Mining Techniques and Technology

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First Edition, 2012

ISBN 978-81-323-1492-9

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Published by:
College Publishing House
4735/22 Prakashdeep Bldg,
Ansari Road, Darya Ganj,
Delhi - 110002
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Chapter 1

Surface Mining

Coal strip mine in Wyoming

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

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

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

Types

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

Strip mining

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

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

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

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

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

Open-pit mining

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

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

Mountaintop removal

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

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

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

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

Blasting at a mountaintop removal mine expels dust and fly-rock into the air, which can then disturb or settle onto private property nearby. This dust may 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 (pushing forward) and shearing (raising or lowering the cutterhead boom to cut the entire height of the coal seam). As the coal recovery cycle continues, the cutterhead is progressively pushed into the coal seam for 20 feet (6.1 m). Then, the Pushbeam Transfer Mechanism (PTM) automatically inserts a 20-foot (6.1 m) long rectangular pushbeam into the center section of the machine between the powerhead and the cutterhead. The

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

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

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

Environmental and health issues

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

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

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

Human health

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

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

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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.

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Chapter 2

Surface Mining Concepts & Techniques

Clay pit

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

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

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

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Costean

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

Glory hole

Abandoned open pit mine in South Africa, the Big Hole

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

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

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

Gravel pit

A gravel pit in Germany

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

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

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

Quarry

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

Portland stone quarry on the Isle of Portland, England

Problems

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

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

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

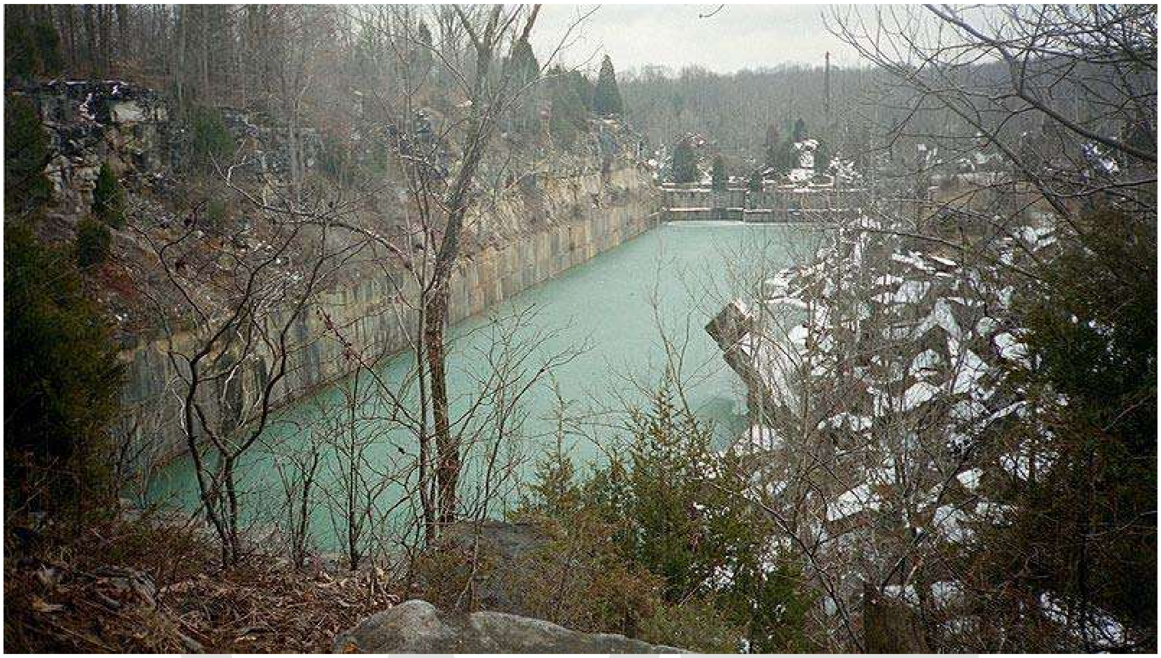
Quarry swimming

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

Types of rock

An abandoned construction aggregate quarry near Adelaide, South Australia

Delabole Slate Quarry, Delabole, Cornwall, UK



An abandoned limestone quarry

Types of rock extracted from quarries include:

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

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Chapter 3

Hydraulic Mining and Landfill Mining

Hydraulic Mining

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

Precursor - ground sluicing

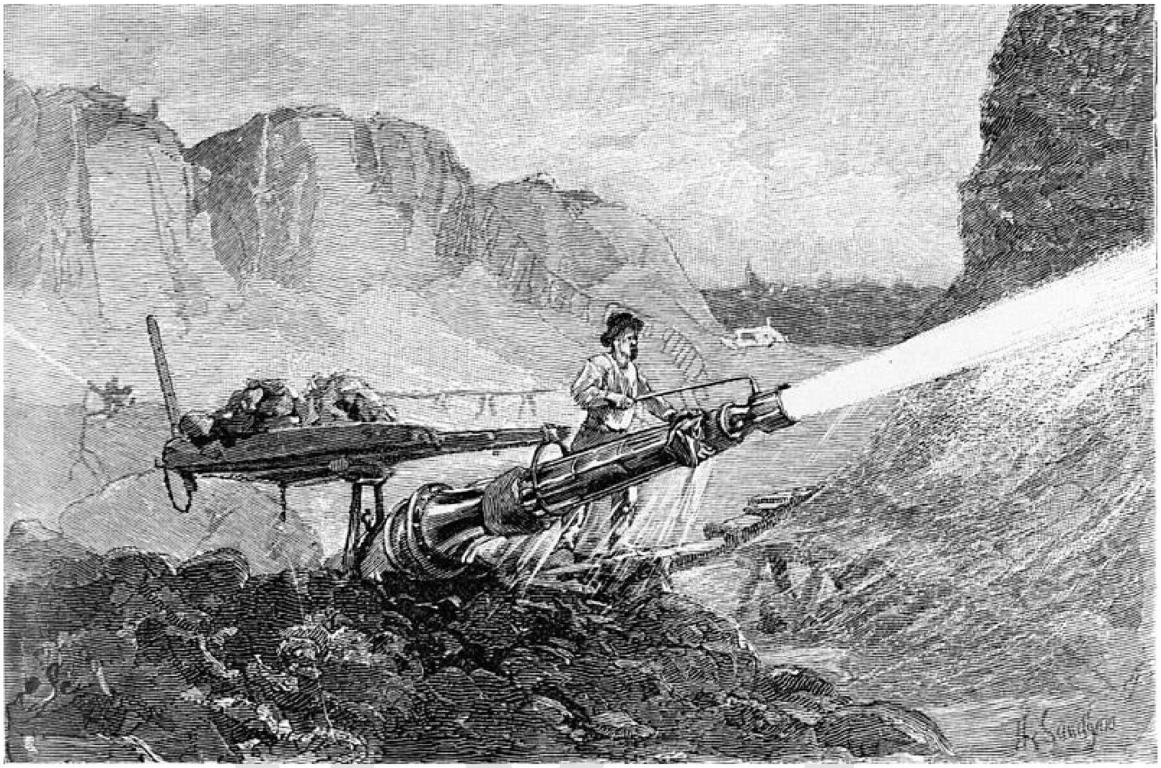
Hydraulicking had its precursor in the millennia-old practice of ground sluicing, also known as "hushing", in which surface streams of water were diverted so as to erode gold-bearing gravels. The Romans used ground sluicing to remove overburden and then gold-bearing debris in Las Médulas of Spain, and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

Panoramic view of Las Médulas

Roman era

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

California hydraulicking



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

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

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

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

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

Environmental consequences

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

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

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

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

Legal ramifications

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

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Beyond California

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

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Lee Moor china clay pit in Devon showing hydraulic mining

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

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

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

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

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

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

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

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

Underground hydraulic mining

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

Landfill mining

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

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

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Practical applications

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

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

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

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

Tools and machinery

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

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

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The mechanics of mining

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

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

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

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

Operational flow

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

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Chapter 4

Open-Pit Mining

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

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

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

For minerals that occur deep below the surface—where the overburden is thick or the mineral occurs as veins in hard rock— underground mining methods extract the valued material.

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

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

A coquina quarry

Extraction

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

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

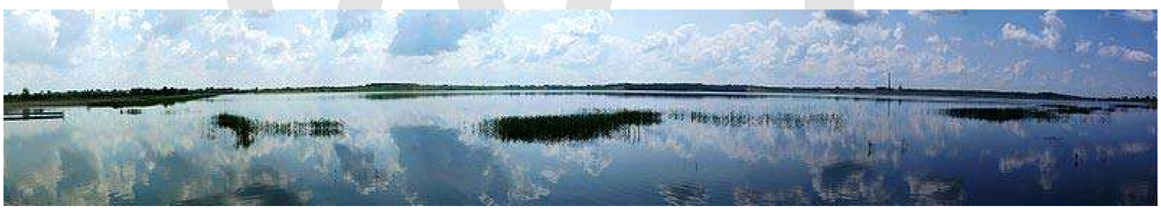
The walls are stepped. The inclined section of the wall is known as the batter, and the flat part of the step is known as the bench or berm. The steps in the walls help prevent rock falls continuing down the entire face of the wall. In some instances additional ground support is required and rock bolts, cable bolts and shotcrete are used. De-watering bores may be used to relieve water pressure by drilling horizontally into the wall, which is often enough to cause failures in the wall by itself.

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

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

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

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



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

Rehabilitation

After mining finishes, the mine area must undergo rehabilitation. Waste dumps are contoured to flatten them out, to further stabilise them. If the ore contains sulfides it is usually covered with a layer of clay to prevent access of rain and oxygen from the air, which can oxidise the sulfides to produce sulfuric acid, a phenomenon known as acid mine drainage. This is then generally covered with soil, and vegetation is planted to help consolidate the material. Eventually this layer will erode, but it is generally hoped that the rate of leaching or acid will be slowed by the cover such that the environment can handle the load of acid and associated heavy metals. There are no long term studies on the success of these covers due to the relatively short time in which large scale open pit mining has existed. It may take hundreds to thousands of years for some waste dumps to become "acid neutral" and stop leaching to the environment. The dumps are usually fenced off to prevent livestock denuding them of vegetation. The open pit is then surrounded with a fence, to prevent access, and it generally eventually fills up with ground water. In arid areas it may not fill due to deep groundwater levels.

Typical open cut grades

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

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

Materials typically extracted from open-pit mines include:

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

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Open-pit mines

Super Pit gold mine

Argentina

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

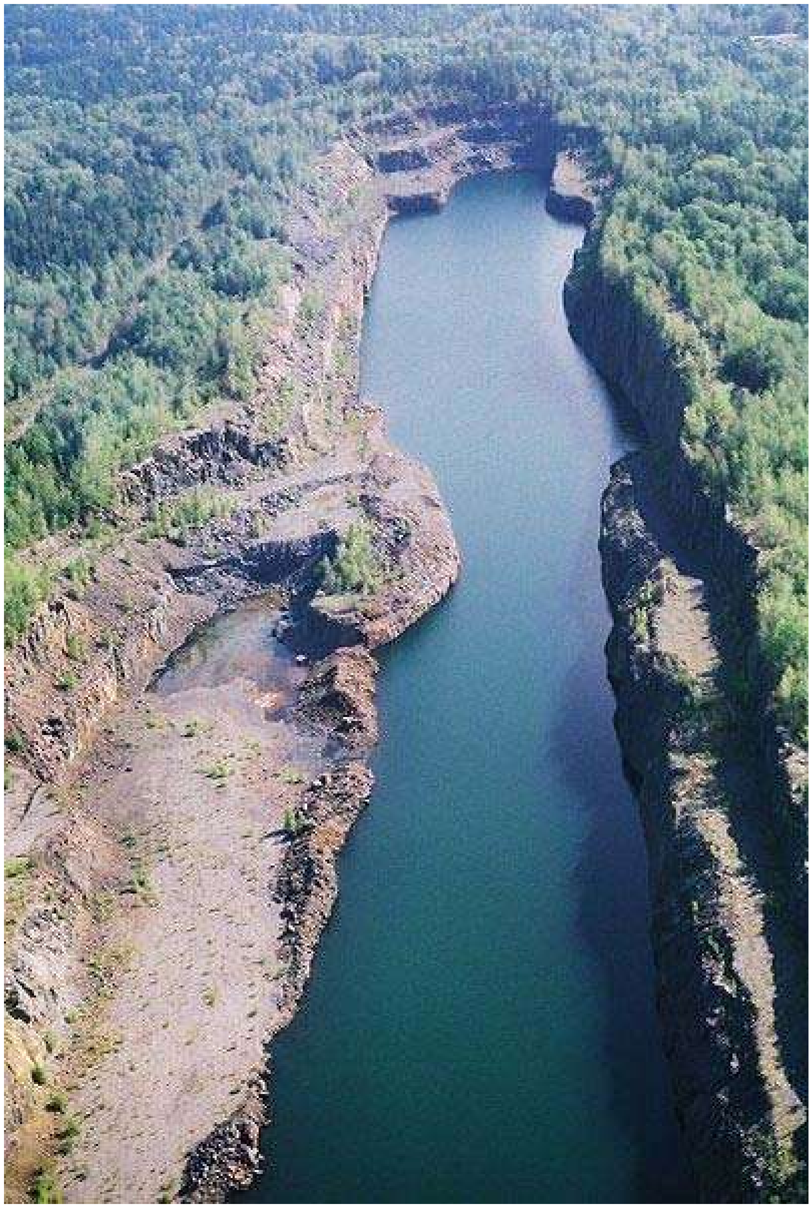
Australia

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

Bulgaria

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

Canada



East Pit of Sherman Mine in Temagami, Ontario, Canada

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

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

Chile

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

Colombia

- Cerrejón – coal mine in Guajira Department.

Egypt

- Sukari gold mine

Germany

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

Indonesia

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

Kyrgyzstan

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

Mongolia

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

Namibia

- Rossing – uranium mine.

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

Peru

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

Portugal

- Sao Domingos Mine – copper mine.

Romania

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

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Russia

The Udachnaya pipe in Russia

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

South Africa

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

Spain

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

Sweden

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

United Kingdom

- Penrhyn Quarry – slate quarry in Wales.

United States

The Lavender Pit, Bisbee, Arizona

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

Zambia

- Nchanga Open Pit Mine, Chingola. The second largest open cast mine in the world , covering nearly 30 km^2 and up to 400m deep.

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Chapter 5

Placer Mining

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

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

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

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

History

A sluice box used in placer mining

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

Methods

A number of methods are used to mine placer gold.

