MINERAL RESOURCES AND MINING

Introduction

The place is Africa, the time 2.6 Million years ago (M.a.). Our ancestors, the Great Apes or Homo habilis, learned how to use rocks as tools to hunt, extract, crush or tear apart the meat or the hard plant substances they gathered. The period ranging from 2.6 million years ago (Ma) to 3000 B.C. is called the Paleolithic, Paleo = antique; lithos = stone. Indeed, the relationship between humans and rocks is very ancient. Rocks helped our kind survive! Rocky shelters and caves provided warmth and their walls served as a canvas to pictorial representations of life back then, the petroglyphs. We used minerals as paints for pigments for their dazzling colors, and ingested clay minerals and soils to supplement our diets or guarded us against phyto-toxins. Many things have changed since our humble origins, but our dependency on Earth's mineral resources is not one of them. In this chapter, we will study mineral resources that shape civilizations, drive human exploration, and inspire human endeavors that include art, literature, and science.

Various stone artifacts showing pointy tips. They resemble the first weapons and tools used by humans.

Figure 9.0 Rocks have provided shelter and building materials since immemorial times. Pictured here are arrow heads made out of iron-rich rocks and chert.

Learning Objectives

After completing this chapter, you should be able to:

Describe the importance of geological resources to your life.

List and differentiate the main mining techniques.

Define acid rock drainage (ARD) and discuss why some mines can lead to ARD and contamination of the environment by metals.

Summarize the types of materials mined in Arizona and explain some of the economic and social impacts associated with their extraction and production.

9.1 Importance of Mineral Resources

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Morenci Mine 2012

Figure 9.1.1 The Morenci mine is the largest copper mine in the United States. This barren landscape, with staircase-like slopes, is man-made. The operation removes over a million tons of rock from the ground every day, working 24/7.

As the saying goes: “If you can’t grow it, you have to mine it”. Think about it. If you account for the totality of all products used in modern society, you will find out either we planted them/they grew, or we extracted them from Earth. This includes water as well as all the other raw materials that we need to construct things like roads, dams, and bridges, or manufacture things like plates, toasters, and telephones. Even most of our energy resources come from Earth, including uranium and fossil fuels, and much of the infrastructure of this electrical age depends on copper (Figure 9.1.2) [3]

The screen of a tablet and text around it identifying the geologic resource used for the different components
Figure 9.1.2 The components of a tablet computer come from mines.

Virtually everything we use in our lives comes from Earth. Let’s take a tablet as an example (Figure 9.1.2). Most of the case is made of a plastic known as ABS, which is made from either gas or petroleum. Some tablets have a case made from aluminum. The glass of a touch screen is made mostly from quartz combined with smaller amounts of sodium oxide (Na_2O), sodium carbonate (Na_2CO_3), and calcium oxide (CaO). To make it work as a touch screen, the upper surface is coated with indium tin oxide. When you touch the screen, you’re actually pushing a thin layer of polycarbonate plastic (made from petroleum) against the coated glass—completing an electrical circuit. The computer can then figure out exactly where you touched the screen. Computer processors are made from silica wafers (more quartz) and also include a significant amount of copper and gold. Gold is used because it is a better conductor than copper and doesn’t tarnish the way silver or copper does. Most computers have nickel-metal-hydride (NiMH) batteries, which contain nickel, of course, along with cadmium, cobalt, manganese, aluminum, and the rare-earth elements lanthanum, cerium, neodymium, and praseodymium. The processor and other electronic components are secured to a circuit board, which is a thin layer of fiberglass sandwiched between copper sheets coated with small amounts of tin and lead. Various parts are put together with steel screws that are made of iron and molybdenum.

Modern technology uses a wide range of elements from the periodic table. See Fig. 9.1.4

That’s not everything that goes into a tablet computer. But to make just those components we need a pure-silica sand deposit, a salt mine for sodium, a rock quarry for calcium, an oil well, a gas well, an aluminum mine, an iron mine, a manganese mine, a copper-molybdenum-gold mine, a cobalt-nickel mine, a rare-earth element and indium mine, and a source of energy to transport all the materials, process them, put them together, and finally transport the computer to your house or the store where you bought it [3]. Production of resources has markedly increased to meet the demand that our modern lives create. Figure 9.1.3 shows the resources that every American born will need in the average lifetime.

For 2020, every American born will need 3.19 million pounds of geological resources.
Fig. 9.1.3. This graphic shows examples of the 3.19 million pounds of minerals, metals, and fuels the average American will need in their lifetime. Calculations are based on a life expectancy of 77.3 years and mineral use data from the National Mining Association, the U.S. Geological Survey and the U.S. Energy Information Administration. Data from 2020.

Image showing the elements that go into important technology applications
Fig 9.1.4 Main elements in modern technology, some examples. Source: D. Londoño, CC-BY.

Exercise 9.1 Where does it come from?
Ballpoint-pen-parts
Figure 9.1.5. Parts of a ball pen. Source: Pavel, K. Wikimedia Commons.
Look around you and find at least five objects (other than a computer or a phone) that have been made from materials that were mined, quarried, or extracted from an oil or gas well. Try to identify the materials involved and think about where they might have come from. This pen is just an example.

9.2 Economic Minerals

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Image of baskets holding mineral-derived pigments, purple, ochre, and intense blue
Figure 9.2.1 Nature's palette produces stunning colors. From left to right, the source minerals could be manganese or azurite, limonite, and azurite, or other copper-bearing minerals.
Mining is the extraction from the Earth of valuable material for societal use. Usually, this includes solid materials (e.g. gold, iron, coal, diamond, sand, and gravel), but can also include fluid resources such as oil and natural gas. Mining has a long relationship with modern society. The oldest evidence of mining, with a concentrated area of digging into the Earth for materials, has a history that may go back 40,000 years to the hematite (used as a red dye) of the Lion Cave in Swaziland [1].

Mineral resources, like other natural resources, are unevenly distributed on Earth. This is not random, geological processes mandate the distribution of mineral resources. For example, notice in Fig 9.2.2. how copper deposits (yellow triangles) appear along the western margin of the Americas. In North America, iron deposits (red triangles) are concentrated mostly in the midwest of the United States. The cause of the heterogeneous distribution relates to the different geologic histories of these areas that have accumulated these elements in those particular areas.

A world map with color-coded symbols that show the distribution of metals and geologic resources. The distribution is not even and some resources are concentrated along belts
Figure 9.2.2. Simplified map of major mineral deposits of the world. Observe and identify any patterns. How can you explain them? U.S. Geological Survey.

