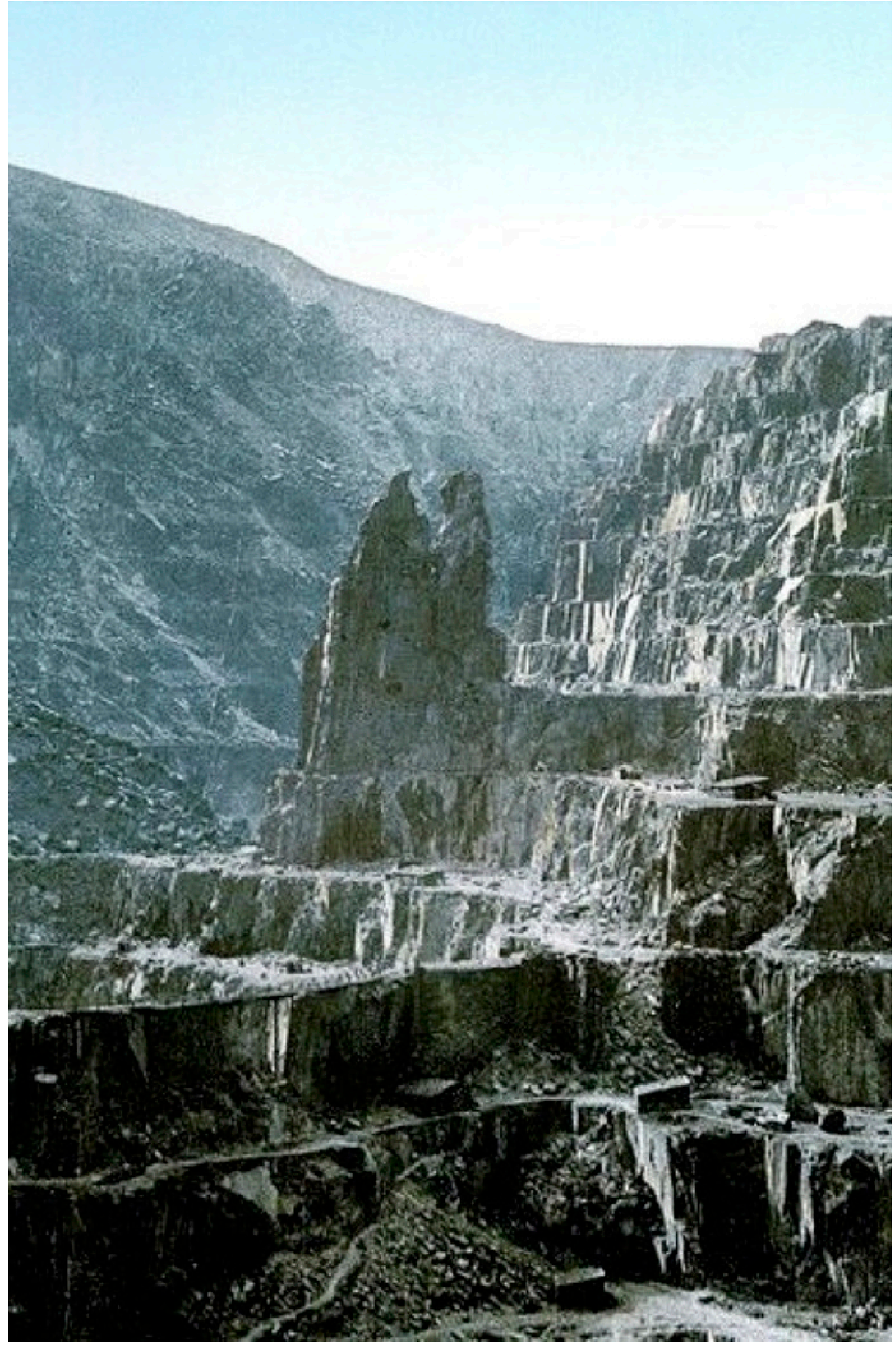
Chapter 5

Resource Extraction

Chapter Objectives:

1. Differentiate between a mineral and a rock.
2. Describe the different identifying properties of minerals.
3. Describe the different categories of minerals.
4. Differentiate between open pit, strip-mining, and subsurface mining. Describe the environmental damage of each.
5. Describe the benefits of recycling.
6. Discuss the role of CERCLA in remediating problems are extractive waste sites



Introduction

In the last chapter, we found that the interior of Earth is a very dynamic place. Unlike the planets Mercury, Venus, and Mars, our planet's interior is a very vibrant place that is in a state of constant change. Old material is recycled into new material every day. Oceanic rock is subducted under the crust and re-emerges as continental rock through an island arc volcano. Dead plant material falls to the ground, becomes buried, and is converted into coal. Water leaches through soil in a rainforest, leaving behind vast deposits of aluminum.

