $\frac{3}{8}''$	$1\frac{1}{2}''$ $2\frac{5}{8}''$
2 Ft.	Fine Coarse	$\frac{1}{4}''$ $\frac{3}{8}''$	$2\frac{1}{4}''$ $3\frac{1}{4}''$
3 Ft.	Fine Coarse	$\frac{3}{8}''$ $\frac{1}{2}''$	$3\frac{7}{8}''$ $5\frac{1}{8}''$
4 Ft.	Fine Coarse	$\frac{3}{8}''$ $\frac{3}{4}''$	$5''$ $7\frac{3}{8}''$
$4\frac{1}{4}$ Ft.	Fine Medium Coarse	$\frac{1}{2}''$ $\frac{5}{8}''$ $\frac{3}{4}''$	$4\frac{1}{2}''$ $7\frac{3}{8}''$ $9\frac{1}{2}''$

5 I/2 Ft.	Fine Medium Coarse	5/8″ 7/8″ 1″	7 I/8″ 8 5/8″ 9 7/8″
7 Ft.	Fine Medium Coarse	3/4″ 1″ 1 I/4″	10″ 11 I/2″ 13 I/2″

Size of crusher	Bowl	Recommended Minimum Discharge Setting C	Feed Opening D	
			Minimum	Maximum
2 Ft.	Fine Coarse	I/8″ — 16″	3/4″ 1 I/2″	1 3/8″ 2″
3 Ft.	Fine Medium Coarse	I/8″ I/8″ I/4″	I/2″ 1″ 2″	1 5/8″ 2″ 3″
4 Ft.	Fine medium Coarse	I/8″ I/8″ I/4″	1 I/8″ 1 I/2″ 2 3/4″	2 I/2″ 2 7/8″ 4″
5 I/2 Ft.	Fine Medium Coarse	3/16″ 3/16″ 3/8″	1 I/4″ 2″ 3 3/4″	2 3/4″ 3 3/8″ 5 I/4″
7 Ft.	Fine Medium Coarse	3/16″ 3/8″ I/2″	2″ 3 7/8″ 5″	3 3/4″ 5 3/4″ 7″

Cone Crusher Components and Operating Principal

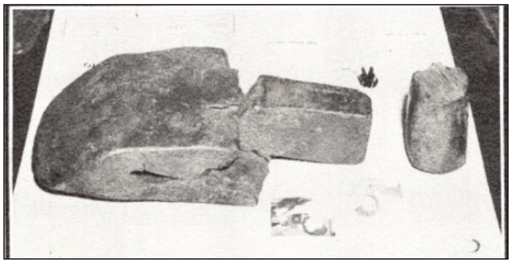
The main components of cone crushers are:

- Bowl Liner
- Mantle
- Pinion and Crown Gear
- Eccentric Inner and Outer Bearing
- Thrust Bearing
- Main Frame
- Tramp Steel Release
- Distributor Plate
- Main Shaft
- Oil System
- Dust Seal

The description of the Operating Principle of cone crushers and how this machine works should begin with the drive line and how the crushing action is generated.

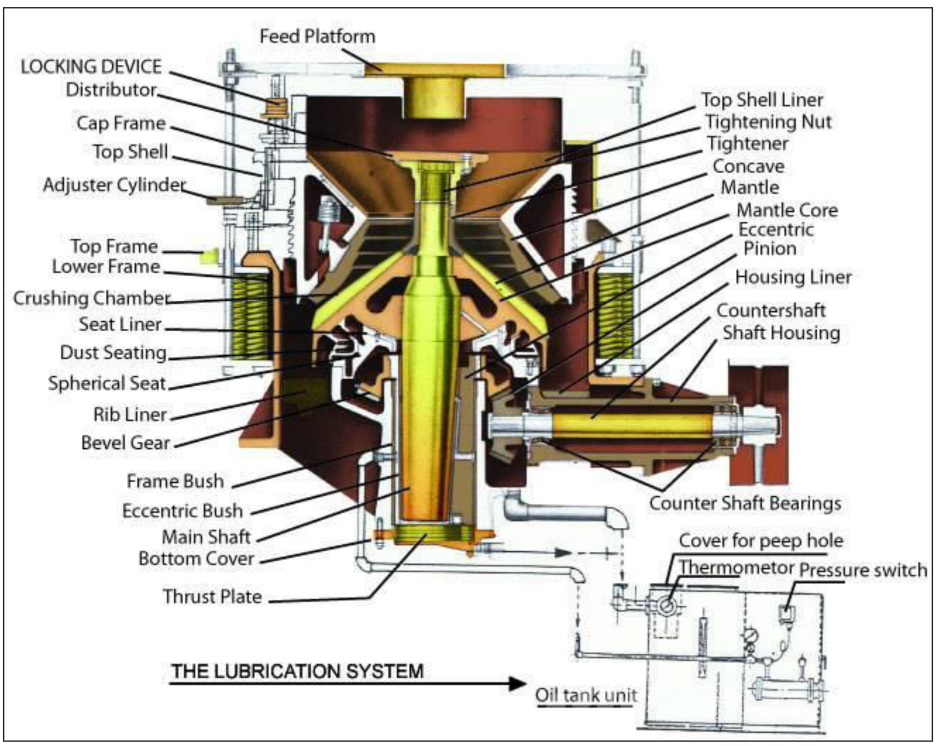
Tramp Iron and Cone Crushers

Tramp iron had long been a source of worry to those engaged in ne crushing. Here is what one operator had to say. "Shutdowns were frequent, costs were uncertain because of enforced delays due to excessive breakage. Plugged machines had to be freed continually with a torch to cut out frozen and wedged-in tramp iron. The cone crusher overcame these troubles, helped reduce and stabilize costs." The best evidence of this statement is the universal acceptance of the cone as the outstanding crusher in its field.



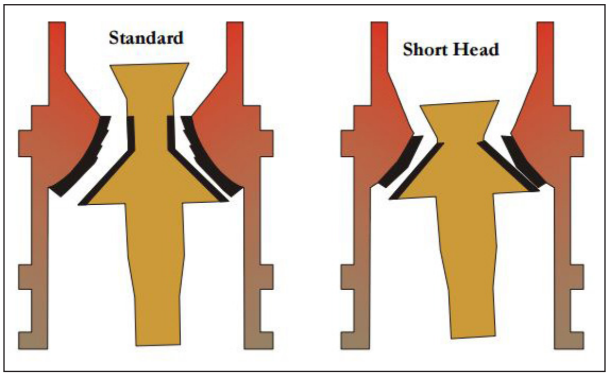
While tramp iron is not recommended as regular diet for a Cone Crusher, its construction is such that damage will not result should any ordinary non crushable material get into the crushing cavity. The band of heavy coil springs encircling the frame allows the bowl to lift from its seat with each movement of the head until Such non-crushable object pass off into the discharge. The tramp iron shown in the accompanying illustration passed the protective devices installed for its removal and would have resulted in expensive repairs and long shutdown periods for any crusher except the Symons Cone.

Cone Crusher Short Head vs Standard Head



Compare the Short and Standard Head of a Cone Crusher

Cone crushers can have two types of 'heads', standard and short head types. The principle difference between the two is in the shape (size and volume) of the crushing cavities and feed plate arrangements. Standard head cone crushers have cavities that are designed to take a primary crushed feed ranging up to 300mm generating product sizes around 20mm to 40mm. For ner products short head cone crushers are normally used. They have a steeper angle of the head and a more parallel crushing cavity than the standard machines. Due to the more compact chamber volume and shorter working crushing length, the much needed higher crushing forces/power can be imparted to the smaller sized material being fed to the crusher. Cavities for the short head machine are designed to produce a crushed product ranging from 5mm to 20mm in closed circuit.



At the discharge end of the cone crusher is a parallel crushing section, where all material passing through must receive at least one impact. This ensures that all particles, which pass through the cone crusher, will have a maximum size, in at least one dimension, no larger than the 'set' of the crusher. For this reason, the set of a cone crusher can be specified as the minimum discharge opening, being commonly known as the "closed side setting" (CSS).

DRAGLINE EXCAVATOR

A dragline excavator is a piece of heavy equipment used in civil engineering and Surface mining.

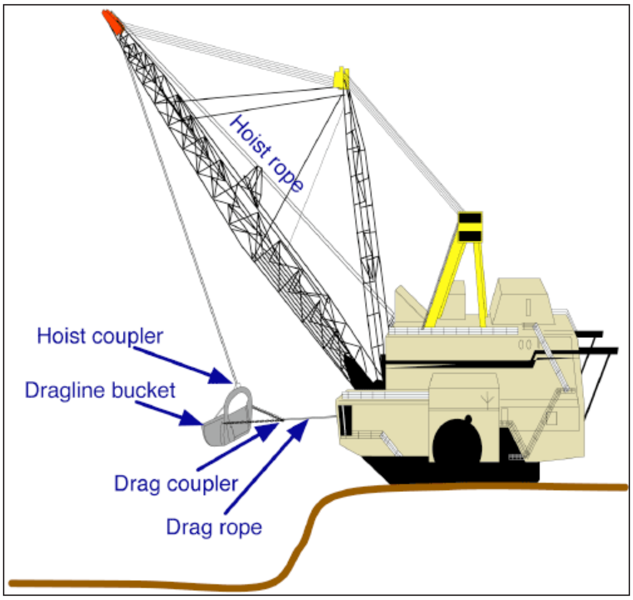
Draglines fall into two broad categories: those that are based on standard, lifting cranes, and the heavy units which have to be built on-site. Most crawler cranes, with an added winch drum on the front, can act as a dragline. These units (like other cranes) are designed to be dismantled and transported over the road on flatbed trailers. Draglines used in civil engineering are almost always of this smaller, crane type. These are used for road, port construction, pond and canal dredging, and as pile driving rigs. These types are built by crane manufacturers such as Link-Belt and Hyster.

The much larger type which is built on site is commonly used in strip-mining operations to remove overburden above coal and more recently for oil sands mining. The largest heavy draglines are among the largest mobile land machines ever built. The smallest and most common of the heavy type weigh around 8,000 tons while the largest built weighed around 13,000 tons.

A dragline bucket system consists of a large bucket which is suspended from a boom (a large truss-like structure) with wire ropes. The bucket is maneuvered by means of a number of ropes and chains. The hoist rope, powered by large diesel or electric motors, supports the bucket and hoist-coupler assembly from the boom. The dragrope is used to draw the bucket assembly horizontally. By skillful maneuver of the hoist and the dragropes the bucket is controlled for various operations.

Operation

In a typical cycle of excavation, the bucket is positioned above the material to be excavated. The bucket is then lowered and the dragrope is then drawn so that the bucket is dragged along the surface of the material. The bucket is then lifted by using the hoist rope. A swing operation is then performed to move the bucket to the place where the material is to be dumped. The dragrope is then released causing the bucket to tilt and empty. This is called a dump operation.



Dragline excavator.

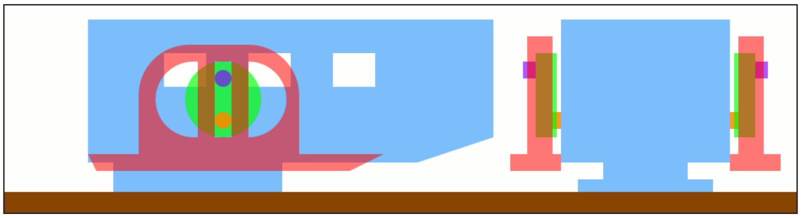
On crane-type draglines, the bucket can also be ‘thrown’ by winding up to the jib and then releasing a clutch on the drag cable. This would then swing the bucket like a pendulum. Once the bucket had passed the vertical, the hoist cable would be released thus throwing the bucket. On smaller draglines, a skilled operator could make the bucket land about one-half the length of the jib further away than if it had just been dropped. On larger draglines, this is not a common practice.

Draglines have different cutting sequences. The first is the side cast method using offset benches; this involves throwing the overburden sideways onto blasted material to make a bench. The second is a key pass. This pass cuts a key at the toe of the new highwall and also shifts the bench further towards the low-wall. This may also require a chop pass if the wall is blocky. A chop pass involves the bucket being dropped down onto an angled highwall to scale the surface. The next sequence is the slowest operation, the blocks pass. However, this pass moves most of the material. It involves using the key to access to bottom of the material to lift it up to spoil or to an elevated bench level. The final cut if required is a pull back, pulling material back further to the low-wall side.

Dragline at the Curragh Coal Mine.

A large dragline system used in the open pit mining industry costs approximately US$50–100 million. A typical bucket has a volume ranging from 40 to 80 cubic yards (30 to 60 cubic metres), though extremely large buckets have ranged up to 168 cubic metres (5,900 cu ft). The length of the boom ranges from 45 to 100 metres (148 to 328 ft). In a single cycle, it can move up to 450 tonnes of material.

Most mining draglines are not diesel-powered like most other mining equipment. Their power consumption on order of several megawatts is so great that they have a direct connection to the high-voltage grid at voltages of between 6.6 and 22 kV. A typical dragline weighing 4000 to 6000 tons, with a 55-cubic-metre bucket, can use up to 6 megawatts during normal digging operations. Because of this, many (possibly apocryphal) storieshave been told about the blackout-causing effects of mining draglines. For instance, there is a long-lived story that, back in the 1970s, if all seven draglines at Peak Downs Mine (a very large BHP coal mine in central Queensland, Australia) turned simultaneously, they would black out all of North Queensland. However even now, if they have been shut down, they are always restarted one at a time due to the immense power requirements of startup.



"Walking" dragline.

In all but the smallest of draglines, movement is accomplished by "walking" using feet or pontoons, as caterpillar tracks place too much pressure on the ground, and have great difficulty under the immense weight of the dragline. Maximum speed is only at most a few metres per minute, since the feet must be repositioned for each step. If travelling medium distances (about 30–100 km), a special dragline carrier can be brought in to transport the dragline. Above that distance, disassembly is generally required. But mining draglines due to their reach can work a large area from one position and do not need to constantly move along the face like smaller machines.

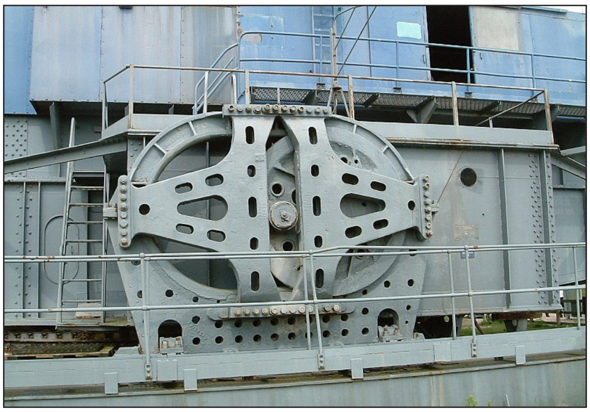
Limitations

The primary limitations of draglines are their boom height and boom length, which limits where the dragline can dump the waste material. Another primary limitation is their dig depth, which is limited by the length of rope the dragline can utilize. Inherent with their construction, a dragline is most efficient excavating material below the level of their base. While a dragline can dig above itself, it does so inefficiently and is not suitable to load piled up material (as a rope shovel or wheel loader can).

Despite their limitations, and their extremely high capital cost, draglines remain popular with many mines, due to their reliability, and extremely low waste removal cost.

Notable Examples

The coal mining dragline known as Big Muskie, owned by the Central Ohio Coal Company (a division of American Electric Power), was the world's largest mobile earth-moving machine, weighing nearly 13,000 tonnes and standing nearly 22 stories tall. It operated in Muskingum County, in the U.S. state of Ohio from 1969 to 1991, and derived power from a 13,800 volt electrical supply. It was scrapped in 1999.



The Walking Mechanism on a preserved Bucyrus-Erie 1150 dragline in the UK.

The British firm of Ransomes & Rapier produced a few large (1400-1800 ton) excavators, the largest in Europe at the time. Power was from internal combustion engines driving electric generators. One, named *SUNDEW*, was used in a quarry from 1957 to 1974. After its working life at the first site in Rutland was finished it walked 13 miles to a new life at Corby; the walk took 9 weeks.

Smaller draglines were also commonly used before hydraulic excavators came into common use, the smaller draglines are now rarely used other than on river and gravel pit works. The small machines were of a mechanical drive with clutches. Firms such as Ruston and Bucyrus made models such as the RB10 which were popular for small building works and drainage work. Several of these can still be seen in the English Fens of Cambridgeshire, Lincolnshire and parts of Norfolk. Ruston's are a company also associated with drainage pumping engines. Electric drive systems were only used on the larger mining machines, most modern machines use a diesel-hydraulic drive, as machines are seldom in one location long enough to justify the cost of installing a substation and supply cables.

Technological Advances

Draglines, unlike most equipment used in earth-moving, have remained relatively unchanged in design and control systems for almost 100 years. Over the last few years, some advances in dragline systems and methodologies have occurred.

Automation

Researchers at CSIRO in Australia have a long-term research project into automating draglines. Mining automation teams at QCAT, a CSIRO division; have been developing the automation technology since 1994. Automated systems include cruise control and Digital Terrain Mapping. Working solutions include the proof-of-concept dragline swing cruise control on a Tarong BE1370.

Simulation Software

Since draglines are typically large, complicated and very expensive, training new operators can be a tricky process. In the same way that flight simulators have developed to train pilots, mining simulator software has been developed to assist new operators in learning how to control the machines.

Universal-Dig-Dump

UDD stands for Universal-Dig-Dump. It represents the first fundamental change to draglines for almost a century, since the invention of the 'miracle hitch'. Instead of using two ropes (the hoist rope and the drag rope) to manipulate the bucket, a UDD machine uses four ropes, two hoist and two drag. This allows the dragline operator to have much greater selectivity in when to pick up the bucket, and in how the bucket may be dumped. UDD machines generally have higher productivity than a standard dragline, but often have greater mechanical issues. Within the mining industry, there is still much debate as to whether UDD improvements justify their costs.