Human populations have historically concentrated at sites that are geologically helpful to commerce, food production, and other aspects of civilization. Indeed, geology has shaped human history! The uneven distribution has extremely important social, economic, and political implications. The opposite is true, policy, economics, and other factors result in uneven production; few countries control mineral production. This means that countries depend on other countries for resources. Although this seems like a problem, it is evidence of our interconnectedness and interdependence, and, ideally; it encourages governments to collaborate and maintain peace with each other. Observe in Figure 9.2.3 which countries supply the most material to the US.

A map of the world to show the countries on which the US depends for minerals
Figure 9.2.3. Major import sources of Non-fuel mineral commodities for which the United States was greater than 50% Net import reliant in 2020. Source: U.S. Geological Survey.

Classification of Mineral Resources

We can classify mineral resources in various ways, according to their use (industrial, agricultural, construction), their relative abundance (scarce, abundant), or their perceived value (precious vs. base metals), etc. A practical classification is to divide them into non-fuel and fuel minerals. Non-fuel minerals can be further divided into metallic resources, natural aggregates, and other industrial minerals, as shown in Table 9.2.1. We will study the general mining aspects of non-fuel minerals. Fuel minerals will be addressed in subsequent chapters.

Table 9.2.1 Classification of Mineral Commodities.

Ch. 9. Nonfuel Minerals	Metal or Metallic	aluminum, iron, copper, lead, zinc, tin, gold, silver, etc.
	Natural Aggregates	cement, sand, gravel, and crushed stone
	Other Industrial Minerals	Borates, salt, lime, phosphate rock, soda ash, clay minerals, gypsum, industrial sand, iron oxide pigments, Iodine, Magnesium compounds, mica, peat, perlite, pumice, talk.
Ch. 10. Energy Fuel Minerals	Hydrocarbons	Petroleum, natural gas, coal, unconventional hydrocarbons
	Non Hydrocarbons	Uranium

Metal Mining

The periodic table contains the known elements that make up the Earth. However, it is rare for the amount of the element to be concentrated to the point where the extraction and processing of the material become profitable. Mineral deposits in which the material can be mined at a profit are called ore deposits. Geologists evaluate the size of the deposit, the concentration of the ore mineral(s), and the production and transportation costs to determine if a deposit is economical. Typically, the term ore is used for only metal-bearing minerals, though the concept of ore as a non-renewable resource can be applied to valuable concentrations of fossil fuels, building stones, and other non-metal deposits, even groundwater. However, the term “natural resource” is more common than ore for these types of materials [1]. It is implicit that the technology to mine is available, economic conditions are suitable, and political, social, and environmental considerations are satisfied in order to classify a natural resource deposit as ore.

PeacockOre
Figure 9.2.4. The mineral Bornite, Cu_5FeS_4, is the ore for copper. It is also known as Peacock ore for its iridescent colors that resemble the peacock feathers.
Ores can be concentrated in a set of narrow veins or they can be distributed over a large area in low concentrations. Some materials are mined directly from bodies of water (e.g. sylvite for potassium; water through desalination) and the atmosphere (e.g. nitrogen for fertilizers). These differences lead to various methods of mining, and differences in terminology. Miners use the term ore mineral resource for ore that is potentially extractable (in theory), and the term ore mineral reserve for a well-defined (proven), profitable amount of extractable ore with the current technology and methods [1]. In other words, a reserve is when you know how much of an ore resource you can actually extract using the current technology.

What are some common ore minerals?
Ore minerals contain elements and compounds concentrated by factors of hundreds, thousands, or tens of thousands as compared to their average concentrations within the Earth’s crust. It is this concentration that makes them economically desirable. For example, the average crustal abundance for gold is 0.0000002%. A gold accumulation should have 4,000-5,000 times the crustal concentration to be profitable. Figure 9.2.4 shows an ore for copper, Bornite. We use copper for electrical wires, plumbing, and electronics, but we need to extract it and further concentrate it from minerals such as bornite, azurite, chalcocite, chalcopyrite, etc. Table 9.2.2 presents other ore minerals. Refer to Chapter 3 if you need a refresher on mineral properties.

Table 9.2.2

MINERAL	STREAK	LUSTER	HARDNESS	OTHER PHYSICAL	ORE FOR

An image of ruby red hexagonal crystals characteristic of the mineral corundum
Fig 9.2.5. Corundum. Formula: Al_2O_3

White Vitreous (Glassy) 9 Forms hexagonal prisms. Aluminum. Used in the automotive industry to create alloys. The cosmetic industry uses aluminum in salts.
Image of hematite cristal, black and red, showing botroildal or bubble-like shapes.
Fig. 9.2.6 Hematite. Formula: Fe_2O_3
Dark gray Metallic 6.5 Color can vary between red, black but the streak color is red Iron is the main ingredient in steel
Cinnabar-69330
Fig.9.2.7. Cinnabar. Formula HgS

Bright red Adamantine 2-2.5 – Gypsum-Finger Nail It can have a lead-gray, brown, brown pink, vermilion, and gray color. Mercury. Used in thermometers, barometers, to separate gold and in vapor/gas form for fluorescent and neon lights

9.3 Arizona: The Copper State

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Image of wire copper
Figure 9.3.1 Copper Electric wires are used in phones, cars, computer devices, and buildings.
Arizona's economy thrives on mining. Arizona's largest copper deposits rank among the biggest in the world, making the state one of the top copper suppliers for the last 150 years. In 2020, Arizona ranked second for the value of non-fuel mineral production in the United States, it produced more than $7 billion worth of non-fuel mineral commodities (USGS, 2021). The principal non-fuel mineral commodities are cement (portland), copper, molybdenum, concentrates, sand and gravel (construction), and stone (crushed) (USGS, 2021). Arizona also produces gemstones. It is world famous for its turquoise, peridotite, and perlite.

A metal deposit is a body of rock in which one or more metals have been concentrated to the point of being economically viable for recovery [3]. Some background levels of important metals in average rocks are shown in Table 4, along with the typical grades, or concentrations, necessary to make a viable deposit and the corresponding concentration factors. For example, if we look at copper we can see that while average rock has around 40 ppm (parts per million) of copper, a grade of around 10,000 ppm or 1% is necessary to make a viable copper deposit. In other words, A copper ore rock has about 250 times as much copper as a typical rock. For the other elements in the list, the concentration factors are much higher. For gold, it's 2,000 times and for silver, it's around 10,000 times.

Some very significant concentration must take place to form a mineable deposit. This concentration may occur during the formation of the host rock, or after the rock forms, through a number of geologic processes. There is a very wide variety of ore-forming processes, and there are hundreds of types of mineral deposits. The origins of a few of them are described below.

