

THIS IS MINING...



U.S. Bureau of Mines

NOTE: In 1996, the U.S. Congress directed that the U.S. Bureau of Mines be abolished. Health and safety research at the research centers at Pittsburgh, PA, and Spokane, WA, was permanently assigned to the National Institute for Occupational Safety and Health (NIOSH). NIOSH is part of the Centers for Disease Control and Prevention within the U.S. Department of Health and Human Services.

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Cover photos: *(Top)* Extracting coal with a remote-operated continuous mining machine in an underground room-and-pillar mine in West Virginia. *(Photo by Christopher C. Jobes, USBM.)*

(Bottom) Loading salt after a blast in a Louisiana salt mine. *(Photo by Gregory M. Molinda, USBM.)*

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

cm	centimeter
ft	foot
ft ³	cubic foot
in	inch
km	kilometer
m	meter
m ³	cubic meter
mi	mile
st	short ton
t	ton (metric)

INTRODUCTION

MINING IS THE BRANCH OF INDUSTRY involving the exploration and removal of minerals from the earth (figure 1). Mining is one of the oldest and most important endeavors of humankind, because it provides the raw ingredients for most of the material world around us and, like agriculture, is the lifeblood of civilization. The main objective of any type of mining is to remove the valuable material economically and safely with minimum damage to the surrounding environment.

The Earth has many natural resources on which we depend that must be mined. Coal, oil, gas, and other mineral fuels are used for heating, electricity, and numerous industrial processes. Nonfuel minerals such as iron ore, precious metals, and industrial metals, and nonmetallic materials like sodium and potassium are used in chemical and agricultural applications. Even crushed stone used in road building and other construction projects must be mined. Mining affects our standard of living and impacts almost everything we do. A myriad of items that we use in our homes and offices and for transportation, communications, and national defense all require minerals (figure 2). For example, more than 30 different minerals are needed to make a television or telephone! Table 1 lists several commonly mined materials and some of the end uses in our daily lives.

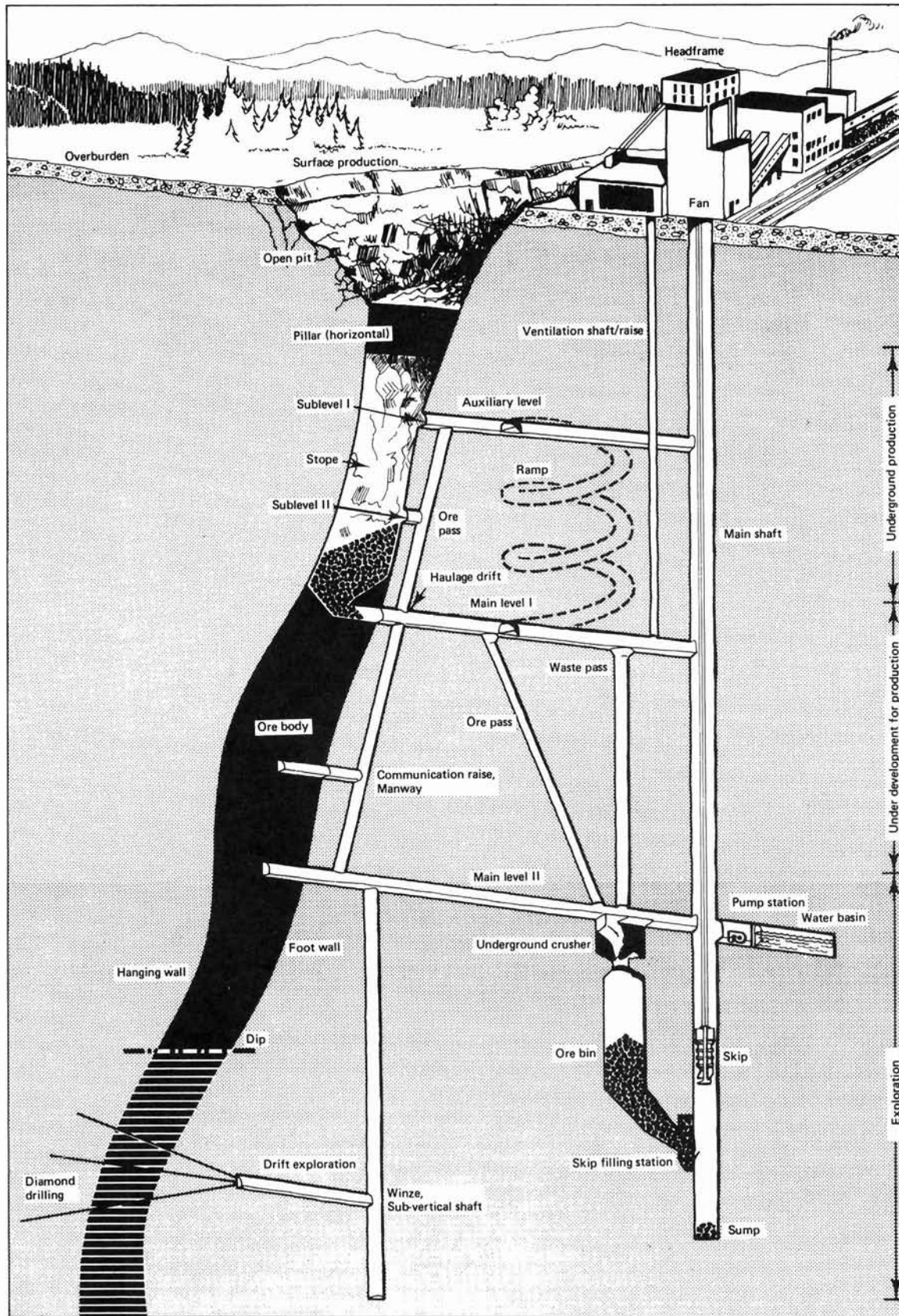


Figure 1.—Typical arrangement of mine development. (© Used with kind permission of Atlas Copco AB.)

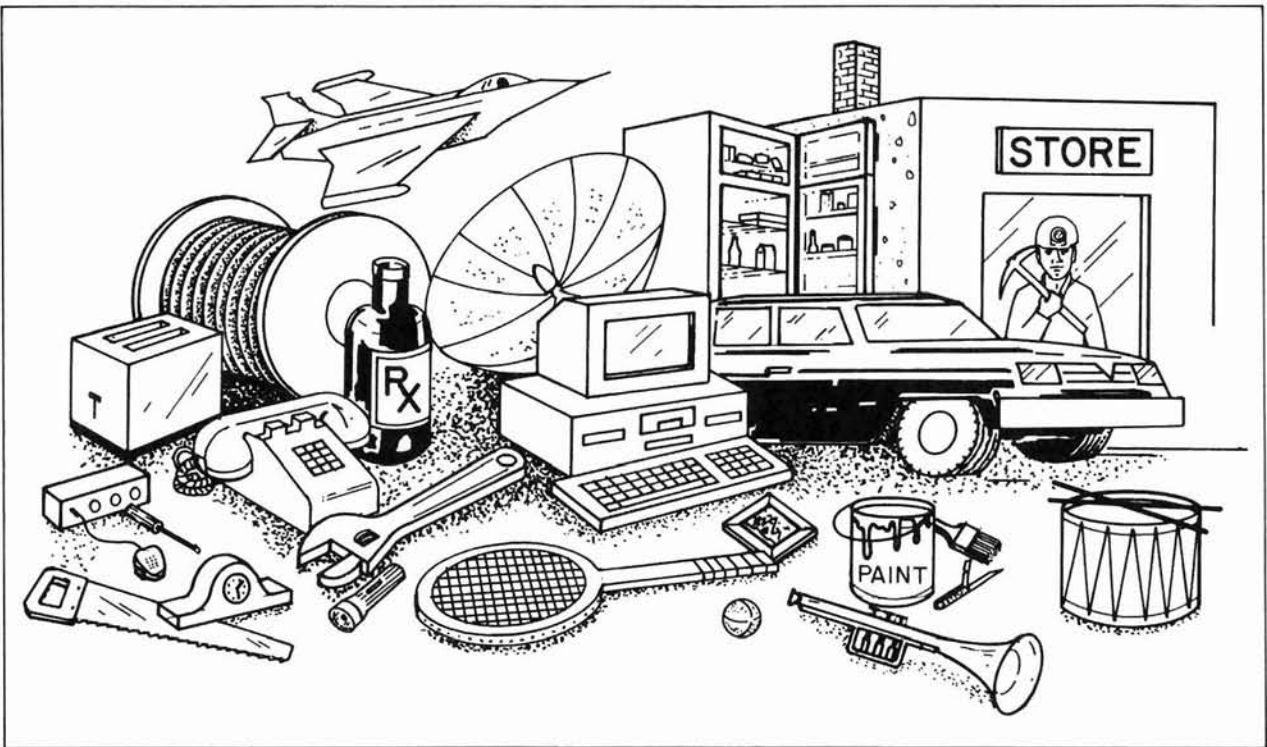


Figure 2.—A diversity of minerals are used to produce a multitude of everyday products.

