

Session 6: Minerals - Earth's Pure Substances!

Minerals are chemical elements and compounds that occur naturally in the Earth. The Earth is our only present resource of all the chemical elements! Except for the 'artificial' elements, we have to dig them out of the ground in one way or another.

Minerals are mainly solid, usually crystalline, even if these are too small to see with the naked eye.

Identification by:

- chemical analysis and properties – may be lengthy and difficult; establishes composition
- physical properties
 - Easy to observe: crystal shape, habit, colour, streak, lustre, cleavage, hardness, density
 - Special equipment needed: optical mineralogy, X-ray diffraction, radioactivity, etc

Over 6000 minerals known; some 300 recognised as common or particularly important.

Rock-forming minerals

Quartz, feldspars, micas, pyroxenes, amphiboles, etc, are mainly silicates, and based on eight abundant elements: O, Si, Al, Fe, Ca, Na, K, Mg.

Granite is formed mainly of orthoclase and plagioclase feldspars (potassium and sodium varieties) and quartz, with lesser amounts of the dark minerals muscovite mica, biotite mica and hornblende.

Economic minerals

A confusing term! The aggregate industry produces sand, gravel, crushed rock...then there are salt, gypsum, limestone, clay...all called 'industrial minerals'... before we come to ore minerals and gemstones!

Uneconomic, non-rock-forming minerals – probably the majority! If these are associated with economic ore minerals, they may be called '**gangue**'.

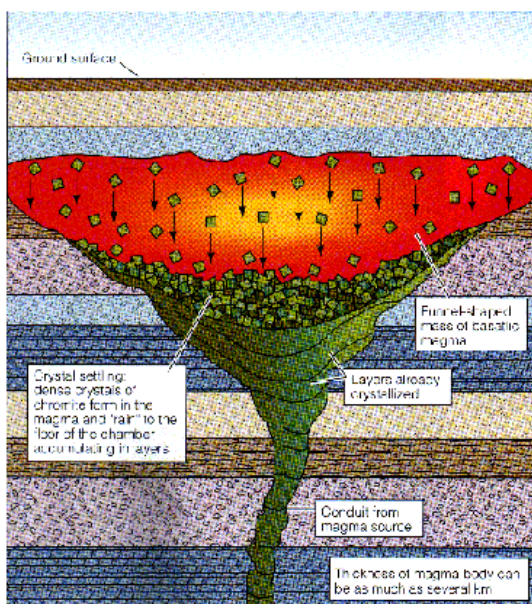
Identifying common minerals

Identification keys will help, but there is really no alternative to familiarity gained through experience!

- on paper: simple, relatively easy to use, but can only cope with a small range of common minerals
- on-line: http://www.rockhounds.com/rockshop/mineral_id/#Key – the ultimate identification key!

Ore minerals

Mainly simple compounds such as metal oxides, sulphides, carbonates, sulphates, and containing most metals of particular interest to industry, e.g. Al, Ag, Au, Ca, Co, Cr, Cu, Fe, Mg, Mn, Pb, Pd, Pt, Zn.



Mineralisation

The separation of an individual mineral from mineral mixtures (rocks and magmas) to form a **mineral deposit**.

Mineralisation by igneous processes

Magmatic segregation: Dense, insoluble minerals settle out at the bottom of a magma chamber.

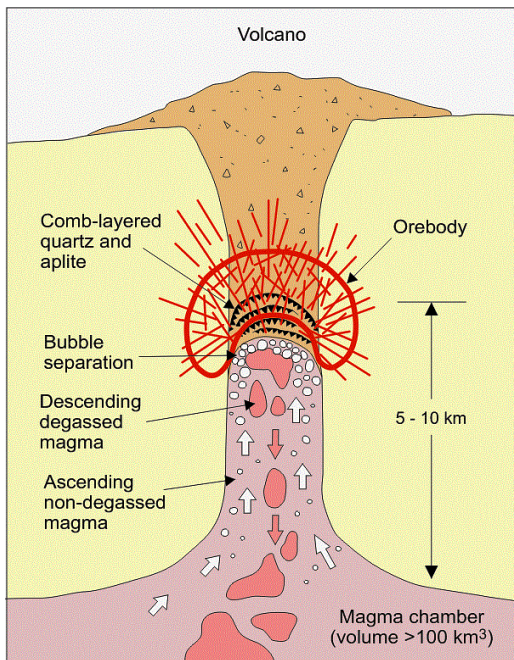
e.g. **Bushveld complex**, South Africa: a gabbro intrusion, with oxide minerals (chromite, magnetite, ilmenite, etc), sulphide minerals (pyrite, pyrrhotite, pentlandite, etc), precious metals (Pt, Pd, etc), containing 90% of the world's known reserves of platinum group metals.