Table 9.3.1. Typical Background levels of important metals

Metal	Typical Background Level	Typical Economic Grade*	Concentration Factor
Copper	40 ppm	10,000 ppm (1%)	250 times
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It is important to note that the economic viability of any deposit depends on a wide range of factors including its grade, size, shape, depth below the surface, proximity to infrastructure, the current price of the metal, the labor and environmental regulations in the area, and many other factors. Source: [3]

Native Americans Contributions to Mining

Native Americans accrued and passed empirical knowledge by direct interaction with the natural world. This body of

Image showing a young woman graduating from school in her traditional Navajo clothes

Figure 9.3.2. Kiara Reed, a young Diné graduate, wears her traditional attire and turquoise and silver jewelry, along with graduation regalia. Photo courtesy of J. Johnson.

knowledge is variously referred to as Native science, ethnoscience, and Traditional Ecological Knowledge, TEK. TEK is practical, sophisticated, and can share the purposes and benefits of mainstream geology and ecology.

Indigenous peoples have expertise with diverse minerals. They hold specialized knowledge about mineral properties, qualities, and their occurrences on the land. For the Diné, a Tribal Nation of the Southwest, turquoise has cultural, religious, social, and economic relevance. The Diné (Navajo) word for turquoise is dotl' izhi. The Navajo have long known where to find turquoise, how to extract it, and how to work with it to produce a myriad of objects. Navajo jewelry is famous around the globe for its beauty and high quality.

Quarrying, surface mining, and metallurgical knowledge have been present throughout the Americas for millennia. Native people applied TEK to manage and use lands and technologies that make their lives better (Cajete,2010). Further, Native miners and metalworkers improved imported European technology. They invented ore-crushing and automated coin-minting machines previously unknown in Europe. The metallurgical knowledge of South American tribes raised the efficiency of silver extraction and was apt for high altitudes, where it originated. These contributions to mining technology boosted the development of the modern industrial era (Cajete, 2010).

Metalogenesis. The Origin of Metal Deposits.

Volcanogenic Massive Sulfides VMS

Certain volcanic processes concentrate minerals, and the resulting deposits are called volcanogenic deposits. The word is composed of volcano and genesis = origin, which means that the deposits are originated by volcanic systems. Geochemists dubbed a particular kind of these mineral deposits “Volcanogenic Massive Sulfides (VMS)” given the unusually abundant mass of sulfide minerals.

Copper in Jerome, central Arizona, was mined from VMS deposits associated with ancient submarine volcanoes. Briefly, 1,750 to 1,650 million years ago (Ma), in the Precambrian, the SW part of the United States did not exist. Instead of continental land, Arizona was under the ocean. The oceanic floor was active, with volcanoes and associated underwater hot springs that spewed hot liquids loaded with metals. Beneath the volcanoes and hot springs, laid a heat source (magmatic heat source in Fig 9.15). Ocean water can circulate through cracks and fractures within oceanic rocks, that is, groundwater flows under the ocean floor too! The groundwater that penetrates the oceanic rocks travels down, absorbing heat from the magmatic source. The deeper the water travels, the hotter it gets and at some point, it rises back up (see figure 9.15). You may remember a lava lamp and how the heat makes the blobs move when they get hot; like the blobs, the cold water from the ocean percolates down and rises as it collects heat.

The super-heated groundwater mobilizes the metals out of the volcanic rock, in a process called leaching. The sulfide minerals (including pyrite (FeS_2), sphalerite (ZnS), chalcopyrite ($CuFeS_2$), and galena (PbS)), are generally present in very high concentrations in the oceanic rocks around the volcanic system. Recall that water is a universal solvent. Its special properties allow water to remove and carry metals from the host rocks to other places. The super-heated water temperatures (250° to 300°C or 482-570 F!) increase the leaching capacity. When the hot, metal-loaded groundwater rises, it sips out through springs. But it encounters cold ocean water and the extreme temperature drop causes metallic minerals precipitation around the vents. The minerals that precipitate contain copper, lead, zinc, silver, and gold. The setting is comparable to what we know today as “black smokers”; submarine hot springs that occur near tectonic spreading centers (Ch 2.)

The mineral deposits at Jerome formed in submarine volcanic settings. You may wonder, if that is true, then why are those deposits now on land in Arizona? The answer is plate tectonics. In short, tectonic forces created what is now the southwest part of the US, and some of that ancient oceanic floor got pushed into the continent.

Figure 9.3.3. Left: A black smoker on the Juan de Fuca Ridge off the west coast of Northern United States. Right: A model of the formation of a volcanogenic massive sulfide deposit on the seafloor.

Video 9.3.1. shows volcanic hydrothermal vents in the Caribbean. As the super hot fluid mixes with cold water, metal-rich minerals precipitate forming chimney-like structures and concentrating metal deposits. Gold and zinc and a host of metals are concentrated in this way. Black smokers are important for a variety of organisms that thrive around them. However, the conditions are so extreme that they are rightfully named ‘extremophiles’ or extreme lovers (4:56)

Porphyry Copper Deposits

Porphyry deposits are the most important source of copper in British Columbia, the western United States, and Central and South America. Figure 9.3.6 shows a sketch of a porphyry copper deposit. Most porphyry deposits also host some gold, and in rare cases, gold is the primary commodity. Arizona examples include several large deposits that occur on a northwest-trending belt, in Fig 9.3.7.

Figure 9.3.4. A model for the formation of a porphyry deposit around an upper-crustal porphyritic stock and associated vein deposits [3].

This type of deposit is associated with intrusive igneous rocks (Ch. 4), such as granite. An intrusion is a body of magma that ascends through the rock layer. As it rises, it loses heat and crystalizes into an intrusive, igneous rock. In Fig. 9.3.4, the intrusive igneous rock is the tongue-shaped feature protruding from the bottom; you can see the label porphyry intrusion to the right. A porphyry describes a rock texture in which individual mineral grains about a tenth to a half-inch in size are surrounded by smaller grains that are barely visible to the naked eye. The metallic mineral deposit forms around the cooling rock body, or stock, in the upper part of the crust. In figure 9.3.4., the porphyritic rock is cooling off, expelling magmatic water and interacting with the surrounding rocks. Similar to VMS, the convection of groundwater heated by the stock results in metal enrichment. A second source of water is the cooling magma, which is loaded with metals (Figure 9.3.3, right). The rocks in this type of deposit are normally highly fractured and brecciated, which facilitates the extraction. The important ore minerals include chalcopyrite ($CuFeS_2$), bornite (Cu_5FeS_4), and pyrite in copper porphyry deposits, or molybdenite (MoS_2) and pyrite in molybdenum porphyry deposits. Gold is present as minute flakes of native gold [3].