Table 1.—Commonly mined materials and end uses

Mined material	End uses
Coal	Generating electricity, making iron and steel, manufacturing chemicals and other products.
Sand and gravel	Building roads, homes, schools, offices, and factories.
Iron ore	Steel products (kitchen utensils, automobiles, ships, buildings).
Aluminum ore (bauxite)	Military aircraft, naval vessels, pots and pans, beverage cans.
Copper ore	Electrical motors, generators, communications equipment, wiring.
Silver ore	Electric and electronics circuitry, coins, jewelry, photographic film.
Gold ore	Jewelry, satellites, sophisticated electronic circuits.
Zinc	Diecasting, galvanizing brass and bronze, protective coatings on steel, chemical compounds in rubber and paints.
Lead	Batteries, solder, electronic components.
Clay	Bricks, paper, paint, glass, pottery, linoleum, concrete, wallboard, spackling, pencils, microwavable containers, vegetable oil.
Gypsum	Concrete, wallboard, spackling, caulking, potting soil.
Phosphate	Plant fertilizers.
Salt	Cooking, drinking water, plastics, highway de-icing, detergents.

Minerals are vital to any industrialized civilization. The United States uses more than 3.6 billion t (4 billion st) of new mineral materials yearly, or about 18,000 kg (40,000 lb) per person, with about half constituting mineral fuels and the other half being metals and nonmetals. Stable and economic domestic mining, mineral, metal, and mineral reclamation industries are essential to our economy and our national defense. The value of processed (nonfuel) materials of mineral origin produced in the United States totaled approximately \$360 billion in 1994. During the lifetime of the average American, he or she will use—

- 1,600 kg (3,600 lb) of aluminum
- 360 kg (800 lb) of zinc
- 11,300 kg (25,000 lb) of clay
- 25,400 kg (56,000 lb) of steel
- 360 kg (800 lb) of lead
- 680 kg (1,500 lb) of copper
- 12,200 kg (27,000 lb) of salt
- More than 226,000 kg (500,000 lb) of coal
- More than 453,000 kg (1 million lb) of stone, sand, gravel, and cement.

As you can see, the mineral extractive industries play a critical role in the vitality of our Nation's economy, in our standard of living, and in our personal lives.

MINING METHODS

THE METHOD USED TO MINE A SPECIFIC commodity depends chiefly on the shape and location of the deposit. In many instances, the deposit is relatively flat and continuous over a large area. Examples of flat, or tabular, deposits are coal, potash, salt, and oil shale. These deposits are found in beds, or seams, between layers of rock. The material above the seam is called the *overburden*; the seam itself may vary in thickness from several centimeters to more than 30 m (100 ft) (figure 3).

Mining of deposits that are not flat and continuous, however, requires one of a variety of methods to extract these deposits either from the surface or underground. The method used depends on the geometry, size, and altitude of the deposit.

Some of the minerals produced, such as coal and salt, are ready to use right after they have been mined. It may be necessary to wash or treat these commodities in different ways to enhance their quality, but their properties remain essentially unchanged.

Metals, conversely, usually occur in nature as ores, i.e., combined with other materials. This means that they must be treated, usually with chemicals or heat, to separate the desired metal from its host material. These processing techniques can be very complex and expensive, but they are necessary to recover the metal of interest.

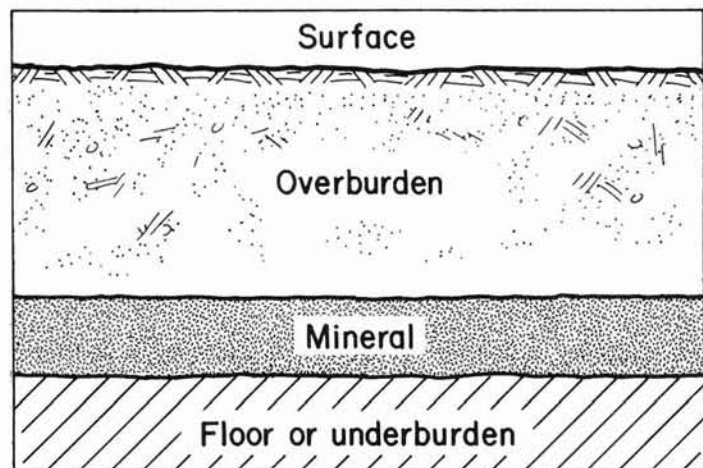


Figure 3.—Cross-section of a mineral deposit.

COAL MINING

Coal was formed from plant remains deposited millions of years ago. There are several types of coals, and their characteristics depend largely on how many million of years it took them to form and the levels of heat and pressure to which they were exposed. Coal deposits range from a soft peat (a kind of "precoal") to a hard, shiny anthracite. Most of the coal mined in the United States is a midrange bituminous coal. Coal is our most abundant fossil fuel. It is used to heat homes and offices, power electric plants, and supply energy to many industries. When heated in the absence of air (carbonization), coal produces coke, which is used to manufacture iron into steel. Coal is also used to produce synthetic products that can be substituted for less abundant natural gas and fuel oil or for the many plastic items we use daily.

Coal and other tabular deposits can be mined underground by various tunneling methods or from the surface by simply removing the covering rocks, called overburden. Underground mining is usually done when the deposit is more than 45 m (150 ft) below the surface, in which case the overburden is simply too thick and expensive to remove. Access to deep coal seams is achieved either by shafts or slopes driven down to the seam or through drifts driven directly into the coalbed if it is exposed on a hillside.

Many years ago, underground coal was mined by pick and shovel and hauled out in carts by people, sometimes even by children. Later, horses and mules

were used to drag the carts (figure 4). Today, powerful machines help miners to cut and transport the coal out of the mine to preparation plants, where it is cleaned, sorted, and readied for industrial use.

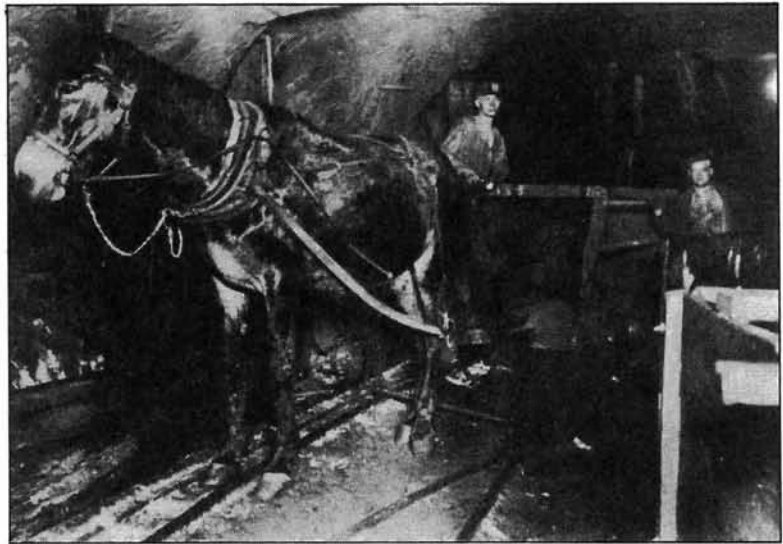


Figure 4.—Horses and mules were used to haul out underground coal in carts years ago.

Coal is usually recovered from underground mines in either of two methods: *room-and-pillar* mining or *longwall* mining.

Room-and-Pillar Mining

The *room-and-pillar* mining method entails the excavation of a series of “rooms” into the coalbed, leaving “pillars” or columns of coal to help support the mine roof (figure 5). In conventional room-and-pillar mining, the coal is broken up by explosives, loaded onto a vehicle by a mechanized loading machine, and transported from the production area by shuttle cars (figure 6).

Continuous mining is a type of room-and-pillar method in which a powerful machine called a *continuous miner* (figure 7) cuts and loads the coal into shuttle cars or onto conveyor belts that remove the coal from the mine. Bolts installed in the mine roof (figure 8) help to ensure that all of the layers of roof are consolidated and properly supported (figure 9), thereby preventing dangerous roof cave-ins that could injure or kill the underground miners.

