Chapter 13
Mining

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INTRODUCTION

Mining is a basic industry, providing modern society with the energy and material resources required for everyday life as we have come to enjoy it. The role of our mineral wealth is apparent when we see copper plumbing, a concrete sidewalk, or a piece of gold jewelry. Although the use of electricity is ubiquitous, many are unaware that over 50% of it is generated in coal-fired plants. Even less obvious dependencies include carpets (whose components include five mined products), plastic pipe (with a pulverized stone content of 50%), computers that contain more than 30 mined products, and paint and many medicines that depend upon mined constituents for their prized properties, to name but a few. Agriculture is heavily dependent on mined products in the form of fertilizers, and other industries utilize mined products even when those mineral commodities do not show up in the manufactured article. Indeed, it is difficult to find any corner of the economy that is not tied to the availability of quality minerals or mineral resources.

Mineral resources come from the Earth's crust, and their extraction is seldom easy. Even after extraction, considerable effort may be expended to separate, refine, and concentrate the valuable minerals that are often mixed or bound with waste materials. Minerals production can be divided into two general phases: the *extraction phase* is concerned with removing the material from the Earth; the *processing phase* separates the valuable component from the less valuable or waste material. In practice the distinction between the two phases is often blurred. Commonly, the term mining is used to describe the extraction phase, while processing is used to describe the phase of preparing the product for human use. Usually, the people involved in both are called miners or mineworkers, although in some quarters other terms are used.

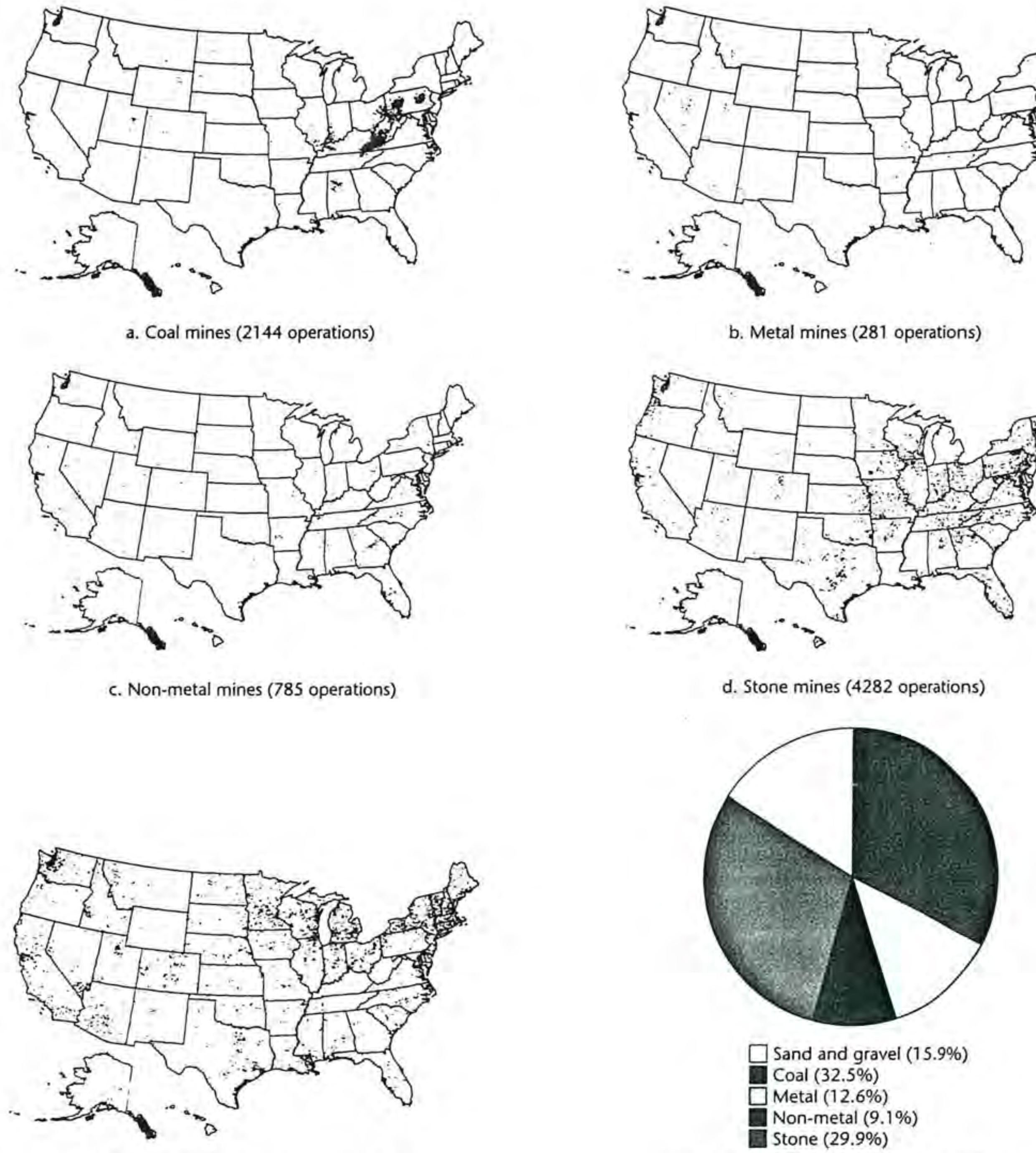
In its simplest definition, mining includes all of the job processes required to produce a mineral commodity in saleable form. A simple example would be the mining of a limestone deposit and the subsequent processing to a crushed stone for sale to a concrete producer. A more complex example would be the mining of an iron ore deposit and the subsequent processing to concentrated taconite pellets for sale to a smelter. An increasing number of mining operations are becoming vertically integrated – that is, an end product for direct sale to the consumer is produced and processed on the mine site.

Economics and globalization of mining

Mining occurs where the deposit is found, of course, and where the mined commodity can be converted economically to the desired product. Transportation costs are often a limiting factor, and accordingly coal will be mined for the use of a nearby power plant or perhaps a plant that is hundreds of miles away but readily served by rail. Stone, on the other hand, has a lower value with respect to its transportation cost, so a stone mine will typically serve customers within only several miles. The transportation factor and the geographic linkage between mining and manufacturing have become more evident in recent years as metal mines employing hundreds of workers (e.g., copper mines) have closed and moved operations to other countries. Shortly thereafter, the associated manufacturing plants (e.g., copper rod and wire), also employing several hundred workers, close and move operations nearer to other mines. Of course, certain rare and precious commodities are completely decoupled from the transportation cost constraint – e.g., gold and diamonds.

Mined products had a value of 60 billion dollars in 2002, and added nearly one-half trillion dollars in value to the US economy. Approximately 300,000 people were directly involved in mining, and another 3 million people were employed downstream in the support, processing, and conversion of these mineral resources. Figure 13.1 illustrates the location of mines, by sector, within the United States – as the data reveal, mining occurs in almost every part of the country. (The sectors in common use are coal, metal, stone, and non-metal. Non-metal includes such commodities as boron, potash, sulfur, salt, and vermiculite. The US Geological Survey[1] provides an excellent discussion of all US mineral commodities.)