To live our modern way of life, we constantly tap into the Earth's interior to extract minerals and resources. The most prevalent form of energy, fossil fuel, comes from drilling and mining oil, gas, and coal out of the ground. All of the metals in our appliances, cars, and homes ultimately came from mines in the ground. Today, even parts of our food come from the ground, and not organically. If you have ever read the ingredient label on ketchup, peanut butter, or one of a host of other processed foods, you are likely to find either silicon dioxide (quartz) or kaolin (clay) listed amongst the items that give the food its unique flavor and consistency.

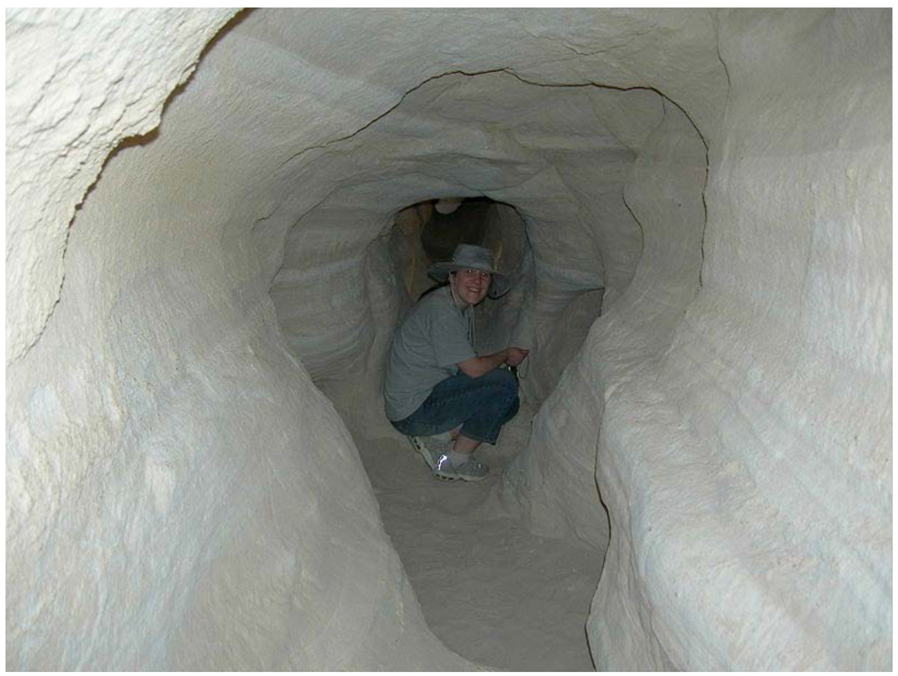


Fig. 1: copper mine in Isreal

In this chapter, we will look first at minerals and how to identify them. Then, we will investigate how solid minerals are extracted from the ground and processed, as well as the environmental impact of doing this. We will save our discussion of the extraction of fluid resources (oil and gas) to a later chapter, as those methods are highly specialized to those two entities.

Animal, Vegetable, or Mineral?

If you are like most Americans, at some time, you have played the guessing game "Animal, Vegetable, or Mineral?" The premise behind the game is that one individual receives a certain number of questions in which to guess what material object another person has chosen. Of course, the first question is the aforementioned one, as every object that we can think of is supposed to fall within one of these three broad classification schemes. Alas, this is not really true. One problem is that some objects fall into 2 or more of these categories (some viruses have a crystalline stage, some animals undergo photosynthesis, etc.). However, the idea behind the game is that everything made of matter will fall into a classification of either living or non-living, with minerals being the catch all for non-living.

The other problem with the game is that a mineral is much more than just a non-living object. What it is exactly, though, will raise a debate amongst geologist. A check of different sources will find many different definitions for mineral. For the purposes of this book, we are going to define a mineral as a substance that is naturally occurring, inorganic, crystalline in nature, and has a definite chemical make-up. The first of these criteria means that anything man-made is not considered a mineral. This is somewhat problematic, as mankind has developed ways of creating certain gemstones in the lab that are almost indistinguishable from their natural counterparts. For instance, industrially created diamonds are used for many different tools, such as diamond-tipped saw blades. The second criterion is not without its problems, too. Certain minerals such as graphite, diamonds, and calcium carbonate can and do have biological origins. Graphite and diamonds can come from plant matter. Calcium carbonate is the chemical that makes up seashells. By convention, they are usually included amongst minerals.

Fig. 2: Calcite crystal (USGS)

The third and fourth criteria are less problematic. The fact that a mineral must have a crystalline structure eliminates all liquids. It also eliminates all glasses, as these are amorphous solids with no definite atomic arrangement. The chemical make-up does come with one caveat: some minerals are allowed to have substitutions of certain chemicals in their molecular structure. As an example, hornblende is a complex mixture of hydrous ferromagnesium silicate that can vary proportions of calcium, aluminum, and sodium within it. These substitutions usually just change the color of the mineral and do not radically alter the other properties of the mineral.