Panning

Coarse Alaskan gold in pan

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

Sluice box

Miners working a sluice on Lucky Gulch, Alaska

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

Trommel

Trommel at the Potato Patch, Blue Ribbon Mine, Alaska

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

Environmental effects

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

A pan used to extract gold

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

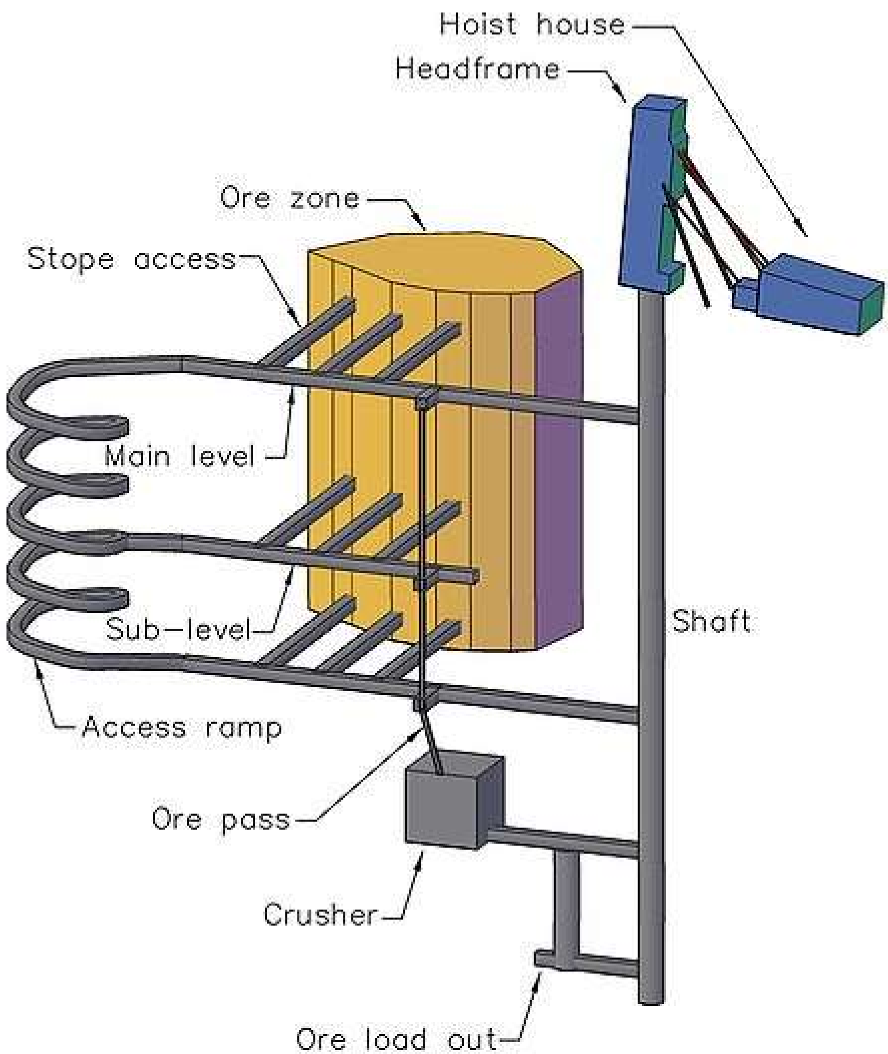
Environmental activists describe the hydraulic mining form of placer mining as environmentally destructive because of the large amounts of silt that it adds to previously clear running streams (also known as the "Dahlonega Method"<Dahlonega, Georgia>). Most placer mines today use settling ponds, if only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

Panoramic view of Las Médulas

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

Chapter 6

Underground Mining (Hard Rock)



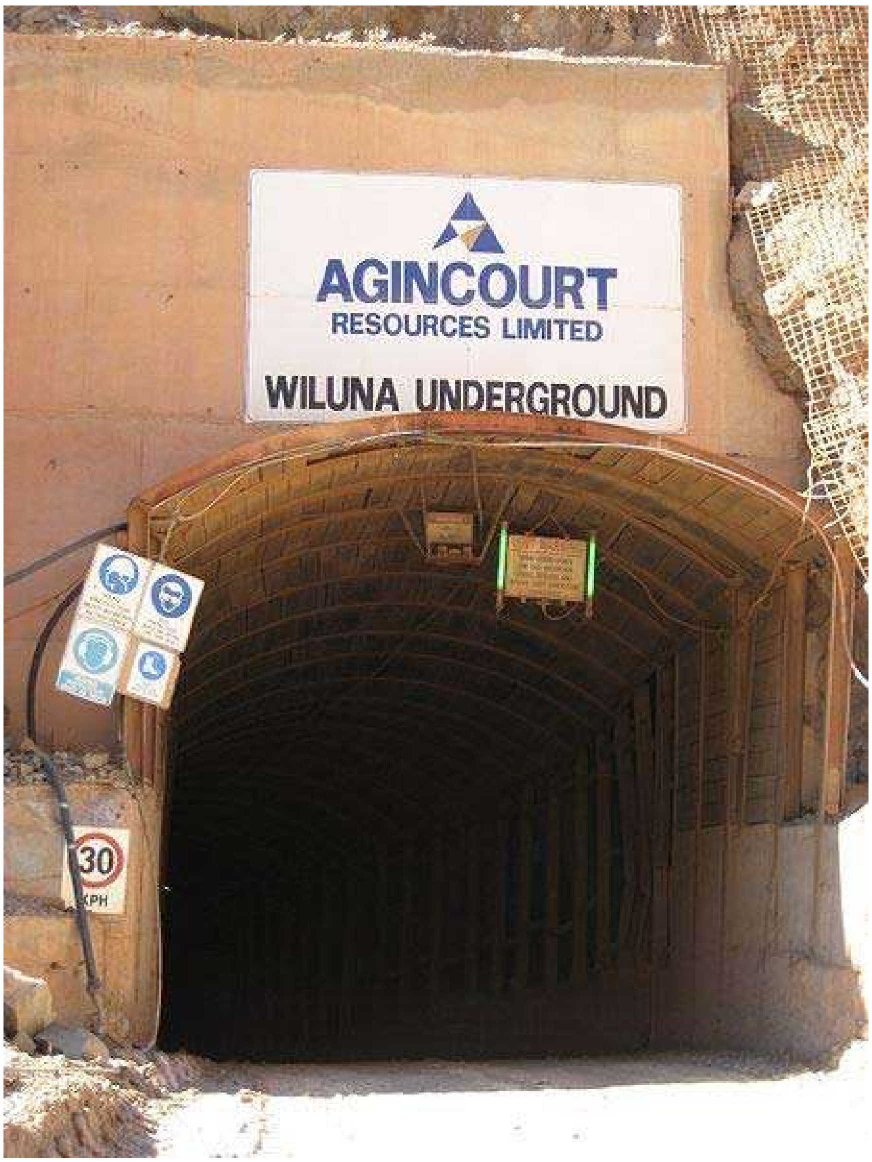
A three dimensional model of an underground mine with shaft access

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

Mine access

Underground access

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



Decline portal at Wiluna Gold Mine

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

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

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

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

Ore access

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

Development mining vs. production mining

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

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

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

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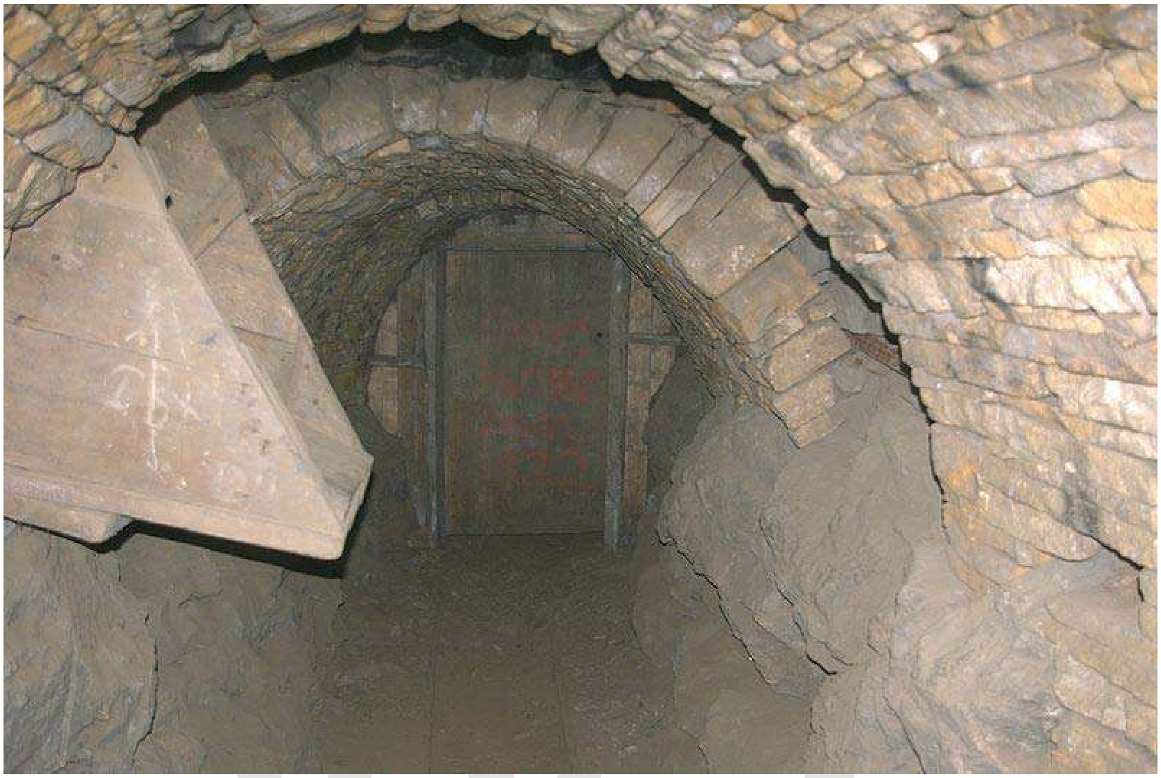
Ventilation



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.

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- **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

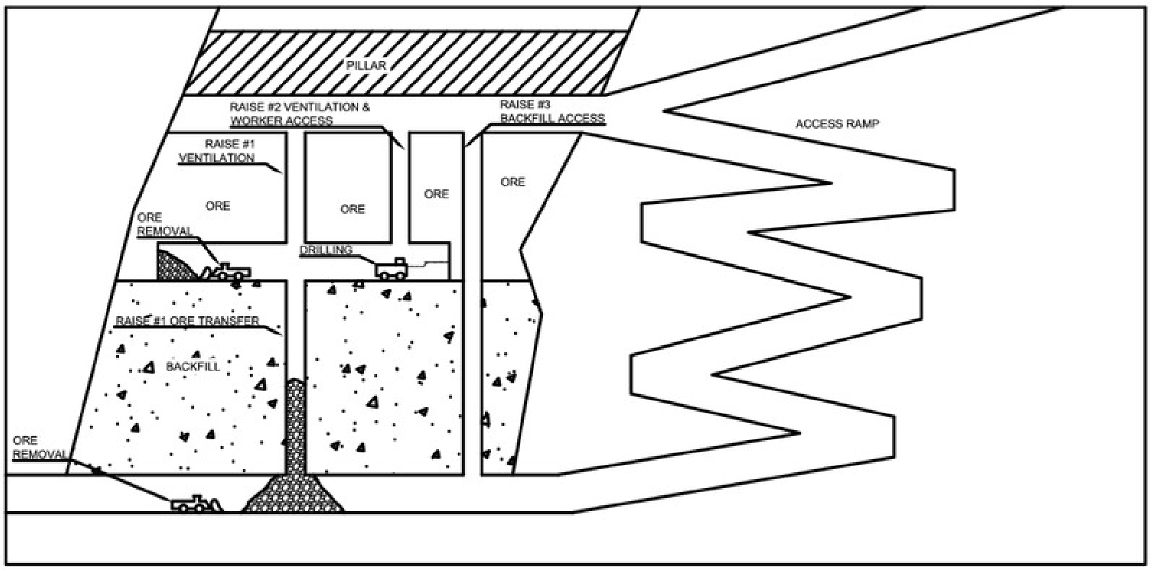
Sub-Level Caving Subsidence reaches surface at the Ridgeway underground mine

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 over the undercut. The drawbells serve as a place for caving rock to fall into. The orebody is drilled and blasted above the undercut, and the ore is removed via the haulage access. Due to the friability of the orebody the ore above the first blast caves and falls into the drawbells. As ore is removed from the drawbells the orebody caves in providing a steady stream of ore. If caving stops and removal of ore from the drawbells continues, a large void may form, resulting in the potential for a sudden and massive collapse and potentially catastrophic windblast throughout the mine.

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

Ore removal

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

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

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

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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).

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Chapter 7

Underground Mining (Soft Rock)

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

Methods

- **Longwall mining -** A set of longwall mining equipment consists of a coal shearer mounted on conveyor operating underneath a series of self-advancing hydraulic roof supports. Almost the entire process can be automated. Longwall mining machines are typically 150-250 metres in width and 1.5 to 3 metres high. Longwall miners extract "panels" **-** rectangular blocks of coal as wide as the face the equipment is installed in, and as long as several kilometres. Powerful mechanical coal cutters (shearers) cut coal from the face, which falls onto an armoured face conveyor for removal. Longwalls can advance into an area of coal, or more commonly, retreat back between development tunnels (called "gateroads") As a longwall miner retreats back along a panel, the roof behind the supports is allowed to collapse in a planned and controlled manner.

- **Room-and-pillar mining** or **continuous mining -** Room and pillar mining is commonly done in flat or gently dipping bedded ores. Pillars are left in place in a regular pattern while the rooms are mined out. In many room and pillar mines, the pillars are taken out, starting at the farthest point from the mine haulage exit, retreating, and letting the roof come down upon the floor. Room and pillar methods are well adapted to mechanization, and are used in deposits such as coal, potash, phosphate, salt, oil shale, and bedded uranium ores.

- **Blast mining** – An older practice of coal mining that uses explosives such as dynamite to break up the coal seam, after which the coal is gathered and loaded onto shuttle cars or conveyors for removal to a central loading area. This process consists of a series of operations that begins with "cutting" the coalbed so it will break easily when blasted with explosives. This type of mining accounts for less than 5% of total underground production in the U.S. today.

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

Mine Shorthand

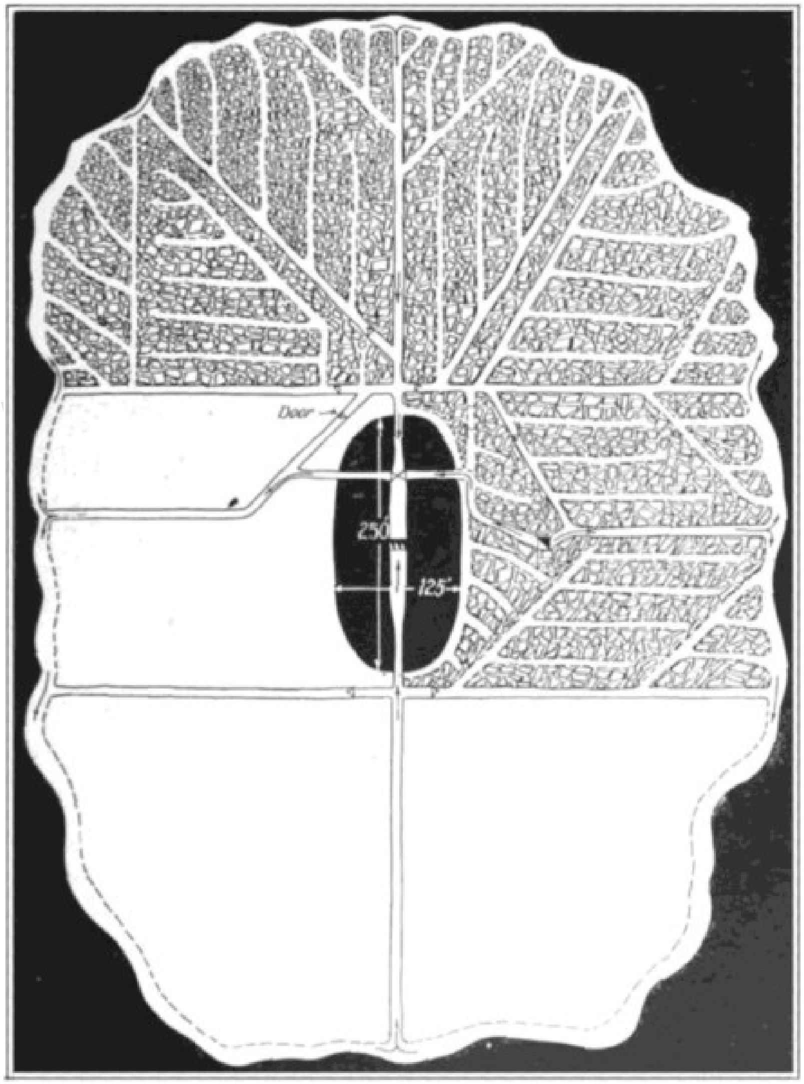
The number sign, or hash sign (#) is often used as shorthand to denote shaft or seam, as in 4# (4 shaft or seam depending on context).

Longwall mining

Longwall mining

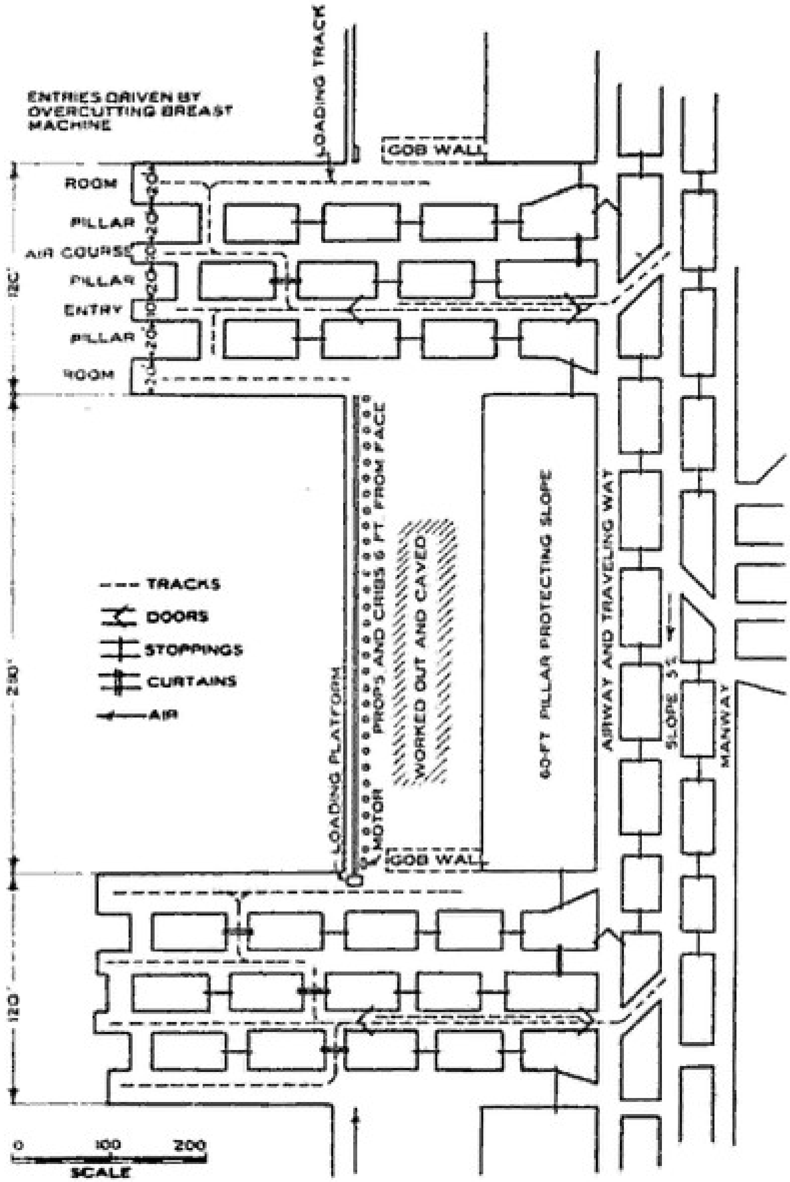
Longwall mining is a form of underground coal mining where a long wall of coal is mined in a single slice (typically 1–2 m thick). The longwall *panel* (the block of coal that is being mined) is typically 3–4 km long and 250–400 m wide.