Arizona’s porphyry copper deposits date back to 70 million years ago. Intrusive activity and groundwater concentrated the copper and other metals below the ground. But, our dynamic planet shifts things around, and thanks to tectonic forces, weathering, and erosion, the rich metal deposits reached the surface millions of years later. Further, the geochemical processes that act during weathering enhance the copper concentration, a process called “secondary enrichment”.

Figure 9.3.5. Map of Arizona showing the location of the most common types of copper deposits. We generated the image using interactive the Mineral Resources Online Spatial Data, U.S. Geological Survey.

Secondary Enrichment
Secondary enrichment is a process that acts after the first enrichment we have already discussed. The secondary enrichment further concentrates metals by weathering processes. Rain precipitation on mineral deposits alters their composition, as you may recall from the weathering and mass wasting chapter. Precipitation can infiltrate and fill in spaces within rocks to become groundwater. In this movement, water can mobilize elements from a host rock and transport them downward, leaching the rock and concentrating elements of interest underground. When the percolating solution reaches the water table, the chemical conditions change and the transported elements precipitate. This leads to an enriched zone below the water table. Copper deposits may have to be enriched in this way to become ore.

Four profiles showing the continuous concentration of elements due to continuous rainfall, erosion of the top layer, more rainfall, further erosion and concentration of metals in rock
Figure 9.3.6. Rainfall and water that infiltrate moves the elements downward in the soil and rock column. Erosion removes the top. The process repeats until economic concentrations of metals are reached in this way.
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Porphyry deposits are the most important source of copper in British Columbia, the western United States, and Central and South America. Figure 9.3.6 shows a sketch of a porphyry copper deposit. Most porphyry deposits also host some gold, and in rare cases, gold is the primary commodity. Arizona examples include several large deposits that occur on a northwest-trending belt, in Fig 9.3.7.

Figure 9.3.4. A model for the formation of a porphyry deposit around an upper-crustal porphyritic stock and associated vein deposits [3].

This type of deposit is associated with intrusive igneous rocks (Ch. 4), such as granite. An intrusion is a body of magma that ascends through the rock layer. As it rises, it loses heat and crystalizes into an intrusive, igneous rock. In Fig. 9.3.4, the intrusive igneous rock is the tongue-shaped feature protruding from the bottom; you can see the label porphyry intrusion to the right. A porphyry describes a rock texture in which individual mineral grains about a tenth to a half-inch in size are surrounded by smaller grains that are barely visible to the naked eye. The metallic mineral deposit forms around the cooling rock body, or stock, in the upper part of the crust. In figure 9.3.4., the porphyritic rock is cooling off, expelling magmatic water and interacting with the surrounding rocks. Similar to VMS, the convection of groundwater heated by the stock results in metal enrichment. A second source of water is the cooling magma, which is loaded with metals (Figure 9.3.3, right). The rocks in this type of deposit are normally highly fractured and brecciated, which facilitates the extraction. The important ore minerals include chalcopyrite (CuFeS2), bornite (Cu5FeS4), and pyrite in copper porphyry deposits, or molybdenite (MoS2) and pyrite in molybdenum porphyry deposits. Gold is present as minute flakes of native gold [3].

Arizona's porphyry copper deposits date back to 70 million years ago. Intrusive activity and groundwater concentrated the copper and other metals below the ground. But, our dynamic planet shifts things around, and thanks to tectonic forces, weathering, and erosion, the rich metal deposits reached the surface millions of years later. Further, the geochemical processes that act during weathering enhance the copper concentration, a process called "secondary enrichment".

Figure 9.3.5. Map of Arizona showing the location of the most common types of copper deposits. We generated the image using interactive the Mineral Resources Online Spatial Data, U.S. Geological Survey.

Secondary Enrichment

Secondary enrichment is a process that acts after the first enrichment we have already discussed. The secondary enrichment further concentrates metals by weathering processes. Rain precipitation on mineral deposits alters their composition, as you may recall from the weathering and mass wasting chapter. Precipitation can infiltrate and fill in spaces within rocks to become groundwater. In this movement, water can mobilize elements from a host rock and transport them downward, leaching the rock and concentrating elements of interest underground. When the percolating solution reaches the water table, the chemical conditions change and the transported elements precipitate. This leads to an enriched zone below the water table. Copper deposits may have to be enriched in this way to become ore.

Four profiles showing the continuous concentration of elements due to continuous rainfall, erosion of the top layer, more rainfall, further erosion and concentration of metals in rock
Figure 9.3.6. Rainfall and water that infiltrate moves the elements downward in the soil and rock column. Erosion removes the top. The process repeats until economic concentrations of metals are reached in this way.

9.5 Environmental Impacts of Metallic Mineral Mining

CAROLINA LONDONO MICHEL

The true cost of mining

Mining comes with a price. We are not talking about the economic investment that companies do, or the price that consumers along the chain pay for the metals. We are talking about the cost to ecosystems, Earth systems, and even social systems that are paid in the places where mining is developed. The impacts can be so large and last for so long that we cannot calculate them in terms of currency.

Environmental impacts caused by mining include soil destruction, erosion, formation of sinkholes, loss of biodiversity, and contamination of soil, groundwater and/or surface water by chemicals released during the mining processes. In some cases, miners log the forests near mines to create space to store the created debris and soil. Often, miners need to use adjacent water sources to process the ore. Contamination from leakage of chemicals can also affect the health of the local population, if not properly controlled. Extreme examples of pollution from mining activities include breaking of dams containing toxic water that flood villages living downstream or contaminate waterways killing the fish and lending the water poisonous, or coal fires, which can last for years or even decades, producing massive amounts of environmental damage. [4]

Mining companies in most countries are required to follow stringent environmental and rehabilitation codes in order to minimize environmental impact and avoid impacting human health. These codes and regulations all require the common steps of environmental impact assessment, development of environmental management plans, mine closure planning (which must be done before the start of mining operations), and environmental monitoring during operation and after closure. However, in some areas, particularly in the developing world, government regulations may not be enforced or it may be hard to hold large, multinational companies accountable. [4]

Mine waste: Tailings

To extract the ore from rock, ore mills need to crush large volumes of rock. This generates piles of non-economic material, a form of “waste” called tailings. For example, for each ton of copper, 99 tons of waste are generated, and the amount of waste is larger for gold and silver. Tailings can be toxic. Tailings are usually produced as a slurry (mixed with water) and are most commonly dumped into ponds made from naturally existing valleys. These tailing ponds are secured by impoundments (dams or embankment dams). In 2000, it was estimated that 3,500 tailings impoundments existed and that every year, 2 to 5 major failures and 35 minor failures occurred; for example, in the Marcopper mining disaster, at least 2 million tons of tailings were released into a local river. The tailings and the waste rock at most mines are an environmental liability because they contain pyrite, FeS2, plus small amounts of ore minerals. Thus, besides dam failure, tailings can produce acid drainage. Tailings ponds and waste-rock storage piles must be carefully maintained to ensure their integrity and monitored to ensure that acidic and metal-rich water is not leaking out.

