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Mineralogy and Petrology

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V. Petrologic basics

1. Introduction

Rocks are formed by large-scale geological processes and are composed of mixtures of minerals in the chemical sense. In other words, they are chemically heterogeneous mineral associations forming the solid material of planets and distributed regionally. Apart from mineral constituents, certain rocks may contain glass constituents and organic components as well. Although the vast majority of rocks are solid, in the wider sense every material that was produced by natural processes in the Earth's crust is classified here. Therefore liquid (oil, water) and gaseous (natural gas) materials are also regarded as rocks.

On the basis of their formation, rocks are classified into three main groups: igneous, sedimentary and metamorphic rocks. **Igneous rocks** are formed fundamentally by the crystallization of the liquid silicate melt, magma. **Metamorphic rocks** are produced by a significant change in temperature and/or pressure or by the effects of shear force by solid state re-crystallization from rocks produced earlier. **Sedimentary rocks** are formed by elevation of formerly produced rocks to the surface, their denudation, weathering via transport, deposition and diagenesis of weathering material. Other types of sedimentary rocks are the result of chemical and biological processes and the decay and transformation of organic matter (animal and plant remnants).

Although solid rocks are generally viewed as the symbols of consistency, still – especially in a greater time context – they are being continuously changed and transformed. In this way igneous-metamorphic-sedimentary rocks can be transformed into each other by geological processes. Rock-forming processes in detail are studied in the fields of petrology and geology.

We here are going to get acquainted with the principles and fundamentals of classifying rocks and are going to be introduced to the most important rocks of the Earth's crust and mantle.

In contrast to minerals, rocks can be characterised as follows:

1. the volume percent distribution of rock-forming minerals is determined in the course of studying the **mineral (modal) composition,**

2. for **chemical (normative) composition** chemical analyses are required that are performed usually for the major chemical components.,

3. determination of the **texture** (structure) includes the size, shape, crystallinity, quantity, distribution, orientation relative to each other of rock constituents – like minerals, volcanic glass, rock particles, grains, fossils, organic components, etc. The characterisation of pores, ruptures, determination of capability to weathering or other transformation also belongs here.

Rock forming minerals

Minerals composing rocks are called **rock-forming minerals**. This term is important because only 20 minerals/mineral groups are classified here from the known (around 4,200) minerals. These are the following: quartz, feldspars (primarily alkali feldspars and plagioclases), feldspathoids, micas, clay minerals, pyroxenes, amphiboles, olivines, garnets, zeolites, spinels, apatites, and calcite. It is important to emphasize that in the course of characterizing rocks – especially in the highly important silicate mineral groups – we do not attempt to determine mineral species here. We are content with giving the mineral groups that can be generally determined by thin-section analysis.

Rock-forming minerals are called either dominant (important) or accessory (subordinate) constituents depending on their ratio. the quantity of the prevailing constituents is great and determinative in the rock (e.g. plagioclases, pyroxenes, micas, olivines, calcite, quartz, clay minerals).

Accessory constituents are generally present in smaller quantities in rocks with no determinative character. They are present in numerous rock types (e.g. apatites, spinels, zircon, epidotes), however, they are characteristic only for a limited number of rocks in which they may accumulate in large quantities (e.g. tourmalines, garnets). Dominant and accessory rock-forming minerals are called primary rock constituents, as they are formed when the rock is formed. In contrast, secondary rock constituents are formed from primary constituents via processes following the formation of the rock (weathering, metasomatism, metamorphism, etc.).

Dominant constituents can be classified into two groups regarding their colour and chemical components:

1) Colourless and white (felsic) components that are free of Mg, Fe and Ti, including feldspars, feldspathoids, muscovite and quartz.

2) Colour (mafic) components that contain Fe, Mg and Ti and are generally dark from iron (black, brown or green), including e.g. olivines, pyroxenes, amphiboles, spinels and biotites.

Based on the above, for accurate determination of the rock type detailed observation by the naked eye or by a hand lens is not enough; mineralogical and chemical analyses – including thin-section analysis by mineralogical microscope – are required. Thin-sections are sheets with a thickness of 30 mm cut from the rock that are transparent except for opaque minerals. This technology is one of the most important methods of detecting both mineral composition and textural characters. Apart from these, electron microprobe analysis performed on the polished part of the rock is becoming more widespread for determining textural characters and mineral (chemical) composition (in this case even opaque minerals can be studied well).

2. Igneous rocks

Igneous rocks can be classified into three groups:

- plutonic (intrusive),
- extrusive (volcanic) and
- volcanic clastic (pyroclastic).

