EENS 1110	Physical Geology
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Mineral Resources	

This page last updated on 20-Mar-2012

Mineral Resources

Almost all Earth materials are used by humans for something. We require metals for making machines, sands and gravels for making roads and buildings, sand for making computer chips, limestone and gypsum for making concrete, clays for making ceramics, gold, silver, copper and aluminum for making electric circuits, and diamonds and corundum (sapphire, ruby, emerald) for abrasives and jewelry.

In this discussion, we hope to answer the following questions:

1. What constitutes a mineral resource and an ore?
2. What determines whether or not a mineral sources is economical to exploit?
3. By what processes do ores form?
4. How are mineral resources found and exploited?
5. What happens when a mineral resource become scarce as a result of human consumption?
6. What are the adverse effects of exploiting mineral resource.

Mineral resources can be divided into two major categories - Metallic and Nonmetallic. Metallic resources are things like Gold, Silver, Tin, Copper, Lead, Zinc, Iron, Nickel, Chromium, and Aluminum. Nonmetallic resources are things like sand, gravel, gypsum, halite, Uranium, dimension stone.

A ***mineral resource*** is a volume of rock enriched in one or more useful materials. In this sense a mineral refers to a useful material, a definition that is different from the way we defined a mineral back in Chapter 5. Here the word mineral can be any substance that comes from the Earth.

Finding and exploiting mineral resources requires the application of the principles of geology that you we have discussed or will discuss throughout this course. Some minerals are used as they are found in the ground, i.e. they require no further processing or very little processing. For example - gemstones, sand, gravel, and salt (halite). Most minerals must be processed before they are used. For example:

- Iron is the found in abundance in minerals, but the process of extracting iron from different minerals varies in cost depending on the mineral. It is least costly to extract the iron from oxide minerals like hematite (Fe_2O_3), magnetite (Fe_3O_4), or limonite [Fe (OH)]. Although iron also occurs in olivines, pyroxenes, amphiboles, and biotite, the concentration of iron in these minerals is less, and cost of extraction is increased because strong bonds between iron, silicon, and oxygen must be broken.

- Aluminum is the third most abundant mineral in the Earth's crust. It occurs in the most common minerals of the crust - the feldspars ($NaAlSi_3O_8$, $KalSi_3O_8$, & $CaAl_2Si_2O_8$, but the cost of extracting the Aluminum from these minerals is high. Thus, deposits containing the mineral gibbsite [$Al(OH)_3$], are usually sought. This explains why recycling of Aluminum cans is cost effective, since the Aluminum in the cans does not have to be separated from oxygen or silicon.

Because such things as extraction costs, labor costs, and energy costs vary with time and from country to country, what constitutes an economically viable deposit of minerals varies considerably in time and place. In general, the higher the concentration of the substance, the more economical it is to mine. Thus we define an ***ore*** as a body of material from which one or more valuable substances can be extracted economically. An ore deposit will consist of ore minerals, that contain the valuable substance. ***Gangue*** minerals are minerals that occur in the deposit but do not contain the valuable substance.

Since economics is what controls the grade or concentration of the substance in a deposit that makes the deposit profitable to mine, different substances require different concentrations to be profitable. But, the concentration that can be economically mined changes due to economic conditions such as demand for the substance and the cost of extraction.

Examples:

- The copper concentration in copper ore deposits has shown changes throughout history. From 1880 to about 1960 the grade of copper ore showed a steady decrease from about 3% to less than 1%, mainly due to increased efficiency of mining. From about 1960 to 1980 the grade increased to over 1% due to increasing costs of energy and an abundant supply produced by cheaper labor in other countries.

- Gold prices vary on a daily basis. When gold prices are high, old abandoned mines re-open, when the price drops, gold mines close. The cost of labor is currently so high in the U.S. that few gold mines can operate profitably, but in third world countries where labor costs are lower, gold mines that have ore concentrations well below those found in the U.S. can operate with a profit.

For every substance we can determine the concentration necessary in a mineral deposit for profitable mining. By dividing this economical concentration by the average crustal abundance for that substance, we can determine a value called the ***concentration factor***. The table below lists average crustal abundances and concentration factors for some of the important materials that are commonly sought. For example, Al, which has an average crustal abundance of 8%, has a concentration factor of 3 to 4. This means that an economic deposit of Aluminum must contain between 3 and 4 times the average crustal abundance, that is between 24 and 32% Aluminum, to be economical.