Meteorite impact! A large meteorite impact is sufficient to penetrate deep into the crust, fracturing, melting, and even causing partial melting of the mantle below. Again, dense sulphide minerals settle out in layers at the bottom of the magma chamber.

e.g. **Sudbury basin, Ontario**, the second largest impact crater on Earth - 62 x 30 x 15 km deep; a gabbro intrusion containing mainly sulphide ores of nickel (30% of world reserves), copper, cobalt, as well as precious metals such as gold.

Pegmatite ore deposits: In some cooling magmas with a lot of water present, individual crystals may grow to enormous sizes – some so large that a mine can be operated in a single crystal! These are called pegmatites, and the crystals separate out from the rest of the magma to form an ore deposit.

e.g. **Rössing uranium mine in Namibia**, large open-cast, producing 8% of the world's uranium.



Porphyry ore deposits: Initial slow cooling of a magma gives larger crystals held in the residue of a melt rich in aqueous solutions. Sudden escape of this mix into rock fractures leads to rapid boiling of the water, fracturing more rock, and all the fractures fill with the mixture of larger crystals and a solution which cools rapidly to surround these with myriads of small crystals. Repeated many times, this can lead to major low-grade ore deposits. 50% of the world's copper reserves are contained in porphyry deposits.

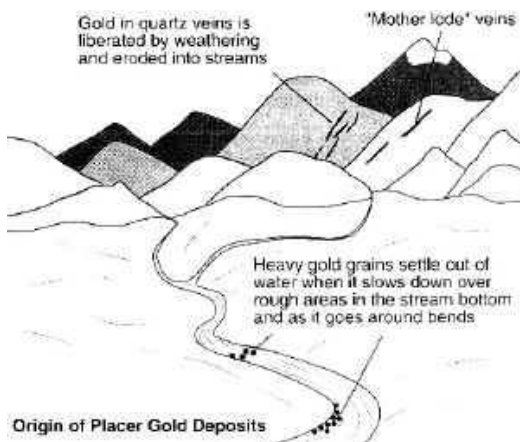
e.g. **Bingham Canyon Mine, Utah**, until recently the world's largest mine! It works a very low grade copper ore (0.4%) on a truly massive scale.

Mineralisation by sedimentary processes

Residual and weathered ore deposits: intense chemical weathering of rocks in hot, wet tropical climates removes soluble materials to leave a residue of deeply rotted material called *laterite*, which contains aluminium oxide mixed with red clay. This is the only process that concentrates aluminium ores

to economic levels – the ore is called **bauxite**.

e.g. **Weipa Mine** in Queensland is one of the world's largest bauxite mines. Australia and Guinea between them produce half the world's bauxite ore.



Placer deposits: mineral grains are transported and sorted by moving water, and deposited when the energy of the water drops too low. There is a wide range of such deposits – gold grains in river gravels (recovered by panning), cassiterite (tin ore) in river gravels in Malaysia, ilmenite (titanium oxide) from beach sands in Australia.

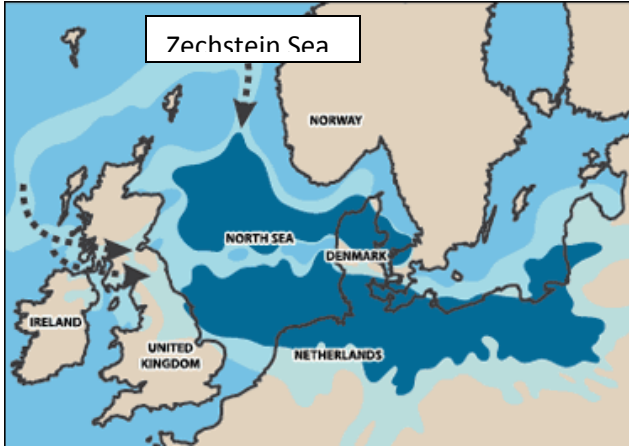
e.g. **Witwatersrand** (South Africa): the gold deposits are placer deposits in old river gravels that have become conglomerates. Similarly the world's largest uranium deposit in **Elliott Lake, Ontario** lies in old river delta gravels.

Deposits by chemical precipitation: these form from sea-water by chemical reactions and settle out on the sea-floor.

e.g. **Mount Isa, Queensland**: silver-lead-zinc ore bodies. Also, all the BIFs (banded iron formations), including the massive deposits of the **Hamersley Ranges, Western Australia**.



Salt deposits – evaporites: deposited by evaporation of ‘sea-water’ in a confined environment until the solution becomes saturated; individual compounds crystallise out in turn, forming a succession of layers. If more ‘sea-water’ breaks in from time to time, the succession may be repeated many times.