Berkeley Pit & Continental Mine (lower and upper right) & Yankee Doodle Tailings Pond on the left(Butte, Montana, USA)

Figure 9.5.1. The Butte Mining District has produced gold, silver, copper, molybdenum, manganese, and other metals. At the lower right is the Berkeley Pit (Berkeley Mine). At the upper right is the Continental Pit (Continental Mine). On the left is the Yankee Doodle Tailings Pond. Source: St. John, J. Wikimedia Commons.

Acid drainage

Rio tinto river CarolStoker NASA Ames Research Center

Figure 9.5.2. An acid river flows in Rio Tinto, Spain, damaging all the native ecosystem. This environment is so extreme that NASA used as a Mars analog. Source: Carol Stocker NASA.

The primary impact of metallic mineral mining comes from the mining itself, including disturbance of the land surface, covering landscapes with tailings impoundments, and increased mass wasting by sped up erosion. In addition, many metal deposits contain pyrite, an uneconomic sulfide mineral placed on waste dumps, which may generate acid rock drainage during weathering. In the presence of oxygenated water, sulfides undergo complex reactions to release metal ions and hydrogen ions, lowering pH to highly acidic levels. Mining and processing of mined materials typically speeds up reactions. If not managed properly, these reactions may lead to acidification of streams and groundwater plumes that can carry dissolved toxic metals.

In mines where limestone is a waste rock or carbonate minerals like calcite or dolomite are present, their acid-neutralizing potential helps reduce the likelihood of generating acid drainage. This happens because the carbonate ion in calcite and dolomite can capture the hydrogens (acidity) generated by the sulfides. Thus, the pH can be close to neutral. Although acid drainage and the neutralization by lime are natural processes, it is very important to isolate mine dumps and tailings from water, both to prevent the dissolution of pyrite and the subsequent percolation of the sulfate-rich water into waterways. The industry has taken great strides in preventing contamination in recent decades, but earlier mining projects are still causing problems with local ecosystems. [3]

What is the chemistry of Acid Mine Drainage?

pyrite(solid) + oxygen + water ↔ iron hydroxide(solid) + sulfate ion + acid ions

$$FeS_2 (s) + 15/4\ O_2 + 7/2\ H_2O \leftrightarrow Fe(OH)_3(s) + 2\ SO_4^{--} + 4\ H^+$$

Notice that each pyrite mineral would produce four hydrogens, which are the ions that decrease the pH, creating acid conditions.

Note: we use pyrite as an example because it is very common and one of the main contributors to acidity in waste rocks of metal mining. But a host of other chemical processes can produce acid mine drainage.

Now let's look at what happens when we add calcite to counter the acid ions:

Calcite(solid) + acid ions ↔ calcium + water + carbon dioxide

$2\ CaCO_3(s) + 4\ H^+ \leftrightarrow 2Ca^{2+} + 2\ H_2O + 2\ CO_2$

What happened to the hydrogens?

What happened to the calcite?

Superfund sites
Source: Environmental Protection Agency.

In the US, the improper, or lack there of, management of hazardous waste has left thousands of contaminated sites accross the nation. Mining byproducts have been dumped, left out in the open, or poorly managed. These contaminated sites include manufacturing facilities, processing plants, landfills, and mining sites. Common contaminants include lead, asbestos, dioxin, and radiation wast.

In the late 1970s, toxic waste dumps such as Love Canal and Valley of the Drums received national attention when the public learned about the risks to human health and the environment posed by contaminated sites.

In response, Congress established the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) in 1980.
CERCLA is informally called Superfund. It allows EPA to clean up contaminated sites. It also forces the parties responsible for the contamination to either perform cleanups or reimburse the government for EPA-led cleanup work.
When there is no viable responsible party, Superfund gives EPA the funds and authority to clean up contaminated sites.
Superfund's goals are to:
Protect human health and the environment by cleaning up contaminated sites;
Make responsible parties pay for cleanup work;
Involve communities in the Superfund process; and
Return Superfund sites to productive use.
Learn more about the process EPA uses to clean up Superfund sites.
Map of Arizona and S California with yellow diamonds and green circles showing clean up cites.
Arizona has 6 clean up sites near Phoenix, one in Prescott and 2 in the south, near Tucson
Figure 9.5.3. Superfund national priorities list. The map shows the southern part of EPA's Region 9. Click on the image to access the interactive map and find more superfunds where you live.

Environmental regulation of copper mining in Arizona

The main environmental protection agencies which govern a mine's potential to contaminate the local environment include the Arizona Department of Environmental Quality (ADEQ) and the United States Environmental Protection Agency (US EPA). These two agencies, as well as other county or local agencies, ensure that operating and closed mines do not release contaminated or hazardous materials outside of the mine site. Hazardous materials might leave a mine site through wind, which can carry dust; rain, which can flow in washes and streams; and in the groundwater flow, which can contaminate local sources of drinking water. If hazardous materials or contaminated water were to leave a mine site, mine owners could face very large fines daily, be rejected for future permits, and even face time in jail.

Mines on reservations must meet environmental quality standards set out by the respective reservations. For instance, the Navajo Nation Environmental Protection Agency (NNEPA) has well-defined water and air quality standards, which the mines must comply with. Many of the laws in NNEPA are modeled after the US EPA; companies working in such areas often follow the governing body with the strictest policies to ensure adequate environmental compliance. If there is no formal tribal environmental protection agency, the mines will be governed by the US EPA. Typically, mining companies will have environmental engineers on staff at the site or use environmental consulting firms to interact with the regulatory agencies.