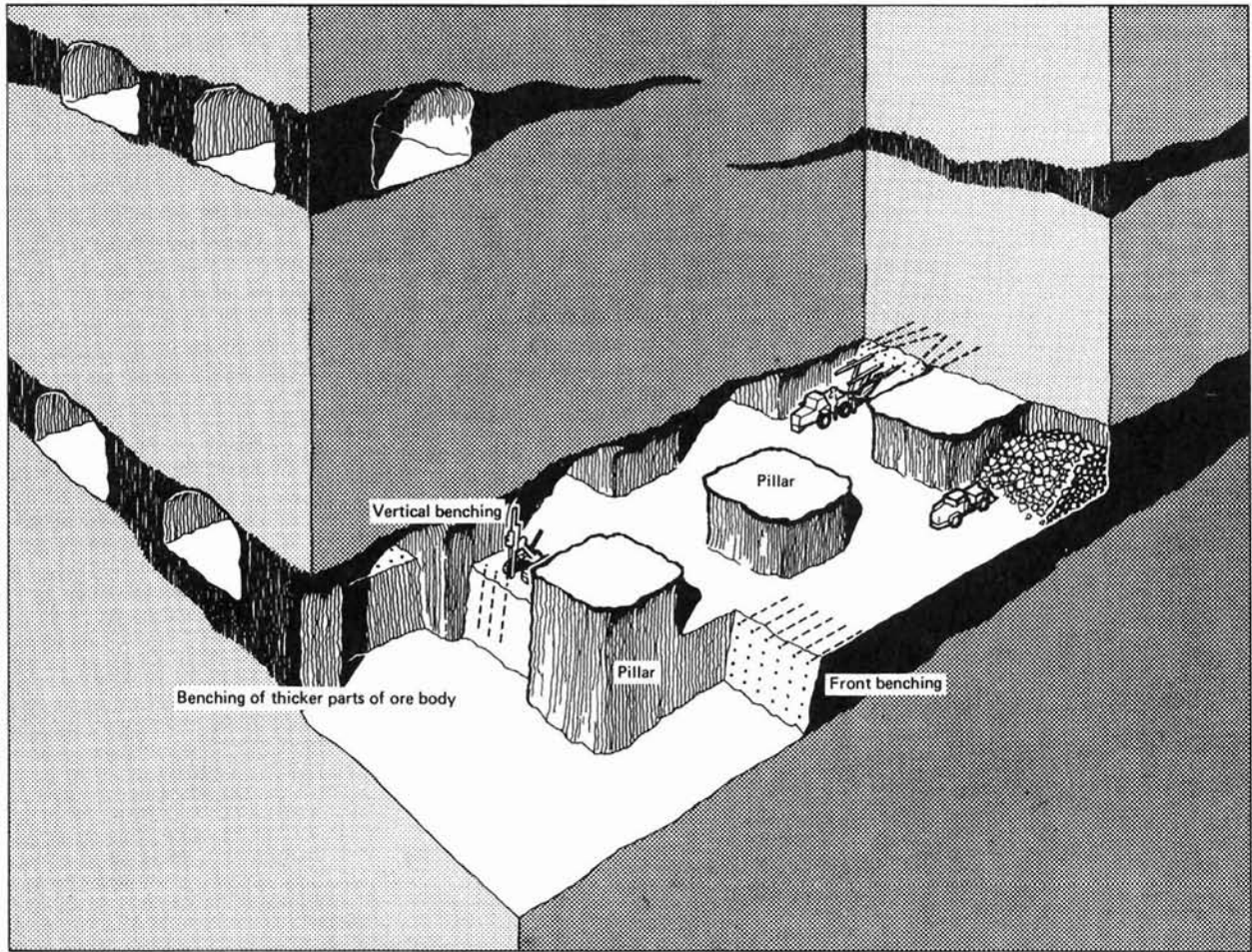


Figure 5.—Room-and-pillar mining. (© Used with kind permission of Atlas Copco AB.)

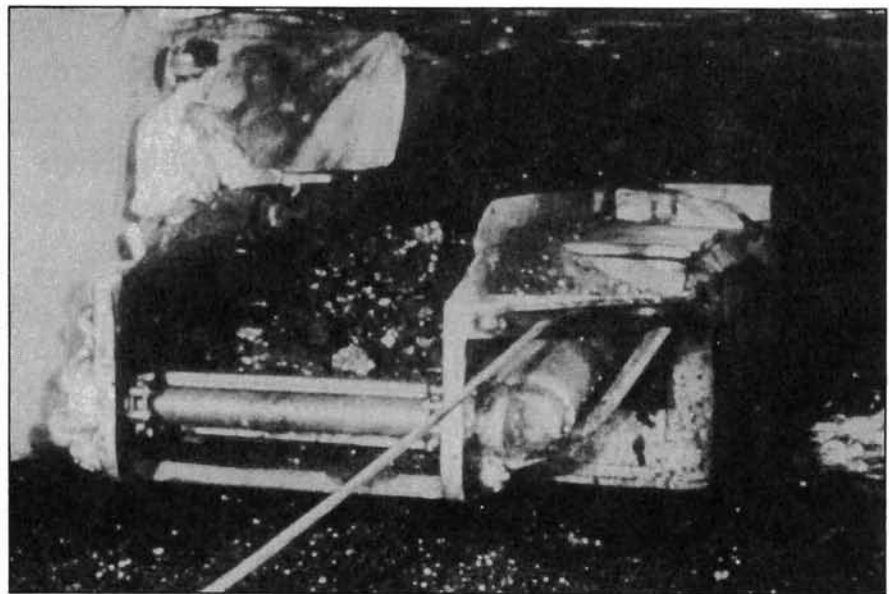


Figure 6.—Shuttle car used to transport coal from the production area.

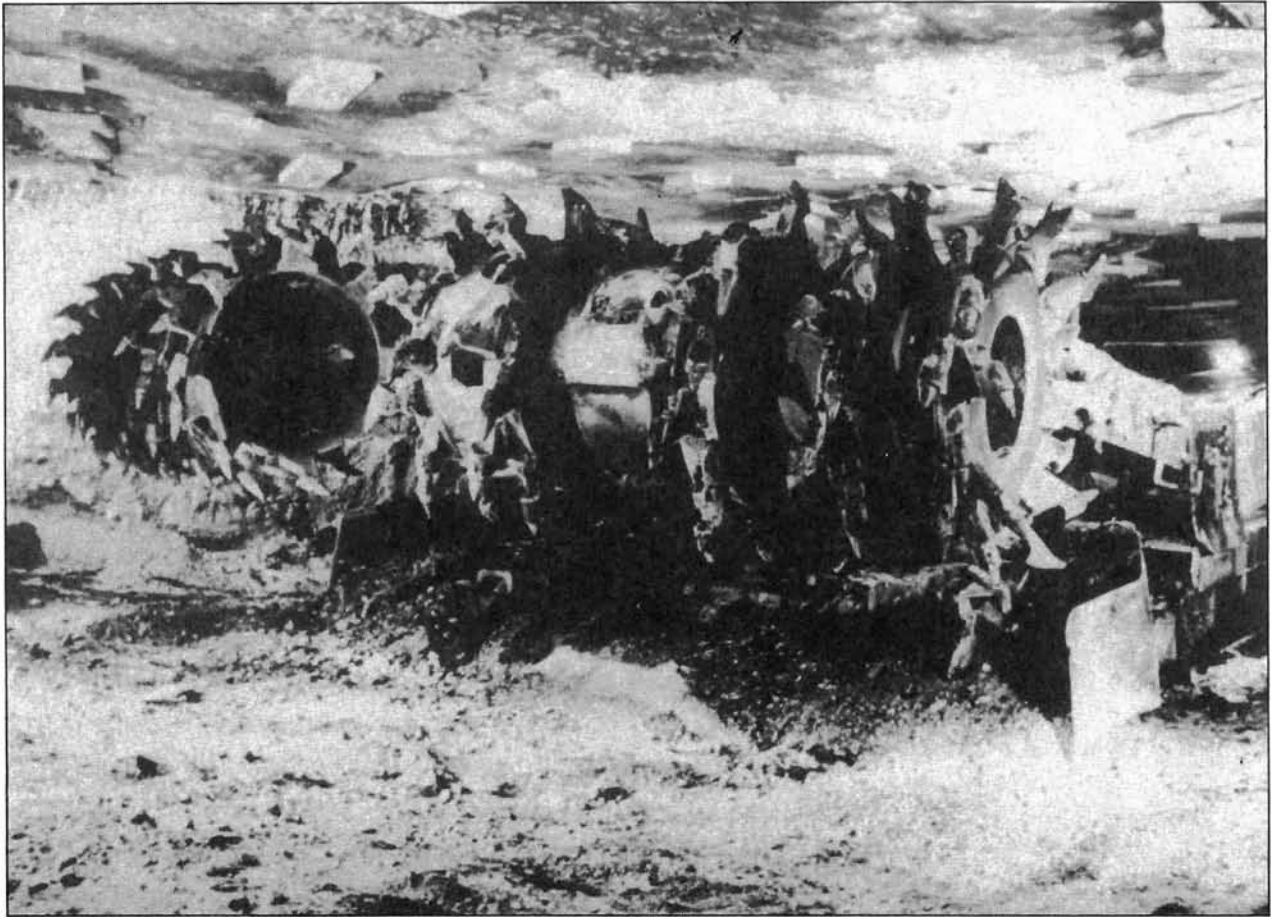


Figure 7.—Continuous mining machine for cutting coal.



Figure 8.—Bolts installed in the mine roof help to prevent roof falls, thereby preventing fatalities and injuries to underground miners.

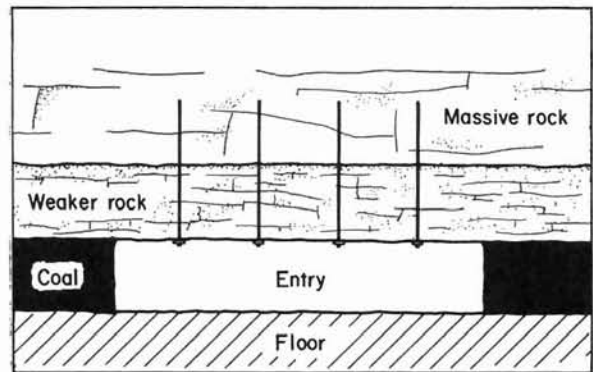


Figure 9.—Diagram of roof bolts supporting the mine roof.

Longwall Mining

The second underground coal mining system is *longwall* mining. Originally developed in Europe, longwall mining is now also popular in the United States because of the greater safety and efficiency it affords. In this method, a rotating shear on the mining machine (figure 10) shaves from blocks or panels of coal in a back-and-forth motion, similar to that of a meat slicer, and dumps the broken coal onto a conveyor belt that extends across the longwall (figure 11). Perhaps the most attractive feature of modern longwall mining is the shielded roof supports that advance with the mining operation, providing maximum protection to the miners (figure 12). As the mining machine advances, the roof behind it caves in. This collapsed area is called the *gob* (figure 11).



