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INTRODUCTION TO MINING

1.1 MINING'S CONTRIBUTION TO CIVILIZATION

Mining may well have been the second of humankind's earliest endeavors— granted that agriculture was the first. The two industries ranked together as the primary or basic industries of early civilization. Little has changed in the importance of these industries since the beginning of civilization. If we consider fishing and lumbering as part of agriculture and oil and gas production as part of mining, then agriculture and mining continue to supply all the basic resources used by modern civilization.

From prehistoric times to the present, mining has played an important part in human existence (Madigan, 1981). Here the term *mining* is used in its broadest context as encompassing the extraction of any naturally occurring mineral substances—solid, liquid, and gas—from the earth or other heavenly bodies for utilitarian purposes. The most prominent of these uses for minerals are identified in Table 1.1.

The history of mining is fascinating. It parallels the history of civilization, with many important cultural eras associated with and identified by various minerals or their derivatives: the Stone Age (prior to 4000 B.C.E.), the Bronze Age (4000 to 5000 B.C.E.), the Iron Age (1500 B.C.E. to 1780 C.E.), the Steel Age (1780 to 1945), and the Nuclear Age (1945 to the present). Many milestones in human history—Marco Polo's journey to China, Vasco da Gama's voyages to Africa and India, Columbus's discovery of the New World, and the modern gold rushes that led to the settlement of California, Alaska, South Africa, Australia, and the Canadian Klondike—were achieved with minerals providing a major incentive (Rickard, 1932). Other interesting aspects of mining and metallurgical history can be found by referring to the historical record provided by Gregory (1980), Raymond (1984), and Lacy and Lacy (1992).

Table 1.1 Humans' Uses of Minerals

Need or Use	Purpose	Age
Tools and utensils	Food, shelter	Prehistoric
Weapons	Hunting, defense, warfare	Prehistoric
Ornaments and decoration	Jewelry, cosmetics, dye	Ancient
Currency	Monetary exchange	Early
Structures and devices	Shelter, transport	Early
Energy	Heat, power	Medieval
Machinery	Industry	Modern
Electronics	Computers, communications	Modern
Nuclear fission	Power, warfare	Modern

The abundance of minerals also provides a method of creating wealth. Minerals can be marketed on the open market, enabling the countries that possess them to obtain valuable currency from countries that do not. This generally results in the minerals-rich countries being the great civilizations of the world while the 'have-not' countries generally suffer from a lower standard of living. For more on this topic, see Section 1.6. The ability to use mineral resources as a means of creating wealth opens the possibility that a given country or countries will attempt to control the entire market in a particular mineral, that is, to create an economic cartel in that mineral. In 1973, the Organization of Petroleum Exporting Countries (OPEC) attempted to control oil prices in a bold maneuver to obtain windfall profits from the oil they produced. Although successful in the short run, the cartel eventually lost effectiveness because of increased oil production elsewhere and difficulty in controlling their own member countries. For a few years, OPEC was successful at regulating petroleum prices in an awesome display of the value of possessing and producing some of the world's most valuable minerals. Other cartels have likewise been attempted. However, the greater freedom in international trade now makes such an attempt less likely to succeed.

1.2 MINING TERMINOLOGY

There are many terms and expressions unique to mining that characterize the field and identify the user of such terms as a "mining person." The student of mining is thus advised to become familiar with all the terms used in mining, particularly those that are peculiar to either mines or minerals. Most of the mining terminology is introduced in the sections of this book where they are most applicable. Some general terms are best defined at the outset; these are outlined here. For a complete list of mining terminology, see a standard reference (Gregory, 1980; American Geological Institute, 1997). The following three terms are closely related:

Mine: an excavation made in the earth to extract minerals

Mining: the activity, occupation, and industry concerned with the extraction of minerals

Mining engineering: the practice of applying engineering principles to the development, planning, operation, closure, and reclamation of mines

Some terms distinguish various types of mined minerals. Geologically, one can distinguish the following mineral categories:

Mineral: a naturally occurring inorganic element or compound having an orderly internal structure and a characteristic chemical composition, crystal form, and physical properties

Rock: any naturally formed aggregate of one or more types of mineral particles

Economic differences in the nature of mineral deposits is evident in the following terms:

Ore: a mineral deposit that has sufficient utility and value to be mined at a profit.

Gangue: the valueless mineral particles within an ore deposit that must be discarded.

Waste: the material associated with an ore deposit that must be mined to get at the ore and must then be discarded. Gangue is a particular type of waste.

A further subdivision of the types of minerals mined by humankind is also common. These terms are often used in the industry to differentiate between the fuels, metals, and nonmetallic minerals. The following are the most common terms used in this differentiation:

Metallic ores: those ores of the ferrous metals (iron, manganese, molybdenum, and tungsten), the base metals (copper, lead, zinc, and tin), the precious metals (gold, silver, the platinum group metals), and the radioactive minerals (uranium, thorium, and radium).

Nonmetallic minerals (also known as industrial minerals): the nonfuel mineral ores that are not associated with the production of metals. These include phosphate, potash, halite, trona, sand, gravel, limestone, sulfur, and many others.

Fossil fuels (also known as *mineral fuels*): the organic mineral substances that can be utilized as fuels, such as coal, petroleum, natural gas, coalbed methane, gilsonite, and tar sands.

It should be noted that the mining engineer is associated with the extraction of nearly all these mineral resources. However, the production of petroleum and natural gas has evolved into a separate industry with a specialized technology of its own. These mineral products will not be discussed in any detail here.

The essence of mining in extracting mineral wealth from the earth is to drive an excavation or excavations from the surface to the mineral deposit. Normally, these openings into the earth are meant to allow personnel to enter into the underground deposit. However, boreholes are at times used to extract the mineral values from the earth. These fields of boreholes are also called mines, as they are the means to mine a mineral deposit, even if no one enters into the geologic realm of the deposit. Note that when the economic profitability of a mineral deposit has been established with some confidence, *ore* or *ore deposit* is preferred as the descriptive term for the mineral occurrence. However, coal and industrial mineral deposits are often not so designated, even if their profitability has been firmly established. If the excavation used for mining is entirely open or operated from the surface, it is termed a *surface mine*. If the excavation consists of openings for human entry below the earth's surface, it is called an *underground mine*. The details of the procedure, layout, and equipment used in the mine distinguish the *mining method*. This is determined by the geologic, physical, environmental, economic, and legal circumstances that pertain to the ore deposit being mined.