Substance	Average Crustal Abundance	Concentration Factor
Al (Aluminum)	8.0%	3 to 4
Fe (Iron)	5.8%	6 to7
Ti (Titanium)	0.86%	25 to 100
Cr (Chromium)	0.0096%	4,000 to 5,000
Zn (Zinc)	0.0082%	300
Cu (Copper)	0.0058%	100 to 200
Ag (Silver)	0.000008%	~1000
Pt (Platinum)	0.0000005%	600
Au (Gold)	0.0000002%	4,000 to 5,000
U (Uranium)	0.00016%	500 to 1000

Note that we will not likely ever run out of a useful substance, since we can always find deposits of any substance that have lower concentrations than are currently economical. If the supply of currently economical deposits is reduced, the price will increase and the concentration factor will increase.

Origin of Mineral Resources

Mineral deposits can be classified on the basis of the mechanism responsible for concentrating the valuable substance.

- Magmatic Ore Deposits - substances are concentrated within a body of igneous rock by magmatic processes like crystal fractionation and crystal settling.

Magmatic process such as partial melting, crystal fractionation, or crystal settling in a magma chamber can concentrate ore minerals containing valuable substances by taking elements that were once widely dispersed in low concentrations in the magma and concentrating them in minerals that separate from the magma.

Examples:

- ***Pegmatites*** - During fractional crystallization water and elements that do not enter the minerals separated from the magma by crystallization will end up as the last residue of the original magma. This residue is rich in silica and water along with elements like the Rare Earth Elements (many of which are important for making phosphors in color television picture tubes), Lithium, Tantalum, Niobium, Boron, Beryllium, Gold, and Uranium. This residue is often injected into fractures surrounding the igneous intrusion and crystallizes as a rock called a pegmatite that characteristically consists of large crystals.

- Crystal Settling. As minerals crystallize from a magma body, heavy minerals may sink to the bottom of the magma chamber. Such heavy minerals as chromite, olivine, and ilmenite contain high concentrations of Chromium, Titanium, Platinum, Nickel, and Iron. These elements thus attain higher concentrations in the layers that form on the bottom of the magma chamber.

- ***Hydrothermal Ore Deposits*** - Concentration by hot aqueous (water-rich) fluids flowing through fractures and pore spaces in rocks.

Hydrothermal deposits are produced when groundwater circulates to depth and heats up either by coming near a hot igneous body at depth or by circulating to great depth along the geothermal gradient. Such hot water can dissolve valuable substances throughout a large volume of rock. As the hot water moves into cooler areas of the crust, the dissolved substances are precipitated from the hot water solution. If the cooling takes place rapidly, such as might occur in open fractures or upon reaching a body of cool surface water, then precipitation will take place over a limited area, resulting in a concentration of the substance attaining a higher value than was originally present in the rocks through which the water passed.

Examples:

- ***Massive sulfide deposits*** at oceanic spreading centers. Hot fluids circulating above the magma chambers at oceanic ridges can scavenge elements like Sulfur, Copper, and Zinc from the rocks through which they pass. As these hot fluids migrate back toward the seafloor, they come in contact with cold groundwater or sea water and suddenly precipitate these metals as sulfide minerals like sphalerite (zinc sulfide) and chalcopyrite (Copper, Iron sulfide).
- ***Vein deposits*** surrounding igneous intrusions. Hot water circulating around igneous intrusions scavenges metals and silica from both the intrusions and the surrounding rock. When these fluids are injected into open fractures, they cool rapidly and precipitate mainly quartz, but also a variety of sulfide minerals, and sometimes gold, and silver within the veins of quartz. Rich deposits of copper, zinc, lead, gold, silver, tin, mercury, and molybdenum result.
- ***Stratabound ore deposits*** in lake or oceanic sediments. When hot groundwater containing valuable metals scavenged along their flow paths enters unconsolidated sediments on the bottom of a lake or ocean, it may precipitate ore minerals in the

pore spaces between grains in the sediment. Such minerals may contain high concentrations of lead, zinc, and copper, usually in sulfide minerals like galena (lead sulfide), sphalerite (zinc sulfide), and chalcopyrite (copper-iron sulfide). Since they are included within the sedimentary strata they are called stratabound mineral deposits.