Mining has always been a global endeavor, but over the past decade the globalization of the industry has accelerated. Large multinational corporations now conduct extensive metal, non-metal, and coal mining in the United States and in South America, Africa, Europe, Asia, and Australia. Mining methods and equipment have become similar throughout much of the developed world, as have occupational health and safety hazards to which mineworkers are exposed. At the same time, this globalization has presented significant parallel opportunities to improve conditions on a global basis. For example, successful health and safety interventions are developed in one country and then applied to similar mines throughout the world. While many of the examples used in this chapter are drawn from



a. Coal mines (2144 operations)

b. Metal mines (281 operations)

c. Non-metal mines (785 operations)

d. Stone mines (4282 operations)

e. Sand and gravel mines (7131 operations)

f. Distribution of mineworkers by mining sector

Figure 13.1: Location of mines and distribution of mineworker employees by mining sector in the Unites States. Parts (a)–(e) from MSHA 2001,[21] part (f) from NIOSH 2003.[22]

the US mining industry, the mining methods, descriptions and associated health and safety issues apply to mining throughout most of the world.

Human costs of mining

In the course of meeting society's direct and multifaceted needs for mineral commodities, mineworkers have been killed, others have suffered lost-time injuries, and still others have endured the silent progression of occupational illnesses brought on by excess exposures to noise, dust, or other potentially harmful substances. Similar injuries and illnesses occur throughout the mining industry. At the most severe levels are traumatic injuries, cumulative trauma disorders, respiratory diseases, and hearing impairment or loss. Certain injuries and illnesses are far worse for certain commodities or mining methods, and a few are particular to a specific commodity or method.

Mines are 'built' directly within the crust of the Earth and therefore are made of whatever geologic materials exist at the site. Thus, the geologic setting can be inhospitable, containing dangerous gases, and the associated rock can be weak and prone to failure. This creates special health and safety challenges well beyond those of a factory setting, where the construction is entirely man-made materials and the factory operations are comparatively routine and predictable. Moreover, the dimensions of the working spaces within the mine are generally limited by the deposit dimensions, and in many cases this results in confined space working conditions.

A more detailed discussion of health and safety issues is presented later in the chapter.

MINING METHODS

The classification of mining methods for engineering purposes is complex, with many individual methods and submethods in use. However, in the interest of focusing on health and safety issues, a number of simplifications can be made. First, all mines can be classified as one of three types: *surface*, *underground*, or *solution*. Deposits that are close to the surface can be accessed by removing the relatively shallow cover or overburden materials, thereby exposing the deposit that can then be recovered. Copper, coal, and stone are examples of materials that are commonly mined by surface mining methods. Deposits buried deeper within the Earth's crust cannot be accessed simply by removing the overlying materials, so access to the deposit is gained by sinking shafts or driving other openings from the surface down one hundred to a few thousand meters deep to the deposit. Then an extensive network of 'tunnels' is driven into the deposit itself and/or within the host rock surrounding the deposit. This network of openings both facilitates the extraction of the ore and provides a way for the services infrastructure to get the ore from the solid ore body to the surface. Underground mining is much more difficult, expensive, and dangerous than surface mining, so it is primarily used for commodities that are otherwise unavailable from surface mines. Examples of underground mines include coal, gold, salt, and stone.

Occasionally a deep deposit can be mined with a solution method, in which 'wells' are drilled into the deposit, a dissolution agent is pumped down the well, and the solution is pumped back out for removal of the desired metal or mineral. This type of mining is used for commodities such as sulfur, trona, salt, and uranium, and is sometimes known as borehole mining. A modification of this is heap leaching, in which low-grade ores are mined, typically by surface methods, and placed into engineered piles where the lixiviant percolates through the pile. The resulting solution is then treated to recover the mineral product of interest. Heap leaching remains an important method for recovering gold.

The mining engineer chooses the mining method based on several technical and market factors. While it may be significantly cheaper to surface mine 100-foot-thick coal seams in Wyoming than to underground mine five-foot-thick seams in West Virginia, the cost of transporting the Powder River Basin coal to the East Coast tips the balance in favor of the more expensively mined coal in West Virginia.

Mine type	Class	Method	Commodities
Surface	–	Strip (open cast)	Coal
		Quarry	Stone
		Open pit	Metal
		Dredging	Metal, non-metal
Underground	Stoping	Room and pillar mining	Coal, non-metal
		Stope and pillar mining	Metal, non-metal
		Sublevel stoping	Metal, non-metal
		Cut and fill stoping	Metal
	Caving	Longwall mining	Coal
		Block caving	Metal
Solution	–	Leaching	Metal
		Borehole	Non-metal

Table 13.1 Important methods used to mine coal, metal, and non-metal commodities

Another example described earlier is stone. As a very low-cost commodity, it would appear that surface mining would be the only economic choice. However, some limestones are of very high purity, often called 'pharmaceutical grade', and because of this they fetch higher prices.

Major mining methods are summarized in Table 13.1. These methods will be described in more detail for each of the major mining sectors of coal, metal, and non-metal. For each sector the more important underground and surface methods will be summarized. The presentation of the mining methods is then followed with an overview of mineral processing operations. A complete treatment of mining methods is given by Hartman and Mutmansky.[2]

Underground coal mining

Deep coal deposits are tabular in nature (i.e., they lie in horizontal layers), and those being mined range from under a meter to several meters in thickness, with a thickness of a few meters accounting for the majority of underground mines. Within the coal seam, rooms are mined and pillars are left behind to support the overlying strata or roof of the mine. This is known as room and pillar mining, and is conducted usually with continuous mining equipment, and rarely today with the older conventional mining equipment. Continuous mining involves equipment that both cuts and removes material without the more conventional use of drills or explosives.

As the rooms are mined a vast network of 'tunnels' is created, stretching for many miles in larger mines. These mined openings are known as 'entries' and 'cross-cuts'. As these are developed they serve as conduits for ventilating air, travel and haulage ways for people, machines, conveyor belts, and even a mine-size railway system. Indeed, the underground mine is like a small city, complete with an electricity distribution system, as well as fresh and contaminated water distribution systems. While it is protected from the weather by virtue of being underground, parts of the mine closer to the intake air portals reflect the outside air temperature due to the high volumes of air drawn into the mine, whereas parts more distant from the fresh air

