ROCKS AND MINERALS

W.K.B.N. Prame

Introduction

In our day-to-day life, many of us have the opportunity to see rocks and minerals mostly in the form of building stones, road metal, gemstones. statues, or natural exposures. Probably you may have noticed that there are different kinds of rocks. However, only a few of us spend some time to think about the ingredients of these material and mechanism by which the rocks and minerals are formed. At the very outset, the distinction between **rocks** and **minerals** should be clarified.

Minerals are defined as naturally occurring crystalline material (usually inorganic compounds within the earth crust) with a definite chemical composition. In spite of this definition, organic substances such as coal and liquid/gas hydrocarbons are also considered as mineral resources. In crystalline material, atoms are arranged in a regular pattern and this pattern is repeated throughout. Usually a mineral contains a number of elements but in rare cases only a single element may be present.

An example of a single-element mineral is graphite containing only C

Examples of (two) bi-element minerals are silica (SiO_2) and galena (PbS)

There are over 2000 known minerals but rocks are mainly made of minerals belonging to five major mineral families known as **silicate minerals**. The science of the study of minerals is called **Mineralogy**. The detailed study of the inter-atomic arrangement of crystalline matter and its surface morphology is known as **crystallography**.

Rocks are natural aggregates of minerals or mass mineral material. Some rocks may contain only a single mineral (mono-mineralic rocks). However, most of the common rocks consist of a number of silicate minerals. The study of the natural history of rocks including their origin and conditions of formation is known as **Petrology**

E.g. Quartzite (contains only silica - SiO_2)
Limestone (contain only calcium carbonate - $CaCO_3$)

Before we proceed further, it is necessary to know some fundamental facts about minerals (ingredients of rocks).

Classification of Minerals

Silicates and Aluminium Silicates:	(are the commonest minerals) olivine $(Fe,Mg)_2SiO_4$ pyroxene $(Fe,Mg)SiO_3$ etc.
Carbonates:	calcite $CaCO_3$, magnesite $MgCO_3$, dolomite $(Ca,Mg)CO_3$
Sulphides:	galena PbS, chalcopyrite $CuFeS_2$, cinnabar HgS
Oxides:	silica SiO_2, rutile, TiO_2

Halides:	fluorite, halite NaCl
Native Elements:	Au, Ag, Pt, C

Average major chemical constituents of the earth crust

In terms of elements (%)		In terms of oxides (%)	
O	46.6	SiO_2	59.3
Si	27.7	Al_2O_3	15.4
Al	8.1	Fe_2O_3+FeO	6.9
Fe	5.0	CaO	5.1
Ca	3.6	Na_2O	3.8
Na	2.8	K_2O	3.1
K	2.6	MgO	3.5
Mg	2.1		

Silicate Minerals and SiO_4- Tetrahedron

As already mentioned, silicate and aluminosilicate minerals are by far the commonest in the earth crust. The crustal rocks are mainly composed of **silica (SiO_2)** and **minerals belonging to five major silicate mineral families**. These mineral families are:

(1) Feldspar
(2) Mica
(3) Pyroxene
(4) Amphibole
(5) Olivine

The fundamental building block of all silicate structures is SiO_{-4} tetrahedron in which 4 oxygen atoms are set at the corners of a tetrahedron with a silica atom at the centre. SiO_{-4} units may occur separately or may link with neighbouring units by sharing the O in different ways. The differences in arrangement of fundamental SiO_4 unit provide a basis for classification of silicate minerals.

Crystals

Under certain physical conditions, minerals are formed as crystals. **Crystals** are bodies usually bounded by flat surfaces arranged in a definite pattern, which depends on internal arrangement of the atoms. Examination of crystals reveals that there is a certain regularity of positioning the crystal faces, edges etc. This regularity may result in varying degrees of crystal symmetry. Crystal symmetry can be expresses as symmetry planes, symmetry axes and symmetry points.

Based on symmetry, all crystals can be grouped into six **crystal systems**. These are cubic system, tetragonal system, hexagonal system, orthorhombic system, monoclinic system and triclinic system.

e.g. halite (NaCl) cubic system.
quartz (SiO_2) hexagonal system

Magma

Magma is hot molten rock material with temperatures usually ranging from 700°C to 1200°C. Some volatile material and solid crystals may also be present. Magma contains ions of O, Si, Al, Ca, K, Mg, Fe, Na, H and C. When it reaches the earth crust (e.g. volcanic eruption) these hot, mobile material is known as *lava*.