LOAD, HAUL AND DUMP MACHINE

Load Haul and Dump (LHD) Machine loaders are similar to conventional front end loaders but developed for the toughest of hard rock mining applications, with overall production economy, safety and reliability in mind. They are extremely rugged, highly maneuverable and exceptionally productive. More than 75% of world's underground metal mines use LHD for handling the muck of their excavations.

Constructional Details

LHD have powerful prime movers, advanced drive train technology, heavy planetary axles, four-wheel drive, articulated steering and ergonomic controls. Their narrower, longer and lower profile make them most suitable for underground application where height and width is limited. As the length is not a limitation in underground tunnel and decline LHD are designed with sufficient length. The length improves axial weight distribution and bucket capacity can be enhanced. The two-part construction with central articulation helps in tracking and maneuverability. In mining there is limitation for shifting heavy equipment. Sometimes, an LHD has to be shifted through a shaft while dismantled.

Capacity

Their tramming capacities varies from 1 to 17-25 metric tons. Their bucket size varies from 0.8 to 10 m^3. Bucket height range from 1.8 to 2.5 m.

Drives

LHD are available in both diesel and electric versions. Diesel version is easily transportable from one location to another and have diesel engines as power drive of 75 to 150 HP or more. Engines are either water or air cooled.

LHD with electric motors as drives have general capacity of 75 to 150 HP. These are operative at medium voltage of 380 to 550 volts. Flexible trailing cable are provided with reeling/unreeling facility to feed power.

These drives operate hydraulic pumps and hydraulic motors for further operation of various movement of bucket and vehicle traction/steering. The speed of the vehicle is controlled mechanically. The transmission is controlled by a hydrostatic drive. In hydrostatic transmission, the motor drives a variable displacement pump hydraulically connected to a hydro-motor driving the axle via a gearbox. The speed is controlled by changing the displacement volume of the axial pump. The power train consists of a closed loop hydraulic transmission, parking brakes, two-stage gear box and, drive lines.

Safety Provisions

Service, emergency and parking brakes with fire resistant hydraulic fluid is used. Head lights, audible warning signal, back up alarm and portable fire extinguisher are provided. Special cabin/canopy is also provided for safety of operator. A safety device is provided to shut off the engine if exhaust gases exceed temperature of 85 °C (or as per set value).

For electric shock safety these LHD's power source(gate end box) are equipped with earth conductivity protection using pilot core in electric trailing cable, which isolate complete power when earth continuity is broken.

HAUL TRUCK

Haul trucks are off-highway, rigid dump trucks specifically engineered for use in high-production mining and heavy-duty construction environments. Haul trucks are also used for transporting construction equipment from job site to job site. Some are multi-axle in order to support the equipment that is being hauled.

Most haul trucks have a two-axle design, but two well-known models from the 1970s, the 350T Terex Titan and 235T Wabco 3200/B, had three axles. Haul truck capacities range from 40 short tons (36 t) to 496 short tons (450 t).

Large quarry-sized trucks range from 40 to 100 tons. A good example of this is the Caterpillar 775 [rated at 70 short tons (64 t)]. Quarry operations are typically smaller than, say, a gold/copper mine, and require smaller trucks.

Ultra Class

The largest, highest-payload-capacity haul trucks are referred to as *ultra class* trucks. The ultra class includes all haul trucks with a payload capacity of 300 short tons (272 t) or greater. As of October 2013, the BelAZ 75710 has the highest payload capacity, 450 metric tons.

Liebherr T 282B ultra class haul truck.

POWER SHOVEL

Power shovel is a bucket-equipped machine, usually electrically powered, used for digging and loading earth or fragmented rock and for mineral extraction. Power Shovels are a type of rope/cable excavator, where the digging arm is controlled and powered by winches and steel ropes, rather than hydraulics like in the more common hydraulic excavators. Basics parts of power shovel including the track system, cabin, cables, rack, stick, boom foot-pin, saddle block, boom, boom point sheaves and bucket. The size of bucket varies from 0.375cu m to 5cu m.

P&H 4100 XPB cable loading shovel.

Design

Shovels normally consist of a revolving deck with a power plant, driving and controlling mechanisms, usually a counterweight, and a front attachment, such as a crane ("boom") which supports a handle ("dipper" or "dipper stick") with a digger ("bucket") at the end. "Dipper" is also sometimes used to refer to the handle and digger combined. The machinery is mounted on a base platform with tracks or wheels. Modern bucket capacities range from 8 m^3 to nearly 80 m^3.

Use

Shovel digging overburden.

Power shovels are used principally for excavation and removal of overburden in open-cut mining operations, though it may include loading of minerals, such as coal. They are the modern equivalent of steam shovels, and operate in a similar fashion.

Other uses of the power shovel are:

- Suitable for close range of work.
- Capable of digging very hard materials.
- Can remove big sized boulders.
- To excavate the earth and to load the trucks.
- It is used in various types of jobs such as digging in gravel banks, clay pits, digging cuts in road works, road-side berms, etc.

Operation

The shovel operates using several main motions:

- Hoist - pulling the bucket up through the bank (i.e. the bank of material being dug).
- Crowd - moving the dipper handle out or in to control the depth of cut and when positioning to dump.
- Swing - rotating the shovel between digging and dumping.
- Propel - moving the shovel unit to different locations or dig positions.

A shovel's work cycle, or digging cycle, consists of four phases:

- Digging,
- Swinging,
- Dumping,
- Returning.

The digging phase consists of crowding the dipper into the bank, hoisting the dipper to fill it, then retracting the full dipper from the bank. The swinging phase occurs once the dipper is clear of the bank both vertically and horizontally. The operator controls the dipper through a planned swing path and dump height until it is suitably positioned over the haul unit (e.g. truck). Dumping involves opening the dipper door to dump the load, while maintaining the correct dump height. Returning is when the dipper swings back to the bank, and involves lowering the dipper into the track position to close the dipper door.

Giant Stripping Shovels

Big Brutus, which is now preserved as a museum.

In the 1950s with the demand for coal at a peak high and more coal companies turning to the cheaper method of strip mining, excavator manufacturers started offering a new super class of power shovels, commonly called giant stripping shovels. Most were built between the 1950s and the 1970s. The world's first giant stripping shovel for the coal fields was the Marion 5760. Unofficially known to its crew and eastern Ohio residents alike as The Mountaineer, it was erected in 1955/56 near Cadiz, Ohio off of Interstate I-70. Larger models followed the successful 5760, culminating in the mid 60s with the gigantic 15,000 ton Marion 6360, nicknamed The Captain. 1 stripping shovel, The Bucyrus-Erie 1850-B known as "Big Brutus" has been preserved as a national landmark and a museum with tours and camping. Another stripping shovel, The Bucyrus-Erie 3850-B known as "Big Hog" was eventually cut down in 1985 and then buried on the Peabody Sinclair Surface Mining site near the Paradise Mining Plant that she worked at, where it remains there today in an area owned by the government that is closed to the public. The rest of the stripping shovel breed have all since then been scrapped.

FEEDING, CONVEYING AND ON-LINE ELEMENTAL ANALYSIS EQUIPMENT

Once the excavator transporter brings the raw material to the crusher for processing, the feeding device feeds the material into the crusher and in return the material is screened and all oversized material is recirculated back to the crusher to ensure correct size fraction is obtained. This weighbelt 'feeding' equipment, usually referred to as "Weighfeeders," conveys and controls the feedrate into the crusher to improve crusher efficiency.

Feeding and conveying equipment are necessary to the mining industry to move and control material flow within a mining and processing operation to facilitate efficient operation of equipment and determine operating rates and yields. In some instances secondary crushing is required prior to processing of the material. Once the material is at the correct size, fraction processing can occur which could include, milling, flotation, leaching etc.

Belt scale systems let you monitor production output and inventory, or regulate product loadout, while providing vital information for the effective management and efficient operation of your business. There are elemental crossbelt analyzers that provide real-time quality analysis of critical process streams to facilitate sorting, blending and out-of-seam dilution control. While materials are on the troughed belt conveyor, an automatic sampling system (which could be single or multi-stage) can take a representative sample directly from the moving material stream. Weighbelt Feeders that convey and control feedrate accurately and reliably can reduce material consumption, help maintain blend consistency, and increase profits.

Flow measurement systems provide continuous, real-time flow measurement of free-falling materials or dense phase, pneumatically conveyed bulk solids, which is important to ensure and maintain product quality and process efficiency.

EQUIPMENT USED IN OPENCAST COAL MINING

Opencast mining is the oldest method of excavating minerals but the mining operations have been mechanised by the use of heavy earth moving machinery during the last 50 years resulting in excavations on a scale which was unthinkable half a century ago.

Bulldozer

A bulldozer is often referred to simply as a dozer. It is a tractor with a pusher blades attached to the front portion. The tractor is the diesel-operated power unit equipped with either crawler chains or rubber tyred wheels for lifting. The pusher blade can be raised or lowered or tilted through small angles horizontally by rams operated through hydraulic pressure or by ropes.

The dozer blade is used for pushing loose material or for digging in earth, sand and soft weathered rock. The machine is also engaged for leveling or spreading earth, for leveling of rock spoil in the dumping yard, grading and compacting temporary roads, pushing mineral into sub-ground level bunkers through grizzly, for towing dumpers, etc.

It also serves the purpose of pushing boulders, pulling down trees, and is an essential equipment to push scrapers. A dozer equipped with a fork like attachment is known as ripper and operates like a plough to loosen moderately hard rock. The loosened rock may be loaded by a scraper. A dozer can dig 1.2 m to 1.5 m below ground in earth or weathered rock.

Craper

This machine is diesel-operated with pneumatic tyred wheels and has at the centre a bowl fitted with a cutting blade at bottom. The blade is reversible and can be replaced when blunt. Its working may be compared to that of a lawn power.

As a scraper is pushed forward by a dozer, its blade cuts a thin slice of earth usually between 75 mm and 225 mm thick over a distance of nearly 30 m. The earth is automatically collected in a central bowl whose capacity ranges from 3 m^3 to 22 m^3 and it takes nearly one minute for loading.

When the scraper is fully loaded its bottom opening is closed by the operator through manipulation of a cable (rope) and the loaded scraper, with the bowl lifted, travels to the dumping yard on its own power. At the dumping yard, as the scraper moves, the bottom opening of the bowl is opened and the contents are unloaded in a layer 150 mm to 250 mm thick, over a distance of 30 to 70 m.

The bowl is always bottom discharging. Scrapers are unsuitable in soils with stumps, large boulders, and hard rocks. When the ground is hard, it is necessary to rip the surface with the help of a ripper before loading by a scraper. Sandy soil is best for a scraper which has to be stopped during rains, if engaged, in aluminum.

Scrapers are used in coal mines for cutting and transporting weathered sandstone as well as coal. The coal excavated by it is however smaller in size. A Scraper may take 5 to 6 minutes for a complete cycle of loading and unloading if the total up-and-down distance of a trip is nearly 300 m. One-way traffic of loaded and empty scrapers is desirable for good results. One dozer is normally sufficient for every two scrapers used.

The scraper manufactured by BEML has the following main specifications:

- Flywheel H.P. of engine 332 at 2100 rpm.
- Capacity- payload 23000 kg; struck 11.5 m^3, heaped 16 m.
- Max., travel speed (forward) 44 km/hr.
- Overall dimensions mm length 12600; width 3470; height 3890.
- Net weight (no load) 26584 kg.

Ripper

A ripper is a machine which cuts, as it travels, 0.6 to 1 m deep furrows in the ground, and it can be well compared with the farmer's plough. The ripper is essentially a crawler mounted heavy duty diesel tractor with a ripper attachment.

Like a farmer's plough, the ripper with the ripping tool thrust into the ground by hydraulic pressure, travels along close paths, 1.2 to 1.5 m apart and during the travel rips open the ground. The broken ground or rock can be dozed to form a stockpile for convenience of loading or can be loaded by a scraper.

If the overburden or mineral is suitable for ripping its breaking is possible with the help of a ripper and the process of drilling and blasting can be dispensed with. Soft rocks and medium hard rocks, below hardness 5 on Moh's scale, which are laminated and stratified, provide suitable material for ripping.

The alluvial surface deposits, weathered sandstones and shales underlying them in the coalfields can be easily ripped and the relative rippability of the rocks can be known with the help of an instrument known as Refraction Seismograph.

The Refraction Seismograph operates on the principle that "Sound waves travel subsurface material at different velocities, depending upon the degree of consolidation of the material". It is believed that the same factors that affect consolidation also affect rippability. Thus poorly consolidated material with low seismic wave velocities could be ripped easily, while highly consolidated material with high velocities would be difficult to rip.

Equipment needed for seismic analysis includes a source of a sound or shock wave, a receiver, an electric counter, and a set of cables.

The main items are:

- Refraction Seismograph – An electronic counter that determines the time interval between the strike of the hammer and the arrival of the seismic wave at the geophone.
- Geophone – Receiver of sound waves. A geophone is a velocity gauge suitable for detecting frequencies in the range of 1-100 Hz. The geophone converts the mechanical vibrations into its electrical analogue. The electrical signal is then amplified and transmitted to the monitoring station.
- Sledge Hammer and Impact Plate – Source of sound wave transmits sound through earth and also through an impact switch having direct connection with seismograph, through a connecting wire.
- A 30 m Tape – For measuring distances between the geophone and various impact points (wave sources).

The seismic wave is produced by a sledge hammer striking a steel plate at various distances from a geophone receiver. Immediately upon impact, a wave "front" composed of innumerable seismic waves travels in all directions away from the point of impact, or source.

Some of the waves are refracted into the layers of sub-surface materials and the angle of refraction is determined by Shell's law which gives the following relationships:

Sine of angle of incidence/ Wave velocity in upper layer = Sine of angle of refraction /Wave velocity in lower layer

The geophone receiver is sensitive only to the first seismic wave that reaches it. Thus, either the wave which travels the shortest distance, or one which travels, a longer path but which includes a high velocity segment, arrives first at the geophone.

In addition to determining the degree of consolidation or rippability of each layer, it is also possible to determine the depth of each layer.

In iron ore areas of Goa the practical results obtained with seismograph were as follows- Seismic velocity in overburden (practically laterite) was 600 to 1,200 m per second. In iron ore it was 1,050 to 1,500 m per second, but in some cases velocities as high as 1,800 to 2,100 m per second were also recorded.

When selecting a tractor for ripping purposes, it is necessary to consider:

- The down pressure on the tooth to determine whether penetration can be accomplished,
- The tractor H.P. which should be capable of advancing the tooth through the rock and break it,
- Tractor weight which provides traction for full use of the H.P. in advancing the tooth.

The tractor speed is 0.8 to 2.5 km/hr during ripping. If the rock is soft it is advisable not to increase the speed but to add one or more ripping teeth. The distance between adjacent furrows during ripping may be 1 to 2 m and the harder the rock, the closer are the furrows. In some rock formations ripping is possible after sparse blasting of widely spaced charges.

Tractor Shovel

It is essentially a diesel operated tractor with a bucket as the front attachment and is called a front-end loader or pay-loader. It may be on pneumatic tyres or crawler chains. The tractor shovel attachment consists of a push frame and a bucket that can be raised, lowered and dumped hydraulically or mechanically. The shovel usually has a pusher fan so that the dirt falling form the bucket will not be sucked back towards the operator and engine air intake.

For digging, the complete tractor shovel has to move forward toward the bench and for unloading the contents of the bucket the entire unit has to come back and position itself conveniently to empty the bucket on to a dumper. Its rate of digging and loading cannot, therefore, be as fast as with a revolving shovel.

Tractor shoveIs have been employed in some mines to load the stacked mineral at the siding into railway wagons or to push it into ground-level bunkers. Capacities of the buckets are from 0.57 m3 upwards. Heavy rock buckets for handling blasted rock carry teeth as standard equipment though the buckets used for coal handling need not be so equipped. Main specifications of two wheel-loaders (B.E.M.L.).

An excavator, technically speaking, is any machine which excavates the rock or earth and swings or transports it, within narrow limits, to an adjacent place or dumps it on to a receptacle like a dumper or railway wagon.

In this sense, a tractor shovel which cuts or digs to some extent below the flow on which it stands, may well be considered an excavator – the name traxcavator for the tractor shovel manufactured by one company apply conveys the meaning- but, in earthmoving terminology the term excavator covers machines of the following type:

- Power shovels like dipper shovels, stripper shovels and back-hose or pull shovels.
- Draglines.
- Bucket wheel excavators.

A power shovel is a shovel using electric or diesel motive power for its operation, as distinct from a hand-operated shovel. The functions of power shovels are very simple. Basically, these machines lift fragmented rock, and swing it to a different location such as dumpers or spoil heaps.

The main components are:

- Propelling arrangements consisting of either crawler chains or pneumatic tyres.
- A deck or cab mounted on a turn table and housing the prime mover, all the controls for operation, cable (wire rope) drums and the operator's seat. The deck or cab can swing through 360° independently of the propelling crawler chains or tyres.
- Deck swinging mechanism. When the deck swings, all the equipment mounted on it, including the boom and the bucket also swings.

A shovels is made in three structural divisions. An automatically, the top or revolving unit is the head and torso, the mounting or travel unit is the legs, and the various attachments are the arms and hands.

A revolving and a travel unit together make up a basic shovel which may be fitted with any of the five front attachments. The machine may thus become any one of the following- a crane, a clam shell, a dipper shovel, a drag line, a pull shovel or a back-hoe.

Dipper Shovel

This is a machine employed for excavating soft rock or loading fragmented rock from a bench and is very commonly used in mines. It is usually mounted on crawler chains. The cab carries the power unit which may be an electrical motor at 3300 V, supplied with power from an external source through a flexible electric cable, or a diesel engine.