Mining is never properly done in isolation, nor is it an entity in itself. It is preceded by *geologic investigations* that locate the deposit and *economic analyses* that prove it financially feasible. Following extraction of the fuel, industrial mineral, or metallic ore, the run-of-mine material is generally cleaned or concentrated. This preparation or beneficiation of the mineral into a higher-quality product is termed *mineral processing*. The mineral products so produced may then undergo further concentration, refinement, or fabrication during *conversion*, *smelting*, or *refining* to provide consumer products. The end step in converting a mineral material into a useful product is *marketing*.

Quite frequently, excavation in the earth is employed for purposes other than mining. These include *civil* and *military works* in which the object is to produce a stable opening of a desired size, orientation, and permanence. Examples are vehicular, water, and sewer tunnels, plus underground storage facilities, waste disposal areas, and military installations. Many of these excavations are produced by means of standard mining technology.

Professionally, the fields of endeavor associated with the mineral industries are linked to the phase or stage in which an activity occurs. Locating and exploring a mineral deposit fall in the general province of *geology* and the earth sciences. *Mining engineering*, already defined, encompasses the proving (with the geologist), planning, developing, and exploiting of a mineral deposit. The mining engineer may also be involved with the closure and reclamation of the mine property, although he or she may share those duties with those in the environmental fields. The fields of processing, refining, and fabricating are assigned to *metallurgy*, although there is often some overlap in the mineral processing area with mining engineering.

1.3 ADVANCEMENTS IN MINING TECHNOLOGY

As one of humanity's earliest endeavors — and certainly one of its first organized industries — mining has an ancient and venerable history (Gregory, 1980). To understand modern mining practices, it is useful to trace the evolution of mining technology, which (as pointed out earlier in this chapter) has paralleled human evolution and the advance of civilization.

Mining in its simplest form began with Paleolithic humans some 450,000 years ago, evidenced by the flint implements that have been found with the bones of early humans from the Old Stone Age (Lewis and Clark, 1964). Our ancestors extracted pieces from loose masses of flint or from easily accessed outcrops and, using crude methods of chipping the flint, shaped them into tools and weapons. By the New Stone Age, humans had progressed to underground mining in systematic openings 2 to 3 ft (0.6 to 0.9 m) in height and more than 30 ft (9 m) in depth (Stoces, 1954). However, the oldest known underground mine, a hematite mine at Bomvu Ridge, Swaziland (Gregory, 1980), is from the Old Stone Age and believed to be about 40,000 years old. Early miners employed crude methods of ground control, ventilation, haulage, hoisting, lighting, and rock breakage. Nonetheless, mines attained depths of 800 ft (250 m) by early Egyptian times.

Metallic minerals also attracted the attention of prehistoric humans. Initially, metals were used in their native form, probably obtained by washing river gravel in placer deposits. With the advent of the Bronze and Iron Ages, however, humans discovered smelting and learned to reduce ores into pure metals or alloys, which greatly improved their ability to use these metals.

The first challenge for early miners was to break the ore and loosen it from the surrounding rock mass. Often, their crude tools made of bone, wood, and stone were no match for the harder rock, unless the rock contained crevices or cracks that could be opened by wedging or prying. As a result, they soon devised a revolutionary technique called *fire setting*, whereby they first heated the rock to expand it and then doused it with cold water to contract and break it. This was one of the first great advances in the science of rock breakage and had a greater impact than any other discovery until dynamite was invented by Alfred Nobel in 1867.

Mining technology, like that of all industry, languished during the Dark Ages. Notably, a political development in 1185 improved the standing of mining and the status of miners, when the bishop of Trent granted a charter to miners in his domain. It gave miners legal as well as social rights, including the right to stake mineral claims. A milestone in the history of mining, the edict has had long-term consequences that persist to this day.

The greatest impact on the need for and use of minerals, however, was provided by the Industrial Revolution at the close of the eighteenth century. Along with the soaring demand for minerals came spectacular improvements in mining technology, especially in scientific concepts and mechanization, that have continued to this day.

During the last two centuries, there has been great progress in mining technology in many different areas. Such progress is often made in an evolutionary rather than a revolutionary manner. Yet every once in a while, a revolutionary discovery comes along and changes the process of mining profoundly. During the nineteenth century, the invention of dynamite was the most important advance. In the twentieth century, the invention of continuous mining equipment, which extracts the softer minerals like coal without the use of explosives, was perhaps the most notable of these acccomplishments. The first continuous miner was tested in about 1940, with its usefulness greatly enhanced by the development of tungsten carbide inserts in 1945 by McKenna Metals Company (now Kennametal). By 1950 the continuous miner had started to replace other coal mining methods. The era of mechanized mining had begun.

It is not possible to chronicle all of the developments that made mining what it is today. A more complete chronology of the important events is outlined in Table 1.2. It has been prepared using the references cited in Section 1.1, as well as those by Stack (1982) and Molloy (1986). These sources can be used to obtain a more comprehensive list of the crucial events in the development of mining technology.

1.4 STAGES IN THE LIFE OF A MINE

The overall sequence of activities in modern mining is often compared with the five stages in the life of a mine: *prospecting*, *exploration*, *development*, *exploitation*, and *reclamation*. Prospecting and exploration, precursors to actual mining, are linked and sometimes combined. Geologists and mining engineers often share responsibility for these two stages — geologists more involved with the former, mining engineers more with the latter. Likewise, development and exploitation are closely related stages; they are usually considered to constitute mining proper and are the main province of the mining engineer. Reclamation has been added to these stages since the first edition, to reflect the times. Closure and reclamation of the mine site has become a necessary part of the mine life cycle because of the demands of society for a cleaner environment and stricter laws regulating the abandonment of a mine. The overall process of developing a mine with the future uses of the land in mind is termed *sustainable development*. This concept was defined in a book entitled *Our Common Future* (World Commission on Environment and Development, 1987) as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." The ideas presented therein have been widely endorsed as a practical means of providing for future generations. The five stages in the life of a mine are summarized in Table 1.3 and are discussed in the following sections. There will be more extensive discussion of these stages in Chapters 2, 3, and 4.