The Concerns of the Apache Tribe over Mining

Throughout history, tribes have faced displacement, discrimination, and marginalization due to mining on their lands (Ballard, 2003). Environmental health is an important concern for communities living near mine sites. The impacts of mining on sacred and ancestral lands are of concern for tribal communities. Although U.S. laws mostly protect sacred lands on and off tribal reservations, there are still potential risks for loss. For example, traditional livelihoods may be limited due to lack of access to land and/or destruction of important resources (e.g., mountains, vegetation, wildlife). Tribal communities often rely on natural resources found on sacred lands for cultural, medicinal, and spiritual purposes. For example, in the Navajo Nation in northeastern Arizona and southeastern Utah, Navajo people living in and near uranium mining areas used mill tailings, a sandy waste containing heavy metals and radium, which is radioactive, to build their traditional earthen homes (hogan), many of which remain in use today (DOE, 2013). Another example is the nearly 100 sacred and cultural sites of the Tohono O'odham Nation, which may be impacted by the proposed development of the Rosemont Copper Mine in southern Arizona (Tohono O'odham, 2009). A last example is the Oak Flat area east of Superior, AZ. Lands sacred to the San Carlos Apache tribe, where Resolution Copper is proposing to mine (Allen, 2015). Innovative mining companies implementing responsible mining have recognized the need for more respectful relationships with tribal nations to ensure that when mining is undertaken, the rights and interests of the People are considered.

Rehabilitation of mined areas

After the mining finishes, the mine area must undergo rehabilitation. Waste dumps are contoured to flatten them out, to further stabilize them. If the ore contains sulfides (e.g., pyrite), engineers usually cover it with a layer of clay to prevent access of rain and oxygen from the air, which can oxidize the sulfides to produce sulfuric acid, acid mine drainage. Then they cover this layer with soil and plant vegetation to help consolidate the material. Eventually, the protective layer will erode. But engineers hope that the rate of acid leaching will be slowed down such that the environment can handle the load of acid and associated heavy metals. There are no long-term studies on the success of these covers due to the relatively short time in which large-scale open pit mining has existed. It may take hundreds to thousands of years for some waste dumps to become "acid neutral" and stop leaching into the environment. They usually fence the dumps off to prevent livestock from denuding them of vegetation. The open-pit is then fenced, to prevent access, and it eventually fills up with groundwater. In arid areas, it may not fill due to deep groundwater levels.

9.6 Industrial Minerals and Aggregates

Metals are critical for our technological age, but a lot of other not-so-shiny materials are needed to facilitate our way of life. For everything made out of concrete or asphalt, we need sand and gravel. To make the cement that holds concrete together, we also need limestone. For the glass in our computer screens and for glass-sided buildings, we need silica sand plus sodium oxide (Na_2O), sodium carbonate (Na_2CO_3), and calcium oxide (CaO). Potassium is an essential nutrient for farming in many areas, and for a wide range of applications (e.g., ceramics and many industrial processes), we also need various types of clay [3].

The best types of aggregate (sand and gravel) resources are those that have been sorted by streams. In Arizona, the most abundant and accessible fluvial deposits are in the "Basin and Range" province, along the streams of the Salt River and the Gila River. Every building activity, from homes to skyscrapers, from roads to bridges, and from dams to power plants, requires these natural stone and mineral products. Sand is used to make glass, but for most types of glass, it has to be at least 95% quartz, and for high-purity glass and the silicon wafers used for electronics, the source sand has to be over 98% quartz.

A satellite image showing mining operations near the main canal of the river in an urban setting
Figure 9.6.1. Mining operations on the North bank of the Salt River, in Phoenix, Arizona.

Industrial minerals are geological materials mined for their commercial value, which are not fuel and are not sources of metals (metallic minerals) but are used in the industries based on their physical and/or chemical properties.

Aggregate is a broad category of coarse to medium grain particulate material used in construction. This includes sand, gravel, crushed stone, slag, recycled concrete, and geosynthetic aggregates. Aggregates are the most mined materials in the world.

Rocks are quarried or mined for many uses, such as building facades, countertops, stone floors, and headstones. In most of these cases, the favored rock types are granitic rocks, slate, and marble. Quarried rock is also used in some applications where rounded gravel isn't suitable, such as the ballast (roadbed) for railways, where crushed angular rock is needed.

This graphic illustrates the quantity of minerals needed for each person in the United States this year. For example, based on 2019 production, 685 lbs. of cement will be needed to make the roads, sidewalks, bridges, schools and houses you will use this year.

Figure 9.6.2. Minerals Needed Every Year (Per capita use of minerals). Source: Minerals Education Coalition, 2020.

How does metal mine production compare to industrial mineral production?

In 2020, the estimated value of non-fuel mineral production in the U.S. was $82.3 billion. The estimated value of metal production was 27.7 billion. Curiously, the pandemic produced increased prices for precious metals, such as gold, which reached a record-high price of $2,060 per troy ounce. The total value of industrial mineral production was $54.6 billion. Almost a half of this value, 27 billion, was produced by construction aggregates (construction sand and gravel and crushed stone). The crushed stone had a production value of $17.8 billion in 2020 and accounted for 22% of the total value of U.S. non-fuel mineral production (U.S. Geological Survey, 2021).

In 2020, 12 states each produced more than $2 billion worth of non-fuel mineral commodities. These states were, in descending order of production value, Nevada, Arizona, Texas, California, Minnesota, Florida, Alaska, Utah, Missouri, Michigan, Wyoming, and Georgia. Construction sand and gravel and crushed stone are among the top mineral products of Arizona. In 2020, Arizona was the third producer in the country (California and Texas were 1st and second) (U.S. Geological Survey, 2021).

Backyard Geology. Casa Grande Ruins

Casa Grande AZ - Casa Grande Ruins (NBY 431882)

Figure. 9.6.3. Casa Grande Ruins, Coolidge, AZ still standing after more than 670 years.

The Casa Grande Ruins defeat the passage of time and weathering agents. Built about 1350, the ruins are testimony of the engineering techniques, material science, and astronomical knowledge held by ancient desert dwellers. The builders used caliche, a concrete-like mix of sand, clay, and calcium carbonate for the walls. The mineral layer covers juniper and pine tree timber that make up the skeleton of the structure. Saguaro ribs and reeds were covered with the caliche to form the roofs. Can you imagine the work it took to build a three-story structure without modern power tools, cranes, transportation, or wheels? An entire village remains covered by dirt around the major structure (Casa Grande), which may have been a cultural or knowledge center for the community. The Casa Grande Ruins are now a National Monument, protected from the elements by a steel-and-concrete canopy built in 1932. The ancient people of the desert continue to teach and amaze us with their accomplishments and knowledge.

Evaporites

Evaporite minerals, like halite, are used in our food as common table salt. Salt was a vitally important economic resource prior to refrigeration as a food preservative. While still used in food, now we mainly mined it as a chemical agent, water softener, or a de-icer for roads. Gypsum is a common nonmetallic mineral used as a building material, being the main component of drywall. It is also used as a fertilizer. Other evaporites include sylvite (potassium chloride, KCl) and bischofite (magnesium chloride MgCl), both of which are used in agriculture, medicine, food processing and other applications. Potash, a group of highly soluble potassium-bearing evaporite minerals present in Arizona, is used as a fertilizer. In hyper arid locations, even more rare and complex evaporites, like borax, trona, ulexite, and hanksite, are found and mined [1].