All three types originate from magma. Magma is a natural silicate melt formed at certain places of the Earth's crust, primarily in the upper part of the mantle and in the deeper zones of the lithosphere that contains more-or-less steam gaseous volatiles. Characteristics of the magma change in relation to temperature, pressure and chemical composition. Magma moves basically from zones of great pressure towards places of less pressure, thus finally towards the surface. When the magma is emplaced into the solid crust and stops and solidifies at a greater depth (between 5-25 km) plutonic rocks are formed. However, if the magma reaches near or to the surface it solidifies rapidly. In this way subvolcanic and volcanic igneous rocks are formed.

The magma is a multi-component system, and therefore its solidification happens sectionally (differentially) and not as a whole. First minerals of high melting point and then those of low melting point are crystallised. The crystallization sequence of the most important silicate rock forming minerals is defined by Bowen's reaction series. It is important to note, however, that this reaction series is characteristic for the calc-alkaline rocks. Most magmas have temperatures between 700 and 1200°C. Its viscosity and liquidity is a function of chemical composition, temperature and the quantity of volatiles. Basic magmas are, for example, less viscous than acid magmas. Two phases of magma crystallization are separated: liquid magmatic and post-magmatic phases. The liquid magmatic phase is further separated into pre-cystallization and main crystallization stages, while the post-magmatic phase is divided into pegmatitic, pneumatolitic and hydrothermal stages. (According to recent views the pneumatolitic stage is interpreted as a high-temperature hydrothermal stage.) The main mass of the magma is crystallized in the main crystallization stage, producing igneous rocks. The outermost 15-20 km thick part of the Lithosphere is composed primarily of such rocks.

3. Metamorphic rocks

Every seemingly solid state transformation is classified as metamorphism that act between the lower and upper limits of metamorphism. Metamorphism is a process that results in the changing of the mineral composition and/or the structure and texture of a rock seemingly in solid state. It is emphasized that these processes are *seemingly* solid state transformations because recent research has revealed that fluids and gases have a role in them as well on a sub-microscopic scale. Metamorphic processes can be best characterised by the temperature and pressure conditions. Pressure can be lithostatic, resulting from the weight of the overburden: differential, caused by tectonic movements; and finally vapour or fluid pressure exerted by volatiles in the system.

The lower limit of metamorphism overlaps with the rock formation process of sediments (diagenesis).

This hardly definable boundary can be determined by the crystallinity degree of certain phyllosilicates (e.g. illites, chlorites) and the occurrence of certain zeolites (e.g. laumontite). If no minerals such as these are found then the process is associated with diagenesis (and ultimately with sedimentary rocks). The lower temperature limit for metamorphic processes – although this is strongly dependant on material quality – is placed at around 150 50°C in the case of silicate rocks.

The upper limit of metamorphism (i.e., the boundary between metamorphic and igneous processes) is indicated by the initial melting of metamorphic rocks.

Melting temperature of metamorphic rocks depends on several factors – like for example, chemical composition, pressure and the water content of fluids in the system – occurring between 650°C and 1100°C depending on these factors.

Metamorphic processes can be classified into two groups regarding the extent of the process: local and regional.

Local metamorphic processes are of small extent (in the scale of m-km) triggered by local geological processes like magma emplacement or shearing phenomena associated with crustal movements or meteorite impact. On the contrary, regional metamorphic processes are of greater extent (on the scale of several km, several hundreds or thousands of km) associated with the tectonic movement of enormous rock bodies. Within the two groups, further types can be identified based on temperature, pressure conditions and on the presence of differential shear forces:

1. Local metamorphism

   Thermal (contact) metamorphism

   Tectonic (dislocation) metamorphism

   Impact (shock) metamorphism

2. Regional metamorphism

   Burial metamorphism

   Dynamothermal (orogene) metamorphism

   Hydrothermal (ocean basement) metamorphism.

4. Sedimentary rocks

Sedimentary rocks, in contrast to most of the igneous and metamorphic rocks, are formed on or near the Earth's surface. Therefore, temperature and pressure play a less significant role in their formation.

On the other hand, surface and near surface rocks are exposed to oxidation and other outer effects (wind, water, ice) that either alone or together tend to change the mineral and chemical composition and textural-structural character of the original rock. The stability of rock-forming minerals tends to decrease as the physical and chemical parameters move farther from those prevailing at the place and time of formation.

The formation of sedimentary rocks is determined by the following four strongly related processes:

- Weathering
- Transport
- Deposition (+ precipitation)
- Diagenesis (rock formation).

Depending on which processes are dominant and what the original material is, sedimentary rocks can be classified into the following three large groups:

1. Clastic sedimentary rocks,
2. Chemical and biogenic sedimentary rocks,
3. Organic sedimentary rocks.