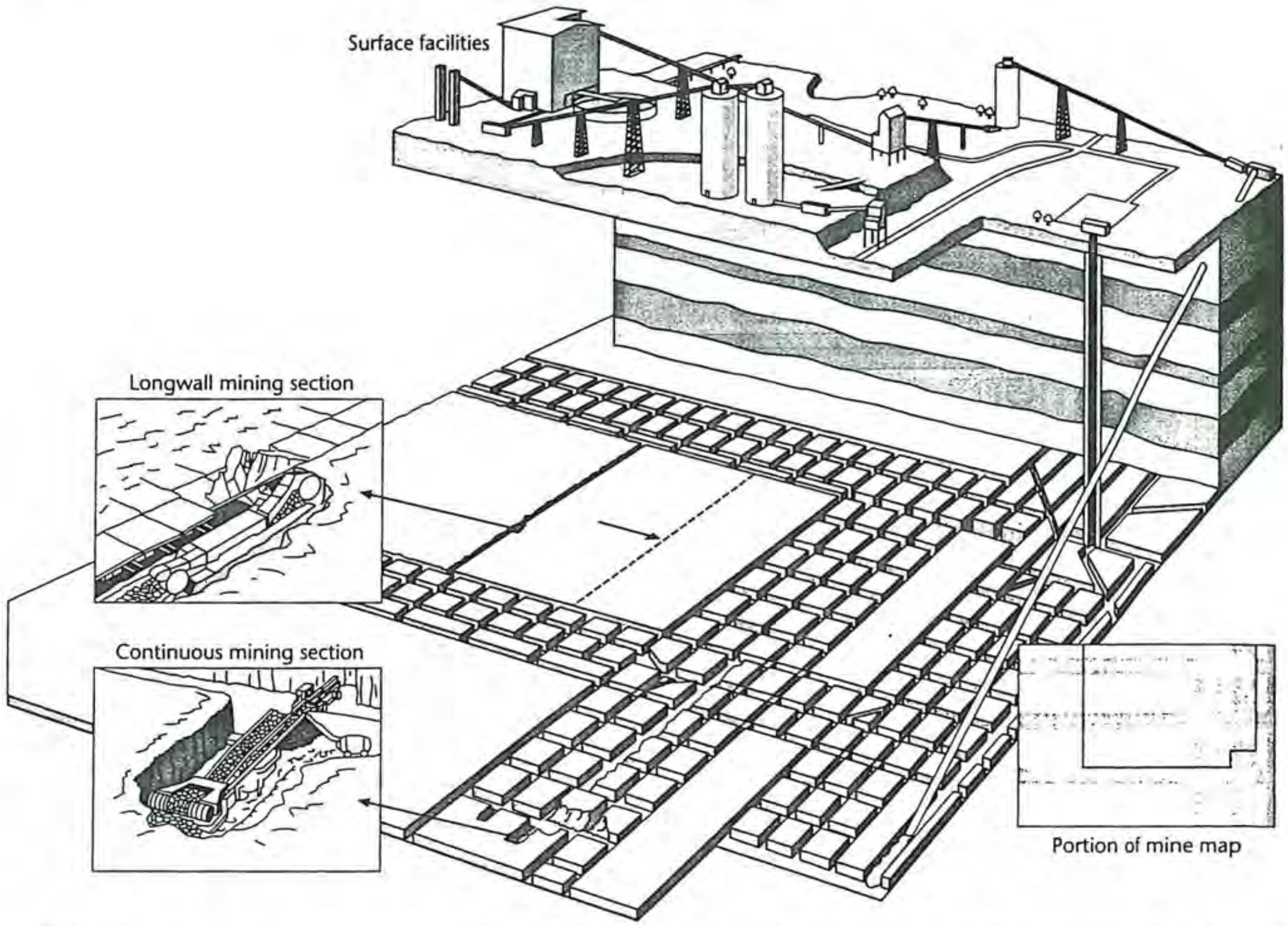


Figure 13.2: Schematic view of an underground coal mine showing the longwall panel and the 'rooms and pillars' comprising the network of underground openings.

intakes more closely reflect the temperature of the deposit. During the winter, for example, the temperature of the intake air may be well below freezing and remain near freezing through much of the main entryways of the mine, although it would be warmed by the underground rock, which may be close to 15 degrees C. By the time this air reaches the working face, the air temperature may approach 25 degrees C. Such significant temperature differentials are not uncommon in other locations and mining types. The air in some parts is further warmed by the equipment, but throughout the mine the air tends to be very humid. Some mine operations cut through or break into the water table, and in these situations it may even seem to be raining in parts of the mine with generally wet conditions throughout.

Room and pillar mining is practiced by itself in smaller mines, whereas in larger mines room and pillar mining is used to facilitate a more productive method known as longwall mining. In this method, room and pillar mining is used to create the main infrastructure – in a sense the major highways and secondary roadways of the mine 'city' – and to delineate large blocks of coal. These large blocks are then longwall mined at great efficiency and with additional safety over the room and pillar method. A brief overview of continuous and conventional mining methods is presented in Chapter 19.10. Figure 13.2 illustrates an underground coal mine with room and pillar workings and longwall panels. A longwall face is shown in Figure 13.3.

The primary hazards of underground coal mining fall into four general categories, each of which is discussed in greater detail below and in subsequent chapters:

- *traumatic injuries* – these are caused by rock falls or the consequence of large machines and people working in close proximity in a confined space;
- *cumulative stress disorders* – these disorders arise from working in a confined space in which the distance between the floor and roof may be well under a meter, necessitating extensive crawling, kneeling, and 'duck walking,' or from operating equipment mechanisms, such as remote control consoles that require repetitive motions;
- *respiratory disease* – respirable coal dust is liberated during the mining process, and silica dust is generated during different phases of mining, especially during drilling to

Figure 13.3: Coal mine longwall face, showing the shearer operator with the remote control pendant for the shearer. An important engineering control, the dust suppression water sprays, is visible, as is the personal protective equipment used by the operator. Note the confined conditions under which the operator performs the job over a period of 8–12 hours. (Photograph courtesy of Joy Mining Machinery, 2003.)

install roof bolts and from the action of longwall shields;

- *hearing loss* – the act of ripping tons of rock per minute from the deposit, rock drilling, and the many associated operations are inherently noisy, and harmful noise levels may result.

Surface coal mining

When the deposit lies close enough to the surface, it may be economically feasible to remove all of the overlying materials to expose and then mine the coal. Various methods used to do this make up surface mining, also known as open cast mining. Regardless of the specific method employed, surface coal mines follow a typical sequence of operations.

1. Vegetation is removed and soil layers are removed and stored for subsequent use.
2. The rock layers overlying the coal seam – referred to as 'overburden' – are removed and stored. Generally this overburden removal involves the drilling of holes for explosives, then blasting, loading, and hauling the overburden.
3. The exposed coal seam is mined, which may involve some additional drilling and blasting prior to loading and hauling.
4. After the coal has been harvested, the overlying materials are then returned in an exact sequence, which may involve the addition of materials such as stone or lime to neutralize acid-bearing layers and to facilitate the reclamation of the disturbed area.

Often the terrain overlying the coal is not flat but mounainous, and as mining advances the depth of the overburden will increase until it is no longer economically wise to remove it. At this point, surface mining stops, leaving an exposed highwall. Sometimes an underground coal mine will be developed, gaining access through the exposed coal seam in the highwall, and other times mining is terminated. An alternative to both of these is to engage in some form of highwall mining, in which a mining machine, such as a thin seam miner or an auger, is set up and operated on the bench – a horizontal working surface created during mining – at the highwall face. This allows some coal to be retrieved at a low cost without the expense or risk of developing an underground mine. The distance to which these machines can 'burrow' under the mountain top is of the order of 300 meters or less. While the mining operations are obviously vastly different for the surface mining of a 30-meter-thick seam in the wide open spaces of Wyoming versus a 1-meter-thick seam on a mountainside of West Virginia, similar health and safety issues exist for both.

