Mining Engineering

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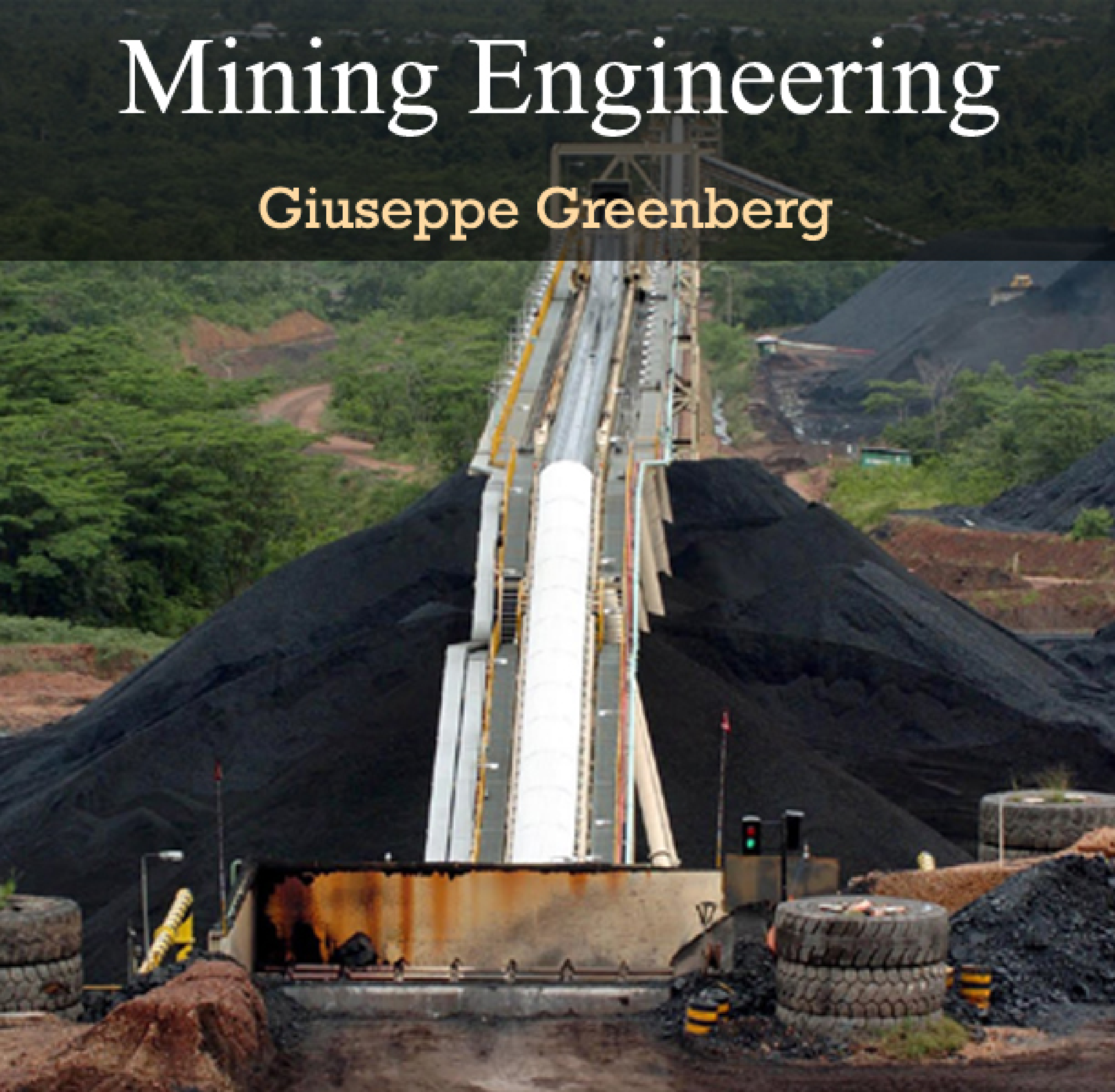

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Introduction

Surface coal mine with haul truck in foreground

Mining engineering is an engineering discipline that involves the practice, the theory, the science, the technology, and application of extracting and processing minerals from a naturally occurring environment. Mining engineering also includes processing minerals for additional value.

The need for mineral extraction and production is an essential activity of modern society. Mining activities by their nature cause a disturbance of the environment in and around which the minerals are located. Modern mining engineers must therefore be concerned not only with the production and processing of mineral commodities, but also with the mitigation of damage or to the environment as a result of that production and processing.

History of Mining Engineering

Since the beginning of civilization people have used stone, ceramics and, later, metals found on or close to the Earth's surface. These were used to manufacture early tools and weapons. For example, high quality flint found in northern France and southern England were used to set fire and break rock. Flint mines have been found in chalk areas where seams of the stone were followed underground by shafts and galleries. The oldest known mine on archaeological record is the "Lion Cave" in Swaziland. At this site, which by radiocarbon dating proves the mine to be about 43,000 years old, paleolithic humans mined mineral hematite, which contained iron and was ground to produce the red pigment ochre.

The ancient Romans were innovators of mining engineering. They developed large scale mining methods, especially the use of large volumes of water brought to the minehead by numerous aqueducts for hydraulic mining. The exposed rock was then attacked by fire-setting where fires were used to heat the rock, which would be quenched with a stream of water. The thermal shock cracked the rock, enabling it to be removed. In some mines the Romans utilized water-powered machinery such as reverse overshot water-wheels. These were used extensively in the copper mines at Rio Tinto in Spain, where one sequence comprised 16 such wheels arranged in pairs, and lifting water about 80 feet (24 m).

Black powder was first used in mining in Banská Štiavnica, Kingdom of Hungary present-day Slovakia in 1627. This allowed blasting of rock and earth to loosen and reveal ore veins, which was much faster than fire setting. The Industrial Revolution saw further advances in mining technologies, including improved explosives and steam-powered pumps, lifts and drills.

US Salary and Statistics

There are an estimated 6,900 employed mining engineers. The median salary for a mining engineer is $75,960. The mining engineer is typically employed in oil and gas extraction, metal ore mining, and coal mining. The occupation is expected to grow about faster than average. The faster growth is due to older mining engineers retiring and few schools that offer an education specific to this discipline.

Mineral Exploration

Mining engineers are consulted for virtually every stage of a mining operation. The first role of engineering in mines is the discovery of a mineral deposit and the determination of the profitability of a mine.

Mineral Discovery

Mining engineers are involved in the mineral discovery stage by working with geologists to identify a mineral reserve. The first step in discovering an ore body is to determine what minerals to test for. The geologists and engineers drill core samples and conduct surface surveys searching for specific compounds and ores. For example a mining engineer and geologist may target metallic ores such as galena for lead or chalcolite for copper. A mining engineer may also search for a non-metal such as phosphate, quartz, or coal.

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 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 engineer 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 profitible; 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 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 minerals 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. There are two types of explosives that can be used in mining: high velocity and low velocity. High velocity blasting uses high explosives while low velocity blasting is done with low explosives. Engineers determine the placement of the explosive charges and the blast sequence to efficiently and safely loosen the maximum amount of ore. They also are responsible for the safety of the miners by determining how best to support the rock ceiling in the newly-formed cave.

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.

United States

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 anytime 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

United States

A mining engineer may be involved at the end of the mine life cycle when mine reclamation operations are planned and carried out. They also decide how to close a mine that has ceased operations to keep the public safe.

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.

Chapter 1

Mineral Exploration

Mineral exploration is the process of finding ore (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.

Stages of mineral exploration

Mineral exploration methods vary at different stages of the process depending on size of the area being explored, as well as the density and type of information sought. Aside from extraplanetary exploration, at the largest scale is a geological mineral Province (such as the Eastern Goldfields Province of Western Australia), which may be sub-divided into Regions. At the smaller scale are mineral Prospects, which may contain several mineral Deposits.

Province scale - area selection

Area selection is a crucial step in professional mineral exploration. Selection of the best, most prospective, area in a mineral field, geological region or terrain will assist in making it not only possible to find ore deposits, but to find them easily, cheaply and quickly.

Area selection is based on applying the theories behind ore genesis, the knowledge of known ore occurrences and the method of their formation, to known geological regions via the study of geological maps, to determine potential areas where the particular class of ore deposit being sought may exist. Oftentimes new styles of deposits may be found which reveal opportunities to find look-alike deposit styles in rocks and terrains previously thought barren, which may result in a process of pegging of leases in similar geological settings based on this new model or methodology. This behaviour is particularly well exemplified by exploration for Olympic Dam style deposits, particularly in South Australia and worldwide based on models of IOCG formation, which results in all coincident gravity and magnetic anomalies in appropriate settings being pegged for exploration.

This process applies the disciplines of basin modeling, structural geology, geochronology, petrology and a host of geophysical and geochemical disciplines to make predictions and draw parallels between the known ore deposits and their physical form and the unknown potential of finding a 'lookalike' within the area selected.

Area selection is also influenced by the commodity being sought; exploring for gold occurs in a different manner and within different rocks and areas to exploration for oil or natural gas or iron ore. Areas which are prospective for gold may not be prospective for other metals and commodities.

Similarly, companies of different sizes (in terms of market capitalisation and financial strength) may look for different sized deposits, or deposits of a minimum size, depending on their will and ability to finance construction. Often the major mining houses will not look for deposits of less than a certain size class because small deposits will not meet their criteria for an internal rate of return. This practise may result in larger mining companies relinquishing control of smaller ore bodies they find, or may preclude them from entering a terrane which is characterised by deposits of a particular type or style. For example, a mining major would not look for a relatively small, high-cost Kambalda style nickel deposit and would direct their efforts toward discovering a Mt Keith style deposit.

Often a company or consortium wishing to enter mineral exploration may conduct market research to determine, if a resource in a particular commodity is found, whether or not the resource will be worth mining based on projected commodity prices and demand growth. This process may also inform upon the Area Selection process as noted above, where areas with small-sized deposit styles will be ruled out based on likely economic returns should a deposit be found. This occurs because often smaller deposits are more expensive to run, and hence, carry greater risks of closure if commodity prices fall significantly.

Area selection may also be influenced by previous finds, a practice affectionately named subsurface control or *nearology*, and may also be determined in part by financial and taxation incentives and tariff systems of individual nations. The role of infrastructure may also be crucial in area selection, because the ore must be brought to market and infrastructure costs may render isolated ore uneconomic.

The ultimate result of an area selection process is the pegging or notification of exploration licenses, known as *tenements*.

Target generation - Regional Scale

The target generation phase involves investigations of the geology via mapping, geophysics and conducting geochemical or intensive geophysical testing of the surface and subsurface geology. In some cases, for instance in areas covered by soil, alluvium and platform cover, drilling may be performed directly as a mechanism for generating targets.

Geophysical methods

Geophysical instruments play a large role in gathering geological data which is used in mineral exploration. Instruments are used in geophysical surveys to check for variations in gravity, magnetism, electromagnetism (resistivity of rocks) and a number of different other variables in a certain area. The most effective and widespread method of gathering geophysical data is via flying airborne geophysics.

Geiger counters and scintillometers are used to determine the amount of radioactivity. This is particularly applicable to searching for uranium ore deposits but can also be of use in detecting radiometric anomalies associated with metasomatism.

Airborne magnetometers are used to search for magnetic anomalies in the Earth's magnetic field. The anomalies are an indication of concentrations of magnetic minerals such as magnetite, pyrrhotite and ilmenite in the Earth's crust. It is often the case that such magnetic anomalies are caused by mineralization events and associated metals.

Ground-based geophysical prospecting in the target selection stage is more limited, due to the time and cost. The most widespread use of ground-based geophysics is electromagnetic geophysics which detects conductive minerals such as sulfide minerals within more resistive host rocks.

Ultraviolet lamps may cause certain minerals to fluoresce, and is a key tool in prospecting for tungsten mineralisation.

Remote sensing

Aerial photography is an important tool in assessing mineral exploration tenements, as it gives the explorer orientation information - location of tracks, roads, fences, habitation, as well as ability to at least qualitatively map outcrops and regolith systematics and vegetation cover across a region. Aerial photography was first used post World War II and was heavily adopted in the 1960s onwards.

Since the advent of cheap and declassified Landsat images in the late 1970s and early 1980s, mineral exploration has begun to use satellite imagery to map not only the visual light spectrum over mineral exploration tenements, but spectra which are beyond the visible.

Satellite based spectroscopes allow the modern mineral explorationist, in regions devoid of cover and vegetation, to map minerals and alteration directly. Improvements in the resolution of modern commercially based satellites has also improved the utility of satellite imagery; for instance GeoEye satellite images can be generated with a 40 cm pixel size.

Geochemical methods

The primary role of geochemistry, here used to describe assaying or geological media, in mineral exploration is to find an area *anomalous* in the commodity sought, or in elements known to be associated with the type of mineralisation sought.

Regional geochemical exploration has traditionally involved use of stream sediments to target potentially mineralised catchments. Regional surveys may use low sampling densities such as one sample per 100 square kilometres. Follow-up geochemical surveys commonly use soils as the sampling media, possibly via the collection of a grid of samples over the tenement or areas which are amenable to soil geochemistry. Areas which are covered by transported soils, alluvium, colluvium or are disturbed too much by human activity (roads, rail, farmland), may need to be drilled to a shallow depth in order to sample undisturbed or unpolluted bedrock.

Once the geochemical analyses are returned, the data is investigated for anomalies (single or multiple elements) that may be related to the presence of mineralisation. The geochemical anomaly is often field checked against the outcropping geology and, in modern geochemistry, normalised against the regolith type and landform, to reduce the effects of weathering, transported materials and landforms.

Geochemical anomalies may be spurious or related to low-grade or sub-grade mineralisation. In order to determine if this is the case, geochemical anomalies must be drilled in order to test them for the existence of economic concentrations of mineralisation, or even to determine why they exist in the place they exist.

The presence of some chemical elements may indicate the presence of a certain mineral. Chemical analysis of rocks and plants may indicate the presence of an underground deposit. For instance elements like arsenic and antimony are associated with gold deposits and hence, are example pathfinder elements. Tree buds can be sampled for pathfinder elements in order to help locate deposits.

Resource evaluation

Resource evaluation is undertaken to quantify the grade and tonnage of a mineral occurrence. This is achieved primarily by drilling to sample the prospective horizon, lode or strata where the minerals of interest occur.

The ultimate aim is to generate a density of drilling sufficient to satisfy the economic and statutory standards of an ore resource. Depending on the financial situation and size of the deposit and the structure of the company, the level of detail required to generate this resource and stage at which extraction can commence varies; for small partnerships and private non-corporate enterprises a very low level of detail is required whereas for corporations which require debt equity (loans) to build capital intensive extraction infrastructure, the rigor necessary in resource estimation is far greater. For large cash rich companies working on small ore bodies, they may work only to a level necessary to satisfy their internal risk assessments before extraction commences.

Resource estimation may require pattern drilling on a set grid, and in the case of sulfide minerals, will usually require some form of geophysics such as down-hole probing of drillholes, to geophysically delineate ore body continuity within the ground.

The aim of resource evaluation is to expand the known size of the deposit and mineralisation. A *scoping study* is often carried out on the ore deposit during this stage to determine if there may be enough ore at a sufficient grade to warrant extraction; if there is not further resource evaluation drilling may be necessary. In other cases, several smaller individually uneconomic deposits may be socialised into a 'mining camp' and extracted in tandem. Further exploration and testing of anomalies may be required to find or define these other satellite deposits.

Reserve definition

Reserve definition is undertaken to convert a mineral resource into an ore reserve, which is an economic asset. The process is similar to resource evaluation, except more intensive and technical, aimed at statistically quantifying the grade continuity and mass of ore.

Reserve definition also takes into account the milling and extractability characteristics of the ore, and generates bulk samples for metallurgical testwork, involving crushability, floatability and other ore recovery parameters.

Reserve definition includes geotechnical assessment and engineering studies of the rocks within and surrounding the deposit to determine the potential instabilities of proposed open pit or underground mining methods. This process may involve drilling diamond core samples to derive structural information on weaknesses within the rock mass such as faults, foliations, joints and shearing.

At the end of this process, a feasibility study is published, and the ore deposit may be either deemed uneconomic or economic.

Extraction

The ultimate goal of mineral exploration is the extraction, beneficiation and profitable and beneficial sale of mineral commodities.

Extraction methods may vary considerably and it is the discipline of engineers trained in mining engineering to determine the most safe, cost effective and efficient method of mining the ore body.

Mineral exploration and development does not cease upon a decision to mine. Exploration of a brownfields nature is conducted to find near-mine repetitions, extensions and continuity of the existing ore body. In-mine exploration and grade control drilling is a major concern of operating mines and can be an effective tool in adding value to existing mineral operations.

Often the lessons learned from studying an exposed ore body, both empirically and scientifically, are invaluable to the exploration geologist and geophysicist, for they get to see the proof of their concepts and the errors of the assumptions they used in the search for the ore body. It is always the case that the exact nature of the ore body does not exactly match the models used to find it.

Greenfields vs brownfields

Exploration is termed either *Greenfields* or *Brownfields* depending on the extent to which previous exploration has been conducted on the tenements in question. Greenfields alludes to unspoilt grass, and brownfields to that which has been trodden on repeatedly. While loosely defined, the general meaning of brownfields exploration is that which is conducted within geological terranes within close proximity to known ore deposits. Greenfields are the remainder.