History

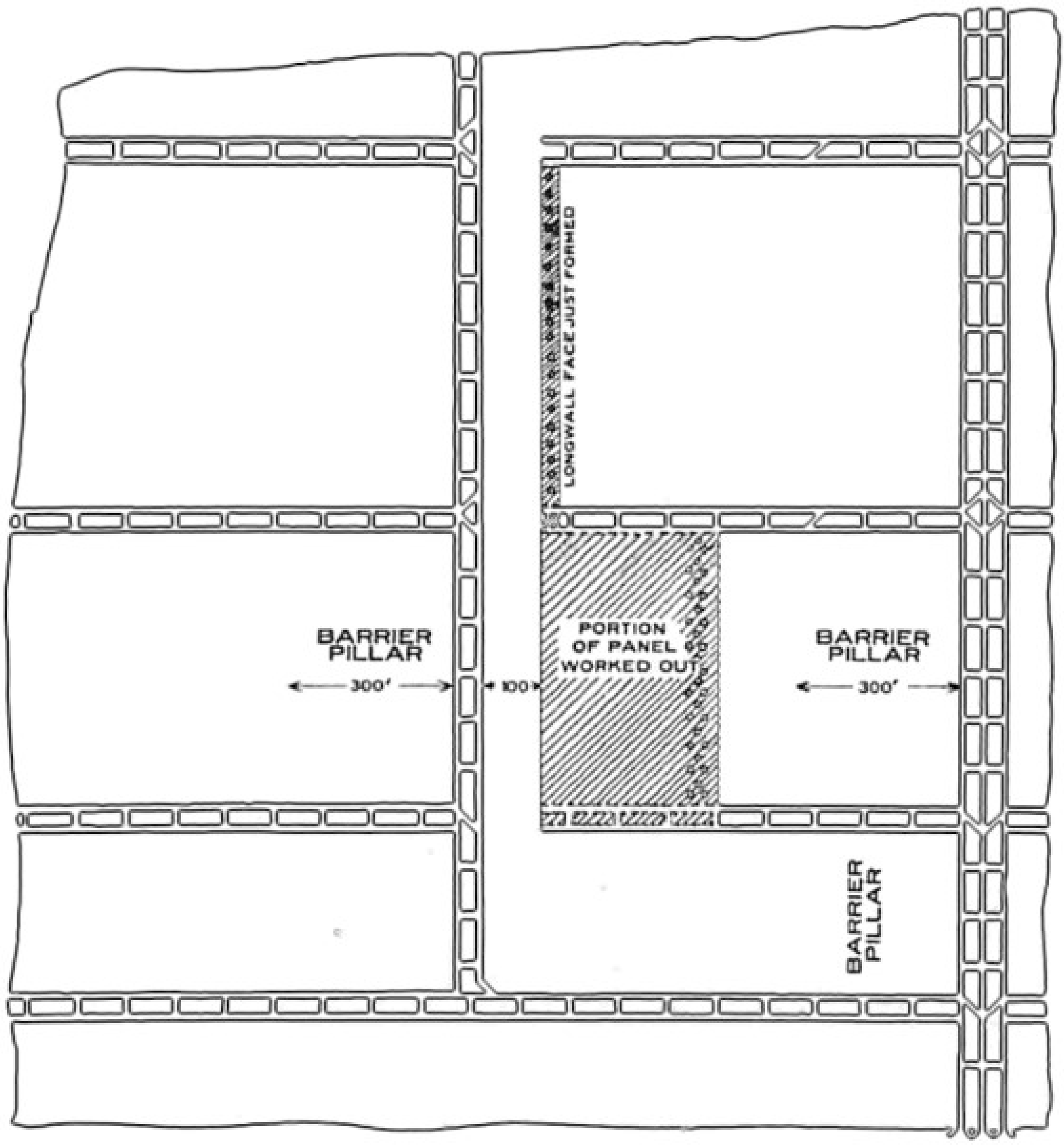


Plan of longwall mine before conveyors, hoist is at the center of the central pillar

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



Oklahoma advancing longwall mine circa 1917, arrows show airflow



West Virginia retreating longwall mine circa 1917

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

Such low-technology longwall mines continued in operation into the 1970s. The best known example of this was the New Gladstone Mine near Centerville, Iowa "one of the last advancing longwall mines in the United States." This longwall mine did not even use a conveyor belt, but relied on ponies to haul coal tubs from the face to the slope where a hoist hauled the tubs to the surface.

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

Layout

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

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

Ventilation

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

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

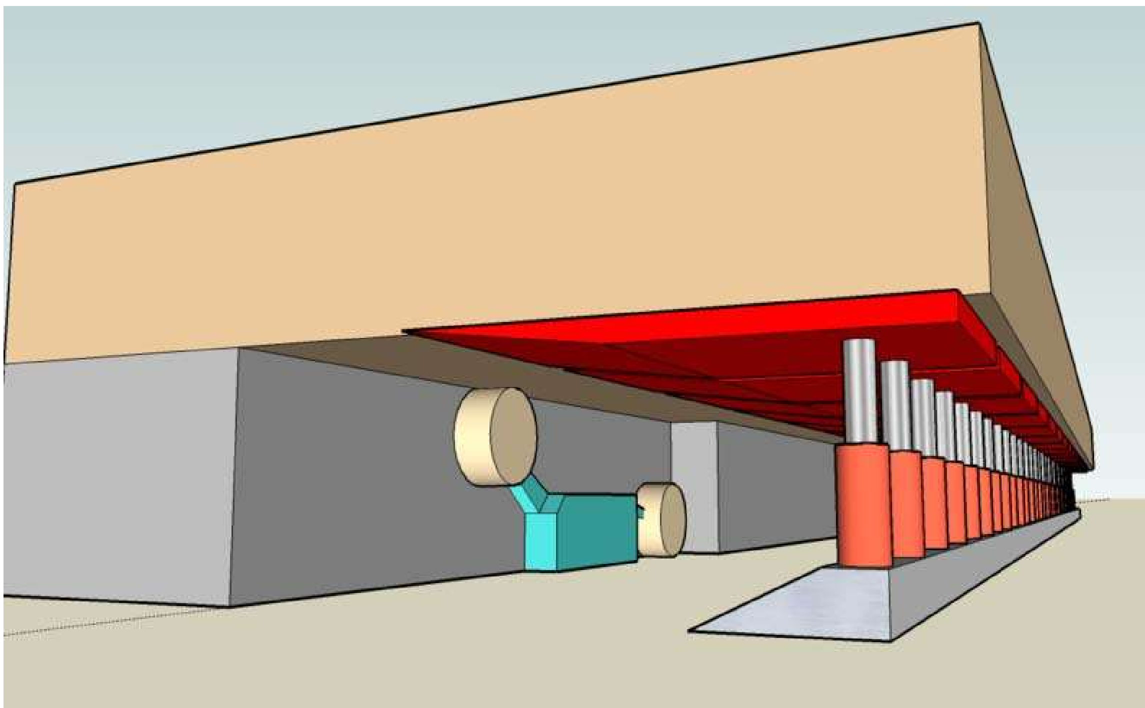
Equipment

Hydraulic chocks

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

Hydraulic chocks, conveyor and shearer

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



Chocks providing support to allow shearer to work

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

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

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

Comparison with room and pillar method

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

Subsidence

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

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

Room and pillar

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

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

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

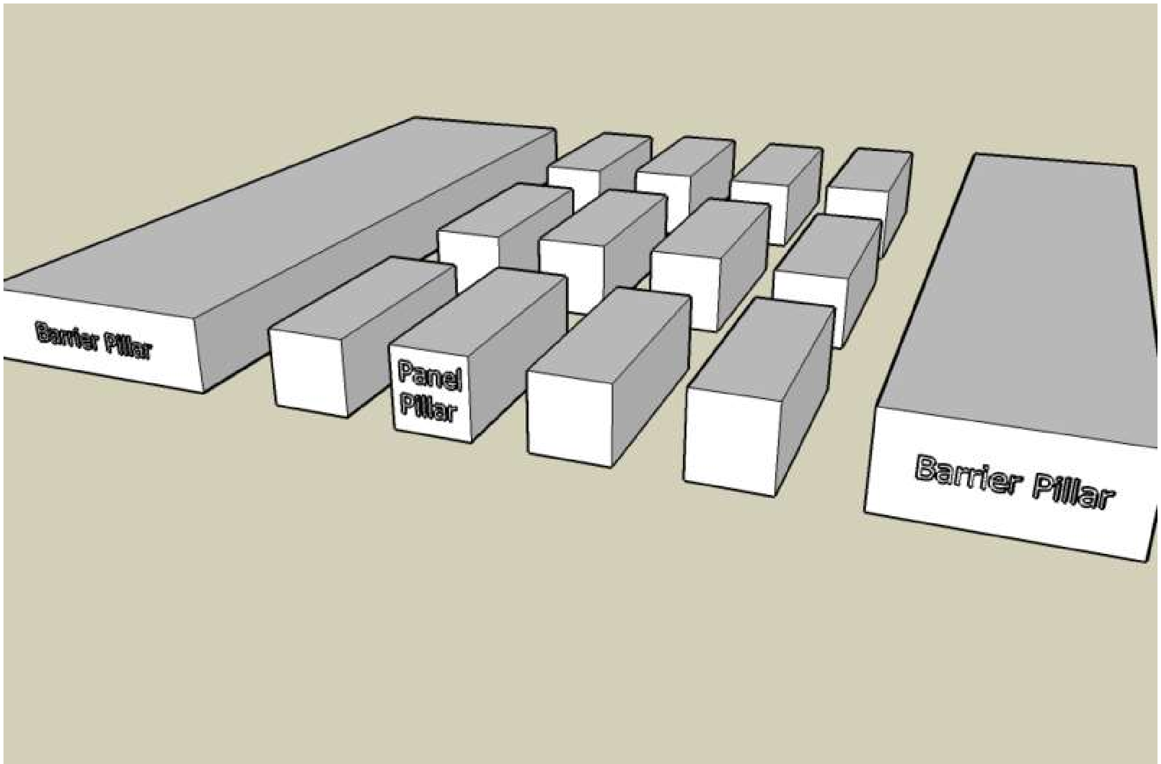
History

A Maryland coal mine from 1850

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

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

Mine Layout



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

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

Rock blasting

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

Blast hole drilling with Tamrock Scout 700

Loading drilled holes with ANFO

Rock surface newly blasted

Sideling Hill road cut formed by rock blasting

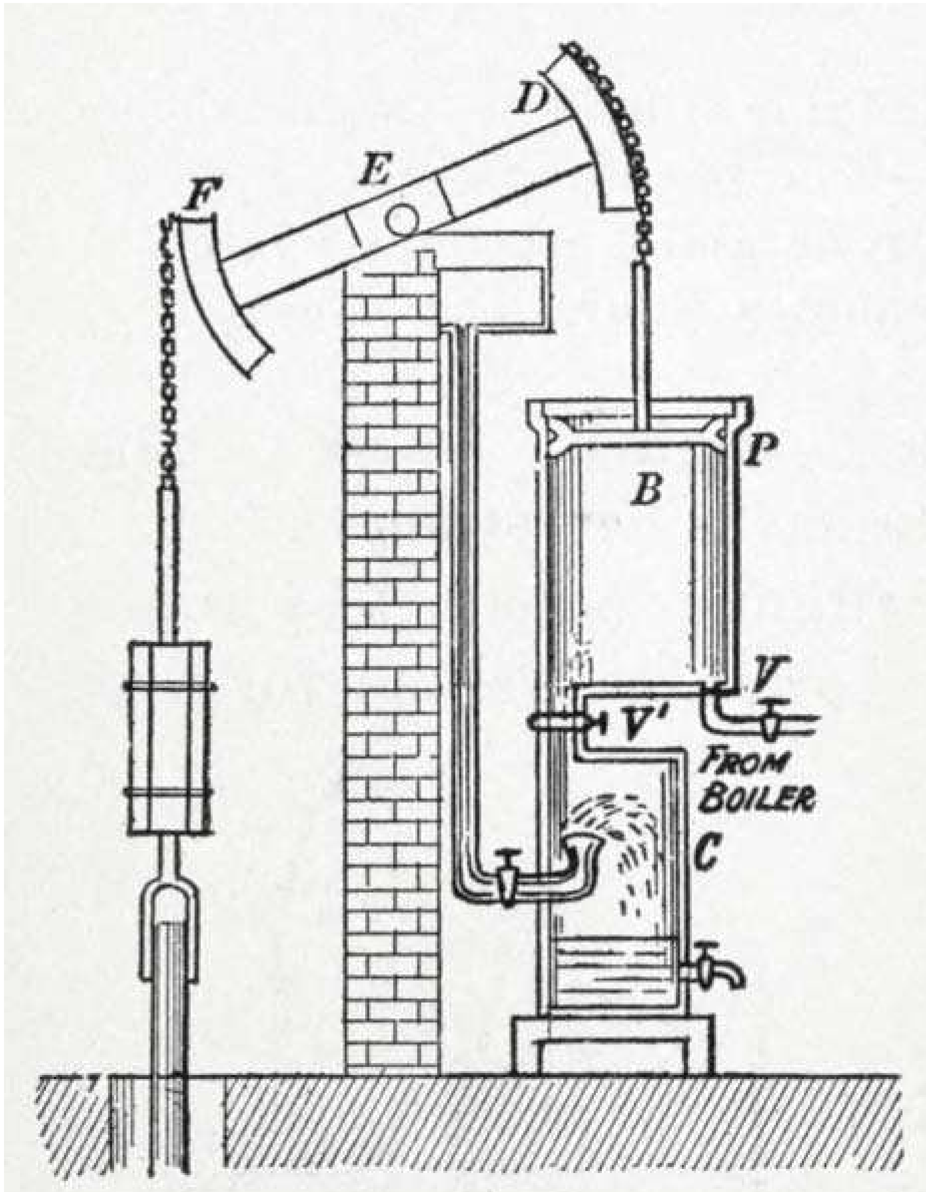
The use of explosives in mining goes back to the year 1627, when gunpowder was first used in place of mechanical tools in the Hungarian (now Slovakian) town of Banská Štiavnica. The innovation spread quickly throughout Europe and the Americas.

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

Chapter 8

Beam Engine

The remains of a water-powered beam engine at Wanlockhead



A Watt engine: showing entry of steam and water

The cast-iron beam of the 1812 Boulton & Watt engine at Crofton Pumping Station – the oldest working example in the world

A **beam engine** is a type of steam engine where a pivoted overhead beam is used to apply the force from a vertical piston to a vertical connecting rod. This configuration, with the engine directly driving a pump, was first used by Thomas Newcomen around 1705 to remove water from mines in Cornwall. The efficiency of the engines was improved by engineers including James Watt who added a condenser, Jonathan Hornblower and Arthur Woolf who compounded the cylinders, and William McNaught (Glasgow) who devised a method of compounding an existing engine. Beam engines were first used to pump water out of mines or into canals, but could be used to pump water to supplement the flow for a waterwheel powering a mill.

The **rotative beam engine** is a later design of beam engine where the connecting rod drives a flywheel, by means of a crank (or, historically, by means of a sun and planet gear). These beam engines could be used to directly power the line-shafting in a mill. They also could be used to power steam ships.

History

The first beam engines were water-powered, and used to pump water from mines. A 'preserved' example may be seen at Wanlockhead, in Scotland.

Beam engines were extensively used to power pumps on the English canal system when it was expanded by means of locks early in the Industrial Revolution, and also to drain water from mines in the same period, and as winding engines.

The first steam-powered beam engine was developed by Thomas Newcomen. The Newcomen steam engine was adopted by many mines in Cornwall and elsewhere, but it was relatively inefficient and consumed a large quantity of fuel. James Watt resolved the main inefficiencies of the Newcomen engine in his Watt steam engine, and these beam engines were used commercially in much larger numbers.