The bucket (also called dipper) commonly used may be of 1 m3 to 4.5 m3 capacity. It is used for loading dumpers and for this purpose it has to stand on the floor of the bench. Watery conditions in the quarry are not suitable for efficient operation of this machine, as dumpers have to move inside the quarry.

During operation, the crawlers are stationary within 3 to 5m of the toe of the bench. To load the bucket, the operator crowds it into the fragmented rock with the dipper stick and hoists it. As it moves through an arc in the rock pile.

It is then retracted and the cab, along with all the machinery mounted on it, the boom and the bucket, is swung horizontally through nearly 90° to position the bucket over the dumper. The bucket is bottom discharging and its door is opened by the trip cable. Normally five buckets are required to load a dumper.

The teeth of the bucket wear out fast and when worn out, have to the built up to size by welding. The trip cable lasts for nearly 35 hours and the hoist cable, for nearly 100 hours. In one shift a shovel loads 450 to 500 buckets. Where the dumping yard is away from the quarry a dipper shovel loading into dumpers is advantageous.

Hydraulic shovels which eliminate use of wire ropes (cables) have become popular in recent years.

The electric motor or diesel engine mounted on the shovel drives the hydraulic pump and the pressure developed is utilised for various operations of the shovel. Hydraulic motors are of low speed, high torque with hydrostatic braking. One example of such hydraulic excavator is Porcelain shovel of Larsen Toubro Ltd.

Figures in brackets show the working ranges in m of Tata dipper shovel, model 1055 B, at a boom angle of 50°. Boom length is 8.53 m.

A – Cutting height (10.83) B – Cutting radius, (11.96) C – Dumping radius (9.51) D – Dumping height (7.25) E – Cutting depth below crawler level (2.51).

Dipper shovels commonly employed in our mines are of 2 m^3 – 4.6 m^3 bucket capacities. Only a few mines employ shovels of 8.3 m^3 or 10 m^3 capacities, e.g. Malanjkhand Copper Project employs 10 m^3 dipper shovels.

Under conditions existing in India the loading capacity of 2 m^3 shovel in good condition and well fragmented rock is as follows:

- Per hour - 80 passes of bucket.
- Per shift - (8-hours) 500 passes.
- Per day (2-shifts) - 950 passes or 190 dumper loads or 1070 m^3 solid.
- Per week - 5,800 m^3.
- Per month, dry - 23,000 m^3.
- Per year - 2,53,000 m^3.

Loading capacities or performance of other shovels may be considered as follows:

- 3.5 m^3 capacity - 400,000 m^3 per year.
- 4.5 m^3 – 550,000 m^3 per year.

Stripper Shovel

A stripper shovel is only a modification of dipper shovel with a long boom and is used for casting fragmented rock or earth into a dump of overburden. It is mostly deployed for overburden.

Pull Shovel or Hoe

A pull shovel, is also known as a hoe, back hoe, drag shovel. It is used for loading dumpers and its best application is for digging below the level on which it stands. The shovel and the dumpers can stand at a higher level free from water and mud of the quarry floor. As the attachments to the bucket are by dipper stick and not by cables, the bucket is under positive control of the operator and therefore suitable for hard digging.

The shovel is used for stripping top soil, and making shallow cuts and trenches upto a depth of 3.5 to 6 m. Compared to dipper shovel, the hoe is slower in digging and less efficient for loading trunks.

In deep digging, the face should be kept fairly straight and the shovel should be as far back from the edge as possible, otherwise there may be danger of caving of the edge.

Dumpers or Tippers

These are heavy duty trucks with a container-body of steel open at the top for receiving material loaded mechanically by tractor shovel, dipper shovel, dragline, etc. All dumpers/ tippers are provided with arrangements to lift the loaded body by utilizing hydraulic pressure to force a ram out.

The body swings from its horizontal position round a fulcrum through nearly 70° to dump its load and the hydraulic system also functions to pull the body back on its seat i.e., the chassis. A typical hydraulic system layout for the tipping gear of a dumper. From an oil tank oil flows by gravity to hydraulic pump.

When the driver engages the power take off (P.T.O.) control lever, power from the engine is transmitted from the transmission countershaft to the power take off which drives the pump. The oil under high pressure from the pump goes to the control valve whose lever can be manipulated for 4 different positions.

- Raise Position: High pressure oil goes through the hose pipes to the bottom of the hoist cylinder and the ram is then forced out. Oil at the top of the hoist travel back to the control valve through the hose connected to the piston rod.
- Hold Position: Both the passages between the control valve and hoist are closed so that oil at the bottom and top of the hoist is at a standstill and the latter is unable to move in either direction.
- Float Position: Both hose passages between the control valve and hoist are open so that oil at either end of the hoist can flow either way. The hoist can then travel in either direction depending upon the direction in which the force is applied.
- Lower Position: High pressure oil goes to the top of the hoist which then telescopes itself by the oil pressure and the oil at the bottom of the hoist travels back to the tank via the control valve. The body is thereby lowered on to the chassis.

Steering on all the heavy duty dumpers is mechanical but assisted by hydraulic power, generated by the engine. The dumper operator's exertion in thereby considerably reduced. Mechanical transmission from the engine to the rear wheels is the standard practice now-a- days, though for some years the rear wheels were driven by individual electric motors controlled from operator's cabin.

Medium sized mechanised quarries employ dumpers of 25-50 te carrying capacity. 50-60 te coal haulers are on the manufacturing line of B.E.M.L. and Hindustan Motors. Future planning of large projects is for employment of 100-150 te dumpers which will be fed by shovel of 8-10 m3 capacity. Bottom discharging coal haulers of 55 te payload, 43 m^3 struck capacity (model GB 60C) are manufactured by BEML.

Brakes on dumpers are operated by compressed air. Some dumpers are equipped with hydraulic retarder (hydrotarder). This is a device used on some trucks and dumpers to prevent the speed from exceeding certain limits when travelling a steep down- slope and also to produce a breaking action on the vehicle.

In a way, it acts as a governor. It uses the hydraulic friction to produce the breaking action. Unline the regular brakes, the hydrotarder will not completely stop the vehicle but will slow it down preparatory to stoppings with the familiar friction brakes, operated by compressed air or hydraulic pressure. The retarder essentially consists of a vane type rotor turned by the driven shaft, a fixed casing or stator fitted with vanes and an oil circulation system.

The machines deployed in the opencast mines, at the crushing and ore preparation plant have to be of matching capacities. At Kudremukh Iron Ore Project, one of the largest opencast mines in India, the capacities of some of the machines are : shovels 10.7 m^3, production trucks 108 te, front end loaders 10 m^3, electric drills for 310 mm dia. blast holes, gyratory crushers 4000 te/hr.

Drag Line

A drag line is a machine used for excavating earth, sand or soft rock and consists essentially of a revolving deck, a long light boom, crawler chains, and a special type of bucket held in position and controlled by cables. The bucket, when it has to be loaded, is lowered in the earth or loose rock by manipulation of the cables and is dragged by them.

As it is dragged it gets loaded. Hence the name dragline. A dragline is operated by diesel engine or a motor which is supplied power at high voltage from external source through a trailing cable. The depth to which a dragline digs is limited by the capacity of the drums to hold the hoist cable. When digging, the bucket, after it is loaded, is hoisted up, the boom given a swing through 90° and the contents then unloaded by manipulation of the cable.

A dragline is suitable for digging alluvium, sandy soil, unconsolidated rock or blasted coal/rock. It digs below the level, at which it stands and from position can dig over a wide working place and cast the earth over a wide area within the reach of the boom.

It is generally not employed to load dumpers as the accurate positioning of the dragline bucket over a limited area of the dumper delays the cycle of operation and the common application is for dumping overburden. It is suitable for working a quarry with watery conditions as the dragline works from a higher and, therefore, dry position.

Loading Capacity of a Dragline

A dragline is capable of dealing with the following quantities of rock/earth (solid) in a year (12 to 14 hours work daily).

A drag line may be crawler mounted or of waling type. Crawler mounted machines have travelling speeds of 0.25 to 5 km/hr. A walking dragline has a travelling speed of 0.18 to 0.6 km/hr.

Road Grader

This is a machine for leveling the road surface by smoothening out the ups and downs and for casting aside the boulders on the road. It is always pneumatic tyre mounted with only rear wheel drive and the front wheels are small.

The grading blade is attached to a circle that is hung from the overhead frame and pulled by a drawbar fastened to the front of the frame. The blade is usually 3.5 to 4 long having replaceable edges on the sides and bottom. Steering is direct-connecting mechanical by a hand wheel though a hydraulic booster is fitted on some models.

The motor grader (Mode GD 605 R-2) of B.E.M.L. has the following main specifications- Engine flywheel HP 145 at 1800 RPM; operating weight 12,650 kg; Max. Drawbar pull 7,280 kg; Max. speed forward – 43.6 kmph; steering – full hydraulic; overall length-8415 mm; width 2375 mm; height-3200 mm, minimum turning radius 10.4 m.

Rock Drills

Rock drill is the term applied to all machines using compressed air for drilling holes into rock by combined percussive and rotary action. The hole diameter is normally upto 100 mm.

The rock drills are classified mainly as follows:

- Jack hammers (also called Sinkers).
- Wagon Drill.

A jack hammer, so familiar to mine workers, is a hand-held and unmounted drill used for vertically downward drilling. It weighs from 15 to 25 kgf and is used for drilling upto a depth of 2 m (rarely 3 m); hole diameter. is generally 30 to 37 mm and rarely 50 mm. In a few cases a jack hammer may be mounted on an air leg. Though ordinary used for dry drilling, it can be adapted for wet drilling as well.

A drifter is a mounted drill, generally designed for horizontal drilling. It is heavier than the Jack hammer and is used in quarries and for tunnel driving. The widely used mounting is the column and arm and the drill may be used for wet as well as dry drilling. Its working is like a jack hammer.

A stopper is a drill for drilling upward and derives its name from its widespread use in mine stopes. It is used normally for wet drilling.

A wagon drill is essentially a drifter type drill capable of movement up and down a vertical guide and mounted on a portable frame fitted with wheels. The hole dia. is from 50 to 100 mm and the depth drilled ranges from 3 to 15 m.

Compressed air was the motive power for wagon drills till recently but now-a-days some wagon drills are operated by hydraulic power, as hydraulic power is more efficient than compressed air power.

Jack Hammer Drill

It is a compressed air operated drill to which air is supplied from external compressors through hose pipes at a pressure of about 6 kgf/cm^2. The drill weighs 15 to 25 kgf and drills holes of diameter. 30 mm to 38 mm (rarely upto 50 mm) upto 3 m depth. The drill rod is hexagonal in cross-section, suitably shaped at one end to form the shank and the other end is so shaped as to form a non-detachable single chisel bit with a tungsten carbide insert.

Drill rods may also be equipped with detachable X type tungsten carbide drill bits. In a shift of 8 hrs, two workers who hold the drill can drill 60 holes, each 1.2 to 1.5 m deep in sand stone, laterite, etc. When hand-held, the machine drills vertically downward holes only but if mounted on air legs, it may be used for drilling inclined holes.

An oil bottle placed between the drill and., the air receiver, and connected by hose pipes to both, provides lubrication to the drill when working. For dust suppression a jack hammer can be adapted to wet drilling by some modifications so that the drill cuttings mixed with water come out of the hole in the form of a sludge. The air consumption is generally 2-2.5 m^3 of free air/min.

Wagon Drill

A compressed air operated drifter mounted on a mobile frame and capable of travel up and down a mast is known as wagon drill. The frame is usually tyred wheel mounted though crawler chain mounting is provided in a few models. Tyred wheel mounted wagon drills can be pulled by the operator and his helper to the hole sites on a level ground.

A wagon drill, is used to drill holes of dia., varying from 50 mm to 100 mm for depth of 3 m to 15 m. The mast for the drifter is usually 3 m long providing for nearly 3 m vertical travel of the latter. This travel is possible with the help of a compressed, air driven feed motor through chain (known as chain feed).

The drifer provides the rotary motion as well as the percussive action to the drill rods, and in turn, to the drill bit. The drill bit is detachable X type with tungsten carbide insert. Compressed air fed through the hollow drill rods blows away the cuttings to the surface.

Total meter age drilled in an 8-hours shift is 60-70 m in rocks like sandstone, coal, etc. including the time spent on shifting the drill from hole to hole. The mast is capable of swiveling from vertical to a horizontal position and it can be kept fixed at any angle between the horizontal and the vertical, thereby facilitating vertical, horizontal or inclined drilling upto 40°. The drill is not self-propelling, and receives air from external compressor.

The maximum air consumption is 8 to 19 m^3/s min. of free air at 6 kgf/cm^2 including air blowing for drill bit of 60-70 mm diameter.

Though a detachable X-bit is the drill bit on most of the wagon drills, some wagon drills used for 100 m diameter. holes used down the hole hammers. Such down-the-hole hammers are used for larger diameter.

Down-the-Hole Hammers

In a large size wagon drill using a drifter a considerable portion of the drifter's energy is utilised in overcoming the inertia of the drill string making up the column of the drill rods and in rotating them. Such loss of the drill energy increases with depth. This waste of energy is considerably reduced by the use of the down-the-hole hammer.

The drill bit used may be a carset bit (a X-bit with little modification) or a button bit which is fitted in the hammer. The compressed air going down the hollow drill rods forces the piston which directly hammers the drill bit without any drill rod in-between. The number of blows is from 500 to 2400 per min.

When using down-the hole hammer the drifter is replaced by a rotary head placed at the top of the drill string and driven by a built-in piston type air motor. The rotational speed of the drill rods is nearly 15-25 r.p.m. The rotary head is also used to tighten and loosen threaded joints on rods.

The up and down travel of the drill rods is by a chain feed. The down-the-hole hammer, type 100 ASS used on HALCO drills for holes of 100 mm to 125 mm dia. Its specifications: Outside dia. 89 mm, length without bit 94 cms; weight without bit 31 kg.

Air consumption at 7 kgf/cm^2 is 5.5 m^3/min.

Hydraulic Wagon Drill

Some of the heavy duty wagon drills are powered by hydraulic pressure system. It is equipped with a rock drill model COP 1308 HB manufactured by the same company. In the drill, compressed air is replaced by hydraulic pressure and the prime mover for the hydraulic power pack is an air cooled diesel engine.

The absence of exhaust air results in a much lower noise level when compared with air-powered rock drill. It can drill holes of diameter. 65 mm to 127 mm and can therefore be used as a well hole drill for 127 mm dia. holes for depth upto about 12 m. The hole is flushed with compressed air at 10 kgf/cm^2.

The rate of penetration in hard rock is generally 1 m/min using 90 mm dia bit. The rock drill 1038 HB is equipped with a hydraulic system incorporates indicators rock condition. The hydraulic system incorporates indicators which point out any fault or malfunction in the system. The boom system is operated by hydraulic pressure.

Automatic disc brakes contribute towards increased safety for the operation when travelling along steep inclines.

Well Hole Drill

This is usually a crawler mounted drill operated by a diesel engine or by an electric motor which is supplied power from an external source through a trailing cable. It drills holes of 125 mm to 300 mm diameter, depth varying from 6 m to 18 m. It has a long mast, 3 m to 6 m, to accommodate the length of the drill rod.

The mast is collapsible and the drill should not be moved over an appreciable distance with the mast raised. The drills are of percussive as well as rotary type but the latter is common in coalmining areas. The drilling tool of rotary drill is a tricone bit on most of the drills but on the machines which are known as "down-the-hole percussive drills" (sometimes called "down-the-hole hammer drill"), the drilling tool is a cross bit (carset bit), or a button bit. In down-the-hole hammer drill the assembly of the drill and its short length pipe is called down-the-hole hammer.

In the rotary drill the string is rotated by the prime mover through suitable gearing. The tricone bit attached at the end of the drill string is thus rotated and it is kept pressed against the rock by hydraulic or pneumatic pressure.

In down-the-hole percussive drill the rotation of the hollow drill rods is provided by a rotary placed at the top of the drill string and driven by a built-in air motor. The air motor is also used to tighten and loosen threaded joints on rods and bits. The up or down travel of the drill rods is by a chain, operated by a reversible piston type air motor (Chain Feed).

A compressor mounted on a well hole drill helps to clean the hole as it is drilled. During drilling, the machine is leveled with the help of 3 hydraulic jacks. Normally twenty holes, each 9 m deep, can be drilled in one shift in sand stone, shale and coal.

Only vertically downward drilling is possible on most models though holes 20° off vertical can be drilled by a few machines. On some machines the drill-rods and the tools are at one end and on others, in the middle of the machine.

The latter arrangement is permissible where the burden of blast hole is large and the ground at the quarry edge strong enough to support the weight of the machine; but where this is not practicable drills rigs with the drill rods and tool at one end have to be used.

A well hole drill appears like a wagon drill suitable for large diam. A rotary well hole drill can drill in a shift of 8 hours nearly 20 holes, 200 mm dia. each 9 m deep, in sandstone, coal, shale and similar rocks.

Inclined Drilling

Where the overburden consists of soft rock which can be conveniently removed by ripper and scraper-dozer combination an alternative to ripper and scraper-dozer combination an alternative to ripper is the method of drilling nearly horizontal blast holes and blasting them. Vertical (or nearly-vertical) blast holes have to be drilled where the overburden consists of hard rock like sandstone, laterite, etc.

30° off vertical may be considered to be the limit for inclined drilling of nearly-vertical holes on a bench. Larger angle increases the length of the hole, difficulties in charging it with explosives of fixed shaped cartridges, proportion of stemmed section of the hole and gives face inclination unsuitable for travel of the shovel bucket.

The toe of a bench can be removed by extra drilling of short length horizontal holes only in the toe and blasting them, or by resort to inclined drilling of the main (nearly vertical) blast holes. In vertical as well as inclined blast holes for the face, it is always essential to extend the hole slightly beyond the level of bench floor to secure proper fragmentation of toe if the hole is terminating in hard rock.