- ***Sedimentary Ore Deposits*** - substances are concentrated by chemical precipitation from lake or sea water.

  Although clastic sedimentary processes can form mineral deposits, the term sedimentary mineral deposit is restricted to chemical sedimentation, where minerals containing valuable substances are precipitated directly out of water.

  Examples:
  - ***Evaporite Deposits*** - Evaporation of lake water or sea water results in the loss of water and thus concentrates dissolved substances in the remaining water. When the water becomes saturated in such dissolved substance they precipitate from the water. Deposits of halite (table salt), gypsum (used in plaster and wall board), borax (used in soap), and sylvite (potassium chloride, from which potassium is extracted to use in fertilizers) result from this process.
  - ***Iron Formations*** - These deposits are of iron rich chert and a number of other iron bearing minerals that were deposited in basins within continental crust during the Proterozoic (2 billion years or older). They appear to be evaporite type deposits, but if so, the composition of sea water must have been drastically different than it is today.

- ***Placer Ore Deposits*** - substances are concentrated by flowing surface waters either in streams or along coastlines.

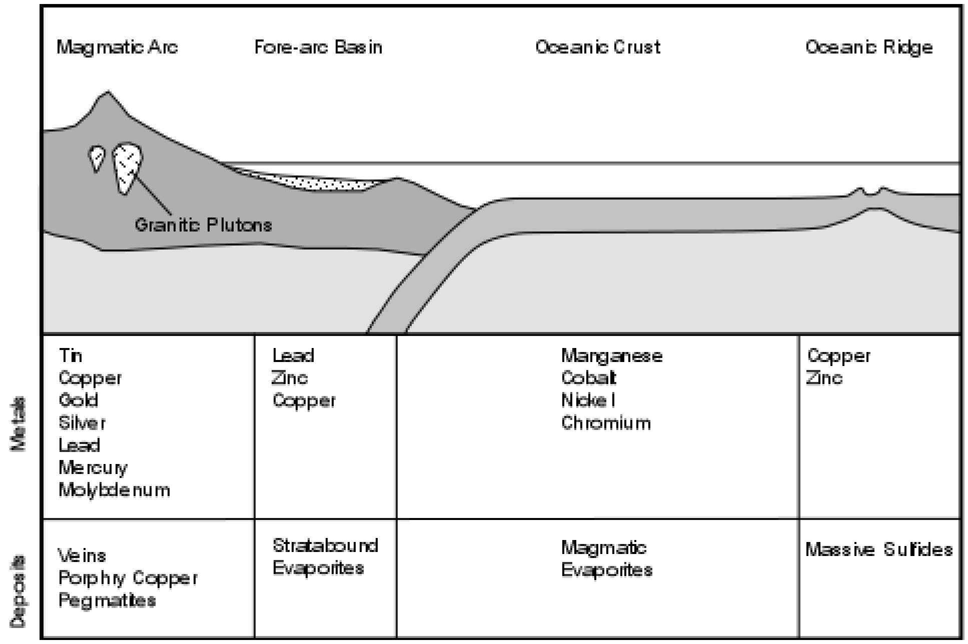
  The velocity of flowing water determines whether minerals are carried in suspension or deposited. When the velocity of the water slows, large minerals or minerals with a higher density are deposited. Heavy minerals like gold, diamond, and magnetite of the same size as a low density mineral like quartz will be deposited at a higher velocity than the quartz, thus the heavy minerals will be concentrated in areas where water current velocity is low. Mineral deposits formed in this way are called placer deposits. They occur in any area where current velocity is low, such as in point bar deposits, between ripple marks, behind submerged bars, or in holes on the bottom of a stream. The California gold rush in 1849 began when someone discovered rich placer deposits of gold in streams draining the Sierra Nevada Mountains. The gold originally formed in hydrothermal veins, but it was eroded out of the veins and carried in streams where it was deposited in placer deposits.
- ***Residual Ore Deposits*** - substances are concentrated by chemical weathering processes.