TABLE 1.2 Chronological Development of Mining Technology

Date	Event
450,000 B.C.E.	First mining (at surface), by Paleolithic humans for stone implements.
40,000	Surface mining progresses underground, in Swaziland, Africa.
30,000	Fired clay pots used in Czechoslovakia.
18,000	Possible use of gold and copper in native form.
5000	Fire setting, used by Egyptians to break rock.
4000	Early use of fabricated metals; start of Bronze Age.
3400	First recorded mining, of turquoise by Egyptians in Sinai.
3000	Probable first smelting, of copper with coal by Chinese; first use of iron implements by Egyptians.
2000	Earliest known gold artifacts in New World, in Peru.
1000	Steel used by Greeks.
100 C.E.	Thriving Roman mining industry.
122	Coal used by Romans in present-day United Kingdom.
1185	Edict by bishop of Trent gives rights to miners.
1524	First recorded mining in New World, by Spaniards in Cuba.
1550	First use of lift pump, at Joachimstal, Czechoslovakia.
1556	First mining technical work, *De Re Metallica*, published in Germany by Georgius Agricola.
1585	Discovery of iron ore in North America, in North Carolina.
1600s	Mining commences in eastern United States (iron, coal, lead, gold).
1627	Explosives first used in European mines, in Hungary (possible prior use in China).
1646	First blast furnace installed in North America, in Massachusetts.
1716	First school of mines established, at Joachimstal, Czechoslovakia.
1780	Beginning of Industrial Revolution; pumps are first modern machines used in mines.
1800s	Mining progresses in United States; gold rushes help open the West.
1815	Sir Humphrey Davy invents miner's safety lamp in England.
1855	Bessemer steel process first used, in England.
1867	Dynamite invented by Nobel, applied to mining.
1903	Era of mechanization and mass production opens in U.S. mining with development of first low-grade copper porphyry, in Utah; although the first modern mine was an open pit, subsequent operations were underground as well.
1940	First continuous miner initiates the era of mining without explosives.
1945	Tungsten carbide bits developed by McKenna Metals Company (now Kennametal).

1.4.1 Prospecting

Prospecting, the first stage in the utilization of a mineral deposit, is the search for ores or other valuable minerals (coal or nonmetallics). Because mineral deposits may be located either at or below the surface of the earth, both direct and indirect prospecting techniques are employed.

TABLE 1.3 Stages in the Life of a Mine

Stage/ (Project Name)	Procedure	Time	Cost/Unit Cost
	Precursors to Mining		
1. Prospecting (Mineral deposit)	Search for ore a. Prospecting methods Direct: physical geologic Indirect: geophysical, geochemical b. Locate favorable loci (maps, literature, old mines) c. Air: aerial photography, airborne geophysics, satellite d. Surface: ground geophysics, geology e. Spot anomaly, analyze, evaluate	1–3 yr	\$0.2–10 million or \$0.05–1.00/ton (\$0.05–1.10/tonne)
2. Exploration (Ore body)	Defining extent and value of ore (examination/evaluation a. Sample (drilling or excavation), assay, test b. Estimate tonnage and grade c. Valuate deposit (Hoskold formula or discount method): present value = income − cost Feasibility study: make decision to abandon or develop.	2–5 yr	\$1–15 million or \$0.20–1.50/ton (\$0.22–1.65/tonne)
	Mining Proper		
3. Development (Prospect)	Opening up ore deposit for production a. Acquire mining rights (purchase or lease), if not done in stage 2 b. File environmental impact statement, technology assessment, permit c. Construct access roads, transport system d. Locate surface plant, construct facilities e. Excavate deposit (strip or sink shaft)	2–5 yr	\$10–500 million or \$0.25–10.00/ton (\$0.275–11.00/tonne)

Stage/ (Project Name)	Procedure	Time	Cost/Unit Cost
4. Exploitation (Mine)	Large-scale production of ore a. Factors in choice of method: geologic, geographic, economic, environmental, societal safety b. Types of mining methods Surface: open pit, open cast, etc. Underground: room and pillar, block caving, etc. c. Monitor costs and economic payback (3–10 yr)	10–30 yr	\$5–75 million/yr or \$2.00–150/ton (\$2.20–165/tonne)
	Post-mining		
5. Reclamation (Real estate)	Restoration of site a. Removal of plant and buildings b. Reclamation of waste and tailings dumps c. Monitoring of discharges	1–10 yr	\$1–20 million \$0.20–4.00/ton (\$0.22–4.40/tonne)

The *direct method* of discovery, normally limited to surface deposits, consists of visual examination of either the exposure (outcrop) of the deposit or the loose fragments (float) that have weathered away from the outcrop. Geologic studies of the entire area augment this simple, direct technique. By means of aerial photography, geologic maps, and structural assessment of an area, the geologist gathers evidence by direct methods to locate mineral deposits. Precise mapping and structural analysis plus microscopic studies of samples also enable the geologist to locate the hidden as well as surface mineralization.

The most valuable scientific tool employed in the *indirect search* for hidden mineral deposits is geophysics, the science of detecting anomalies using physical measurements of gravitational, seismic, magnetic, electrical, electromagnetic, and radiometric variables of the earth. The methods are applied from the air, using aircraft and satellites; on the surface of the earth; and beneath the earth, using methods that probe below the topography. Geochemistry, the quantitative analysis of soil, rock, and water samples, and geobotany, the analysis of plant growth patterns, can also be employed as prospecting tools.

1.4.2 Exploration

The second stage in the life of a mine, *exploration*, determines as accurately as possible the size and value of a mineral deposit, utilizing techniques similar to but more refined than those used in prospecting. The line of demarcation between prospecting and exploration is not sharp; in fact, a distinction may not be possible in some cases. Exploration generally shifts to surface and subsurface locations, using a variety of measurements to obtain a more positive picture of the extent and grade of the ore body. Representative samples may be subjected to chemical, metallurgical, X ray, spectrographic, or radiometric evaluation techniques that are meant to enhance the investigator's knowledge of the mineral deposit. Samples are obtained by chipping outcrops, trenching, tunneling, and drilling; in addition, borehole logs may be provided to study the geologic and structural makeup of the deposit. Rotary, percussion, or diamond drills can be used for exploration purposes. However, diamond drills are favored because the cores they yield provide knowledge of the geologic structure. The core is normally split along its axis; one half is analyzed, and the other half is retained intact for further geologic study.