Watt held patents on key aspects of his engine's design, and it was not until these patents expired that others could develop modifications to improve it. The beam engine was considerably improved and enlarged in the tin- and copper-rich areas of south west England, which enabled the draining of the deep mines that existed there. Consequently the Cornish beam engines became world famous, as they remain the most massive beam engines ever constructed.

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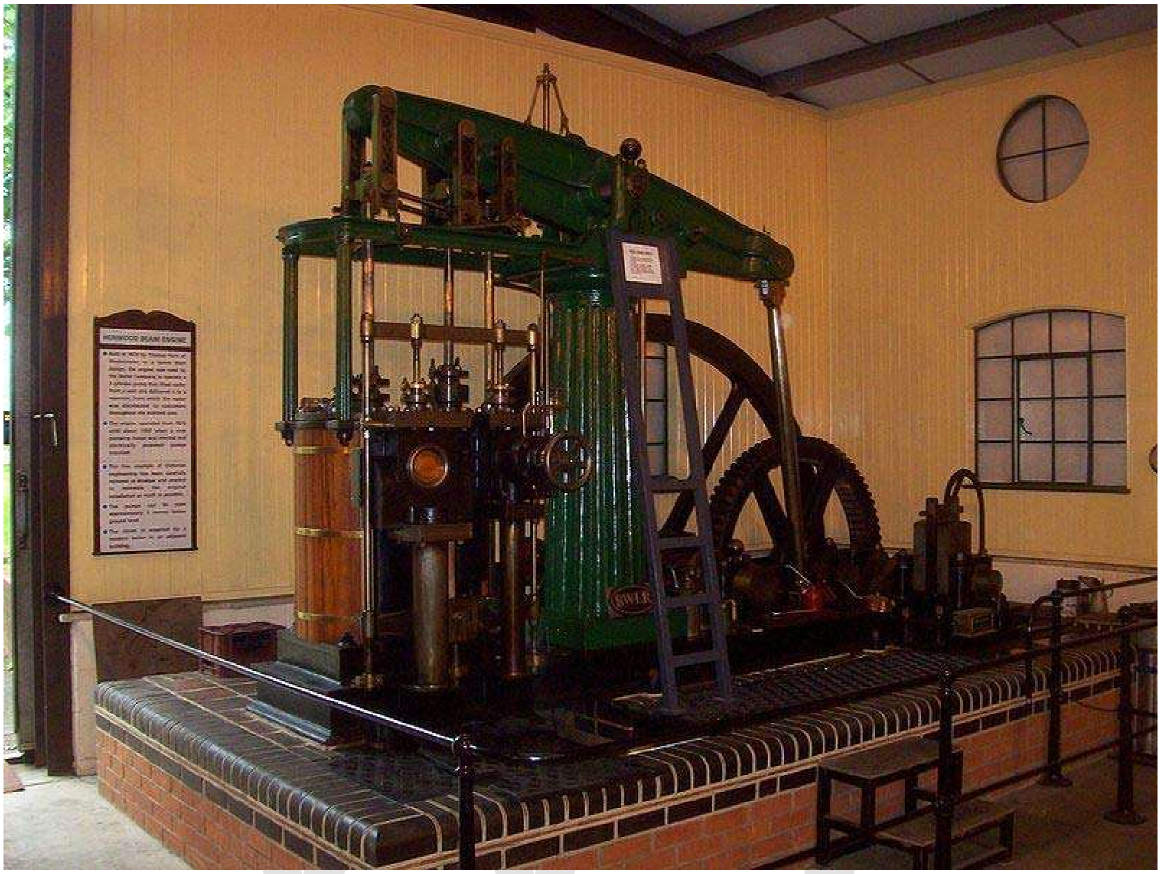
Rotative beam engines



A small rotative beam engine, built in 1870 by Thomas Horn to a design by James Watt. The crank is visible at the front, the flywheel part-hidden by the engine. (Originally installed in a waterworks in Ashford, now operational and preserved at the Bredgar and Wormshill Light Railway.)

In a rotative beam engine, the piston is mounted vertically, and the piston rod does not connect directly to the connecting rod, but instead to a rocker or *beam* above both the piston and flywheel. The beam is pivoted in the middle, with the cylinder on one side and the flywheel, which incorporates the crank, on the other. The connecting rod connects to the opposite end of the beam to the piston rod, and then to the flywheel.

Early Watt engines used Watt's patent sun and planet gear, rather than a simple crank, as use of the latter was protected by a patent owned by someone else. Once the patent had expired, the simple crank was employed universally.

Compounding

Compounding involves two or more cylinders; waste low-pressure steam from the first, high-pressure, cylinder is passed to the second cylinder where it expands further and provides more drive. This is the compound effect; the waste steam from this can produce further work if it is then passed into a condenser in the normal way. The first experiment with compounding was conducted by Jonathan Hornblower, who took out a patent in 1781. His first engine was installed at Tincroft Mine, Cornwall. It had two cylinders – one 21-inch (0.53 m) diameter with 6-foot (1.8 m) stroke and one 27-inch (0.69 m) diameter with 8-foot (2.4 m) stroke – placed alongside each other at one end of the beam. The early engines showed little performance gain: the steam pressure was too low, interconnecting pipes were of small diameter and the condenser ineffective.

At this time the laws of thermodynamics were not adequately understood, particularly the concept of absolute zero. Engineers such as Arthur Woolf were trying to tackle an engineering problem with an imperfect understanding of the physics. In particular, their valve gear was cutting-in at the wrong position in the stroke, not allowing for expansive working in the cylinder. Successful Woolf compound engines were produced in 1814, for the Wheal Abraham copper mine and the Wheal Vor tin mine.

McNaught engines

William McNaught of Glasgow, not to be confused with William McNaught of Rochdale (Petrie and McNaught), patented a compound beam engine in 1845. On a beam engine of the standard Boulton & Watt design he placed a high-pressure cylinder, on the opposite side of the beam to the existing single cylinder, where the water pump was normally fitted. This had two important effects: it massively reduced the pressure on the beam, and the connecting steam pipe, being long, acted as an expansive receiver – the element missing in the Woolf design. This modification could be made retrospectively, and engines so modified were said to be "McNaughted". The advantages of a compound engine were not significant at pressures under 60psi, but showed at over 100psi.

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Chapter 9

Bucket-Wheel Excavator

Bucket wheel excavator in Ferropolis, Germany

Bucket-wheel excavators (BWEs) are heavy equipment used in surface mining and civil engineering. The primary function of BWEs is to act as a continuous digging machine in large-scale open pit mining operations. What sets BWEs apart from other large-scale mining equipment, such as bucket chain excavators, is their use of a large wheel consisting of a continuous pattern of buckets used to scoop material as the wheel turns. They are among the largest vehicles ever constructed, and the biggest bucket-wheel excavator ever built, Bagger 293, is the largest terrestrial (land) vehicle in human history according to the Guinness Book of World Records.

History

Bucket-wheel excavator in the open-pit mining Garzweiler

Bucket-wheel excavators have been used in mining for the past century, with some of the first being manufactured in the 1920s. They are used in conjunction with many other pieces of mining machinery (conveyer belts, spreaders, crushing stations, heap-leach systems, etc.) to move and mine massive amounts of overburden (waste). While the overall concepts that go into a BWE have not changed much, their size has grown drastically. BWEs built since the 1990s, such as the Bagger 293, have reached sizes as large as 96 meters (314.9 feet) tall, 225 meters (738.2 feet) long, and as heavy as 14,200 tons (31.3 million lb). The bucket-wheel itself can be over 70 feet in diameter with as many as 20 buckets, each of which can hold over 15 cubic meters of material. BWEs have also advanced with respect to the extreme conditions in which they are now capable of operating. Many BWEs have been designed to operate in climates with temperatures as low as -45°C (-49°F). Developers are now moving their focus toward automation and the use of electrical power.

Structure

A bucket wheel excavator (BWE) consists of a superstructure to which several more components are fixed.

The bucket wheel from which the machines get their name is a large, round wheel with a configuration of scoops which is fixed to a boom and is capable of rotating. Material picked up by the cutting wheel is transferred back along the boom. In early cell-type bucket wheels, the material was transferred through a chute leading from each bucket, while newer cell-less and semi-cell designs use a stationary chute through which all of the buckets discharge.

A discharge boom receives material through the superstructure from the cutting boom and carries it away from the machine, frequently to an external conveyer system.

A counterweight boom balances the cutting boom and is cantilevered either on the lower part of the superstructure (in the case of compact BWEs) or the upper part (in the case of mid-size C-frame BWEs). In the larger BWEs, all three booms are supported by cables running across towers at the top of the superstructure.

Beneath the superstructure lay the movement systems. On older models these would be rails for the machine to travel along, but newer BWEs are frequently equipped with crawlers, which grant them increased flexibility of motion.

To allow it to complete its duties, the superstructure of a BWE is capable of rotating about a vertical axis (slewing). The cutting boom can be tilted up and down (hoisting). The speeds of these operations are on the orders of 30 m/min and 5 m/min, respectively. Slewing is driven by large gears, while hoisting generally makes use of a cable system.

Size

The scale of BWEs varies drastically and is dependent on the intended application. Compact BWEs designed by ThyssenKrupp may have boom lengths as small as 6m, weigh 50 tons, and move 100 fm3/hr of earth. Their larger models reach boom lengths of 80m, weigh 13,000 tons, and move 12,500 fm3/hr. The largest BWE ever constructed is TAKRAF's Bagger 293, which weighs 14,200 tons and is capable of moving 240,000 cubic meters of overburden every day. Excavations of 380,000 cubic meters have been recorded. The BWEs used in the United States tend to be smaller than those constructed in Germany.

Bucket chain excavators

Bucket chain excavators (BCEs) are similar in structure and function to BWEs. However, instead of the buckets being placed in a ring, they are strung out in a manner reminiscent of a trencher. They remove material from below their plane of movement, which is useful if the pit floor is unstable or underwater. TAKRAF's BCEs travel on rails rather than crawlers.

Operation

BWEs are used for continuous overburden removal in surface mining applications. They use their cutting wheels to strip away a section of earth (the working block) dictated by the size of the excavator. Through hoisting, the working block can include area both above and below the level of the machine (the bench level). By slewing, the excavator can reach through a horizontal range.

The overburden is then delivered to the discharge boom, which transfers the cut earth to another machine for transfer to a spreader. This may be a fixed belt conveyer system or a mobile conveyer with crawlers similar to those found on the BWE. Mobile conveyers permanently attached to the excavator takes the burden of directing the material off of the operator. The overburden can also be transferred directly to cross-pit spreader, which reaches across the pit and scatters overburden at the dumping ground.

Automation

Automation of the BWEs requires integrating many sensors and electrical components such as GPS, data acquisition systems, and online monitoring capabilities. The goal of these systems is to take away some of the work from the operators in order to achieve higher mining speeds. Project managers and operators are now able to track crucial data regarding the BWEs and other machinery in the mining operations via the Internet. Sensors can detect how much material is being scooped onto the conveyor belt, and the automation system can then vary the speed on the conveyor belts in order to feed a continuous amount of material. Further development of these types of automation may make it possible to, someday, operate these enormous machines with fewer operators.

Applications

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Bucket wheel excavators and bucket chain excavators take jobs that were previously accomplished by rope shovels and draglines. They have been replaced in most applications by hydraulic excavators, but still remain in use for very large-scale operations, where they can be used for the transfer of loose materials or the excavation of soft to semi-hard overburden.

Lignite mining

The primary application of BWEs is the in lignite (brown coal) mining, where they are used for soft rock overburden removal in the absence of blasting. They are useful in this capacity for their ability to continuously deliver large volumes of materials to processors, which is especially important given the continuous demand for lignite.

Because of the great demand for lignite, lignite mining has also been one of the areas of greatest development for BWEs. The additions of automated systems and greater maneuverability, as well as components designed for the specific application, have increased the reliability and efficiency with which BWEs deliver materials.

Materials handling

Bucket wheel technology is used extensively in bulk materials handling. Bucket wheel reclaimers are used to pick up material that has been positioned by a stacker for transport to a processing plant. Stacker/reclaimers, which combine tasks to reduce the number of required machines, also use bucket wheels to carry out their tasks.

In shipyards, bucket wheels are used for the continuous loading and unloading of ships, where they pick up material from the yard for transfer to the delivery system. Bucket chains can be used to unload material from a ship's hold. TAKRAF's continuous ship unloader is capable of removing to 95% of the material from a ship's hold, owing to a flexibly-configured digging attachment.

Heap leaching

An extension of their other uses, BWEs are used in heap leaching processes. Heap leaching entails of constructing stacks of crushed ore, through which a solvent is passed to extract valuable materials. The construction and removal of the heaps are an obvious application of stacking and reclaiming technology.

Manufacturers and market

Current use of bucket-wheel excavators is mainly focused in the area of lignite (brown coal) mining for the production of electricity. Most of these mining operations are located in Germany and East/Southeastern Europe. The manufacturers of BWEs and similar mining systems receive a large amount of business in maintenance and refurbishing projects. Many of the systems set up in the European mining operations need refurbishment and upgrading. One of the main reasons it is favorable to refurbish instead of replace these machines is the cost of the large gears needed to build them. There are few companies willing to manufacture these massive gears in such low quantity for a reasonable price.

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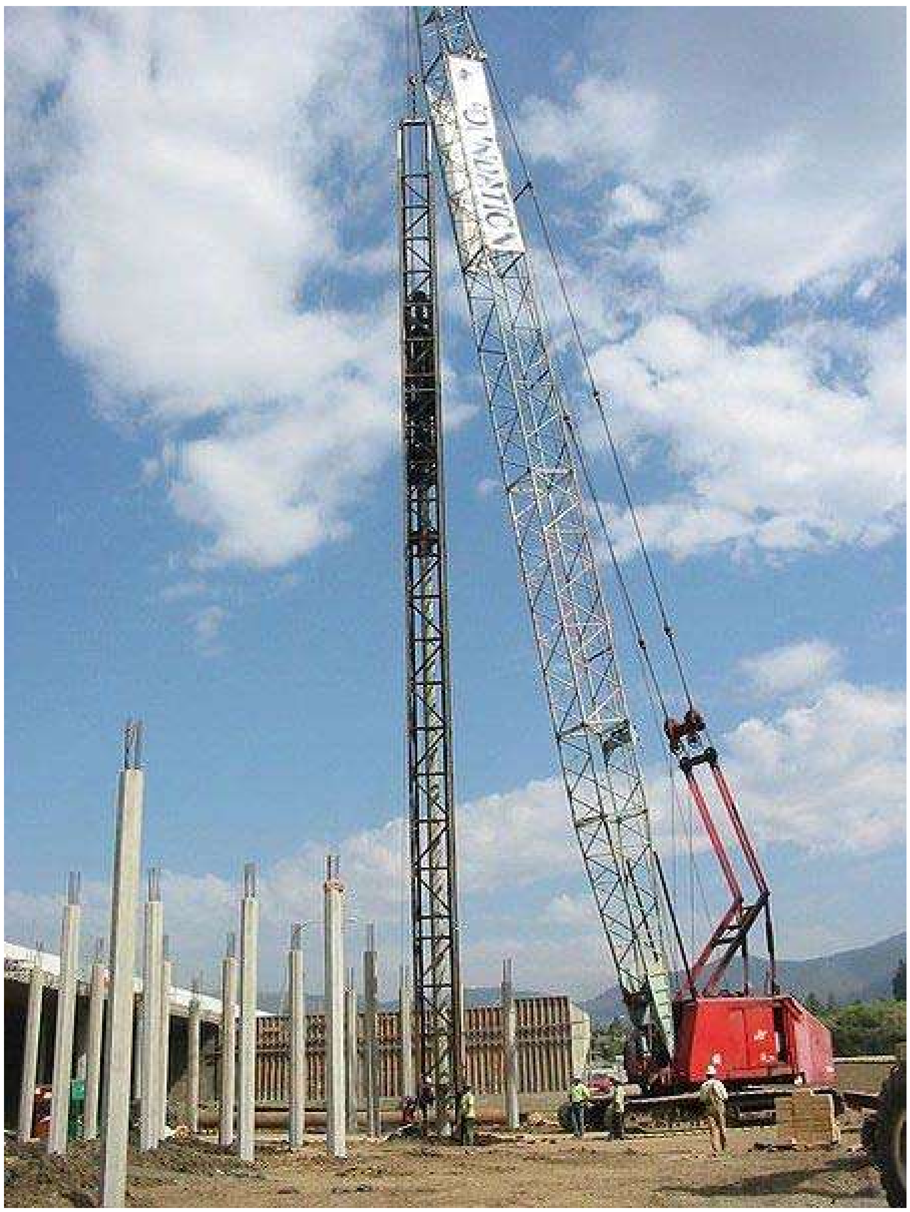
Chapter 10

Dragline Excavator



Dragline excavator with pile driver attachment

WORLD TECHNOLOGIES

A **dragline excavator** is a piece of heavy equipment used in civil engineering and surface mining.

