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MINERALOGY AND PETROLOGY

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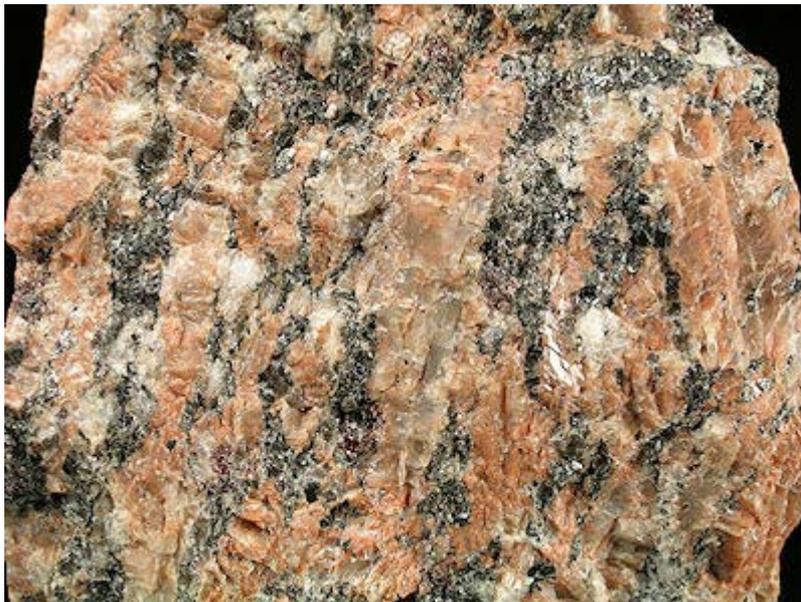
A Műszaki Földtudományi Alapszak tananyagainak kifejlesztése a
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II. FORMATION OF MINERALS (AND ROCKS)

1. INTRODUCTION

Minerals and rocks may form anywhere when steam or melts cool, solutions become oversaturated or in other chemical reactions material particles become solid, mainly in crystalline state.

Crystallization starts with the formation of crystal germs. When the cooling of the solution of the melt is slow, a small number of relatively large crystals are formed; however, when cooling is fast, crystal germs have no time to grow and numerous smaller crystals will be formed. Most often several crystals grow parallel to other crystals, and therefore no space will be left for the development of crystal sheets. In this case **polycrystalline aggregates** are formed.



Granite is a polycrystalline aggregate

Minerals formed in this way, however, may be transformed if placed into different physical-chemical environments producing new minerals (and rocks at the same time). This is a process continuously repeated during the history of the Earth; however, on the human time-scale the velocity of the surface processes counts primarily. The most important geological processes in the course of which minerals and rocks may be formed are discussed below.

2. IGNEOUS MINERAL FORMATION

Minerals crystallized in the inner spheres of the Earth at temperature and pressure greater than on the surface have to be mentioned first. These are of igneous origin.

Magma is a melt rich in silicates that contains dissolved volatile material (e.g. hydrogen chloride, carbon dioxide, water vapour) and – although in very different ratios – the chemical elements of almost the complete periodic table can be found. Magma is formed in the deeper zones of the Earth, where solid rocks melt partially or entirely. When magma less dense than its environment moves upward and enters the surface it is called lava. The hot lava is also a continuously solidifying silicate melt in which minerals have less time for crystallization due to rapid cooling, and therefore very small crystals – or even volcanic glass due to extremely fast cooling -- are formed. If the magma cannot reach the surface it is emplaced into the fractures of the Earth's crust or it may even melt the surrounding country rock into its own material. As the surrounding country rock is much cooler than the magma material, the melt starts to cool down at the margins and the first minerals, according to their decreasing melting points, are crystallized there as well. These products of the early crystallization stage subside to the bottom of the melt due to gravity. This is the **pre-crystallization stage** of igneous mineral formation.

With decreasing temperature, minerals of lower melting points crystallize in increasing quantities. In this stage the majority of the melt crystallizes; thus it is called the **main crystallization stage**. Most of the igneous rocks are formed here, and their major components – rock forming minerals of igneous origin – are the most frequent chemical elements of the Earth's crust: Si, Al, O, Fe, Mg, K, Na, Ca. In the residual magma the ratio of insoluble gases (e.g. water vapour, carbon dioxide, hydrogen sulphur, hydrogen fluoride, hydrogen chloride) together with chemical elements present in smaller quantities so far increase significantly.

A crystallization depth of around 2-12 km and a very slowly changing temperature of around 600-800°C enable calm crystallization, and thus enormous crystals of even several metres may form. This early phase of the post-crystallization stage is called the **pegmatitic phase**. In this phase those chemical elements become abundant that could not be incorporated into the structure of any of the previously crystallized minerals due to – for example – their greater ion radius or valence. These elements are mainly rarer elements like Li, Be, W, B, Sn and U. In the course of pegmatitic rock formation, rock fractures are filled, and therefore the inner pressure of the water and chemically very aggressive halogen-rich fluid containing less silica is increased, producing even more fractures in the surrounding rocks; and in the fractures minerals are produced via cooling. The fluids also interact with the country rock thanks to its fluor, chlorine and boron containing very aggressive fluids. This stage was formerly called the **pneumatolitic stage** but nowadays we rather call it **metasomatism** (element replacement).

