**Metal Madness:**
**The geology of metallic mineral deposits**

## Native metals

The metals used by early humans were undoubtedly in pure elemental or *native* form.

The great value of metals in ancient times reflected, in part, the rarity of native metal deposits.


Native copper


Native gold


Native silver



## Metal compounds

Increased usage of metals necessitated the development of smelting methods to separate metals from impure forms. Many metals mined today are derived from metal-bearing mineral compounds (most combined with sulphur or oxygen)


Galena
$PbS$
(lead sulphide)


Sphalerite
$ZnS$
(zinc sulphide)


Magnetite
$Fe_3O_4$
(iron oxide)

## Classification of Metals

Metals are all united by having high electrical conductivity, luster, and malleability/ductility, and the ability of their atoms to lose electrons to form positive ions (cations).

In our culture, the term “metal” generally refers to “fusible metals”- metals of moderate hardness and relatively low melting point that can be fused with other metals to form *alloys* (metal mixtures).

In turn, we commonly classify these fusible metals in two main categories:

- Precious metals
- Base metals

## Precious metals

Metals of high economic value (often used to make coins or jewelry due to their high metallic lustre and distinctive colour).

Examples: Silver, gold, platinum (and other PGEs).

These are typically less reactive than other metals and melt at higher temperatures.

Many of these metals (with the exception of silver) are desirable for the manufacture of electrical components due to their resistance to corrosion and oxidation.

## Base metals

Metals of low inherent value (as compared to precious metals).

Most base metals oxidize readily (rust/tarnish) in air. As a result of the high reactivity of these metals, most are found naturally primarily in the form of ore minerals and other compounds.

The most widely used base metals include iron, lead, copper, zinc, and tin.

Cultural Significance of Term: Name derived from the practice of alchemists who attempted to make (transmute) gold (and other noble metals) from less valuable (base) metals.

## Abundance of Elements in Earth’s Crust

Most metals (excluding iron and aluminum) that are useful to society occur in very low abundances in Earth’s crust, relative to other elements.

Approximately 98.5% of Earth’s crust (by weight) is accounted for by only 8 of the 92 naturally occurring elements:
46.6% Oxygen (O)
27.7% Silicon (Si)
8.1% Aluminum (Al)
5.0% Iron (Fe)
3.6% Calcium (Ca)
2.8% Sodium (Na)
2.6% Potassium (K)
2.1% Magnesium (Mg)
All other elements: 1.5 %

Note that the majority of the familiar metals used in society (aside from aluminum and iron) don’t even appear on this list

## Abundance of Culturally Significant Metals

Base metals (other than iron, aluminum and titanium) in weight percent of continental crust.

| | |
|---|---|
| Copper | 0.0055 % |
| Nickel | 0.0075 % |
| Zinc | 0.0070 % |
| Lead | 0.00125 % |
| Tin | 0.00020 % |

Precious metals in weight percent of continental crust.

| | |
|---|---|
| Silver | 0.000007 % |
| Gold | 0.0000004 % |
| Platinum | 0.0000005 % |

## Importance of Enrichment

Metals do not occur in uniform abundance throughout the crust.

There are certain geological circumstances in which culturally valuable metals occur in higher concentrations.

Knowledge of the geological processes that lead to enrichment of metals, and of the geological environments in which these processes operate, are essential to the discovery of metal-rich deposits.

Geologists impact your life at the most fundamental level !

## The Economics of Metal Extraction

An important cultural aspect in determining the feasibility of extracting any given metal is the cost of extraction.

A mineral body that can be mined at a profit is called an ore.

Economic factors that qualify a mineral body to be called an ore are numerous. These factors include the following:

- The concentration of the metal(s) of interest (due to enrichment)
- Size of the ore body.
- Cost associated with infrastructure (e.g. cost of mining, transportation and smelting).
- Market value of the metal(s) of interest.

## Igneous Processes: Magmatic Cooling

Some metals, such as iron and chromium can be concentrated by fractional crystallization and simple gravitational settling of heavy minerals such as magnetite- $Fe_3O_4$ and chromite- $[(Fe, Mg)Cr_2O_4]$ from cooling magma within an intrusive body.