Igneous rocks are formed by cooling of magmas. When magma solidifies at or near the earth surface, **volcanic rocks** are formed. Solidification of magma at depths causes the formation of **plutonic rocks**. With cooling of magma, certain minerals are (formed) crystallized. Generally, if the cooling rate is slow, well-formed large size crystals are formed. If the cooling rate is very high there is no chance for crystallization and thus **amorphous** (non-crystallized) material is formed (e.g. volcanic glass).

Crystal Growth is a two-step process.

(1) **Nucleation** or formation of seeds
(2) **Growth** around nucleus or accretion of atoms onto nucleus

The growth of crystals depends on chemical properties of magma as well as the physical environment (pressure, temperature and rate of cooling etc.)

Stability of Minerals and Polymorphism

Depending on pressure (P) and temperature (T) conditions, a substance of a given chemical composition may crystallize in different crystal systems with different internal atomic arrangements. In such cases, the substance may exhibit drastic differences in physical properties. This phenomenon is called polymorphism.

e.g.	C	graphite→		diamond		
	$CaCO_3$	calcite	→	aragonite		
	Al_2SiO_5	andalusite	→	sillimanite	→	kyanite

A mineral being a chemical compound has a specific **chemical potential** at a given pressure (P) and temperature (T). The natural tendency is to crystallize a substance (to plan the atomic arrangement) in such a way that this chemical potential (**Gibbs Energy**) is minimum at the given P & T. This is the simplified thermodynamic reasoning for polymorphic transition.

Diadochy

The substitution of one ion for another in a mineral without changing the atomic structure is called **diadochy**.

e.g. $Mg^{+2} \leftrightarrow Fe^{+2}$ substitution in olivine $(Mg,Fe)_2SiO_4$.

Some Important Physical Properties of Minerals

Colour:
Colour of a mineral depends on absorption and reflection of vibrations of ordinary white light.

Lustre:
metallic (of gold, galena), vitreous (of broken glass), pearly (of talc), silky etc.

Specific Gravity:
A mineral having a specific gravity that is greater than that of quartz (2.65) is considered to be heavy. Heavy liquids (e.g. bromoform) are used to separate light and heavy minerals.

Magnetism:
Minerals exhibit varying degrees of magnetism. Magnetite is affected by an ordinary hand magnet while other minerals may be affected by strong electromagnets. Magnetic properties are used to separate minerals from mineral mixtures.

Radioactivity:
Minerals containing elements of high atomic weight such as U, Th, are radioactive. Examples of radioactive minerals are pitchblende, uranite and monazite.

Hardness:
A soft mineral is scratched by rubbing against a harder mineral. To determine relative hardness *Mohs* scale can be used.

Mineral	Hardness
Talc	01
Gysum	02
Calcite	03
Fluorspar	04
Apatite	05
Orthoclase	06
Quartz	07
Topas	08
Corundum	09
Diomond	10

Gem minerals have hardness greater than 07 (of quartz) and therefore these minerals are highly resistant to physical abrasion.

Cleavages:
Cleavages are planes along which minerals tend to split easily. Minerals have characteristic cleavage planes. Mica for example has excellent basal cleavages.

Optical Properties of Minerals

Optical properties of minerals are mostly studied under specially designed microscopes known as petrological microscopes. These instruments provide facilities to observe minerals through polarized light and to accurately measure their optical orientations. Transparent minerals are examined through transmitted light while opaque minerals are studied under reflected light.

Rocks

Igneous Rocks:

With a knowledge of some basic facts on minerals you are now in a position to understand the processes of rock formation. As already mentioned, igneous rocks are formed by solidification of magma. Magmas are generated underneath specific sites (zones) located well below the earth surface due to extremely high temperatures and pressures. These magmas may come up to the surface as lava and form volcanic rocks. Plutonic rocks are formed when the magma solidifies well below the surface. The colour of an igneous rock is a good indicator of its composition. Darker rocks (**mafic rocks**) contain more Fe & Mg while light or pale coloured rocks (**acidic rocks**) contain more Si, K and Na. True igneous rocks are not found in Sri Lanka.