  During chemical weathering and original body of rock is greatly reduced in volume by the process of leaching, which removes ions from the original rock. Elements that are not leached form the rock thus occur in higher concentration in the residual rock. The most important ore of Aluminum, ***bauxite***, forms in tropical climates where high temperatures and high water throughput during chemical weathering produces highly leached lateritic soils rich in both iron and aluminum. Most bauxite deposits are relatively young because they form near the surface of the Earth and are easily removed by erosion acting over long periods of time.

  In addition, an existing mineral deposit can be turned in to a more highly concentrated mineral deposit by weathering in a process called ***secondary enrichment***.

Mineral Deposits and Plate Tectonics

Because different types of mineral deposits form in different environments, plate tectonics plays a critical role in the location of different geological environments. The diagram to the right shows the different mineral deposits that occur in different tectonic environments.



Mineral Exploration and Production

Ores are located by evidence of metal enrichment. Geologists look for hints in rocks exposed near the surface, for example, the enrichment process often results in discoloration of the soil and rock. When such hints are found, geophysical survey's involving measuring gravity, magnetism, or radioactivity are conducted. Geochemical surveys are conducted which analyze the composition of water, sediment, soil, rocks, and sometimes even plants and trees.

Once it is determined that a valuable material could be present, the deposit is assessed by conducting core drilling to collect subsurface samples, followed by chemical analysis of the samples to determine the grade of the ore If the samples show promise of being economic to mine, then plans are made to determine how it will me mined.

If the ore body is within 100 meters from the surface, open-pit mines, large excavations open to the air.are used to extract the ore before processing. Open pit mines are less expensive and less dangerous than tunnel mines, although they do leave large scars on the land surface. If the ore body is deeper, or narrowly dispersed within the non-ore bearing rock tunneling is necessary to extract the ore from underground mines. Mine tunnels are linked to a vertical shaft, called and adit. Ores are removed from the walls of the tunnels by drilling and blasting, with the excavated ores being hauled to the surface from processing. Underground mines are both more expensive and dangerous than open pit mines and still leave scares on the landscape where non-ore bearing rock is discarded as tailings. .

Global Mineral Needs

Because the processes that form ores operate on geologic time scales, the most economic mineral resources are essentially nonrenewable.New deposits cannot be generated in human timescales. But, as mentioned previously, as the reserves of materials become depleted it is

possible to find other sources that are more costly to exploit. Furthermore, mineral resources are not evenly distributed.
Some countries are mineral-rich; some are mineral-poor. This is a particular issue for strategic mineral resources. These strategic metals are those for which economical source do not exist in the U.S., must be imported from other potentially non-friendly nations, but are needed for highly specialized applications such as national security, defense, or aerospace applications. These metals include, Manganese, Cobalt, Platinum, and Chromium, all of which are stockpiled by the U.S. government in case supplies are cut off.

How long current mineral resources will last depends on consumption rates and reserve amounts.
Some mineral resources will run out soon, for example global resources of Pb, Zn, and Au? will likely run out in about 30 years. U.S. resources of Pt, Ni, Co, Mn, Cr less than 1 year. Thus, continued use of scarce minerals will require discovery of new sources, increase in price to make hard-to-obtain sources more profitable, increased efficiency, conservation, or recycling, substitution of new materials, or doing without.

Environmental Issues

Extraction and processing has large environmental impacts in terms of such things as air quality, surface water quality, groundwater quality, soils, vegetation, and aesthetics. Acid mine drainage is one example, Sulfide minerals newly exposed to Oxygen and water near the surface create sulfuric acid. Rainwater falling on the mine tailings becomes acidified and can create toxic conditions in the runoff. This can mobilize potentially dangerous heavy metals and kill organisms in the streams draining the tailings.

Questions on this material that could be asked on an exam.

1. Define the following: (a) ore, (b) concentration factor, (c) secondary enrichment, (d) strategic metal, (e) acid mine drainage.

2. Explain how each of the following types of ore deposits form and give examples of each (a) magmatic ore deposits, (b) hydrothermal ore deposits, (c) sedimentary ore deposits, (d) residual ore deposits, (e) placer ore deposits.

3. What techniques are used to find ore deposits.

4. Explain why such things seemingly common things such as sand, gravel, limestone, and gypsum can also be considered mineral resources.

5. What are the adverse effects of the exploitation of mineral resources.

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