By definition, the health and safety hazards are somewhat less in surface than underground mining. Many of the confined space issues of underground mining disappear, as do many of the respiratory hazards. The open spaces of surface mining also permit the use of cabs on equipment to protect workers from excessive noise levels, which cannot be done as practicably in an underground mine. Generally, all of these facts are also reflected in surveillance data. Nevertheless, some surface coal mineworkers are exposed to hazardous levels of respirable coal dust, and drillers have the potential to be exposed to silica dust when the overburden contains crystalline quartz. Traumatic injuries still occur, and cumulative stress disorders are as prevalent as in underground mining, although slightly different in cause.

Underground metal mining

Underground mining of deposits containing metal – called 'metaliferous' – is dramatically declining in the United States, due to the high cost of recovering relatively low-grade ores, although many new metal mines are being developed in South America, Australia, and Asia. Within the US, there are some remaining underground mines, primarily in the western part of the country, principally for mining gold, silver, lead, zinc, molybdenum, and platinum. Of course, if a high-grade deposit were discovered, it is likely that new operations would open. Metaliferous deposits tend to be complex in shape when compared to the relatively tabular coal deposits, and accordingly, the mines tend to be more complex as their workings access different parts of the deposit. These mines are typically developed at many different depths or levels, and there may be extensive development within the host rock as well as in the ore body itself.

Access into the mine is usually by way of a vertical or inclined shaft (called a 'winze'), although ramps may wind between levels as well. Various openings are mined to access the ore body, and various levels are interconnected by raises and winzes. The term 'stopes' refers to working areas where ore is being removed. Depending on the method, openings are mined to provide chutes and funneling channels to drawpoints, where the broken material is concentrated and removed. Given the complex three-dimensional nature of the mine and the varying combination of properties between the deposit and surrounding rock, a variety of caving and stoping methods have evolved. In the *caving method*, the relatively weak ore is undercut in some fashion, and the ore then 'caves' under its own weight, with or without some blasting, into areas from which it will be loaded and removed. In the *stoping method*, openings are driven into the ore body and the material is drilled, blasted, loaded, and removed. As caving methods are less costly than stoping, they can be used to recover lower-grade ores economically. As with the underground coal mine, underground metal mines usually have a significant infrastructure of utilities and materials handling systems. From an occupational health and safety perspective, however, the complex mining nuances are less important than the commonalities of health and safety risks inherent in all mining processes.

Drilling and blasting

Drilling – which utilizes large rubber-tired equipment such as jumbo drills or portable drills such as drifters or stoppers – is a major unit operation in underground metal mining. This drilling is done to provide a cavity to accept explosives and the holes are drilled to exact, calculated depths and in carefully controlled patterns. Care is taken to ensure safe and efficient rock breakage without undue overbreakage of the surrounding rock, proper size distribution of the fragments, and appropriate positioning of the blasted material. In any drilling operation, respiratory hazards are associated with generated dust and air-borne lubricants in the drill exhaust. Repetitive stress trauma and noise exposure are also common health issues associated with drilling. Cumulative stress and vibration problems are especially worrisome with portable drills.

Established blasting practices ensure that the substantial hazards of handling explosives result in very few injuries. As personnel are evacuated prior to blasting, the potential hazards of toxic fumes, dust, and noise are drastically reduced. However, it is possible for fumes to remain in a pile of blasted rock until the pile is disturbed by loading operations, with the fumes then liberated. A more common worry is the possibility of a 'bootleg' hole that failed to 'fire', leaving open the possibility of an inadvertent explosive discharge during loading with potentially serious consequences to workers in the area.

Loading and haulage

Loading of the ore, or waste rock, is likely to be done using diesel-powered vehicles in the form of separate loaders and trucks, or using a hybrid vehicle known as a load-haul-dump (LHD). The hazards associated with loading include excessive noise, diesel exhaust, and repetitive stress trauma. In some operations, electrically powered trucks may be used with a significant reduction in the respiratory hazards to the miner. Electrically powered slushers – machines that employ scraper blades to move material – are still used in some mining methods to move the ore from a drawpoint to a point where it is either loaded or flows by gravity to a collection point.

Mining support workers

In all types of mining, a large number of workers who are not involved directly in the extraction or processing nevertheless perform essential support services. Ground control, ventilation, electrical power, compressed air, and materials handling are but a few examples. In addition to being at risk for traumatic injuries, these workers also undergo health and safety risks due to their exposure to high-noise environments and from repetitive stress trauma. A significant health hazard present in many underground metal mines, but absent from most coal mines, is heat stress. Often there are significant geothermal gradients in proximity to the metaliferous deposits, and it is not unusual for the wall rock to exceed temperatures of 35 degrees C.

Surface metal mines

Open pit mining is a common method used to extract metaliferous ore bodies lying close to the surface. Unlike coal deposits, these can be a thousand meters or more in thickness, and as a result mining develops and continues downward until an economic limit is reached. In the case of an especially large deposit, this can take many years or several decades. The need to gradually spiral down through the deposit – and to facilitate the movement of equipment and ore in and out of the pit – gives rise to the characteristic shape of open pit mines. The 'steps' or benches are built to provide a working surface, and the combination of benches reduces the chance of a slope failure – when sections of the pit walls break free and fall downward with potentially disastrous results for workers below.

The general sequence of mining in open pit operations is as follows. Large drills are used to drill blastholes, which are then filled with explosives. Periodically these explosives are 'shot', resulting in a large pile of broken material, which is then loaded using front end loaders, shovels, or hydraulic excavators, and finally placed in large haul trucks. The trucks then travel out of the pit to a dump where the ore is often crushed and transported by belt to a plant for processing. Sometimes the trucks only travel partway out of the pit and then dump onto an in-pit crusher. This crusher feeds a conveyor belt that transports the ore more economically out of the pit and directly to the nearby processing plant.

The health and safety hazards are again less in surface metal mines as compared to underground mines, but still include traumatic injury, repetitive stress trauma, noise exposure, and dust. Drillers and blasters have the greatest exposure to dust and noise, and jarring and jolting can be particularly problematic for truck drivers.

Underground non-metal mining

The primary non-metallic materials mined underground include salt, trona (a mineral used as a source of sodium carbonate), and stone. Trona mining is concentrated in Wyoming, while underground salt mines are dotted in a few locations of the East and Midwest. Underground stone mines are primarily located in the East, and their numbers are increasing. Methods similar to the room and pillar used in coal mining are frequently used in these tabular stone deposits, although a more irregular spacing of the pillars is necessary in both salt and stone, and thus the method is often termed stope and pillar rather than room and pillar mining.

Trona mines utilize mining machinery similar to coal mines, whereas salt and stone mines utilize equipment more characteristic of underground metal mining. Thus continuous mining machines, full-face boring machines, and roadheaders (boom-type tunneling machines) are found in underground non-metal operations such as trona, while diesel-powered drills, front end loaders, and haul trucks are found in stone and salt mines.

Surface non-metal mining

The surface mining of non-metallics ranges over several important materials, but such mining constitutes a small portion of overall mining activity with the exception of aggregates – the mineral materials used in making concrete – including stone, sand, gravel, and dimension stone. Aggregate operations occur in large numbers throughout the country. Dimension stone is a localized but important industry in certain parts of the country, where granite, marble, and slate are carefully mined for a variety of architectural uses.