Identification

To accurately identify a mineral and be 100% certain, an individual would have to run a number of laboratory tests on a sample. He or she would have to run an X-ray diffraction analysis of the material to find out what its true crystalline shape is. A ground-up and prepared sample would have to be put through a chemical analyzer to determine its chemical formula. Both of these procedures would take a lot of time and money, and some of the sample would be destroyed in order to perform the analysis. For these reasons, we rarely run such test unless there is a great need to know the answer for sure.

Instead, most minerals are identified by their physical properties. Since minerals have a definite chemical make-up and crystalline shape, one can usually identify them things like their hardness, color, or crystalline shape. Some of the more common properties used to identify them are listed below.

1. Hardness - One of the most common properties upon which to base identification, this is a measure of the scratchability of a mineral. It is evaluated on the basis of the Mohs' hardness scale,

which identifies the hardness of certain keystone minerals on a 1-10 scale. The scale is 1 for talc, 2 for gypsum, 3 for calcite, 4 for fluorite, 5 for apatite, 6 for orthoclase, 7 for quartz, 8 for topaz, 9 for corundum, and 10 for diamond, the hardest substance known to humans. The principle behind the scale is that any substance that is higher in number is able to scratch a substance of a lower number. Topaz will scratch quartz, fluorite will scratch gypsum, and diamond will scratch them all. For further reference, it should be noted that the average human fingernail is about a 2 ¼, a copper coin is a 3.5, a steel nail is about a 5 - 5 ½, and glass is about a 5.5 - 6. To do the hardness test, you will sometimes need to use considerable force. You should try to minimize the scratching of the mineral by limiting the size of the mark. Further, you should wipe the mineral after the scratch test to make sure that it did indeed scratch, and that you are not just seeing powdered residue on the surface left behind by the device with which you performed the test.

Fig. 3: Friedrich Moh

2. Luster - This is the appearance of the mineral surface in reflected light. This test can be very hard to perform, as dirt on the surface or an uneven surface will skew results. The test is best carried out when you are looking at a large crystal face. The different categories are metallic (reflect a considerable amount of light and look like a metal surface), adamantine (brilliant, like a polished jewel), vitreous (glassy), resinous, pearly, silky, and earthy (dull, very little reflection).

3. Color - While this seems to be a very simple property, it is far from easy to use this property. Impurities can greatly change the color of a mineral. Dirt or other substances on the surface can also give a false reading. Color is also very subjective. What one person would call green, another might call grayish. This property is most reliable for metallic minerals, and fails a lot for transparent minerals. As an example, gold and iron pyrite often look very similar in color (see Figure 4). This is one reason why iron pyrite is often called “fool’s gold”.

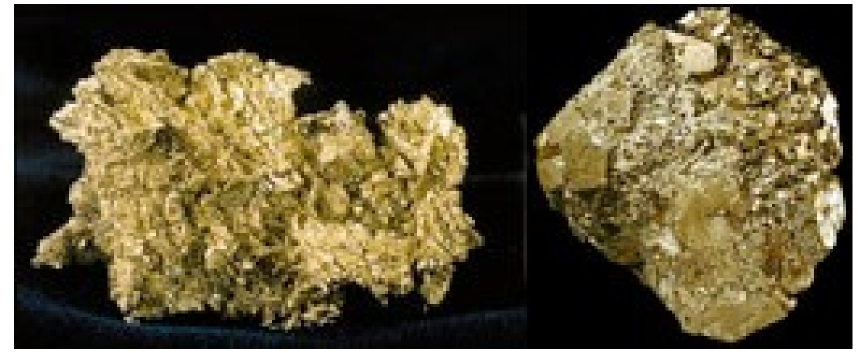
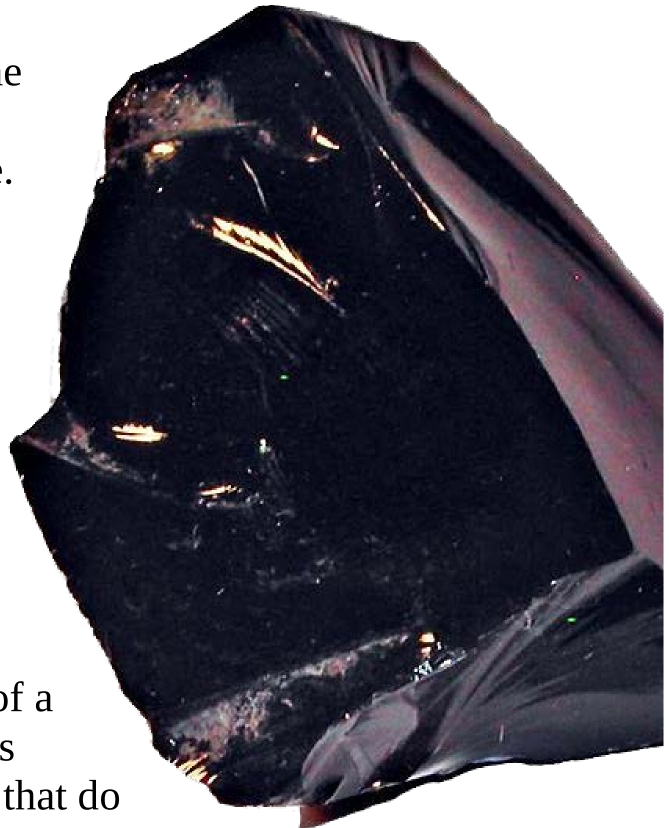


