HOW AND WHERE MINERALS FORM – Topic 5

Some 4.7 thousand million years ago, our sun, and then the planets, condensed from cosmic dust. A million years later, the sun 'ignited' and started converting hydrogen into helium by nuclear fusion. Energy was released as sunshine. That energy heated the rocky inner planets. On earth, [Diameter 12,700 kms;] that generated several hundred minerals then thousands more as the crust underwent cyclic heating and cooling, erosion, weathering and interaction with oxygen produced by photosynthesis of primitive vegetation. These processes continue today forming additional, and even new, mineral species.

As far as we are aware, the minerals of the earth comprise that crust which is the top 50km weighing about 10^{20} tonnes. Excepting for the water and organic matter, it is all minerals. The composition of the crust was determined by the composition of the cosmic dust swept up as the sun and planets formed.

Crust Composition

Material	Composition	%	Rock	Minerals
Silica	SiO_2	59	Silicates	**Quartz**, others
Alumina	Al_2O_3	15	**Feldspars** of Ca, Na or K	
Iron Oxides	Fe_2O_3	7	**Iron Ores**	Mostly Hematite
Lime	CaO	5	**Limestone & Marble**	Calcite
Soda	Na_2O	4		
Magnesia	MgO	4		
Potash	K_2O	3		
Water, Atmosphere,		2	*& organic matter*	

It is not surprising that the minerals of the crust are mainly **quartz** (SiO_2), **feldspars** (alumino-silicates of Ca, Na and K), **limestone** and **marble** ($CaCO_3$) and iron ores (Fe_2O_3).

Where geological processes concentrated other elements in small regions, different minerals based on those elements were formed there.

THERMODYNAMICS

The influence on heat & other forms of energy on the formation of rocks & minerals.

-every natural process reduces the local energy level.

KINETICS

The measure of rate [i.e. duration] of rock & mineral forming reactions.

-The fastest available method will occur.

-Determines how a change will occur.

To understand why the crust comprises mineral crystals, it is necessary to appreciate that for any event (in the universe) to occur naturally, it must be accompanied by a local decrease in energy. Additionally, it is necessary to appreciate for a change to occur naturally, a means must be available for that change to take place, and if several different means are available, it is the fastest that will dominate. So, of all the changes that could have occurred in the crust, we deduce that the formation of minerals must have occurred faster than all possible competing events, and we further deduce that the formation of minerals as crystals must have occurred faster than the formation of the same chemical compounds in some other form.

There are only four different processes by which those mineral crystal could have formed. They are **solidification**, **condensation**, **transformation** and **precipitation**.

SOLIDIFICATION

As magma, (liquid rock, underground), cools by loss of heat, it will ultimately reach that temperature at which it begins to solidify. Further loss of heat will result in complete solidification by the formation of crystals of minerals of the same kind or of different kinds. Magma with high silicon content has low fluidity (it is sticky and tacky) and nearly always solidifies while still underground to quartz, feldspar and other minerals collectively called intrusive rocks, (they intrude into existing rock). **Granite** is the most common of these and because solidification is slow, the crystal size can be large and is called **pegmatite**. Magma with low silicon content is fluid and flows easily to the surface in volcanic eruptions to solidify there to feldspars and other minerals called extrusive rocks, (they extrude to the surface). The most common of these is **basalt** which comprises small grains due to the relatively rapid solidification.

CONDENSATION

Near the surface where space permits, magma emits hot gases containing water vapour, H_2S, SO_2, SO_3, CO, CO_2, NH_3, S and other elements and compounds. Some of these will combine to form compounds (such as ammonia), and as cooling occurs, these and others ultimately reaching their condensation temperatures. Further loss of heat results in the gas condensing to form mineral crystals. This behaviour is particularly evident in volcanic regions where the gases escape through vents called fumeroles at the top of which condensates of sulphur, sal ammoniac (NH_4Cl) and other minerals form.

TRANSFORMATION

Some minerals can change into other minerals in the solid state provided the temperature and/or pressure are high enough. This is known as a **metamorphic** change or a **metasomatic** change if the composition changes as well. For example, quartz as sandstone changes to **quartzite** and calcite as limestone changes to **marble** both without any alteration of composition. Composition changes do occur when garnets form from clay, quartz, iron oxide and other minerals at high enough temperature and pressure. Other minerals to form this way include olivine, talc, kyanite tremolite and zoisite.

PRECIPITATION

Under normal circumstances, minerals such as halite and gypsum are soluble in water which is regarded as the solvent and the mineral is the solute. Loss of water by evaporation increases the concentration of the solute until the solution becomes saturated. Then, further loss of water results in precipitation of crystals of the solute mineral. These are called **hydrothermal processes**. At high temperature, water is highly corrosive dissolving large amounts of most minerals (including quartz), which are precipitated at lower temperatures, (quartz at Muttama for example).

HOW DO MINERAL CRYSTALS FORM?

In these four processes, mineral crystals form by a two-step process. The first is nucleation in which a cluster of atoms with the correct composition and structure is formed. The second is growth by atoms attaching to the (growing) nucleus to form the mineral crystal. The process is called **nucleation and growth**. If growth is constrained by the surroundings, the crystals form as irregularly shaped grains – called **anhedral crystals**. If there is some freedom during growth, then some crystal faces develop and a part crystal shape forms – called **subhedral crystals**. But if all crystal faces develop the perfect crystal shapes are called **euhedral crystals**.

Noel Kennon - 2023