Greenfields exploration is highly conceptual, relying on the predictive power of ore genesis models to search for mineralisation in unexplored virgin ground. This may be territory which has been drilled for other commodities, but with a new exploration concept is considered prospective for commodities not sought there before.

The success rate of exploration and the return on investment is low because exploration is an inherently risky business. Figures for success rates depend on the commodity in question but a good strike rate can be measured in the oil industry; the supergiant Prudhoe Bay oilfield was found on the 12th well drilled into the area. Within gold deposits a discovery hole may be one in one thousand and within some base metals commodities strike rates range from one in fifty to one in one hundred.

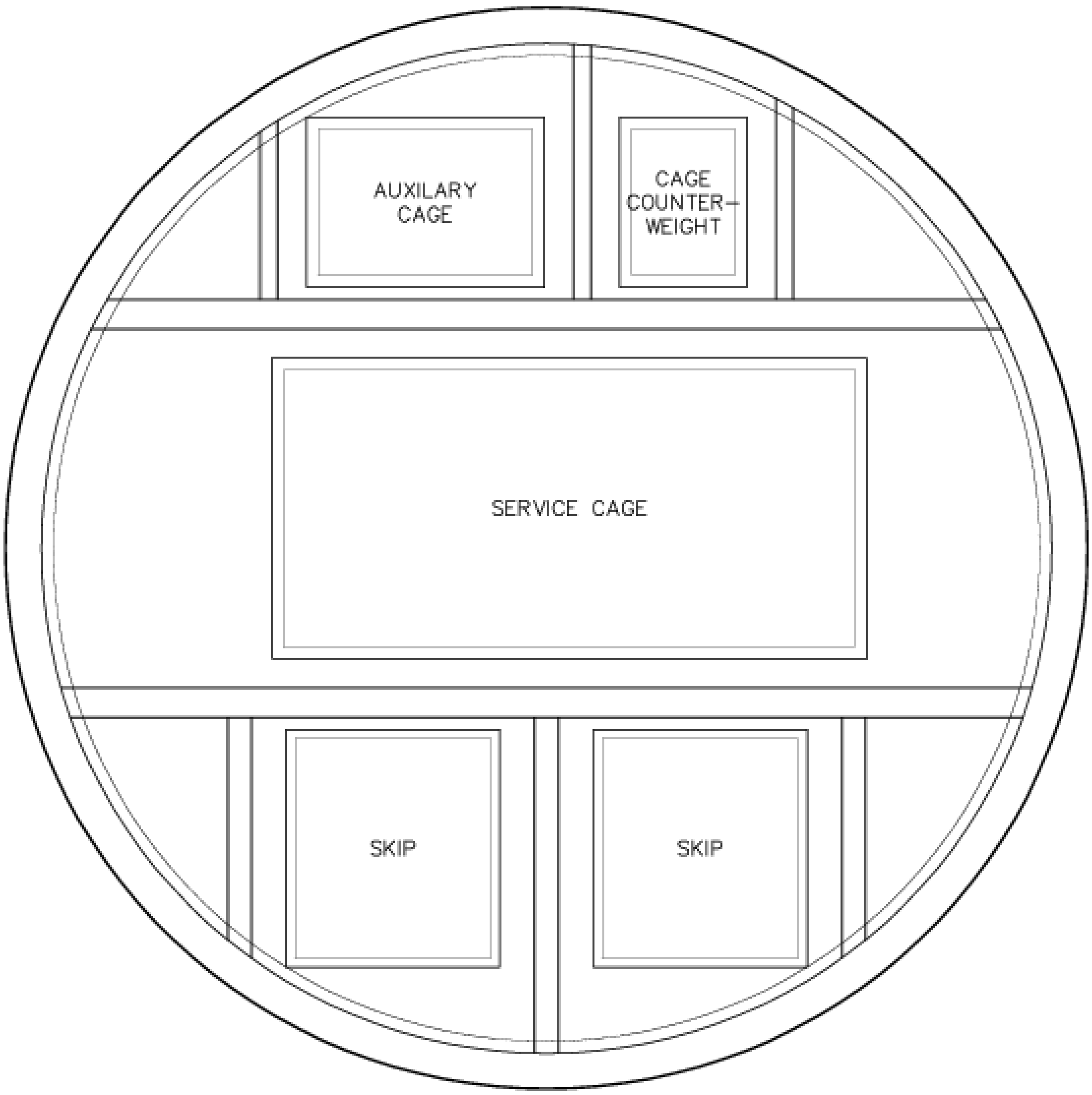
Greenfields exploration has a lower strike rate, because the geology is poorly understood at the conception of an exploration program but the rewards are greater because it is easier to find the biggest deposit in an area earlier, and it is only with more effort that the smaller satellite deposits are found. Brownfields exploration is less risky, as the geology is better understood and exploration methodology is well known, but since most large deposits are already found the rewards are incrementally less.

Chapter 2

Shaft Mining & Mine Railway

Shaft Mining

Abandoned mine shafts in Marl, Germany.



A plan-view schematic of a mine shaft showing cage and skip compartments. Services may be housed in either of the four open compartments.

Shaft mining or **Shaft sinking** refers to the method of excavating a vertical or near-vertical tunnel from the top down, where there is initially no access to the bottom. When the top of the excavation is the ground surface, it is referred to as a shaft or portal, when the top of the excavation is underground, it is called a winze.

Off-shaft access

The mine shaft is used to gain access to an underground mining facility. Horizontal workings off the shaft are called drifts, galleries or levels. These extend from the central shaft toward the ore body. The point of contact between these levels and the shaft itself is known as the inset, shaft station or plat.

Surface facilities

On the surface above the shaft stands a building known as the headframe (or winding tower, poppet head or pit head). Depending on the type of hoist used the top of the headframe will either house a hoist motor or a sheave wheel (with the hoist motor mounted on the ground). The headframe will also contain bins for storing ore being transferred to the processing facility. If the shaft is used for mine ventilaton a plenum or casing, is incorporated into the headframe to ensure the proper flow of air into and out of the mine.

Shaft lining

In North and South America, smaller shafts are designed to be rectangular with timber supports. Larger shafts are round and are concrete lined.

Shaft compartments

A mine shaft is frequently split into multiple compartments. The largest compartment is typically used for the cage, a conveyance used for moving workers and supplies below the surface. It functions in a similar manner to an elevator. The second compartment is used for one or more skips, used to hoist ore to the surface. Smaller mining operations use a skip mounted underneath the cage, rather than a separate device, while some large mines have separate shafts for the cage and skips. The third compartment is used for an emergency exit; it may house an auxiliary cage or a system of ladders. An additional compartment houses mine services such as high voltage cables and pipes for transfer of water, compressed air or diesel fuel.

A second reason to divide the shaft is for ventilation. One or more of the compartments discussed above may be used for air intake, while others may be used for exhaust.

Mine Railway

1938 Deutz mine railway locomotive.

A **mine railway** is a railway constructed to carry materials and workers in and out of a mine. Materials transported typically include ore, coal and spoil. Today most mine railways are electrically powered; in former times pit ponies, such as Shetland ponies, were used to haul the trains. In very cramped conditions, children were also used.

General

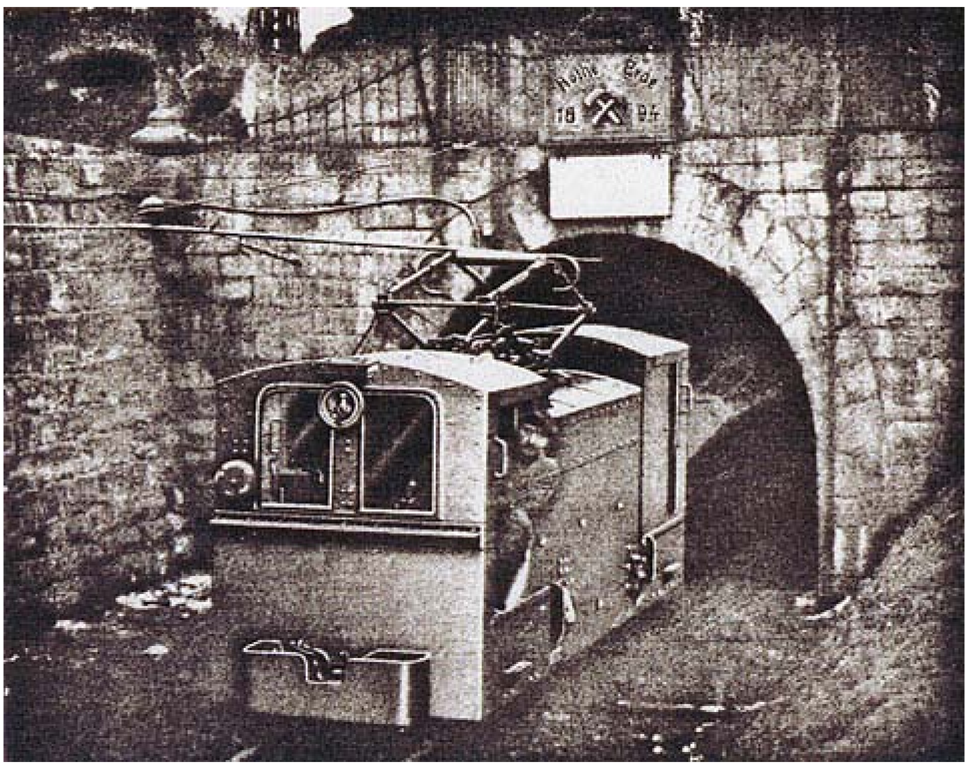
There is usually no direct connexion from a mine railway to the mine's industrial siding or the public railway network because of the narrow gauge track that is normally employed.

Until 1995 the largest single, narrow gauge, above-ground, mine and coal railway network in Europe was in the Leipzig-Altenburg lignite field in Germany. It had 726 kilometres of 900 mm track - the largest 900 mm network in existence. Of this, about 215 kilometres was removable track inside the actual pits and 511 kilometres was fixed track for the transportation of coal to the main rail network.

The last 900 mm gauge mine railway in the German state of Saxony, a major mining area in central Europe, was closed in 1999 at the Zwenkau Mine in Leipzig. Once a very extensive railway network, towards the end it only had 70 kilometres of movable 900 mm track and 90 kilometres of 900 mm fixed railway track within the Zwenkau open cast mine site itself, as well as a 20-kilometre, standard gauge, link railway for the coal trains to the power stations (1995-1999). The closure of this mine marked the end of the history of 900 mm mine railways in the lignite mines of Saxony. In December 1999, the last 900 mm railway in the Central German coal mining field in Lusatia was closed.

Electric operations

The electric motor technology used pre-1900 to DC with a few hundred volts and a direct supply of power to the motor from the catenary enabled the use of efficient, small and sturdy tractors of simple construction. This met the needs of mine railways very well, especially for underground working and so the use of electrically-powered trains soon became widespread on mine railways.



Mine locomotive U 28 from AEG at the *Verein Rothe Erde*, Esch-sur-Alzette 1894

Locomotive of the Zwenkau Mine

Underground mine locomotive for the RAG, supplied by *Schalker Eisenhütte*

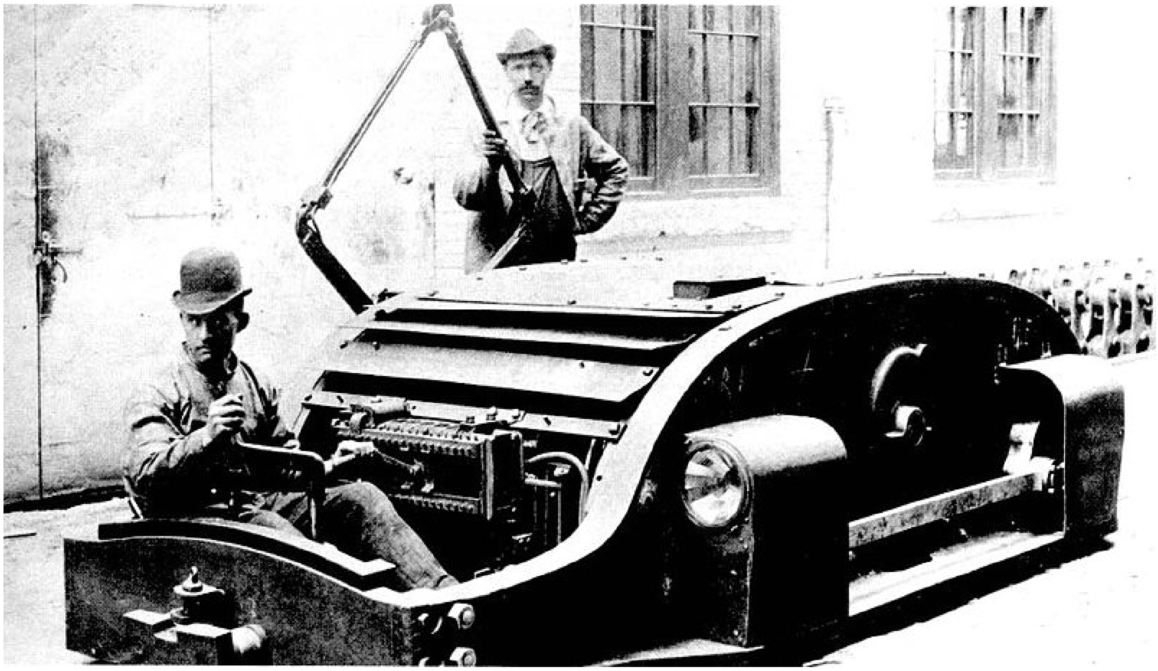
The first electric mine railway in the world was developed by Siemens & Halske for stone coal mining in Saxon Zauckerode near Dresden (now Freital) and was being worked as early as 1882 on the 5th main cross-passage of the Oppel Shaft run by the Royal Saxon Coal Works.

In 1894, the mine railway of the Aachen smelting company, *Rothe Erde*, was electrically driven, as were subsequently numerous other mine railways in the Rhineland, Saarland Lorraine, Luxembourg and Belgian Wallonia. There were large scale deliveries of electric locomotives for these railways from AEG, Siemens & Halske, Siemens-Schuckert Works (SSW) and the Union Electricitäts-Gesellschaft (UEG) in these countries.

Explosion-proof mining locomotives from *Schalker Eisenhütte* are used in all the mines owned by *Ruhrkohle* (today *Deutsche Steinkohle*).

Mine wagon on wooden rails at Siebenbürgen, end of the 19th century

Passenger wagon on a mine railway



2 ton mine locomotive, USA, 1895

Compressed air mine locomotive

Compressed-air operation

Compressed-air locomotives were powered by compressed air that were carried on the locomotive in compressed-air containers. This method of propulsion had the advantage of being safe but the disadvantage of high operating costs.

Combustion-engined operation

For safety (flammability of the fuel) modern mine railway locomotives are only operated using diesel fuel. By contrast, 19th and early 20th century mine railway locomotives were operated with petrol benzene and alcohol / benzene mixtures . Although such engines were probably preferred in metal mines, firedamp safety has been achieved by special types of motors and special exhaust system with cooling water injection, and mesh, chipboard or disc protection over the exhaust openings. These filters contribute greatly to reducing noxious fumes.

Mine railways as museum and heritage railways

A remnant of the coal railways in the Leipzig-Altenburg Lignite Field may be visited and operated as a museum railway. Regular museum trains also run on the line from Meuselwitz via Haselbach to Regis-Breitingen.

Chapter 3

Sigma Heat

Sigma heat, denoted ***S***, is a is a measure of the specific energy of humid air. It is used in the field of mining engineering for calculations relating to the temperature regulation of mine air. Sigma heat is sometimes called *total heat*, although total heat may instead mean enthalpy.

Definition

Sigma heat is the energy which would be extracted from a unit mass of humid air if it were cooled to a certain reference temperature under constant pressure while simultaneously removing any condensation formed during the process. Because sigma heat assumes that condensation will be removed, any energy which would be extracted by cooling the water vapor below its condensaton point does not count towards sigma heat. The reference temperature is usually 0 °F (−18 °C), although 32 °F (0 °C) is sometimes used as well.

Assuming a reference temperature of 0°F, the following formula may be used under standard temperature ranges and pressure:

$$S = 0.24\frac{\mathrm{BTU}}{\mathrm{lb{\cdot}^\circ F}}\,t + W\ (0.45\frac{\mathrm{BTU}}{\mathrm{lb{\cdot}^\circ F}}\,t + 1061\frac{\mathrm{BTU}}{\mathrm{lb}})$$

where
S is the sigma heat of the air (in BTU/lb),
t is the dry bulb temperature of the air (in °F), and
W is the specific humidity of the air (unitless).

Comparison with enthalpy

Sigma heat is not the same as the enthalpy of the humid air above the reference temperature. (Enthalpy is sometimes called *total heat* or *true total heat*) Unlike sigma heat, enthalpy does include the energy which would be extracted in cooling the condensed water vapor all the way to the reference temperature. Essentially, enthalpy assumes that *all* components of the system must be cooled during the cooling process, whereas sigma heat assumes that some of those components (liquid water) are removed part way through the process. Nevertheless, some writers mistakenly use the term enthalpy when they actually mean sigma heat, creating some confusion.

Assuming a reference temperature of 0°F, the relationship between enthalpy and sigma heat may be shown mathematically as:

$$h = S + 1\,\frac{\mathrm{BTU}}{\mathrm{lb}}\,Wt'$$

where
h is the specific enthalpy of the air above its reference temperature,
S is the sigma heat of the air (in BTU/lb),
W is the specific humidity of the air (unitless), and
t' is the wet bulb temperature (in °F).
(Standard temperature ranges are assumed.)

