

ENVIRONMENTS OF MINERAL FORMATION

A) Magmatic Environment:

Magma is a molten rock material of $> 1200^{\circ}\text{C}$ of complicated structure with gases and volatiles present in magmatic chambers at depths of 60-100 km below the Earth's surface. It is heavy and viscous.

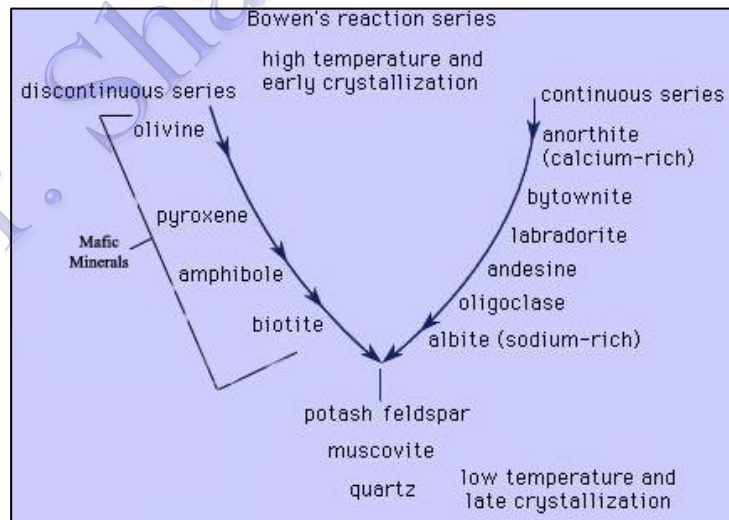
The main process is the cooling of this magma to crystallize the minerals, giving at the end the igneous rocks.

The gases and volatiles (H_2O vapor, Cl, F, S, CO_2 , SO_2 ...etc.) comprise 2-3% of magma volume. If those gases and volatiles escape to the Earth's surface by volcanic eruption, they will crystallize suddenly to form halite, sulfur, and boric acid and precipitate around the volcanic crater.

Four different stages of magmatic (igneous) processes are responsible for forming igneous minerals.

1) Orthomagmatic stage:

It represents the early stage of crystallization after cooling of magma. In this stage, many metals, magnetite, ilmenite, metallic sulphide (pyrite), and chromite are formed in minor amounts and fine grains as accessory minerals at high temperatures. After that the silicate minerals begin to crystallize as given by Bowen's reaction series.



2) Pegmatite stage:

At the late stage of magma crystallization, gases and volatiles, which cannot escape from the magmatic chamber, will concentrate, causing lower viscosity, i.e., high mobility of magma, with very slow cooling. The time will allow large crystals to grow as pegmatite (quartz, feldspars, mica, beryl, and zircon) having a few to tens of centimetres. Most important precious minerals (gems) such as gold associated with quartz veins, beryl (Be-Al silicate), and zircon (Zr-Al silicate) are formed in this stage.

3) Pneumatolytic stage:

After stage (2), the residual gases and volatiles will go through fissures or cracks of the surrounding rocks (country rocks) and react to form new minerals such as cassiterite and fluorite.

4) Hydrothermal stage:

At the latest stage of magmatic crystallization, hot water, as known as hydrothermal solutions, will penetrate further through fissures, cracks, joints, and faults and transfer for longer distances with the dissolved materials at different temperatures to form many minerals as deposits as follows:

- a. Hypothermal deposits:** At 500-300°C and under high pressure in the deep Earth's crust, the hydrothermal solutions precipitate, for example wolframite (Mn, Fe)WO₄, topaz, molybdenite, cassiterite, garnet, and apatite.
- b. Mesothermal deposits:** At 330-200°C and medium depth and pressure, galena (PbS), sphalerite (ZnS), barite (BaSO₄), and calcite (CaCO₃) form.
- c. Epithermal deposits:** At 200-50°C, near the Earth's surface, cinnabar (HgS), calcite, quartz, opal, and marcasite (FeS₂) form. When ionic substitution of Fe in place of Ca ions completely in calcite (CaCO₃)

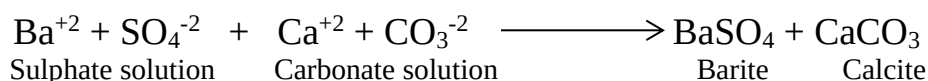
happens in this stage by the process known as metasomatism, calcite will be siderite (FeCO_3).