The surface mining of stone is known as quarrying, and the open pit mine is called a quarry. The unit operations and sequence of quarrying are nearly identical to those of open pit metal mining – i.e., drilling, blasting, loading, and hauling – as are the health and safety hazards.

A few different methods are used to surface mine sand and gravel. Sometimes a pit is created and the material is simply dug out with an excavator. Other times the pit is flooded and a dredge is used to recover the material. Occasionally water cannons, which generate high-powered water-jet impulses, or hydraulic monitors, devices that employ large flows of water under high pressure, are used to break the material away from a bank where it is then recovered, although this is more likely to be used in placer deposits to access precious metals. Dredging is often utilized on lakes, rivers, and harbors to recover gravel. The primary risks with sand and gravel operations are traumatic injury and noise exposure.

Dimension stone mines have remained relatively unchanged over the years. Everything in these operations centers on cutting large blocks of material, such as granite or marble, from the solid deposit, with minimal damage to either the cut block or the remaining material. Blocks of material are removed by the careful use of explosives or a high-powered mechanical saw, and then they are hoisted intact or toppled and broken into smaller blocks. The use of ever larger and more powerful mining machines has no place here. Consequently, it is still a difficult and tedious process to carefully cut sections off the solid. Many of the cutting operations are deafeningly loud, and noise exposure is a high risk. Repetitive stress trauma is also a risk, and at a lower level, so is traumatic injury. Respirable dust risks have not appeared as a significant problem in this setting.

Solution mining

Solution mining methods are limited in application, but are becoming increasingly important especially for certain commodities. Consider, for example, that approximately 35% of gold, 50% of common salt, and 100% of lithium are derived from one of the solution mining methods. Sulfur is recovered using a solution mining process known as the Frasch method, in which superheated water is pumped down holes that have been drilled into the sulfur dome to melt the sulfur. The molten mixture is then recovered through other holes, or parts of the same borehole, and the sulfur is separated from the water and other impurities. The solution mining of uranium in particular offers a much safer method than the underground room and pillar method once used in uranium mines in the US, and like the solution mining of other commodities, it offers improved health and safety benefits as well as economic ones.

A modification of the solution mining method is heap leaching, discussed earlier in 'Mining methods'. Heap leaching remains an important method for recovering gold from low-grade deposits because it is unprofitable to run the low-grade ore through the traditional circuit of a mineral processing plant. Another similar application is the leaching of copper from waste piles created from material too low in grade to be sent to the mill, or from mill tailings that may still contain small percentages of copper. Vat leaching is a similar process that is conducted in large vats rather than heaps. Evaporation operations are an important method of solution mining, in which the liquid part of the solution is evaporated, typically with solar energy, leaving the desired component.

There are no documented health problems associated with solution mining, although the hazards associated with the use of solvents containing cyanide and acids, among other chemicals, are clear. In the past, some leaching sites have created serious environmental contamination, but modern environmental regulations and engineering practices are believed to be adequate to prevent future contamination of the environment from solution mining.

Mineral processing

Mineral processing plants are part of most mining operations. Their purpose is to convert the mined ore into a product for sale or subsequent use. A sand and gravel operation typically has a plant to wash the product and separate it by size. A stone plant typically includes several circuits to crush and separate the rock into a variety of sizes. In some cases this crushing includes pulverizing the stone down to micron sizes.

Coal preparation plants are somewhat more complex. While some crushing and sizing occur to meet customer requirements, most of the processing is concerned with separating the coal from impurities to reduce the ash and sulfur content. Thus, in addition to screen sizing, gravity separations are usually performed – where specialized machinery uses gravity to separate heavier and lighter materials. Moreover, as more sulfur can be released through crushing coal to increasingly smaller sizes, there is a significant fine coal component that must be recovered through sink-float processes that are heavily dependent upon organic chemicals. The plants associated with metal mines can be the most complex, with crushing and screening circuits and significant chemical circuits to isolate and concentrate the desired and undesirable constituents. These plants may include circuits for the beneficiation of metals associated with the primary metal, e.g., bismuth from a gold operation.

The health and safety hazards related to processing depend to some extent on the type of plant. Most plants have large machinery and are multileveled with numerous potential slipping hazards, and the processes are intrinsically noisy. Respirable dust can be a problem in certain locations of these plants, particularly near crushers. Traumatic injury problems and the problems associated with excess levels of noise or respirable dust are well known and well understood in mineral processing plants. The use of toxic chemicals such as cyanide has been studied extensively, whereas the risks associated with the use of neurotoxic chemicals in coal preparation plants, for example, is understood less well. Acids and other caustic materials used in these plants present safety hazards, if proper precautions are not applied.

MINING SAFETY AND HEALTH PROBLEMS

At the end of the 19th century, mining fatalities within the US numbered greater than 2000 a year; today the figure is less than 100 per year. Similar reductions have occurred for many injury classes and occupational illnesses. In some parts of the world these metrics are slightly better than in the US and in other parts are far worse. Efforts within the US by organized labor and progressive companies, research in university and government labs, and increasingly stringent regulations by state and federal agencies have all had a positive impact on mineworkers. Nonetheless, mining occurs under extremely difficult, and sometimes unpredictable, physical and environmental conditions. The Mine Safety and Health Administration (MSHA) has a mandatory reporting system for mine injuries and fatalities, and therefore good data are available to study the number and type of fatalities and injuries by commodity, work location, geographic region, and other variables.

Occupational illnesses in mining do not occur as discrete events, and as a result they are not reported with the same degree of certainty as fatalities or lost-time injuries. In fact, it is commonly believed that occupational illnesses among mineworkers are grossly under-reported, although this has not been substantiated through study.

Non-fatal lost-time injuries

Lost-workday injuries have declined over the past decade for mine operators in all commodities. Still, the rate in 2001 was 4.4 cases per 100 full-time coal mineworkers, as compared to a rate of 2.6 for general industry. Table 13.2 summarizes the number and annual average rate of lost-workday cases associated with various types of employers and commodities by work location. Note that the order and approximate magnitude of the injuries have changed little over the past few decades. During the period 1988 to 1997, for example, the five leading types of injuries were associated with materials handling (34%), slips or falls (21%), powered haulage (11%), machinery (11%), and hand tools (9.5%). The five most severe injuries, as reflected in the median number of days lost per injury between 1996 and 2000, were falling or caving rock (20 days for underground mining and 21 days for surface mining), slips or falls (25 days for underground and 17 days for surface), powered haulage (23 days for underground and 16 days for surface), stepping/kneeling on an object (22.5 days for underground and 9 days for surface), and materials handling (19 days for underground and 12 days for surface). Sprains to the back region due to overexertion accounted for the largest proportion of lost workdays. On a positive note, the number of back injuries has decreased over the years from nearly 5500 in 1992 to approximately 3500 in 2001.[3]

Many of these injuries are attributable to the natural conditions under which mining is conducted. Small slabs of rock may peel off the roof or back of the underground mine, striking a worker and causing a serious non-fatal injury. The presence of water and clay materials in the floor can cause a dangerously slippery condition. The close proximity of large machines and workers is always hazardous, but even more so in the confined spaces of underground mines. Visibility is often limited, further exacerbating the confined space hazard.