Towards the end of igneous activity gases moving across rock fractures cool below 400°C and the hot water solution system occurs. This stage is called the **hydrothermal stage**. This only partially originates from the magma, as the solution system is fed by heated deep groundwater of the country rock. Around mid-ocean ridges, where hot magma flows onto the ocean floor periodically, descending seawater in the rock fractures is heated by the heat of the magma, dissolving numerous mineral materials and triggering hydrothermal activity. Hydrothermal solutions enter the fractures-holes of the country rock, producing mineralization due to cooling and other factors. In this way most of the ore minerals that are important economically are formed.

3. FORMATION OF SEDIMENTARY MINERALS

Sedimentary minerals are formed frequently from cool waters (streams, lakes, sea, groundwater) at temperatures lower than in the hydrothermal stage, by chemical or biological means.

As a result of intense weathering at the surface, fluvial or Aeolian transportation rocks found on the surface are disintegrated and their material is transported into streams, lakes and then into the seas where particles are deposited and then solidified, producing **clastic sedimentary mineral associations**. In the bends, at the banks of rivers where the velocity of the water is reduced, minerals fallen from the rocks, disintegrated and then transported away by the river are deposited according to their density. Therefore sandy parts consisting of one type of mineral (placer) are frequent in the load. Important tin, titanium and zircon-containing minerals can be concentrated in this way in the sand of rivers. Also native gold and gemstones were washed out from placers through thousands of years.



Dripstone in caves

In contrast to the above, limestone, rock salt and gypsum are formed primarily by chemical reactions. Dripstone in caves and freshwater limestone of lime-rich streams are produced by the transformation of the transported or adsorbed carbon dioxide content of the water into carbonic acid, which dissolves carbonate rocks when contacting them. However, when such calcium hydrogen carbonate-rich water arrives into places of less pressure, e.g., at waterfalls, dripping from a cave wall, or when water plants extract carbon dioxide from the water via photosynthesis, dripstone is formed in caves and freshwater limestone is formed in streams. Rock salt and gypsum are also found dissolved in lakes and seas from which they are precipitated when water evaporates, so that the solution becomes oversaturated. This is frequent in bays and in salty lakes when water evaporates dissolved sodium chloride or calcium sulphate precipitate in the form of anhydrite. Certain chemically produced carbonate mineral associations can be transformed chemically by metasomatism (element replacement). This is how dolomite and magnesite are formed from calcite. The above are the primary ways and places of **chemical sedimentary rock formation**.

Rocks exposed to climatic challenges on the surface (e.g. water, ice, wind, temperature undulation) weather due to the effect of air oxygen and precipitation water. This is the process of **physical and chemical weathering**. The stability of minerals produced by magmatic processes lessens with the degree to which the new environment differs from the one in which the mineral was formed. In this way, for example, the already mentioned minerals – crystallized from magma at high temperature – weather soon into other minerals via weathering processes. Main rock-forming minerals, for example, turn into clay minerals, while from sulphides via oxidation processes sulphates and oxides are formed.

Biological weathering has been active since the evolution of the biosphere. In the course of biological weathering living organisms dissolve the surface of minerals and rocks via biogenic processes (organic acids formed around plant roots, microorganisms, etc.). Living organisms themselves can produce mineral precipitations that are called **minerals of biogenic origin**. These include sea animals secreting a calcareous skeleton (corals, shells) producing limestone, or eukaryotes secreting a silica skeleton that produce silica deposits. Certain microorganisms and algae can produce various mineral precipitations from solutions (sulphides, oxides, phosphates) that may be accumulated in industrially utilizable quantity.

4. METAMORPHIC MINERAL FORMATION

All rock-forming minerals – igneous, sedimentary or metamorphic – can be recrystallized into new minerals if placed into completely new physical-chemical conditions. If in this process the change of temperature and/or pressure is dominant then it is termed metamorphism.

During metamorphism transforming minerals remain mostly in a solid state. In other words, the polycrystalline unit does not become melt entirely; however, its chemical composition and/or crystal structure are changed. Metamorphic processes can take place in a wide range of pressure and temperature conditions and on a local or regional scale. Some examples of this: thermal or contact metamorphism can occur locally when hot magma is emplaced into cooler country rock. In this case contact belts develop in both the igneous rock and the country rock (primarily in the contact zone) and new mineral phases are formed due to the high temperature and the effects of escaping volatiles. If for example the contact effect affects relatively clean limestone, it will be crystallised into marble.

On a regional scale, with changing temperature and/or pressure new mineral phases are formed by large rock movements and metasomatic processes. This phenomenon is called **dynamothermal metamorphism**. In general minerals formed at low, medium or high pressure can be identified, where temperature also plays a significant role. The degree of metamorphism is indicated by **index minerals** that occur only in certain pressure and temperature intervals. The mineral association of metamorphic rocks formed in this way depends strongly on the mineral (and chemical) composition of the original rock, in addition to the temperature and pressure conditions.

Finally, it has to be mentioned that mineral forming processes have been active continuously since the formation of the Earth, and igneous, metamorphic and sedimentary mineral formations are in close connection to each other. Igneous rocks, for example, may come to the surface via plate tectonic processes and their certain minerals may become transformed due to atmospheric conditions or denuded to become constituents of clastic sediments and then of other sedimentary rocks. These sedimentary rocks, due to the weight of continuously deposited rocks, and emplaced into greater depths as a result of crustal movements, can be re-crystallized into metamorphic rocks at greater pressure and temperature. At even greater pressure and temperature they can be melted partially or completely, producing new magma and igneous rocks. And the process can be started all over again.