An evaluation of the samples enables the geologist or mining engineer to calculate the tonnage and grade, or richness, of the mineral deposit. He or she estimates the mining costs, evaluates the recovery of the valuable minerals, determines the environmental costs, and assesses other foreseeable factors in an effort to reach a conclusion about the profitability of the mineral deposit. The crux of the analysis is the question of whether the property is just another mineral deposit or an ore body. For an ore deposit, the overall process is called *reserve estimation*, that is, the examination and valuation of the ore body. At the conclusion of this stage, the project is developed, traded to another party, or abandoned.

1.4.3 Development

In the third stage, *development*, the work of opening a mineral deposit for exploitation is performed. With it begins the actual mining of the deposit, now called the ore. Access to the deposit must be gained either (1) by stripping the overburden, which is the soil and/or rock covering the deposit, to expose the near-surface ore for mining or (2) by excavating openings from the surface to access more deeply buried deposits to prepare for underground mining.

In either case, certain preliminary development work, such as acquiring water and mineral rights, buying surface lands, arranging for financing, and preparing permit applications and an environmental impact statement (EIS), will generally be required before any development takes place. When these steps have been achieved, the provision of a number of requirements — access roads, power sources, mineral transportation systems, mineral processing facilities, waste disposal areas, offices, and other support facilities — must precede actual mining in most cases. Stripping of the overburden will then proceed if the minerals are to be mined at the surface. Economic considerations determine the *stripping ratio*, the ratio of waste removed to ore recovered; it may range from as high as 45 yd^3/ton (38 m^3/tonne) for coal mines to as low as 1.0 yd^3/ton (0.8 m^3/tonne) in metal mines. Some nonmetallic mines have no overburden to remove; the mineral is simply excavated at the surface.

Development for underground mining is generally more complex and expensive. It requires careful planning and layout of access openings for efficient mining, safety, and permanence. The principal openings may be shafts, slopes, or adits; each must be planned to allow passage of workers, machines, ore, waste, air, water, and utilities. Many metal mines are located along steeply dipping deposits and thus are opened from shafts, while drifts, winzes, and raises serve the production areas. Many coal and nonmetallic mines are found in nearly horizontal deposits. Their primary openings may be drifts or entries, which may be distinctly different from those of metal mines. These differences are outlined in Chapters 4, 7, 8, and 10 to 14.

1.4.4 Exploitation

Exploitation, the fourth stage of mining, is associated with the actual recovery of minerals from the earth in quantity. Although development may continue, the emphasis in the production stage is on production. Usually only enough development is done prior to exploitation to ensure that production, once started, can continue uninterrupted throughout the life of the mine.

The mining method selected for exploitation is determined mainly by the characteristics of the mineral deposit and the limits imposed by safety, technology, environmental concerns, and economics. Geologic conditions, such as the dip, shape, and strength of the ore and the surrounding rock, play a key role in selecting the method. *Traditional exploitation methods* fall into two broad categories based on locale: surface or underground. *Surface mining* includes mechanical excavation methods such as open pit and open cast (strip mining), and aqueous methods such as placer and solution mining. *Underground mining* is usually classified in three categories of methods: unsupported, supported, and caving.

1.4.4.1 Surface Mining. Surface mining is the predominant exploitation procedure worldwide, producing in the United States about 85% of all minerals, excluding petroleum and natural gas. Almost all metallic ores (98%), about 97% of the nonmetallic ores, and 61% of the coal in the United States are mined using surface methods (U.S. Geological Survey, 1995; Energy Information Administration, 2000), and most of these are mined by open pit or open cast methods. In *open pit mining*, a *mechanical extraction method*, a thick deposit is generally mined in benches or steps, although thin deposits may require only a single bench or face. Open pit or open cast mining is usually employed to exploit a near-surface deposit or one that has a low stripping ratio. It often necessitates a large capital investment but generally results in high productivity, low operating cost, and good safety conditions.

The *aqueous extraction methods* depend on water or another liquid (e.g., dilute sulfuric acid, weak cyanide solution, or ammonium carbonate) to extract the mineral. *Placer mining* is used to exploit loosely consolidated deposits like common sand and gravel or gravels containing gold, tin, diamonds, platinum, titanium, or coal. *Hydraulicking* utilizes a high-pressure stream of water that is directed against the mineral deposit (normally but not always a placer), undercutting it, and causing its removal by the erosive actions of the water. *Dredging* performed from floating vessels, accomplishes the extraction of the minerals mechanically or hydraulically. *Solution mining* includes both *borehole mining*, such as the methods used to extract sodium chloride or sulfur, and *leaching*, either through drillholes or in dumps or heaps on the surface. Placer and solution mining are among the most economical of all mining methods but can only be applied to limited categories of mineral deposits.

1.4.4.2 Underground Mining. Underground methods — unsupported, supported, and caving — are differentiated by the type of wall and roof supports used, the configuration and size of production openings, and the direction in which mining operations progress. The *unsupported methods* of mining are used to extract mineral deposits that are roughly tabular (plus flat or steeply dipping) and are generally associated with strong ore and surrounding rock. These methods are termed *unsupported* because they do not use any artificial pillars to assist in the support of the openings. However, generous amounts of roof bolting and localized support measures are often used. *Room-and-pillar mining* is the most common unsupported method, used primarily for flat-lying seams or bedded deposits like coal, trona, limestone, and salt. Support of the roof is provided by natural pillars of the mineral that are left standing in a systematic pattern. *Stope-and-pillar mining* (a stope is a production opening in a metal mine) is a similar method used in noncoal mines where thicker, more irregular ore bodies occur; the pillars are spaced randomly and located in low-grade ore so that the high-grade ore can be extracted. These two methods account for almost all of the underground mining in horizontal deposits in the United States and a very high proportion of the underground tonnage as well. Two other methods applied to steeply dipping deposits are also included in the unsupported category. In *shrinkage stoping*, mining progresses upward, with horizontal slices of ore being blasted along the length of the stope. A portion of the broken ore is allowed to accumulate in the stope to provide a working platform for the miners and is thereafter withdrawn from the stope through chutes. *Sublevel stoping* differs from shrinkage stoping by providing sublevels from which vertical slices are blasted. In this manner, the stope is mined horizontally from one end to the other. Shrinkage stoping is more suitable than sublevel stoping for stronger ore and weaker wall rock.

