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ROCKS AND MINERALS

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FOREWORD TO THE SERIES

The dissemination of scientific information is one of the functions of the Natural Resources, Energy & Science Authority. The Journal of the National Science Council published by this Authority provides a medium for the publication of scientific research papers, and "Vidurawa", the quarterly science bulletin contains scientific articles of a general nature which is of interest to the public.

There is still a wide gap in the availability of reading material on scientific subjects of local interest. One result of this is that science students confine their reading only to their school notes and to the few available text books which are mostly published abroad. In an attempt to improve this situation, the Working Committee on Science Education Research of the Natural Resources, Energy and Science Authority decided to publish a series of booklets on scientific topics of local interest as supplementary reading material for students and the general public. The authors who have been selected by the Committee to prepare these booklets are experts in their respective fields. The manuscripts that were submitted by the authors were examined by referees before being accepted for publication. The views expressed in these publications are those of the authors and are not necessarily those of the Natural Resources, Energy & Science Authority.

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R.P. Jayewardene
Director-General

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CHAPTER 1
Introduction

1.1 The earth's crust

The earth is a planet in our solar system, which revolves around the sun. A cross section of the earth is said to have three main layers; the core, the mantle and the crust, (Fig. 1). The core is the innermost part of the earth and it is further divided into inner and outer cores. The inner core is probably composed of molten nickle and iron, while the outer core is composed of solid nickle and iron. The molten material in the inner core is usually called magma, and when it flows out through volcanic vents or fissures, as it often does, it is termed lava. The mantle is the middle layer, and is believed to be the largest in volume. It is composed of iron magnesium silicate material. The thin outermost layer of the earth, the crust or the lithosphere, is composed of mineral matter. These minerals generally occur in aggregated forms, either singly or mixed. These are rocks.

An estimate of the average elemental composition of the earth's crust is presented in Table I, which shows that more than 97 per cent is composed of eight elements. Of these, the most abundant are oxygen and silicon.

1.2 Minerals

A mineral may be defined as a naturally occuring element or compound with definite chemical composition, and generally, with fairly constant physical properties. Most minerals are of inorganic origin, and they are the

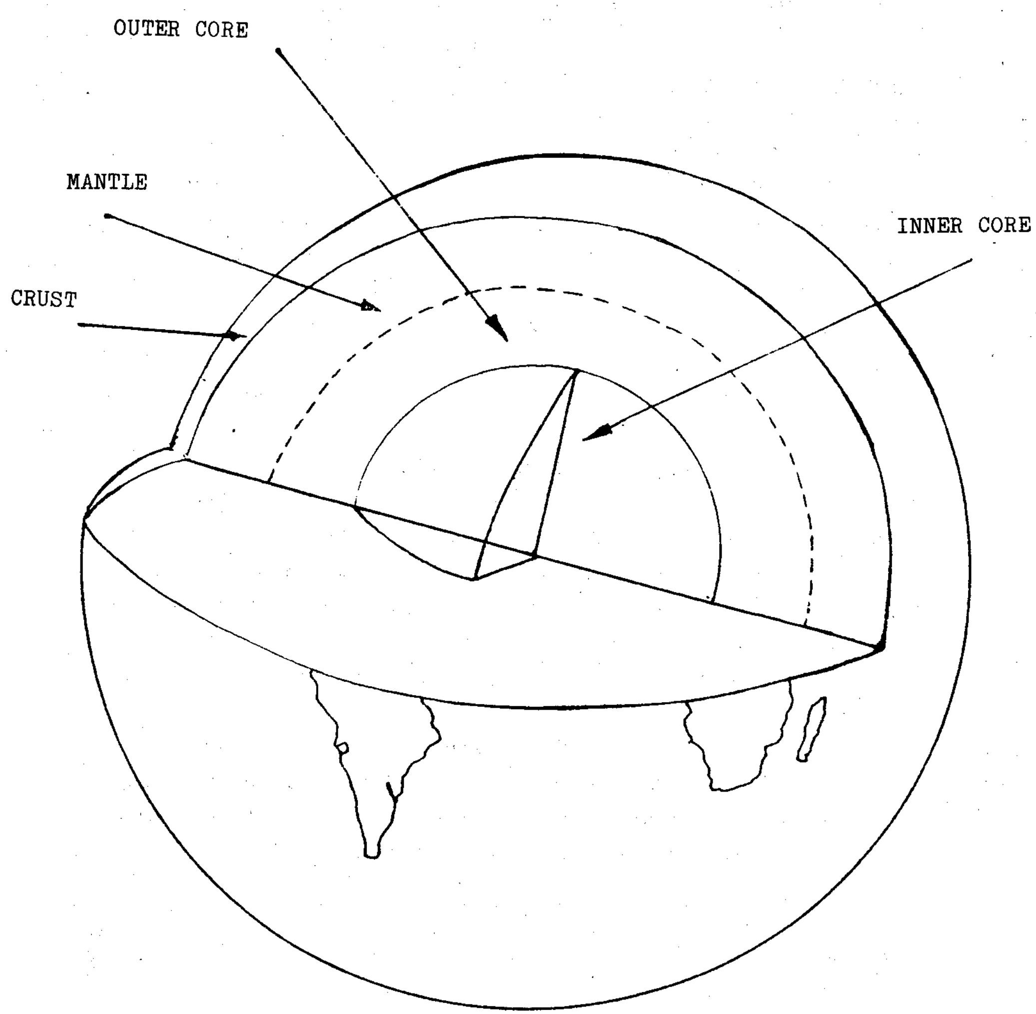

Fig. 1 - Cross Section of the Earth

Table I - COMPOSITION OF THE EARTH'S CRUST BY WEIGHT
(Based on Rankama and Sahama, 1950)

Element	Per cent by weight
Oxygen	49.4
Silicon	25.8
Aluminium	7.5
Iron	4.7
Calcium	3.4
Sodium	2.6
Potassium	2.4
Magnesium	2.0
Hydrogen	0.9
Titanium	0.5
Chlorine	0.2
Phosphorus	0.1

building blocks of rocks which make up the earth's crust. Minerals not found on earth may be present in other planets, and their satellites as well. For example, two new minerals, pyroxerrite and armalcolite, have been found in the crust of the moon.