These heavy minerals are formed during the earliest stages of cooling and sink to the bottom of the magma chamber.

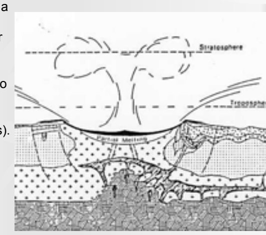
Dark bands: magnetite, chromite, platinum
Light bands: silicates

## Igneous Processes: Immiscibility

The concentrated nickel deposits of the Sudbury Igneous Complex are thought to be the product of immiscibility – the separation of a metal-rich magma from silicate-rich magma (in a similar manner as oil separates from water).

The Sudbury Basin is believed to be a meteorite impact crater (circular, later compressed into an oval shape by tectonic forces).

The impact of a ~10 km bolide penetrated through, or at least heated, the entire crust causing shock melting and mixing of layers of various compositions. Most of the nickel probably came from the lower crust.



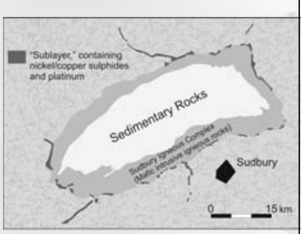



## Igneous Processes: Immiscibility

As the molten material rose to the surface, metal-rich liquid separated from the silicate liquid into density-stratified layers.

The molten metal material was concentrated in cracks surrounding the impact crater (forming a nickel-rich sublayer).

The crater basin was later infilled with sediment.




## Igneous Processes: Immiscibility

This is a section of a sample of nickel ore from Sudbury.

The nickel occurs in the rounded bodies of bronze-coloured pentlandite- $(Fe, Ni)_9S_8$ that crystallized from the metal-rich melt.

Dark coloured mafic silicate minerals surround the pentlandite bodies.

The ore also contains lots of copper (in chalcopyrite), iron (pyrrhotite) and significant concentrations of platinum group elements (PGEs).

## Hydrothermal Processes

Among the best-known and most important ore deposits are those formed from hydrothermal (hot-water) solutions.

Such solutions may be left-over fluids of cooled magma, or can be generated by the warming of groundwater or seawater that seeps into rock below the surface (the heat source is always assumed to be magma).

A critical factor in the ability of hot water to dissolve metals appears to be its "saltiness" – brine solutions containing dissolved salts are able to dissolve metals more readily than pure water.

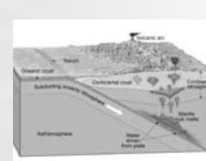
Also, the the higher the water temperature, the greater the amount of ions and other substances the water can hold in solution (most compounds are more soluble at higher temperatures).

A warm brine containing lots of dissolved metals drops (precipitates) its metals (usually combined with other elements, e.g. sulphur, as ore minerals) when it is cooled, forming a metallic mineral deposit.

## Hydrothermal Processes: Convergent Boundaries

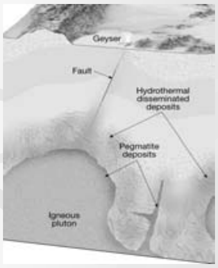
Recall that magma generated at convergent boundaries (by hydration melting) tends to be intermediate to felsic in composition.

Only a little bit of fluid can exists in a magma chamber when most of the silica has crystallized into minerals – this fluid is very salty and is also highly concentrated in heavier metal ions that can't easily be incorporated into the common rock-forming minerals.



This fluid can penetrate cracks around igneous intrusions– once cooled, metals are precipitated out of solution in the form of mineral compounds or native metals.

## Disseminated Deposits

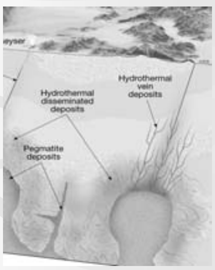



Pressure from the intrusion of an igneous body can generated many microscopic cracks into which residual fluid (thermally buoyant) can penetrate and cool.