Supported mining methods are often used in mines with weak rock structure. *Cut-and-fill stoping* is the most common of these methods and is used primarily in steeply dipping metal deposits. The cut-and-fill method is practiced both in the overhand (upward) and in the underhand (downward) directions. As each horizontal slice is taken, the voids are filled with a variety of fill types to support the walls. The fill can be rock waste, tailings, cemented tailings, or other suitable materials. Cut-and-fill mining is one of the more popular methods used for vein deposits and has recently grown in use. *Square-set stoping* also involves backfilling mine voids; however, it relies mainly on timber sets to support the walls during mining. This mining method is rapidly disappearing in North America because of the high cost of labor. However, it still finds occasional use in mining high-grade ores or in countries where labor costs are low. *Stull stoping* is a supported mining method using timber or rock bolts in tabular, pitching ore bodies. It is one of the methods that can be applied to ore bodies that have dips between 10° and 45°. It often utilizes artificial pillars of waste to support the roof.

Caving methods are varied and versatile and involve caving the ore and/or the overlying rock. Subsidence of the surface normally occurs afterward. *Longwall mining* is a caving method particularly well adapted to horizontal seams, usually coal, at some depth. In this method, a face of considerable length (a long face or wall) is maintained, and as the mining progresses, the overlying strata are caved, thus promoting the breakage of the coal itself. A different method, *sublevel caving*, is employed for a dipping tabular or massive deposit. As mining progresses downward, each new level is caved into the mine openings, with the ore materials being recovered while the rock remains behind. *Block caving* is a large-scale or bulk mining method that is highly productive, low in cost, and used primarily on massive deposits that must be mined underground. It is most applicable to weak or moderately strong ore bodies that readily break up when caved. Both block caving and longwall mining are widely used because of their high productivity.

In addition to these conventional methods, *innovative methods* of mining are also evolving. These are applicable to unusual deposits or may employ unusual techniques or equipment. Examples include automation, rapid excavation, underground gasification or liquifaction, and deep-sea mining.

1.4.5 Reclamation

The final stage in the operation of most mines is *reclamation*, the process of closing a mine and recontouring, revegetating, and restoring the water and land values. The best time to begin the reclamation process of a mine is before the first excavations are initiated. In other words, mine planning engineers should plan the mine so that the reclamation process is considered and the overall cost of mining plus reclamation is minimized, not just the cost of mining itself. The new philosophy in the mining industry is *sustainability*, that is, the meeting of economic and environmental needs of the present while enhancing the ability of future generations to meet their own needs (National Mining Association, 1998).

In planning for the reclamation of any given mine, there are many concerns that must be addressed. The first of these is the safety of the mine site, particularly if the area is open to the general public. The removal of office buildings, processing facilities, transportation equipment, utilities, and other surface structures must generally be accomplished. The mining company is then required to seal all mine shafts, adits, and other openings that may present physical hazards. Any existing highwalls or other geologic structures may require mitigation to prevent injuries or death due to geologic failures.

The second major issue to be addressed during reclamation of a mine site is restoration of the land surface, the water quality, and the waste disposal areas so that long-term water pollution, soil erosion, dust generation, or vegetation problems do not occur. The restoration of native plants is often a very important part of this process, as the plants help build a stable soil structure and naturalize the area. It may be necessary to carefully place any rock or tailings with acid-producing properties in locations where rainfall has little effect on the material and acid production is minimized. The same may be true of certain of the heavy metals that pollute streams. Planning of the waste dumps, tailings ponds, and other disturbed areas will help prevent pollution problems, but remediation work may also be necessary to complete the reclamation stage of mining and satisfy the regulatory agencies.

The final concern of the mine planning engineer may be the subsequent use of the land after mining is completed. Old mine sites have been converted to wildlife refuges, shopping malls, golf courses, airports, lakes, underground storage facilities, real estate developments, solid waste disposal areas, and other uses that can benefit society. By planning the mine for a subsequent development, mine planners can enhance the value of the mined land and help convert it to a use that the public will consider favorable. The successful completion of the reclamation of a mine will enhance public opinion of the mining industry and keep the mining company in the good graces of the regulatory agencies. The fifth stage of the mine is thus of paramount importance and should be planned at the earliest possible time in the life of the mine.

1.5 UNIT OPERATIONS OF MINING

During the development and exploitation stages of mining when natural materials are extracted from the earth, remarkably similar unit operations are normally employed. The *unit operations* of mining are the basic steps used to produce mineral from the deposit, and the auxiliary operations that are used to support them. The steps contributing directly to mineral extraction are *production operations*, which constitute the production cycle of operations. The ancillary steps that support the production cycle are termed *auxiliary operations*.

The production cycle employs unit operations that are normally grouped into *rock breakage* and *materials handling*. Breakage generally consists of drilling and blasting, and materials handling encompasses loading or excavation and haulage (horizontal transport) and sometimes hoisting (vertical or inclined transport). Thus, the basic production cycle consists of these unit operations:

$$\text{Production cycle} = \text{drill} + \text{blast} + \text{load} + \text{haul}$$

Although production operations tend to be separate and cyclic in nature, the trend in modern mining and tunneling is to eliminate or combine functions and to increase continuity of extraction. For example, in coal and other soft rock mines, continuous miners break and load the mineral to eliminate drilling and blasting; boring machines perform the same tasks in medium-hard rock. The cycle of operations in surface and underground mining differs primarily by the scale of the equipment. Specialized machines have evolved to meet the unique needs of the two regimes.

In modern surface mining, blastholes of 3 to 15 in. (75 to 380 mm) in diameter are produced by rotary or percussion drills for the placement of explosives when consolidated rock must be removed. The explosive charge is then inserted and detonated to reduce the overburden or ore to a size range suitable for excavation. The broken material is loaded by shovel, dragline, or wheel loader into haulage units — generally trucks — for transport. Railroad cars are also used for haulage, and belt conveyors are often used after the material is crushed. Soil and coal are often moved in the same manner, though blasting is sometimes unnecessary. In the quarrying of dimension stone, the blocks are often freed without blasting, using wire saws or other mechanical devices.

In underground mining, the production cycle is similar, although the equipment used may be scaled down in size. Smaller drillholes are used, trucks are sometimes replaced by shuttle cars, and belt conveyors are more prevalent. Coal, salt, potash, and trona are often mined without the use of explosives or mined after undercutting the face to reduce the consumption of explosives.

In addition to the operations of the production cycle, certain auxiliary operations must be performed in many cases. Underground, these usually include roof support, ventilation and air-conditioning, power supply, pumping, maintenance, lighting, communications, and delivery of compressed air, water, and supplies to the working sections. In surface mining, the primary auxiliary operations include those providing slope stability, pumping, power supply, maintenance, waste disposal, and supply of material to the production centers.