Wet bulb temperature vs. dry bulb temperature

Assuming constant pressure, sigma heat is solely a function of the wet bulb temperature of the air. For this reason, humidity need not be taken into account unless dry bulb temperature measurements are used. Like sigma heat, the wet bulb temperature is not directly affected by the temperature of any condensed water vapor (liquid water), and it varies only when there is a net energy change to the system. In contrast, the dry bulb temperature can vary even for processes where there is no such net energy change. This difference may be understood by examining evaporative cooling. During evaporative cooling, all energy lost from air molecules as sensible heat is gained as latent heat by water molecules evaporating into that air. With no net energy gained or lost from the now more humid air, sigma heat remains unchanged. In keeping with this, the wet bulb temperature also remains unchanged, as its reading already represented the maximum possible amount of evaporative cooling. The dry bulb temperature however is in conflict with the sigma heat since it decreases during such evaporative cooling. This is why measurements of sigma heat which use dry bulb temperatures must also take into account the humidity of the air.

Chapter 4

Surface Mining

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

Surface mining is used when deposits of commercially useful minerals or rock are found near the surface; that is, where the overburden is relatively thin or the material of interest is structurally unsuitable for tunneling (as would usually be the case for sand, cinder, and gravel). Where minerals occur deep below the surface—where the overburden is thick or the mineral occurs as veins in hard rock— underground mining methods are used to extract the valued material. Surface mines are typically enlarged until either the mineral deposit is exhausted, or the cost of removing larger volumes of overburden makes further mining no longer economically viable.

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

Types

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

Strip mining

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

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

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

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

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

Open-pit mining

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

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

Mountaintop removal

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

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

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

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

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

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

Dredging

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

Highwall mining

Highwall mining is another form of surface mining that evolved from auger mining. In Highwall mining, the coal seam is penetrated by a continuous miner propelled by a hydraulic Pushbeam Transfer Mechanism (PTM). A typical cycle includes sumping (launch-pushing forward) and shearing (raising and lowering the cutterhead boom to cut the entire height of the coal seam). As the coal recovery cycle continues, the cutterhead is progressively launched into the coal seam for 19.72 feet (6.01 m). Then, the Pushbeam Transfer Mechanism (PTM) automatically inserts a 19.72-foot (6.01 m) long rectangular Pushbeam (Screw-Conveyor Segment) into the center section of the machine between the

Powerhead and the cutterhead. The Pushbeam system can penetrate nearly 1,000 feet (300 m) into the coal seam. One patented Highwall mining systems use augers enclosed inside the Pushbeam that prevent the mined coal from being contaminated by rock debris during the conveyance process. Using a video imaging and/or a gamma ray sensor and/or other Geo-Radar systems like a coal-rock interface detection sensor (CID), the operator can see ahead projection of the seam-rock interface and guide the continuous miner's progress. Highwall mining can produce thousands of tons of coal in contour-strip operations with narrow benches, previously mined areas, trench mine applications and steep-dip seams with controlled water-inflow pump system and/or a gas (inert) venting system.

Recovery is much better than Augering, but the mapping of areas that have been developed by a Highwall miner are not mapped as rigorously as deep mined areas. Very little spoil is displaced in contrast with mountain top removal; however a large amount of capital is required to operate and own a Highwall miner. But then this Highwall mining system is the innovative roadmap future potential and stay or being better competitive in the area of environmental friendly non mountain-top (overburden) removal operated by only 4 crew members.

Mapping of the outcrop as well as core hole data and samples taken during the bench making process are taken into account to best project the panels that the Highwall miner will cut. Obstacles that could be potentially damaged by subsidence and the natural contour of the Highwall are taken into account, and a surveyor points the Highwall miner in a line (Theoretical Survey Plot-Line) mostly perpendicular to the Highwall. Parallel lines represent the drive cut into the mountain (up to 1,000 feet (300 m) deep), without heading or corrective steering actuation on a navigation Azimuth during mining results in missing a portion of the coal seam and is a potential danger of cutting in pillars from previous mined drives due to horizontal drift (Roll) of the Pushbeam-Cuttermodule string. Recently Highwall miners have penetrated more than 1050 feet into the coal seam, and today's models are capable of going farther, with the support of gyro navigation and not limited anymore by the amount of cable stored on the machine. The maximum depth would be determined by the stress of further penetration and associated power draw, but today’s optimized Pushbeam Discrete Element Modeling (DEM) shows smart-drive extended penetrations are possible.

Environmental and health issues

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

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

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

Human health

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

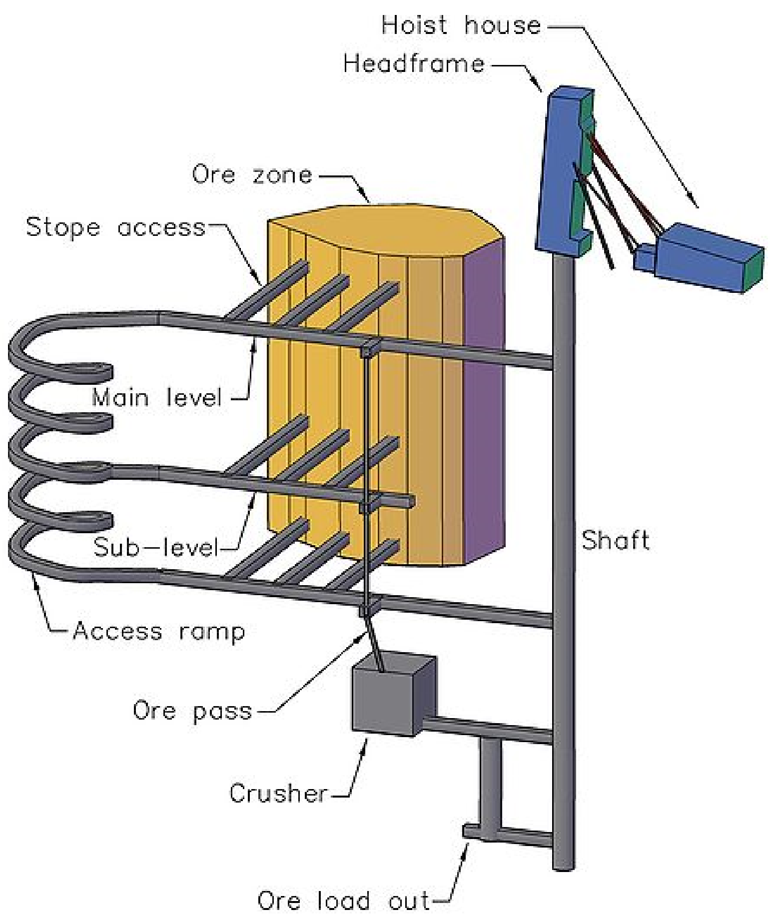
On August 20, 2004 at 2:30 a.m. a boulder accidentally pushed off an A&G Coal surface mine above the town of Inman, Virginia rolled 649 feet (198 m) down the mountain and into a home. Three-year-old Jeremy Davidson was crushed in his bed while he slept. The Davidson family settled with A&G Coal for $3 million in 2006, and left the region.

Environmental impact

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

Chapter 5

Underground Mining (Hard Rock)



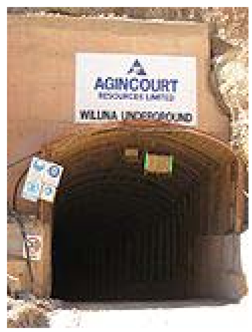
A three dimensional model of an underground mine with shaft access

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

Mine access

Underground access

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



Decline portal at Wiluna Gold Mine

- **Declines** can be a spiral tunnel which circles either the flank of the deposit or circles around the deposit. The decline begins with a box cut, which is the portal to the surface. Depending on the amount of overburden and quality of bedrock, a galvanized steel culvert may be required for safety purposes. They may also be started into the wall of an open cut mine.

- **Shafts** are vertical excavations sunk adjacent to an ore body. Shafts are sunk for ore bodies where haulage to surface via truck is not economical. Shaft haulage is more economical than truck haulage at depth, and a mine may have both a decline and a ramp.

- **Adits** are horizontal excavations into the side of a hill or mountain. They are used for horizontal or near-horizontal ore bodies where there is no need for a ramp or shaft.

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

Ore access

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

Development mining vs. production mining

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

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

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

Ventilation

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

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

Ground support

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

Area ground support

Area ground support is used to prevent major ground failure. Holes are drilled into the back (ceiling) and walls and a long steel rod (or rock bolt) is installed to hold the ground together. There are three categories of rock bolt, differentiated by how they engage the host rock. They are:

Mechanical bolts

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

Grouted bolts

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

Friction bolts

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

Local ground support

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

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

Stope and retreat vs. stope and fill

Stope and retreat

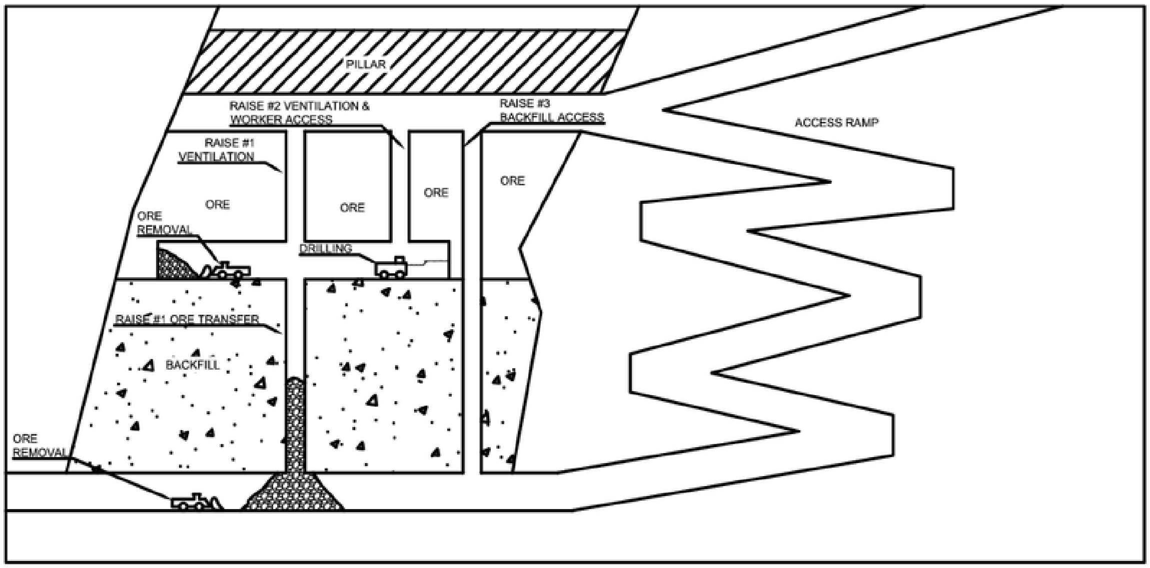
Sub-Level Caving Subsidence reaches surface at the Ridgeway underground mine.

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

Stope and fill

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

Mining methods



Schematic diagram of Cut and Fill mining

Selective mining methods

- **Cut and Fill** mining is a method of short hole mining used in steeply dipping or irregular ore zones, in particular where the hanging wall limits the use of long hole methods. The ore is mined in horizontal or slightly inclined slices, and then filled with waste rock, sand or tailings. Either fill option may be consolidated with concrete, or left unconsolidated. Cut and fill mining is an expensive but selective method, with low ore loss and dilution.

- **Drift and Fill** is similar to cut and fill, except it is used in ore zones which are wider than the method of drifting will allow to be mined. In this case the first drift is developed in the ore, and is backfilled using consolidated fill. The second drift is driven adjacent to the first drift. This carries on until the ore zone is mined out to its full width, at which time the second cut is started atop of the first cut.

- **Shrinkage Stoping** is a short hole mining method which is suitable for steeply dipping orebodies. The method is similar to cut and fill mining with the exception that after being blasted, broken ore is left in the stope where it is used to support the surrounding rock and as a platform from which to work. Only enough ore is removed from the stope to allow for drilling and blasting the next slice. The stope is emptied when all of the ore has been blasted. Although it is very selective and allows for low dilution, since the most of the ore stays in the stope until mining is completed there is a delayed return on capital investments.

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

Bulk mining methods

- **Block Caving** is used to mine massive steeply dipping orebodies (typically low grade) with high friability. An undercut with haulage access is driven under the orebody, with "drawbells" excavated 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.

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

Ore removal

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

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

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

Deepest mines

- The deepest mines in the world are the TauTona (Western Deep Levels) and Savuka gold mines in the Witwatersrand region of South Africa, which are currently working at depths exceeding 3,900 m (12,800 ft). There are plans to extend Mponeng mine, a sister mine to TauTona, down to 4,500 m (14,800 ft) in the coming years.

- The deepest hard rock mine in North America is Agnico-Eagle's LaRonde mine, which mines gold, zinc, copper and silver ores roughly 45 km (28 mi) east of Rouyn-Noranda in Cadillac, Quebec. LaRonde's Penna shaft (#3 shaft) is believed to be the deepest single lift shaft in the Western Hemisphere. The new #4 shaft bottoms out at over 3,000 m (9,800 ft) down. Their LaRonde mine expansion sees open stopes down to a depth of over 3,000 m (9,800 ft), the deepest longhole open stopes in the world.

- The deepest hard rock mines in Australia are the copper and zinc lead mines in Mount Isa, Queensland at 1,800 m (5,900 ft).
- The deepest platinum-palladium mines in the world are on the Merensky Reef, in South Africa, with a resource of 203 million Troy ounces, currently worked to approximately 2,200 m (7,200 ft) depth.
- The harshest conditions for hard rock mining are in the Witwatersrand area of South Africa, where workers toil in temperatures of up to 45°C (113°F). However, massive refrigeration plants are used to bring the air temperature down to around 28°C (82°F).

Chapter 6

Drilling Rig

Drilling rig preparing rock blasting

Drilling rig, reverse circulation in western Australia

A **drilling rig** is a machine which creates holes (usually called boreholes) and/or shafts in the ground. Drilling rigs can be massive structures housing equipment used to drill water wells, oil wells, or natural gas extraction wells, or they can be small enough to be moved manually by one person. They sample sub-surface mineral deposits, test rock, soil and groundwater physical properties, and also can be used to install sub-surface fabrications, such as underground utilities, instrumentation, tunnels or wells. Drilling rigs can be mobile equipment mounted on trucks, tracks or trailers, or more permanent land or marine-based structures (such as oil platforms, commonly called 'offshore oil rigs' even if they don't contain a drilling rig). The term "rig" therefore generally refers to the complex of equipment that is used to penetrate the surface of the Earth's crust.

Drilling rigs can be:

- Small and portable, such as those used in mineral exploration drilling, water wells and environmental investigations.
- Huge, capable of drilling through thousands of meters of the Earth's crust. Large "mud pumps" circulate drilling mud (slurry) through the drill bit and up the casing annulus, for cooling and removing the "cuttings" while a well is drilled. Hoists in the rig can lift hundreds of tons of pipe. Other equipment can force acid or sand into reservoirs to facilitate extraction of the oil or natural gas; and in remote locations there can be permanent living accommodation and catering for crews (which may be more than a hundred). Marine rigs may operate many hundreds of miles or kilometres distant from the supply base with infrequent crew rotation.

Petroleum drilling industry

A petroleum drilling rig capable of drilling thousands of feet

Modern oil driller, La Pampa Argentina

Oil and Natural Gas drilling rigs can be used not only to identify geologic reservoirs but also to create holes that allow the extraction of oil or natural gas from those reservoirs. Primarily in onshore oil and gas fields once a well has been drilled, the drilling rig will be moved off of the well and a service rig (a smaller rig) that is purpose-built for completions will be moved on to the well to get the well on line. This frees up the drilling rig to drill another hole and streamlines the operation as well as allowing for specialization of certain services, i.e., completions vs. drilling.

