GY 111 Lecture Note Series
Economic Geology

Lecture Goals:

A) **Economic Minerals** (resources versus reserves)
B) Mineral formation
C) Mineral extraction

A) Economic Minerals

By now, you have been introduced to the minerals that you are going to be responsible for in the lab component of GY 111L. I hope that you have also begun to recognize the importance of some of these materials. If not, consider this table that I extracted directly from the GY 111L Lab manual:

Table 1.5. Economic uses of some minerals

Mineral	Economic Use
bauxite	aluminum ore
calcite	Portland cement, chalk, antacids
dolomite	vitamins, antacid, garden lime
chalcopyrite	copper ore
galena	lead ore
garnet	gemstones, jewelry, sand paper
gypsum	sheetrock, plaster, cosmetics
graphite	lubricants, pencil lead
halite	table salt
olivine	jewelry (mineral peridot)
diamond	abrasives, girl's best friends
sulfur	pharmaceuticals, asphalt, plastics
fluorite	dental applications, steel flux
kaolinite	clay, pottery, tile, Kaopectate, cosmetics
hematite	iron ore
limonite	iron ore
magnetite	iron ore
malachite	jewelry, copper ore
quartz	electronic applications
sphalerite	zinc ore
talc	lubricant, talcum powder

It lists the main uses of some of the GY 111L minerals in the collection. Truth be told, there are *many* other uses of geological materials that are have not listed here and of course *many* other minerals that are important to our society that are also not listed here. Definition time. Any mineral that has economic potential (i.e., it makes someone money), is defined as an **economic mineral**. All of the minerals listed in table 1.5 are economic minerals. Additional economic minerals include the native elements Gold, Silver and Platinum, virtually every sulfide known (e.g., Molybdenite-MoS, cinnabar-HgS etc.),