Minerals containing copper, molybdenum, gold and silver are distributed throughout the fractured rock in low concentrations (disseminated).

Although disseminated ore deposits are of a very low grade (low concentration of metals), they are immense in scale and can be mined at a profit assuming that large volumes of rock and the metal can be extracted at relatively low costs.

## Vein (Lode) Deposits



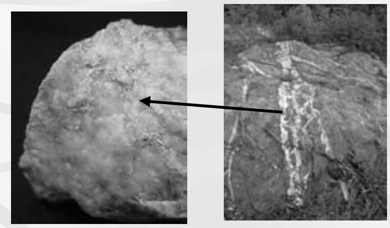

Fluids superconcentrated in metals can penetrate larger fractures, forming mineral-filled veins.

Native gold and silver can be found in the spaces between quartz crystals.

Vein deposits are sometimes called “Lode Deposits” .

The common term “Mother Lode” refers to a belt of quartz veins in California that was the source of the gold in the famous California gold rush of the mid 1800s.

## Vein (Lode) Deposits



Gold-bearing quartz veins (Timmins, Ontario)

## Vein (Lode) Deposits

“Leaf silver” from vein deposit (Cobalt, Ontario)

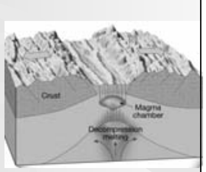


## Hydrothermal Processes: Divergent Boundaries

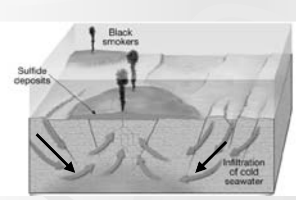
Magma generated at convergent boundaries (by decompression melting) tends to be mafic in composition. Accordingly, metallic mineral deposits in divergent boundary settings tends to be associated with mafic igneous rocks.

As in convergent settings, metal-bearing brines left over from the cooling of magma can penetrate cracks in the crust and form metal deposits.

However, a more important contributor to the concentration of metals is the interaction of seawater with oceanic crust.



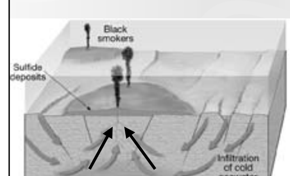

## Volcanogenic Massive Sulphide (VMS) deposits




At a midocean ridge, salty seawater flows down into faults and other cracks of the ocean floor.

As it is warmed, it dissolves sulphide ions, and metal ions (including iron, copper, lead and gold).

## Volcanogenic Massive Sulphide (VMS) deposits

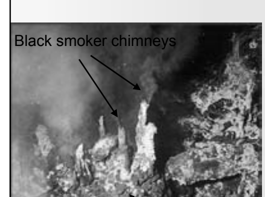



The heated water, now concentrated in metal ions, rises to the surface along fractures and escape through volcanic vents called “black smokers”.

When the solution hits cold water, the metals precipitate as sulphide minerals (or in native form in the case of gold).

Fine crystals of the metallic sulphides that emanate from black smokers accumulate in pods at the surface below).

## Volcanogenic Massive Sulphide (VMS) deposits




VMS pod surrounding black smokers

Note:

the “black smoke” is actually fine-grained metal sulphide crystals that are precipitated from hot vent water.

## Volcanogenic Massive Sulphide (VMS) deposits

The resulting pod-like deposit is called a volcanogenic massive sulphide (VMS) deposit (so-named because their formation is associated with seafloor volcanism, and the orebody is not well-defined in shape)

VMS deposit in Noranda, Quebec

## Deposits Associated with Sedimentary Processes

Some metallic mineral deposits can form by simple sedimentary processes (erosion, transport, segregated deposition).

In some cases, minerals eroded from pre-existing rocks can be concentrated via physical transportation and sorting.

Such deposits are largely confined to occurrence in siliciclastic sediments.

However, some metals of interest can also be concentrated in chemical sediments.