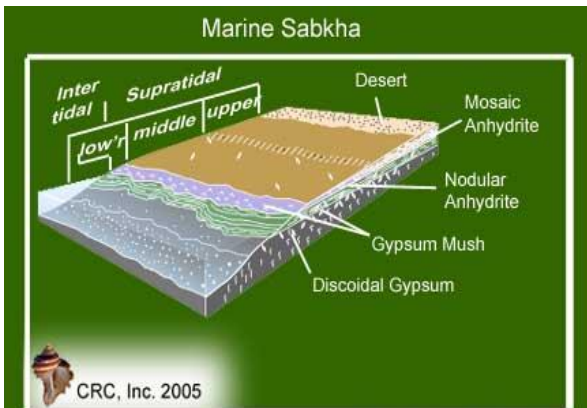
e.g. **Winsford Salt Mine, Cheshire; Kirby Thore**

Gypsum Mine, Cumbria; Boulby Potash Mine, N. Yorkshire. Evaporites include **calcium sulphate** (gypsum, alabaster and anhydrite), **sodium chloride** (halite, rock salt), **potassium chloride** (sylvine, potash), **sodium borate** (borax), **strontium sulphate** (Celestine)

Mineralisation by hydrothermal processes

These form by crystallisation from hot aqueous solutions moving through pathways in the rocks. The water can come from various sources:

- Rainwater (meteoric water)
- Sea water
- Formation water (sea water trapped in sediments)
- Magmatic water (expelled from igneous intrusions)



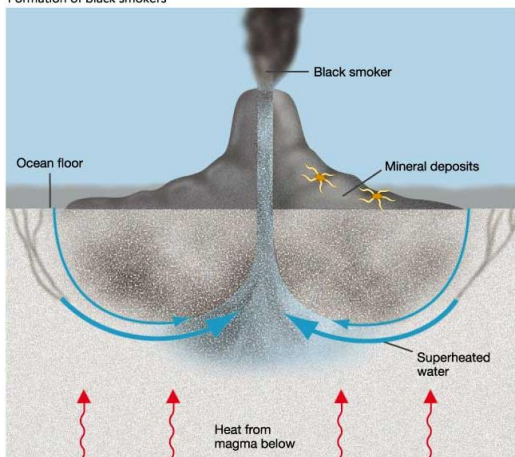
- Temperature: 40°C - 300°C+).
- May contain dissolved ions from its source, may be acidic, and will dissolve more minerals as it moves through the rocks.

The resulting solutions are often called **brines**. As these hot brines move through the rocks – in fractures, or even, if strongly acidic, dissolving their own way through – conditions will change (temperature, pH, pressure) causing metal ions to precipitate rapidly or crystallise slowly to form mineral deposits. This may happen:

- At or near the surface
- Deep below the surface in sedimentary basins
- Deep below and heated by igneous intrusions

Most ore mineral deposits in Britain were formed in these ways.

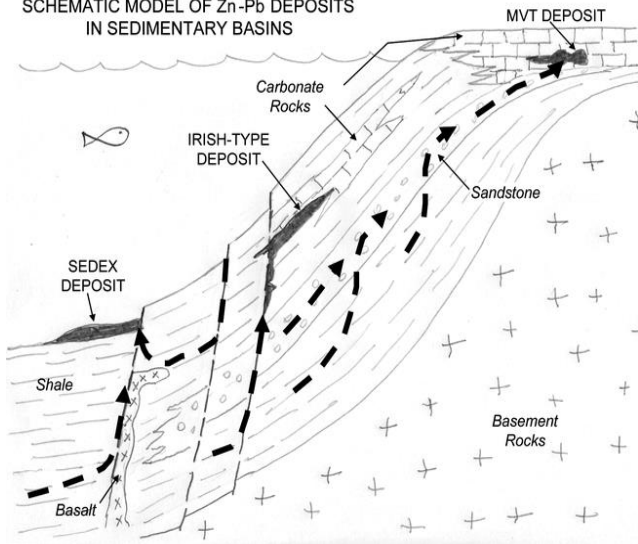
Formation of black smokers



Black smokers!

Hydrothermal vents on the ocean floor around mid-ocean ridges (sea-floor spreading), where sea-water comes in contact with rising magma, and intensive chemistry results to create **massive sulphide deposits**. No mining of active ‘black smokers’ yet, but ancient systems have been extensively mined, including the historic area of the **Troodos Mountains, Cyprus**, and the current mining at **Kidd Creek, Ontario** – one of the world’s largest zinc mines.