1.6 ECONOMICS OF THE MINERAL INDUSTRIES

1.6.1 Mineral Production

It has been estimated that only a fraction of 1% of the earth's surface is underlain with mineral deposits of commercial value. From this resource, the United States extracted nearly 60 billion in mineral values in 1997: $27 billion

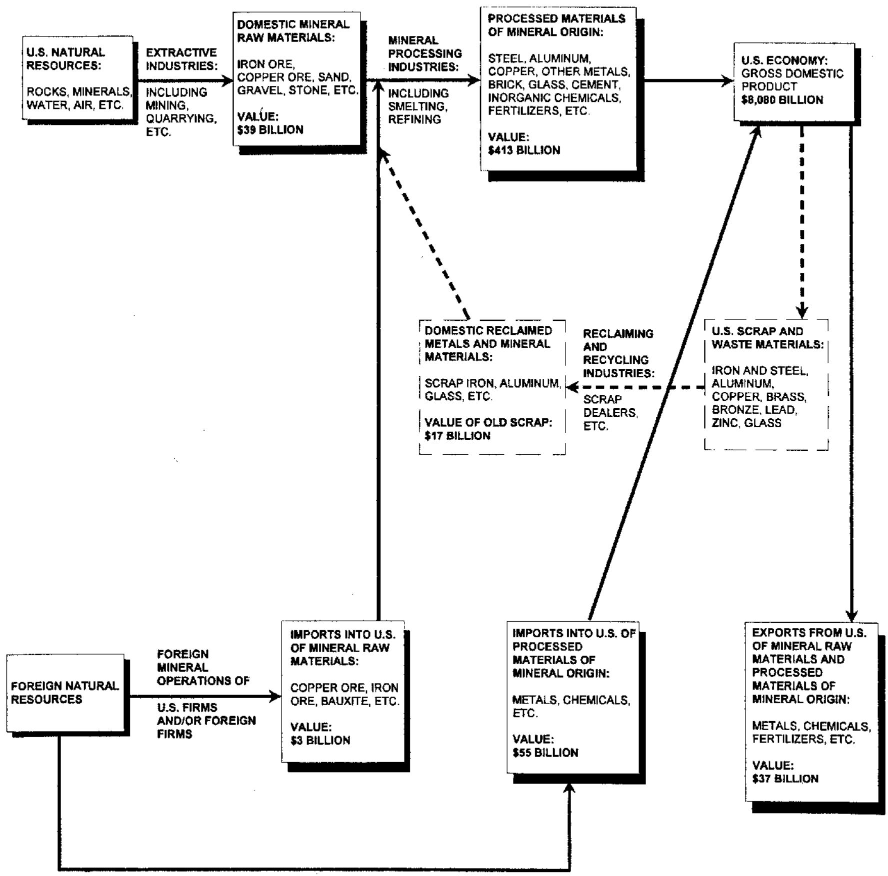

FIGURE 1.1. The role of nonfuel minerals in the U.S. economy (estimated values in 1998). *Source:* U.S. Geological Survey (1999).

worth of industrial minerals, $20 billion worth of coal, and $12 billion worth of metals (National Mining Association, 1998). Additional information on the value of minerals production in the United States can be found in Figure 1.1 (U.S. Geological Survey, 1999). This figure shows that the net value of exports of nonfuel mineral raw materials and materials processed from minerals has a value of about $35 billion per annum. In addition, about 355,000 people are employed by the mining industry in the United States, and every man, woman, and child in this country requires 23 tons (21 tonnes) of minerals, including nearly 4 tons (3.6 tonnes) of coal, each year to maintain his or her modern lifestyle (National Mining Association, 1998).

World consumption of minerals has increased to such an extent in modern times that more minerals were used in the twentieth century than were used since the beginning of history. This has occurred because we are now a society that depends on automobiles, trains, and airplanes for transportation; telephones, television, and computers for communications; fertilizers and heavy machinery for our agricultural output; industrial minerals for home building products; and coal-fired and nuclear plants for our electrical power. These human and industrial services in turn depend on the production of minerals and mineral products in great amounts.

The United States produces a very large tonnage of mineral products, but it has nevertheless become a major and growing importer of minerals, as shown in Figure 1.2. This country now imports more than 70% of its potash, chromium, tungsten, tin, and cobalt, plus almost all (better than 90%) of its fluorspar, manganese, and aluminum ore. Although it has increased imports of

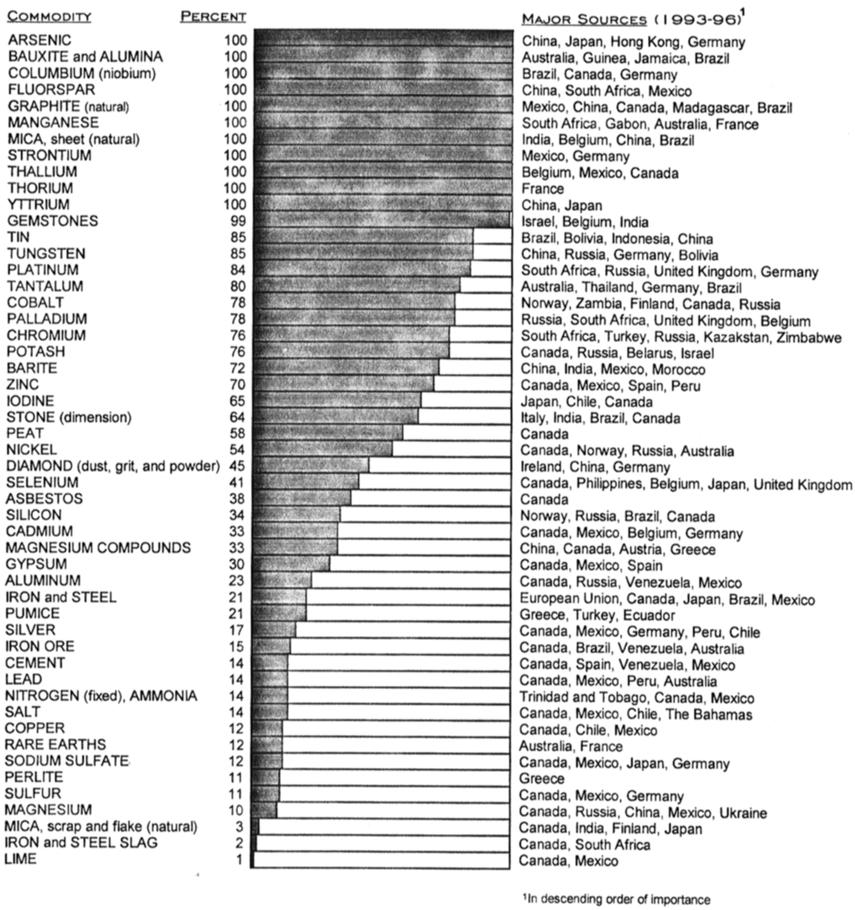

FIGURE 1.2. U.S. net import reliance for selected nonfuel mineral materials in 1998. *Source:* U.S. Geological Survey (1999).

many minerals, the United States is also producing more of the platinum group metals, gold, and diamonds.