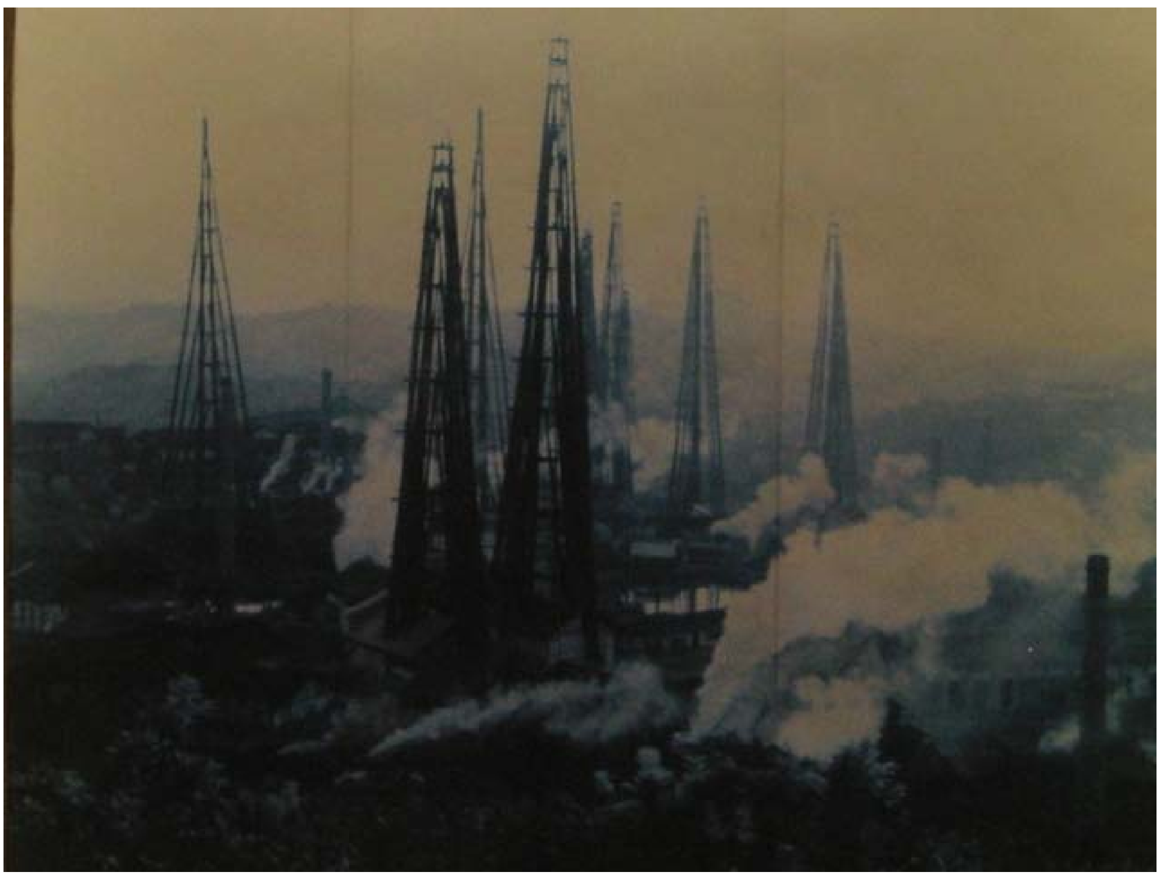
Water well drilling

New technology uses smaller portable trailer mounted rigs with shorter 10 foot (3.0 m) drill pipe. DIY users and missionary groups use these to drill water wells as they can be operated by 1 or 2 people with a minimal skill level. The shorter drill pipe also allows a much smaller mast, which gives a smaller and lighter rig which is cheaper to ship overseas and can fit in a standard 20 foot (6.1 m) shipping container. Drillcat portable trailer mounted drilling rigs have drill ratings from 300 to 800 feet (91 to 240 m) depending on mud pump flow and pressure ratings.

Other, heavier, truck rigs are more complicated, thus requiring more skill to run. They're also more difficult to handle safely due to the longer 20 to 30 foot (6.1 to 9.1 m) drill pipe. Large truck rigs also require a much higher over head clearance to operate. Large truck drills can use over 150 or more gallons of fuel per day, while the smaller portable drills use a mere 5 to 20 gallons of fuel per day. This makes smaller, more portable rigs preferable in remote or hard-to-reach places.

History

Antique drilling rig now on display at Western History Museum in Lingle, Wyoming. It was used to drill many water wells in that area—many of those wells are still in use.



Antique drilling Rigs in Zigong, China

Until internal combustion engines were developed in the late 19th century, the main method for drilling rock was muscle power of man or animal. Rods were turned by hand, using clamps attached to the rod. The rope and drop method invented in Zigong, China used a steel rod or piston raised and dropped vertically via a rope. Mechanised versions of this persisted until about 1970, using a cam to rapidly raise and drop what, by then, was a steel cable.

In the 1970s, outside of the oil and gas industry, roller bits using mud circulation were replaced by the first pneumatic reciprocating piston Reverse Circulation (RC) drills, and became essentially obsolete for most shallow drilling, and are now only used in certain situations where rocks preclude other methods. RC drilling proved much faster and more efficient, and continues to improve with better metallurgy, deriving harder, more durable bits, and compressors delivering higher air pressures at higher volumes, enabling deeper and faster penetration. Diamond drilling has remained essentially unchanged since its inception.

Mobile drilling rigs

In early oil exploration, drilling rigs were semi-permanent in nature and the derricks were often built on site and left in place after the completion of the well. In more recent times drilling rigs are expensive custom-built machines that can be moved from well to well. Some light duty drilling rigs are like a mobile crane and are more usually used to drill water wells. Larger land rigs must be broken apart into sections and loads to move to a new place, a process which can often take weeks.

Small mobile drilling rigs are also used to drill or bore piles. Rigs can range from 100 ton continuous flight auger (CFA) rigs to small air powered rigs used to drill holes in quarries, etc. These rigs use the same technology and equipment as the oil drilling rigs, just on a smaller scale.

The drilling mechanisms outlined below differ mechanically in terms of the machinery used, but also in terms of the method by which drill cuttings are removed from the cutting face of the drill and returned to surface.

Drilling rig classification

There are many types and designs of drilling rigs, with many drilling rigs capable of switching or combining different drilling technologies as needed. Drilling rigs can be described using any of the following attributes:

By power used

- Mechanical — the rig uses torque converters, clutches, and transmissions powered by its own engines, often diesel
- Electric — the major items of machinery are driven by electric motors, usually with power generated on-site using internal combustion engines
- Hydraulic — the rig primarily uses hydraulic power
- Pneumatic — the rig is primarily powered by pressurized air

- Steam — the rig uses steam-powered engines and pumps (obsolete after middle of 20th Century)

By pipe used

- Cable — a cable is used to raise and drop the drill bit
- Conventional — uses metal or plastic drill pipe of varying types
- Coil tubing — uses a giant coil of tube and a downhole drilling motor

By height

(All rigs drill with only a single pipe. Rigs are differentiated by how many connected pipe they are able to "stand" in the derrick when needing to temporarily remove the drill pipe from the hole. Typically this is done when changing a drill bit or when "logging" the well.)

- Single — can pull only single drill pipes. The presence or absence of vertical pipe racking "fingers" varies from rig to rig.
- Double — can hold a stand of pipe in the derrick consisting of two connected drill pipes, called a "double stand".
- Triple — can hold a stand of pipe in the derrick consisting of three connected drill pipes, called a "triple stand".

By method of rotation or drilling method

- No-rotation includes direct push rigs and most service rigs
- Rotary table — rotation is achieved by turning a square or hexagonal pipe (the "Kelly") at drill floor level.
- Top drive — rotation and circulation is done at the top of the drill string, on a motor that moves in a track along the derrick.
- Sonic — uses primarily vibratory energy to advance the drill string
- Hammer — uses rotation and percussive force

By position of derrick

- Conventional — derrick is vertical
- Slant — derrick is slanted at a 45 degree angle to facilitate horizontal drilling

Drill types

There are a variety of drill mechanisms which can be used to sink a borehole into the ground. Each has its advantages and disadvantages, in terms of the depth to which it can drill, the type of sample returned, the costs involved and penetration rates achieved. There are two basic types of drills: drills which produce rock chips, and drills which produce core samples.

Auger drilling

Auger drilling is done with a helical screw which is driven into the ground with rotation; the earth is lifted up the borehole by the blade of the screw. Hollow stem auger drilling is used softer ground such as swamps where th hole will not stay open by itself for environmental drilling, geotechnical drilling, soil engineering and geochemistry reconnaissance work in exploration for mineral deposits. Solid flight augers/bucket augers are used inharder ground construction drilling. In some cases, mine shafts are dug with auger drills. Small augers can be mounted on the back of a utility truck, with large augers used for sinking piles for bridge foundations.

Auger drilling is restricted to generally soft unconsolidated material or weak weathered rock. It is cheap and fast.

Cable tool water well drilling rig in Kimball, West Virginia. These slow rigs have mostly been replaced by rotary drilling rigs in the U.S.

Percussion rotary air blast drilling (RAB)

RAB drilling is used most frequently in the mineral exploration industry. (This tool is also known as a Down-the-hole drill.) The drill uses a pneumatic reciprocating piston-driven "hammer" to energetically drive a heavy drill bit into the rock. The drill bit is hollow, solid steel and has ~20 mm thick tungsten rods protruding from the steel matrix as "buttons". The tungsten buttons are the cutting face of the bit.

The cuttings are blown up the outside of the rods and collected at surface. Air or a combination of air and foam lift the cuttings.

RAB drilling is used primarily for mineral exploration, water bore drilling and blast-hole drilling in mines, as well as for other applications such as engineering, etc. RAB produces lower quality samples because the cuttings are blown up the outside of the rods and can be contaminated from contact with other rocks. RAB drilling at extreme depth, if it encounters water, may rapidly clog the outside of the hole with debris, precluding removal of drill cuttings from the hole. This can be counteracted, however, with the use of "stabilisers" also known as "reamers", which are large cylindrical pieces of steel attached to the drill string, and made to perfectly fit the size of the hole being drilled. These have sets of rollers on the side, usually with tungsten buttons, that constantly break down cuttings being pushed upwards.

The use of high-powered air compressors, which push 900-1150 cfm of air at 300-350 psi down the hole also ensures drilling of a deeper hole up to ~1250 m due to higher air pressure which pushes all rock cuttings and any water to the surface. This, of course, is all dependent on the density and weight of the rock being drilled, and on how worn the drill bit is.

Air core drilling

Air core drilling and related methods use hardened steel or tungsten blades to bore a hole into unconsolidated ground. The drill bit has three blades arranged around the bit head, which cut the unconsolidated ground. The rods are hollow and contain an inner tube which sits inside the hollow outer rod barrel. The drill cuttings are removed by injection of compressed air into the hole via the annular area between the innertube and the drill rod. The cuttings are then blown back to surface up the inner tube where they pass through the sample separating system and are collected if needed. Drilling continues with the addition of rods to the top of the drill string. Air core drilling can occasionally produce small chunks of cored rock.

This method of drilling is used to drill the weathered regolith, as the drill rig and steel or tungsten blades cannot penetrate fresh rock. Where possible, air core drilling is preferred over RAB drilling as it provides a more representative sample. Air core drilling can achieve depths approaching 300 meters in good conditions. As the cuttings are removed inside the rods and are less prone to contamination compared to conventional drilling where the cuttings pass to the surface via outside return between the outside of the drill rod and the walls of the hole. This method is more costly and slower than RAB.

Cable tool drilling

SpeedStar cable tool drilling rig, Ballston Spa, New York

Cable tool rigs are a traditional way of drilling water wells. The majority of large diameter water supply wells, especially deep wells completed in bedrock aquifers, were completed using this drilling method. Although this drilling method has largely been supplanted in recent years by other, faster drilling techniques, it is still the most practicable drilling method for large diameter, deep bedrock wells, and in widespread use for small rural water supply wells. The impact of the drill bit fractures the rock and in many shale rock situations increases the water flow into a well over rotary.

Also known as ballistic well drilling and sometimes called "spudders", these rigs raise and drop a drill string with a heavy carbide tipped drilling bit that chisels through the rock by finely pulverizing the subsurface materials. The drill string is composed of the upper drill rods, a set of "jars" (inter-locking "sliders" that help transmit additional energy to the drill bit and assist in removing the bit if it is stuck) and the drill bit. During the drilling process, the drill string is periodically removed from the borehole and a bailer is lowered to collect the drill cuttings (rock fragments, soil, etc.). The bailer is a bucket-like tool with a trapdoor in the base. If the borehole is dry, water is added so that the drill cuttings will flow into the bailer. When lifted, the trapdoor closes and the cuttings are then raised and removed. Since the drill string must be raised and lowered to advance the boring, the casing (larger diameter outer piping) is typically used to hold back upper soil materials and stabilize the borehole.

Cable tool rigs are simpler and cheaper than similarly sized rotary rigs, although loud and very slow to operate. The world record cable tool well was drilled in New York to a depth of almost 12,000 feet. The common Bucyrus Erie 22 can drill down to about 1,100 feet. Since cable tool drilling does not use air to eject the drilling chips like a rotary, instead using a cable strung bailer, technically there is no limitation on depth.

Cable tool rigs now are nearly obsolete in the United States. They are mostly used in Africa or Third-World countries. Being slow, cable tool rig drilling means increased wages for drillers. In the United States drilling wages would average around US$200 per day per man, while in Africa it is only US$6 per day per man, so a slow drilling machine can still be used in undeveloped countries with depressed wages. A cable tool rig can drill 25 feet to 60 feet of hard rock a day. A newer rotary top head rig equipped with down-the-hole (DTH) hammer can drill 500 feet or more per day, depending on size and formation hardness.

Reverse circulation (RC) drilling

Reverse Circulation (RC) rig, outside Newman, Western Australia

Track mounted Reverse Circulation rig (side view).

RC drilling is similar to air core drilling, in that the drill cuttings are returned to surface inside the rods. The drilling mechanism is a pneumatic reciprocating piston known as a "hammer" driving a tungsten-steel drill bit. RC drilling utilises much larger rigs and machinery and depths of up to 500 metres are routinely achieved. RC drilling ideally produces dry rock chips, as large air compressors dry the rock out ahead of the advancing drill bit. RC drilling is slower and costlier but achieves better penetration than RAB or air core drilling; it is cheaper than diamond coring and is thus preferred for most mineral exploration work.

Reverse circulation is achieved by blowing air down the rods, the differential pressure creating air lift of the water and cuttings up the "inner tube", which is inside each rod. It reaches the "bell" at the top of the hole, then moves through a sample hose which is attached to the top of the "cyclone". The drill cuttings travel around the inside of the cyclone until they fall through an opening at the bottom and are collected in a sample bag.

The most commonly used RC drill bits are 5-8 inches (13–20 cm) in diameter and have round metal 'buttons' that protrude from the bit, which are required to drill through shale and abrasive rock. As the buttons wear down, drilling becomes slower and the rod string can potentially become bogged in the hole. This is a problem as trying to recover the rods may take hours and in some cases weeks. The rods and drill bits themselves are very expensive, often resulting in great cost to drilling companies when equipment is lost down the bore hole. Most companies will regularly re-grind the buttons on their drill bits in order to prevent this, and to speed up progress. Usually, when something is lost (breaks off) in the hole, it is not the drill string, but rather from the bit, hammer, or stabiliser to the bottom of the drill string (bit). This is usually caused by a blunt bit getting stuck in fresh rock, over-stressed metal, or a fresh drill bit getting stuck in a part of the hole that is too small, owing to having used a bit that has worn to smaller than the desired hole diameter.

Although RC drilling is air-powered, water is also used, to reduce dust, keep the drill bit cool, and assist in pushing cutting back upwards, but also when "collaring" a new hole. A mud called "Liqui-Pol" is mixed with water and pumped into the rod string, down the hole. This helps to bring up the sample to the surface by making the sand stick together. Occasionally, "Super-Foam" (a.k.a. "Quik-Foam") is also used, to bring all the very fine cuttings to the surface, and to clean the hole. When the drill reaches hard rock, a "collar" is put down the hole around the rods, which is normally PVC piping. Occasionally the collar may be made from metal casing. Collaring a hole is needed to stop the walls from caving in and bogging the rod string at the top of the hole. Collars may be up to 60 metres deep, depending on the ground, although if drilling through hard rock a collar may not be necessary.

Reverse circulation rig setups usually consist of a support vehicle, an auxiliary vehicle, as well as the rig itself. The support vehicle, normally a truck, holds diesel and water tanks for resupplying the rig. It also holds other supplies needed for maintenance on the rig. The auxiliary is a vehicle, carrying an auxiliary engine and a booster engine. These engines are connected to the rig by high pressure air hoses. Although RC rigs have their own booster and compressor to generate air pressure, extra power is needed which usually isn't supplied by the rig due to lack of space for these large engines. Instead, the engines are mounted on the auxiliary vehicle. Compressors on an RC rig have an output of around 1000 cfm at 500 psi (500 $L \cdot s^{-1}$ at 3.4 MPa). Alternatively, stand-alone air compressors which have an output of 900-1150cfm at 300-350 psi each are used in sets of 2, 3, or 4, which are all routed to the rig through a multi-valve manifold.

Diamond core drilling

Multi-combination drilling rig (capable of both diamond and reverse circulation drilling). Rig is currently set up for diamond drilling.

Diamond core drilling (exploration diamond drilling) utilizes an annular diamond-impregnated drill bit attached to the end of hollow drill rods to cut a cylindrical core of solid rock. The diamonds used are fine to microfine industrial grade diamonds. They are set within a matrix of varying hardness, from brass to high-grade steel. Matrix hardness, diamond size and dosing can be varied according to the rock which must be cut. Holes within the bit allow water to be delivered to the cutting face. This provides three essential functions — lubrication, cooling, and removal of drill cuttings from the hole.

Diamond drilling is much slower than reverse circulation (RC) drilling due to the hardness of the ground being drilled. Drilling of 1200 to 1800 metres is common and at these depths, ground is mainly hard rock. Diamond rigs need to drill slowly to lengthen the life of drill bits and rods, which are very expensive.

Core samples are retrieved via the use of a "lifter tube", a hollow tube lowered inside the rod string by a winch cable until it stops inside the core barrel. As the core is drilled, the core barrel slides over the core as it is cut. An "overshot" attached to the end of the winch cable is lowered inside the rod string and locks on to the "backend", located on the top end of the core barrel. The winch is retracted, pulling the core barrel to the surface. The core does not drop out of the inside of the core barrel when lifted because either a split ring core lifter or basket retainer allow the core to move into, but not back out of the tube.