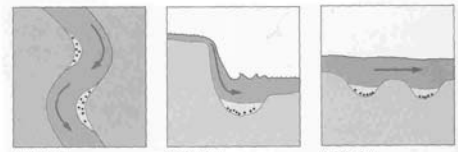


## Aqueous Placer Deposits

Many rock fragments eroded from rocks are ultimately affected by running water.

Particles of gold and other heavy minerals can be concentrated in areas affected by stream currents (remember light particles are preferentially washed away, leaving heavy particles behind).

Good prospect areas include point bars, waterfalls and potholes in the stream bed, where fast moving water slows suddenly.




## Panning

The sizes of gold particles transported in running water can range from dust-sized (gold dust), to pea-sized or larger (nugget-sized).

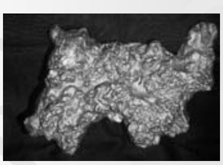
The practice of panning uses the same principle as placer formation (sediment and water are agitated in the pan and the suspended sediment is decanted with the water).

The "pay dirt" is left behind

## Largest Gold Nugget in the World:

"Welcome Stranger" Nugget, Moliagul, Australia

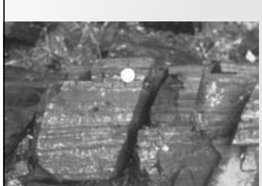
Gross weight: 78.4 kilograms.



Welcome Stranger Nugget

Replica for Scale

## Banded Iron Formation



Banded Iron Formation
(example from northern Ontario)

Much of the iron mined today comes from a deposit type called Banded Iron Formation.

During the Proterozoic, iron was dissolved from rocks on continents.

This iron remained dissolved in river water due to the absence of oxygen in the atmosphere (and in turn, in river water) and was transported to the sea

Oxygen liberated by bacteria in the sea reached sufficient levels to allow iron oxides (as magnetite or hematite) to precipitate as a chemical sediment (1.8-2.5 Ga).

## Banded Iron Formation

Red bands: hematite
White bands: chert

Interlayered with the bands of iron oxide are bands of chert, which was also precipitated as a chemical sediment.

Banded iron formation does not form today because

- The oxygen in the atmosphere rusts iron on land (so is precipitated before it can reach the sea).
- Most silica dissolved in the sea is taken up by some organisms (e.g. sponges) to make their skeletons, so is typically no longer deposited as a true chemical sediment

## Deposits Associated With Weathering: Laterites

Chemical weathering can lead to economically significant metal deposits.

A good example: bauxite (aluminum ore)

Aluminum is very abundant in continental crust, but is generally so tightly bonded within silicate minerals that it is very difficult to extract.

Intense chemical weathering over long periods of time removes aluminum from feldspar and mica and combines it with water to form the mineral gibbsite – $Al_2O_3.3H_2O$

Gibbsite is heated to drive off the water, and further heated to separate pure aluminum metal from bonded oxygen.

## Bauxite

Most of the readily dissolved ions are washed away from the soil,leaving a residue rich in gibbsite

In effect, bauxite just is a highly weathered soil.

Field photo of bauxite deposit

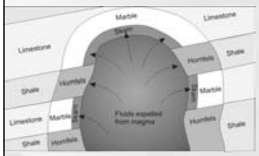
Hand sample of bauxite

## Skarn

Red chalcocite (copper sulphide) crystals in marble skarn.

Skarns can also host some unusual silicate minerals due to reaction of hot fluids with the rock into which the intrusion was emplaced.

## Deposits Associated with Metamorphism




Chemical sediments affected by contact metamorphism can host deposits called skarns.

In this example, the intrusion of magma into sedimentary rock layers has metamorphosed limestone to marble.

Injection of acidic fluids into fractures in the country rock open and expand cavities (through dissolution) in the marble, and metallic minerals can precipitate in these cavities.

## Some Final Comments

The examples shown in this lecture are but a few of the different ore deposit types of metallic minerals.

Deposit types can be loosely categorized according to their main processes of formation, but each has unique features.

This is where a knowledge of geology is important !

Think about all the products you use that contain metal of some sort – you have geologists to thank for these products.

*END OF LECTURE*