Conservation of mineral resources is currently an important issue to the general public. Society is becoming much more cognizant of the need to conserve energy, minerals, and the environment. Accordingly, the mining industry has endorsed a policy that favors extraction of minerals in a more sustainable manner (National Mining Association, 1998). This policy favors mining as long as the effects on the environment or the economic welfare are not a burden on future generations. Extreme conservationist groups often attempt to push for punitive regulatory controls of mining activities and even a ban on mining. However, societal needs dictate that a compromise between the most strident conservationist viewpoint and the most open mineral development concept be adopted for the present and the future. This text attempts to present a balanced approach to mining in the environmental world in which we live.

1.6.2 Mineral Economics

The uniqueness of minerals as economic products accounts for the complexity of mineral economics and the business of mining (Vogely, 1985; Strauss, 1986). Minerals are unevenly distributed and, unlike agricultural or forest products, cannot reproduce or be replaced. A mineral deposit may therefore be considered a depleting asset whose production is restricted to the area in which it occurs. These factors impose limitations on a mining company in the areas of business practices, financing, and production practices. Because its mineral assets are constantly being depleted, a mining company must discover additional reserves or acquire them by purchase to stay in the mining business.

Other peculiar features of the mineral industries are associated with operations. Production costs tend to increase with depth and declining grade. Thus, low-cost operations are mined first, followed by the harder-to-mine deposits. In addition, commodity prices are subject to market price swings in response to supply and demand, which can make the financial risk of a long-term minerals project quite risky. A change in mining or processing technology can also drastically alter the economic landscape. The pattern of usage, in terms of intensity of use (lb/capita or kg/capita) and total consumption of metals on the world market for the nonferrous metals, shows that the intensity of usage of many of these metals continues to go down while overall consumption goes up (Crowson, 1998). Any swing in intensity of use due to substitution or recycling can greatly affect the market price of a metal. Mining companies must therefore keep their prices low by further improvements in productivity, or market price drops can easily create great economic hardships.

Some minerals, such as precious metals, iron, and most of the base metals, can be recycled economically, thereby affecting the markets for freshly mined metal. This is good practice and favorable for the future of humankind, but it can create economic problems if the market price is adversely affected.

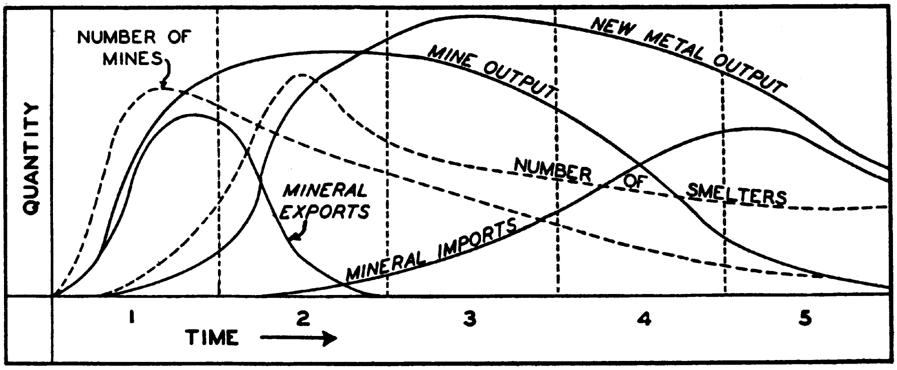

FIGURE 1.3. Periods in the growth of a country's mineral industries. (After Hewett, 1929; Lovering, 1943. By permission from the Society for Mining, Metallurgy, and Exploration, Inc., Littleton, CO.)

Substitutes for a particular mineral may be developed, particularly if the price of the mineral remains high. For example, aluminum and plastics have often been substituted for copper, and plastics have been substituted for a variety of other metals as well as for glass.

At times in recent history certain minerals have been exceptions to economic laws because their prices have been fixed by government decree or cartels. Official prices of gold, silver, and uranium have been regulated by government action, although they now fluctuate in free world markets. Cartels controlling industrial diamonds, oil, mercury, and tin have strongly influenced their market prices during certain time periods. However, many of these cartels have weakened or collapsed because of competition from new suppliers.

It has long been recognized that a given mineral-rich country can follow a fairly predictable pattern in its economic development, based on the state of its minerals industry (Hewett, 1929; Lovering, 1943). Five periods have been identified that reflect the periods of discovery, exploitation, and exhaustion of its mineral industry. The characteristic periods of mineral industry development are shown in Figure 1.3; each is described in the following list.

1. *Period of mine development:* Exploration, discovery of new districts, many small mines working; first recognition of large deposits and development of larger mines; rapidly increasing production of metals.
2. *Period of smelter development:* Fewer new discoveries; small mines becoming exhausted, but increasing output from large mines; many smelters competing for ore.
3. *Period of industrial development:* Decreasing costs, increasing standard of living; rapid accumulation of wealth; expanding internal and external markets; approaching the zenith of commercial power.

4. *Period of rapid depletion of inexpensive raw materials at home:* Ever-increasing costs of mining and materials produced; more and more energy is required to get the same amount of raw material. Mines and smelters continue to decline. Some foreign markets are lost; foreign imports, both raw materials and manufactured products, invade the home market.
5. *Period of decreasing internal and external markets:* Increasing dependence on foreign sources of raw materials brings increasing costs to manufacturers. This period can be characterized by a decreasing standard of living with its accompanying social and political problems; quotas, tariffs, subsidies, cartels, and other artificial expedients are used in the effort to maintain a competitive price in the domestic and world markets. This is a period of decreasing commercial power.