Fig. 4: gold (left) and pyrite (USGS)

4. Streak - This property is the color of the mineral residue when it is powdered. Amazingly, this property is usually much more reliable than color. To create a streak, one would usually use a mortar and pestle to crush a small sample. However, the most used tool for measuring this is to use a piece of white, unglazed pottery. Since pottery has a hardness of about 6, this tool is unusable for minerals that have hardnesses of 6 and greater.

5. Cleavage - This is the tendency of a mineral to split along certain planes. A great example of a mineral that has excellent cleavage would be mica, which cleaves along flat planes to give very thin sheets. Other minerals such as halite will have several

different faces upon which they will cleave, while some other minerals such as quartz have no cleavage (and yes, geologist are known to make bad, sexist jokes during the discussion of this property).



6. Crystalline shape - This is the geometric pattern that a lone crystal of the mineral will have. To see this pattern, though, the crystal needs to be reasonably large and not convoluted by many crystals growing over one another. Oftentimes, all that one sees is just a face or two of the crystal. This might be enough if the shape of the crystal is simple.

7. Fracture - This is the shape of a mineral when it is broken. This occurs for minerals like quartz that do not have cleavage. The different types of fractures are conchoidal (concave breakage reminiscent of glass), splintery, or uneven.

8. Specific gravity - This is the density of the mineral compared to water (1 gm/cm3). Most minerals will have a specific gravity in the 2.5-3.5 range. Some, such as the natural metal ores and few other minerals rich in metals, will have specific gravities much higher than this. Others, such as halite and gypsum, will be much less than this. To determine this property, one needs a graduated cylinder with water in it and a mass scale. Putting the mineral in the graduated cylinder will tell one the volume of the mineral by the amount of water it displaces. Putting the mineral on the scale will give its mass, which when divided by its volume in cubic centimeters, gives its specific gravity.

There are other specialized properties that exist that will identify one or two minerals. Magnetism is a property that quickly identifies magnetite or loadstone. Taste can be very useful in identifying halite, although one can get very sick of licking every transparent mineral in their collection hoping to find it. Calcite has the unusual property of birefringence, which means that unpolarized light traveling through it will be bent at two different angles. In other words, light passing through clear calcite will produce two different images.

Classes of Minerals

There are eight major classifications of minerals. These classification categories are differentiated by the particular radical group that all minerals in that category share. The value of a mineral to our modern way of life might depend upon what elements are found in these radical groups, or the elements that combine with these groups to form a particular type of rock. It might also depend on the characteristics that a particular mineral might have, such as a pearly luster or its hardness.

The largest group of minerals is the silicates, which are based chemically on silicon dioxide. As pointed out in the last chapter, silicon dioxide is the major constituent of crustal rock, which makes it easy to believe that this is the largest category of minerals. Most of the minerals in this category are useful for their mechanical properties, like hardness. Quartz, which has a hardness of 7 on the Mhos Scale, is an example of such a mineral. Other minerals in this category that are important include garnet, mica, feldspars, and pyroxenes.

Carbonates are defined by the presence of the anion CO3 in the mineral. Many examples in this category, such as calcite and dolomite, can have biological origins and are associated with marine environments. Those that fit this description are usually very soft and are valued for their softness or chemical composition. These minerals tend to be alkaline in nature, which is useful in agriculture as an acid neutralizer for soil.