Despite extensive research over the years, significant improvements can still be made to reduce injuries resulting from these factors. Slips and falls have been a particularly difficult injury to reduce, because they occur in diverse settings and from many causes. Materials handling injuries have been reduced through improved workplace design. The increasing practice of palletizing supplies and providing vehicles with lifting forks has dramatically reduced the lifting and manual handling of supplies and materials that must be done each day in the mine. The development of stronger yet lighter materials for roof supports and stoppings has led to a reduction in materials handling injuries. A few mines have even installed exercise facilities at the mine site and encouraged employee fitness programs, and they report anecdotal evidence of reduced back injuries.

Work-related musculoskeletal disorders (WMSDs)

The leading illnesses among mine workers reported to MSHA in 2001 (excluding hearing loss) were repetitive trauma, accounting for 45.7% of illnesses. Numerous tasks

	Work location													
			Underground mines				Surface mines							
	All		Underground		Surface areas		Strip/ open pit/ quarry		Dredge		Other surface operations†		Mills/plants	
Type of employer and commodity	Number	Rate	Number	Rate	Number	Rate	Number	Rate	Number	Rate	Number	Rate	Number	Rate
All	170,635	5.5	74,264	10.9	6272	5.7	46,396	3.6	2270	4.1	1250	4.7	40,183	4.3
Mine operator:														
Coal	89,895	7.9	65,668	11.9	4348	8.0	12,453	3.2	9	1.7	848	5.4	6569	5.0
Metal	17,622	3.9	4534	7.2	641	3.9	5152	3.1	193	4.5	214	3.3	6888	3.5
Non-metal	9855	3.7	1528	4.4	308	5.0	1623	2.7	31	5.6	NA‡	NA	6365	3.8
Stone	31,642	4.7	748	4.7	270	6.9	13,426	4.8	66	5.6	82	3.3	17,00	4.7
Sand and gravel	12,059	4.1	NA	NA	NA	NA	10,106	4.1	1953	4.2	NA	NA	NR§	NR
Independent contractor:														
Coal	4363	3.4	1367	12.1	499	2.2	1385	2.2	2	1.0	96	4.9	1014	3.8
Metal and non-metal**	5199	3.3	419	7.1	206	3.4	2251	2.4	16	1.5	10	2.3	2297	4.6

Source: MSHA 1999[23]
* Computed per 100 full-time workers or 200,000 employee hours.
† Includes culm banks, auger mining, independent shops and yards, and surface mining n.e.c.
‡ NA = Not applicable for this commodity.
§ NR = Not reported separately. Sand and gravel operators report mill employment under strip or dredge operations.
** Includes metal, non-metal, stone, and sand and gravel.

Table 13.2 Number and annual average rate* of lost-workday cases associated with various types of employers and commodities by work location, 1988–1997[3]

within mining require repetitive actions, and many of these are physically demanding. Often, especially in underground mining, these actions must be performed in awkward postures. Many underground coal miners perform tasks where the total vertical clearance available to them is less than their body height. Over the past two decades, more attention, primarily through research, has been focused on WMSDs, and on the design of mining equipment, supplies, and processes (see Chapter 23). However, during this same time, equipment innovations to achieve higher levels of efficiency and productivity have at times placed even more demands on the human body. A comprehensive treatment of ergonomic issues in mining is presented by Gallagher.[4]

Lower back problems make up a significant proportion of the WMSDs in mining. Upper body problems of the shoulder and hands are not as severe, and carpal tunnel syndrome is relatively rare in mining.[5] The increased use of remote controls, as well as other changes to mining machinery, may contribute to an increase in upper-body WMSDs.

A final WMSD of note is miner's knee. This problem occurs in workers mining in thin seams, which requires extensive walking on the hands and knees. The resulting constant pressure leads to bursitis in the knee. The combination of pressure and frequently wet conditions also leads to infected hair follicles and thickened macerating skin that is easily infected. Miner's knee is confined primarily to the low coal fields, and in the United States, predominantly appears in mineworkers from Pennsylvania, West Virginia, and Virginia. Knee pads are provided to workers, but in many cases the design of the knee pads may worsen the problem by trapping moisture under the pad, or concentrating stresses behind the knee.[6]

Hearing loss

Unlike many occupational illnesses in mining, noise-induced hearing loss (NIHL) is of epidemic proportion. NIHL and noise exposures are discussed in Chapters 20.2 and 35 respectively. Despite 30 years of regulation, research, and intervention, 91% of coal miners and 64% of metal/non-metal miners have a hearing impairment greater than 25 dB by age 50, as compared to 9% of non-exposed males of the same age.[7,8] The resulting problems of hearing-impaired mineworkers go beyond quality of life issues, and include difficulties in communication or understanding speech, along with an increased accident risk on the job when normal safety cues cannot be discerned. MSHA's enactment of more protective rules combined with significant research efforts should help stem the tide of new cases in the future. However, mining is an inherently noisy endeavor, and even if engineering controls were 100% effective and applied diligently throughout the industry, it is estimated that only 20% of future cases would be prevented. Reduction of the remaining cases will depend heavily on the use of recommended hearing protectors. While engineering or administrative controls are the preferred approach, the proper use of individual hearing protective devices must be part of the solution to address the problem effectively.

Mineworkers, like those in other occupations, do not fully appreciate the risks to their hearing, nor do they fully understand the consequences of noise-induced hearing loss. For example, a common belief is that it will simply become quieter as hearing is lost – miners are often completely unaware of tinnitus and the fact that it often accompanies NIHL. Mineworker understanding of the risks posed by excessive noise levels is essential to gaining their co-operation in maintaining noise controls, as well as getting them to take steps to protect their hearing, such as wearing hearing protectors. New training approaches are being explored to more effectively educate miners on the causes of NIHL and the actions they can take to prevent it. Low-cost personal dosimeters have been developed to empower individual mineworkers to measure their noise exposure and take protective actions as their dose accumulates during the shift.

Most noise sources found in mining cause a temporary threshold shift, and given sufficient exposures over time, the temporary shifts will become permanent. There are a few noise sources, however, which are loud enough to cause damage over relatively short time periods, so-called "impulse" noise. These include air arc welding, channel jet drilling, and the impulse noise from the detonation of some explosives. For workers exposed to these tasks in particular, it is imperative that adequate hearing protection be worn and that exposure to these sources is limited.

Work-related lung diseases

Coal worker pneumoconiosis (CWP) and silicosis are the two lung diseases most relevant to mining, discussed in greater detail in Chapters 19.10 and 19.9, respectively. CWP is more commonly referred to as black lung. CWP primarily affects underground coal workers, although cases in surface mine and coal preparation plant workers do occur infrequently. Silicosis, while affecting fewer miners, occurs across all sectors. Among the illnesses reported to MSHA in 2001, dust-related diseases made up 13.4%. Fiber-related dust diseases associated with the mining and processing of asbestos or vermiculite are rare among US mineworkers, but might be seen in areas where these commodities are actively mined.