Figure 10.—Longwall shearer cutting coal.

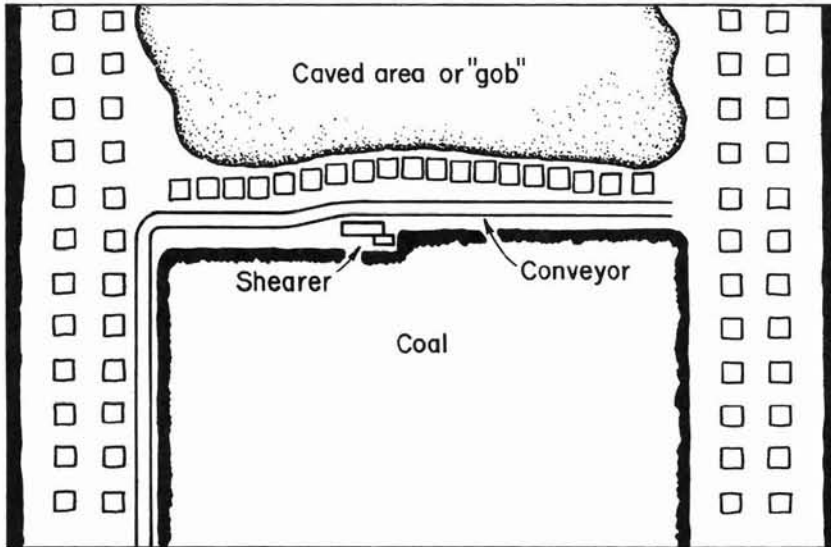


Figure 11.—Plan view of longwall mining.

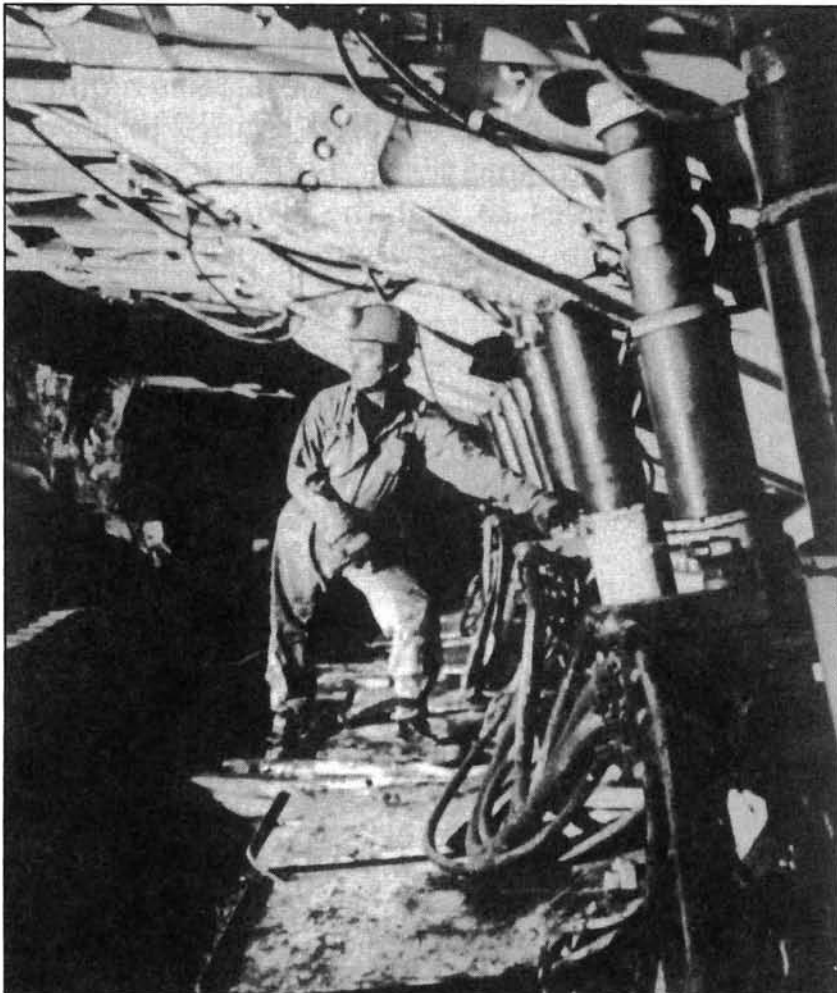


Figure 12.—Longwall roof supports.

Surface Mining

Surface, or open pit, mining of coal is done where the overburden is relatively shallow. Large earth-moving equipment, draglines (figure 13), or shovels are used to remove the fractured overburden from the coal (figure 14). The coal is then typically broken up by blasting it with explosives. The coal is loaded into special haulage trucks (figure 15) that carry it away to preparation plants, where the rock, soil, and impurities, such as sulfur, are removed. Federal laws require that the resulting open pits be filled, graded to about their original contour, and planted for agricultural or recreational purposes so that the natural environment is protected and our Nation is kept beautiful.



Figure 13.—Dragline used to remove overburden.

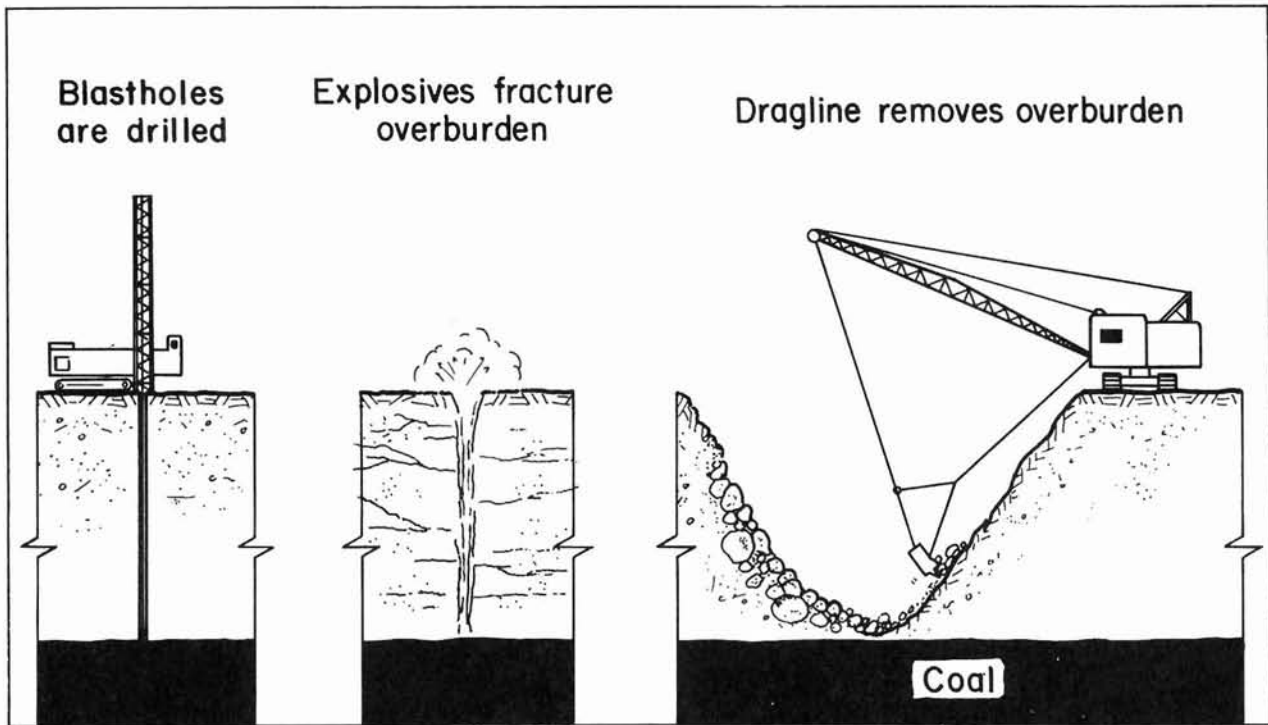


Figure 14.—Overburden is fractured with explosives, then removed with a dragline or large excavating shovel.



Figure 15.—Large haulage trucks are used to transport coal from the mine.

METAL/NONMETAL MINING

Most metallic and nonmetallic deposits are found in a variety of shapes of varying size and mineral content, properties that dictate the economic feasibility of mining these commodities in the first place and that also determine the most appropriate mining method. The highest-volume commodity produced by the U.S. minerals industry is crushed stone. An estimated 1.2 billion t (1.3 billion st) of crushed stone was produced in the United States in 1994 valued at approximately \$6.4 billion.

Room-and-Pillar Mining

A wide range of methods can be used to mine such deposits. Underground room-and-pillar mining methods for many metal/nonmetal deposits differ from those of coal and other softer mineral deposits. These differences primarily involve equipment used, method of breaking up the ore, and ways of removing the ore from the mine.

The ore-breaking system used in these instances differs from coal breakage systems because of hardness. Whereas coal can be cut continuously with a shearer or continuous mining machine, almost all metal mines use pneumatic or hydraulic percussion drills of the jackhammer type to drill small-diameter holes (6.4 cm by 3 m (2.5 in by 10 ft)). These holes are filled with explosives, which are then detonated. Some mines may use larger holes (15 cm by 12 m (6 in by 40 ft)) if the physical limits of the ore allow it. The holes in a limited section are blasted, the area is then made safe, and ore removal can begin.