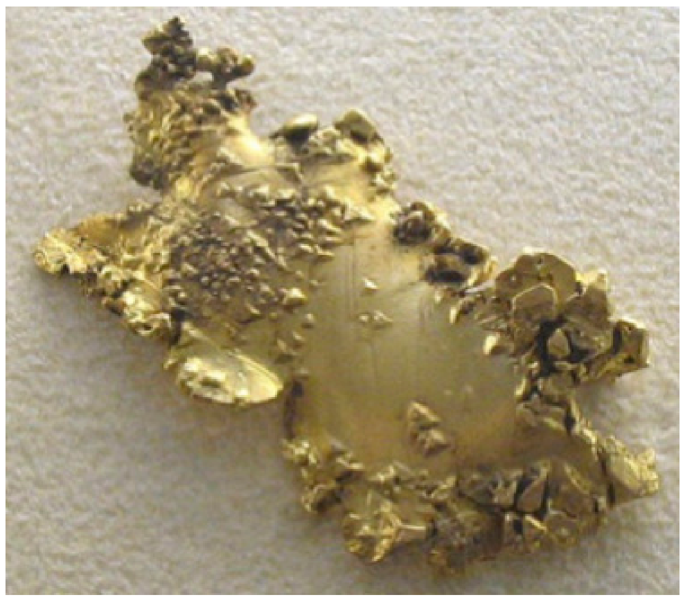
Sulfur is an element that is key to two different mineral categories: sulfates and sulfides. In the sulfate category, sulfur combines with oxygen to form a sulfate anion SO4. These minerals normally form in evaporitic settings, such as those in a saline desert lakebed, or near hydrothermal vents, where sulfur is very ubiquitous. One of the more prominent sulfates is gypsum, which is used to make wallboard. In sulfides, sulfur combines with a metal(s) to form a mineral. These minerals are usually mined for their metal content. For example, iron pyrite (fool's gold) is mined for its iron, while galena (lead sulfide) is mined for its lead.

Another group of minerals that is mined for its metal content is the oxide group. As you might guess, this category includes the oxidized version of metals, which means that it forms in rocks that are near the surface were the atmosphere can be exposed to the magma before it cools from melting. Familiar examples from this group include hematite and magnetite, which are both versions of iron oxide.

One of the more important mineral categories for the survival of our species is the halide group. This category includes all of the natural salts that form when acids and bases interact. Most of the minerals in this category formed in evaporatic marine environments, such as that in a dry desert lakebed. The most obvious example from this group is halite (table salt or sodium chloride), although some will recognize other salts such as fluorite (calcium fluoride), which is used in some toothpastes.

Another set of minerals that is essential for life is the phosphate group. This category includes minerals that contain the PO4 anion, which is a critical anion in DNA and other biological molecules. An example of a mineral from this group is apatite, which is also found in teeth and bones. Phosphates also are important as fertilizers, and mining for these minerals is key to our farming industry.

The last category of minerals we will discuss are the native elements. When most people think of minerals, this is the category to which their mind often leaps, as it contains native gold, silver, and copper. These days, it is rare to find large deposits of these minerals, as we have mined many seams of them out of existence. Today, most metals are mined from one of the other groups of above, especially sulfides. However, the allure is still there, as anyone who has ever gone panning for gold can attest.



Mining

The traditional image that we have of mining is one of an old man with a long beard, a pickaxe, and a donkey descending into a tunnel in the side of a mountain that follows a vein of some ore.

This image has been fed to us many times on television and film, and was true at one time back in the 1800's. However, this type of mining went out of style in the early half of the 1900's when tunneling and other forms of mining equipment began to replace human power in the movement of rock. This equipment could do the job of many men, and increased the rate at which minerals could be removed from the ground.

This also led to a vastly different aim in mining. When very little rock could be moved, the aim of mining was the purest example of a mineral you could find (this does not include coal, which will burn at any stage). Hence, you had single miners with pickaxes and dynamite looking for native gold, silver, and copper that needed little to no processing after extraction. As more and more rock could be moved and processed using electricity, it was possible to go after ores that had lower and lower concentrations of the element or molecule that was being mined. The result of this is that a lot of material is pulled out of a mine that is not used. This material will end up in a slag heap or tailings pile at the end of the process, which we will discuss later.

Mining is accomplished today in one of three ways throughout most of the world: subsurface mining, strip-mining, or open pit mining. Subsurface mining is done when the mineral is deep within the ground (more than 500 feet) and is in thin seams or wide lateral deposits. While this is what comes to mind when we think of mining, it is not the predominate form of extraction. Less than half of the coal in the U.S. and less than 15% of other minerals are mined in this fashion. The reasons for this are simple: it is expensive and dangerous to mine this way.