Coal worker pneumoconiosis

Over the past three decades, average shift production levels have increased by an order of magnitude while respirable coal dust concentrations have been cut nearly in half. This is a remarkable testament to the development and application of engineering controls during this period. Despite these gains, however, CWP remains a large problem of the coal mining industry, and while there has been a steady decline in the number of cases reported per year, there is still a significant problem.

Respirable coal dust generation is largely a function of cutting rates, and therefore respirable dust increases with production. Longwall mining is the most productive coal mining method, and it is not surprising that the two highest exposure occupations are stationed at the longwall. Advances in control technology in recent years have just been able to keep up with the increasing production levels. Of course, there is less margin of error as well. If one of several control parameters is set incorrectly or a part of the dust control system malfunctions even briefly, significant concentrations of respirable dust can become air-borne. The coursing of ventilating air throughout the working face is a primary means of diluting and carrying away excess dust. However, in many cases limiting factors that could negatively affect mineworkers prevent further increases in this quantity of ventilating air.[9]

Full-shift sampling using the traditional gravimetric sampler – which employs quartz filters to collect particulate matter – captures the mineworker's exposure, but this information is not available until the sample has been weighed at the MSHA lab and the results are reported back to the mine – a process that takes weeks. Thus, the use of a real-time dust dosimeter is a crucial step towards the elimination of black lung. After years of development, prototypes of a new personal dust monitor (PDM) have been successfully tested in underground coal mines, and they are expected to be commercially available in 2005. These devices will allow mineworkers to make nearreal-time changes to the dust control system to reduce respirable dust levels. MSHA is also developing more stringent regulations, which include provisions requiring operators to utilize the PDM, to aid in the fight against CWP.

Silicosis

A chronic overexposure to respirable crystalline silica causes the progressive lung disease known as silicosis (see Chapter 19.9). The respirable crystalline silica is released by silica-bearing minerals as they are fragmented during mining processes. The strata surrounding many coal seams contain these quartz minerals. Three common sources of silica exposures in underground coal mines are:

1. cutting by the continuous miner into the roof for additional clearance or to construct overcasts;
2. drilling by the roof bolter into the roof to install bolts;
3. advancing longwall shields, which crush the immediate roof and distribute this dust as the shields move forward.

Dust exposure in coal mines

Water sprays and fan-powered dust collectors are commonly used on continuous miners to limit respirable coal dust, and are effective for reducing silica. The dry dust collection systems on roof bolters also capture much of the generated silica. A water misting system to reduce noise levels during the drilling cycle of roof bolting is undergoing field trials, and air-borne silica reduction may be an important side benefit from this noise control technology.

Despite these engineering controls, roof bolter operators are often careless when they empty and dispose of dust from the dust collection system, spilling the contents. In addition to the immediate air-borne exposure they suffer, significant amounts of respirable silica dust remain on the miner's clothes, which become a source of additional exposure for the remainder of the shift. Although this is smaller than the exposure from the actual drilling, it is not insignificant.

Dust exposure during surface coal mining occurs primarily during the drilling or handling of the silica-bearing overburden materials. Blasthole drillers can be exposed, particularly if the dust collection system around the drill-hole collar is functioning poorly, which many do. Dozer operators can have a significant exposure as they move and further break silica-bearing overburden. Front end loader operators can be overexposed as they handle these materials. Workers in the vicinity of drilling and materials handling operations can receive an overexposure as well.

To address these issues, better dust collection technology is needed for surface drills, and existing systems need to be better maintained. Part of the problem is that workers underestimate the hazard, so better worker training is needed. The widespread adoption of environmentally controlled cabs has been a boon to reducing dust as well as noise exposures, and fortunately most equipment in the surface mining industry now has cabs. Surprisingly, respirable dust concentrations within these cabs can be high. The obvious case occurs with older equipment in which cabs have holes and are poorly sealed to the outside. Many of these older cabs have poor air-conditioning systems that are unable to filter out much of the dust. These deficiencies are being addressed through the development of retrofit kits and training materials on cab sealing.

An unexpected but significant source of respirable silica is tracked into the cab on the operator's boots, and then recirculated within the cab. Some effective means of reducing this hazard are operator training, the sprinkling of a natural canola oil-base sweeping compound onto the cab floor, and improvements to the cab filtration system.[10]

Dust exposure in other mines

The generation and exposure mechanisms in metal/non-metal surface and underground mining are similar to those described for coal. In underground mining, exposure occurs primarily from drilling operations and materials handling by loaders, load-haul-dump vehicles, trucks, and slushers. Surface mining exposures come from drills, dozers, and loaders. One important difference, however, is that the crystalline silica is part of the ore itself, rather than only being present in the surrounding rock, as is the case for coal. Accordingly, a significant dust source in metal/non-metal mining occurs around crushers. For underground crushers, the problem is amplified because of the confined space and the limited ventilation. For surface crushers, dust generation is generally less of a problem because of the open-air nature of the application. Sometimes an operator is stationed at the primary crusher, but is normally inside an environmentally controlled booth and well protected from the noise and dust of the crushing operation. If the crusher is fed by trucks dumping into it, the truck driver can be overexposed depending on the site arrangements.[11]

Air quality regulations by the Environmental Protection Agency to control visible or fugitive dust help reduce the respirable dust concentrations in the vicinity of the crusher. Dust reduction in surface plants – e.g., at transfer points and stock piles – is accomplished through the use of water sprays and to a lesser extent shrouds and mechanical efforts to limit dust generation. As with coal, training of metal/non-metal mineworkers is important to ensure that available control technologies are maintained and used effectively.

Many of the silica hazards present in mining also occur in other industries where surface drilling is an integral activity. Two large populations are water well drillers and heavy construction workers. Efforts are under way to apply the lessons learned in mining to these workers as well.

Heat stress

Heat stress can occur from mining in hot environments, further discussed in Chapter 34. The temperature of virgin rock in a mine is dependent on several factors including the depth of the deposit, the proximity to geothermal gradients, and the thermal conductivity of rock overlying the deposit. As an example, the temperature may be 25 degrees C at 250 m of depth and rise to 45 degrees C at 2000 m. Heat is released into the mine environment as mining progresses, and then ventilating air passing over the hot rock is warmed, increasing the ambient air temperature. The common use of water to control dust contributes to very high humidity levels in addition to elevated temperatures. The high temperature alone, and especially in combination with the additional high wet bulb temperature, creates significant health hazards to miners. Chilling of the air used to ventilate the mine can reduce the temperature and humidity levels to uncomfortable but safe values. Heat acclimatization regimens have been developed and have been shown to reduce heat stroke among miners.[12]

The problems of mining in hot environments have not been as severe in the US as in some other mining countries, due to the nature of the deposits. This may change as deeper deposits are mined in the future. Two fatalities from heat stroke occurred in the Nevada gold mines in 2003, after several years with none reported. In addition to adverse health effects of heat stress, the adverse impact on safety is also well documented. Accident rates are decidedly higher for persons working in hot humid conditions,[13] likely due to the resulting fatigue.