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Impacts of Mining

CHAPTER 5

Mining has severe impacts on the environment such as air pollution, water pollution, soil erosion and soil pollution, loss of biodiversity and formation of sink holes. This chapter has been carefully written to provide an easy understanding of these various environmental effects of mining.

ENVIRONMENTAL IMPACTS OF MINING

Mining activities can harm the environment in several ways. These are as follows:

Air Pollution

Air quality is adversely affected by mining operations. Unrefined materials are released when mineral deposits are exposed on the surface through mining. Wind erosion and nearby vehicular traffic cause such materials to become airborne. Lead, arsenic, cadmium, and other toxic elements are often present in such particles. These pollutants can damage the health of people living near the mining site. Diseases of the respiratory system and allergies can be triggered by the inhalation of such airborne particles.

Water Pollution

Mining also causes water pollution which includes metal contamination, increased sediment levels in streams, and acid mine drainage. Pollutants released from processing plants, tailing ponds, underground mines, waste-disposal areas, active or abandoned surface or haulage roads, etc., act as the top sources of water pollution. Sediments released through soil erosion cause siltation or the smothering of stream beds. It adversely impacts irrigation, swimming, fishing, domestic water supply, and other activities dependent on such water bodies. High concentrations of toxic chemicals in water bodies pose a survival threat to aquatic flora and fauna and terrestrial species dependent on them for food. The acidic water released from metal mines or coal mines also drains into surface water or seeps below ground to acidify groundwater. The loss of normal pH of water can have disastrous effects on life sustained by such water.

Damage to Land

The creation of landscape blots like open pits and piles of waste rocks due to mining operations can lead to the physical destruction of the land at the mining site. Such disruptions can contribute to the deterioration of the area's flora and fauna. There is also a huge possibility that many of the surface features that were present before mining activities cannot be replaced after the process has ended. The removal of soil layers and deep underground digging can destabilize the ground which threatens the future of roads and buildings in the area. For example, lead ore mining in Galena, Kansas between 1980 and 1985 triggered about 500 subsidence collapse features that led to the abandonment of the mines in the area. The entire mining site was later restored between 1994 and 1995.

Loss of Biodiversity

Often, the worst effects of mining activities are observed after the mining process has ceased. The destruction or drastic modification of the pre-mined landscape can have a catastrophic impact on the biodiversity of that area. Mining leads to a massive habitat loss for a diversity of flora and fauna ranging from soil microorganisms to large mammals. Endemic species are most severely affected since even the slightest disruptions in their habitat can result in extinction or put them at high risk of being wiped out. Toxins released through mining can wipe out entire populations of sensitive species.

Long-term Ill-effects of Mining

A landscape affected by mining can take a long time to heal. Sometimes it never recovers. Remediation efforts do not always ensure that the biodiversity of the area is restored. Species might be lost permanently.

EFFECTS OF MINING ON AQUATIC ECOSYSTEMS

Effects of mining on aquatic resources are both physical and chemical in nature. Most of earth-moving activities of mining occurred well before the enactment of laws designed to protect aquatic resources - particularly the 1977 Federal Water Pollution Control Act. Strip mining and the deposition of culm material occurred without any regard to wetlands, watercourses, and other waterbodies. Thus, miles of stream channel habitat and many hundreds of acres of wetland in the anthracite areas have been destroyed by indiscriminate digging and filling. One prime example of such destruction can be seen in the Nanticoke Creek corridor in central Luzerne County. There, the normal course of water that drains the unmined upper slopes of Wilkes-Barre Mountain is blocked by a huge culm bank complex near Warrior Run. As a result, the headwaters of Nanticoke Creek are completely isolated from the lower reaches of that creek, and ultimately the Susquehanna River. Results from preliminary studies indicate that biological diversity and food chain support are lower than expected in the Nanticoke Creek headwaters, compared to similar creeks that are directly connected to lower reaches of their watershed.

In many places where streams flow through mine impacted areas, the fractured bedrock allows surface streamflow to seep underground. That loss of water is directly opposite to the typical gain in flow as one proceeds to lower positions in watersheds not impacted by mining. As will be noted shortly, that “lost” water is only temporarily hidden from view. Instead, the water resurfaces further down the watershed, often in a highly contaminated form.

Even if not completely obliterated, stream channels are often altered and degraded on mined sites. Studies of stream channel morphology on mined sites show that creeks there have unusually steep banks composed of unstable material. That morphology is highly unfavorable during floods because it causes unacceptably high levels of erosion, and because it often exacerbates downstream flooding. Siltation of creeks lower in the watershed is especially problematic because many valuable stream invertebrate species cannot tolerate sediment deposition.

The loss of wetlands in mined areas is another source of concern. Wetlands have many environmental benefits and enjoy the protection of federal and state laws. Wetland soils are typically porous and absorb water during periods of heavy precipitation, therefore reducing the severity of downstream flooding. Wetlands also act as excellent natural water purifiers because they trap suspended sediments and remove dissolved pollutants like nitrates, phosphates, and heavy metals. Wetlands also provide habitat to plants and animals. In that context, wetlands serve as spawning and rearing sites for fish and amphibians, breeding locations for many birds, and locations for food chain support for dozens of mammal species. The loss of wetlands due to mining activities has led to dirtier water downstream, exacerbated flooding in some cases, and a regional loss of biological diversity and ecological productivity.

Concurrent with the loss of healthy aquatic habitat, mining has created two types of unproductive open-water conditions: stripping-pit pools and sedimentation lagoons. The former are bodies of open water that develop in strip mine operations, where the excavated pit intercepts the prevailing water table. These inadvertent, artificial lakes are characterized by steep walls and depths that exceed 30’. Aside from the inherent danger that they pose, stripping-pit pools have low ecological productivity because they are typically isolated from other aquatic habitats, and because their water often contains pollutants that cannot support life. Sedimentation lagoons are natural or artificial bodies of water that are found near old mining operations. They functioned as settling basins to clarify water used to wash coal. As a result, the substrate of such lagoons is composed of deposits of fine-grained mine-wash. Such deposits are infertile and often contain high concentrations of toxic elements. Therefore, sedimentation lagoons are typically lifeless, save a few very hardy species of low ecological value.

MINING AND WATER POLLUTION

Water is essential to life on our planet. A prerequisite of sustainable development must be to ensure uncontaminated streams, rivers, lakes and oceans. There is growing public concern about the condition of fresh water. Mining affects fresh water through heavy use of water in processing ore, and through water pollution from discharged mine effluent and seepage from tailings and waste rock impoundments. Increasingly, human activities such as mining threaten the water sources on which we all depend. Water has been called “mining’s most common casualty”. There is growing awareness of the environmental legacy of mining activities that have been undertaken with little concern for the environment. The price we have paid for our everyday use of minerals has sometimes been very high. Mining by its nature consumes, diverts and can seriously pollute water resources.

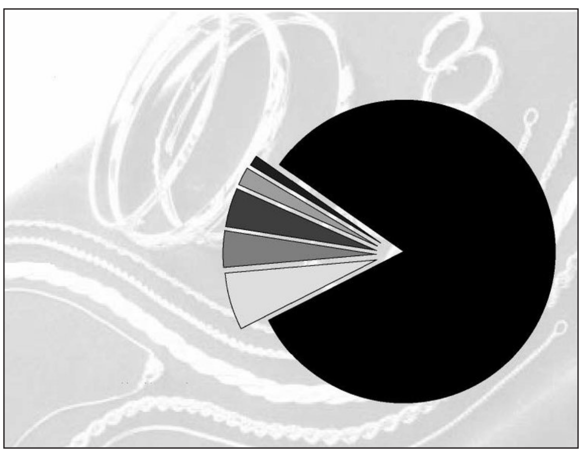
Negative Impacts

While there have been improvements to mining practices in recent years, significant environmental risks remain. Negative impacts can vary from the sedimentation caused by poorly built roads during exploration through to the sediment, and disturbance of water during mine construction. Water pollution from mine waste rock and tailings may need to be managed for decades, if not centuries, after closure. These impacts depend on a variety of factors, such as the sensitivity of local terrain, the composition of minerals being mined, the type of technology employed, the skill, knowledge and environmental commitment of the company, and finally, our ability to monitor and enforce compliance with environmental regulations. One of the problems is that mining has become more mechanized and therefore able to handle more rock and ore material than ever before. Therefore, mine waste has multiplied enormously. As mine technologies are developed to make it more profitable to mine low grade ore, even more waste will be generated in the future.

Waste from the Mining Process

Ore is mineralized rock containing a valued metal such as gold or copper, or other mineral substance such as coal. Open-pit mining involves the excavation of large quantities of waste rock (material not containing the target mineral) in order to extract the desired mineral ore. The ore is then crushed into finely ground tailings for processing with various chemicals and separating processes to extract the final product. In Canada on average for every tonne of copper extracted 99 tonnes of waste material (made up of soil, waste rock and the finely ground "tailings") must also be removed. Amount of copper removed compared to amount of waste material that must also be removed.

The amount of gold extracted per tonne of material disturbed is even less. Almost three tonnes of ore is needed to produce enough gold for one typical wedding band.



- Jewellery 83%.
- Electronics 6%.
- Metals & Fake Coins 4%.
- Other Uses 4%.

- Official Coins 2%.
- Dentistry 1%.

The Canadian mineral industry generates one million tonnes of waste rock and 950,000 tonnes of tailings per day, totaling 650 million tonnes of waste per year. After being removed, waste rock, which often contains acid-generating sulphides, heavy metals, and other contaminants, is usually stored above ground in large free-draining piles. This waste rock and the exposed bedrock walls from which it is excavated are the source of most of the metals pollution caused by mining in British Columbia. In other regions of North America tailings also represent a major source of heavy metals contamination of waterways.

Types of Water Pollution from Mining

There are four main types of mining impacts on water quality:

- Acid Mine Drainage: Acid Rock Drainage (ARD) is a natural process whereby sulphuric acid is produced when sulphides in rocks are exposed to air and water. Acid Mine Drainage (AMD) is essentially the same process, greatly magnified. When large quantities of rock containing sulphide minerals are excavated from an open pit or opened up in an underground mine, it reacts with water and oxygen to create sulphuric acid. When the water reaches a certain level of acidity, a naturally occurring type of bacteria called Thiobacillus ferroxidans may kick in, accelerating the oxidation and acidification processes, leaching even more trace metals from the wastes. The acid will leach from the rock as long as its source rock is exposed to air and water and until the sulphides are leached out – a process that can last hundreds, even thousands of years. Acid is carried off the minesite by rainwater or surface drainage and deposited into nearby streams, rivers, lakes and groundwater. AMD severely degrades water quality, and can kill aquatic life and make water virtually unusable.
- Heavy Metal Contamination & Leaching: Heavy metal pollution is caused when such metals as arsenic, cobalt, copper, cadmium, lead, silver and zinc contained in excavated rock or exposed in an underground mine come in contact with water. Metals are leached out and carried downstream as water washes over the rock surface. Although metals can become mobile in neutral pH conditions, leaching is particularly accelerated in the low pH conditions such as are created by Acid Mine Drainage.
- Processing Chemicals Pollution: This kind of pollution occurs when chemical agents (such as cyanide or sulphuric acid used by mining companies to separate the target mineral from the ore) spill, leak, or leach from the mine site into nearby water bodies. These chemicals can be highly toxic to humans and wildlife.
- Erosion and Sedimentation: Mineral development disturbs soil and rock in the course of constructing and maintaining roads, open pits, and waste impoundments. In the absence of adequate prevention and control strategies, erosion of the exposed earth may carry substantial amounts of sediment into streams, rivers and lakes. Excessive sediment can clog riverbeds and smother watershed vegetation, wildlife habitat and aquatic organisms.

Acid Mine Drainage: Prevention is the Key

Acid Mine Drainage is a watershed issue of importance to the full range of public stakeholders. To begin to address the very real problems posed by AMD, the government must:

- Prevent future loss of aquatic habitat to Acid Mine Drainage,
- Inventory and cleanup existing acid generating mine sites,
- Improve public access to information on monitoring and enforcement of AMD treatment and reclamation,
- Prevent future AMD by improving environmental risk assessment and adopting a liability prevention approach to future AMD mine assessments.

Water Quantity

Mining can deplete surface and groundwater supplies. Groundwater withdrawals may damage or destroy streamside habitat many miles from the actual mine site. In Nevada, the driest state in the United States of America, the Humboldt River is being drained to benefit gold mining operations along the Carlin Trend. Mines in the northeastern Nevada desert pumped out more than 580 billion gallons of water between 1986 and 2001 – enough to feed New York City's taps for more than a year. Groundwater withdrawn from the Santa Cruz River Basin in Southern Arizona for use at a nearby copper mine is lowering the water table and drying up the river.

What can be Done?

"Once a mine is in operation water protection must remain the highest goal of the company, even if it means reduced mineral productivity. Adopting this common-sense ethic is the only way we can ensure that the golden dreams of mining do not turn into the nightmare of poisoned streams".

Changes in laws, technologies and attitudes have begun to address some of the most immediate threats posed by mineral development, but there are still many areas of mining practices and regulations that need to be addressed. Unfortunately, significant reductions in federal and provincial government budgets have affected the capacity to administer, monitor and enforce existing laws and policies. As a result, there have been ongoing water quality and waste management problems at many mines. There have been a number of preventable accidents including massive sediment loading into fish-bearing streams, the building of roads with acid generating waste rock, non-compliance with waste handling plans, and repeated violations of water quality standards. Alan Young, of the Environmental Mining Council of BC, notes that "over the last year, we have seen an inability in regional government offices to monitor and enforce environmental standards at several mine sites. The agencies do not have the resources to do the job, and unfortunately, some companies don't seem to respond unless penalized. Without enforceable standards we are faced with decreased corporate accountability, and increased ecological liability." According to Young, "we can pay now or pay later, and history has shown us that, especially with mining, clean up is always more expensive than prevention. Good companies understand this concept, but the laws are not there for the good guys." Deregulation favoured by the industry would further reduce accountability, consistency and transparency with respect to protecting clean water. Without an effective regulatory base, voluntary measures have not, and will not deliver reliable, consistent safeguards and environmental performance improvements.

For the sake of current and future generations we need to safeguard the purity and quantity of our water against irresponsible mineral development. We need to ensure the best pollution prevention strategies are employed in cases where the risks can be managed. We also need to recognize that in some places mining should not be allowed to proceed because the identified risks to other resources, such as water, are too great.

In the right place – and with conscientious companies, new technologies and good planning – many of the potential impacts are avoidable. In fact, most mine pollution arises from negligence not necessity.

ENVIRONMENTAL IMPACT OF THE COAL INDUSTRY

The environmental impact of the coal industry includes issues such as land use, waste management, water and air pollution, caused by the coal mining, processing and the use of its products. In addition to atmospheric pollution, coal burning produces hundreds of millions of tons of solid waste products annually, including fly ash, bottom ash, and flue-gas desulfurization sludge, that contain mercury, uranium, thorium, arsenic, and other heavy metals. Coal is the largest contributor to the human-made increase of CO_2 in the atmosphere.

There are severe health effects caused by burning coal. According to a report by the World Health Organization in 2008, coal particulates pollution are estimated to shorten approximately 1,000,000 lives annually worldwide. A 2004 study commissioned by environmental groups, but contested by the US EPA, concluded that coal burning costs 24,000 lives a year in the United States. More recently, an academic study estimated that the premature deaths from coal related air pollution was about 52,000. When compared to electricity produced from natural gas via hydraulic fracturing, coal electricity is 10–100 times more toxic, largely due to the amount of particulate matter emitted during combustion. When coal is compared to solar photovoltaic generation, the latter could save 51,999 American lives per year if solar were to replace coal generation in the U.S. Due to the decline of jobs related to coal mining a study found that approximately one American suffers a premature death from coal pollution for every job remaining in coal mining.

In addition, the list of historical coal mining disasters is a long one, although work related coal deaths has declined substantially as safety measures have been enacted and underground mining has given up market share to surface mining. Underground mining hazards include suffocation, gas poisoning, roof collapse and gas explosions. Open cut hazards are principally mine wall failures and vehicle collisions. In the United States, an average of 26 coal miners per year died in the decade 2005–2014.

Land use Management

Impact to Land and Surroundings

Strip mining severely alters the landscape, which reduces the value of the natural environment in the surrounding land. The land surface is dedicated to mining activities until it can be reshaped and reclaimed. If mining is allowed, resident human populations must be resettled off the mine site; economic activities, such as agriculture or hunting and gathering food and medicinal plants are interrupted. What becomes of the land surface after mining is determined by the manner in which the mining is conducted. Usually reclamation of disturbed lands to a land use condition is not equal to the original use. Existing land uses (such as livestock grazing, crop and timber production) are temporarily eliminated in mining areas. High-value, intensive-land-use areas like urban and transportation systems are not usually affected by mining operations. If mineral values are sufficient, these improvements may be removed to an adjacent area.

Strip mining eliminates existing vegetation, destroys the genetic soil profile, displaces or destroys wildlife and habitat, alters current land uses, and to some extent permanently changes the general topography of the area mined. Adverse impacts on geological features of human interest may occur in a coal strip mine. Geomorphic and geophysical features and outstanding scenic resources may be sacrificed by indiscriminate mining. Paleontological, cultural, and other historic values may be endangered due to the disruptive activities of blasting, ripping, and excavating coal. Stripping of overburden eliminates and destroys archeological and historic features, unless they are removed beforehand.

The removal of vegetative cover and activities associated with the construction of haul roads, stockpiling of topsoil, displacement of overburden and hauling of soil and coal increase the quantity of dust around mining operations. Dust degrades air quality in the immediate area, has an adverse impact on vegetative life, and constitutes health and safety hazards for mine workers and nearby residents.