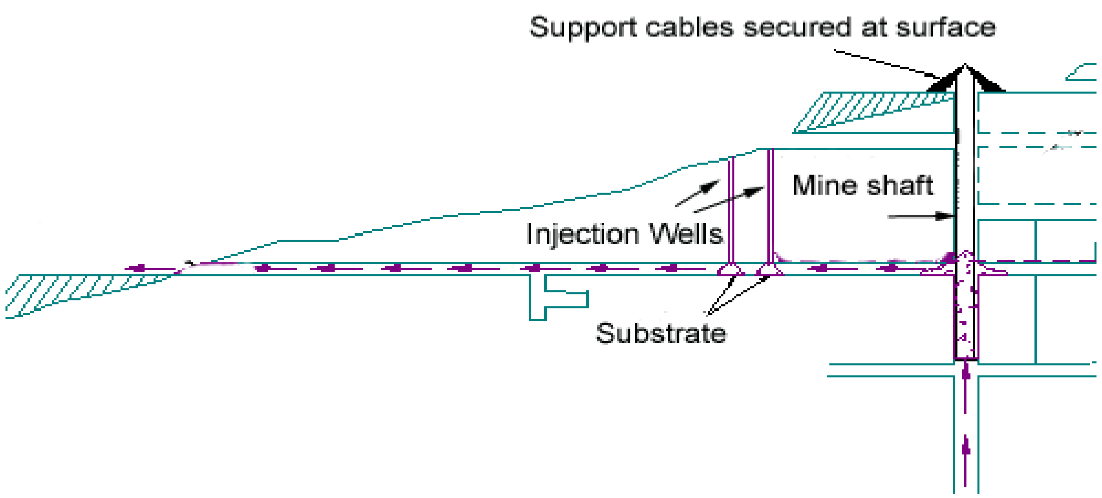


Fig. 4: Subsurface mine (EPA)

Subsurface mining requires cutting multiple shafts through the rock to access the ore or deposit. Tunneling equipment is put in place, and a removal system, such as conveyer belts, are arranged in some of the shaft to remove the ore and excess rock. The exact method for removal depends on the type of mineral being mined and the positioning of the deposits. For example, some coal mines use a room and pillar method whereby rectangular areas are excavated from the coal seam with large pillars between the areas to act as supports. In some instances, when the seam is almost depleted, the miners will collapse the mine as they leave by removing the pillars starting on the far end. Depending on the depth of the mine, this can cause considerable sinking at the surface.

Fig. 5: Appalachian strip-mining (NASA)

Strip-mining is now the predominant form of mining for coal in the U.S., as large deposits of coal sit near the surface in Western states such as Wyoming. The reason why this method is popular in use for extracting coals is that it works well for long, thin, lateral deposits that are very near the surface (less than 500 feet). As the name implies, the method for removing the deposit is simple: strip off the topsoil, vegetation, and rock until you get down to the deposit and then scoop out the material desired. The material can be removed with large bulldozers and cranes and placed in trucks for transport to the processing facility. These mines can cover many square miles as the miners work their way across the landscape. After the coal is scooped out of one location, the excess rock and soil from new parts of the mine are used to fill in the hole

Over the last several decades, miners in the Eastern U.S. have had to develop a variation on this method in order to remain competitive with mines in the West. **Mountaintop removal** involves performing strip-mining near the tops of ridges in mountainous terrain. After the coal is removed, the material that was removed is put back in an approximation of the original ridge or mountain terrain.

U.S. law requires that this type of mine be remediated, which means that the land must be put back in the original condition. In the West, this is made difficult by the limited amount of rainfall the region receives. Without significant moisture, it is hard to create a topsoil that will support vegetation. In the Eastern U.S., the topography makes this task almost impossible. Besides the possibility of the fill material sliding and slumping, the prevalence of rain in this region creates runoff from the fill material that carries sediment and toxic chemicals into the locals streams and rivers.

Open pit mining is used when target deposits are near the surface, but extend vertically from the surface many hundreds of feet. In these cases, it is necessary to dig much deeper holes than those involved in a strip mining. One important aspect of this type of mining is that the hole in the ground must get wider as the mine goes deeper. The reason for this is that the material being extracted at the bottom of the mine must be removed to the surface. The easiest way to do this is to build roads along the edges of the mine that trucks and cranes can use to get from the top to the bottom. If the mine does not expand laterally as it goes deeper, these roads become too steep to use safely.

Fig. 6: Coeur Rochester mine (USGS)

Eventually, either the deposit runs out, or it is found that it is too uneconomical to continue to expand the size of the mine to go deeper. At this point, the mines are normally abandoned, which creates a tremendous environmental problem. The rock along the sides of the mine was, until recently, buried deep within the ground and was not exposed to the atmosphere. As air and water pass over it, heavy metals and other toxic chemicals are oxidized and leached from the rock. This creates very acidic runoff that also carries toxic waste. If it goes into the local river system, it can do substantial harm to the plant and animal life. If it is captured within the pit, it will begin to fill up like a lake with these toxic substances. This creates a local hazard. A good example of this is the Berkeley Pit Mine near Butte, Montana. A copper mine that was abandoned in 1985, this pit has almost filled with water and is so acidic that it can dissolve a quarter-inch plate of steel in less than a day.