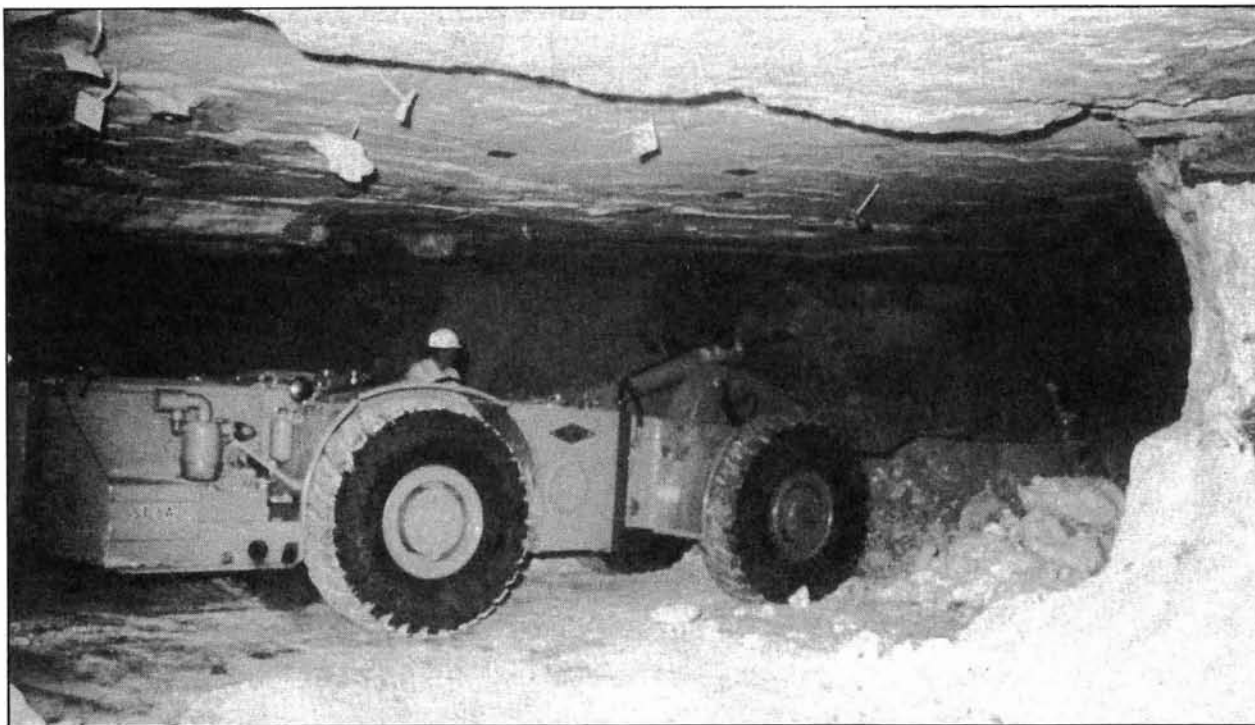


Figure 16.—Load-haul-dump unit for ore transfer.

Front-end loaders or load-haul-dump machines (figure 16) remove the broken ore from where it was blasted. Normally, a load-haul-dump unit will not haul ore out of the mine, but rather transfers the ore to a truck. In addition to diesel vehicle haulage, a conveyor belt or rail may be used for hauling ore to a shaft, which then hoists the ore to the surface. On rare occasions when a deposit is shallow, ore can be carried directly to the surface processing facilities.

Sublevel Caving

Caving methods require that the ground surface be permanently available for closure and isolation and that the rock above and around the ore body be weak so that it will break into a fractured mass and the ore will fracture into small pieces. *Sublevel caving* (figure 17) applies best to wide, vertically oriented, vein-type ore bodies (figure 18). This mining method entails a ramp and borehole from which sublevels, spaced 6 to 12 m (20 to 40 ft) apart vertically, extend

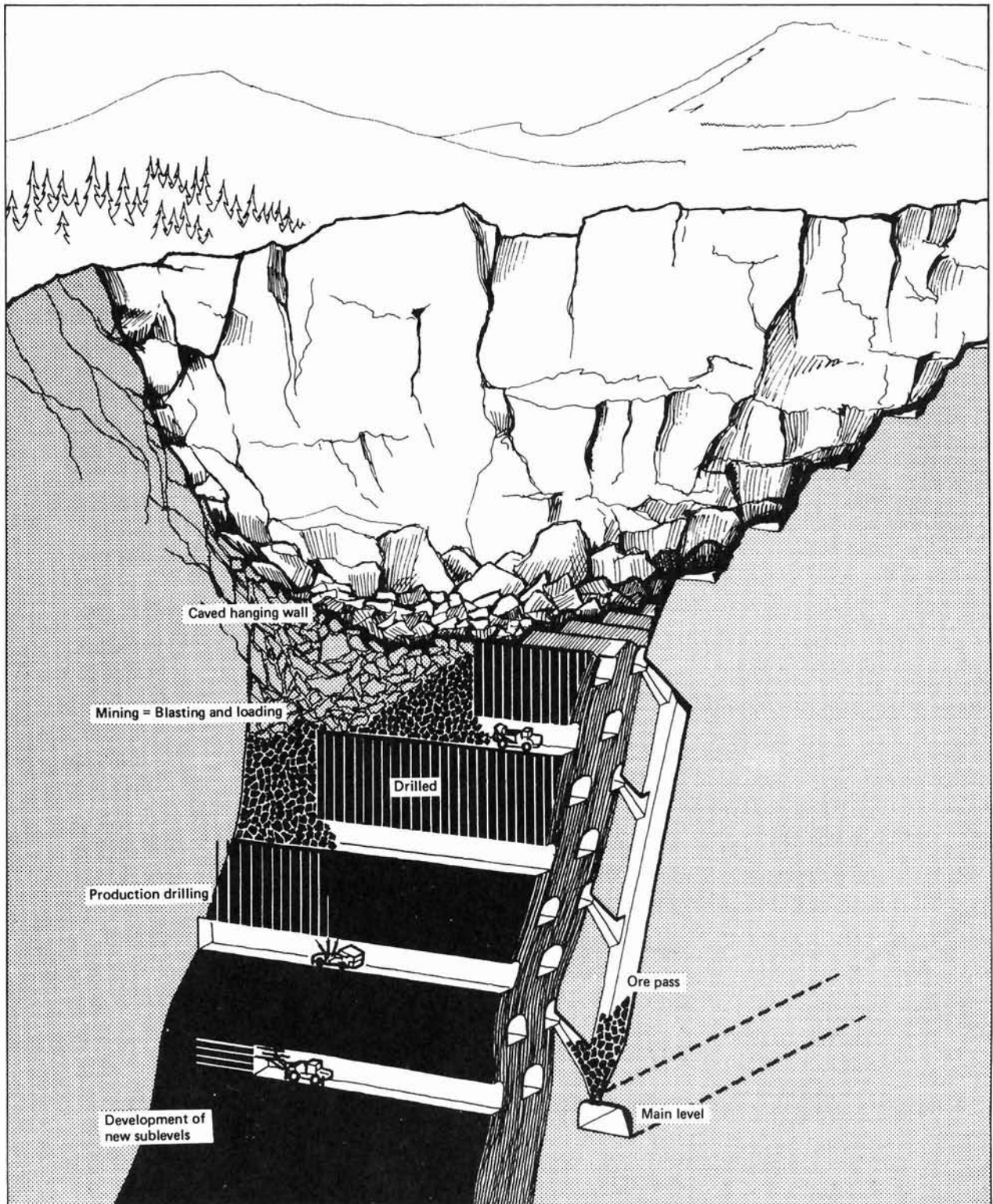


Figure 17.—Sublevel caving mining method. (© Used with kind permission of Atlas Copco AB.)

through the ore body. Each main level, which is 60 to 120 m (200 to 400 ft) apart vertically, may intersect one or more of the boreholes with chutes to transfer the broken ore to rail or other haulage systems out of the mine. Each sublevel advances sequentially by drilling and blasting, with supports added as necessary until the sublevel has penetrated through the ore body.

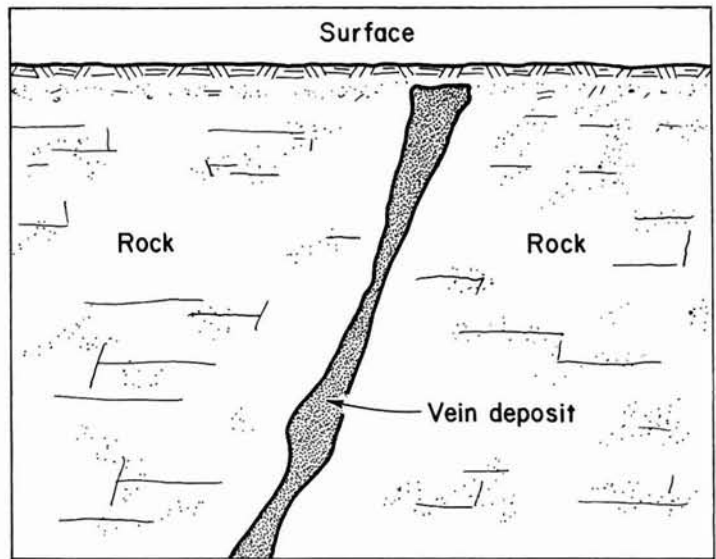


Figure 18.—Vein-type deposit.