Diamond core drill bits

Once the core barrel is removed from the hole, the core sample is then removed from the core barrel and catalogued. The Driller's offsider screws the rod apart using tube clamps, then each part of the rod is taken and the core is shaken out into core trays. The core is washed, measured and broken into smaller pieces using a hammer or sawn through to make it fit into the sample trays. Once catalogued, the core trays are retrieved by geologists who then analyse the core and determine if the drill site is a good location to expand future mining operations.

Diamond rigs can also be part of a multi-combination rig. Multi-combination rigs are a dual setup rig capable of operating in either a reverse circulation (RC) and diamond drilling role (though not at the same time). This is a common scenario where exploration drilling is being performed in a very isolated location. The rig is first set up to drill as an RC rig and once the desired metres are drilled, the rig is set up for diamond drilling. This way the deeper metres of the hole can be drilled without moving the rig and waiting for a diamond rig to set up on the pad.

Direct push rigs

Direct push technology includes several types of drilling rigs and drilling equipment which advances a drill string by pushing or hammering without rotating the drill string. While this does not meet the proper definition of drilling, it does achieve the same result — a borehole. Direct push rigs include both cone penetration testing (CPT) rigs and direct push sampling rigs such as a PowerProbe or Geoprobe. Direct push rigs typically are limited to drilling in unconsolidated soil materials and very soft rock.

CPT rigs advance specialized testing equipment (such as electronic cones), and soil samplers using large hydraulic rams. Most CPT rigs are heavily ballasted (20 metric tons is typical) as a counter force against the pushing force of the hydraulic rams which are often rated up to 20 kN. Alternatively, small, light CPT rigs and offshore CPT rigs will use anchors such as screwed-in ground anchors to create the reactive force. In ideal conditions, CPT rigs can achieve production rates of up to 250–300 meters per day.

Direct push drilling rigs use hydraulic cylinders and a hydraulic hammer in advancing a hollow core sampler to gather soil and groundwater samples. The speed and depth of penetration is largely dependent on the soil type, the size of the sampler, and the weight and power the rig. Direct push techniques are generally limited to shallow soil sample recovery in unconsolidated soil materials. The advantage of direct push technology is that in the right soil type it can produce a large number of high quality samples quickly and cheaply, generally from 50 to 75 meters per day. Rather than hammering, direct push can also be combined with sonic (vibratory) methods to increase drill efficiency.

Hydraulic rotary drilling

Oil well drilling utilises tri-cone roller, carbide embedded, fixed-cutter diamond, or diamond-impregnated drill bits to wear away at the cutting face. This is preferred because there is no need to return intact samples to surface for assay as the objective is to reach a formation containing oil or natural gas. Sizable machinery is used, enabling depths of several kilometres to be penetrated. Rotating hollow drill pipes carry down bentonite and barite infused drilling muds to lubricate, cool, and clean the drilling bit, control downhole pressures, stabilize the wall of the borehole and remove drill cuttings. The mud travels back to the surface around the outside of the drill pipe, called the annulus. Examining rock chips extracted from the mud is known as mud logging. Another form of well logging is electronic and is frequently employed to evaluate the existence of possible oil and gas deposits in the borehole. This can take place while the well is being drilled, using Measurement While Drilling tools, or after drilling, by lowering measurement tools into the newly drilled hole.

The rotary system of drilling was in general use in Texas in the early 1900s. It is a modification of one invented by Fauvelle in 1845, and used in the early years of the oil industry in some of the oil-producing countries in Europe. Originally pressurized water was used instead of mud, and was almost useless in hard rock before the diamond cutting bit. The main breakthrough for rotary drilling came in 1901, when Anthony Francis Lucas combined the use of a steam-driven rig and of mud instead of water in the Spindletop discovery well.

The drilling and production of oil and gas can pose a safety risk and a hazard to the environment from the ignition of the entrained gas causing dangerous fires and also from the risk of oil leakage polluting water, land and groundwater. For these reasons, redundant safety systems and highly trained personnel are required by law in all countries with significant production.

Sonic (vibratory) drilling

A sonic drill head works by sending high frequency resonant vibrations down the drill string to the drill bit, while the operator controls these frequencies to suit the specific conditions of the soil/rock geology. Vibrations may also be generated within the drill head. The frequency is generally between 50 and 120 hertz (cycles per second) and can be varied by the operator.

Resonance magnifies the amplitude of the drill bit, which fluidizes the soil particles at the bit face, allowing for fast and easy penetration through most geological formations. An internal spring system isolates these vibrational forces from the rest of the drill rig.

Limits of the technology

An oil rig

Drill technology has advanced steadily since the 19th century. However, there are several basic limiting factors which will determine the depth to which a bore hole can be sunk.

All holes must maintain outer diameter; the diameter of the hole must remain wider than the diameter of the rods or the rods cannot turn in the hole and progress cannot continue. Friction caused by the drilling operation will tend to reduce the outside diameter of the drill bit. This applies to all drilling methods, except that in diamond core drilling the use of thinner rods and casing may permit the hole to continue. Casing is simply a hollow sheath which protects the hole against collapse during drilling, and is made of metal or PVC. Often diamond holes will start off at a large diameter and when outside diameter is lost, thinner rods put down inside casing to continue, until finally the hole becomes too narrow. Alternatively, the hole can be reamed; this is the usual practice in oil well drilling where the hole size is maintained down to the next casing point.

For percussion techniques, the main limitation is air pressure. Air must be delivered to the piston at sufficient pressure to activate the reciprocating action, and in turn drive the head into the rock with sufficient strength to fracture and pulverise it. With depth, volume is added to the in-rod string, requiring larger compressors to achieve operational pressures. Secondly, groundwater is ubiquitous, and increases in pressure with depth in the ground. The air inside the rod string must be pressurised enough to overcome this water pressure at the bit face. Then, the air must be able to carry the rock fragments to surface. This is why depths in excess of 500 m for reverse circulation drilling are rarely achieved, because the cost is prohibitive and approaches the threshold at which diamond core drilling is more economic.

Diamond drilling can routinely achieve depths in excess of 1200 m. In cases where money is no issue, extreme depths have been achieved, because there is no requirement to overcome water pressure. However, circulation must be maintained to return the drill cuttings to surface, and more importantly to maintain cooling and lubrication of the cutting surface.

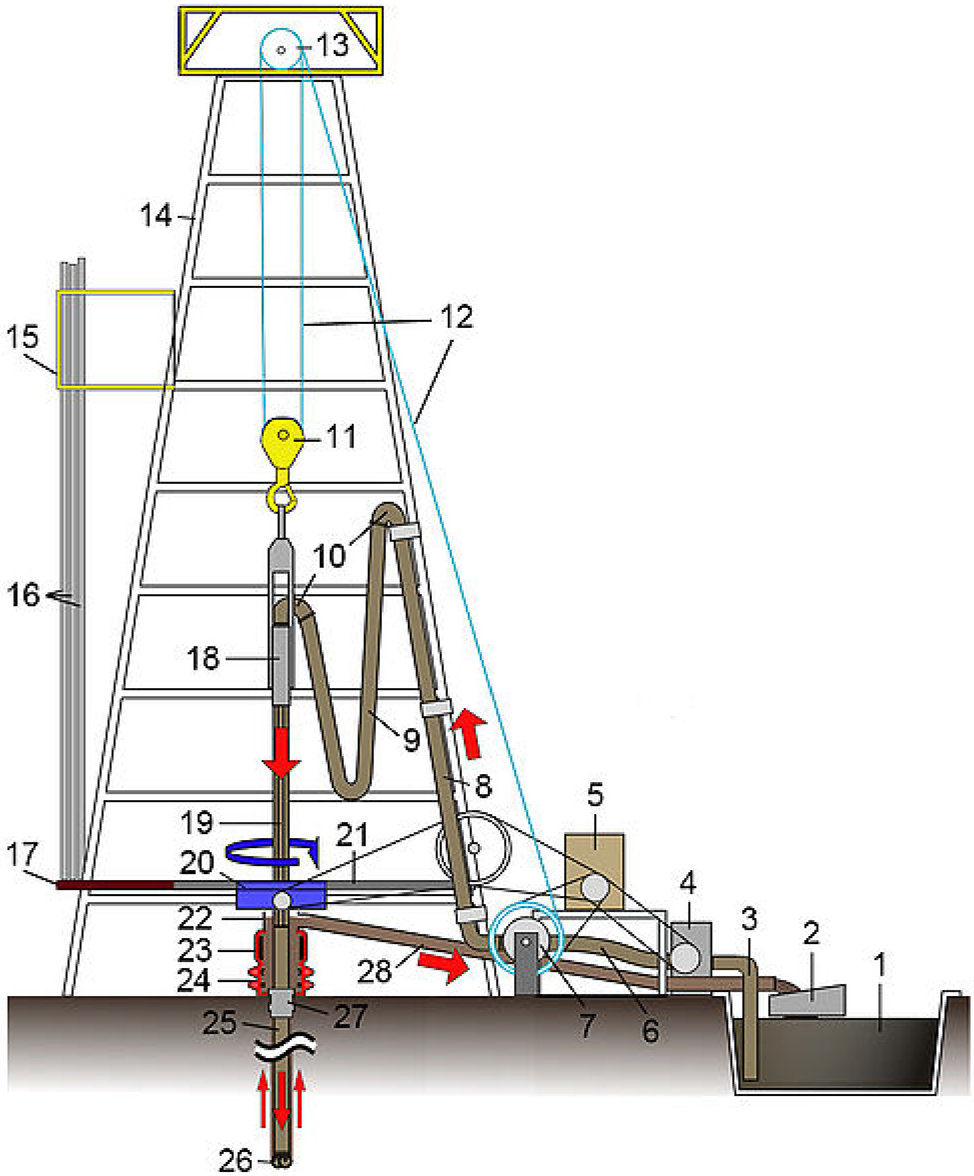
Without sufficient lubrication and cooling, the matrix of the drill bit will soften. While diamond is the hardest substance known, at 10 on the Mohs hardness scale, it must remain firmly in the matrix to achieve cutting. Weight on bit, the force exerted on the cutting face of the bit by the drill rods in the hole above the bit, must also be monitored.

A unique drilling operation in deep ocean water was named Project Mohole.

Causes of deviation

Most drill holes deviate from the vertical. This is because of the torque of the turning bit working against the cutting face, because of the flexibility of the steel rods and especially the screw joints, because of reaction to foliation and structure within the rock, and because of refraction as the bit moves into different rock layers of varying resistance. Additionally, inclined holes will tend to deviate upwards because the drill rods will lie against the bottom of the bore, causing the drill bit to be slightly inclined from true. It is because of deviation that drill holes must be surveyed if deviation will impact the usefulness of the information returned. Sometimes the surface location can be offset laterally to take advantage of the expected deviation tendency, so the bottom of the hole will end up near the desired location. Oil well drilling commonly uses a process of controlled deviation called directional drilling (e.g., when several wells are drilled from one surface location).

Rig equipment



Simple diagram of a drilling rig and its basic operation

Drilling rigs typically include at least some of the following items

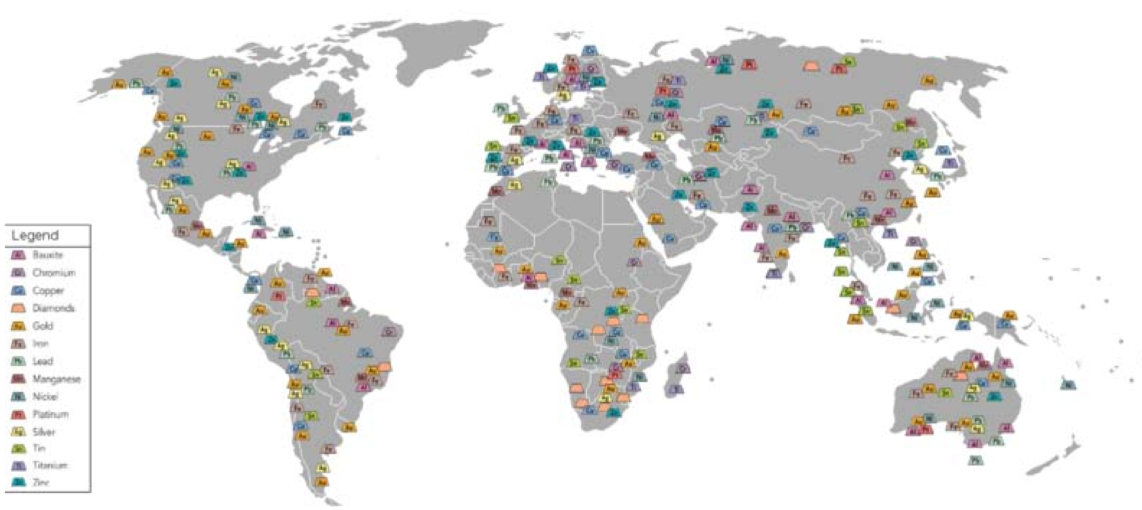
- Blowout preventers: (BOPs)

The equipment associated with a rig is to some extent dependent on the type of rig but (#23 & #24) are devices installed at the wellhead to prevent fluids and gases from unintentionally escaping from the borehole. #23 is the annular (often referred to as the "Hydril", which is one manufacturer) and #24 is the pipe rams and blind rams. In the place of #24 Variable bore rams or VBR's can be used, they offer the same pressure and sealing capacity found in standard pipe rams, while offering the versatility of sealing on various sizes of drill pipe, production tubing and casing without changing standard pipe rams. Normally VBR's are used when utilizing a tapered drill string (when different size drill pipe is used in the complete drill string).

- Centrifuge: an industrial version of the device that separates fine silt and sand from the drilling fluid.
- Solids control: solids control equipments for preparing drilling mud for the drilling rig.
- Chain tongs: wrench with a section of chain, that wraps around whatever is being tightened or loosened. Similar to a pipe wrench.
- Degasser: a device that separates air and/or gas from the drilling fluid.
- Desander / desilter: contains a set of hydrocyclones that separate sand and silt from the drilling fluid.
- Drawworks: (#7) is the mechanical section that contains the spool, whose main function is to reel in/out the drill line to raise/lower the traveling block (#11).
- Drill bit: (#26) device attached to the end of the drill string that breaks apart the rock being drilled. It contains jets through which the drilling fluid exits.
- Drill pipe: (#16) joints of hollow tubing used to connect the surface equipment to the bottom hole assembly (BHA) and acts as a conduit for the drilling fluid. In the diagram, these are "stands" of drill pipe which are 2 or 3 joints of drill pipe connected together and "stood" in the derrick vertically, usually to save time while Tripping pipe.
- Elevators: a gripping device that is used to latch to the drill pipe or casing to facilitate the lowering or lifting (of pipe or casing) into or out of the borehole.
- Mud motor: a hydraulically powered device positioned just above the drill bit used to spin the bit independently from the rest of the drill string.
- Mud pump: (#4) reciprocal type of pump used to circulate drilling fluid through the system.
- Mud tanks: (#1) often called mud pits, provides a reserve store of drilling fluid until it is required down the wellbore.
- Rotary table: (#20) rotates the drill string along with the attached tools and bit.
- Shale shaker: (#2) separates drill cuttings from the drilling fluid before it is pumped back down the borehole.

Chapter 7

Mining



Simplified world active mining map

Chuquicamata, Chile, site of the largest circumference and second deepest open pit copper mine in the world.

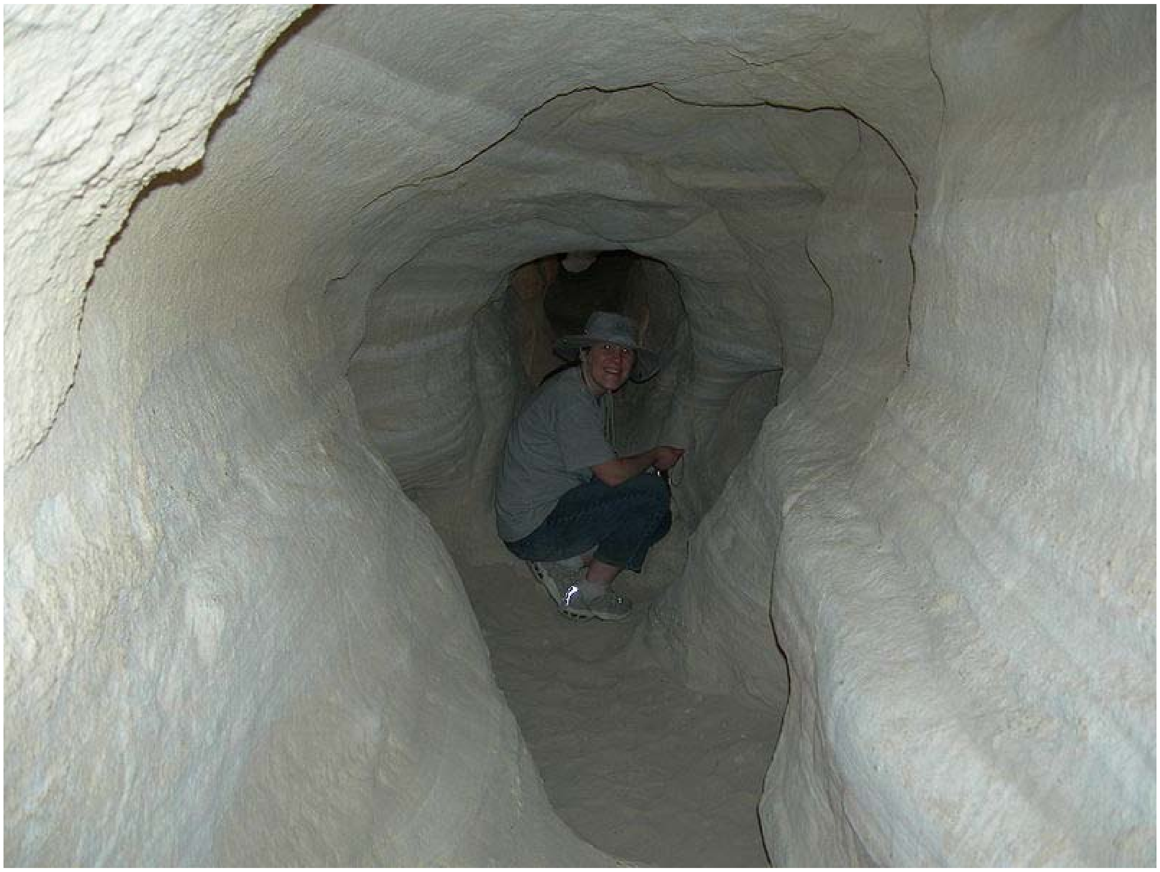
Mining is the extraction of valuable minerals or other geological materials from the earth, usually from an ore body, vein or (coal) seam. The term also includes the removal of soil. Materials recovered by mining include base metals, precious metals, iron, uranium, coal, diamonds, limestone, oil shale, rock salt and potash. Any material that cannot be grown through agricultural processes, or created artificially in a laboratory or factory, is usually mined. Mining in a wider sense comprises extraction of any non-renewable resource (e.g., petroleum, natural gas, or even water).