Sedimentary Rocks

Physical and chemical weathering leads to the decomposition of igneous or metamorphic rocks (see below). These disintegrated parts are deposited in-situ (at the site of decomposition) or carried away by natural agents such as water, wind or gravity and deposited as **sediments** far away from the original rock. Due to the weight of the overlying portion of a sediment pile, its lower parts are subject to compaction and dehydration. Sediment grains and fragments are then cemented as a cohesive mass. Ultimate product is a **sedimentary rock.** Some sedimentary rocks are formed by biological processes. Formation of sediments and sedimentary rocks takes place at or near the earth surface and therefore **under low pressure/temperature conditions.** Examples of sedimentary rocks are sandstone, limestone, shale and arkose. In Sri Lanka limestone is found in the north-western part, as a narrow belt extending from Puttalam to Jaffna. Sandstone and shale occur in Tabbowa and Andigama areas.

Metamorphic Rocks

Igneous or sedimentary rocks may be buried to deeper levels of the earth crust due to tectonic activity (large scale movements of crustal segments). High pressure and temperature conditions prevailing at such depths causes recrystallization of existing minerals and formation of new minerals without significantly changing the composition of the original material. This process is called **metamorphism** and the products are called **metamorphic rocks**. These mineralogical and textural changes vary depending on the pressure/temperature conditions and their relative importance. Extreme heat around an igneous body could metamorphose the sedimentary rocks in the surrounding areas. More than 2/3 of Sri Lanka is covered by metamorphic rocks. Both metamorphosed igneous rocks and metamorphosed sedimentary rocks occur in Sri Lanka. These rocks are known as high-grade metamorphic rocks as they have been metamorphosed at high temperatures (700-900oC) and pressures (5-9 kb).

Economic Minerals

Minerals are concentrated at certain locations through geological processes. Industry is heavily dependent on mineral raw material and therefore minerals are of great economic significance. To be economically important, the cost of exploitation and extraction should be much lower than the market value of that particular mineral or element. Mineral exploitation and trade should be planned to obtain optimum benefits since mineral resources are **non-renewable**. Occurrences of small quantities of expensive and rare minerals are of significance while moderate amounts of inexpensive material may not be of interest. Although precious metals such as gold and platinum usually occur in traces (measured in PPM -parts per million) technology has advanced to economically extract these elements from highly diluted distributions.

Economic Minerals of Sri Lanka

Economic minerals of Sri Lanka mainly belong to the non-metallic group. Many mineral commodities such as graphite and mineral sands are exported in the raw-form although it is always **economically advantageous** to sell a value-added product. At present, there is increasing concern over the need for utilization of these resources to develop the local industry. Local raw material is extensively used in ceramic and porcelain industry.

Graphite:
Graphite is naturally occurring carbon. Sri Lankan graphite occurs as veins within the Precambrian rocks. Sri Lankan graphite is well known for its high purity (C>99%). The graphite mining industry in the Island blossomed during the second world war. Presently, major graphite mines are located at Bogala and Kahatagaha. There are numerous abandoned mines in the south-western part of Sri Lanka. Graphite is used in manufacturing lubricants, crucibles, and electrodes.

Silica Sand (SiO_2):
Well-known silica sand deposits of Sri Lanka (beach accumulations and wind blown deposits) occur in the areas of Marawila, Nattandiya, Madampe and Vallipuram. Silica sand is the major raw material in glass industry.

Vein Quartz:
This is a form of quartz (SiO_2) which is usually of high purity (SiO_2>98%). Major deposits are at Galaha, Opanayake, Pelmadulla, Pussella and Rattota. Vein-quartz is widely used in middle level technology (as abrasives and refractories) to produce silicon carbide, ceramics and walltiles. Applications of high-quality vein quartz are in the manufacture of ferro-silicon/metallic silicon, optical glass, photo voltaic cells, high temperature glass and lead crystals. The current export price is about 100 US$ per MT.

Feldspar:
Potash feldspar ($K_2O.Al_2O_3.Si_2O_{12}$) occurs in Sri Lanka in the form of pegmatites. Well-known deposits are located at Kaikawela, Rattota, Namaloya, Talagoda, Koslanda and Mailapitiya. It is used in the manufacture of glass, vetrified enamels and porcelain.

Limestone ($CaCO_3$):
Sedimentary limestone from the north-western belt (Aruwakkalu area) is used in the cement industry. Coral limestone and shell beds from the south-western Sri Lanka were extensively used to produce lime although this has been discouraged due to the environmental damage caused by mining activities.