Surface mining disrupts virtually all aesthetic elements of the landscape. Alteration of land forms often imposes unfamiliar and discontinuous configurations. New linear patterns appear as material is extracted and waste piles are developed. Different colors and textures are exposed as vegetative cover is removed and overburden dumped to the side. Dust, vibration, and diesel exhaust odors are created (affecting sight, sound, and smell). Residents of local communities often find such impacts disturbing or unpleasant. In case of mountaintop removal, tops are removed from mountains or hills to expose thick coal seams underneath. The soil and rock removed is deposited in nearby valleys, hollows and depressions, resulting in blocked (and contaminated) waterways.

Removal of soil and rock overburden covering the coal resource may cause burial and loss of topsoil, exposes parent material, and creates large infertile wastelands. Soil disturbance and associated compaction result in conditions conducive to erosion. Soil removal from the area to be surface-mined alters or destroys many natural soil characteristics, and reduces its biodiversity and productivity for agriculture. Soil structure may be disturbed by pulverization or aggregate breakdown.

Mine collapses (or mine subsidences) have the potential to produce major effects above ground, which are especially devastating in developed areas. German underground coal-mining (especially in North Rhine-Westphalia) has damaged thousands of houses, and the coal-mining industries have set aside large sums in funding for future subsidence damages as part of their insurance and state-subsidy schemes. In a particularly spectacular case in the German Saar region (another historical coal-mining area), a suspected mine collapse in 2008 created an earthquake measuring

4.0 on the Richter magnitude scale, causing some damage to houses. Previously, smaller earthquakes had become increasingly common and coal mining was temporarily suspended in the area.

In response to negative land effects of coal mining and the abundance of abandoned mines in the US the federal government enacted the Surface Mining Control and Reclamation Act of 1977, which requires reclamation plans for future coal mining sites. These plans must be approved by federal or state authorities before mining begins.

Water Management

Surface mining may impair groundwater in numerous ways: by drainage of usable water from shallow aquifers; lowering of water levels in adjacent areas and changes in flow direction within aquifers; contamination of usable aquifers below mining operations due to infiltration (percolation) of poor-quality mine water; and increased infiltration of precipitation on spoil piles. Where coal or carbonaceous shale is present, increased infiltration may result in: increased runoff of poor-quality water and erosion from spoil piles, recharge of poor-quality water to shallow groundwater aquifers and poor-quality water flow to nearby streams.

The contamination of both groundwater and nearby streams may be for long periods of time. Deterioration of stream quality results from acid mine drainage, toxic trace elements, high content of dissolved solids in mine drainage water, and increased sediment loads discharged to streams. When coal surfaces are exposed, pyrite comes in contact with water and air and forms sulfuric acid. As water drains from the mine, the acid moves into the waterways; as long as rain falls on the mine tailings the sulfuric-acid production continues, whether the mine is still operating or not. Also waste piles and coal storage piles can yield sediment to streams. Surface waters may be rendered unfit for agriculture, human consumption, bathing, or other household uses.

To anticipate these problems, water is monitored at coal mines. The five principal technologies used to control water flow at mine sites are: diversion systems, containment ponds, groundwater pumping systems, subsurface drainage systems, and subsurface barriers.

River Water Pollution

Coal-fired boilers/power plants when using coal or lignite rich in limestone produces ash containing calcium oxide (CaO). CaO readily dissolves in water to form slaked lime/$Ca(OH)_2$ and carried by rainwater to rivers/irrigation water from the ash dump areas. Lime softening process precipitates Ca and Mg ions/removes temporary hardness in the water and also converts sodium bicarbonates in river water into sodium carbonate. Sodium carbonate (washing soda) further reacts with the remaining Ca and Mg in the water to remove/precipitate the total hardness. Also, water-soluble sodium salts present in the ash enhance the sodium content in water further. Thus river water is converted into soft water by eliminating Ca and Mg ions and enhancing Na ions by coal-fired boilers. Soft water application in irrigation (surface or ground water) converts the fertile soils into alkaline sodic soils. River water alkalinity and sodicity due to the accumulation of salts in the remaining water after meeting various transpiration and evaporation losses, become acute when many coal-fired boilers and power stations are installed in a river basin. River water sodicity affects downstream cultivated river basins located in China, India, Egypt, Pakistan, west Asia, Australia, western US, etc.

Waste Management

Aerial photograph of Kingston Fossil Plant coal fly ash slurry spill site taken the day after the event.

The burning of coal leaves substantial quantities of fly ash, which is usually stored in impoundment ponds. In the low-coal-content areas waste forms spoil tip. The U.S. EPA classified the 44 sites as potential hazards to communities (which means the waste sites could cause death and significant property damage if an event such as a storm, a terrorist attack or a structural failure caused a spill). The U.S. EPA estimated that about 300 dry landfills and wet storage ponds are used around the country to store ash from coal-fired power plants. The storage facilities hold the noncombustible ingredients of coal and the ash trapped by equipment designed to reduce air pollution.

Wildlife

Surface mining of coal causes direct and indirect damage to wildlife. The impact on wildlife stems primarily from disturbing, removing and redistributing the land surface. Some impacts are short-term and confined to the mine site however others have far-reaching, long-term effects.

The most direct effect on wildlife is destruction or displacement of species in areas of excavation and spoil piling. Pit and spoil areas are not capable of providing food and cover for most species of wildlife. Mobile wildlife species like game animals, birds, and predators leave these areas. More sedentary animals like invertebrates, reptiles, burrowing rodents, and small mammals may be destroyed. The community of microorganisms and nutrient-cycling processes are upset by movement, storage, and redistribution of soil.

Degradation of aquatic habitats is a major impact by surface mining and may be apparent many miles from a mining site. Sediment contamination of surface water is common with surface mining. Sediment yields may increase a thousand times their former level as a result of strip mining.

The effects of sediment on aquatic wildlife vary with the species and the amount of contamination. High sediment levels can kill fish directly, bury spawning beds, reduce light transmission, alter temperature gradients, fill in pools, spread streamflows over wider, shallower areas, and reduce the production of aquatic organisms used as food by other species. These changes destroy the habitat of valued species and may enhance habitat for less-desirable species. Existing conditions are already marginal for some freshwater fish in the United States, and the sedimentation of their habitat may result in their extinction. The heaviest sediment pollution of drainage normally comes within 5 to 25 years after mining. In some areas, unvegetated spoil piles continue to erode even 50 to 65 years after mining.

The presence of acid-forming materials exposed as a result of surface mining can affect wildlife by eliminating habitat and by causing direct destruction of some species. Lesser concentrations can suppress productivity, growth rate and reproduction of many aquatic species. Acids, dilute concentrations of heavy metals, and high alkalinity can cause severe damage to wildlife in some areas. The duration of acidic-waste pollution can be long; estimates of the time required to leach exposed acidic materials in the Eastern United States range from 800 to 3,000 years.

Air Pollution

Air Emissions

Coal and coal waste products (including fly ash, bottom ash and boiler slag) release approximately 20 toxic-release chemicals, including arsenic, lead, mercury, nickel, vanadium, beryllium, cadmium, barium, chromium, copper, molybdenum, zinc, selenium and radium, which are dangerous if released into the environment. While these substances are trace impurities, enough coal is burned that significant amounts of these substances are released.

The Mpumalanga highveld in South Africa is the most polluted area in the world due to the mining industry and coal plant power stations and the lowveld near the famous Kruger Park is under threat of new mine projects as well.

During combustion, the reaction between coal and the air produces oxides of carbon, including carbon dioxide (CO_2, an important greenhouse gas), oxides of sulfur (mainly sulfur dioxide, SO_2), and various oxides of nitrogen (NO_x). Because of the hydrogenous and nitrogenous components of coal, hydrides and nitrides of carbon and sulfur are also produced during the combustion of coal in air. These include hydrogen cyanide (HCN), sulfur nitrate (SNO_3) and other toxic substances.

SO_2 and nitrogen oxide react in the atmosphere to form fine particles and ground-level ozone and are transported long distances, making it difficult for other states to achieve healthy levels of pollution control.

The wet cooling towers used in coal-fired power stations, etc. emit drift and fog which are also an environmental concern. The drift contains Respirable suspended particulate matter. In case of cooling towers with sea water makeup, sodium salts are deposited on nearby lands which would convert the land into alkali soil, reducing the fertility of vegetative lands and also cause corrosion of nearby structures.

Fires sometimes occur in coal beds underground. When coal beds are exposed, the fire risk is increased. Weathered coal can also increase ground temperatures if it is left on the surface. Almost all fires in solid coal are ignited by surface fires caused by people or lightning. Spontaneous combustion is caused when coal oxidizes and airflow is insufficient to dissipate heat; this more commonly occurs in stockpiles and waste piles, rarely in bedded coal underground. Where coal fires occur, there is attendant air pollution from emission of smoke and noxious fumes into the atmosphere. Coal seam fires may burn underground for decades, threatening destruction of forests, homes, roadways and other valuable infrastructure. The best-known coal-seam fire may be the one which led to the permanent evacuation of Centralia, Pennsylvania, United States.

Approximately 75 Tg/S per year of Sulfur Dioxide (SO_2) is released from burning coal. After release, the Sulfur Dioxide is oxidized to gaseous H_2SO_2 which scatters solar radiation, hence their increase in the atmosphere exerts a cooling effect on climate that masks some of the warming caused by increased greenhouse gases. Release of SO_2 also contributes to the widespread acidification of ecosystems.

Mercury Emissions

In New York State winds deposit mercury from the coal-fired power plants of the Midwest, contaminating the waters of the Catskill Mountains. Mercury is concentrated up the food chain, as it is converted into methylmercury, a toxic compound which harms both wildlife and people who consume freshwater fish. The mercury is consumed by worms, which are eaten by fish, which are eaten by birds (including bald eagles). As of 2008, mercury levels in bald eagles in the Catskills had reached new heights. “People are exposed to methylmercury almost entirely by eating contaminated fish and wildlife that are at the top of aquatic food chains.” Ocean fish account for the majority of human exposure to methylmercury; the full range of sources of methylmercury in ocean fish is not well understood.

In February 2012, the U.S. EPA issued Mercury and Air Toxics Standards (MATS), which require all coal plants to substantially reduce mercury emissions. “Today, more than half of all coal-fired power plants already deploy pollution control technologies that will help them meet these achievable standards. Once final, these standards will level the playing field by ensuring the remaining plants – about 40 percent of all coal-fired power plants – take similar steps to decrease dangerous pollutants.”

Annual Excess Mortality and Morbidity

In 2008 the World Health Organization (WHO) and other organizations calculated that coal particulates pollution cause approximately one million deaths annually across the world, which is approximately one third of all premature deaths related to all air pollution sources, for example in Istanbul by lung diseases and cancer.

Pollutants emitted by burning coal include fine particulates (PM2.5) and ground level ozone. Every year, the burning of coal without the use of available pollution control technology causes thousands of preventable deaths in the United States. A study commissioned by the Maryland nurses association in 2006 found that emissions from just six of Maryland’s coal-burning plants caused 700 deaths per year nationwide, including 100 in Maryland. Since installation of pollution abatement equipment on one of these six, the Brandon Shores plant, now “produces 90 percent less nitrogen oxide, an ingredient of smog; 95 percent less sulfur, which causes acid rain; and vastly lower fractions of other pollutants.”

Economic Costs

A 2001 EU-funded study known as ExternE, or Externalities of Energy, over the decade from 1995 to 2005 found that the cost of producing electricity from coal would double over its present value, if external costs were taken into account. These external costs include damage to the environment and to human health from airborne particulate matter, nitrogen oxides, chromium VI and arsenic emissions produced by coal. It was estimated that external, downstream, fossil fuel costs amount up to 1–2% of the EU’s entire Gross Domestic Product (GDP), with coal being the main fossil fuel accountable, and this was before the external cost of global warming from these sources was even included. The study found that environmental and health costs of coal alone were 0.06/kWh, or 6 cents/kWh, with the energy sources of the lowest external costs being nuclear power 0.0019/kWh, and wind power at 0.0009/kWh.

High rates of motherboard failures in China and India appear to be due to "sulfurous air pollution produced by coal that's burned to generate electricity. It corrodes the copper circuitry," according to Intel researchers.

Greenhouse Gas Emissions

The combustion of coal is the largest contributor to the human-made increase of CO_2 in the atmosphere. Electric generation using coal burning produces approximately twice the greenhouse gasses per kilowatt compared to generation using natural gas.

Coal mining releases methane, a potent greenhouse gas. Methane is the naturally occurring product of the decay of organic matter as coal deposits are formed with increasing depths of burial, rising temperatures, and rising pressure over geological time. A portion of the methane produced is absorbed by the coal and later released from the coal seam (and surrounding disturbed strata) during the mining process. Methane accounts for 10.5 percent of greenhouse-gas emissions created through human activity. According to the Intergovernmental Panel on Climate Change, methane has a global warming potential 21 times greater than that of carbon dioxide over a 100-year timeline. The process of mining can release pockets of methane. These gases may pose a threat to coal miners, as well as a source of air pollution. This is due to the relaxation of pressure and fracturing of the strata during mining activity, which gives rise to safety concerns for the coal miners if not managed properly. The buildup of pressure in the strata can lead to explosions during (or after) the mining process if prevention methods, such as "methane draining", are not taken.

In 2008 James E. Hansen and Pushker Kharecha published a peer-reviewed scientific study analyzing the effect of a coal phase-out on atmospheric CO_2 levels. Their baseline mitigation scenario was a phaseout of global coal emissions by 2050. Under the *Business as Usual* scenario, atmospheric CO_2 peaks at 563 parts per million (ppm) in the year 2100. Under the four coal phase-out scenarios, atmospheric CO_2 peaks at 422–446 ppm between 2045 and 2060 and declines thereafter.

Radiation Exposure

Coal also contains low levels of uranium, thorium, and other naturally occurring radioactive isotopes which, if released into the environment, may lead to radioactive contamination. Coal plants emit radiation in the form of radioactive fly ash, which is inhaled and ingested by neighbours, and incorporated into crops. A 1978 paper from Oak Ridge National Laboratory estimated that coal-fired power plants of that time may contribute a whole-body committed dose of 19 μSv/a to their immediate neighbours in a 500 m radius. The United Nations Scientific Committee on the Effects of Atomic Radiation's 1988 report estimated the committed dose 1 km away to be 20 μSv/a for older plants or 1 μSv/a for newer plants with improved fly ash capture, but was unable to confirm these numbers by test.

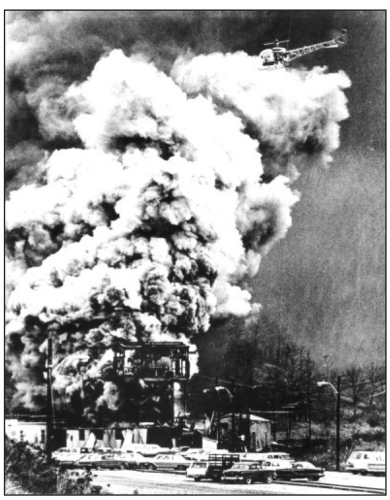
Excluding contained waste and unintentional releases from nuclear plants, coal-plants carry more radioactive wastes into the environment than nuclear plants per unit of produced energy. Plant-emitted radiation carried by coal-derived fly ash delivers 100 times more radiation to the surrounding environment than does the normal operation of a similarly productive nuclear plant. This comparison does not consider the rest of the fuel cycle, i.e., coal and uranium mining and refining and waste disposal. The operation of a 1000-MWe coal-fired power plant results in a nuclear radiation dose of 490 person-rem/year, compared to 136 person-rem/year, for an equivalent nuclear power plant including uranium mining, reactor operation and waste disposal.

Dangers to Miners

Historically, coal mining has been a very dangerous activity, and the list of historical coal mining disasters is long. The principal hazards are mine wall failures and vehicle collisions; underground mining hazards include suffocation, gas poisoning, roof collapse and gas explosions. Chronic lung diseases, such as pneumoconiosis (black lung) were once common in miners, leading to reduced life expectancy. In some mining countries black lung is still common, with 4,000 new cases of black lung every year in the US (4 percent of workers annually) and 10,000 new cases every year in China (0.2 percent of workers). Rates may be higher than reported in some regions.

In the United States, an average of 23 coal miners per year died in the decade 2007–2016. Recent U.S. coal-mining disasters include the Sago Mine disaster of January 2006. In 2007, a mine accident in Utah's Crandall Canyon Mine killed nine miners, with six entombed. The Upper Big Branch Mine disaster in West Virginia killed 29 miners in April 2010.

However, in lesser developed countries and some developing countries, many miners continue to die annually, either through direct accidents in coal mines or through adverse health consequences from working under poor conditions. China, in particular, has the highest number of coal mining related deaths in the world, with official statistics claiming that 6,027 deaths in 2004. To compare, 28 deaths were reported in the US in the same year. Coal production in China is twice that in the US, while the number of coal miners is around 50 times that of the US, making deaths in coal mines in China 4 times as common per worker (108 times as common per unit output) as in the US.



The Farmington coal mine disaster kills 78. West Virginia, US, 1968.

Build-ups of a hazardous gas are known as damps:

- Black damp: A miture of carbon dioxide and nitrogen in a mine can cause suffocation. The anoxic condition results of depletion of oxygen in enclosed spaces, e.g. by corrosion.
- After damp: Similar to black damp, after damp consists of carbon monoxide, carbon dioxide and nitrogen and forms after a mine explosion.
- Fire damp: Consists of mostly methane, a highly flammable gas that explodes between 5% and 15% – at 25% it causes asphyxiation.
- Stink damp: So named for the rotten egg smell of the hydrogen sulphide gas, stink damp can explode and is also very toxic.
- White damp: Air containing carbon monoxide which is toxic, even at low concentrations.

Firedamp explosions can trigger the much more dangerous coal dust explosions, which can engulf an entire pit. Most of these risks can be greatly reduced in modern mines, and multiple fatality incidents are now rare in some parts of the developed world. Modern mining in the US results in approximately 30 deaths per year due to mine accidents.

