Lesson: Mineral Resources
(corresponding to Chapter 13: Mineral Resources & Society)

This gold nugget weighs about 3.5 pounds. Gold prices vary over time, but at $300 per ounce (a reasonable price in recent markets), this nugget would be worth more than $16,000.

This is an example of PLACER GOLD -- gold found in the bottoms of stream channels. Gold is heavier than any of the common minerals in the crust. Therefore when gold is eroded out of veins in mountains and washed downhill into streams, it tends to accumulate in the bottoms of the channels.
Summary of Important Concepts

- **Mineral Resources** are all the physical materials that we extract from the earth for our use. Modern society is dependent on a huge amount and variety of mineral resources.

- Mineral resources are classified as **metallic** or **non-metallic**. As measured by total consumption, the most important metallic resources are: *iron, aluminum, copper, zinc, and lead*. The most important non-metallic resources are: *crushed stone, sand and gravel, cement, clays, salt, and phosphate*.

- **Mineral Reserves** are known deposits of minerals that can be legally mined economically (for profit) using existing technology. Changes in technology, laws, and market prices cause mineral deposits to change from reserve to non-reserve status.

- To be mined profitably, most mineral resources (particularly metals) must be concentrated in amounts greater than their normal abundance in the crust. The amount of this concentration is called the **concentration factor**.
Various geological processes cause particular minerals to be concentrated to form mineral deposits. The main types of concentrating processes, and the resulting mineral deposits, are these:

1. Igneous Processes
   - **Intrusive deposits** - crystals from solidifying magma
   - **Disseminated deposits** - scattered small deposits of valuable minerals developing above intrusive magma bodies
   - **Hydrothermal deposits** - precipitation of valuable minerals from hot aqueous solutions in contact with magma bodies
   - **Volcanogenic deposits** - precipitation of valuable minerals where hot sea water forms “black smokers” at ocean ridges

2. Sedimentary Processes
   - **Precipitation deposits** - crystals precipitating out of water
   - **Placer deposits** - heavy minerals concentrated by flowing water, typically in the bottoms of stream channels
Summary of Important Concepts, continued

3. Weathering Processes
   • Laterite deposits - concentrations forming due to weathering of soils in hot, wet, tropical climates

4. Metamorphic Processes
   • Metamorphic deposits – concentrations created when heat and pressure in the crust cause new minerals to form

CATEGORIES OF MINERAL RESERVES

• Abundant metals are defined as those with abundances in the crust of greater than 0.1 percent. (Ex: iron, aluminum, magnesium.)

• Scarce metals are defined as those with abundances in the crust of less than 0.1 percent. (Ex: copper, lead, gold.)

• Non-metallic minerals are defined as all minerals that do not have metallic properties, and include certain industrial minerals (Ex: halite, sulfur, diamond), agricultural minerals (Ex: phosphate, nitrate), and construction materials (Ex: sand, gravel, stone).
ENVIRONMENTAL IMPACTS OF MINING

Negative environmental impacts of mining have been reduced somewhat in recent times by laws and regulations. However, a number of negative effects, especially from older mines, continue to have serious environmental impacts. Three particularly important environmental impacts of mining are:

- Acid Mine Drainage
- Impacts of Surface Mining
- Impacts of Mineral Processing

Land Reclamations involves restoring mined land to a better, more natural, condition and minimizing the toxic by-products of mining.
What are the main mineral resources that we use?

This figure shows the main non-metallic resources (upper row) and metallic resources (lower row). The annual consumption per person in the U.S. is given by weight in kilograms (kg) below each type. (1 kg = 2.2 lbs)
Mineral Reserves

Mineral reserves are known deposits of mineral resources that can be legally mined economically (that is, for profit) using existing technology. The term ore is commonly used for reserves of metallic minerals that can be mined for profit.

Because the definition of “mineral reserve” (or “ore”) involves technological, legal and economic considerations, a particular mineral deposit may change its status from reserve to non-reserve, or vice versa, depending on circumstances.

For example:
- A new technology might make a particular mineral deposit profitable to mine when it wasn’t profitable to mine it before.
- New laws may close off areas, or restrict mining in areas that were open to mining before. Alternatively, new laws may open up areas that were closed before.
- The market price of a certain mineral commodity may go up enough to make mining a particular deposit profitable. Or the market price might drop so as to make it no longer profitable to mine a particular deposit.
Concentration Factors

To be mined profitably, nearly all mineral resources (particularly metals) must be concentrated in amounts greater than their normal abundance in the crust. The amount of this concentration is called the concentration factor.

For example, the average concentration of iron in the crust is about 5%. The concentration needed to mine iron profitably is about 20%. Thus the concentration factor for iron is about 4. (20 / 5 = 4).

Consider a much rarer mineral: gold. The average concentration of gold in the crust is about 0.0000004%. The concentration needed to mine gold profitably is about 0.001%. Thus the concentration factor for gold is about 2500. (0.001 / 0.0000004 = 2500).