Mining of stone and metal has been done since pre-historic times. Modern mining processes involve prospecting for ore bodies, analysis of the profit potential of a proposed mine, extraction of the desired materials and finally reclamation of the land to prepare it for other uses once the mine is closed.

The nature of mining processes creates a potential negative impact on the environment both during the mining operations and for years after the mine is closed. This impact has led to most of the world's nations adopting regulations to moderate the negative effects of mining operations. Safety has long been a concern as well, though modern practices have improved safety in mines significantly.

History

Prehistoric mining



Chalcolithic copper mine in Timna Valley, Negev Desert, Israel.

Since the beginning of civilization, people have used stone, ceramics and, later, metals found on or close to the Earth's surface. These were used to manufacture early tools and weapons, for example, high quality flint found in northern France and southern England were used to create flint tools. Flint mines have been found in chalk areas where seams of the stone were followed underground by shafts and galleries. The mines at Grimes Graves are especially famous, and like most other flint mines, are Neolithic in origin (ca 4000 BC-ca 3000 BC). Other hard rocks mined or collected for axes included the greenstone of the Langdale axe industry based in the English Lake District.

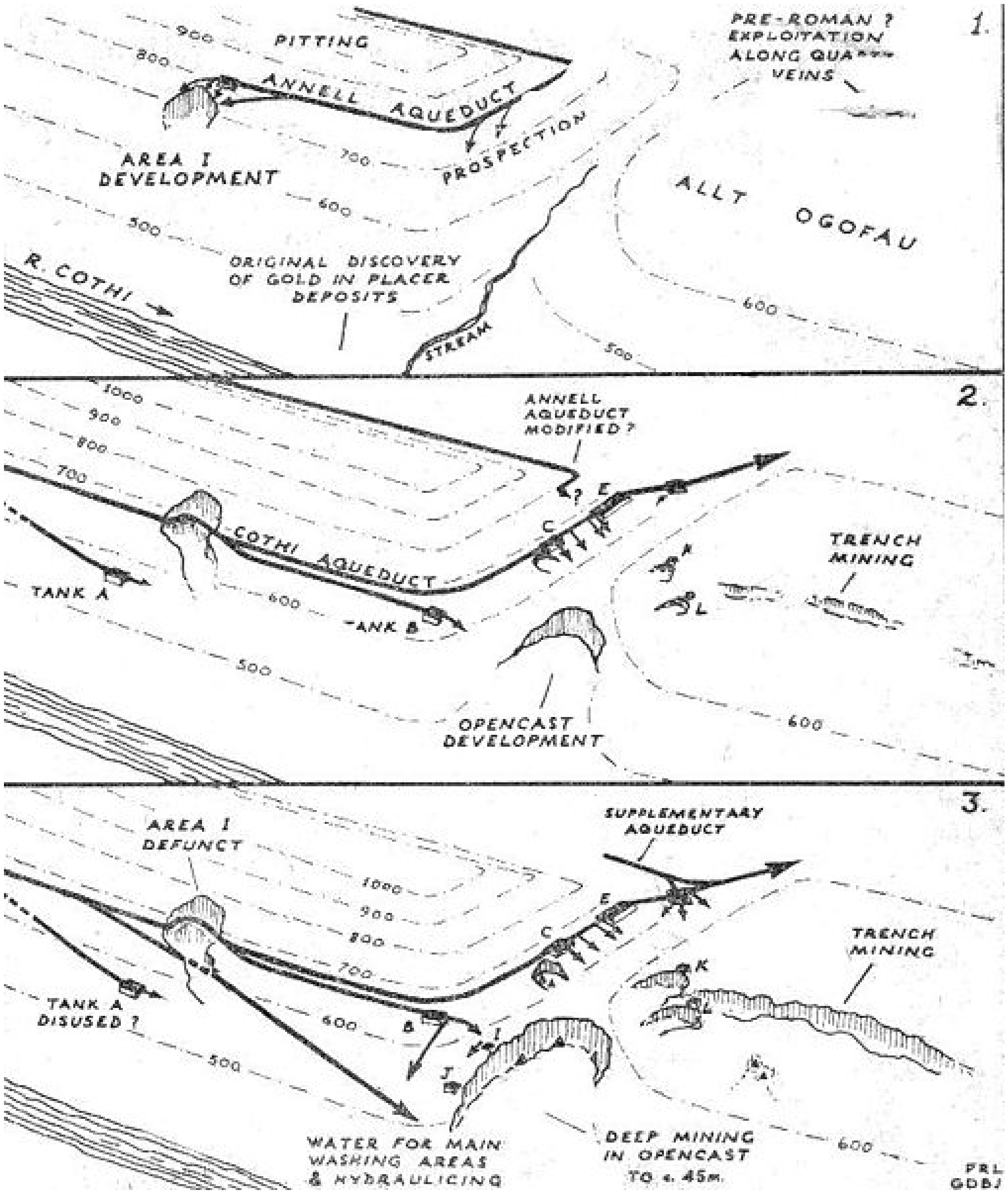
The oldest known mine on archaeological record is the "Lion Cave" in Swaziland. At this site, which by radiocarbon dating proves the mine to be about 43,000 years old, paleolithic humans mined mineral hematite, which contained iron and was ground to produce the red pigment ochre. Mines of a similar age in Hungary are believed to be sites where Neanderthals may have mined flint for weapons and tools.

Ancient Egypt

Ancient Egyptians mined malachite at Maadi. At first, Egyptians used the bright green malachite stones for ornamentations and pottery. Later, between 2,613 and 2,494 BC, large building projects required expeditions abroad to the area of Wadi Maghara in order "to secure minerals and other resources not available in Egypt itself." Quarries for turquoise and copper were also found at "Wadi Hamamat, Tura, Aswan and various other Nubian sites" on the Sinai Peninsula and at Timna.

Mining in Egypt occurred in the earliest dynasties, and the gold mines of Nubia were among the largest and most extensive of any in Ancient Egypt, and are described by the Greek author Diodorus Siculus. He mentions that fire-setting was one method used to break down the hard rock holding the gold. One of the complexes is shown in one of earliest known maps. They crushed the ore and ground it to a fine powder before washing the powder for the gold dust.

Ancient Greece and Rome



Ancient Roman development of the Dolaucothi Gold Mines, Wales.

Mining in Europe has a very long history, examples including the silver mines of Laurium, which helped support the Greek city state of Athens. However, it is the Romans who developed large scale mining methods, especially the use of large volumes of water brought to the minehead by numerous aqueducts. The water was used for a variety of purposes, including using it to remove overburden and rock debris, called hydraulic mining, as well as washing comminuted or crushed ores, and driving simple machinery.

The Romans used hydraulic mining methods on a large scale to prospect for the veins of ore, especially a now obsolete form of mining known as hushing. It involved building numerous aqueducts to supply water to the minehead where it was stored in large reservoirs and tanks. When a full tank was opened, the wave of water sluiced away the overburden to expose the bedrock underneath and any gold veins. The rock was then attacked by fire-setting to heat the rock, which would be quenched with a stream of water. The thermal shock cracked the rock, enabling it to be removed, aided by further streams of water from the overhead tanks. They used similar methods to work cassiterite deposits in Cornwall and lead ore in the Pennines.

The methods had been developed by the Romans in Spain in 25 AD to exploit large alluvial gold deposits, the largest site being at Las Medulas, where seven long aqueducts were built to tap local rivers and to sluice the deposits. Spain was one of the most important mining regions, but all regions of the Roman Empire were exploited. They used reverse overshot water-wheels for dewatering their deep mines such as those at Rio Tinto. In Great Britain the natives had mined minerals for millennia , but when the Romans came, the scale of the operations changed dramatically.

The Romans needed what Britain possessed, especially gold, silver, tin and lead. Roman techniques were not limited to surface mining. They followed the ore veins underground once opencast mining was no longer feasible. At Dolaucothi they stoped out the veins, and drove adits through barren rock to drain the stopes. The same adits were also used to ventilate the workings, especially important when fire-setting was used. At other parts of the site, they penetrated the water table and dewatered the mines using several kinds of machine, especially reverse overshot water-wheels. These were used extensively in the copper mines at Rio Tinto in Spain, where one sequence comprised 16 such wheels arranged in pairs, and lifting water about 80 feet (24 m). They were worked as treadmills with miners standing on the top slats. Many examples of such devices have been found in old Roman mines and some examples are now preserved in the British Museum and the National Museum of Wales.

Medieval Europe

Agricola, author of *De Re Metallica*

Mining as an industry underwent dramatic changes in medieval Europe. The mining industry in the early Middle Ages was mainly focused on the extraction of copper and iron. Other precious metals were also used mainly for gilding or coinage. Initially, many metals were obtained through open-pit mining, and ore was primarily extracted from shallow depths, rather than though the digging of deep mine shafts. Around the 14th century, the demand for weapons, armor, stirrups, and horseshoes greatly increased the demand for iron. Medieval knights for example were often laden with up to 100 pounds of plate or chain link armor in addition to swords, lances and other weapons. The overwhelming dependency on iron for military purposes helped to spur increased iron production and extraction processes.

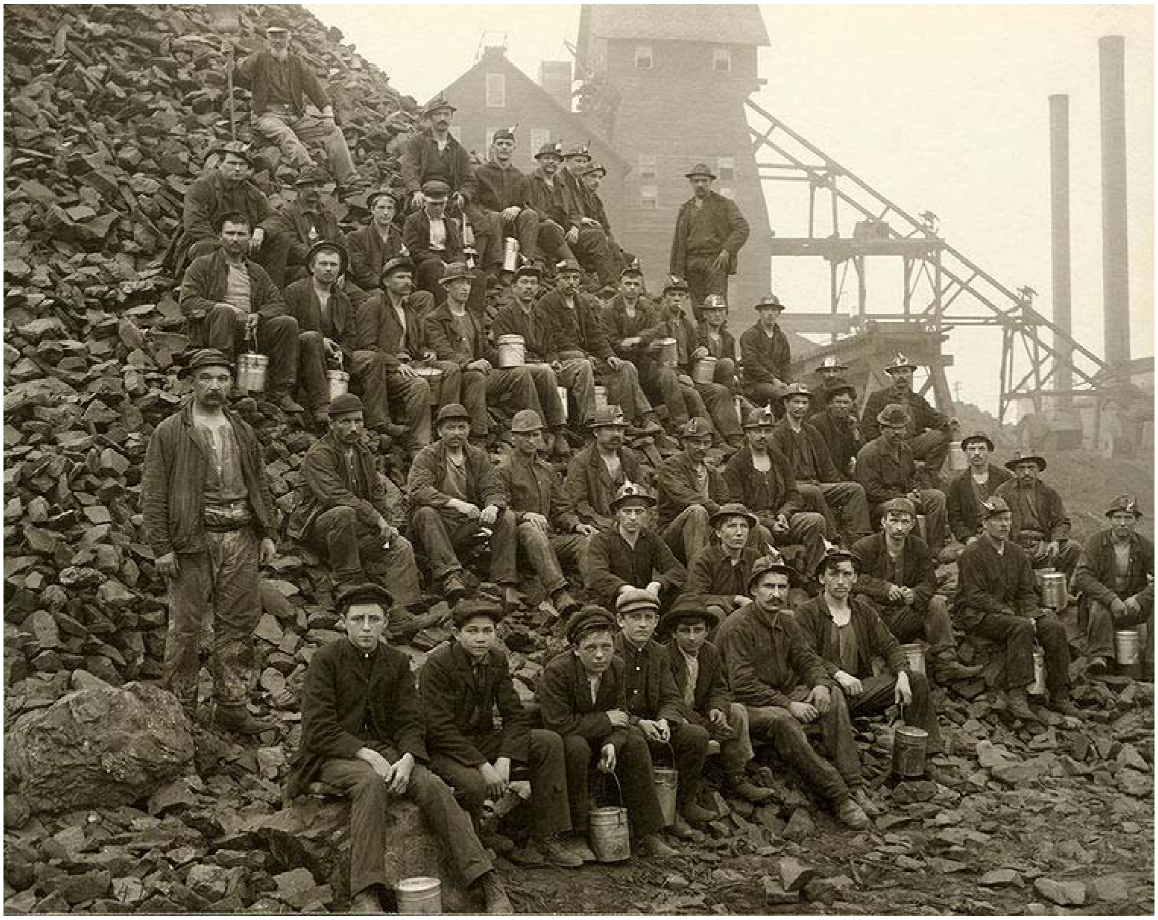
These new military applications coincided with a population explosion throughout Europe in the 11th-14th centuries which enriched the demand for precious metals in order to fill a currency shortage. The silver crisis of 1465 occurred when the mines had all reached depths at which the shafts could no longer be pumped dry with the available technology. Although the increased use of bank notes and the use of credit during this period did decrease the dependence and value of precious metals, these forms of currency still remained vital to the story of medieval mining. Use of water power in the form of water mills was extensive; they were employed in crushing ore, raising ore from shafts and ventilating galleries by powering giant bellows. Black powder was first used in mining in Selmecbánya, Kingdom of Hungary (present-day Banská Štiavnica, Slovakia) in 1627. Black powder allowed blasting of rock and earth to loosen and reveal ore veins, which was much faster than fire-setting, in which rock was exposed to heat and then doused with cold water. Black powder allowed the mining of previously impenetrable metals and ores. In 1762, the world's first mining academy was established in the same town.

The widespread adoption of agricultural innovations such as the iron plowshare, as well as the growing use of metal as a building material, was also a driving force in the tremendous growth of the iron industry during this period. Inventions like the arrastra were often used by the Spanish to pulverize ore after being mined. This device employed animal power and utilized mechanical principles similar to that of the ancient Middle Eastern technology of grain threshing.

Much of our knowledge of Medieval mining techniques comes from books such as Biringuccio's *De la pirotechnia* and probably most importantly from Georg Agricola's *De re metallica* (1556). These books detail many different mining methods used in German and Saxon mines. One of the prime issues confronting medieval miners (and one which Agricola explains in detail) was the removal of water from mining shafts. As miners dug deeper to access new veins, flooding became a very real obstacle. As a result the mining industry became dramatically more efficient and prosperous as the use of various mechanical and animal driven pump systems were implemented.

North and South America

Lead mining in the upper Mississippi River region of the U.S., 1865.



Miners at the Tamarack Mine in Copper Country, Michigan, U.S. in 1905.