In civil engineering the smaller types are used for road, port construction, and as pile driving rigs. The larger types are used in strip-mining operations to move overburden above coal, and for tar-sand mining. Draglines are amongst the largest mobile equipment ever built on land, and weigh in the vicinity of 2000 metric tonnes, though specimens weighing up to 13,000 metric tonnes have also been constructed.

A dragline bucket system consists of a large bucket which is suspended from a boom (a large truss-like structure) with wire ropes. The bucket is manoeuvred by means of a number of ropes and chains. The hoist rope, powered by large diesel or electric motors, supports the bucket and hoist-coupler assembly from the boom. The dragrope is used to draw the bucket assembly horizontally. By skillful manoeuvre of the hoist and the dragropes the bucket is controlled for various operations. A schematic of a large dragline bucket system is shown below.

History

The dragline was invented in 1904 by John W. Page (as a partner of the firm Page & Schnable Contracting) for use digging the Chicago Canal. By 1912, Page realized that building draglines was more lucrative than contracting so he created the Page Engineering Company to build draglines. Page build its first crude, walking dragline in 1923. These used legs operated by rack and pinion on a separate frame that lifted the crane. The body was then pulled forward by chain on a roller track and then lowered again. Page developed the first diesel engines exclusively for dragline application in 1924. Page also invented the arched dragline bucket, a design still commonly used today by draglines from many other manufacturers, and in the 1960s pioneered an archless bucket design. With its walking mechanism badly behind Monighan, Page updated the mechanism to an eccentric drive in 1935. This much improved mechanism gave a proper elliptical motion and was used until 1988. Page modernized its draglines further with the 700 series in 1954. Page's largest dragline was the Model 757 delivered to the Obed Mine near Hinton, Alberta in 1983. It featured a 75-yard bucket on a 298-foot boom and an operating weight of 4,500 tons. In 1988, Harnischfeger Corporation (P&H Mining Equipment) purchased Page Engineering Company.

In 1907, Monighan's Machine Works of Chicago became interested in manufacturing draglines when local contractor John W. Page placed an order for hoisting machinery to install a dragline. In 1908, Monighan changed its name to the Monighan Machine Company. In 1913, a Monighan engineer named Oscar Martinson invented the first walking mechanism for a dragline. The device, known as the Martinson Tractor, was installed on a Monighan dragline, creating the first walking dragline. This gave Monighan a significant advantage over other draglines and the company prospered. The cam mechanism was further improved in 1925 by eliminating the drag chains for the shoes and changing to a cam wheel running in an oval track. This gave the shoe a proper elliptical motion. The first dragline using the new mechanism was the 3-W available in

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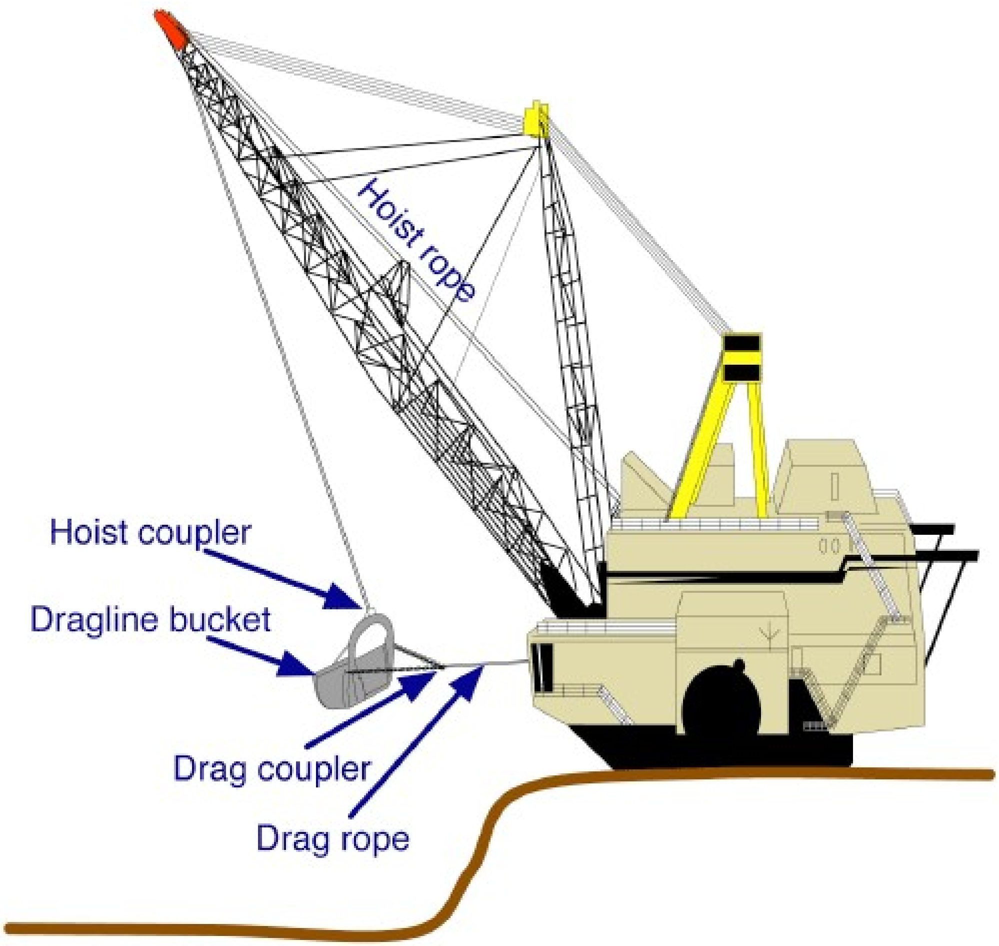
1926. So popular were these machines that the name Monighan became a generic term for dragline. In the early 1930s, Bucyrus-Erie began purchasing shares of Monighan stock with Monighan's approval. Bucyrus purchased a controlling interest and the joint company became known as Bucyrus-Monighan until the formal merger in 1946.

Bucyrus International supplied about two thirds of the steam shovels used on the Panama Canal. In 1910, they entered the dragline market with the purchase of manufacturing rights for the Heyworth-Newman dragline excavator. Their "Class 14" dragline was introduced in 1911 as the first crawler mounted dragline. In 1912 Bucyrus helped pioneer the use of electricity as a power source for large stripping shovels and draglines used in mining. After the merger with Monighan in 1946, Bucyrus began producing much larger machines using the Monighan walking mechanism such as the 800 ton 650-B which used a 15-yard bucket. Bucyrus' largest dragline was Big Muskie built for the Ohio Coal Company in 1969. This machine featured a 220-yard bucket on a 310-foot boom and weighed 14,000 tons. The market for draglines began shrinking rapidly after the boom of the 1960s and 1970s. P&H's acquisition of Page and then Bucyrus' acquisition of Marion has cut the number of worldwide suppliers in half. Today these two companies are the sole remaining manufacturers of large draglines.

In 1914, Harnischfeger Corporation (established as P&H Mining in 1884 by Alonzo Pawling and Henry Harnischfeger) introduced the world's first gasoline engine-powered dragline. An Italian company, Fiorentini, produced dragline excavators from 1919 licensed by Bucyrus. In 1988 Page was acquired by the Harnischfeger Corp., makers of the P&H line of shovels, draglines, and cranes. Besides Bucyrus, P&H is the only surviving company that still makes large draglines.

The Marion Steam Shovel Dredge Company (established in 1880) supplied about one third of the steam shovels used for the Panama Canal. Marion continued making larger power shovels until they built The Captain in 1965 with a 180-yard bucket and a weight of 15,000 tons. In 1939, it built its first walking dragline with a simple single-crank mechanism. The company changed its name to the Marion Power Shovel Company in 1946. Its largest dragline was the 8950 sold to Amax Coal Company in 1973. It featured a 150-cubic yard bucket on a 310-foot boom and weighed 7,300 tons. Marion was acquired by Bucyrus in 1997.

Operation



In a typical cycle of excavation, the bucket is positioned above the material to be excavated. The bucket is then lowered and the dragrope is then drawn so that the bucket is dragged along the surface of the material. The bucket is then lifted by using the hoist rope. A swing operation is then performed to move the bucket to the place where the material is to be dumped. The dragrope is then released causing the bucket to tilt and empty. This is called a dump operation.

The bucket can also be 'thrown' by winding up to the jib and then releasing a clutch on the drag cable. This would then swing the bucket like a pendulum. Once the bucket had passed the vertical, the hoist cable would be released thus throwing the bucket. On smaller draglines, a skilled operator could make the bucket land about one-half the length of the jib further away than if it had just been dropped. On larger draglines, only a few extra metres may be reached.

Draglines have different cutting sequences. The first is the side cast method using offset benches; this involves throwing the overburden sideways onto blasted material to make a bench. The second is a key pass. This pass cuts a key at the toe of the new highwall and also shifts the bench further towards the low-wall. This may also require a chop pass if the wall is blocky. A chop pass involves the bucket being dropped down onto an angled highwall to scale the surface. The next sequence is the slowest operation, the blocks pass. However, this pass moves most of the material. It involves using the key to access to bottom of the material to lift it up to spoil or to an elevated bench level. The final cut if required is a pull back, pulling material back further to the low-wall side.

Draglines in mining

Dragline at the Curragh Coal Mine

A large dragline system used in the open pit mining industry costs approximately US$50-100 million. A typical bucket has a volume ranging from 30 to 60 cubic metres, though extremely large buckets have ranged up to 168 cubic metres. The length of the boom ranges from 45 to 100 metres. In a single cycle it can move up to 450 metric tonnes of material.

Most mining draglines are not diesel-powered like most other mining equipment. Their power consumption is so great that they have a direct connection to the high-voltage grid at voltages of between 6.6 to 22 kV. A typical dragline, with a 55 cubic metre bucket, can use up to 6 megawatts during normal digging operations. Because of this, many (possibly apocryphal) stories have been told about the blackout-causing effects of mining draglines. For instance, there is a long-lived story that, back in the 1970s, if all seven draglines at Peak Downs Mine (a very large BHP coal mine in central Queensland, Australia) turned simultaneously, they would black out all of North Queensland. However even now, if they have been shutdown they are always restarted one at a time due to the immense power requirements of startup.

In all but the smallest of draglines, movement is accomplished by "walking" using feet or pontoons, as caterpillar tracks place too much pressure on the ground, and have great difficulty under the immense weight of the dragline. Maximum speed is only at most a few metres per minute since the feet must be repositioned for each step. If travelling medium distances, (about 30–100 km), a special dragline carrier can be brought in to transport the dragline. Above this distance, disassembly is generally required. But mining draglines due to their reach can work a large area from one position and do not need to constantly move along the face like smaller machines.

Limitations

The primary limitations of draglines are their boom height and boom length, which limits where the dragline can dump the waste material. Another primary limitation is their dig depth, which is limited by the length of rope the dragline can utilize. Inherent with their construction, a dragline is most efficient excavating material below the level of their base. While a dragline can dig above itself, it does so inefficiently and is not suitable to load piled up material (as a rope shovel or wheel loader can).

Despite their limitations, and their extremely high capital cost, draglines remain popular with many mines, due to their reliability, and extremely low waste removal cost.

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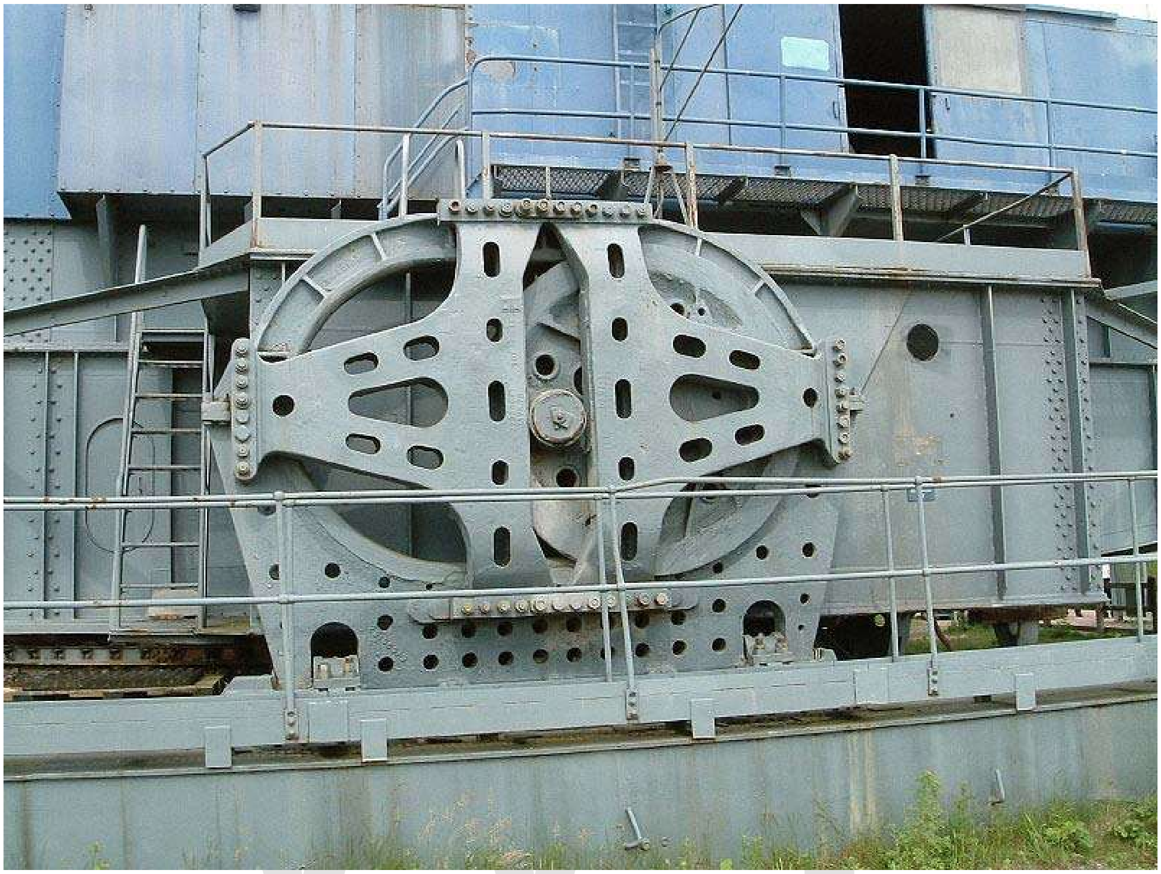
Examples



The Walking Mechanism on a preserved Bucyrus-Erie 1150 dragline in the UK

The coal mining dragline known as Big Muskie, owned by the Central Ohio Coal Company (a division of American Electric Power), was the world's largest mobile earth-moving machine, weighing nearly 13,000 metric tons and standing nearly 22 stories tall. It operated in Muskingum County, in the U.S. state of Ohio from 1969 to 1991, and was powered by 13,800 volts of electricity. It was scrapped in 1999.

The British firm of Ransomes & Rapier produced a few large (1400-1800 ton) excavators, the largest in Europe at the time (1960s). Power was from internal combustion engines driving electric generators. One, named *SUNDEW*, was used in a quarry from 1957 to 1974. After its working life at the first site in Rutland was finished it walked 13 miles to a new life at Corby; the walk took 9 weeks.

Smaller draglines were also commonly used before hydraulic excavators came into common use, the smaller draglines are now rarely used other than on river and gravel pit works. The small machines were of a mechanical drive with clutches. Firms such as Ruston and Bucyrus made models such as the RB10 which were popular for small building works and drainage work. Several of these can still be seen in the English Fens of Cambridgeshire, Lincolnshire and parts of Norfolk. Ruston's are a company also associated with drainage pumping engines. Electric drive systems were only used on the larger mining machines, most modern machines use a diesel-hydraulic drive, as machines are seldom in one location long enough to justify the cost of installing a substation and supply cables.

Technological Advances

Draglines, unlike most equipment used in earth-moving, have remained relatively unchanged in design and control systems for almost 100 years. Over the last few years, some advances in dragline systems and methodologies have occurred.

Automation

Researchers at CSIRO in Australia have a long-term reaearch project into automating draglines and have moved over 250,000 tonnes of overburden under computer control.

Simulation software

Since draglines are typically large, complicated and very expensive, training new operators can be a tricky process. In the same way that flight simulators have developed to train pilots, mining simulator software has been developed to assist new operators in learning how to control the machines.

UDD

UDD stands for Universal-Dig-Dump. It represents the first fundamental change to draglines for almost a century, since the invention of the 'miracle hitch'. Instead of using two ropes (the hoist rope and the drag rope) to manipulate the bucket, a UDD machine uses three ropes, two hoist and one drag. This allows the dragline operator to have much greater selectivity in when to pick up the bucket, and in how the bucket may be dumped. UDD machines generally have higher productivity than a standard dragline, but often have greater mechanical issues. Within the mining industry, there is still much debate as to whether UDD improvements justify their costs.