IMPACTS OF MINING PROJECTS ON SOCIAL VALUES

The social impacts of large-scale mining projects are controversial and complex. Mineral development can create wealth, but it can also cause considerable disruption. Mining projects may create jobs, roads, schools, and increase the demands of goods and services in remote and impoverished areas, but the benefits and costs may be unevenly shared. If communities feel they are being unfairly treated or inadequately compensated, mining projects can lead to social tension and violent conflict.

Communities feel particularly vulnerable when linkages with authorities and other sectors of the economy are weak, or when environmental impacts of mining (soil, ai, and water pollution) affect the subsistence and livelihood of local people.

Power differentials can leave a sense of helplessness when communities confront the potential for change induced by large and powerful companies. Mineral activities must ensure that the basic rights of the individual and communities affected are upheld and not infringed upon. These must include the right to control and use land; the right to clean water, a safe environment, and livelihood; the right to be free from intimidation and violence; and the right to be fairly compensated for loss.

Human Displacement and Resettlement

According to the International Institute for Environment and Development:

“The displacement of settled communities is a significant cause of resentment and conflict associated with large-scale mineral development. Entire communities may be uprooted and forced to shift elsewhere, often into purpose-built settlements not necessarily of their own choosing. Besides losing their homes, communities may also lose their land, and thus their livelihoods. Community institutions and power relations may also be disrupted. Displaced communities are often settled in areas without adequate resources or are left near the mine, where they may bear the brunt of pollution and contamination. Forced resettlement can be particularly disastrous for indigenous communities who have strong cultural and spiritual ties to the lands of their ancestors and who may find it difficult to survive when these are broken".

Impacts of Migration

According to the International Institute for Environment and Development:

One of the most significant impacts of mining activity is the migration of people into a mine area, particularly in remote parts of developing countries where the mine represents the single most important economic activity. For example, at the Grasberg mine in Indonesia the local population increased from less than 1000 in 1973 to between 100,000 and 110,000 in 1999. Similarly, the population of the squatter settlements around Porgera in PNG, which opened in 1990, has grown from 4000 to over 18,000.10 This influx of newcomers can have a profound impact on the original inhabitants, and disputes may arise over land and the way benefits have been shared. (These were among the factors that led to violent uprisings at Grasberg in the 1970s and the 1990s).

"Sudden increases in population can also lead to pressures on land, water, and other resources as well as bringing problems of sanitation and waste disposal".

"Migration effects may extend far beyond the immediate vicinity of the mine. Improved infrastructure can also bring an influx of settlers. For instance, it is estimated that the 80- meter-wide, 890-kilometre-long transportation corridor built from the Atlantic Ocean to the Carajas mine in Brazil created an area of influence of 300,000 square kilometres".

Lost Access to Clean Water

Impacts on water quality and quantity are among the most contentious aspects of mining projects. Companies insist that the use of modern technologies will ensure environmentally friendly mining practices. However, evidence of the negative environmental impacts of past mining activity causes local and downstream populations to worry that new mining activities will adversely affect their water supply.

"There are major stakes in these conflicts, affecting everything from local livelihood sustainability to the solvency of national governments. Fears for water quantity and quality have triggered numerous and sometimes violent conflicts between miners and communities".

Impacts on Livelihoods

Mining activities are not adequately managed, the result is degraded soils, water, biodiversity, and forest resources, which are critical to the subsistence of local people. When contamination is not controlled, the cost of the contamination is transferred to other economic activities, such as agriculture and fishing. The situation is made worse when mining activities take place in areas inhabited by populations historically marginalized, discriminated against, or excluded.

Proponents of mining projects must insure that the basic rights of affected individuals and communities are upheld and not infringed upon. These include rights to control and use land, the right to clean water, and the right to livelihood. Such rights may be enshrined in national law, based on and expressed through a range of international human rights instruments and agreements. All groups are equal under the law, and the interests of the most vulnerable groups (low-income and marginalized) need to be identified and protected.

Impacts on Public Health

Hazardous substances and wastes in water, air, and soil can have serious, negative impacts on public health. The World Health Organization (WHO) defines health as a "state of complete physical, mental and social well-being, and not merely the absence of disease or infirmity."

The term 'hazardous substances' is broad and includes all substances that can be harmful to people and the environment. Because of the quantity, concentration, or physical, chemical or infectious characteristics, hazardous substances may (1) cause or contribute to an increase of mortality or an increase in serious irreversible or incapacitating illness; or (2) pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, disposed of, or otherwise managed.

Frequent public health problems related to mining activities include:

- Water: Surface and ground water contamination with metals and elements; microbiological contamination from sewage and wastes in campsites and mine worker residential areas;
- Air: Exposure to high concentrations of sulfur dioxide, particulate matter, heavy metals, including lead, mercury and cadmium; Soil: Deposition of toxic elements from air emissions.

Mining activities can suddenly affect quality of life and the physical, mental, and social well-being of local communities. Improvised mining towns and camps often threaten food availability and safety, increasing the risk of malnourishment. Indirect effects of mining on public health can include increased incidence of tuberculosis, asthma, chronic bronchitis, and gastrointestinal diseases.

EFFECTS OF MINING ON HUMANS

The mining industry has a reputation for being a risky business, with health risks that are varied and often quite serious, and it is important for miners to protect themselves accordingly.

Nevertheless, mining doesn't have to be unsafe. With the introduction of strict safety legislation and protocol, as well as advances in safety equipment, the industry has seen its fatality rate drop over time.

Although the goal of zero harm has not yet been achieved, it remains the standard that mining companies continue to strive towards.

"Understanding and being aware of your environment is the first step to preventing illness or injury in the workplace".

1. Coal dust: Dust inhalation or coal dust is one of the most common concerns for miners.

"The ongoing inhalation of coal dust can cause what is colloquially known as 'miner's lung' or 'black lung'. Miner's lung is a form of the occupational lung disease group pneumoconiosis. It varies in severity, but symptoms include shortness of breath and scarring of lung tissue, which can cause ongoing respiratory issues".

Even though measures to prevent black lung have been legally enforced for many years now, new cases still occur among coal miners.

Mining companies need to develop a dust control plan, and supervisors should ensure that dust control systems are working properly for every production shift.

Mine workers should be trained on the hazards of over-exposure to coal mine dust.

Respiratory protection should be used when dust control protection is being installed, maintained or repaired. Medical screening and surveillance is also essential.

2. Noise: Mines are noisy places, with the constant of drilling and heavy machinery, and the potential for hearing damage is quite serious.

"It can be easy for you to mentally get used to loud noises, but that doesn't mean that damage isn't still being done. Many people don't notice the damage to their hearing until long after they were first exposed to the noisy environment, as most damage occurs very slowly."

"Over-exposure to excessive noise can result in tinnitus (ringing in the ears), sleep disturbances, concentration problems and even permanent hearing loss".

To protect workers against noise, mining companies should evaluate working conditions and noise exposure through risk assessments.

Avoiding and reducing exposure can be achieved by appling engineering controls at the noise source or along the noise path to reduce exposures, such as vibration dampeners or absorptive panels.

Regular maintenance of machines is also essential to reducing noise. Employer must ensure proper use of personal hearing protection amongst noise-exposed employees, while providing necessary health and safety training and maintaining up-to-date health surveillance records.

3. Whole body vibration: Whole body vibration (WBV) is a slow forming physical hazard that occurs in mining workers and other occupations that work with heavy machinery.

"In the mining environment, WBV can be caused either by spending a lot of time sitting on machinery, which is most of the time in mining extraction, or by standing, such as working on jumbo operators."

"Some forms of vibration are ok, but they become dangerous when they involve uneven surfaces, vehicle activity such as ripping versus pushing material in a bulldozer, and engine vibrations."

“Symptoms of WBV include musculoskeletal disorders, reproductive damage in females, vision impairment, digestive problems and cardiovascular changes”.

Again, reducing exposure also reduces the health risks and should be the first step that mining companies take. This might include filling in potholes on unmade roads, minimising the transport of goods or materials, or replacing manned with unmanned machines such as remotely controlled conveyors.

Where risks cannot be avoided, supervisors should reduce the time for which the employee uses the machine each day. Instruction and training are critical, and symptoms of back pain in employees should be closely monitored.

4. UV Exposure: For open-pit miners, understanding the risk of over-exposure to UV (ultraviolet) radiation in sunlight is essential.

“Over exposure of ultraviolet rays can put you at risk of skin cancer, of which Australia has the highest rate in the world. Not only can UV rays cause melanomas to form, but they can cause serious damage to your eyes if you are not wearing protective eye wear.”

“In the short-term, overexposure to the sun can cause dehydration, headaches and nausea. Mine workers often spend whole days out in the baking hot sun, so are naturally at a very high risk of developing cancer and eye problems if they are not adequately protected”.

Employers should conduct a risk assessment on outdoor work scheduled to assist in developing appropriate sun protection measures.

The most effective way of reducing UV exposure is to use a combination of protection methods, including re-organising work to avoid the UV peak of the day, providing natural or artificial shade, providing appropriate protective clothing, and applying sunscreen.

It is also important that employers train employees to raise awareness of the risks associated with exposure to UV and the sun protection measures required.

Employers can provide skin cancer checks as part of regular workplace medical examinations and in pre-employment medical checks.

5. Musculoskeletal disorders: Musculoskeletal disorders (MSDs) refer to any problems affecting your bones, muscles, blood vessels and nerves.

“Mine workers are exposed to a variety of potential health risks that fall under this broad category. While musculoskeletal damage can occur due to a trip, fall or heavy lift, the more serious ones occur slowly over time. This could be due to ongoing heavy lifting or repetitive strains”.

Preventing MSDs needs to be a key part of every workplace health and safety program. In safe and healthy workplaces, employers should identify and assess job-related MSD hazards and put in place controls to reduce workers’ exposure to MSD hazards.

Furthermore, workers should be advised and trained about MSD hazards in their job and workplace and should be encouraged to participate in health and safety programs through early reporting of MSD symptoms or concerns to their supervisors.

Employers should follow up to ensure preventative measures are working.

6. Thermal stress: A common health risk that miners face is thermal – or heat – stress.

“Mining environments are often very hot and humid, particularly those in outback Australia, which over time can cause thermal stress in workers.

“Overexposure to heat and humidity can cause the body to become fatigued and distressed. This can result in heat stroke or more serious ongoing health problems.”

Where there is a possibility of heat stress occurring, companies need to carry out a risk assessment that considers the work rate, working climate and worker clothing and respiratory protective equipment.

Where possible, control the temperature using engineering solutions, provide mechanical aids where possible to reduce the work rate, and regulate the length of exposure to hot environments.

Furthermore, personal protective equipment should be provided, such as specialised protective clothing that incorporates personal cooling systems or breathable fabrics.

Furthermore, companies should provide training for workers, especially new and young employees, and monitor the health of workers at risk.

7. Chemical hazards: Mine workers are often exposed to harmful chemicals.

“As an example, the most common group of chemicals that cause concern in a coal mining environment are polymeric chemicals”.

Regardless of the chemicals you work in close proximity to, appropriate safety wear and precautions need to be taken to minimise your body’s exposure to them. Risks include chemical burns, respiratory problems and poisoning.

Each chemical has a unique set of hazards and needs to be handled properly to ensure worker safety, so employers need to conduct risk assessments to establish best practices.

A standard operating procedure (SOP) that addresses the use of correct personal protective equipment, safe handling, safe use, and proper disposal should be established.

Ventilation is also an important factor in minimizing exposure, as well as general housekeeping and cleanliness. Thorough training and drills should be conducted regarding the company’s spill response plans and chemical hygiene plans.

The impacts of wet tailings impoundments, waste rock, heap leach, and dump leach facilities on water quality can be severe. These impacts include contamination of groundwater beneath these facilities and surface waters. Toxic substances can leach from these facilities, percolate through the ground, and contaminate groundwater, especially if the bottom of these facilities are not fitted with an impermeable liner.

Tailings (a by-product of metallic ore processing) is a high-volume waste that can contain harmful quantities of toxic substances, including arsenic, lead, cadmium, chromium, nickel, and cyanide (if cyanide leaching is used). Although it is rarely the environmentally-preferable option, most mining companies dispose of tailings by mixing them with water (to form a slurry) and disposing of the slurry behind a tall dam in a large wet tailings impoundment. Because the ore is usually extracted as a slurry, the resulting waste contains large amounts of water, and generally forms ponds at the top of the tailings dams that can be a threat to wildlife. Cyanide tailings in precious metals mines are particularly dangerous.

Ultimately, tailing ponds will either dry, in arid climates, or may release contaminated water, in wet climates. In both cases, specific management techniques are required to close these waste repositories and reduce environmental threats.

During periods of heavy rain, more water may enter a tailings impoundment than it has the capacity to contain, necessitating the release of tailings impoundment effluent. Since this effluent can contain toxic substances, the release of this effluent can seriously degrade water quality of surrounding rivers and streams, especially if the effluent is not treated prior to discharge.

Dozens of dam breaks at wet tailings impoundments have created some of the worst environmental consequences of all industrial accidents. When wet tailings impoundments fail, they release large quantities of toxic waters that can kill aquatic life and poison drinking water supplies for many miles downstream of the impoundment.

IMPACT OF GOLD MINING ON THE ENVIRONMENT

Dirty gold mining has ravaged landscapes, contaminated water supplies, and contributed to the destruction of vital ecosystems. Cyanide, mercury, and other toxic substances are regularly released into the environment due to dirty gold mining.

Toxic Waste

Modern industrial gold mining destroys landscapes and creates huge amounts of toxic waste. Due to the use of dirty practices such as open pit mining and cyanide heap leaching, mining companies generate about 20 tons of toxic waste for every 0.333-ounce gold ring. The waste, usually a gray liquid sludge, is laden with deadly cyanide and toxic heavy metals.

Many gold mines dump their toxic waste directly into natural water bodies. The Lihir gold mine in Papua New Guinea dumps over 5 million tons of toxic waste into the Pacific Ocean each year, destroying corals and other ocean life. Companies mining for gold and other metals in total dump at least 180 million tons of toxic waste into rivers, lakes, and oceans each year—more than 1.5 times the waste that U.S. cities send to landfills on a yearly basis.

To limit the environmental damage, mines often construct dams and place the toxic waste inside. But these dams do not necessarily prevent contamination of the surrounding environment. Toxic waste can easily seep into soil and groundwater, or be released in catastrophic spills. At the world's estimated 3,500 dams built to hold mine waste, one or two major spills occur every year.

Toxic waste spills have had devastating consequences in Romania, China, Ghana, Russia, Peru, South Africa, and other countries. In 2014, a dam collapsed at the Mount Polley gold and copper mine in British Columbia, sending about 25 million cubic meters of cyanide-laden waste into nearby rivers and lakes—enough to fill about 9,800 Olympic-sized swimming pools. The spill poisoned water supplies, killed fish, and harmed local tourism.

Acid Mine Drainage

Dirty gold mining often leads to a persistent problem known as acid mine drainage. The problem results when underground rock disturbed by mining is newly exposed to air and water. Iron sulfides (often called "fool's gold") in the rock can react with oxygen to form sulfuric acid. Acidic water draining from mine sites can be 20 to 300 times more concentrated than acid rain, and it is toxic to living organisms.

The dangers increase when this acidic water runs over rocks and strips out other embedded heavy metals. Rivers and streams can become contaminated with metals such as cadmium, arsenic, lead, and iron. Cadmium has been linked to liver disease, while arsenic can cause skin cancer and tumors. Lead poisoning can cause learning disabilities and impaired development in children. Iron is less dangerous, although it gives rivers and streams a slimy orange coating and the smell of rotten eggs.

Once acid mine drainage starts, it is difficult to stop. Acidic waters flowing from abandoned mines can raise acidity levels and destroy aquatic life for generations. Roman mining sites in England are still causing acid mine drainage more than 2000 years later.

Mercury Pollution

The use of mercury in gold mining is causing a global health and environmental crisis. Mercury, a liquid metal, is used in artisanal and small-scale gold mining to extract gold from rock and sediment. Unfortunately, mercury is a toxic substance that wreaks havoc on miners' health, not to mention the health of the planet.

For every gram of gold produced, artisanal gold miners release about two grams of mercury into the environment. Together, the world's 10 to 15 million artisanal gold miners release about 1000 tons of mercury into the environment each year, or 35 percent of man-made mercury pollution.

Artisanal gold mining is actually among the leading causes of global mercury pollution, ahead of coal-fired power plants.

When mercury enters the atmosphere or reaches rivers, lakes, and oceans, it can travel across great distances. About 70 percent of the mercury deposited in the United States is from international sources. Still more mercury reaches the United States through imported fish. Once it reaches a resting place, mercury is not easily removed. Sediments on the floor of San Francisco Bay remain contaminated with mercury left by the California gold rush of the 19th century.

Mercury is extremely harmful to human health. The amount of vapor released by mining activities has been proven to damage the kidneys, liver, brain, heart, lungs, colon, and immune system. Chronic exposure to mercury may result in fatigue, weight loss, tremors, and shifts in behavior. In children and developing fetuses, mercury can impair neurological development.

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Mining: Hazard Prevention and Safety

CHAPTER 6

Mining hazard can be defined as the dangers related to the working in mines. The most critical hazards that are linked to mining are gas or dust explosions, fire, flood, collapse and toxic atmospheric contaminants. All these mining hazards and their prevention and safety protocols have been carefully analyzed in this chapter.

SPECIFIC AND NON-SPECIFIC HAZARDS IN MINES

Fire, flood, collapse, toxic atmospheric contaminants, and dust or gas explosion are the most critical hazards specifically linked to underground mining.

Blasting related hazards must also be added to that list. Although not specific to underground operations, their consequences may be exacerbated by the confined atmosphere and the workplace configuration.

Specific Hazards in Underground Mines

Accidents are always a combination of hazards and causes. Making the issue more comprehensible is the only reason for presenting the hazards listed below. The collapse and flood of underground workings may be a consequence of a dust or gas explosion. Similarly, a fire can cause dust explosion and release toxic contaminants.