Reversing the process, either the supports are gradually removed in 0.6- or 1.2-m (2- or 4-ft) segments or the ore overhead is drilled and blasted in the same pattern. The ore falls, and the load-haul-dump unit hauls it to the borehole. As the ore is removed, the rock above gradually falls. When this rock (called waste) appears, the operator removes additional supports or blasts in a retreat pattern, repeating the process until all ore on that sublevel is removed and the waste has filled the sublevel. Other sublevels are similarly activated in sequence. Gradually, the process progresses down the ore body while the surface subsides into the opening. The method does not apply to narrow veins that would cause hangup or dilution of the ore with waste or to flat-lying ore bodies where gravity cannot be used to cause the ore to break.

Block Caving

Large ore bodies of lower grade can be mined with the *block caving* method (figure 19), so called because mining occurs sequentially in segments or blocks 60 to 150 m (200 to 500 ft) on a side in all three directions. A series of railroad tunnels is constructed under the

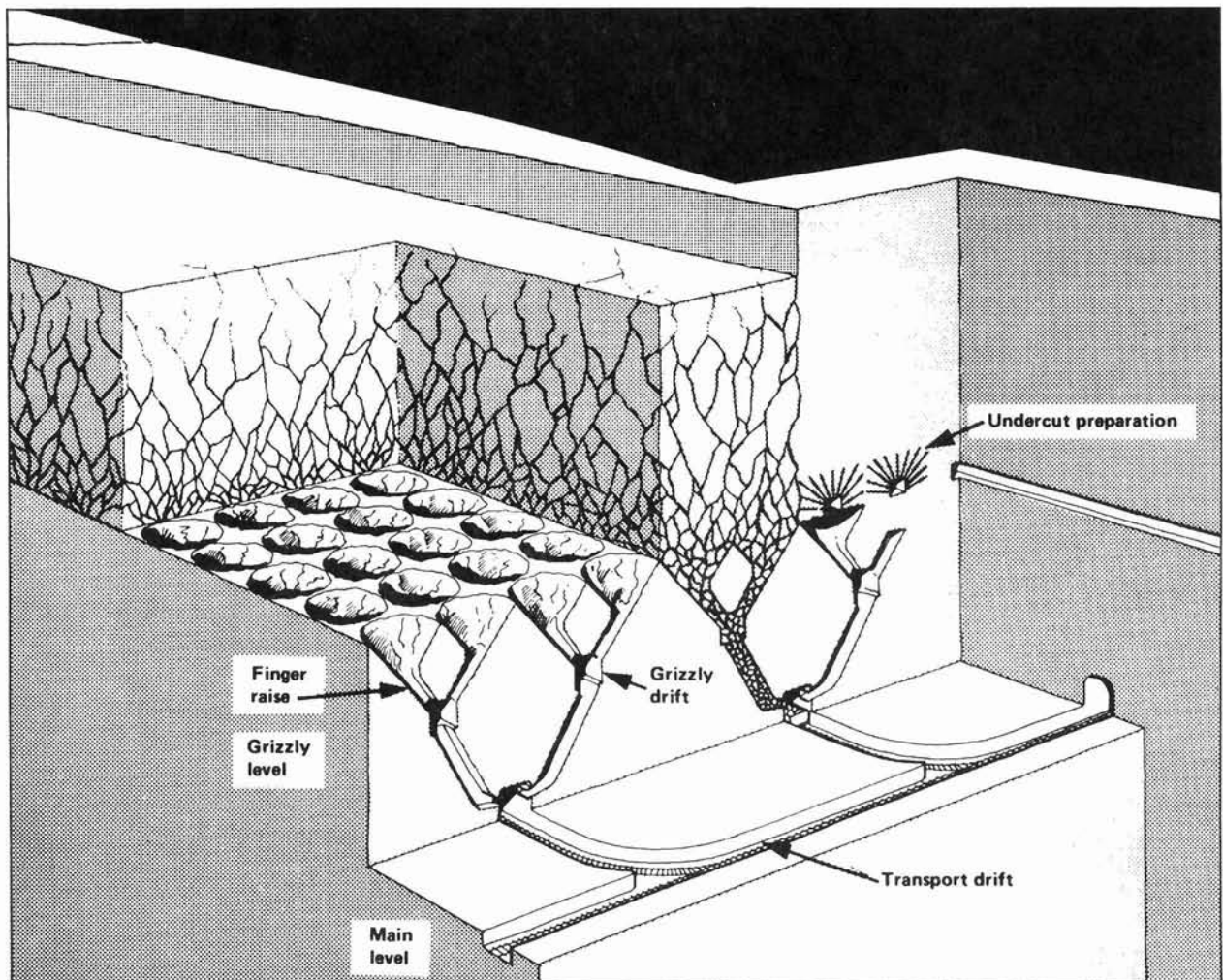


Figure 19.—Block caving mining method. (© Used with kind permission of Atlas Copco AB.)

ore to be mined. At approximately 30-m (100-ft) intervals along each tunnel in a checkerboard pattern, 3- to 6-m (10- to 20-ft) diameter raises connect the rail tunnels with another series of cross drifts. In the cross drifts, scrapers (hoes pulled by a cable from an electric motor) pull the ore back to the raised areas to dump the ore in railroad cars. The ore falls down finger raises intersecting the cross drifts below. These raises are driven in many directions into the ore above, usually with four or more intersecting at one point in the cross drift. These raises act first as a place to blast the entire underside of the ore block, then later as a funnel to draw the blasted ore. The ore continues to fall from the bottom of the block as it is pulled from the raises, for it now has no foundation. No further entry can be made in the finger raises once the block begins to cave in.

On extremely large ore bodies, many parallel and abutting blocks are mined, a process that can last several years. If the ore extends in depth, additional levels develop in the same manner below. Ore and waste that are separated may exceed 90,000 t (100,000 st) daily from such an operation.

Cut-and-Fill Mining

Some ore deposits are essentially tabular but irregular, with varying thickness, inclination, and strength. The *cut-and-fill* mining method (figure 20) provides adaptability to all of these variables. Its name is derived from the way the ore is mined. The ore is removed, or cut, from a small segment of the ore body

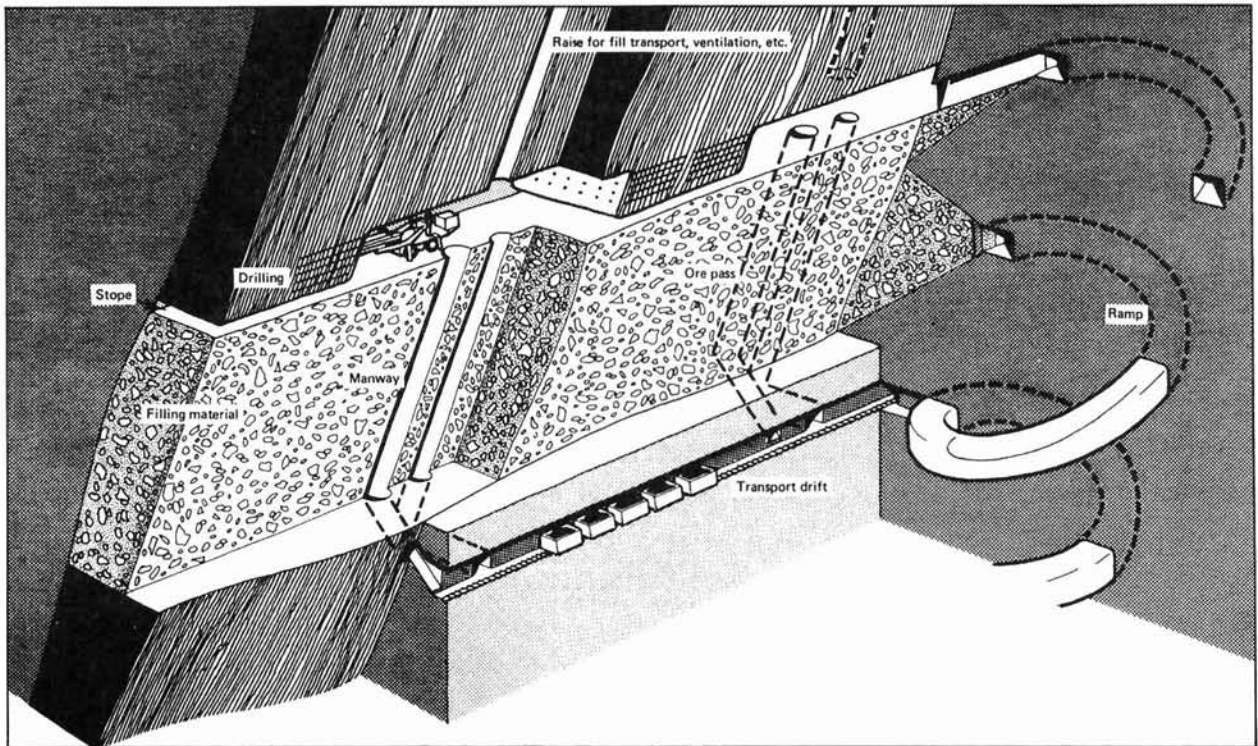


Figure 20.—Cut-and-fill mining method. (© Used with kind permission of Atlas Copco AB.)