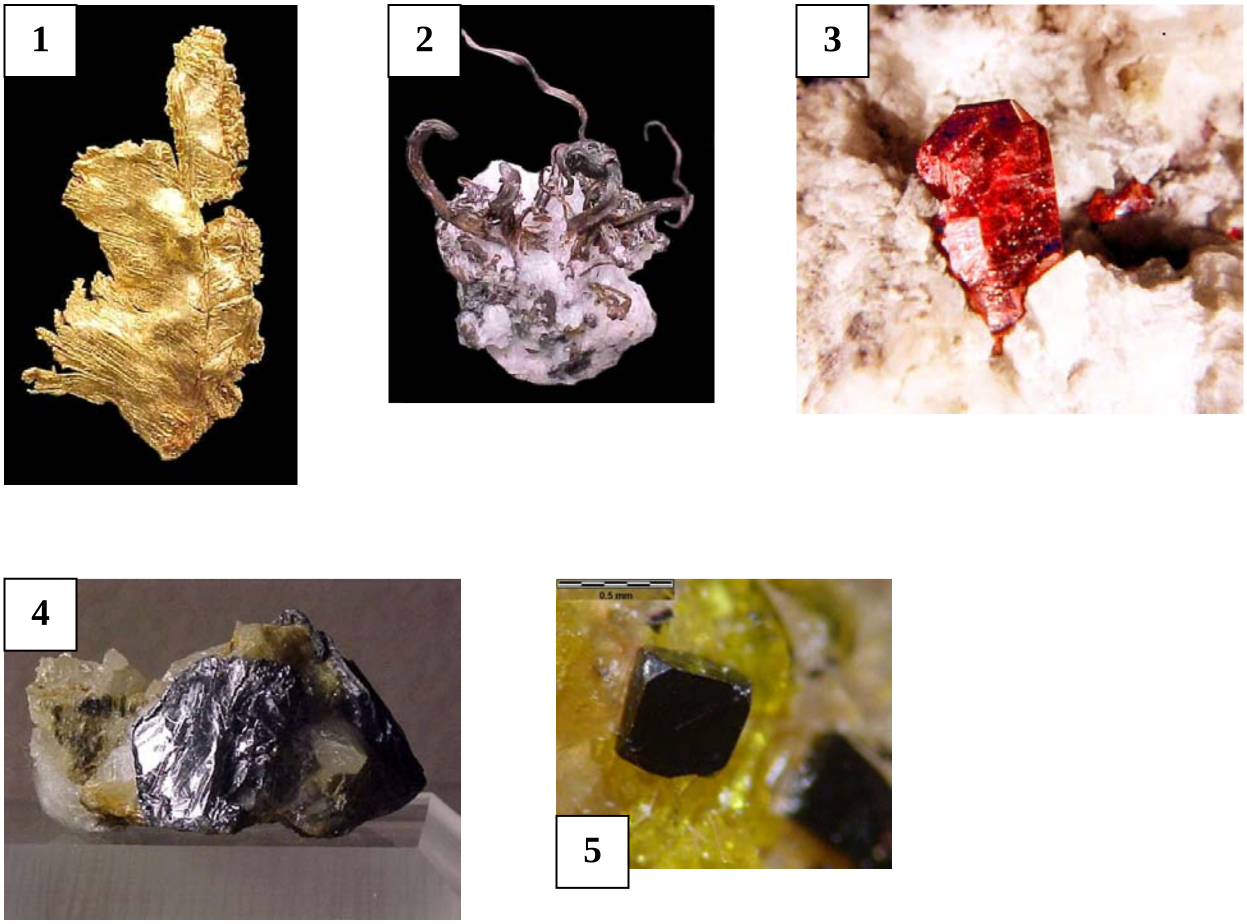


Figure 1: Examples of important economic minerals. 1-gold; 2-silver; 3-cinnabar; 4-molybdenite; 5-uraninite. All images from http://webmineral.com/specimens/picshow.php?id=1478

most of the oxides (e.g., uraninite-UO_2), and lots of the minerals comprising the remaining mineral classes. You will not see these other economic minerals in GY 111/GY111L, but if you are a geology major, you will see them in GY 302. Can't wait? The minerals that are underlined are pictured above.

Right now, you are probably thinking that on *minerals* factor in as economically-important geological materials. As it turns out, neither, gold, nor diamonds, nor platinum are as economically important to the US economy as limestone, sand or gravel (crushed rock). These rocks are considered important **building materials** and are used so extensively in the United States that they dwarf the economic significance of the economic minerals; however, that's not necessarily the case in other countries. In Canada and Australia, where there are much lower populations (and therefore less demand for building materials), and much more extensive economic mineral deposits, gold, diamond

Gold mining data (USGS Commodities information for 2007)

World Mine Production, Reserves, and Reserve Base:	Mine production		Reserves[7]	Reserve base[7]
	2005	2006[e]		
United States	256	260	2,700	3,700
Australia	262	260	5,000	6,000
Canada	119	120	1,300	3,500
China	225	240	1,200	4,100
Indonesia	140	145	1,800	2,800
Peru	208	210	3,500	4,100
Russia	169	162	3,000	3,500
South Africa	295	270	6,000	36,000
Other countries	793	840	[8]17,000	[8]26,000
World total (rounded)	2,470	2,500	42,000	90,000

and sulfide mineral mining are major components of their economies. In fact., Canada[1] and Australia are considered to be primary **resource** economies which is why, in 2008, they are escaping the economic turndown that is really hurting the USA. At least for now. If the US economy does not improve soon, there will be a big decrease in the demand for economic minerals so even primary resource economies will start to contract.

It's time to now consider two other terms. **Resources** are defined as *any substance vital or necessary for a society.* Obviously the term **mineral resources** refers to those minerals that we require. **Building resources** are materials that we need for construction like sand, gravel etc., **energy resources** are fossil fuels that we need for energy, and **water resources** are supplies of drinking water. For your information, geologists are responsible for locating and extracting *all* of these substances. If it sounds like you owe you very existence to geology, you are absolutely correct. In fact, there is a saying…

Any resource that is not grown or raised, is ultimately geological in nature.

…and when you consider that you have to grow plants in soil and raise animals on plants that grow on soil, even food is somewhat geological in origin (soil *is* a geological material too). Perhaps now you can appreciate why geologists are in such high demand even despite the poor economy and why, should you ever pass a geologists, you should give them a hug.