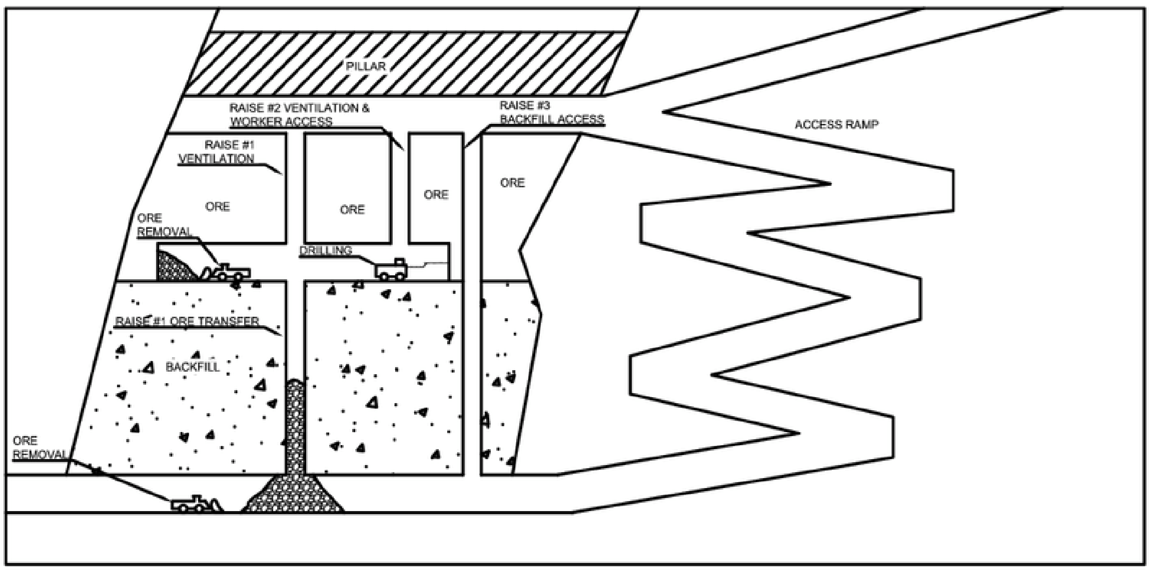
In North America there are ancient, prehistoric copper mines along Lake Superior. "Indians availed themselves of this copper starting at least 5000 years ago," and copper tools, arrowheads, and other artifacts that were part of an extensive native trade network have been discovered. In addition, obsidian, flint, and other minerals were mined, worked, and traded. While the early French explorers that encountered the sites made no use of the metals due to the difficulties in transporting it, the copper was eventually traded throughout the continent along major river routes. In Manitoba, Canada, there also are ancient quartz mines near Waddy Lake and surrounding regions.

In the early colonial history of the Americas, "native gold and silver was quickly expropriated and sent back to Spain in fleets of gold- and silver-laden galleons" mostly from mines in Central and South America. Turquoise dated at 700 A.D. was mined in pre-Columbian America; in the Cerillos Mining District in New Mexico, estimates are that "about 15,000 tons of rock had been removed from Mt Chalchihuitl using stone tools before 1700."

Mining in the United States became prevalent in the 19th century, and the General Mining Act of 1872 was passed to encourage mining of federal lands. As with the California Gold Rush in the mid 19th century, mining for minerals and precious metals, along with ranching, was a driving factor in the Westward Expansion to the Pacific coast. With the exploration of the West, mining camps were established and "expressed a distinctive spirit, an enduring legacy to the new nation;" Gold Rushers would experience the same problems as the Land Rushers of the transient West that preceded them. Aided by railroads, many traveled West for work opportunities in mining. Western cities such as Denver and Sacramento originated as mining towns.

Mining methods and procedures

Steps of mine development



Schematic of a cut and fill mining operation in hard rock.

The process of mining from discovery of an ore body through extraction of minerals and finally to returning the land to its natural state consists of several distinct steps. The first is discovery of the ore body, which is carried out through prospecting or exploration to find and then define the extent, location and value of the ore body. This leads to a mathematical resource estimation to estimate the size and grade of the deposit.

This estimation is used to conduct a pre-feasibility study to determine the theoretical economics of the ore deposit. This identifies, early on, whether further investment in estimation and engineering studies is warranted and identifies key risks and areas for further work. The next step is to conduct a feasibility study to evaluate the financial viability, technical and financial risks and robustness of the project.

This is when the mining company makes the decision to develop the mine or to walk away from the project. This includes mine planning to evaluate the economically recoverable portion of the deposit, the metallurgy and ore recoverability, marketability and payability of the ore concentrates, engineering concerns, milling and infrastructure costs, finance and equity requirements and an analysis of the proposed mine from the initial excavation all the way through to reclamation. The proportion of a deposit that is economically recoverable is dependent on the enrichment factor of the ore in the area.

Once the analysis determines a given ore body is worth recovering, development begins to create access to the ore body. The mine buildings and processing plants are built and any necessary equipment is obtained. The operation of the mine to recover the ore begins and continues as long as the company operating the mine finds it economical to do so. Once all the ore that the mine can produce profitably is recovered, reclamation begins to make the land used by the mine suitable for future use.

Mining techniques

Underground Longwall mining.

Mining techniques can be divided into two common excavation types: surface mining and sub-surface (underground) mining. Surface mining is much more common, and produces, for example, 85% of minerals (excluding petroleum and natural gas) in the United States, including 98% of metallic ores. Targets are divided into two general categories of materials: *placer deposits*, consisting of valuable minerals contained within river gravels, beach sands, and other unconsolidated materials; and *lode deposits*, where valuable minerals are found in veins, in layers, or in mineral grains generally distributed throughout a mass of actual rock. Both types of ore deposit, placer or lode, are mined by both surface and underground methods.

Processing of placer ore material consists of gravity-dependent methods of separation, such as sluice boxes. Only minor shaking or washing may be necessary to disaggregate (unclump) the sands or gravels before processing. Processing of ore from a lode mine, whether it is a surface or subsurface mine, requires that the rock ore be crushed and pulverized before extraction of the valuable minerals begins. After lode ore is crushed, recovery of the valuable minerals is done by one, or a combination of several, mechanical and chemical techniques.

Uranium mine near Moab, Utah.

Some mining, including much of the rare earth elements and uranium mining, is done by less-common methods, such as in-situ leaching: this technique involves digging neither at the surface nor underground. The extraction of target minerals by this technique requires that they be soluble, e.g., potash, potassium chloride, sodium chloride, sodium sulfate, which dissolve in water. Some minerals, such as copper minerals and uranium oxide, require acid or carbonate solutions to dissolve.

Surface mining is done by removing (stripping) surface vegetation, dirt, and if necessary, layers of bedrock in order to reach buried ore deposits. Techniques of surface mining include; Open-pit mining which consists of recovery of materials from an open pit in the ground, quarrying or gathering building materials from an open pit mine, strip mining which consists of stripping surface layers off to reveal ore/seams underneath, and mountaintop removal, commonly associated with coal mining, which involves taking the top of a mountain off to reach ore deposits at depth. Most (but not all) placer deposits, because of their shallowly buried nature, are mined by surface methods. Landfill mining, finally, involves sites where landfills are excavated and processed.

Sub-surface mining consists of digging tunnels or shafts into the earth to reach buried ore deposits. Ore, for processing, and waste rock, for disposal, are brought to the surface through the tunnels and shafts. Sub-surface mining can be classified by the type of access shafts used, the extraction method or the technique used to reach the mineral deposit. Drift mining utilizes horizontal access tunnels, slope mining uses diagonally sloping access shafts and shaft mining consists of vertical access shafts.

Other methods include shrinkage stope mining which is mining upward creating a sloping underground room, long wall mining which is grinding a long ore surface underground and room and pillar which is removing ore from rooms while leaving pillars in place to support the roof of the room. Room and pillar mining often leads to retreat mining which is removing the pillars which support rooms, allowing the room to cave in, loosening more ore. Additional sub-surface mining methods include hard rock mining which is mining of hard materials, bore hole mining, drift and fill mining, long hole slope mining, sub level caving and block caving

Garzweiler open-pit mine, Germany

Machinery

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

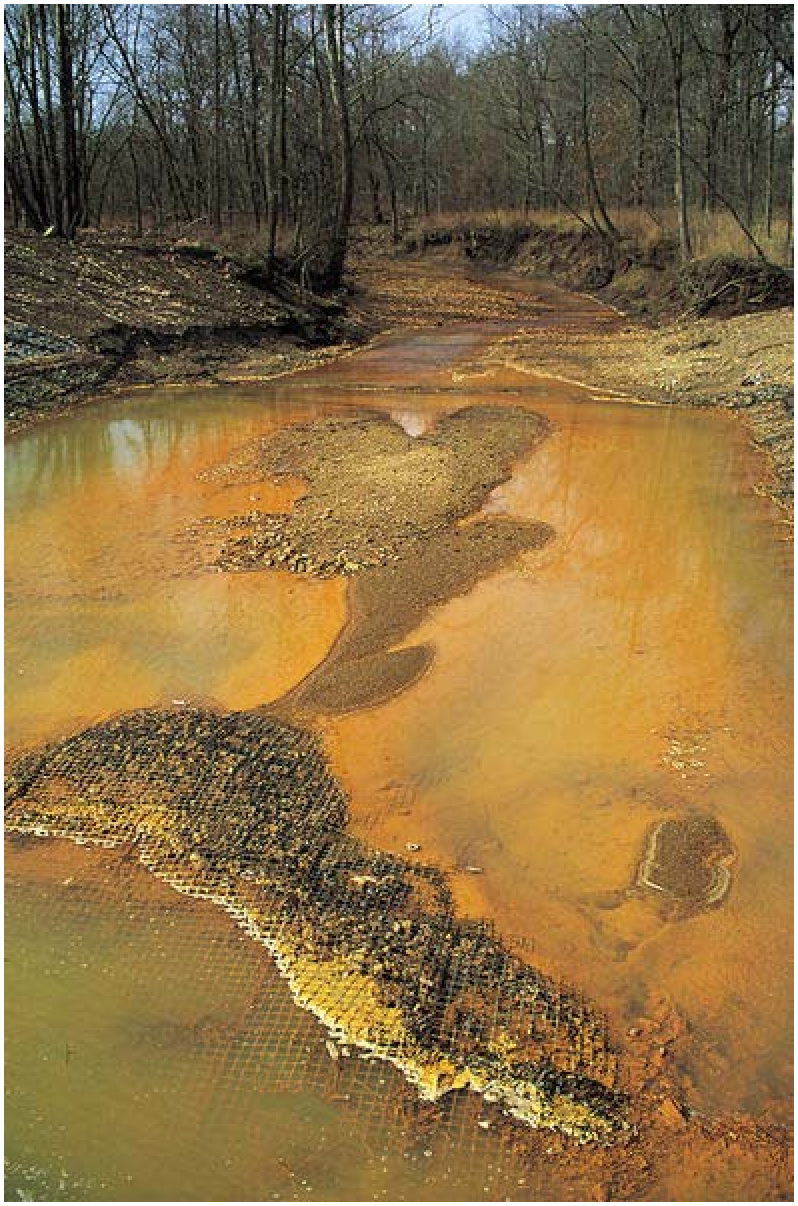
Heavy machinery is needed in mining for exploration and development, to remove and stockpile overburden, to break and remove rocks of various hardness and toughness, to process the ore and for reclamation efforts after the mine is closed. Bulldozers, drills, explosives and trucks are all necessary for 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.

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, as well as moving 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 can 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.

Extractive metallurgy

The science of extractive metallurgy is a specialized area in the science of metallurgy that studies the extraction of valuable metals from their ores, especially through chemical or mechanical means. Mineral processing (or mineral dressing) is a specialized area in the science of metallurgy that studies the mechanical means of crushing, grinding, and washing that enable the separation (extractive metallurgy) of valuable metals or minerals from their gangue (waste material). Since most metals are present in ores as oxides or sulfides, the metal needs to be reduced to its metallic form. This can be accomplished through chemical means such as smelting or through electrolytic reduction, as in the case of aluminum. Geometallurgy combines the geologic sciences with extractive metallurgy and mining.

Environmental effects



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

Environmental issues can include erosion, formation of sinkholes, loss of biodiversity, and contamination of soil, groundwater and surface water by chemicals from mining processes. In some cases, additional forest logging is done in the vicinity of mines to increase the available room for the storage of the created debris and soil. Contamination resulting from leakage of chemicals can also affect the health of the local population if not properly controlled.

Mining companies in most countries are required to follow stringent environmental and rehabilitation codes in order to minimize environmental impact and avoid impacts on human health. These codes and regulations all require the common steps of Environmental impact assessment, development of Environmental management plans, Mine closure planning (which must be done before the start of mining operations), and Environmental monitoring during operation and after closure. However, in some areas, particularly in the developing world, regulation may not be well enforced by governments.

For major mining companies, and any company seeking international financing, there are however a number of other mechanisms to enforce good environmental standards. These generally relate to financing standards such as Equator Principles, IFC environmental standards, and criteria for Socially responsible investing. Mining companies have used this financial industry oversight to argue for some level of self-policing. In 1992 a Draft Code of Conduct for Transnational Corporations was proposed at the Rio Earth Summit by the UN Centre for Transnational Corporations (UNCTC), but the Business Council for Sustainable Development (BCSD) together with the International Chamber of Commerce (ICC) argued successfully for self-regulation instead.

This was followed up by the Global Mining Initiative which was initiated by nine of the largest metals and mining companies, and led to the formation of the International Council on Mining and Metals to "act as a catalyst" for social and environmental performance improvement in the mining and metals industry internationally. The mining industry has provided funding to various conservation groups, some of which have been working with conservation agendas that are at odds with emerging acceptance of the rights of indigenous people - particularly rights to make land-use decisions.

Ore mills generate large amounts of waste, called tailings. For example, 99 tons of waste are generated per ton of copper, with even higher ratios in gold mining. These tailings can be toxic. Tailings, which are usually produced as a slurry, are most commonly dumped into ponds made from naturally existing valleys. These ponds are secured by impoundments (dams or embankment dams). In 2000 it was estimated that 3,500 tailings impoundments existed, and that every year, 2 to 5 major failures and 35 minor failures occurred; for example, in the Marcopper mining disaster at least 2 million tons of tailings were released into a local river. Subaqueous tailings disposal is another option. The mining industry has argued that submarine tailings disposal (STD), which disposes of tailings in the sea, is ideal because it avoids the risks of tailings ponds; although the practice is illegal in the United States and Canada, it is used in the developing world.

Certification of mines with good practices occurs through the International Organization for Standardization (ISO) such as ISO 9000 and ISO 14001, which certifies an 'auditable environmental management system'; this certification involves short inspections, although it has been accused of lacking rigor. Certification is also available through Ceres' Global Reporting Initiative, but these reports are voluntary and unverified. Miscellaneous other certification programs exist for various projects, typically through nonprofit groups.

Regulations and World Bank relationship

The World Bank has been involved in mining since 1955, mainly through grants from its International Bank for Reconstruction and Development, with the Bank's Multilateral Investment Guarantee Agency offering political risk insurance. Between 1955 and 1990 it provided about $2 billion to fifty mining projects, broadly categorized as reform and rehabilitation, greenfield mine construction, mineral processing, technical assistance, and engineering. These projects have been criticized, particularly the Ferro Carajas project of Brazil, begun in 1981. The bank established mining codes intended to increase foreign investment, in 1988 solicited feedback from 45 mining companies on how to increase their involvement.

In 1992 the bank began to push for privatization of government-owned mining companies with a new set of codes, beginning with its report *The Strategy for African Mining*. In 1997, Latin America's largest miner Companhia Vale do Rio Doce (CVRD) was privatized. These and other movements such as the Philippines 1995 Mining Act led the World Bank to publish a third report (*Assistance for Minerals Sector Development and Reform in Member Countries*) which endorsed mandatory environment impact assessments and attention to the locals. The codes based on this report are influential in the legislation of developing nations. The new codes are intended to encourage development through tax holidays, zero custom duties, reduced income taxes, and related measures. The results of these codes were analyzed by a group from the University of Quebec, which concluded that the codes promote foreign investment but "fall very short of permitting sustainable development". The observed negative correlation between natural resources and economic development is known as the resource curse.

Mining industry

Mining exists in many countries but Australia and Canada have a reputation for domestic mining expertise, and London is known as the capital of global "mining houses" such as Rio Tinto, BHP Billiton, and Anglo American PLC. The US mining industry is also large but it is dominated by the coal and nonmetal minerals, and the various regulations have worked to reduce the significance of mining in the United States. In 2007 the total market cap of mining companies was reported at US$962 billion, which compares to a total global market cap of publicly traded companies of about US$50 trillion in 2007.

While exploration and mining can sometimes be conducted by individual entrepreneurs or small business, most modern-day mines are large enterprises requiring large amounts of capital to establish. Consequently, the mining sector of the industry is dominated by large, often multinational companies, most of them publicly listed. It can be argued that what is referred to as the 'mining industry' is actually two sectors, one specializing in exploration for new resources, the other specializing in mining those resources. The exploration sector is typically made up of individuals and small mineral resource companies ("juniors") dependent on venture capital. The mining sector is typically large and multi-national companies sustained by mineral production from their mining operations. In addition to these two sectors, various other industries such as equipment manufacture, environmental testing and metallurgy analysis also rely on and support the mining industry throughout the world. Canadian stock exchanges have a particular focus on mining companies, particularly junior exploration companies through the TSX Venture Exchange; Canadian companies raise capital on these exchanges and then invest the money in exploration globally. Some have argued that below juniors there exists a substantial sector of illegitimate companies primarily focused on manipulating stock prices.

Mining operations can be grouped into five major categories in terms of their respective resources. These are, oil and gas extraction, coal mining, metal ore mining, nonmetallic mineral mining and quarrying, and support activities for mining. Out of all these categories, oil and gas extraction remains one of the largest in terms of its global economic importance. Prospecting potential mining sites, a vital area of concern for the mining industry is now done using sophisticated new technologies such as seismic prospecting and remote-sensing satellites.

Corporate classifications

Mining companies can be classified based on their size and financial capabilities:

- **Major** companies are considered to have an adjusted annual mining-related revenue of more than US$500 million, with the financial capability to develop a major mine on its own.

- **Intermediate** companies have at least $50 million in annual revenue but less than $500 million.

- **Junior** companies rely on equity financing as their principal means of funding exploration. Juniors are mainly pure exploration companies, but may also produce minimally, and do not have a revenue of US$50 million.