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Chapter 11

Dredging

Dredging is an excavation activity or operation usually carried out at least partly underwater, in shallow seas or fresh water areas with the purpose of gathering up bottom sediments and disposing of them at a different location. This technique is often used to keep waterways navigable.

It is also used as a way to replenish sand on some public beaches, where too much sand has been lost because of coastal erosion.

A **dredge** is a device for scraping or sucking the seabed, used for dredging. A **dredger** is a ship or boat equipped with a dredge. The terms are sometimes interchanged.

The process of dredging creates spoils (excess material), which are carried away from the dredged area. Dredging can produce materials for land reclamation or other purposes (usually construction-related), and has also historically played a significant role in gold mining. Dredging can create disturbance in aquatic ecosystems, often with adverse impacts.

Uses

- **Capital**: dredging carried out to create a new harbour, berth or waterway, or to deepen existing facilities in order to allow larger ships access. Because capital works usually involve hard material or high-volume works, the work is usually done using a cutter suction dredge or large trailing suction hopper dredge, but for rock works drilling and blasting along with mechanical excavation may be used.
- **Preparatory**: work and excavation for future bridges, piers or docks/wharves, often connected with foundation work.
- **Maintenance**: dredging to deepen or maintain navigable waterways or channels which are threatened to become silted with the passage of time, due to sedimented sand and mud, possibly making them too shallow for navigation. This is often carried out with a trailing suction hopper dredge. Most dredging is for this purpose, and it may also be done to maintain the holding capacity of reservoirs or lakes.
- **Land reclamation**: dredging to mine sand, clay or rock from the seabed and using it to construct new land elsewhere. This is typically performed by a cutter-

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suction dredge or trailing suction hopper dredge. The material may also be used for flood or erosion control.

- **Beach nourishment**: mining sand offshore and placing on a beach to replace sand eroded by storms or wave action. This is done to enhance the recreational and protective function of the beaches, which can be eroded by human activity or by storms. This is typically performed by a cutter-suction dredge or trailing suction hopper dredge.
- **Harvesting materials**: dredging sediment for elements like gold, diamonds or other valuable trace substances.
- **Seabed mining**: a possible future use, recovering natural metal ore nodules from the sea's abyssal plains.
- **Construction materials**: dredging sand and gravels from offshore licensed areas for use in construction industry, principally for use in concrete. Very specialist industry focused in NW Europe using specialized trailing suction hopper dredgers self discharging dry cargo ashore.
- **Anti-eutrophication**: Dredging is an expensive option for the remediation of eutrophied (or de-oxygenated) water bodies. However, as artificially elevated phosphorus levels in the sediment aggravate the eutrophication process, controlled sediment removal is occasionally the only option for the reclamation of still waters.
- **Contaminant remediation**: to reclaim areas affected by chemical spills, storm water surges (with urban runoff), and other soil contaminations. Disposal becomes a proportionally large factor in these operations.
- **Removing trash and debris**: often done in combination with maintenance dredging, this process removes non-natural matter from the bottoms of rivers and canals and harbors.
- **Flood prevention**: this can help to increase channel depth and therefore increase a channel's capacity for carrying water.
- **Peat extraction**: in former times, so-called *dredging poles* or *dredge hauls* were used on the back of small boats to manually dredge the beds of peat-moor waterways before extracting the peat for use as a fuel. This tradition has now become more or less obsolete and the tools used to do this have also changed significantly.

Relevance

Without the many and almost non-stop dredging operations world wide, much of the world's commerce would be impaired, often within a few months, since much of world's goods travel by ship, and need to access harbours or seas via channels. Recreational boating also would be constrained to the smallest vessels. The majority of marine dredging operations (and the disposal of the dredged material) will require that appropriate licences are obtained from the relevant regulatory authorities, and dredging is usually carried out by (or for) harbour companies or corresponding government agencies.

Types of dredging vessels

Suction

The Geopotes 14 lifting its boom on a canal in The Netherlands. (*gēopotēs* is Greek for "that which drinks earth")

These operate by sucking through a long tube, like some vacuum cleaners but on a big scale.

A plain suction dredger has no tool at the end of the suction pipe to disturb the material. This is often the most commonly used form of dredging.

Trailing suction

A trailing suction hopper dredger (TSHD) trails its suction pipe when working, and loads the dredge spoil into one or more hoppers in the vessel. When the hoppers are full, the TSHD sails to a disposal area and either dumps the material through doors in the hull or pumps the material out of the hoppers. Some dredges also self-offload using drag buckets and conveyors. The largest trailing suction hopper dredger in the world is currently Jan De Nul's *Cristobal Colon* (launched July 4, 2008); its sister ship *Leiv Eriksson* is under construction as of the end of 2008 (keel laid August 27, 2008, expected launch July 2009). Main design specs for the *Cristobal Colon* and the *Leiv Eriksson* are: 46,000 cubic meter hopper and a design dredging depth of 155 m. Next largest is *HAM 318* (Van Oord) with its 37,293 cubic meter hopper and a maximum dredging depth of 101 m.

Cutter suction

A cutter-suction dredger's (CSD) suction tube has a cutter head at the suction inlet, to loosen the earth and transport it to the suction mouth. The cutter can also be used for hard surface materials like gravel or rock. The dredged soil is usually sucked up by a wear-resistant centrifugal pump and discharged through a pipe line or to a barge. In recent years, dredgers with more powerful cutters have been built in order to excavate harder rock without blasting.

The two largest cutter suction dredgers in the world are currently (as at August 2009) DEME's *D'Artagnan* (28,200 kW total installed power) and Jan De Nul's *J.F.J. DeNul* (27,240 kW). Jan de Nul has by far the most heavy cutters in the market.

Auger suction

This process functions like a cutter suction dredger, but the cutting tool is a rotating Archimedean screw set at right angles to the suction pipe. The first widely used auger dredges were designed by Mud Cat Dredges in the 1980s which was run by National Car Rental, but is now a Division of Ellicott Dredges. In 1996, IMS introduced a self-propelled version of the auger dredge that allows the system to propel itself without the use of anchors cables. During the 1980s and 1990s auger dredges were primarily used for sludge removal applications from waste water treatment plants. Today, auger dredges are used for a wider variety of applications including river maintenance and sand mining. The most common auger dredge on the global market today is the Versi-Dredge. The turbidity shroud on auger dredge systems creates a strong suction vacuum and creates much less turbity than conical (basket) type cutterheads and that is why they are preferred for environmental type applications. The vacuum created by the shroud and the ability to convey material to the pump faster makes auger dredge systems more productive than similar sized conical (basket) type cutterhead dredges.

Jet-lift

These use the Venturi effect of a concentrated high-speed stream of water to pull the nearby water, together with bed material, into a pipe.

Air-lift

An airlift is a type of small suction dredge. It is sometimes used like other dredges. At other times, an airlift is used, handheld underwater by a diver. It works by blowing air into the pipe, and that air, being lighter than water, rises inside the pipe, dragging water with it.

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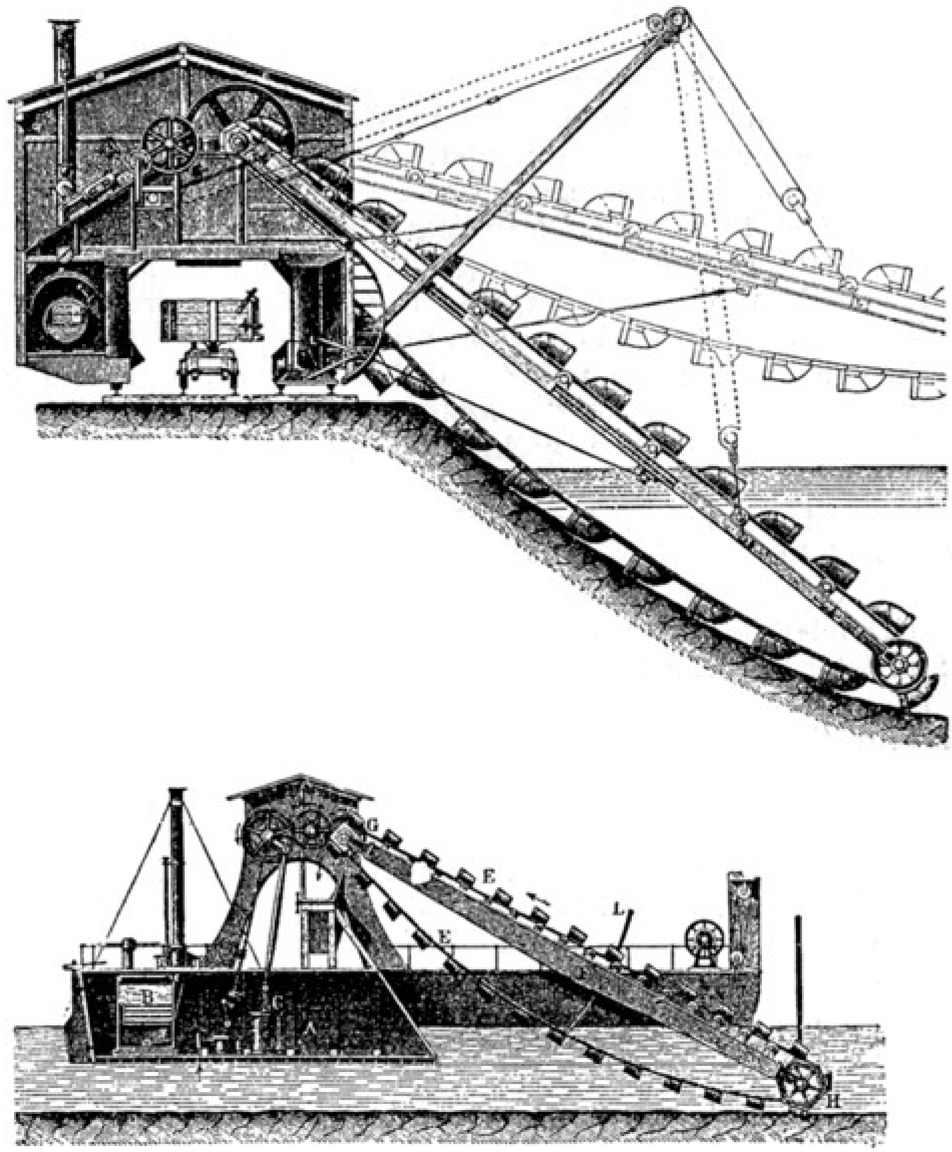
Bucket



Bucket dredging

A bucket dredger is equipped with a bucket dredge, which is a device that picks up sediment by mechanical means, often with many circulating buckets attached to a wheel or chain. Some bucket dredgers and grab dredgers are powerful enough to rip out coral to make a shipping channel through coral reefs.

Grab

Grab dredging in process in Port Canaveral, Florida

A grab dredger picks up seabed material with a clam shell grab, which hangs from an onboard crane or a crane ship, or is carried by a hydraulic arm, or is mounted like on a dragline. This technique is often used in excavation of bay mud. Most of these dredges are crane barges with spuds.

Backhoe/dipper

A backhoe/dipper dredge has a backhoe like on some excavators. A crude but usable backhoe dredger can be made by mounting a land-type backhoe excavator on a pontoon. The six largest backhoe dredgers in the world are currently the Vitruvius, the Mimar Sinan, Postnik Jakovlev (Jan De Nul), the Samson (DEME), the Simson and the Goliath (Van Oord). They featured barge-mounted excavators. Small backhoe dredgers can be track-mounted and work from the bank of ditches. A backhoe dredger is equipped with a half-open shell. The shell is filled moving towards the machine. Usually dredges material is loaded in barges. This machine is mainly used in harbors and other shallow water.

Water injection

A water injection dredger uses a small jet to inject water under low pressure (to prevent the sediment from exploding into the surrounding waters) into the seabed to bring the sediment in suspension, which then becomes a turbidity current, which flows away down slope, is moved by a second burst of water from the WID or is carried away in natural currents. Water injection results in a lot of sediment in the water which makes measurement with most hydrographic equipment (for instance: singlebeam echosounders) difficult.

Pneumatic

These dredgers use a chamber with inlets, out of which the water is pumped with the inlets closed. It is usually suspended from a crane on land or from a small pontoon or barge. Its effectiveness depends on depth pressure.

Bed leveler

Steam dredger *Bertha* from 1844

This is a bar or blade which is pulled over the seabed behind any suitable ship or boat. It has an effect similar to that of a bulldozer on land. The chain-operated steam dredger *Bertha*, built in 1844 to a design by Brunel and now the oldest operational steam vessel in Britain, was of this type.

Krabbelaar

This is an early type of dredger which was formerly used in shallow water in the Netherlands. It was a flat-bottomed boat with spikes sticking out of its bottom. As tide current pulled the boat, the spikes scraped seabed material loose, and the tide current washed the material away, hopefully to deeper water. *Krabbelaar* is Dutch for "scratcher".

Snagboat

A snagboat is designed to remove big debris such as dead trees and parts of trees from rivers and canals.

Amphibious

Some of these are any of the above types of dredger, which can operate normally, or by extending legs, also known as spuds, so it stands on the seabed with its hull out of the water. Some forms can go on land.

Some of these are land-type backhoe excavators whose wheels are on long hinged legs so it can drive into shallow water and keep its cab out of water. Some of these may not have a floatable hull and, if so, cannot work in deep water.

- Oliver Evans (1755–1819) in 1804 invented an amphibious dredger which was America's first steam-powered road vehicle.

Submersible

These are usually used to recover useful materials from the seabed. Many of them travel on caterpillar tracks. A unique variant is intended to walk on legs on the seabed.

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Fishing

Dredge haul including live clams and empty shells

Fishing dredges are used to collect various species of clams scallops, oysters or crabs from the seabed. These dredges have the form of a scoop made of chain mesh, and are towed by a fishing boat. Careless dredging can be destructive to the seabed. Nowadays some scallop dredging is replaced by collecting via scuba diving.

Police drag

In some police departments a small dredge (sometimes called a *drag*) is used to find and recover objects and bodies from underwater. The bodies may be murder victims, or people who committed suicide by drowning, or victims of accidents. It is sometimes pulled by men walking on the bank.

Disposal of materials

In a "hopper dredger", the dredged materials end up in a large onboard hold called a "hopper." A suction hopper dredger is usually used for maintenance dredging. A hopper dredge usually has doors in its bottom to empty the dredged materials, but some dredges empty their hoppers by splitting the two halves of their hulls on giant hinges. Either way, as the vessel dredges, excess water in the dredged materials is spilled off as the heavier solids settle to the bottom of the hopper. This excess water is returned to the sea to reduce weight and increase the amount of solid material (or slurry) that can be carried in one load. When the hopper is filled with slurry, the dredger stops dredging and goes to a dump site and empties its hopper.

Some hopper dredges are designed so they can also be emptied from above using pumps if dump sites are unavailable or if the dredge material is contaminated. Sometimes the slurry of dredgings and water is pumped straight into pipes which deposit it on nearby land. Other times, it is pumped into barges (also called scows), which deposit it elsewhere while the dredge continues its work.

A number of vessels, notably in the UK and NW Europe de-water the hopper to dry the cargo to enable it to be discharged onto a quayside 'dry'. This is achieved principally using self discharge bucket wheel, drag scraper or excavator via conveyor systems.

When contaminated (toxic) sediments are to be removed, or large volume inland disposal sites are unavailable, dredge slurries are reduced to dry solids via a process known as dewatering. Current dewatering techniques employ either centrifuges, large textile based filters or polymer flocculant/congealant based apparatus.

In many projects, slurry dewatering is performed in large inland settling pits, although this is becoming less and less common as mechanical dewatering techniques continue to improve.

Similarly, many groups (most notable in east Asia) are performing research towards utilizing dewatered sediments for the production of concretes and construction block, although the high organic content (in many cases) of this material is a hindrance toward such ends.

Environmental impacts

Dredging can create disturbance to aquatic ecosystems, often with adverse impacts. In addition, dredge spoils may contain toxic chemicals that may have an adverse effect on the disposal area; furthermore, the process of dredging often dislodges chemicals residing in benthic substrates and injects them into the water column.

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The activity of dredging can create the following principal impacts to the environment:

- Release of toxic chemicals (including heavy metals and PCB) from bottom sediments into the water column.
- Short term increases in turbidity, which can affect aquatic species metabolism and interfere with spawning.
- Secondary effects from water column contamination of uptake of heavy metals, DDT and other persistent organic toxins, via food chain uptake and subsequent concentrations of these toxins in higher organisms including humans.
- Secondary impacts to marsh productivity from sedimentation
- Tertiary impacts to avifauna which may prey upon contaminated aquatic organisms
- Secondary impacts to aquatic and benthic organisms' metabolism and mortality
- Possible contamination of dredge spoils sites

The nature of dredging operations and possible environmental impacts cause the industry to be closely regulated and a requirement for comprehensive regional environmental impact assessments with continuous monitoring. The U.S. Clean Water Act requires that any discharge of dredged or fill materials into "waters of the United States," including wetlands, is forbidden unless authorized by a permit issued by the Army Corps of Engineers. As a result of the potential impacts to the environment, dredging is restricted to licenced areas only with vessel activity monitored closely using automatic GPS systems.