Potash, an evaporite

The term Potash refers to manufactured or mine salts with high concentrations of water-soluble potassium (K). Potash is an important ingredient for fertilizers. Arizona has a significant deposit of potash in the east-central part of the state, near and below the Petrified Forest National Park. The salt accumulated in the Holbrook basin during the Permian (~290-245 million years ago). The potash (KCl) is at the top of a much thicker halite (NaCl rock salt) deposit. The salt deposit is what is left of an ancient sea that inundated the area. Sodium is required for a wide range of industrial processes, and the most convenient source is sodium chloride (rock salt).

Currently, the Arizona potash deposit is not mined. Most of the potash used in the U.S. comes from two mines in southeastern New Mexico. Two companies operated two underground mines and one deep-well solution mine.

To learn more, read this article by the Arizona Geological Survey: Arizona has Potash!

Gypsum

Demand for gypsum depends principally on construction industry activity, particularly in the United States, where the majority of gypsum consumed is used for agriculture, building plasters, the manufacture of portland cement, and wallboard products. In 2020, domestic production of crude gypsum was estimated to be 22 million tons, with a value of about $190 million. The leading crude gypsum-producing states were estimated to be Iowa, Kansas, Nevada, Oklahoma, and Texas (U.S. Geological Survey, 2021).

Figure 9.6.4. Commercial product advertising gypsum to reduce soil compaction due to clay, a common problem in Arizona. Image may be subject to copyright.

9.8 Attributions and References

Creative Commons Attributions for Chapter Text

Media Assets

Fig. 9.0. Maps, D. (2018). [Pointes foliacées, culture du Szeletien, Musée de Moravie, Brno, République Tchèque] [Photograph]. Wikimedia Commons. Retrieved April 21, 2021, https://commons.wikimedia.org/wiki/File:Pointes_foliac%C3%A9es_Brno_Museum.jpg

Image showing various stone artifacts showing pointy tips. They resemble the first weapons and tools used by humans.

9.1

Fig. 9.1.1. Salisbury, S. (2012). Morenci Mine 2012. Wikimedia Commons. Retrieved March 13, 2021, https://commons.wikimedia.org/wiki/File:Morenci_Mine_2012.jpg, CC BY 2.0

Image of the open-pit copper mine in Arizona

Fig. 9.1.2. Earle, S (n.d.). The key components of an Ipad Air. Physical Geology. Retrieved April 6, 2021, https://opentextbc.ca/physicalgeology2ed/part/chapter-20-geological-resources/ CC BY-SA

Image of a digital device showing the elemental composition of the main components.

Fig 9.1.3. Minerals Education Coalition. (2020). Mineral Baby 2020 [Image]. Minerals Education Coallition. Retrieved April 20, 2021, https://mineralseducationcoalition.org/mining-mineral-statistics/

Fig 9.1.4. Londoño, D. (2021). Main elements in technology objects. CC-BY-NC 4.0

Image created for this textbook showing some of the main elements used for high-tech objects.

Fig. 9.1.5. Pavel, K. (2005). Schneider K15 ballpoint pen and the pen in parts. Wikimedia Commons. Retrieved April 6, 2021,
https://commons.wikimedia.org/wiki/File:Ballpoint-pen-parts.jpg CC BY-SA 2.5

Image of a ball pen whole and separated into its components used to show the geologic origin of the raw materials.
9.2
Fig. 9.2.1. Thomas, A. (2017). [Image of baskets containing colorful powdered minerals, from left to right, deep blue, ochre and vivid blue colors]][Photograph]. Unsplash. Retrieved April 20, 2021,

Image of different mineral-derived pigments.
Fig 9.2.2. U. S. Geological Survey (2021). Major mineral deposits of the world. Image created using the interactive maps and downloadable data. Adapted from U.S. Geological Survey (n.d.) Retrieved March 28, 2021, https://mrdata.usgs.gov/general/map-global.html#home. Public Domain CC-BY-SA

A world map with color-coded symbols that show the distribution of metals and geologic resources. The distribution is not even and some resources are concentrated along belts.
Fig 9.2.3. U.S. Geological Survey. (2021). Major Import Sources of Nonfuel Mineral Commodities for which the United States was greater than 50% Net Import Reliant in 2020.

A map of the world showing the main countries from where the U.S. imports minerals. China and Canada are highlighted.
Fig. 9.2.4. Ma'at Publishing. (2019). Peacock ore [Photograph]. Wikimedia Commons. Retrieved April 6, 2021, https://commons.wikimedia.org/wiki/File:PeacockOre.jpg

Image of bornite mineral, a common ore for copper in Arizona.
Fig. 9.2.5. Lavinsky, R. (2010). Corundum-53802 [Photograph]. Wikimedia Commons. Retrieved April 26, 2021,
https://commons.wikimedia.org/wiki/File:Corundum-53802.jpg#/media/File:Corundum-53802.jpg

Image of a typical corundum mineral, ore for the metal aluminum
Fig 9.2.6. Beregminer. (2020). Hematites botryoidal. Mina Santa Rosa, Tierga (Zaragoza). [Photograph]. Wikimedia Commons. Retrieved April 26, 2021,
https://commons.wikimedia.org/wiki/File:Hematites_tierga.jpg#/media/File:Hematites_tierga.jpg

Image of hematite, mineral ore for iron
Fig. 9.2.7 Lavinsky, R. (2010). Cinnabar-69330 [Photograph] Wikimedia Commons. Retrieved April 26, 2021,
https://commons.wikimedia.org/wiki/File:Cinnabar-69330.jpg#/media/File:Cinnabar-69330.jpg

Image of cinnabar, ore for mercury
9.3

Fig 9.3.1. PublicDomainPictures. (n.d.). Wire copper scrap [Photograph]. Pixabay. Retrieved April 20, 2021, https://pixabay.com/photos/wire-copper-electric-stop-closeup-2681887/

Image of copper wire.
Fig 9.3.2. Johnson, J. (2020). [Image of a young woman wearing a traditional Navajo dress and turquoise jewelry along with graduation regalia] [Photograph]. Source: Jenni Johnson, may not be reproduced without permission.

A young Diné graduate wears her traditional attire and jewelry along with graduation regalia showcasing the relationships between the Navajo and the mineral turquoise.
Fig. 9.3.3. (left): Butterfield, D and Holden, J. Black Smoker. Public domain. (right) Earl, S. (n.d.). Physical Geology. Retrieved April 6, 2021, from https://opentextbc.ca/physicalgeology2ed/chapter/20-1-metal-deposits/#footnote-885-1CC BY.