Fig. 7: Berkeley Pit mine

Processing

The environmental effects of a mine are not just limited to the inevitable hole in the ground and the leachate from it. As previously stated, most minerals mining (excludes coal) today is for ores that have traces of the elements desired. Unlike native elements, these ores need substantial processing in order to extract the desired chemicals. Many times, this processing is achieve by a combination of acids/bases and electricity. For example, bauxite is an ore that contains a relatively high concentration of aluminum in the form of alumina. The rock is first crushed to powder and then dissolved in a concentrated solution of lie (sodium hydroxide), which preferentially reacts with the aluminum to create aluminum hydroxide. This is then baked to drive off some water, which results in alumina. The alumina is then dissolved in molten cryolite. Two electrodes are then placed into the solution and a current is passed between them. The aluminum comes out of solutions as the solution undergoes electrolysis and is siphoned off. The process for other metal ores is different from this, but most of them use similar techniques.

Even under ideal conditions in which the acid/base does not leak or get into the environment, this process still creates a tremendous amount of unwanted rock and sediment that are harmful to the environment. Crushed rock that is not processed will end up in a tailing pile. Just as in the exposed surface of the mine, rain and water passing through this pile will leach toxic substances into the local environment. The waste products in either the melt or the acid/base dissolving will end up in a slag heap. As with the tailings pile, this heap will continue to leach toxic chemicals into the environment for years to come. The electrolytic process can give off carbon dioxide, and the process itself uses a tremendous amount of electricity, which if created from fossil fuels, gives off even more carbon dioxide.

Garbage 101

The environmental damage of mining does not stop at the processing stage. Most materials that are mined will one day find their way into the garbage pile. To say that "Garbage is a dirty business" is to be both trite and true. A visit to your local landfill will tell you that it is not only a dirty business, but a smelly business, as well. Several thousand years ago, getting rid of garbage was as simple taking it outside of the city or town and dumping it. With low population

densities, this procedure did not present too many problems, other than the eventual rat problems of bringing in fleas that contain bubonic plague. As population densities increased, more attention had to be paid to this issue, as the runoff from a waste pile can have serious negative side effects.

In the U.S., a country that is blessed with many wide-open spaces, garbage has always been a "somebody else's" business. For most of our history, we have treated garbage the same way as prehistoric man: dump it somewhere away from our towns and cities. For cities near the ocean, this has meant dumping it at sea, or possibly close to shore if land was being reclaimed. For inland cities, this has resulted in burying it in open pits. As long as the citizens of the cities or towns did not have to see it, there was no problem.

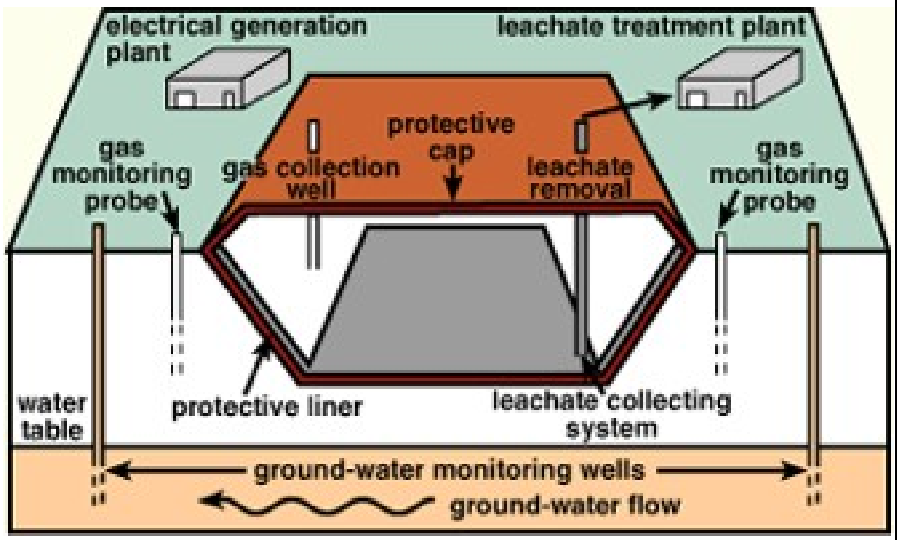


Fig. 8: landfill cross section (Ohio DNR)

Given the modern type of waste we have, this has created tremendous problems. A hundred years ago, almost all of the waste had organic origins and broke down. Today, one is more likely to throw away a container of herbicide, insecticide, paint, petroleum distillates, or any other of the thousands of chemicals that we use on a daily basis. As the products that go into the waste stream became more toxic, concern has escalated, along with requirements that our landfills be sealed and secured. A modernized landfill (see Figure 8 for an example), with barriers to leachate and methane recovery systems, is a vast improvement to the old style dump. The cap on top limits the amount of water getting into the pile, the liner and clay on the bottom limit the amount of leachate getting out of the pile, and the gas collection pipes prevent explosions as well as possible fuel for either heating or electricity generation.