Here are five hazards related to underground mines:

Fire

Fires and explosions have been some of the most destructive and dangerous hazards in the mining industry. It is also one of the most challenging safety issues that miners face. They can occur at any time, whether that's in an active or abandoned facility.

The document "The prevention and control of fire and explosion in mines" issued by the Health and Safety Executive (HSE) lists a number of potential sources of fire in underground mines:

- Friction from defective bearings such as conveyor idlers, drums and wheels/axles,; conveyor belts rubbing against some fixed object, such as a roadway support or a tail end structure, or running in spillage; and seized brakes on vehicles.

- Internal combustion engines, including exhaust systems, air inlets, hot surfaces.
- Spontaneous heating of coal in the waste or of broken coal in the roadside in high-risk seams.
- Electrical and mechanical machinery and equipment, electrical sparking and hot surfaces from electrical equipment and distribution systems.
- Short circuits and earth faults on electrical equipment and distribution systems.
- Explosives and detonators, compression of air or gasses, and hot work such as burning, welding, and grinding.
- Smokers' materials, e.g. cigarettes, lighters and matches.

Some of fires can be so devastating that they can ruin entire towns. The town of Centralia, Pa., was evacuated because of a coal mine fire that began in 1962 and has since been burning. The exact cause of the fire has never been determined.

Flood

Just like fires, floods can cause just as much devastation in a mine. There are many reasons why mines can become flooded. Some floods are controlled — meaning, they are planned. But in other cases, flooding is unintentional. Some of the reasons why floods occur may be:

- Unsafe conditions in the mine itself.
- Intentional explosions, which can lead to an inrush of water.
- Lack of, improper or old mining infrastructure, which includes leaks, broken water mains and pipes in need of repair.

The Gleision Colliery mining accident took place on Sept. 15, 2011, when seven miners intentionally detonated an explosive. Following the blast, the mine began filling with water. Three of the miners managed to escape. But rescue workers were not able to save the other four, who were trapped and died underground.

After the inrush at Gleision Colliery, the Health and Safety Executive (HSE) in the United Kingdom issued the HID 4-2011 safety bulletin focusing on Regulations 1979 (Precautions Against Inrushes). This regulation was introduced in 1973 after the Lofthouse Colliery accident, Yorkshire, where seven miners were killed after the mine flooded.

Collapse

Mine collapse might be caused by the following factors:

- Induced Seismicity: Mines located in seismically active regions, such as the Andean region — also known to be one of the wealthiest metallic mining zones in the world — are particularly at risk. Especially dangerous in underground mining areas, mine-induced seismicity also causes slope instability in surface mining.

- Use of Explosives: The use of explosives may cause earthquake-like events that collapse mine workings, and traps miners, as happened to the 33 miners stuck underground from August to October 2010 in a Chilean mine near the city of Copiapo, or kill them, flood the mine and damage structures on the surface.

- Dust or Gasses Explosion: Explosions from gasses such as methane and coal dust have caused some of the largest mining disasters. They have led to miners being trapped or killed.

- Layers of coal trap methane — A highly explosive gas. Methane can be released, leading to coal dust explosions when there are mechanical errors from tools that are improperly used or that malfunction. When explosives are also detonated intentionally, they can also lead to coal dust explosions.

- One of the world's worst coal mining accidents took place at the Benxihu Colliery in Benxi, China. In April 1962, a fire broke out after gas and coal dust exploded. More than 1,500 miners died in the accident.

- Timbering/Pillar Failure: Accidents in mines can be presented by properly securing areas in which miners work with pillars and timbers. These timbers support the roof or a tunnel's face during the excavation or lining process. If these are not properly secured, they may lead to collapse.

  The role of pillars or timbers is obviously key in underground operations. The instability of pillars induced by stress or other unfavorable causes may lead to horrendous cascading pillar failure mechanisms.

Toxic Contaminant

Considering the atmosphere underground is limited and confined, the contaminants may include dust, aerosols, diesel fumes and particulates and fumes from blasting, as well as gasses released from the rock strata. Ventilation is key to extract or dilute to a harmless level the toxic contaminants.

Other Blasting-Related Hazards

Mine-induced seismicity is also another hazard. According to the National Institute for Occupational Safety and Health (NIOSH), many fatalities in underground mines related to explosives were caused by miners being too close to the blast.

Here are some other blasting-related hazards:

- Fly-Rocks: Workers struck by rocks, either because they are too close to the blast or because the rock is thrown much farther than expected, remains one of the main causes of accidents both in surface or underground mines.

- Explosives Fumes: According to the Dangers of Toxic Fumes from Blasting, surface mine blasters are far more complacent about fumes as those in underground mines. This is because there is a general belief that the open air would cause the fumes to disperse. But toxic fumes can be hazardous regardless of where they occur.

- The explosive products used in surface and underground blasting operations produce a variable quantity of toxic gasses. Harmful concentrations of such gasses are more likely to appear in underground confined environments. An efficient, well designed and maintained ventilation system is key to preventing or mitigate this risk.
- Premature Blast: This can be due to carelessness or be accidental. Faulty wiring and fuses can also be the cause. The explosive or pyrotechnical products that remain on the ground or in the muck pile might be triggered by any mechanical effect during the digging, milling or crushing stages of the mining process, causing injuries or fatalities to blasters or operators.
    - Nitrogen dioxide (NO_2).
    - Nitric oxide (NO).
    - Carbon monoxide (CO).

PRECAUTIONS FOR THE PREVENTION OF MINE ACCIDENTS AND RELATED RESPIRATORY EMERGENCIES

Mine accidents and related respiratory emergencies can be prevented. Employers and governments have responsibilities to protect employees from mine accident-associated respiratory emergencies. Effective ventilation in the mines, usage of new mining technologies, and education of employees are the primary routes. Use of the personal protective equipment is valid when general precautions are not adequate.

In general, the occurrence of mine accidents and related respiratory emergencies are associated with the outdated systems and technologies that are used in mines. It has been suggested that compared to conventional methods, using new technologies reduces the number of injured people as a result of accidents. It has been noted that systematic training programs that are implemented to improve occupational safety in order to reduce accidents are effective. Expert opinions corroborate that the deaths resulting from accidents are caused by a lack of application of occupational health and safety. It is considered that the reasons for accidents and deaths are infrastructure and technological problems such as problems in the ventilation system, lack of escape routes, insufficient personal protective equipment. It is emphasized that these are avoidable problems and are caused by the lack of control and enforcement in terms of occupational health and safety.

In the manual prepared by International Labour Organization (ILO), Underground Coal Mining Safety and Health 2009, the measures pertaining to occupational health and safety in underground mining were discussed in detail. Acute inhalation injuries occur from accidental explosions, fires, and blasting techniques that are used in underground coal mining. Methane and carbon monoxide (CO) are the most common toxic inhalant agents in coal mining. ILO manual recommends safe working systems and implementation of engineering control measures to eliminate risks. Despite these measures, if the risks still remains, using personal protective equipment is recommended.

In order to prevent acute inhalation injuries, employers have substantial responsibility for the most frequently used personal respirators. Provision and periodic maintenance of respirators and training of the workers are among these responsibilities. Having respirators in proper size and model and their disinfection are essential. For escape from coal mines, if instead of a personal rescuer, a less protective, filter type personal rescuer or a gas mask is used, this device should also provide protection against carbon monoxide for at least one hour. Mine manager should provide a sufficient number of portable devices that can detect the presence of methane, carbon monoxide, and oxygen in the mine air.

Workers and their representatives should be informed regarding the toxicological properties of substances, protective technical measures, safe working methods, protective equipment, and emergency procedures to compensate exposure. Training should be given before the incidents that lead to the release of respirable substances and their formation. Educational activities should also include first aid.

In the mine, if the number of workers in a shift exceeds the figure permitted by national laws or regulations, there should be a first aid center with the appropriate requirements. The first aid center should be on the ground located on a separate place that is not used for other purposes, appropriately close to the main entrance of the mine, equipped with an untroubled entrance that provides an access for people carrying a stretcher. Except for a registered nurse or people who have completed an approved first aid training course, no one should be appointed by the manager in the first aid center.

First aid training should include the following functions:

- Shock therapy and resuscitation.
- Wound review and evaluation.
- Making dressings.
- Medical and surgical status review and evaluation.
- Disconnecting people who were in a live circuit on an electronic device and treating their electric shock and serious bodily injuries.
- Providing emergency treatment and referring the patient to a hospital.
- Maintaining simple records.

It is useful to examine true stories while discussing the measures to be used in the prevention of mining accidents. In a publication written by Hopkins, the causes of an accident that had occurred in Moura mine, Australia were examined. The accident occurred as a methane gas explosion, and 11 workers died. As a result of official investigations, the management was reported to be at fault. Researchers listed the incorrect application of the process leading to the mine accident as a result of the analysis of audit reports.

- The mistaken belief "This accident would not happen here" has not led to provide any necessary measures. It is known that in coal mines, coal that is in contact with air slowly heats and spontaneously ignites. Mine managers assumed that this was a normal process which could be seen in every mine and since they predicted (!) an explosion would not take place before a certain incubation period (here 6 months), they caused an accident waiting to happen.

- "To ignore the warning signs" is another lack of management. Pre-accident high carbon monoxide levels were linked to the technology used in mines by the management, and it was an invitation to disaster.
- Another form of management error-related accidents is to approach intermittent danger signals as normal. For instance, in Moura, labor safety representatives connected high levels of CO to misreading and malfunctioning of the measuring devices or exhaust pollution caused by a diesel-powered vehicle passing by in that area at that moment instead of taking it as a danger signal.
- Disregarding the odor caused by toxic gas production in mines has also led to the accident. The odor emitted is similar to flammable coal tar or petrol smell. Although inspectors had detected such an odor before the accident, senior officials argued that no odor was present, and, in another case, that the odor was related to grease barrels.
- Finally, managerial resistance shown in withdrawal of workers from the hazardous area had led to fatal accidents.

The analysis of Moura accident should be taken as an example for Soma also.

Pulmonary specialists should discuss their part on the implications of Soma disaster. Pulmonary specialists working in coal mining areas should know the following:

- Knowledge regarding acute inhalation injuries as well as diagnosis and follow-up of pneumoconiosis and diagnosis, treatment and follow-up of CO and methane gas poisoning.
- Should be actively involved in the organization of treatment and follow-up of acute inhalation injuries in primary care (first aid unit in the mines, ambulance, health center), secondary care (the emergency departments of the hospital, thoracic diseases centers, etc.), and private healthcare centers (hyperbaric oxygen centers, fixed or portable).
- Through associations and other organizations, workplace physicians must take an active role in occupational health and safety elements, education of the miners' representatives, and employers in terms of health and safety in mines. The organization of the screening of chronic CO poisoning, training, and notification of workers might be carried out jointly by workplace physicians, pulmonary specialists, and emergency service specialists. The encouragement and education of the workplace physician in terms of selecting and using the ideal respirator is also a proper cooperation field.

WAYS TO MAKE MINES MORE ENVIRONMENTALLY FRIENDLY

Closing Illegal and Unregulated Mines

In context with enforcing regulations and maintaining steadfast legislation regarding a mine's behavior and processes, the strict and swift closing of illegal or unregulated mining activity will set an environmental precedent within the industry.

For example, before 2010, most mines in China were completely unregulated when it came to the environment and the shortcomings it was bringing to surrounding Chinese areas. After years of lax regulation and undisciplined treatment of illegal, unpermitted mines, China's government responded to a wave of public protest and partly in its own self-interest enacted new policy measures for greener mining. These were codified in the Rare Earth Industrial Development Policy. The following regulations are the most important out of those now in practice, and they are being enforced to discourage illegal and environmentally careless mining. These measures are not yet all fully implemented in China, but the legal productivity and environmental impact are set to increase by two-fold thanks to the closure of the illegal activity, and the cultivation of the existing legal mines.

Scrap Mining and Recycling

On a global scale, mining corporations around the world are discovering efficient ways to capitalize fully on materials in order to provide the goods and services people want using much less wood, metal, stone, plastic and other materials. By reducing the amount of wasteful use on a public and private level, and by steering production towards the sole use of durable goods that can be easily reusable, re-manufactured, or recycled, the mining industry can begin to reduce its impact on an international scale.

This creative trend of scrap mining, or utilizing ever-reusable resource for other mining initiatives, stems from the recognition of the environmental costs of excessive materials use. Mining exacts a severe and sometimes irreversible toll on public health, water and air quality, fish and wildlife habitat, and community interests. Recognizing that "business-as-usual" practices are unsustainable, some nations, international organizations, and environmental groups are calling for major reductions in materials use-often by as much as 90 percent.

Better Legislation and Regulations

Standard legislation concerning the efficiency of mining is a long way off from being the most productive and most strict government mandates that exists today. Obviously these regulations differ between nations, with some countries more advanced in terms of their legislation than others, however the need for improvement is always there in this industry, which inevitably causes some environmental damage.

In Canada for example, mines like the Island Copper Mine on Vancouver Island stands as a highly regulated mine site that operated from 1971 until 1995 when it was closed for resource depletion. It was due to the regulation and control of the government that a detailed mine closure plan was developed to comfortably close the mine in order to protect the few resources which remained, and the B.C. enacted the contaminated sites regulation process which was awarded the Certificate of Conditional Compliance. It is this kind of federal regulation that will not only protect environmental and public health, but that will improve the lifespan of the mining industry.

Improving Environmental Performance

Mining impacts the environment in unnatural ways, which not only disrupts its natural decaying process, but also does more damage long-term than natural erosion processes. With exorbitant numbers of materials excavated and used daily, it is important to see that this destruction is actually going towards productive use.

By systematically examining environmental impacts and adopting measures to mitigate these impacts, it is possible to make mining less destructive of the environment. Incremental efficiency gains will not do the job. Instead, an imaginative remaking of the industrial world-one that aligns economies with the natural environment that supports them is the sustainable way forward. Recycling has a number of advantages.

Accurate Tallying of Toxic Mining Waste

Another problem with the whole sustainable mining debate has to do with secrecy in reporting toxic mining waste. Mining companies have not been accurately reporting the amounts being dumped into the environment and in doing so, have kept the public in the dark. Most notably this has been occurring with the Canadian people as of late, with a huge public backlash being the center of much of the mining industry controversy being targeted on accurate waste tallying lately. While sustainable mining looks good on paper and seems easy enough to follow provincial or federal guidelines, the industry has a way to go before it can be considered even remotely green.

Building from Reusable Waste

Not only can mining present a hazard to the environment, but it can also be seen as a toll on public health if appropriate measures are not taken to ensure that the mining process is being done as safely and efficiently as possible. Case studies from mines around the world have provided numerous success stories of corporations and private mines alike being able to build new construction and infrastructure from the reusable materials that a mine site presents. For example, aluminum can be substituted as a recyclable material rather than using bauxite ore, which is a rarer and less reusable item.

By noticing the small details of the products used and generated in a mine site, the mining industry can make strides towards being a more sustainable industry. Tricks like recycling copper, which takes seven times less energy than processing ore, recycling steel which uses three-and-a-half times less energy than ore, can go a long way in determining the longevity of a mine and its positive environmental impact.

Closing and Reclaiming Sites of Shut-down Mines

The dangers of allowing no longer working mines to exist can not only allowing wasted debris the opportunity to rot and decay on site, but it can lead to illegal or unregulated mining activity. Enacting small decommissioning groups and contractors to take apart the mining processing facilities and plants; this process will allow the pipelines to be drained, equipment and parts of the mine to be cleaned and sold off, the buildings can be repurposed or demolished, warehouse materials recovered, and wasted disposed of.

The main objective in the reclaiming process is to return the sire and the land which surrounds it back to reusable standards, ensuring that any landforms and structures are stable, and why watercourses need to be evaluated in order to regain water quality within the affected area.

Investing in Research and Development of Green Mining Technology

The mining industry is one that is always in need of proper research and development in order to make sure the industry to ever-changing with today's commitment to sustainability and turning the world into a more "green friendly" place. Through either state of federal agencies, collecting funding and allowing that funding to be dispersed into ROD funds for Green Mining can be one way to positively impact the environment before and after mining projects. By pushing the envelope and never letting the future slip too far from reach, staying ahead can prevent unnecessary waste in the sense of less reusable materials, better efficiency and a better understood industry.

Replenishing the Environment

A seemingly simple but rarely prioritized activity, replenishing mine sites and mine environments is one of the key factors to not only earning the respect and cooperation of those living near the mine, but will ultimately protect the mine's impact on the environment. Simple solutions like replenishing native soils and grasses, cleaning excess waste, proper waste removal, site inspections and replanting trees and natural forestry can rejuvenate a long-term ecosystem repair and sustain the environment for years beyond when the mine is no longer operating. The entire reclamation process should include: removing hazardous materials, reshaping land, restoring topsoil, and planting native grasses, trees or ground cover natural to the site.

Improving the Efficiency of Manufacturing Processes

By targeting the goal of closely monitoring the standard mining supply chain, mining industry giants will be forced to confront the ways in which a company can improve its efficiency by seeing exactly where the organization is lacking in terms of sustainability and green mining initiatives. This supervision of the manufacturing process is essential in order to develop new ways of thinking, new metrics, and new management/supervisory tools that will help cushion the transition into more efficient and less environmentally-harmful patterns of resource use in modern societies.

Organizations are currently conducting research on the most frequently used resources and materials, in order to better understand how the industry can conserve its non-renewable materials. Material flows analyses will track the physical flows of natural resources through extraction, production, fabrication, use and recycling, and final disposal, accounting for both the gains and losses occurring throughout the supply chain.

MINE SAFETY

Mine safety refers to the management of operations and events within the mining industry, for protecting miners by minimizing hazards, risks and accidents. Most of the safety issues related to mining are addressed in the relevant laws, compliance and best practices that are to be considered for the best possible protection of the mining workers. Employers are to abide by the laws and practices to ensure the maximum observances of safety.