The concentration factor needed to make a particular mineral deposit worth mining varies with:
- the average abundance of the mineral in the earth’s crust
- the costs of extracting and processing the mineral
- the price that mineral fetches on the market
Geological processes cause concentrations of particular mineral resources. Thus it makes sense to classify and study mineral deposits by the processes that form them. Four main types of geological processes form mineral deposits:

1. Igneous Processes
2. Sedimentary Processes
3. Weathering Processes
4. Metamorphic Processes

For example, the beautiful tourmaline crystals shown here formed by an igneous process: magma intruding into the crust and solidifying to form crystals.
Within each of the four main processes (igneous, sedimentary, weathering, and metamorphic) there are several specific types of mineral deposits.

**Igneous Processes**

- **Intrusive deposits** - when magma solidifies, it may precipitate valuable crystals (gemstones), or crystals rich in valuable elements (chromium, nickel, platinum, and others).

- **Disseminated deposits** - where a large magma body intrudes into the crust, small disseminated (scattered) veins of valuable minerals may develop in the crust above the intrusion. The most important form of disseminated deposits are *porphyry copper* deposits, which are sources of much of the world’s copper.

- **Hydrothermal deposits** - where a large magma body intrudes it heats up water within the crust. This hot water can dissolve minerals over large areas and then precipitate them in local rich concentrations as *veins*, or what miners sometimes call *lodes*. Much gold, lead, zinc, and silver comes from such sources.
• **Volcanogenic deposits** - volcanic activity near mid-ocean ridges (where *sea floor spreading* occurs) results in sea water percolating into cracks in the sea floor and heating up. As it moves through the crust, this hot sea water dissolves large amounts of material. When the hot water exits and hits cold water, the materials carried in solution precipitate as sulfide-based minerals. These “black smokers” create ore deposits called **massive sulfides**, which can be valuable sources of copper and other metals.

The photograph, taken from a deep sea submarine, shows a “black smoker” -- an area where hot sea water is exiting the oceanic crust near a mid-ocean ridge and precipitating sulfide minerals.
Sedimentary Processes

• **Precipitation deposits** - many important mineral deposits form when water (particularly ocean water) precipitates various types of minerals.

  One common way for this to occur is by the water evaporating. Evaporation of ocean water forms deposits of sodium and potassium salts, gypsum, anhydrite, and phosphates. These deposits are collectively called **evaporites**.

  Another important deposit formed by precipitation from ocean water are **banded iron formations**. These deposits formed early in earth history (more than one billion years ago). The great majority of the earth’s iron and steel come from these deposits.

• **Placer deposits** form when moving water concentrates dense, heavy minerals (such as gold, platinum, diamonds, or uranium).

  The most common type of placer deposit occurs at the bottoms of stream channels. The heavy minerals are left behind as the lighter sand and silt are washed away by the flowing streams.
This figure shows how a **gold placer** can form. A source of gold (a **vein**) is eroded and pieces of gold are washed downhill into the stream. The pieces are concentrated in the bottoms of the channel by flowing water, which washes away lighter particles and leaves the heavy gold behind.
Placer deposits of gold were the major cause of the California Gold Rush of the 1840’s. The gold was eroded out of veins in the Sierra Nevada mountains and washed into the channels of west-flowing rivers. Both modern and ancient river channels were heavily mined.

The California Gold Rush caused tremendous population growth, propelled California to early statehood, and helped finance the north during the Civil War (1861-1865).
Weathering Processes

• **Laterite deposits** - soils that form in hot, wet, tropical climates are called laterites (recall *Lesson 6 on Soils*). Under such conditions many minerals are washed out of the soil and the relatively insoluble materials are left behind and concentrated. For example, deposits of aluminum commonly form this way. **Bauxite** is the main aluminum ore mineral formed by laterite weathering.

Metamorphic Processes

• **Metamorphic deposits** – where existing rock is extensively altered by heat and/or pressure, we have metamorphism. The high temperatures and pressures cause chemical reactions that form assorted types of new minerals. Deposits containing tungsten, molybdenum, asbestos, and talc typically form by metamorphic processes.
This figure shows how a “halo” of new minerals can form around an igneous intrusion due to the high temperatures. This is an example of a contact metamorphic deposit.
ENVIROMENTAL IMPACTS OF MINING

Negative environmental impacts of mining have been reduced somewhat in recent times by laws and regulations. However a number of negative effects, especially from older mines, continue to have serious environmental impacts.

Some Legal Background

The Mining Law of 1872 opened up federal land to anyone who wanted to stake a claim and open a mine. This law as originally written contained no provision for environmental damages. Today this law has been substantially amended to include protection for the environment.

There are many other laws that regulate mining and its negative environmental effects. The most important of these are:

• SMCRA – Surface Mining Control and Reclamation Act (1977): established to regulate the coal industry, particularly to require land reclamation after an area has been mined.
NEPA – National Environmental Policy Act (1969): requires mining companies to conduct public hearings and file an **environmental impact report** before being granted a permit.