Marble (Crystalline Limestone):

Marble (crystalline limestone) is metamorphosed ancient limestone beds. Major chemical components are carbonates of Ca and Mg. If the MgO content is more than 21% the material is called dolomite. But dolomitic limestones with MgO contents between 15-19% are more common. In Sri Lanka, there are two major applications of crystalline limestones. The low-MgO variety is burnt to produce lime while the high-MgO variety (dolomite) is used as a fertilizer or soil conditioner. Marble chips are used in the terrazzo industry. Dolomite is useful as a flux material in various industries and as a refractory material in open-hearth furnaces. Excellent marble exposures occur in Matale, Digana (Kandy) and Sigiriya areas.

Mica:

A group of sheet silicate minerals characterized by excellent basal cleavages (split easily parallel to the basal section) and hydroxyl ions is called mica. The economically significant mica occurrences in Sri Lanka mainly contain phlogopite (brown or magnesian mica), Muscovite (white or potash mica) or biotite (black or ferro-magnesian mica). Micas are commercially graded into sheets (blocks), scraps and flakes. Sheet micas are good electrical insulators and have a wide range of applications in electrical and electronic industries. Much of the Sri Lankan mica fall into scrap grade and the material is presently exported after manual beneficiation. Current FOB value is about 350 US$ per metric ton. Ground scrap- and flake-type mica is a good filling material in plastic and paint industries. It is also used as a lubricant and as an ingredient in decorative printing work. Prominent mica occurrences are at Talagoda, Kambarawa (Matale), Haldummulla, Madumana, Kebitigollewa and Mailapitiya.

Clay Minerals:

Clays are finely crystalline hydrated silicates. Kaolinite is extensively used as a ceramic raw material and a filling material. Major kaolin fields are located at Meetiyagoda, Nindana (Galle District) and Borellasgamuwa. Clays suitable for manufacture of tiles and bricks are found at numerous locations associated with ancient river planes and lakes. The brick and tile industry is particularly extensive along the lower reaches of Keleni River.

Mineral Sand:

Significant heavy-mineral deposits occur along the north-eastern beach of Sri Lanka, at Pulmoddai, Nilaweli and Nayaru. These heavy sands contain ilmenite ($FeTiO_2$), rutile (TiO_2). zircon ($ZrSiO_4$) and a minor amount of monazite $(Ce,La,Yt)PO_4$. Average percentages of ilmenite, rutile and zircon are 70%, 8% and 9% respectively. Minerals are separated by magnetic methods and exported in the raw-form. The principal sources of Ti are ilmenite and rutile. Monazite-concentrated sands are found along the south-western coast near Beruwala and Induruwa.

Apatite:
A very large apatite ($Ca_3FP_3O_{12}$) deposit is located at Eppawala, Anuradhapura. Apatite is economically important as a source of phosphate fertilizer and the possibility of large scale exploitation of the deposit at Eppawala is now being considered.

Gemstones:
Sri Lanka is one of the major gem-mining countries. A variety of gemstones is found although members of the following gem-families are more common.

Corundum (Al_2O_3) - saphires and rubys
Topaz - $Al_2SiO_4(F,OH)_2$ - white, yellow, green and blue topaz
Tourmaline - (borosilicate of Na, Li, Fe, Mg and Al)
Garnet - pyrope - almandine and grossularite
Spinel - $(Mg,Fe)Al_2O_4$
Zircon - $ZrSiO_4$-hyacinth and jargon
Quartz - SiO_2 - amethyst, citrine, rose quartz
Feldspar- $KAlSi_3O_8$ - moonstones and amazon stone

Gem minerals in Precambrian rocks, pegmatites and scarns are released during rock weathering. They may deposit in-situ or may transport well away from the place of origin. Major gem-bearing areas are Sabaragamuwa, Buttala, Okkampitiya, Elehera, Kaluganga, Bibile and Horton Plains areas.

Laterite:
Ferrugenous laterite is extensively developed in the south-western Sri Lanka. These deposits locally known as **KABOK** are formed by concentration of Fe through superficial weathering processes under tropical climatic conditions.

Some Techniques of Mineral and Rock Analysis

(1) Conventional Wet-Chemical Methods
(2) Atomic Absorption Photospectrometry (AAS)
(3) X-Ray Fluorescence Spectrometry (XRF)
(4) Inductively Coupled Plasma Spectrometry (ICP)
(5) Electron-Probe Microanalysis
(6) Polarizing Microscope Method