Left is an image of a black smoker on the Juan de Fuca Ridge. The right figure presents a model of the formation of a volcanogenic massive sulfide deposit on the seafloor.
Video 9.3.1. National Oceanographic Center. (n.d.). Cayman Hydrothermal vent field. Online Video. Retrieved May 17, 2022 from https://www.youtube.com/watch?v=RwiyGaOiLgs&ab_channel=NationalOceanographyCentre.

Images captured from the world deepest hydrothermal vents (in the Caribbean) showing the formation of mineral rich chimneys an the extrusion of mineral rich fluids. At sites like this mineral deposits are formed, including Gold and Zink.
Fig. 9.3.4. Earl, S. (n.d.). [Schematic cross-section of a porphyry deposit model] [Image]. Physical Geology. Retrieved April 20, 2021, https://opentextbc.ca/geology/chapter/20-1-metal-deposits/

A concept sketch showing the geologic setting for a porphyry deposit.
Fig. 9.3.5. United States Geological Survey (2021). Map of Copper deposit types in Arizona. Image created using the interactive maps and downloadable data from U.S. Geological Survey (n.d.) Retrieved March 28, 2021, https://mrdata.usgs.gov/general/map-global.html#home. Public Domain CC-BY-SA

A screenshot of the copper deposits in Arizona.
9.4
Video 9.4.1. Dorsey, S. (2019). Bisbee Lavender Pit Mine, Arizona. [Online Video]. Retrieved May 17, 2022 https://www.youtube.com/watch?v=WP2uKNy5tSs&ab_channel=SteveDorsey

Flight over the Lavender Pit copper mine, Bisbee, Arizona. This video exemplifies the open pit mine operation.
Fig. 9.4.1. Earl, S. (n.d.) [Schematic cross-section of a typical underground mine] [Image]. Physical Geology. Retrieved April 20, 2021, https://opentextbc.ca/geology/chapter/20-1-metal-deposits/

Schematic of the underground mining operations.
Video 9.4.2. Fung, K. (2018) What is mineral processing? [Online Video]. Retrieved from: https://youtu.be/IgFo8Yi9k74

Short video showing the basics of separating minerals from rock.
Video 9.4.3. Pugh, D. (n.d.). Processing copper ore in Kitwe, Zambia. [Online Video]. Retrieved from https://www.youtube.com/watch?v=Scxxx7ywRLk&t=20s&ab_channel=DonaldPugh.

Video containing all the details of the processing of the copper ore to retrieve the metal.
9.5
Fig. 9.5.1. St. John, J. (2010). Berkeley Pit & Continental Mine & Yankee Doodle Tailings Pond (Butte, Montana, USA).jpg [Aerial Photograph} Wikimedia Commons, Retrieved June 6, 2021, https://commons.wikimedia.org/wiki/File:Berkeley_Pit_%26_Continental_Mine_%26_Yankee_Doodle_Tailings_Pond_(Butte,_Montana,_USA).jpg

An image showing the size that a tailing pond can achieve.
Fig. 9.5.2 Stocker, C. NASA. (2002). Rio Tinto River. [Photograph].Wikimedia Commons, Retrieved June 6, 2021, https://commons.wikimedia.org/wiki/File:Rio_tinto_river_CarolStoker_NASA_Ames_Research_Center.jpg

A picture showing an acid river running, making the landscape alien.
Fig. 9.5.3. United States Environmental Protection Agency (n.d.). Superfund National Priorities Responsive Map [Screenshot]. Retrieved May 18, 2022, from https://epa.maps.arcgis.com/apps/webappviewer/index.html?id=33cebcdfdd1b4c3a8b51d416956c41f1 CC-BY-SA.

Map of Arizona and S California with yellow diamonds and green circles showing clean up cites. Arizona has 6 clean up sites near Phoenix, one in Prescott and 2 in the south, near Tucson.
9.6
Fig. 9.6.1. Google Maps. (2021). Screenshot showing the mines near Tempe lake. Google Maps fair use.

A satellite image showing mining operations near the main canal of the river in an urban setting
Fig. 9.6.2. Minerals Education Coalition (2020). 2020 MEC Minerals Needed Every Year (Per Capita Use of Minerals). Mining and Mineral Statistics. Retrieved June 6, 2021, https://mineralseducationcoalition.org/mining-mineral-statistics

This graphic illustrates the quantity of minerals needed for each person in the United States this year. For example, based on 2019 production, 685 lbs. of cement will be needed to make the roads, sidewalks, bridges, schools and houses you will use this year.
Fig. 9.6.3. Unknown. (n.d.). Casa Grande AZ- Casa Grande Ruins. [Photograph]. Wikimedia Commons. Retrieved June 6,

2021,https://commons.wikimedia.org/wiki/File:Casa_Grande_AZ_-_Casa_Grande_Ruins_(NBY_431882).jpg

Historic picture of the Casa Grande archeological site in Coolidge AZ. The first masters of the desert built it more than 670 years ago.
Fig. 9.6.4. Commercial product advertising gypsum to reduce soil compaction due to clay, a common problem in Arizona. Image may be subject to copyright.

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Instructor Resources

AGI Goli course: Assessing and Tracking Critical Mineral Commodities. https://www.americangeosciences.org/workforce/goli

The Minerals Education Coalition Website
https://mineralseducationcoalition.org/mining-mineral-statistics/ contains a wealth of resources for educators, including downloadable datasheets and curriculum. Instructors could consider using the minerals in your life data sheets, careers in mining and importance of mining webpages.

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Transcript for video 9.4.2

Mineral processing is the process of separating valuable minerals from ore. Imagine you have a chocolate-chip cookie, that is your ore, and the chocolate chips represent your valuable minerals, and the cookie dough is the waste rock. Your job as a mineral processor is to figure out how to extract the chocolate chips in the most efficient manner. But it is not as simple as that. Mineral processors need to have a strong understanding of physics, mineralogy, and chemistry to find the optimal method to process the ore. When you first receive the ore from the haul trucks, you will need to reduce the size of the ore through a series of crushing and grinding stages. This is where physics and mineralogy come in. Afterward, the size-reduced ore will proceed to the recovery stage, where the valuable minerals will be separated from the ore, and usually, it is done based on their surface chemical properties. As you gain more experience, you can even venture into different specialties such as process automation, developing nano drying technologies, or dive into electronics recycling. If you have a passion for physics and chemistry, and you like to design, analyze, and optimize processes, then you should consider a career in mineral processing!