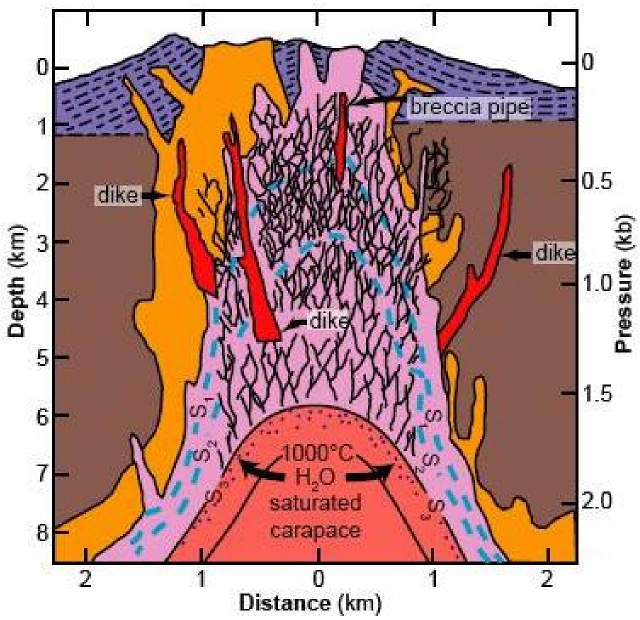
The last definition that is required at this point in the lecture is **reserves,** as in **mineral reserves**. This is *the total amount of an economic mineral that has been found and that is likely to be found in the future.* For example, we can estimate the likely amount of gold in the United States based upon the known amounts that have been found in all of the active mines in the country and in the new "plays" currently worked (see table at the start of this page). Reserves are not necessarily the absolute total of a mineral that exists, just how much we've found to date. In some cases (e.g., uranium, aluminum), we will probably

[1] This is especially true for Canada if you throw in the other major economic geology materials like oil, natural gas and fresh water.

never run out of reserves. In most cases however (e.g., gold, platinum), we will run out someday.

B) Mineral Formation

Sadly, in this course, it is not possible to spare the time to go over how all economic minerals form. We have to choose one or two. In this country, much of the economic wealth in geology is courtesy of base metal sulfides. These include the GY 111L minerals sphalerite, chalcopyrite, galena, and other minerals like molybdenite, cinnabar and covellite (CuS). The list is a long one that you need not concern yourself about here. For this lecture, we'll stick with copper minerals.

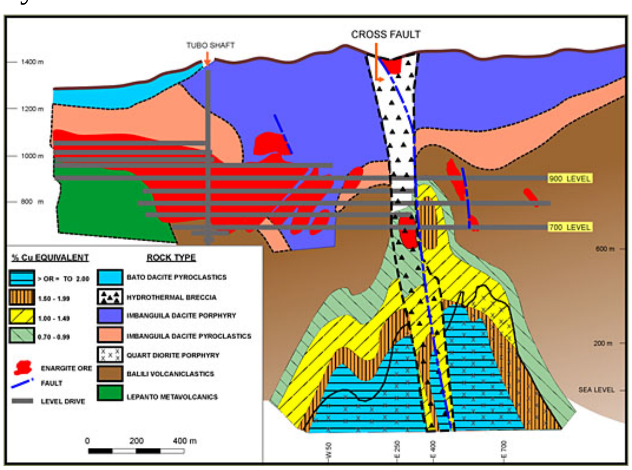


Copper-bearing sulfides like chalcopyrite and covellite are mostly formed through the action of hot water. Deposits like this are called **hydrothermal** and form in areas where either groundwater[2] comes in contact with hot magma deep below the surface of the Earth, or a particularly "wet" magma dewaters near the surface of the Earth (see cartoon to the left from www.answersingenesis.org). Under these conditions, liquid water can heat up to 400 or 500 ˚C; however, it remains a fluid owing to high confining pressure 1000's of m below the surface. Water this hot becomes extremely "aggressive" and is capable of striping normally insoluble materials from the host rocks. This includes Cu^{2+} as well as Au^{2+} gold and other metallic cations. The thing to note about this process is that hydrothermal water is really effective at extracting ions that are normally in low concentration within rocks. Remember also that this stripping process may be going on for 100's or thousands of years. The trick is that you somehow have to reprecipitate and concentrate the dissolved Cu^{2+} somewhere else.

[2] There will be an upcoming lecture on groundwater in GY 111. For now, just assume that all groundwater gets there from infiltrated rainwater.

Hydrothermal water tends to rise upward as it is heated because it become less dense. In contrast, groundwater tends to sink and/or flow "downhill" over time. If hydrothermal fluids diffuse outwards as they rise, the result will be an **ore deposit** that is finely disseminated over a large area (see porphyry copper ore pictured to the left). These are called after the igneous rock that they form in (more about this in the igneous section of the course) and they consist of a wide variety of copper sulfides as well as pyrite (FeS_2) and other non-economic minerals like quartz. Mining geologists call the non-economic stuff **gangue** and need to consider it's presence when determining if an economic deposit is worth mining or not. Ultimately it all comes down to how much money you can make. If it's a lot (i.e., the ore deposit contains a lot of reserves), the extra cost of disposing of the gangue is not an issue. However, this might not be the case for a small deposit.