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Major dredging companies

- Royal Boskalis Westminster (Netherlands)
- Jan De Nul (Belgium)
- Van Oord Dredging and Marine Contractors (Netherlands)
- Gezhouba Group (China CGGC)
- DEME (Belgium)

Chapter 12

Drilling Rig

Drilling rig, Reverse circulation in western Australia

Drilling rig preparing rock blasting

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

Petroleum drilling rig. Capable of drilling thousands of feet

Modern Oil Driller La Pampa Argentina

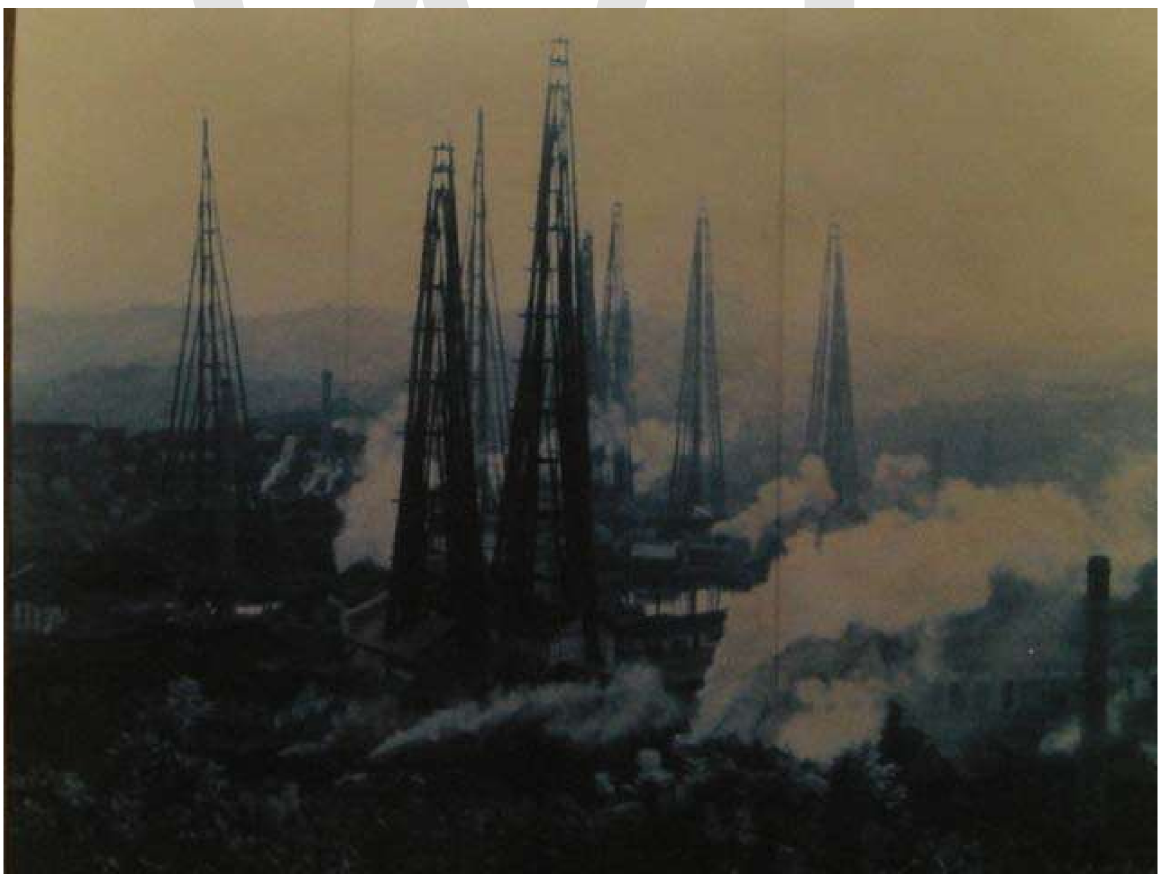
Oil and Natural Gas drilling rigs can be used not only to identify geologic reservoirs but also to create holes that allow the extraction of oil or natural gas from those reservoirs. Primarily in onshore oil and gas fields once a well has been drilled, the drilling rig will be moved off of the well and 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 more complicated and heavy truck rigs require much more skill to run, and the longer 20 to 30 foot (6.1 to 9.1 m) drill pipe is more difficult to handle safely than the shorter pipe on smaller rigs. Large truck rigs also have a much higher over head to operate. Large truck drills can use over 150 or more gallons of fuel per day, compared to smaller portable drills that use 5 to 20 gallons of fuel per day. The larger truck drills still have there place, but in remote or hard to get places , the newer portable drill technology is a money saver.

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

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- 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

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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 for environmental drilling, geotechnical drilling, soil engineering and geochemistry reconnaissance work in exploration for mineral deposits. Solid flight augers/bucket augers are used in 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.

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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.

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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.

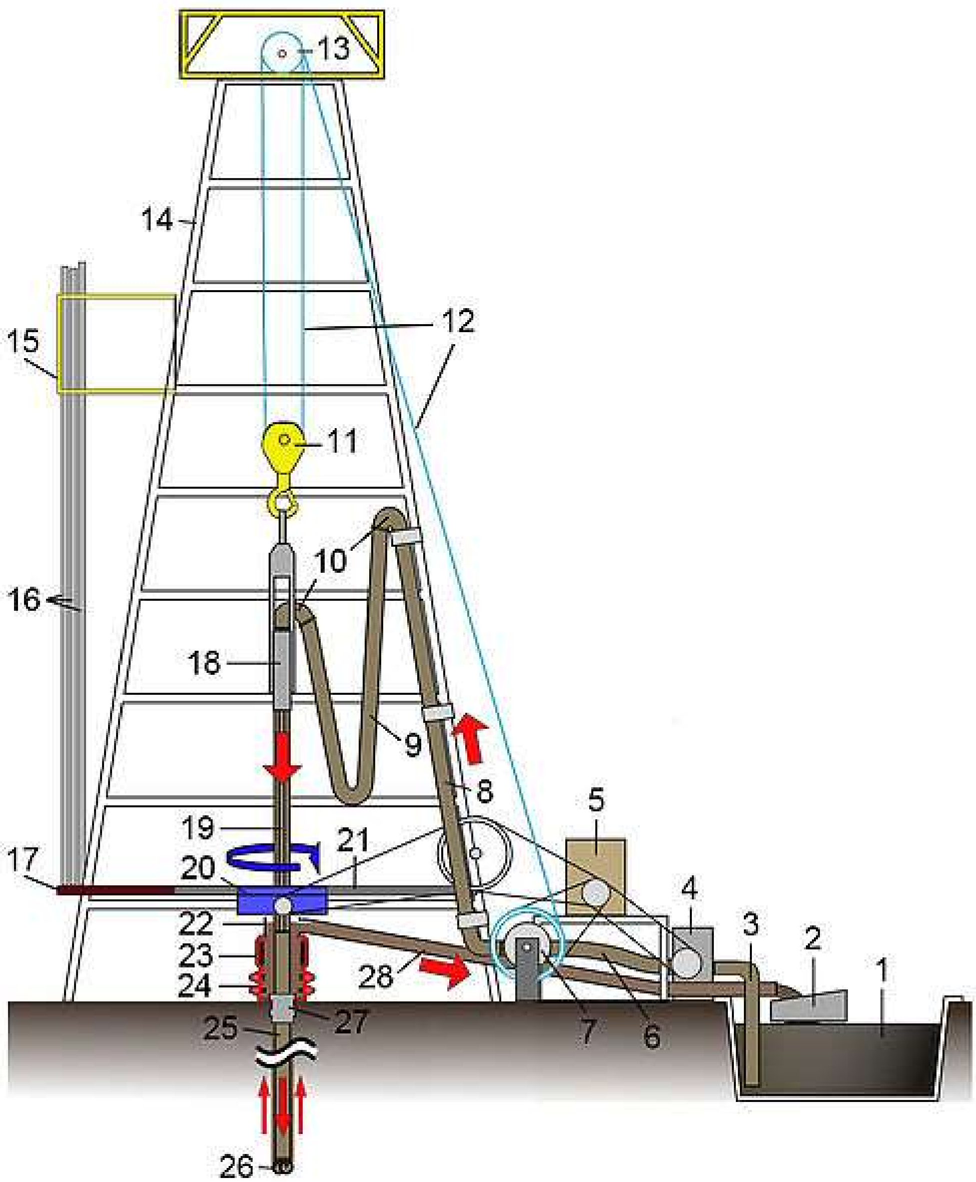
Without sufficient lubrication and cooling, the matrix of the drill bit will soften. While diamond is the hardest substance known, at 10 on the Mohs hardness scale, it must remain firmly in the matrix to achieve cutting. Weight on bit, the force exerted on the cutting face of the bit by the drill rods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

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.

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Chapter 13

Excavator

A typical modern excavator: a CAT 325C, fitted with quick coupler and tilting bucket

Excavators are heavy construction equipment consisting of a boom, bucket and cab on a rotating platform (known as the "house"). The house sits atop an undercarriage with tracks or wheels. All movement and functions of the excavator are accomplished through the use of hydraulic fluid, be it with rams or motors. Their design is a natural progression from the steam shovel.

Terminology

Excavators are also called **diggers** , a **JCB** (which is a proprietary name) or **360-degree excavators** sometimes abbreviated simply to **360**. Tracked excavators are sometimes called "trackhoes" by analogy to the backhoe. In the UK, wheeled excavators are sometimes known as "rubber ducks." In Japan, the alias **Yumbo** (ユンボ *Yunbo*?) is sometimes used for excavators, after the 1961 Mitsubishi Yumbo Y35.

Usage

Excavators are used in many ways:

- Digging of trenches, holes, foundations
- Material handling
- Brush cutting with hydraulic attachments
- Forestry work
- Demolition
- General grading/landscaping
- Heavy lift, e.g. lifting and placing of pipes
- Mining, especially, but not only open-pit mining
- River dredging
- Driving piles, in conjunction with a Pile Driver

Link-Belt excavator trenching

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An old excavator under the Northwest (now Terex) name at the Pageant of Steam grounds

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Excavator demolishing a house. Note the hydraulic thumb

Configurations

Excavators come in a wide variety of sizes. The smaller ones are called mini or compact excavators. Caterpillar's smallest mini-excavator weighs 3,549 pounds (1,610 kg) and has 19 hp; their largest model weighs 187,360 pounds (84,990 kg) and has 513 hp. The largest excavator available is the Bucyrus RH400, it weighs in excess of 2,160,510 pounds (979,990 kg), has 4500 hp and has a bucket size of about 52.0 m³.

Engines in excavators drive hydraulic pumps; there are usually 3 pumps: the two main pumps are for supplying oil at high pressure (up to 5000 psi) for the rams, slew motor, track motors, and accessories, and the third is a lower pressure (700 psi) pump for Pilot Control, this circuit used for the control of the spool valves, this allows for a reduced effort required when operating the controls.

The two main sections of an excavator are the undercarriage and the house. The undercarriage includes the blade (if fitted), tracks, track frame, and final drives, which have a hydraulic motor and gearing providing the drive to the individual tracks, and the house includes the operator cab, counterweight, engine, fuel and hydraulic oil tanks. The house attaches to the undercarriage by way of a center pin, allowing the machine to slew 360° unhindered.

The main boom attaches to the house, and can be one of 3 different configurations:

- Most are mono booms: these have no movement apart from straight up and down.
- Some others have a knuckle boom which can also move left and right in line with the machine.
- The other option is a hinge at the base of the boom allowing it to hydraulically pivot up to 180° independent to the house, however this is generally available only to compact excavators.

Attached to the end of the boom is the stick (or dipper arm). The stick provides the digging force needed to pull the bucket through the ground. The stick length is optional depending whether reach (longer stick) or break-out power (shorter stick) is required.

On the end of the stick is usually a bucket. A wide, large capacity (Mud) bucket with a straight cutting edge is used for cleanup and levelling or where the material to be dug is soft, and teeth are not required. A general purpose (GP) bucket is generally smaller, stronger, and has hardened side cutters and teeth used to break through hard ground and rocks. Buckets have numerous shapes and sizes for various applications. There are also many other attachments which are available to be attached to the excavator for boring, ripping, crushing, cutting, lifting, etc.

Before the 1990s, all excavators had a long or conventional counterweight that hung off the rear of the machine to provide more digging force and lifting capacity. This became a nuisance when working in confined areas. In 1993 Yanmar launched the world's first Zero Tail Swing excavator, which allows the counterweight to stay inside the width of the tracks as it slews, thus being safer and more user friendly when used in a confined space. This type of machine is now widely used throughout the world.

Excavator attachments

In recent years, hydraulic excavator capabilities have expanded far beyond excavation tasks with buckets. With the advent of hydraulic powered attachments such as a breaker, a grapple or an auger, the excavator is frequently used in many applications other than excavation. Many excavators feature a quick coupler for simplified attachment mounting, increasing the machine's utilization on the jobsite. Excavators are usually employed together with loaders and bulldozers. Most wheeled, compact and some medium sized (11 to 18 tonne) excavators have a backfill (or dozer) blade. This is a horizontal bulldozer-like blade attached to the undercarriage and is used for levelling & pushing removed material back into a hole.

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Notable manufacturers

- Benati
- Bobcat Company
- Case CE
- Caterpillar Inc.
- CNH Global
- Doosan Infracore (formerly Daewoo Heavy Industries & Machinery) - including Solar brand
- Hitachi Construction Machinery
- Hidromek
- Hydrema
- Hyundai Heavy Industries
- John Deere
- J. C. Bamford (JCB)
- Komatsu Limited
- LBX (Link-Belt) Excavators
- ThyssenKrupp
- Kobelco
- Kubota
- Liebherr
- LiuGong
- Manitowoc Cranes
- Mitsubishi Heavy Industries
- New Holland
- Orenstein & Koppel (O&K)
- Poclain
- Sandvik Mining and Construction
- ST Kinetics
- Terex Corporation
- Volvo Construction Equipment

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Chapter 14

Steam Shovel

A derelict steam shovel in Alaska; major components visible include boiler, water tank, winch, main engine, boom, dipper stick, crowd engine, wheels and bucket.

A **steam shovel** is a large steam-powered excavating machine designed for lifting and moving material such as rock and soil. It is the earliest type of power shovel or excavator. They played a major role in public works in the 19th and early 20th century, being key to the construction of railroads and the Panama Canal. The development of simpler, cheaper diesel-powered shovels caused steam shovels to fall out of use in the 1930s.

Origins and development

A Marion steam shovel excavating the Panama Canal in 1908

A steam shovel excavating for the San Diego and Arizona Railway line, circa 1919

A Link-Belt steam shovel crane, circa 1890

The steam shovel was invented by William Otis, who received a patent for his design in 1839.

The first machines were known as 'partial-swing', since the dipper arm could not rotate through 360 degrees. They were built on a railway chassis, on which the boiler and movement engines were mounted. The shovel arm and driving engines were mounted at one end of the chassis, which accounts for the limited swing. Bogies with flanged wheels were fitted, and power was taken to the wheels by a chain drive to the axles. Temporary rail tracks were laid by workers where the shovel was expected to work, and repositioned as required.

Steam shovels became more popular in the latter half of the nineteenth century. Originally configured with chain hoists, the advent of steel cable in the 1870s allowed for easier rigging to the winches.

Later machines were supplied with caterpillar tracks, obviating the need for rails.

The full-swing, revolving shovel was developed in England in 1884, and became the preferred format for these machines.

Expanding railway networks (in the US and the UK) fostered a demand for steam shovels. The extensive mileage of railways, and corresponding volume of material to be moved, forced the technological leap. As a result, steam shovels became commonplace.

During the 1930s steam shovels lost out to the simpler, cheaper diesel-powered excavating shovels that were the forerunners of those still in use today. Open-pit mines were electrified at this time. Only after the Second World War, with the advent of robust high-pressure hydraulic hoses, did the more versatile hydraulic backhoe shovels take pre-eminence over the cable-hoisting winch shovels.

Many steam shovels remained at work on the railways of developing nations until diesel engines supplanted them. Most have since been scrapped.

History (US)

American manufacturers included the Marion Steam Shovel Company, which was founded in 1884, Erie, P and H, and Bucyrus-Erie Shovel Companies.

The booming cities in North America used shovels to dig foundations and basements for the early skyscrapers.

The Panama Canal

The only Bucyrus model 50-B remaining from the Panama Canal, now in the Nederland, Colorado Mining Museum, USA

Perhaps the most famous application of steam shovels is the digging of the Panama Canal across the Isthmus of Panama. One hundred and two shovels worked in that decade-long dig. Of these, seventy-seven were built by Bucyrus ; the remainder were Marion shovels. These machines 'moved mountains' in their labours. The shovel crews would race to see who could move the most dirt.