Recycling

But even a modernized landfill does not get to the heart of the matter. As long as people continue to produce garbage at the rate that they are, we are going to continue to run out of places to put it. In high-density population centers along the northeastern seaboard, this situation is becoming more critical every day. Nothing better epitomizes the situation in this area than the barge full of trash from Long Island in 1987 that could not find any takers. After a 3,000-mile trip down the eastern seaboard and into Mexico, the barge had to be returned to New York because no other city or state would allow the shipment to be dumped in their landfill. While the situation in Long Island has improved, other municipalities find themselves in similar situations today.

The solution to this problem of what to do with waste is rather simple: reduce, reuse, and recycle. This simplistic mantra is really quite powerful, but it takes a change in lifestyle. Usually, the change only comes about when the situation becomes critical. In high population density areas such as Japan and certain countries in Europe, systems of laws and fee penalties exist to force the citizens to limit how much garbage they throw away. This causes people to reconsider how much packaging is involved when they buy something and to recycle as much of their waste as possible. This situation is beginning to occur in the U.S., as well. As we can see in the Long Island garbage barge story, the shutting down of all landfills in 1990 and the refusal of other communities to take their garbage forced the local system into greater recycling (about 35% of the waste is now recycled).

Beyond the end use issue, though, recycling also saves all of the environmental damage in processing the materials in the first place. Given the amount of aluminum in ores that are mined for it, recycling one ton of aluminum equates to saving about 4 tons of ore and the 3 tons of slag that are left behind after the ore processing. It also saves about 95% of the electricity that goes into making that ton of aluminum. Similarly, recycling steel saves about 1.5 tons of iron ore and anywhere from 60-75% of the energy required to process it. While recycling glass is mostly a one-to-one savings of raw materials, it does save 25% of the energy required to create it. Recycling plastic is somewhat unique, in that plastic is created from a fuel source (petroleum). If you recycle it, this not only saves about 33% of the energy required to create it in the first place, it also saves an equal amount of petroleum, which could be used elsewhere.

The amount of energy and resources saved by recycling is one reason why it is becoming more popular as we run out of cheap energy and places to dig. However, outside of large urban areas, it is still very hard to recycle many types of materials. For example, while most recyclers will take #1 and #2 plastics, very few take #5 plastics, which are used to make many food containers and lids. Aluminum cans can be recycled almost everywhere, but it is harder to find recyclers that will take other metals, such as steel or nickel. Recycling of electronic equipment, which can contain precious metals such as gold and platinum, is even harder. As we move forward as a planet, we have to become more aware of this issue and continue to work on saving resources.

Superfund Sites

All of the above shows that mining is a dirty business, both literally and figuratively. Extracting the material from the ground destroys habitat, produces tailing piles, and exposes fresh rock to the oxidative atmosphere that leaches toxic chemicals from it. Refining the minerals possibly exposes the environment to strong acids and requires a tremendous amount of energy. Our throwaway society means that even the last step, consumption, results in ecological damage due to waste.

These are the most obvious signs of the dirtiness of this industry. The dark, untold dirtiness is that most mineral mines are run by either small companies or small subsidiaries of larger companies that can go under very quickly once the deposits have been extracted from the mine. This means that the necessary remediation of the land never occurs, as the company declares bankruptcy once they have gotten as much money as they can out of the mine. This allows them to circumvent federal laws and exposes the public to the toxic effects of the mine. In 1980, Congress passed the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) or "Superfund" Act. That act authorized the executive branch to tax extractive industry corporations to build up an account that could pay for cleanup if the company bailed out. In the first five years, this tax garnered $1.6 billion for the fund. In 1986, this act was amended by the Superfund Amendments and Reauthorization Act (SARA) based upon the experiences of the previous five years. SARA increased the fund to $8.6 billion and created a Hazard Ranking System that allowed the most dangerous and lethal sites to be taken care of first.

In 1995, the authorization for both of these expired, and all attempts to get it back on the books have failed. This means that the EPA, which oversees CERCLA/SARA, has to pay for any cleanup of an abandoned mine with federal dollars, allowing the corporation that built the mine to get off with no repercussions. This can be very serious; by some estimates, there are over 560,000 abandoned hard rock mines in the U.S. alone, not to mention processing plants of chemical wastes. Some of these are quite small, but some of them, like the Berkeley Pit Mine are large and could devastate a large region if no action is taken.

Problems

1. Which is better for the land: strip or open pit mining?
2. What are the primary mined resources in Arkansas?
3. Are all rocks minerals?
4. What items are recyclable on ASU's campus? What items are recyclable in Jonesboro?
5. Why must an open pit mine get larger laterally as it goes deeper?
6. You are given a large white crystal. You scratch it against glass, and the glass shows a scratch, while the crystal does not. Is the crystal a diamond?
7. How do you differentiate between iron pyrite and gold if you are out in the field?

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See Appendix A for a list of minerals and their features.