Finely disseminated ore deposits are great to find, but even more impressive are ore deposits that are concentrated over a small area. A very common location for concentrated ore deposits is along faults and what were originally open fractures (**vein ore deposits**) (see image to right from warrandyte.bizhat.com and image below from www.lepantomining.com). Hydrothermal fluids pass easily along these planes of weakness and as they get closer to the Earth's surface, they either cool and precipitate out minerals directly from water, or flash to steam as the confining pressure is reduced precipitating minerals during the process. By the way, the latter process whereby hydrothermal water flashes to steam near the surface of the Earth is how geysers like Old



Faithful in Yellowstone National Park work. Analysis of the minerals precipitated at geysers (see image at top of next page) demonstrates that they contain relatively high concentrations of gold and other economic minerals which leads economic geologists to speculate that many ancient vein deposits (especially gold) formed just below geysers.

Not all metallic ore deposits were formed through really hot

hydrothermal waters. Some were formed through distinctly tepid water. **Low-temperature hydrothermal fluids** as low as 25˚C are thought to be responsible for extensive deposits of sphalerite (ZnS) and galena (PbS) in sedimentary rocks around the world. The mechanism of formation was first extensively studied in outcrops along the Mississippi River in Missouri and for this reason, they are commonly referred to as **Mississippi Valley-Type Lead-Zinc Ore deposits (MVT** ores). The mechanism of formation is remarkably similar to that of the other hydrothermal deposits. Groundwater seeps downward through sedimentary rocks and gets a little bit warmer as it sinks. There is no hot magma source. This heating is due entirely to the **geothermal gradient**, which is a natural consequence of living on a planet with a hot core: the deeper you go into the interior of the Earth, the hotter it gets. The normal geothermal gradient is about 30˚C per 1000 m. Fluids that sink 3 km are heated up to almost the boiling point of water. This fluid is capable of dissolving and transporting Zn^{2+} and Pb^{2+} from the sedimentary rocks that they are passing through. The fluid is also very good at dissolving Ca^{2+}. Since the host rocks for MVT ores are usually limestone, a type of rock composed of calcite, this means that a lot of holes open up as the fluids pass through. These voids end up being the sites of precipitation of galena, sphalerite and gangue minerals like calcite, dolomite and fluorite. This combination of minerals frequently produces absolutely gorgeous mineral specimens, some of which go for $1000.00 or more. I have a few cheaper ($20.00) examples in my office should you wish to see them. If you would like to see the really expensive ones, I accept donations toward their purchase. Leave a few dollars in the "Support My Professor's Mineral Collection" cookie jar on your way out.

C) Mineral Extraction

Geologists do not have the best environmental reputation in part because of the way mineral resources are extracted out of the Earth. This is unfortunate as most geologists have more respect for the environment than does the average person. But there is no doubt that extraction of minerals does leave a pretty significant footprint.

Minerals are extracted via a number of different techniques depending upon the nature of the deposit. If the minerals are suitably concentrated, say in a vein deposit or along a fault or fracture, an **underground mine** like that one pictured to the left (Golden Giant Mine) is the most cost effective and least environmentally destructive method. If, however, the ore body is more disseminated (e.g., porphyry copper deposits), **open pit**

mining is the most economical option. This method is pretty nasty as it leaves a big hole in the ground. The image to the left is the Berkley Pit at Butte, MO. It is a mile deep and is now abandoned. Worst of all, it is filling with very acidic water that must be cleaned up eventually or it will destroy the entire groundwater supply of this area of Montana.

The world's current largest copper open pit mine (it used to be Butte) is in Chile (see the satellite image to the right). It's a big hole but if current environmental laws are applied when the ore is finally exhausted, will not become the toxic time bomb that Butte is. Mine reclamation (the "repair" of a mine site) is now required for most mines in the western world[3] and like the other careers that I've discussed in today's lecture, it requires that geologists lead the clean up team. If you think about it, this makes sense. Not only did geologists make the mess in the first place, they know more about the processes operating in the Earth and how best to repair the damage.

If you would like to know more about geo-careers, feel free to contact me

Important terms/concepts from today's lecture

(Google any terms that you are not familiar with)

Economic minerals
Building material
Resources (mineral, energy, water)
Reserves
Mine (underground, open pit)
Geothermal Gradient
Hydrothermal
Ore deposit (disseminated, concentrated)
Vein deposite
Gangue
Porphyry ore deposit
Mississippi Valley Type Ore Deposit
Hydrothermal

[3] I'm not entirely sure about how Chile fits into these laws. I suspect they have strict rules.