CERCLA – Comprehensive Environmental Response, Compensation, and Liability Act (1980): established to clean up hazardous mine sites and reclaim land damaged by mining.

**Examples of Specific Environmental Impacts**

We will discuss three major environmental impacts of mining:
1. Acid Mine Drainage
2. Impacts of Surface Mining
3. Impacts of Mineral Processing

We will conclude by discussing **Mine Land Reclamation** methods.
Acid Mine Drainage (AMD)

AMD is the most serious environmental problem in mining today. It results from the formation of sulfuric acid caused by mining of sulfur-based materials, particularly high-sulfur coal and metal-sulfide ores.

AMD occurs when oxygen-rich water percolates through sulfur-bearing minerals exposed by mining. Water containing sulfuric acid drains out of the mine. Notice in this photo how the acidic mine water has eaten away at the concrete wall!
Not only is the sulfuric acid from AMD itself toxic, but acidic reactions also release other toxic materials in the rock, particularly metals like iron, zinc and copper. The acid plus the toxic metals wreak havoc on aquatic (river, stream and lake) ecosystems.

Mitigation of AMD involves a number of strategies. One is to collect and hold the water that drains out of mines. The water can then be treated by alkaline substances to neutralize the acid. Alkaline materials can also be pumping into the ground to help neutralize acidic ground waters. Formation of AMD can be reduced by grading the ground surface and covering potential acid-forming (sulfur-containing) materials to reduce infiltration of water. Furthermore, it has been found that some wetland plants are effective at removing toxic metals from the water. Toxicity levels can be reduced by planting such plants in affected areas.
Impacts of Surface Mining

The main impacts of surface mining operations are scarring and altering of the landscape, soil erosion, and increased mud and silt in rivers and streams (which impacts river ecosystems, irrigation, and drinking water supplies).

Strip-mining and open pit-mining operations scar and alter large areas of land. The only way to mitigate these effects is to back-fill and replant the areas after mining is completed. (More on this at the end of the lesson.)
Impacts of Mineral Processing

With few exceptions, minerals need to be processed in some way once they have been extracted from the earth. Processing is done to concentrate the valuable materials and remove the undesirable materials. Many extraction processes have environmental impacts.

Tailings are waste rock left over from mine tunnels and extraction operations. Large piles of tailings are common around nearly all mines. Tailings piles are at best unpleasant to look at, and at worst are potential sources of AMD.

Chemical processes are commonly used to concentrate mined materials. The most common method is leaching -- pouring a chemical solution over crushed ore to extract the valuable materials in solution. For example, sulfuric acid is commonly added to crushed copper ore to dissolve the copper and produce a solution of copper sulfate, from which the copper can be extracted.
Cyanidation is a common leaching method used to extract gold and silver. It takes advantage of the fact that gold and silver will dissolve in cyanide. In cyanide heap-leaching (shown in the picture here) a solution of cyanide is pumped over a heap of crushed ore. The cyanide drains through the ore and picks up the metal. The solution containing the metal is passed through activated charcoal, which collects the metal, and the cyanide (stripped of the metal now) is returned to leach through the ore heap again.
This diagram shows the main components of a cyanide heap-leaching operation. On the left is the ore heap being leached by cyanide, in the center are ponds of cyanide solution, and on the right are the carbon columns which remove the metal from the cyanide solution.
Cyanide is extremely toxic, and strict regulations govern its use in mineral processing.

- Linings of impermeable clay or plastic must be used under ore heaps and cyanide ponds to prevent leakage (see photo below).
- The cyanide solution must be kept highly alkaline to prevent formation of lethal cyanide gas.
- Cyanide ponds must be secured to prevent wildlife from drinking the poisonous water.
- Upon completion of a heap-leaching operation, the cyanide must be thoroughly cleaned up and ground water wells must be monitored for several years afterward to ensure the cleanup was successful.
Mine Land Reclamation

In the past mining companies could abandon mines after using the site, leaving badly scarred land and possible toxic side effects (such as AMD). Regulations today force companies to return the land to a more natural state after using it, and to prevent toxic byproducts from entering the environment.

The “before” (left) and “after” (right) photographs below illustrate a successful land reclamation project (from the Copper Basin, Tennessee).
As an example of **mine land reclamation**, let us examine the processes involved in restoring land after a coal mining operation.

First, potential AMD-producing materials are buried, and the area is graded so that water will drain away and slopes will not erode. This will prevent future formation of AMD.
Second, after grading and drainage controls are completed, the area is covered with topsoil and seeded with a fast-growing cover crop.
The cover crop, a fast-growing but temporary ground cover, helps prevent surface erosion, and as it dies back it enriches the soil with organic matter.
Once the cover crop dies back, native grasses and trees are encouraged to take over, returning the area to a relatively natural condition. It's hard to tell in this picture that there was ever a large mining operation in the area!