SCHEMATIC MODEL OF Zn-Pb DEPOSITS IN SEDIMENTARY BASINS



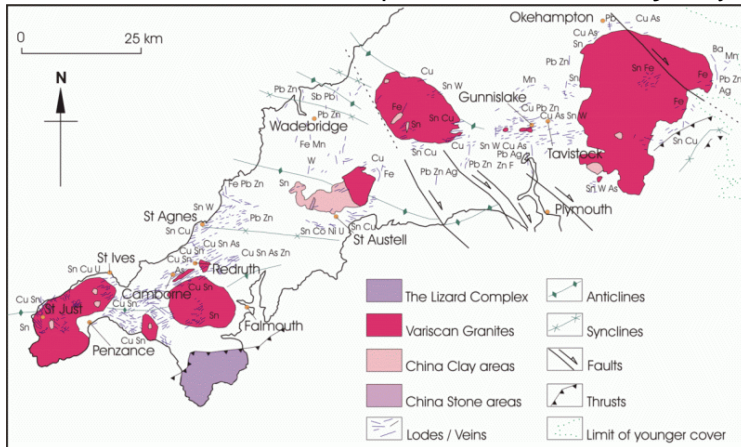
Deep under sedimentary basins - Mississippi Valley Type deposits

- formation water trapped below impermeable shales
- this water already carries many dissolved ions and is heated to moderate temperatures (50-150°C)
- more ions dissolve as it migrates up the permeable limestone rocks towards the edges of the basin, including more chloride ions from evaporite layers
- hydrocarbons from decaying organic matter flow with this water, reducing sulphates to sulphides
- at the basin margins as the solutions cool, the pH changes and carbonate ions increase, the solutions crystallise in joints, fractures & voids to form veins and pipes

The common minerals in MVT deposits are:

calcite: CaCO_3 galena: PbS barite: BaSO_4 sphalerite: ZnS

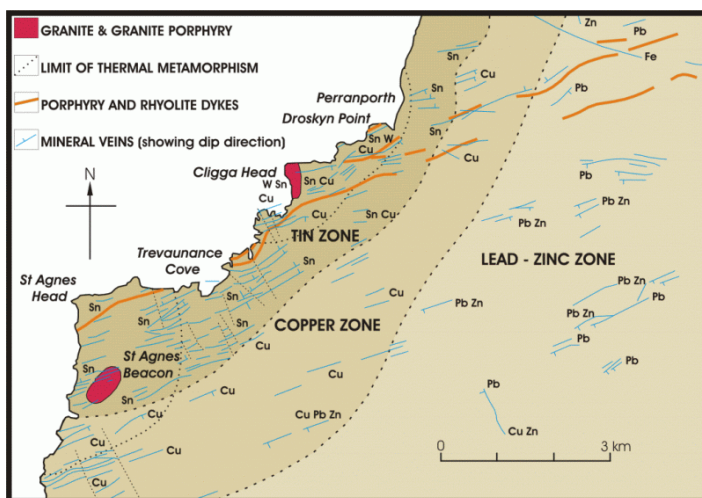
- MVT deposits form the **North and South Pennine orefields** (ancient North Sea sedimentary basin)
- The world-class barite deposits near **Aberfeldy** may have been formed in a similar way.



Related to igneous intrusions

1. As an igneous intrusion cools and becomes solid, it expels large quantities of magmatic water bearing a wide range of ions.
2. The hot solutions migrate through cracks in the surrounding country rocks (faults, joints, etc).
3. As they travel, they cool, and different minerals crystallise in turn at different distances from the intrusion, producing zones of mineralisation.

The major UK example is the tin-mining area of Cornwall and Devon.



Minerals in Scotland

Major deposits: coal, oil, industrial minerals, limestone.

Non-metallic minerals:

barite (Aberfeldy, Strontian, Arran, Muirshiel, Gasswater); talc (Unst); silica sand (Lochaline, Clackmannan); mica (Glen Lyon)

Gemstone minerals (rarely gem quality!): agates (Carrick Hills, Ayrshire; Arran); beryl (Arran); sapphires (Mull, Ardnamurchan); serpentine (Shetland); topaz (Arran); tourmaline (Cairngorms, New Galloway) zeolites (Ardnamurchan, Mull, Skye)

Metallic Ore Minerals:

- chalcopyrite (Wanlockhead, Arduaine)
- chromite (Unst)
- strontianite (Strontian)
- galena & sphalerite (Leadhills-Wanlockhead, Tyndrum, Strontian, Islay, etc)
- silver (Leadhills-Wanlockhead)
- platinum group elements (Unst)
- gold (Cononish, Helmsdale, Unst, Rhynie, Glen Almond, Comrie, Leadhills-Wanlockhead, Fore Burn, etc)