(0.6 to 110 m³ (20 to 4,000 ft³)), then waste rock is placed back in the hollow for support. This process is repeated, advancing along a horizontal level through the ore body.

After one level is mined and filled, the process is repeated in the ore body above the fill material. Most frequently today, the filling material comes from the processing plant in the form of fine sand and water called slurry or tailings, which is mixed with cement to form a stable fill.

The cut-and-fill method provides a reasonably safe, versatile system for recovering ore that could not otherwise be mined. Throughout the world, hundreds of mines use this method in almost as many variations. However, the ore deposit must be of sufficiently high concentration and value to economically justify this approach.

Sublevel Stoping

Wide-vein deposits contained within competent waste rock and at vertical or steeply angled inclination permit use of a method called *sublevel stoping* (figure 21). This method can be likened to the month on the page of a calendar, with the top and bottom

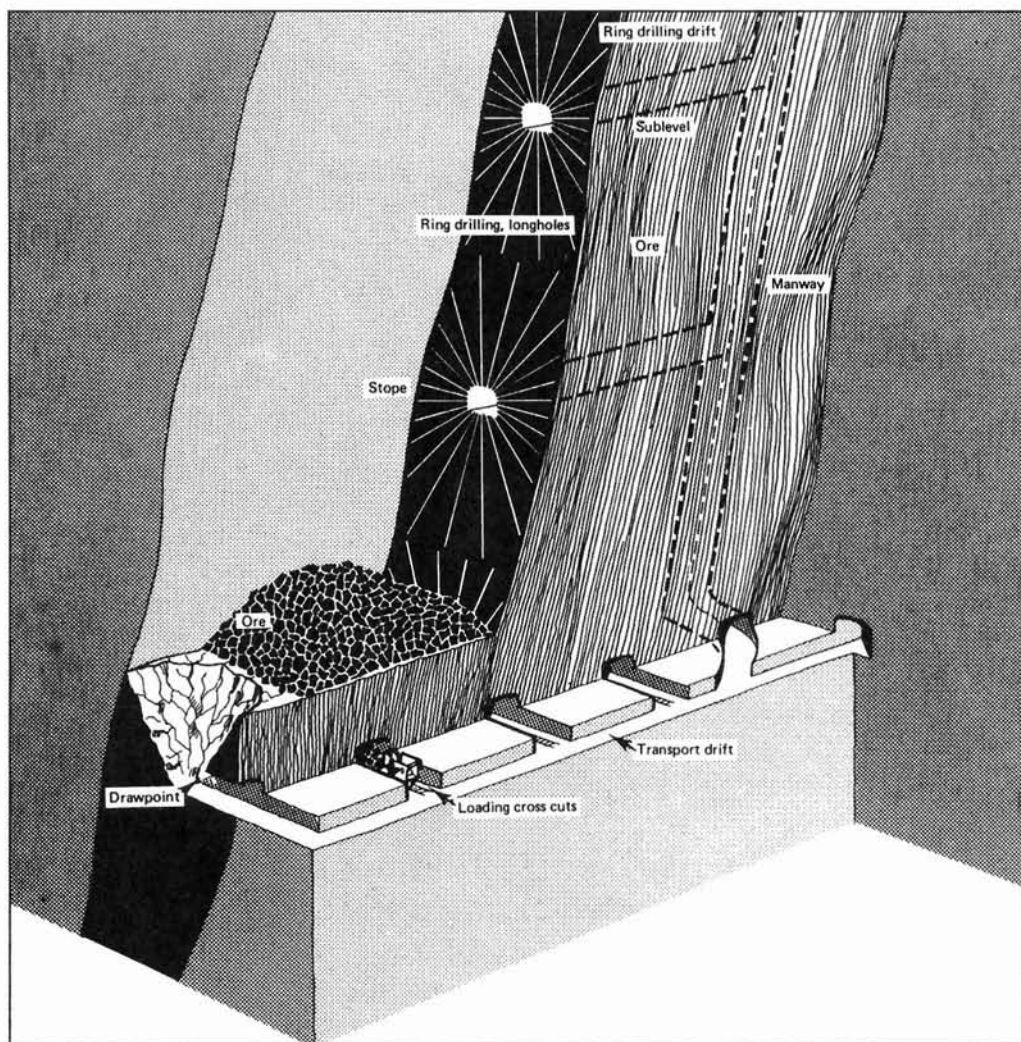


Figure 21.—Sublevel stoping mining method. (© Used with kind permission of Atlas Copco AB.)

edges representing the main haulage levels where all of the ore from above is removed. Each row of weeks on the calendar page represents sublevels started from the right-hand edge raise toward the left-hand edge raise widened to full-vein width. The sublevels starting at the bottom left day of the calendar page are drilled with long holes in a circle around the opening, then blasted in one large blast, removing a segment of rock 0.6 to 1.2 m (2 to 4 ft) along the sublevel. It would be like removing one day of the week from left to right, bottom to top of the calendar page, and dropping it to the bottom edge, where previously installed chutes funnel them to the train or load-haul-dump unit for haulage to the shaft.

The sublevel stoping method works only if the walls of the opening around the ore do not cave. The safety of this method relies on exposing personnel to a small tunnel opening that can be supported. Variations of the method include *vertical crater retreat* (figure 22) and blasthole mining. Large-tonnage production can be provided in veins 3 m (10 ft) to hundreds of meters wide with ingenuity in design and planning.

Borehole Mining

Some commodities, such as salt or phosphate, which are soluble in water, are mined through boreholes (figure 23). A borehole is drilled into the formation. A jet of water is then used to loosen the desired material, which is pumped to the surface with the water. Here, the salt is separated from the water, usually by evaporation.

Materials like copper and precious metals can have the minerals dispersed. With *in situ mining*, a fluid

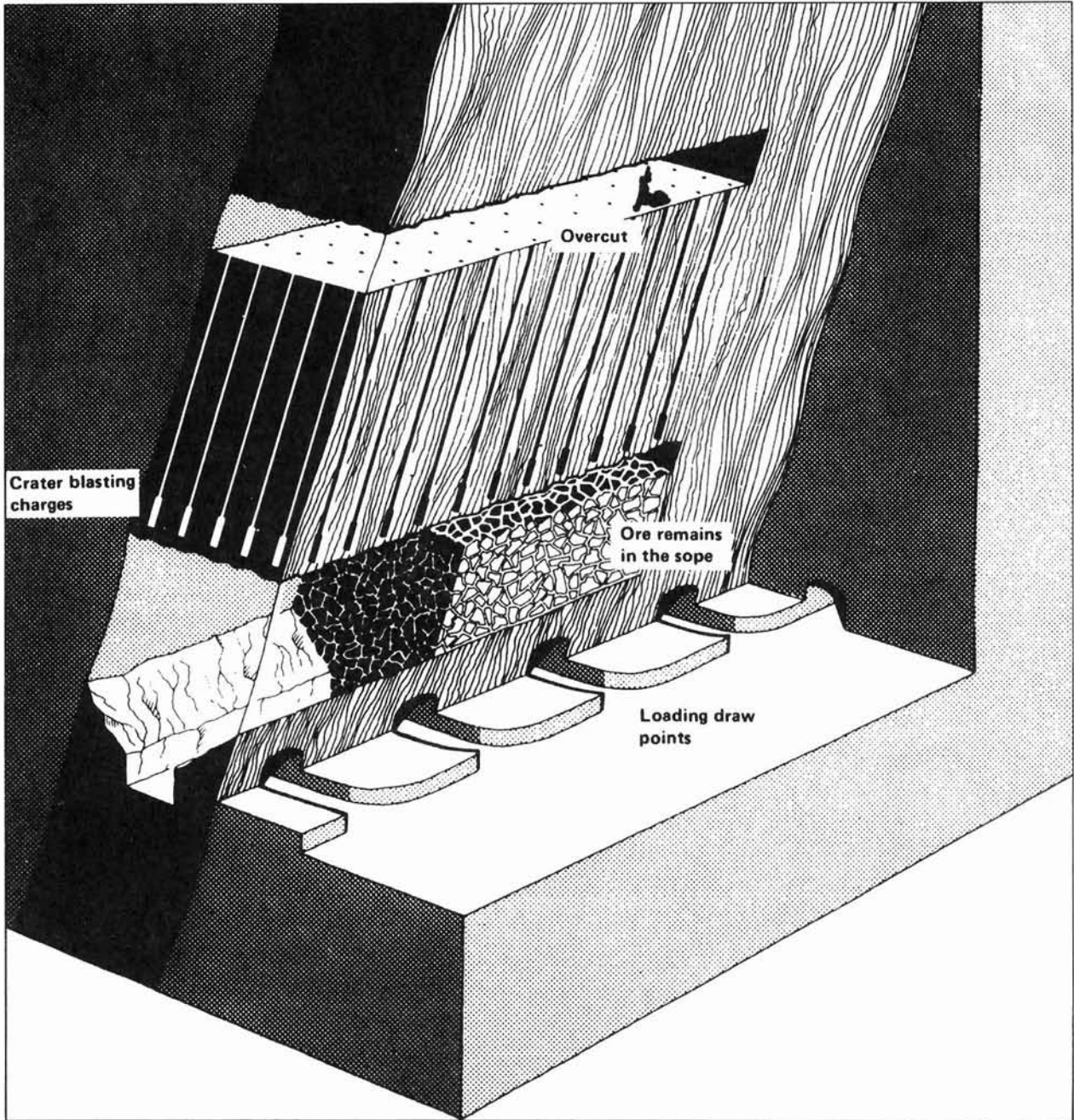


Figure 22.—Vertical crater retreat mining method. (© Used with kind permission of Atlas Copco AB.)

that will dissolve the ore is circulated through the deposit. The fluid, with the mineral in solution, is then pumped to the surface where the minerals are separated from the fluid, which is reused (figure 24).