As current-day examples of the cycle in Figure 1.3, many less-developed countries fall into period 1, Australia into period 2, Russia in period 3, the United States in period 4, and the United Kingdom and Japan in period 5. Some economists maintain that this cycle is oversimplified and that it can be modified by technology or dedication to efficient production. For example, Japan after World War II arose from the ashes to become a world power without the benefit of extensive mineral resources. The Japanese had previously extracted nearly all of their inexpensive minerals. However, they purchased raw materials on the open market, created efficient automobile and electronics industries, and prospered by means of the "value added" to the mineral products.

At times during its history, the U.S. government has maintained a stockpile of strategic minerals to guard against shortages in case of war or economic blackmail. The practice became common after 1939 and sharply increased after 1946 because of Cold War tensions. More recently, the government has been reducing its stockpiles. This shift is the result of better access to minerals around the world and a less threatening world political scene since the breakup of the Soviet Union. Mineral companies have often been critical of the stockpiling policy, inasmuch as sudden large purchases from the stockpile can have drastic effects on the price of a given commodity. An informative history of the U.S. strategic minerals stockpile is given by Perkins (1997).

A further aspect of mineral economics concerns the financing and marketing of mines and mineral properties. Mining enterprises are financed in much the same manner as other businesses (Wanless, 1984; Tinsley et al., 1985). Because of greater financial risks, however, the expected return on investment is higher and the payback period shortened in a mining enterprise. Mineral properties as well as mines are marketable. The selling price is determined generally by a valuation based on the report of an engineer or geologist; the value of future earnings is usually discounted to the date of purchase in computing the present value of the property. Mineral properties may be determined to have worth because they are very rich, very large, easily accessible, in great demand, favorably located, cheaply mineable, or militarily strategic.

1.7 COMPUTER APPLICATIONS AND USAGE

In today's world, computers are becoming more useful and finding more application to composition, engineering calculations, library research, and general communications than ever before. It is perhaps worthwhile to compare the progress in the area of computations over the last few decades. Both authors of this text were trained as engineers to perform their computations on a slide rule in their respective university educations. You, the student, were probably introduced to computers in elementary school and most likely became quite proficient in their use before entering your first college course. It is important, therefore, that you continue to develop your skills on computers for every aspect of your future as professionals.

The first aspect of computers considered here is their use in retrieval of information of value in your studies. To provide useful information, the following World Wide Web (WWW) sites are provided as an introduction to useful sources of minerals data and other information of interest to mineral engineers. The web addresses are current at the time of publication; however, web sites are constantly changing. Your web browser may be necessary to provide access to the sites listed here at some future time. It should be noted that the prefix "http://" is omitted from all the WWW sites listed in this book. You must prefix that to each address.

U.S. Geological Survey www.usgs.gov

Energy Information Administration, U.S. Department of Energy www.eia.doe.gov

National Institute of Occupational Safety and Health www.cdc.gov/niosh/homepage.html

Mine Safety and Health Administration www.msha.gov

Society for Mining, Metallurgy, and Exploration, Inc. www.smenet.org

Office of Surface Mining, Department of the Interior www.osmre.gov

These sites will be of use to you in your upcoming assignments and in your professional life as well.

1.8 SPECIAL TOPIC: ECONOMIC ANALYSIS OF A MINERAL COMMODITY

Prepare a summary analysis of pertinent production and economic data for several important mineral commodities, using Table 1.4 as a format. Obtain statistics for mine production (world and domestic) and domestic imports, exports, scrap, stockpile changes (private and government), and net consumption (total and by use). Determine data for the most recent year available. State the commodity price, preferably on an as-mined basis ($/ton, or $/tonne, of mineral, F.O.B., mine).

TABLE 1.4 Economic Analysis of Mineral Commodity

Mineral ____________ Year ____ Average price ________

Mine Production

World	Country	Tonnage	Percentage	Value
	Total			
Domestic (P)	State			
	Total			
	District			
	Total			
	Company		Mine	
	Total			

Domestic Use

Imports (I)		Exports (E)		Scrap (S)
Country	Tonnage	Country	Tonnage	Tonnage ________
				Stockpile (SP)
				Private
				Tonnage ________
Total		Total		Government
				tonnage ________

Net Consumption (C)		Consumers	
		Industry or Use	Tonnage or Percentage
Actual tonnage			
Apparent tonnage			
$C = P + S + I - E \pm SP$			
=			

Sources: ____

Select the metallic and nonmetallic commodities you wish to study by referring to and utilizing the following references:

1. U.S. Geological Survey web page (www.usgs.gov). This reference provides a two-page summary of more than 30 of the primary metallic and nonmetallic minerals produced in the United States. It may not supply you, however, with all the information you need to complete the summary in Table 1.4.
2. U.S. Geological Survey, *Mineral Commodities Survey* (1999 or latest edition). This volume is produced annually. It covers more than 80 metallic and nonmetallic mineral products. Each product is summarized in approximately two pages using statistics that are about a year or two old.
3. U.S. Geological Survey, *Minerals Yearbook* (1995 or latest edition). The most complete mineral production analysis is provided in this yearbook, which is printed every several years. It is produced in three volumes, with the largest (Vol. 3) covering the U.S. production statistics for all the nonfuel minerals. More information is available here than in any other reference, though the data may be two to five years old.
4. *Engineering and Mining Journal* (monthly), "Prices, American Metal Market." This monthly journal provides the prices being paid for metals on a specific date each month; it is useful for more current price information.

Similar information on coal production can be found in the following references. The statistics contained therein are generally a year or two old.

1. Energy Information Administration, *Coal Industry Annual* (2000 or most recent edition). This resource provides several hundred pages each year on the primary statistics of coal production in the United States, including state-by-state information, production, employment, prices, distribution, exports, and imports.
2. Energy Information Administration web page (www.eia.doe.gov). This resource provides exactly the same information as the previously cited publication, as well as many other sources of information available for downloading.

PROBLEMS

1.1 Select one of the web sites listed in Section 1.7 (or use one selected for you by your instructor) and write a one- or two-page summary of the important elements of the web site. Evaluate the usefulness of the information found therein. Your instructor may ask you to share these with your classmates for future use.

1.2 Go to the web site of the U.S. Geological Survey (www.usgs.gov) and find the list of the metallic and nonmetallic minerals produced in the United States. Pick the one you know the least about and write a one-page summary of the mineral and its production picture in the United States.