Toxic fumes from blasting

Gases, including some that are toxic, are produced during the chemical reaction process of explosive detonation and deflagration. Generally these are well understood, and proper material selection and blasting techniques are used to minimize any risk to workers. A relatively new problem has shown up with increasing frequency over the past several years, and that is carbon monoxide poisoning in structures and manholes at some distance form the blast site. The problem has been observed in trench blasting for construction purposes – e.g., municipal sewer projects – and in surface coal mining. Significant quantities of CO are produced during a normal blast, but this and other gases may not be vented to the atmosphere; rather the gas is confined beneath the surface, where it then travels along a path of least resistance. This path may be fractures in the bedrock, a gas or water line path into a residential basement, and so forth.

CO is a very stable gas and may persist for days. CO poisonings (discussed further in Chapters 19.5 and 47) have been documented in both the US and Canada. Ironically, practices designed to minimize ground vibration and flyrock (rocks being propelled from the blast area), both of which are undesirable at blast sites near population centers, may contribute to excess entrapment of gas. Techniques to minimize the presence of gas and to provide relief to the atmosphere are under investigation. Until they are in practice, however, blasters are being encouraged to deploy CO detectors in nearby buildings and to recommend CO checks before workers enter any confined space, such as a manhole, near a blast site.[14,15]

Other toxic substances

A variety of toxic or potentially toxic substances are used or encountered in mining, and they range from chemicals used in mineral processing to the byproducts of operations. There are no proven adverse effects from the presence of these agents in the mining workplace. However, studies that would detect adverse health effects have not been conducted for many of these substances, or in some cases studies have been conducted but were inconclusive. Four such agents of note are diesel particulate matter, froth flotation chemicals (where chemicals are used to separate minerals from one another), solcenic (a hydraulic fluid similar in formulation to emulsifiable metalworking fluids), and molds.

Diesel particulate matter (DPM) in diesel exhaust is considered carcinogenic and DPM levels are regulated in mining (see Chapter 44). DPM emissions into the mine environment can be reduced by fuel selection, through the use of filters and catalytic converters, or with newer engine designs. However, there are significant gaps in the current understanding of these control technologies. For example, the reduction of DPM by certain converters can result in dangerously elevated levels of nitrogen oxide or the release of potentially harmful heavy metals in respirable particles.[16]

Direct worker exposure to chemicals used in modern coal preparation plants has been reduced through changes to the delivery, mixing, and application phases. Nonetheless, some exposure during maintenance and operation does occur. A link between Parkinson's disease and exposure to neurotoxic chemicals used in coal preparation has been postulated, but remains unproven.[17]

Solcenic, a non-flammable hydraulic fluid commonly used in underground coal mining, was suspected of causing respiratory disorders, work-related asthma, and allergic and irritant skin disorders among longwall coal miners, but studies have failed to establish any relationship.[18] Reasonable precautions to minimize exposure, for example from leaks in the hydraulic lines, will prevent adverse effects in susceptible individuals. Large spills may result in atmospheric formaldehyde concentrations at or above the NIOSH-recommended REL, and precautions should be taken during these atypical events to protect workers. Notwithstanding, chemical exposures in the mining industry are poorly understood, and any unexplained symptoms presented in mineworkers should be investigated with chemical exposure in mind.

Humidity and temperature conditions in mines are particularly well suited to the growth of molds. There has been increasing interest in the health effects of these molds, but no investigations have been performed to date. Special precautions are necessary for underground lead miners to ensure that lead ore is not ingested or tracked out of the workplace. Strict rules regarding showering and changing clothes before eating or leaving the mine site, among others, are successfully applied.

Work-related stress and fatigue

Work schedules in mining have changed over the years. Work-related stress and fatigue (see Chapter 28.3) are increasingly being recognized in the mining industry. Many modern operations are in production 24 hours per day or in some combination of maintenance and production round the clock. Some operations stay open on the weekends, and some work almost every day of the year. Thus, workforce scheduling is obviously a challenge in these operations, and has resulted in various shift schedules in relation to consecutive days of work, i.e., a worker might be on the job 10 consecutive days, followed by a smaller block of days off, e.g., 4. Sometimes a more extended off-period is given after several of these cycles to help reduce work-related stress and fatigue.

Rotations from first to second and then to third shift still occur, but are not as common as they once were. Mining has become increasingly capital intensive, and as such, idle time of the expensive equipment involved is less acceptable. In underground coal mining, for example, it used to be common for one crew to leave the working face and travel to the outside portal for arrival at the end of the 8-hour shift. Then the next crew departed from the portal and traveled to the working face, where it restarted the production cycle. Travel times of 30 minutes or more on each end of the shift, along with the lost-time of cycling down and then restarting production, meant that less than 60% of the total shift time was spent in production. As mining became more competitive, the practice of changing crews directly at the working face, sometimes called a hot-seat change at the face, became common. This significantly improved productivity and effectively increased the shift length by as much as 2 hours because a full 8 hours of production time per crew was established. Two 10-hour production shifts with a 4-hour maintenance period evolved as one popular schedule. Some companies even went to 12-hour shifts.

Studies have been conducted primarily on the effect of these work schedules on safety, and as expected worker fatigue and disorientation from shift rotations is a factor in accidents, although the findings are not as dramatic or definitive as might be expected. Long-term health effects on workers are less understood, although significant interest in examining stress-related health effects on cardiovascular disease and worker depression is developing in the research community, and work schedules would likely be an important focus.[19]

There was significant research interest in the effects of work organization in mining several years ago, as the changes described previously began to evolve. More recently, a new complication has developed. Deposits located far from established communities are being mined. In the US, workers are now being transported by bus for up to 2 hours each way, each day, to work a 10- or 12-hour shift as part of an extended workweek schedule. This is common in the coal fields of the Powder River Basin in Wyoming and the gold fields of Nevada, and less common elsewhere. In Australia, even more remote locations are being mined, and workers are flown in, stay for several weeks, and are then flown back out. Concern over the health effects of these practices on workers in Australia has spawned several research studies, which are now in progress.[20]

Informational resources on mining health and safety

The understanding of mining safety and health problems is increasing, as are prevention and intervention measures. The clinician is ideally positioned to detect heretofore unknown adverse health effects from occupational exposures. A detailed occupational history of the patient may provide key clues, and unexplained or otherwise worrisome relationships should be reported. NIOSH scientists can conduct targeted health hazard evaluations to investigate such concerns.

Several sources can provide timely information to supplement the technical literature. The NIOSH and MSHA websites (http://www.cdc.gov/niosh/homepage.html and http://www.msha.gov/) are good places to start. Labor unions such as the United Mineworkers of America (coal), the United Steelworkers of America (metal), and the International Union of Operating Engineers (stone) have active health and safety departments. Finally, trade associations such as the Bituminous Coal Operators' Association (coal), the National Mining Association (metal/non-metal and coal), and the National Stone, Sand, and Gravel Association also aggressively promote health and safety for mineworkers. Labor and trade organizations have partnered to solve a number of important health and safety problems, and they provide a valuable source of information and training materials, in addition to the government agencies. States with significant mining interests often have their own mining agencies as well, which provide yet another source of information.

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