Mining

Steam shovels assisted mining operations: the iron mines of Minnesota, the copper mines of Chile and Montana, placer mines of the Klondike – all had earth-moving equipment. But it was with the burgeoning open-pit mines – first in Bingham Canyon, Utah – that shovels came into their own. The shovels systematically removed hillsides. As a result, steam shovels were used around the world from Australia to Russia to coal mines in China. Shovels were also used for construction, road and quarry work.

Later history (US)

Steam shovels came into their own in the 1920s with the publicly-funded road building programmes around North America. Thousands of miles of State Highways were built in this time period, together with new factories, such as Henry Ford's River Rouge Plant, and many docks, ports, buildings, and grain elevators.

Preservation

Most steam shovels have been scrapped, although a few reside in industrial museums and private collections.

The Le Roy Marion

The world's largest steam shovel surviving intact is a 1906-built Marion machine, located in the small American town of Le Roy, New York. It was listed on the National Register of Historic Places in 2008.

Ruston Proctor Steam Navvy No 306

This machine was originally used at a chalk pit at Arlesey, in Bedfordshire, England. After the pit was closed, the steam navvy was simply abandoned and 'lost' as the pit became flooded with water. By the mid-1970s, the area had become a local beauty spot, known as *The Blue Lagoon* (from chemicals from the quarry colouring the water), and after long periods of drought, the top of the rusty navvy could be seen protruding from the water. Ruston & Hornsby expert Ray Hooley heard of its existence, and organised the difficult task of rescuing it from the water-filled pit. Hooley arranged for its complete restoration to working order by apprentices at the Ruston-Bucyrus works. Subsequently it passed into the care of the Museum of Lincolnshire Life, although it is not known whether it remains in operational condition.

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The navvy was recovered with hundreds of hours labour and free help from many organisations but today (2010) this Lincolnshire industrial monument stands unprotected with water allowed to pour down the boiler chimney. Many Lincolnshire residents and Ruston engineers wish to see this icon rescued.

Operation

A steam shovel comprises:

- a bucket
- boom and 'dipper stick'
- boiler
- water tank and coal bunker
- steam engines and winches
- operator's controls
- a rotating platform on a truck, on which everything is mounted
- wheels (or sometimes caterpillar tracks or railroad wheels)
- a house (on the platform) to contain and protect 'the works'

The shovel has several individual operations: it can raise or luff the boom, rotate the house, or extend the dipper stick with the boom or crowd engine, and raise or lower the dipper stick.

When digging at a rock face, the operator simultaneously raises and extends the dipper stick to fill the bucket with material. When the bucket is full, the shovel is rotated to load a railway car or motor truck. The locking pin on the bucket flap is released and the load drops away. The operator lowers the dipper stick, the bucket mouth self-closes, the pin relocks automatically and the process repeats.

Steam shovels usually had a three-man crew: engineer, fireman and ground man. There was much jockeying to do to move shovels: rails and timber blocks to move; cables and block purchases to attach; chains and slings to rig; and so on. On soft ground, shovels used timber mats to help steady and level the ground. The early models were not self-propelled, rather they would use the boom to manoeuvre themselves.

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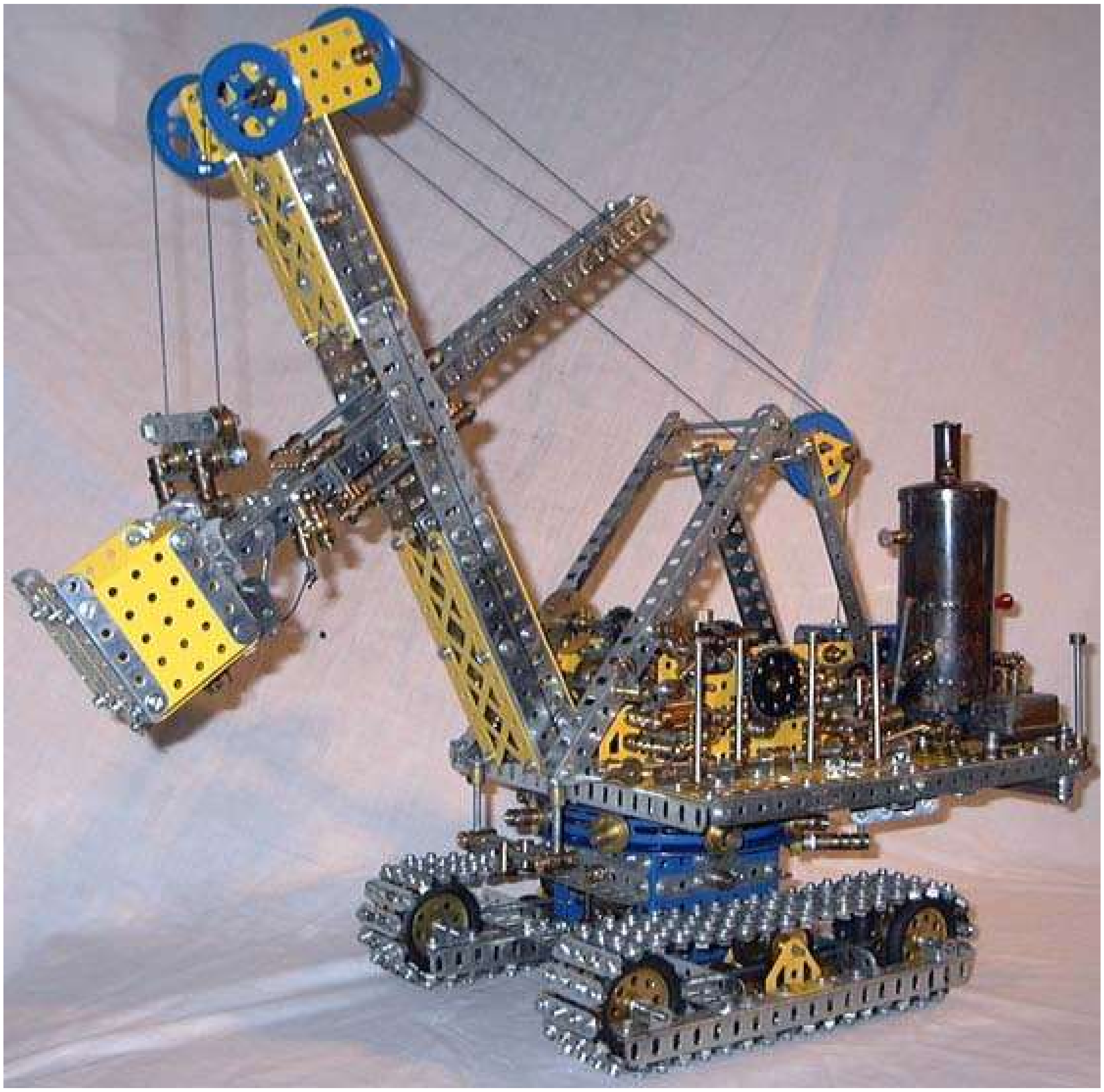
Steam shovel manufacturers



Model of a steam shovel built from Meccano and powered by a restored 1929 Meccano steam engine. (Model details here)

North American manufacturers:

- Ball Engine Co.
- Bucyrus
- Erie
- Marion Steam Shovel Dredge Company
- Moore Speedcrane *(later Manitowoc Cranes)*
- Northwest Shovels
- Vulcan Iron Works

European manufacturers:

- Demag *(Germany)*
- Fiorentini *(Italy)*
- Lubecker
- Menck
- Newton & Chambers *(UK)*
- Orenstein and Koppel GmbH *(Germany)*
- Ruston & Hornsby *(UK)*

Power shovels

Large, multi-ton mining shovels still use the cable-lift shovel arrangement.

In the 1950s and 1960s Marion Shovel built massive stripping shovels for coal operations in the Eastern US. Shovels of note were the Marion 360, the Marion 5900, and the Marion 6360 – with a 180-cubic-yard (140 m^3) bucket – while Bucyrus constructed one of the most famous monsters: the Big Brutus, the largest power shovel ever built and the largest still in existence. The *GEM of Egypt* (GEM standing for "Giant Excavating Machine" and Egypt referring to the Egypt Valley in Belmont County, eastern Ohio where it was first put to use), which operated from 1967 to 1988, was of comparable size; it has since been dismantled.

Although these big machines are still called *steam shovels*, they are more correctly known as *power shovels* since they use electricity to wind their winches.

Power shovel/dragline manufacturers

- Bucyrus International
- Insley Manufacturing Co.
- Komatsu
- Lima Locomotive Works
- Link Belt
- Marion Power Shovel
- P&H Mining Equipment
- Priestman Bros *(UK)*
- Ransomes & Rapier *(UK)*
- Ruston-Bucyrus *(UK)*

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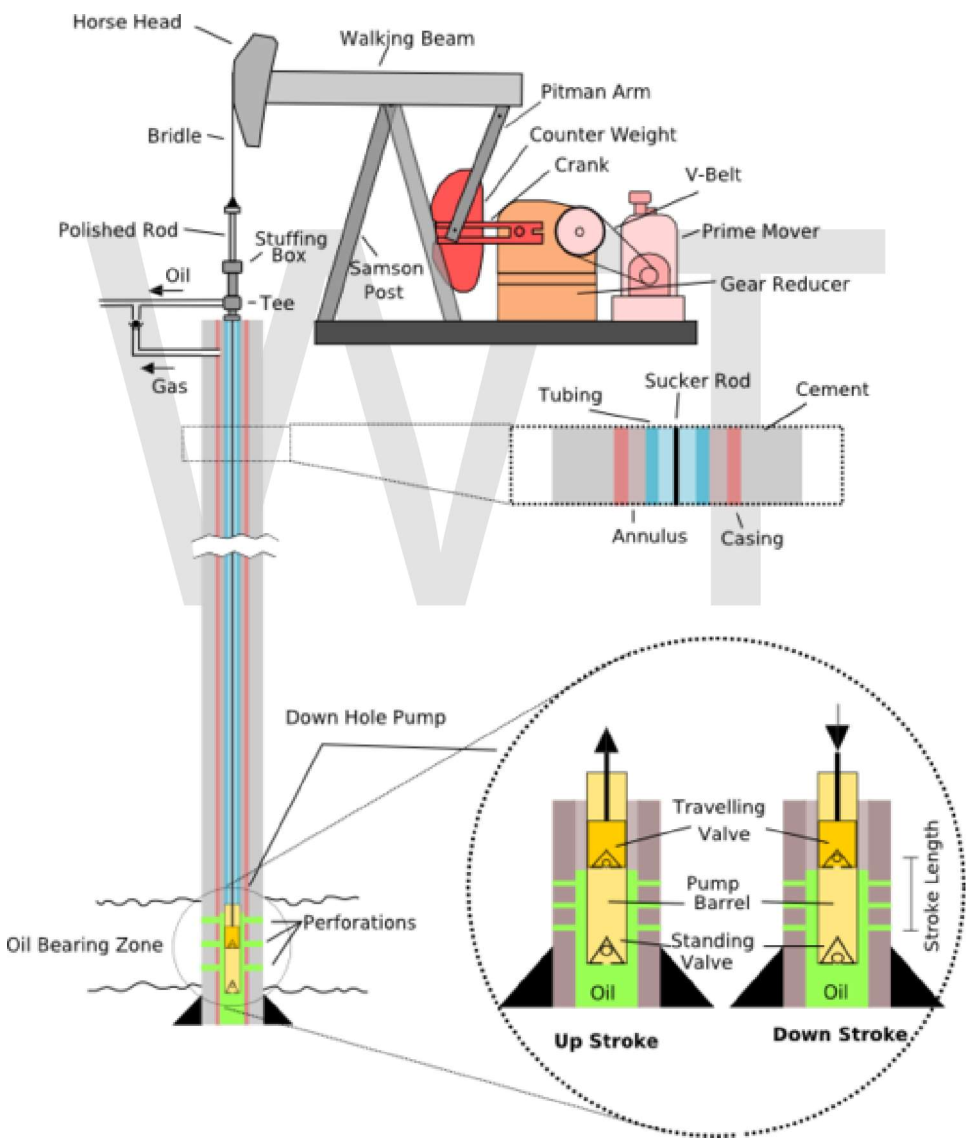
Chapter 15

Pumpjack



A diagram of a pumpjack

A **pumpjack** (also known as **nodding donkey**, pumping unit, **horsehead pump**, **beam pump**, sucker rod pump (SRP), grasshopper pump, **thirsty bird** and **jack pump**) is the overground drive for a reciprocating piston pump installed in an oil well.

It is used to mechanically lift liquid out of the well if there is not enough bottom hole pressure for the liquid to flow all the way to the surface. The arrangement is commonly used for onshore wells producing relatively little oil. Pumpjacks are common in many oil-rich areas, dotting the countryside and occasionally serving as local landmarks.

Depending on the size of the pump, it generally produces 5 to 40 litres of liquid at each stroke. Often this is an emulsion of crude oil and water. The size of the pump is also determined by the depth and weight of the oil to be removed, with deeper extraction requiring more power to move the heavier lengths of sucker rods.

A pumpjack converts the rotary mechanism of the motor to a vertical reciprocating motion to drive the pump shaft, and is exhibited in the characteristic nodding motion. The engineering term for this type of mechanism is a walking beam. It was often employed in stationary and marine steam engine designs in the 18th and 19th centuries.

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Above ground

Pumpjacks, such as this one located south of Midland, TX, are a common sight in West Texas.

Pumpjacks are powered by a "prime mover". This is commonly an electric motor, but combustion engines are used in isolated locations without economic access to electricity. The most common "off-grid" pumpjack engines run on casing gas produced from the well, but pumpjacks have been run on many types of fuel, such as propane (LPG) and diesel. In harsh climates such motors and engines may be housed inside a shack to protect them from the elements.

A nodding donkey-type pumpjack (painted to resemble a toucan) in the United States

A pumpjack in southern Alberta operating on natural gas. Location: 4-31-5-4 W4M

A field of pumpjacks along Interstate 20 in Texas

The prime mover of the pumpjack runs a set of pulleys to the transmission which in turn drives a pair of cranks, generally with counterweights on them to assist the motor in lifting the heavy string of rods. The cranks in turn raise and lower one end of an I-beam which is free to move on an A-frame. On the other end of the beam, there is a curved metal box called a Horse Head or Donkeys Head, named so due to its appearance. A cable made of steel (or, occasionally, fiberglass) called a bridle, connects the horse head to the polished rod, a piston that passes through the stuffing box. The polished rod has a very close fit to the stuffing box, letting it move in and out of the tubing without fluid escaping. (The tubing is a pipe that runs to the bottom of the well through which the liquid is produced.) The bridle follows the curve of the horse head as it lowers and raises to create an almost completely vertical stroke. The polished rod is connected to a long string of rods called sucker rods, which run through the tubing all the way to the down-hole pump, usually positioned near the bottom of the well.

Down-hole

A pump jack in California, USA

At the bottom of the tubing is the "down-hole pump". This pump consists of two ball check valves: a stationary valve at bottom called the "standing valve", and a valve on the piston connected to the bottom of the sucker rods that travels up and down as the rods reciprocate, known as the "traveling valve". Reservoir fluid enters from the formation into the bottom of the borehole through perforations that have been made through the casing and cement (the casing is a larger metal pipe that runs the length of the well, which has cement placed between it and the earth; the tubing, pump and sucker rods are all inside the casing). When the rods at the pump end are traveling up, the traveling valve is closed and the standing valve is open (due to the drop in pressure in the pump barrel). Consequently, the pump barrel fills with the fluid from the formation as the traveling piston lifts the previous contents of the barrel upwards. When the rods begin pushing down, the traveling valve opens and the standing valve closes (due to an increase in pressure in the pump barrel). The traveling valve drops through the fluid in the barrel (which had been sucked in during the upstroke). The piston then reaches the end of its stroke and begins its path upwards again, repeating the process.

Often, gas is produced through the same perforations as the oil. This can be problematic if gas enters the pump, because it can result in "gas locking", where insufficient pressure builds up in the pump barrel to open the valves (due to compression of the gas) and little or nothing is pumped. To preclude this, the inlet for the pump can be placed below the perforations. As the gas-laden fluid enters the well bore through the perforations, the gas bubbles up the annulus (the space between the casing and the tubing) while the liquid moves down to the standing valve inlet. Once at the surface, the gas is collected through piping connected to the annulus.

There are hundreds of pumpjacks on Lost Hills Oil Field near route 46 in California

Double pumpjacks pumping from the same oil well

A pumpjack on display in New Mexico

Water well pump jacks

Pumpjacks can also be used to drive what would now be considered "old fashioned" hand-pumped water wells. The scale of the technology is much smaller than for an oil well, and can typically fit on top of an existing hand-pumped well head. The technology is very simple, typically using a parallel-bar double-cam lift driven from a very low horsepower electric motor.

Although the flow rate for a water well pumpjack is very low compared to a modern jet pump and the lifted water is not pressurized, the water well pumpjack does at least have the option of falling back to hand pumping in an emergency, by simply hand-rotating the pumpjack cam to its lowest position, and attaching a manual handle to the top of the wellhead rod.