Safety

Abandoned mine entrance in Yorkshire, England, United Kingdom

Firefighter training in fell slate mine, Germany

Safety has long been a controversial issue in the mining business especially with sub-surface mining. While mining today is substantially safer than it was in the previous decades, mining accidents are often very high profile, such as the Quecreek Mine Rescue saving 9 trapped Pennsylvania coal miners in 2002. The Courrières mine disaster, Europe's worst mining accident, caused the death of 1,099 miners (including many children) in Northern France on 10 March 1906. It seems that this disaster was surpassed only by the Benxihu Colliery accident in China on April 26, 1942, which killed 1,549 miners. Government figures indicate that 5,000 Chinese miners die in accidents each year, while other reports have suggested a figure as high as 20,000. Mining ventilation is a significant safety concern for many miners. Poor ventilation of the mines causes exposure to harmful gases, heat and dust inside sub-surface mines. These can cause harmful physiological effects, including death. The concentration of methane and other airborne contaminants underground can generally be controlled by dilution (ventilation), capture before entering the host air stream (methane drainage), or isolation (seals and stoppings).

Ignited methane gas is a common source of explosions in coal mines, or, the more violent coal dust explosions. Gases in mines can also poison the workers or displace the oxygen in the mine, causing asphyxiation. For this reason, the MHSA requires that workers have gas detection equipment in groups of miners. It must be able to detect common gases, such as CO, O_2, H_2S, and % Lower Explosive Limit. Additionally, further regulation is being requested for more gas detection as newer technology such as nanotechnology is introduced.

High temperatures and humidity may result in heat-related illnesses, including heat stroke which can be fatal. Dusts can cause lung problems, including silicosis, asbestosis and pneumoconiosis (also known as miners lung or black lung disease). A ventilation system is set up to force a stream of air through the working areas of the mine. The air circulation necessary for the effective ventilation of a mine is generated by one or more large mine fans, usually located above ground. Air flows in one direction only, making circuits through the mine such that each main work area constantly receives a supply of fresh air.

Miners utilize equipment strong enough to break through extremely hard layers of the Earth's crust. This equipment, combined with the closed workspace that underground miners work in, can cause hearing loss. For example, a roof bolter (commonly used by mine roof bolter operators) can reach sound power levels of up to 115 dB. Combined with the reverberant effects of underground mines, a miner without proper hearing protection is at a high risk for hearing loss.

Since mining entails removing dirt and rock from its natural location creating large empty pits, rooms and tunnels, cave-ins are a major concern within mines. Modern techniques for timbering and bracing walls and ceilings within sub-surface mines have reduced the number of fatalities due to cave-ins, but accidents still occur. The presence of heavy equipment in confined spaces also poses a risk to miners, and despite modern improvements to safety practices, mining remains dangerous throughout the world.

Abandoned mines

Abandoned mine in Nevada.

Warning sign near Jerome, Arizona

There are upwards of 560,000 abandoned mines on public and privately owned lands in the United States alone. Abandoned mines may be dangerous to anyone who attempts to explore them without proper knowledge and safety training. Old mines are often dangerous and can contain deadly gases. Standing water in mines from seepage or infiltration poses a significant hazard as the water can hide deep pits and trap gases below the water. Additionally, since weather may have eroded the earth and rock surrounding it, the entrance to an old mine in particular can be very dangerous. Old mine workings, caves, etc. are commonly hazardous simply due to the lack of oxygen in the air, a condition in mines known as blackdamp.

Records

As of 2008, the deepest mine in the world is TauTona in Carletonville, South Africa at 3.9 kilometers, replacing Savuka Mine in the North West Province of South Africa at 3,774 meters. East Rand Mine in Boksburg, South Africa briefly held the record at 3,585 meters, and the first mine declared the deepest in the world was also TauTona when it was at 3,581 meters. The deepest mine in Europe is Pyhäsalmi Mine in Pyhäjärvi, Finland at 1,444 meters. The second deepest mine in Europe is Boulby Mine England at 1,400 meters (shaft depth 1,100 meters).

The deepest open pit mine in the world is Bingham Canyon Mine in Bingham Canyon, Utah, United States at over 1,200 meters. The largest and second deepest open pit copper mine in the world is Chuquicamata in Chuquicamata, Chile at 900 meters, 940,600 tons of copper and 17,700 tons of molybdenum produced annually.

The deepest open pit mine with respect to sea level is Tagebau Hambach in Germany, where the ground of the pit is 293 meters below sea level.

The largest underground mine: El Teniente, in Rancagua, Chile, 2,400 kilometers of underground drifts, 418,000 tons of copper yearly. The deepest borehole in the world is Kola Superdeep Borehole at 12,262 meters. This, however, is not a matter of mining but rather related to scientific drilling.

Chapter 8

Surface Mining

Coal strip mine in Wyoming

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

Surface mining is used when deposits of commercially useful minerals or rock are found near the surface; that is, where the overburden is relatively thin or the material of interest is structurally unsuitable for tunneling (as would usually be the case for sand, cinder, and gravel). Where minerals occur deep below the surface—where the overburden is thick or the mineral occurs as veins in hard rock— underground mining methods are used to extract the valued material. Surface mines are typically enlarged until either the mineral deposit is exhausted, or the cost of removing larger volumes of overburden makes further mining no longer economically viable.

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

Types

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

Strip mining

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

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

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

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

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

Open-pit mining

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

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

Mountaintop removal

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

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

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

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

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

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

Dredging

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

Highwall mining

Highwall mining is another form of surface mining that evolved from auger mining. In Highwall mining, the coal seam is penetrated by a continuous miner propelled by a hydraulic Pushbeam Transfer Mechanism (PTM). A typical cycle includes sumping (launch-pushing forward) and shearing (raising and lowering the cutterhead boom to cut the entire height of the coal seam). As the coal recovery cycle continues, the cutterhead is progressively launched into the coal seam for 19.72 feet (6.01 m). Then, the Pushbeam Transfer Mechanism (PTM) automatically inserts a 19.72-foot (6.01 m) long rectangular Pushbeam (Screw-Conveyor Segment) into the center section of the machine between the Powerhead and the cutterhead. The Pushbeam system can penetrate nearly 1,000 feet (300 m) into the coal seam. One patented Highwall mining systems use augers enclosed inside the Pushbeam that prevent the mined coal from being contaminated by rock debris during the conveyance process. Using a video imaging and/or a gamma ray sensor and/or other Geo-Radar systems like a coal-rock interface detection sensor (CID), the operator can see ahead projection of the seam-rock interface and guide the continuous miner's progress. Highwall mining can produce thousands of tons of coal in contour-strip operations with narrow benches, previously mined areas, trench mine applications and steep-dip seams with controlled water-inflow pump system and/or a gas (inert) venting system.

Recovery is much better than Augering, but the mapping of areas that have been developed by a Highwall miner are not mapped as rigorously as deep mined areas. Very little spoil is displaced in contrast with mountain top removal; however a large amount of capital is required to operate and own a Highwall miner. But then this Highwall mining system is the innovative roadmap future potential and stay or being better competitive in the area of environmental friendly non mountain-top (overburden) removal operated by only 4 crew members.

Mapping of the outcrop as well as core hole data and samples taken during the bench making process are taken into account to best project the panels that the Highwall miner will cut. Obstacles that could be potentially damaged by subsidence and the natural contour of the Highwall are taken into account, and a surveyor points the Highwall miner in a line (Theoretical Survey Plot-Line) mostly perpendicular to the Highwall. Parallel lines represent the drive cut into the mountain (up to 1,000 feet (300 m) deep), without heading or corrective steering actuation on a navigation Azimuth during mining results in missing a portion of the coal seam and is a potential danger of cutting in pillars from previous mined drives due to horizontal drift (Roll) of the Pushbeam-Cuttermodule string. Recently Highwall miners have penetrated more than 1050 feet into the coal seam, and today's models are capable of going farther, with the support of gyro navigation and not limited anymore by the amount of cable stored on the machine. The maximum depth would be determined by the stress of further penetration and associated power draw, but today’s optimized Pushbeam Discrete Element Modeling (DEM) shows smart-drive extended penetrations are possible.

Environmental and health issues

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

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

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

Human health

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

On August 20, 2004 at 2:30 a.m. a boulder accidentally pushed off an A&G Coal surface mine above the town of Inman, Virginia rolled 649 feet (198 m) down the mountain and into a home. Three-year-old Jeremy Davidson was crushed in his bed while he slept. The Davidson family settled with A&G Coal for $3 million in 2006, and left the region.

Environmental impact

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

Chapter 9

Mountaintop Removal Mining

Mountaintop removal site.

Mountaintop Removal in Martin County, Kentucky

Mountaintop removal mining is a form of surface mining that involves the mining of the summit or summit ridge of a mountain. Entire coal seams are removed from the top of a mountain, hill or ridge by removing the so-called overburden (soil,lying above the economically desired resource). After the coal is extracted, the removed material is put back onto the ridge to approximate the mountain's original contours. Any overburden the mining company considers excess (that which it's not able to place back onto the ridge top) is moved into neighboring valleys. Mountaintop removal is most closely associated with coal mining in the Appalachian Mountains in the eastern United States.

Peer-reviewed studies show that mountaintop mining has serious environmental impacts, including loss of biodiversity, that mitigation practices cannot successfully address. There are also adverse human health impacts which result from contact with affected streams or exposure to airborne toxins and dust.

Overview

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, summit ridge, or significant portion of a mountain, hill, or ridge in order to obtain a desired geologic material.

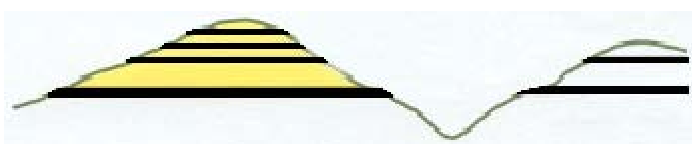
The MTR process involves the removal of coal seams by first fully removing the overburden laying atop them, exposing the seams from above. This method differs from more traditional underground mining, where typically a narrow shaft is dug which allows miners to collect seams using various underground methods, while leaving the vast majority of the overburden undisturbed. The overburden waste resulting from MTR is either placed back on the ridge, attempting to reflect the approximate original contour of the mountain, and/or it is moved into neighboring valleys.

The process involves blasting with explosives to remove up to 400 vertical feet (120 m) of overburden to expose underlying coal seams. Excess rock and soil laden with toxic mining byproducts are often dumped into nearby valleys, in what are called "holler fills" or "valley fills."

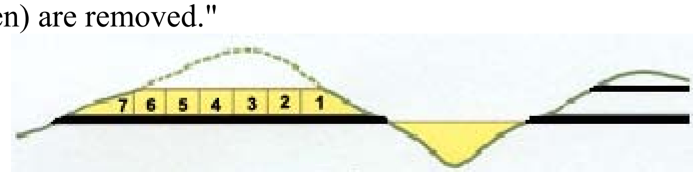
MTR in the United States is most often associated with the extraction of coal in the Appalachian Mountains, where the United States Environmental Protection Agency (EPA) estimates that 2,200 square miles (5,700 km^2) of Appalachian forests will be cleared for MTR sites by the year 2012. Sites range from 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.

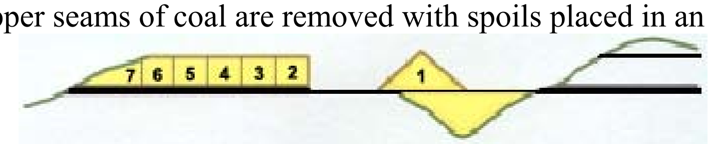
Process



US EPA diagram of mountaintop mining: "**Step 1.** Layers of rock and dirt above the coal (called overburden) are removed."

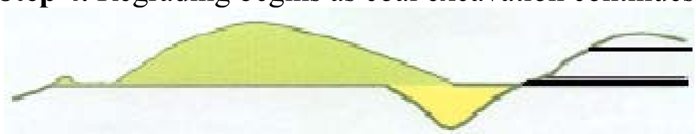


"**Step 2.** The upper seams of coal are removed with spoils placed in an adjacent valley."



"**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 complete, 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 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

Just under half 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).

Legislation in the United States

In the United States, MTR is allowed by section 515(c)(1) of SMCRA. 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."

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. However, if passed, the Clean Water Protection Act (*H.R.1310*), a bill in the House of Representatives, would revert this change by specifying that coal mining waste does not constitute fill material, in effect disallowing valley fills.

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 to end a policy that waives detailed federal Endangered Species Act reviews for new mining permits. The current policy states that MTR can never damage endangered species or their habitat as long as mining operators comply with federal surface mining law, despite the complexities of species and ecosystems. Since 1996, this policy has exempted many strip mines from being subject to permit-specific reviews of impact on individual endangered species.

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.

Environmental and health impacts

The Hobet mine in West Virginia taken by NASA LANDSAT in 1984

The Hobet mine in West Virginia taken by NASA LANDSAT in 2009

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.

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 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. The statement also estimates that 724 miles (1,165 km) of Appalachian streams were buried by valley fills between 1985 to 2001.

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. 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 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.

Books and films

Many personal interest stories of coalfield residents have been written, including *Lost Mountain* by Erik Reese and *Moving Mountains: How One Woman and Her Community Won Justice From Big Coal* by Penny Loeb. In April 2005, a group of Kentucky writers traveled together to see the devastation from mountaintop removal mining, and Wind Publishing produced the resulting collection of poems, essays and photographs, co-edited by Kristin Johannesen, Bobbie Ann Mason and Mary Ann Taylor-Hall -- *Missing Mountains: We went to the mountaintop, but it wasn't there*. In 2007, Ann Pancake released the novel *Strange As This Weather Has Been*, the first major fiction work about the subject. Mountaintop removal is a major plot element of the 2010 best-selling novel *Freedom* by Jonathan Franzen, wherein a major character helps to secure land for surface mining with the promise that it will be restored and turned into a nature preserve.

To date, Dr. Shirley Stewart Burns, a coalfield native, has written the only academic book on mountaintop removal, titled *Bringing Down The Mountains*, which is loosely based on the 2005 Ph.D. dissertation of the same name. Cultural historian Jeff Biggers has also published *The United States of Appalachia* examined the cultural and human costs of mountaintop removal.

In 2006, Catherine Pancake released the first comprehensive feature-length documentary on mountaintop removal, *Black Diamonds: Mountaintop Removal and the Search for Coalfield Justice*, a selection in the Documentary Fortnight at the Museum of Modern Art. The film features Julia Bonds who won the 2003 Goldman Prize. A 2007 documentary, *Mountain Top Removal*, focuses on Mountain Justice Summer activists, coal field residents, and coal industry officials. On April 18, 2008 the film received the

Reel Current award selected and presented by Al Gore at the Nashville Film Festival. Another feature documentary, titled *Burning the Future: Coal in America*, was awarded the International Documentary Association's 2008 Pare Lorentz award for Best Documentary.

Chapter 10

Deep Sea Mining

Deep sea mining is a relatively new 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 about 1,400 - 3,700 meters below the ocean's surface. The vents create sulfide deposits, which contain precious 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 environmental damages to the surrounding areas.

Brief history

In the mid 1960s the prospect of deep-sea mining was brought up by the publication of J. L. Mero's *Mineral Resources of the Sea*. The book claimed that nearly limitless supplies of cobalt, nickel and other metals could be found throughout the planet's oceans. Mero stated that these metals occurred in deposits of manganese nodules, which appear as lumps of compressed sediment on the sea floor at depths of about 5,000 m. Some nations including France, Germany and the United States sent out research vessels in search of nodule deposits. Initial estimates of deep sea mining viability turned out to be much exaggerated. This overestimate, coupled with depressed metal prices, led to the near abandonment of nodule mining by 1982. From the 1960s to the 1984 an estimated US $650 million had been spent on the venture, with little to no return.

Over the past decade a new phase of deep-sea mining has begun. Rising demand for precious metals in Japan, China, Korea and India has pushed these countries in search of new sources. Interest has recently shifted toward hydrothermal vents as the source of metals instead of scattered nodules.

Currently, the best potential deep sea site, the Solwara 1 Project, has been found in the waters off Papua New Guinea, a high grade copper-gold resource and the world's first Seafloor Massive Sulphide (SMS) resource. The Solwara 1 Project is located at 1600 metres water depth in the Bismarck Sea, New Ireland Province. Using the latest ROV (remotely operated underwater vehicles) technology, Nautilus Minerals Inc. will be the first company of its kind to begin full-scale undersea excavation of mineral deposits. First production is expected in early 2013.

Laws and regulations

The most noteworthy regulations on deep sea mining came through the United Nations Conventions on the Law of the Sea from 1973 to 1982, which finally came into force in 1994. The convention set up the International Seabed Authority (ISA), which regulates nations' deep sea mining ventures outside each nations' Exclusive Economic Zone (a 200-nautical-mile (370 km) area surrounding coastal nations). The ISA requires nations interested in mining to explore two equal mining sites and turn one over to the ISA, along with a transfer of mining technology over a 10 to 20 year period. This seemed reasonable at the time because it was widely believed that nodule mining would be extremely profitable. However, these strict requirements led some industrialized countries to refuse to sign the initial treaty in 1982.

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, usually in higher concentrations than terrestrial mines.

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.

Environmental impacts

Because deep sea mining is a relatively new field, the complete consequences of full scale mining operations are unknown. However, experts are certain 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 disturbs the habitat of benthic organisms, possibly, depending on the type of mining and location, causing permanent disturbances. Aside from direct impact of mining the area, leakage, spills and corrosion would 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.