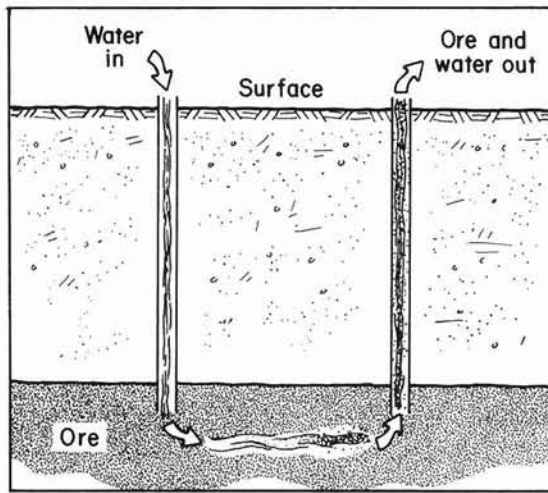


Figure 23.—Borehole mining method.

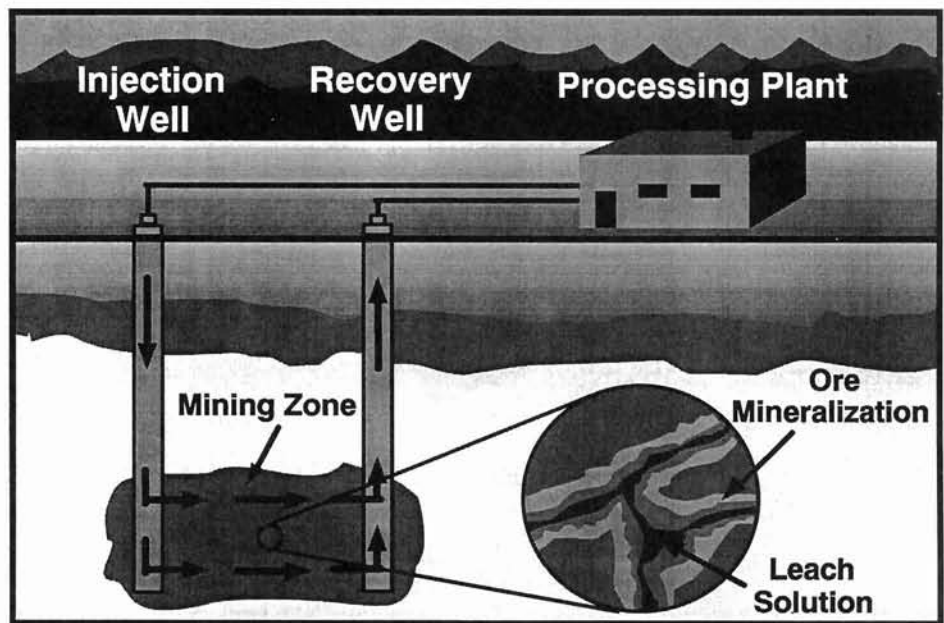


Figure 24.—In situ mining operation.

Surface Mining

Deposits that can be mined using surface mining techniques differ greatly in character. They may vary from small surface gold, sand, gravel, or stone to large metal sulfide or oxide deposits that are several kilometers wide and long and possibly 0.8 km (0.5 mi) deep, but most readily mined from the surface. Other metallic deposits may fill cracks in the rocks, twist, or form large underground areas, but are so deep that they require shafts and tunnels to reach them. Even some relatively flat-lying deposits are so deep that they require shafts more than 3.2 km (2 mi) deep to reach them.

Today's surface mining methods in metal/nonmetal mines usually require removal of soil and/or useless rock before drilling and blasting the deposit in benches or stairsteps. Since few deposits are pure, waste rock may be removed to the waste pile by shovel and truck or front-end loader while ore is loaded into other vehicles to be taken to processing plants.

Generally, surface mining includes (1) identification of the ore and waste rock, (2) removal of surface soil and debris, (3) drilling and blasting of ore and waste, (4) removal of ore to processing facilities and waste to the dump, and (5) reclamation and environmental rehabilitation.

The first step, identification, must include as much as possible about the size, geometry, values, environment, water, strength, and physical qualities of the ore and waste in and around the ore body to be mined. This requires drilling holes that recover samples, making test pits and openings, and using geophysical methods involving waves, rays, or other systems to acquire information. Identification may take years at great costs, but without the information, the engineer cannot design a safe, economical plan to remove the desired material.

The next four steps often proceed in sequence, with each process overlapping if possible. Surface soil and debris may be placed to one side for later reclamation and replanting. At the very least, such soil is removed and protected against erosion and environmental damage. Surface rain and drainage must also be controlled for the life of the mine and future environmental protection after mine shutdown.

Although the stripped soil may uncover the rock, the remaining surface is often irregular and weathered, requiring leveling and removal by either bulldozing or drilling holes that are loaded with explosives and blasted. This initial work establishes the mining plan for haul roads, bench width and height, drilling, loading, and blasting of the ore body and the waste that is included in the ore and external to the ore body.

Information gathered from exploration, as well as the initial excavation activities, help to develop the plan for appropriate bench height and width, slope of each

segment of the pit, tonnage and value to be recovered each shift, and other parameters necessary for successful, orderly recovery of the ore body at maximum safety and economy. Gradually, the pit deepens, and problems of water encroachment, haulage road maintenance, pit slope, and increasing waste-to-ore ratio are resolved until a predetermined closure point is reached or economical changes occur that no longer make it profitable to mine.

MINE CLOSURE

CLOSURE NORMALLY MEANS CESSATION OF all mining at a site. Of course, some temporary disruption to the environment is unavoidable when taking minerals from the ground and turning them into useful products. Mine closure, therefore, usually requires some environmental activities such as removal of hazards, recontouring, and planting where possible.

Closure occurs when all scheduled reclamation plans have been completed and safety of the area is ensured. In fact, through comprehensive environmental planning, mining companies can now return mined land to the identical condition that existed before mining occurred (figure 25). Mining can thus be executed



Figure 25.—Protecting the environment through reclamation is a vital part of mining. With modern mining technology, the land is left as close as possible to the way it was found before mining.

with mindful concern for our health and respect for ecological needs. If plans consider future reactivation, Federal, State, and local regulations provide for protection of the public.

The time to locate and define the mineral deposit, prepare and mine, and finally close the deposit can vary from 2 to more than 100 years. Capital costs to begin mining can range from \$100,000 for a small 90-t (100-st) per day mine to \$1 billion for a large 18,000-t (20,000-st) per day remote mine. Comparisons may be misleading because of diversity of location, physical situations, and products involved. However, in the free-world marketplace, profitability controlled by economics of costs and prices dictates whether and how long a deposit will be operated as a mine.

IN CONCLUSION

MOST OF US TAKE FOR GRANTED THAT THE mining and processing of raw materials from the ground are the basic building blocks from which all technological advancements and products are made—products that we need and use in our everyday life, from the cars we drive to the planes we fly... from the chemicals used in medicines to the fertilizers we feed our crops... from the multitude of appliances, tools, and machinery to, in general, all of the useful devices that humankind can imagine and fashion. Fossil fuels from the earth—coal, oil, natural gas—provide the energy to heat, cool, and light our homes, refrigerate and cook our food, power our factories, and transport ourselves and our products around the world.

Yes, there are few times, if any, that we stop to consider the importance of mining and minerals. Yet the quality of our life, our national security, the stability of domestic and world economies, science, industry, and the arts are all based on the minerals we mine from the earth. No matter how complex or simple a finished product may be or how routine its use, it exists because of something found in the ground that we can mix, mold, melt, cast, extrude, alloy, grind, stamp, or stretch into something useful.

But first it must be mined!

ABOUT THE U.S. BUREAU OF MINES

THE MISSION OF THE U.S. BUREAU OF MINES (USBM) is to help ensure that the United States has an adequate, dependable supply of minerals and materials to meet its national security and economic needs at acceptable social, environmental, and economic costs. The USBM is engaged in all aspects of mining and minerals processing research—coal, metal, and nonmetal—as well as mineral data collection and analysis. The USBM research program has reached a high degree of maturity, with numerous techniques already in use or approaching the point where they can be applied by the industry.

Nevertheless, changing mining conditions, such as deeper and/or thinner deposits with unstable formations, will continue to dictate the need for improvements in existing mining processes. Also, improvements in mine efficiency have increased the need for new or alternative methods to maintain current health and safety achievements. The USBM is committed to addressing these needs through new and radical approaches that will provide the information and technology necessary to improve mining health, safety, and efficiency while maintaining high environmental standards.

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