Mine safety is designed to prevent death, disease and injury in the mining industry and to promote safe workplaces for the miners. Mine safety covers a number of issues and topics effecting safety of personnel and equipment in the mining industry.

The following topics are typical when discussing mine safety:

- General safety: General aspects of safety which are common to all types of mines (electrical and machine safety).
- Occupational safety and health: Issues particularly associated to the mining. These include: blasting explosives, ergonomics, diesel and dust control and hearing loss etc.
- Process and production safety: Safety within the processes associated with mining.
- Workplace safety: Safety issues directly related to the workplace (Ex. ventilation).
- Fire and explosion safety: In particular, the risks associated to fires and explosions in the mining industry.
- Structural safety: Safety in mine construction and geologic characterization.
- Environmental safety: Issues of environmental safety (direct or indirect impact of the mining industry).

EFFICIENT WAYS TO MAKE MINES SAFER

Here are seven ways mine operators can make their facilities safer (and more efficient):

Invest in Wireless Underground Communications

Swap your hard-wired pagers for a mobile leaky-feeder communications system. This is a handheld radio which every worker who has one to communicate with colleagues underground and also allows miners (and equipment) to be quickly located. Effective communications and tracking technology is essential in case of an accident underground.

Automation can Improve Safety Underground

"If you take human error out of it you can have a lot safer working environment, in most cases. We do and there are a lot of devices in mining that are that way. We're doing a lot of things with remote, wireless remote controls now, so the individual doesn't have to be on that piece of machinery to run it – he stays out of harm's way and doesn't have to get under unsupported top, or stay out of hazardous areas and check equipment remotely".

Using Data to Improve Mine Safety

Atmospheric monitoring information collected through leaky-feeder devices can be used to provide mine managers with vital safety data.

It's critical for these operations to have proper ventilation to keep air flowing throughout the mines underground, and they can measure, on this system, the amount of air flow in particular areas.

"And that's recorded, in case they want to go back and look and see what that air flow is, they can go back and look at the history of that."

How Drones can Improve Mine Safety

Joe Carr, of Inmarsat, told Mining Technology: " Freeport-McMoRan is already using drones to create steeper pit slope angles in its mines, reducing the stripping ratio and amount of waste rock hauled before ore can be extracted. These drones not only scan the mines from perspectives that are dangerous and near-inaccessible to humans, they also instantaneously communicate any information they pick up. This makes for a more rapid and detailed analysis of the mine slopes without having to deploy highly skilled geologists or geotechnical engineers into an inherently hazardous environment or affecting production by closing haul roads.

"With machines becoming progressively more capable of acting with little manual intervention, a future where adaptable and autonomous machines carry out the on-site, operational tasks of mining while human employees monitor them remotely looks probable and highly profitable."

Kit Miners out with self-contained Rescuers

Self-contained rescuers are a portable device which provides a supply of breathable oxygen to miners should they become trapped underground, or should poisonous gases leak into mineshafts.

The standard SCSR features an oxygen scrubber, which can chemically remove impurities from the atmosphere to provide a miner with breathable oxygen.

Suppliers like Carroll Technologies can also provide an oxygen-producing unit for more specialised operations. This device is rarer in metal/non-metal mines, but is becoming increasingly widespread. It consists of a small tank filled with oxygen to which a miner has immediate access.

Many of the most significant mining accidents occur due to a lack of oxygen or the presence of poisonous gases.

Consider Switching from Wire to Synthetic Rope

According to Donna Poll of Samson rope: "When wire rope breaks there's a danger of damaging the surrounding area and people. Synthetic rope has much more predictable recoil properties."

She said that because synthetic rope is much lighter than wire there is also less likelihood of strain and sprain injuries when handling it.

Put Systems in Place to avoid Collisions Underground

Collisions involving heavy vehicles are one of the major causes of injuries underground.

One way to reduce the risks is to install proximity detection devices which sound an alarm when a large piece of equipment is getting close to another one.

Carroll Engineering president Allen Heywood explained: "As an example, the driver of a large rock truck would actually have a screen – what they call a hardened, rugged screen – and tags would be installed on personnel or smaller pieces of equipment if they just want the monitor to see where those are. They don't necessarily need to see the large piece of equipment; the one that has trouble seeing and identifying has the screen in his vehicle, and they can put one of these tags on anything".

Satellite tracking technology can be used to avoid collisions between vehicles and equipment on the surface of mines.

SAFETY OF MINING WORKERS

Following are the steps required for the safety of mining workers:

- Ensure compliance with safety and health standards. Make sure you're complying in every detail with every standard that applies to your operations and your workplace. Also check state regulations, which if they're stricter than federal standards, take precedence. And don't forget about your own safety policies. Ensure compliance with those rules, too.
- Keep employees informed about hazards. Identify every hazard in every work area and in every job, and make sure employees who might be exposed to any hazards know:
    - What the hazards are?
    - How they are dangerous?
    - How to protect against them?
    - What to do in the event of exposure to a particular hazard?
- Take appropriate steps to minimize risks. This involves many things including:
    - Well-conceived and implemented workplace safety and health programs.
    - Routine and thorough inspections and safety audits.
    - Effective engineering, administrative, and work practice controls.
    - Frequent and effective employee training.
    - Appropriate PPE to protect employees from hazards when controls are not enough.
    - Routine workplace maintenance.
- Teach employees to work safely.
    - Training is one of your most power accident-prevention tools. Teach the information, skills, techniques, and procedures employees need to know to be safe and healthy. Train frequently to keep workers up to date on workplace and regulatory changes and to keep them aware, alert, and prepared to work safely.

- Monitor performance and provide feedback. Don't assume that workers will use what they learn in training or do what their supervisors tell them to do. For all kinds of reasons workers will decide to take risks or ignore warnings and instructions. Make sure your supervisors monitor safety performance and provide positive or corrective feedback to maintain safe and healthy behavior.
- Pay attention to employees' suggestions and complaints. You may not be able to use all the suggestions or be thrilled about the complaints, but listening to employees is essential if you want to get them to be on board with your safety and health programs and to follow your safety rules. The big plus here is that employee participation leads to employee ownership, which leads to employee-driven safety and a safer workplace.
- Move quickly to correct problems. Foot-dragging over hazard abatement sends a bad message to employees. It says you don't care about their safety. So take swift and effective action whenever a safety or health problem is brought to your attention.

PERSONAL PROTECTIVE EQUIPMENT IN MINING

Head Protection

In most countries miners must be provided with, and must wear, safety caps or hats which are approved in the jurisdiction in which the mine operates. Hats differ from caps in that they have a full brim rather than just a front peak. This has the advantage of shedding water in mines which are very wet. It does, however, preclude the incorporation of side slots for mounting of hearing protection, flashlights and face shields for welding, cutting, grinding, chipping and scaling or other accessories. Hats represent a very small percentage of the head protection worn in mines.

The cap or hat would in most cases be equipped with a lamp bracket and cord holder to permit mounting of a miner's cap lamp.

The traditional miner's cap has a very low profile which significantly reduces the propensity for the miner to bump his or her head in low seam coal mines. However, in mines where head room is adequate the low profile serves no useful purpose. Furthermore, it is achieved by reducing the clearance between the crown of the cap and the wearer's skull so that these types of cap rarely meet the top impact standards for industrial head protection. In jurisdictions where the standards are enforced, the traditional miner's cap is giving way to conventional industrial head protection.

Standards for industrial head protection have changed very little since the 1960s. However, in the 1990s, the boom in recreational head protection, such as hockey helmets, cycle helmets and so on, has highlighted what are perceived to be inadequacies in industrial head protection, most notably lack of lateral impact protection and lack of retention capabilities in the event of an impact. Thus, there has been pressure to upgrade the standards for industrial head protection and in some jurisdictions this has already happened. Safety caps with foam liners and, possibly, ratchet suspensions and chin straps are now appearing in the industrial marketplace. They have not been widely accepted by users because of the higher cost and weight and their lesser comfort. However, as the new standards become more widely entrenched in labour legislation the new style of cap is likely to appear in the mining industry.

Cap Lamps

In areas of the mine where permanent lighting is not installed, the miner's cap lamp is essential to permit the miner to move and work effectively and safely. The key requirements for a cap lamp are that it be rugged, easy to operate with gloved hands, provide sufficient light output for the full duration of a work shift (to illumination levels required by local regulation) and that it be as light as possible without sacrificing any of the above performance parameters.

Halogen bulbs have largely replaced the incandescent tungsten filament bulb in recent years. This has resulted in three- or fourfold improvement in illumination levels, making it feasible to meet the minimum standards of illumination required by legislation even at the end of an extended work-shift. Battery technology also plays a major part in lamp performance. The lead acid battery still predominates in most mining applications, although some manufacturers have successfully introduced nickel-cadmium (nicad) batteries, which can achieve the same performance with a lower weight. Reliability, longevity and maintenance issues, however, still favour the lead acid battery and probably account for its continued dominance.

In addition to its primary function of providing lighting, the cap lamp and battery have recently been integrated into mine safety communications systems. Radio receivers and circuitry embedded in the battery cover permit the miners to receive messages, warnings or evacuation instructions through very low frequency (VLF) radio transmission and enable them to be made aware of an incoming message by means of an on/off flashing of the cap lamp.

Such systems are still in their infancy but they do have the potential to provide an advance in early warning capability over traditional stench gas systems in those mines where a VLF radio communication system can be engineered and installed.

Eye and Face Protection

Most mining operations around the world have compulsory eye protection programmes which require the miner to wear safety spectacles, goggles, faceshields or a full facepiece respirator, depending on the operations being performed and the combination of hazards to which the miner is exposed. For the majority of mining operations, safety spectacles with side shields provide suitable protection. The dust and dirt in many mining environments, most notably hard-rock mining, can be highly abrasive. This causes scratching and rapid wear of safety glasses with plastic (polycarbonate) lenses. For this reason, many mines still permit the use of glass lenses, even though they do not provide the resistance to impact and shattering offered by polycarbonates, and even though they may not meet the prevailing standard for protective eye wear in the particular jurisdiction. Progress continues to be made in both anti-fog treatments and surface hardening treatments for plastic lenses. Those treatments which change the molecular structure of the lens surface rather than simply applying a film or coating are typically more effective and longer lasting and have the potential to replace glass as the lens material of choice for abrasive mining environments.

Goggles are not worn frequently below ground unless the particular operation poses a danger of chemical splash.

A faceshield may be worn where the miner requires full-face protection from weld spatter, grinding residues or other large flying particles which could be produced by cutting, chipping or scaling. The faceshield may be of a specialized nature, as in welding, or may be clear acrylic or polycarbonate. Although faceshields can be equipped with their own head harness, in mining they will normally be mounted in the accessory slots in the miner's safety cap. Faceshields are designed so that they can be quickly and easily hinged upwards for observation of the work and down over the face for protection when performing the work.

A full facepiece respirator may be worn for face protection when there is also a requirement for respiratory protection against a substance which is irritating to the eyes. Such operations are more often encountered in the above ground mine processing than in the below ground mining operation itself.

Respiratory Protection

The most commonly needed respiratory protection in mining operations is dust protection. Coal dust as well as most other ambient dusts can be effectively filtered using an inexpensive quarter facepiece dust mask. The type which uses an elastomer nose/mouth cover and replaceable filters is effective. The moulded throw-away fibre-cup type respirator is not effective.

Welding, flame cutting, use of solvents, handling of fuels, blasting and other operations can produce air-borne contaminants that require the use of twin cartridge respirators to remove combinations of dust, mists, fumes, organic vapours and acid gases. In these cases, the need for protection for the miner will be indicated by measurement of the contaminants, usually performed locally, using detector tubes or portable instruments. The appropriate respirator is worn until the mine ventilation system has cleared the contaminant or reduced it to levels that are acceptable.

Certain types of particulates encountered in mines, such as asbestos fibres found in asbestos mines, coal fines produced in longwall mining and radionuclides found in uranium mining, may require the use of a positive pressure respirator equipped with a high-efficiency particulate absolute (HEPA) filter. Powered air-purifying respirators (PAPRs) which supply the filtered air to a hood, tight-fitting facepiece or integrated helmet facepiece assembly meet this requirement.

Hearing Protection

Underground vehicles, machinery and power tools generate high ambient noise levels which can create long-term damage to human hearing. Protection is normally provided by ear muff type protectors which are slot-mounted on the miner's cap. Supplementary protection can be provided by wearing closed cell foam ear plugs in conjunction with the ear muffs. Ear plugs, either of the disposable foam cell variety or the reusable elastomeric variety, may be used on their own, either because of preference or because the accessory slot is being used to carry a face shield or other accessory.

Skin Protection

Certain mining operations may cause skin irritation. Work gloves are worn whenever possible in such operations and barrier creams are provided for additional protection, particularly when the gloves cannot be worn.

Foot Protection

The mining work boot may be of either leather or rubber construction, depending on whether the mine is dry or wet. Minimum protective requirements for the boot include a full puncture-proof sole with a composite outer layer to prevent slipping, a steel toe-cap and a metatarsal guard. Although these fundamental requirements have not changed in many years, advances have been made towards meeting them in a boot that is far less cumbersome and far more comfortable than the boots of several years ago. For example, metatarsal guards are now available in moulded fibre, replacing the steel hoops and saddles that were once common. They provide equivalent protection with less weight and less risk of tripping. The lasts (foot forms) have become more anatomically correct and energy absorbing mid-soles, full moisture barriers and modern insulating materials have made their way from the sports/recreation footwear market into the mining boot.

Clothing

Ordinary cotton coveralls or treated flame-resistant cotton coveralls are the normal workwear in mines. Strips of reflective material are usually added to make the miner more visible to drivers of moving underground vehicles. Miners working with jumbo drills or other heavy equipment may also wear rain suits over their coveralls to protect against cutting fluid, hydraulic oil and lubricating oils, which can spray or leak from the equipment.

Work gloves are worn for hand protection. A general purpose work glove would be constructed of cotton canvas reinforced with leather. Other types and styles of glove would be used for special job functions.

Belts and Harnesses

In most jurisdictions, the miners belt is no longer considered suitable or approved for fall protection. A webbing or leather belt is still used, however, with or without suspenders and with or without a lumbar support to carry the lamp battery as well as a filter self-rescuer or self-contained (oxygen generating) self-rescuer, if required.

A full body harness with D-ring attachment between the shoulder blades is now the only recommended device for protecting miners against falls. The harness should be worn with a suitable lanyard and shock absorbing device by miners working in shafts, over crushers or near open sump or pits. Additional D-rings may be added to a harness or a miner's belt for work positioning or to restrict movement within safe limits.

Protection from Heat and Cold

In open-pit mines in cold climates, miners will have winter clothing including thermal socks, underwear and gloves, wind resistant pants or over-pants, a lined parka with hood and a winter liner to wear with the safety cap.

In underground mines, heat is more of a problem than cold. Ambient temperatures may be high because of the depth of the mine below ground or because it is located in a hot climate. Protection from heat stress and potential heat stroke can be provided by special garments or undergarments which can accommodate frozen gel packs or which are constructed with a network of cooling tubes to circulate cooling fluids over the surface of the body and then through an external heat exchanger. In situations where the rock itself is hot, heat resistant gloves, socks and boots are worn. Drinking water or, preferably, drinking water with added electrolytes must be available and must be consumed to replace lost body fluids.

Other Protective Equipment

Depending on local regulations and the type of mine, miners may be required to carry a self-rescue device. This is a respiratory protection device which will help the miner to escape from the mine in the event of a mine fire or explosion that renders the atmosphere unbreathable because of carbon monoxide, smoke and other toxic contaminants. The self-rescuer may be a filtration type device with a catalyst for carbon monoxide conversion or it may be a self-contained self-rescuer, i.e., a closed-cycle breathing apparatus which chemically regenerates oxygen from exhaled breath.

Portable instruments (including detector tubes and detector tube pumps) for the detection and measurement of toxic and combustible gases are not carried routinely by all miners, but are used by mine safety officers or other designated personnel in accordance with standard operating procedures to test mine atmospheres periodically or before entry.

Improving the ability to communicate with personnel in underground mining operations is proving to have enormous safety benefits and two-way communication systems, personal pagers and personnel locating devices are finding their way into modern mining operations.

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We would like to thank the editorial team for lending their expertise to make the book truly unique. They have played a crucial role in the development of this book. Without their invaluable contributions this book wouldn't have been possible. They have made vital efforts to compile up to date information on the varied aspects of this subject to make this book a valuable addition to the collection of many professionals and students.

This book was conceptualized with the vision of imparting up-to-date and integrated information in this field. To ensure the same, a matchless editorial board was set up. Every individual on the board went through rigorous rounds of assessment to prove their worth. After which they invested a large part of their time researching and compiling the most relevant data for our readers.

The editorial board has been involved in producing this book since its inception. They have spent rigorous hours researching and exploring the diverse topics which have resulted in the successful publishing of this book. They have passed on their knowledge of decades through this book. To expedite this challenging task, the publisher supported the team at every step. A small team of assistant editors was also appointed to further simplify the editing procedure and attain best results for the readers.

Apart from the editorial board, the designing team has also invested a significant amount of their time in understanding the subject and creating the most relevant covers. They scrutinized every image to scout for the most suitable representation of the subject and create an appropriate cover for the book.

The publishing team has been an ardent support to the editorial, designing and production team. Their endless efforts to recruit the best for this project, has resulted in the accomplishment of this book. They are a veteran in the field of academics and their pool of knowledge is as vast as their experience in printing. Their expertise and guidance has proved useful at every step. Their uncompromising quality standards have made this book an exceptional effort. Their encouragement from time to time has been an inspiration for everyone.

The publisher and the editorial board hope that this book will prove to be a valuable piece of knowledge for students, practitioners and scholars across the globe.

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