B) Sedimentary Environment:

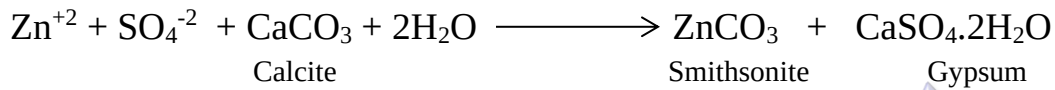
In this environment, deposits occur mainly in an aqueous region (oceans, seas, lakes, deltas, and rivers) either by chemical or detrital precipitation. The processes of sedimentation begin with erosion of the original pre-existing rocks, disintegrating them into undissolved grains or dissolving them into ions by the effect of the atmosphere and hydrosphere, followed by transportation in water as either a detrital grain load (not dissolved) or an ionic load (dissolved), and finally, precipitation or deposition of the water load occurs as a result of the following sedimentary processes:

- 1) **Evaporation:** The dissolved ions in water precipitate chemically after evaporation in the following sequence: carbonates (calcite) of less soluble ions of Ca, then sulfates (gypsum), and finally halides (halite) of the highest soluble ions Na and Cl after complete evaporation.
- 2) **Loss of CO_2 (degassing):** Dissolved carbon dioxide (CO_2) acts as a solvent, yielding weak carbonic acid (H_2CO_3) that causes dissolution of Ca^{+2} ions and preventing its precipitation. By loss of a quantity of this solvent gas, Ca^{+2} begins to combine with the rest of CO_2 forming calcite and other carbonate minerals. This kind of chemical precipitation is well-known in caves as stalactites and stalagmites. The same process happens in hot springs called "geysers"; precipitating "travertine", also called "geyserite" or "calcsinter", as calcite crystals in recent springs.
- 3) **Reaction between solutions:** At the Earth's crust, solutions react with each other to form new minerals.

Example:



4) Reaction between solutions and solids: A solution containing, for example $\text{Zn}^{+2} + \text{SO}_4^{-2}$ can react with calcite in an aqueous medium to form a new carbonate mineral known as 'smithsonite' as well as gypsum as in this equation:



5) Extraction by bio-organisms: Some bio-organisms have the ability to extract dissolved materials and salts from the seawater to build their shells or their solid organs, like pelecypods and coral reefs.

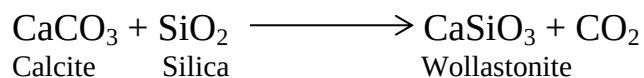
Another example is some bacteria are able to absorb dissolved iron oxides or sulfur from seawater, which then will form iron and sulfur deposits when they accumulate after death.

A sponge is an animal who can build his crust from silica (SiO_2) extracted by him from seawater.

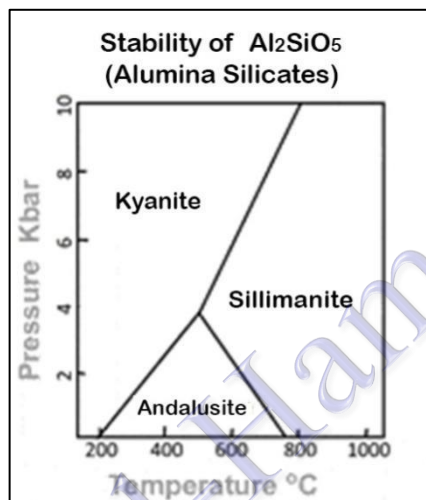
C) Metamorphic Environment:

Metamorphism is the process of forming new minerals by temperature, pressure, and sometimes solutions at deep crust on the condition that no melting should happen to the parent rocks. Only a rearrangement, i.e., recrystallization, of the minerals of the parent rocks occurs to overcome the new higher temperature or higher pressure that influenced them.

By thermal metamorphism “contact metamorphism” (T), the metamorphic mineral wollastonite is formed as in this example:

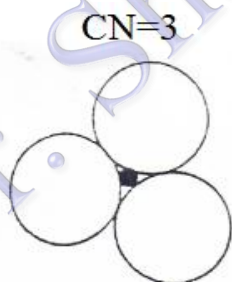


By regional metamorphism (T and P), many new minerals are formed. For example, garnet and cordierite, and the best example is the formation of alumina silicates (andalusite, kyanite, and sillimanite) due to changes in temperature and/or pressure as shown in this diagram:

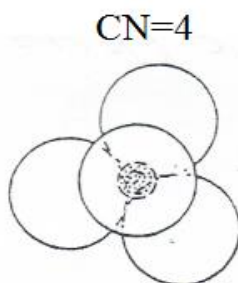


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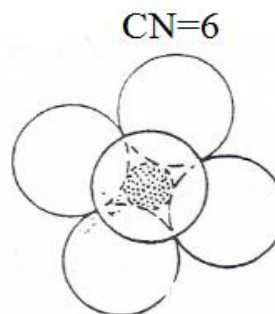
It is the number of anions that can fit around each cation.



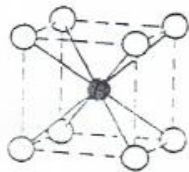
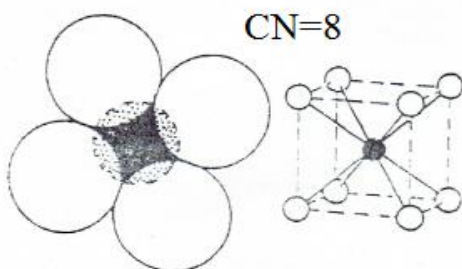
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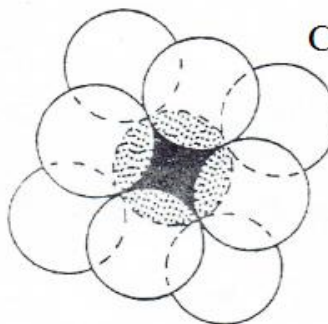
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c



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