Although more than 2000 minerals have been identified, only around hundred are of economic importance, due to certain specific characteristics they possess. Some minerals play a significant role as rock-forming minerals. However, all minerals in the earth's crust have not yet been discovered and identified, and each year new minerals are being found.

Minerals may be either solids or liquids, mercury being a good example of the latter. Most solid minerals have a definite crystal form. Some are amorphous, i.e. they have no regular shape. Opal is a good example of an amorphous mineral.

As for nomenclature there is no uniform system. A mineral may be named for different reasons. The distinguishable physical properties and the chemical compositions of minerals have been used in naming some minerals, whereas some are named after famous scientists, geologists etc., or the locality where the mineral was first found. For example, in olivine, the name refers to the olive green colour, while in tetrahedrite the name refers to the tetrahedron crystal form. The minerals calcite and magnesite have been named with reference to their chemical composition, containing calcium and magnesium respectively. Scheelits was named after Scheele, a Swedish chemist, while anandite was named after the Sri Lankan scientist Ananda Coomaraswamy, (Pattiarachchi et. al, 1967). The mineral vesuvianite refers to Mount Vesuvias where it was first reported. Similarly a recently found new mineral was named Sri Lankite as it was first found in this country, (Willgallis et. al, 1983).

The formation of minerals occur in different ways. Minerals are categorized as primary and secondary according to their mode of formation. Primary minerals are those that have either been crystallized from magma, precipitated from aqueous solutions or formed under the influence of organizms. Secondary minerals are those formed through the synthesis or recrystallization from primary minerals. At the earth's surface minerals are found in numerous associations. An example is the association of quartz and feldspar.

1.3 Rocks

A rock is an aggregate of fragments of one or more minerals. Therefore, the composition of a rock is very variable. According to the proportion in which the chemical elements are present in the earth's crust it is obvious, that minerals consisting of silicon, oxygen, aluminium and other metal elements found abundantly, constitute most of the rocks. These minerals are therefore rock-forming minerals. A rock may consist of a single mineral as in the case of limestone or quartz, but in the majority of rocks two or more minerals are present.

Rocks may be considered as the basis of life, since it gives rise to soil, which supports plant life and therefore ultimately all life. The processes by which a soil is formed through the action of climate, topography, biosphere and time, upon rocks, will be discussed later, in Chapter 3. Some rocks are useful in building construction, while some are used in civil engineering. Granite, sandstone, gneiss are some examples of rocks used in building and civil engineering. Shale is used for manufacturing of bricks and tiles, while limestone is used as the raw material for portland cement. Rocks like marble and serpentine are used for ornamental purposes.

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CHAPTER 2
Main rock categories

Rocks are grouped into three main categories depending on their origin. These are : i) igneous, ii) sedimentary and iii) metamorphic rocks. These rocks differ greatly from each other in chemical composition which is detemined by the method of rock formation. In each of these main rock groups, there are several varieties, of which only a few are found widely.

The approximate distribution of the main rock groups in the earth's crust is given in Table II. Although sedimentary rocks form only about 7.9 per cent of the earth's crust, they cover much of the earth's surface, due to the fact that they could form over the other two groups.

Table II - Appropriate distribution of the main rock groups on the earth's crust (Foster, 1982).

Group	Distribution (per cent)
Igneous	64.7
Sedimentary	7.9
Metamorphic	27.4

2.1 Igneous rocks

2.1.1 Properties and classification

Igneous rocks are those formed due to solidification of lava. The crystallization of lava occurs when the temperature falls below a certain point. These rocks are made up of a few minerals of definite composition, and the individual minerals that constitute igneous rocks can be easily recognized, either with the naked eye or with the aid of a lens or microscope. Most igneous rocks are crystalline in nature.

Igneous rocks have been further classified into various types on the basis of their origin and texture. According to the origin there are three types of igneous rocks.

1. Extrusive igneous rocks
2. Hypabyssal igneous rocks
3. Intrusive (plutonic) igneous rocks

Extrusive igneous rocks are those formed due to solidification of lava after penetration into the earth's surface along volcanic vents. Thus crystallization occurs at the earth's surface. Due to the rapid rate of cooling, rocks of this type are, generally fine grained, ie the crystals formed are very small in size. Some even do not form crystals and are like glass. Obsidian is a good example of this kind of rock formed due to very rapid cooling. Basalt, andesite and rhyolite are some of the common extrusive igneous rocks.

Hypabyssal igneous rocks are formed from lava which has penetrated through the crust, but had not come to the earth's surface. These are therefore found at some depth in the earth's crust. The cooling of lava would be at a slower rate than in the case of extrusive rocks, and therefore the

crystals formed are of medium size. Examples of hypabyssal rocks are quartz, porphyry and dolerite.

Intrusive or plutonic igneous rocks are formed due to solidification of lava below the earth's surface in the relatively lower parts of the earth's crust, under a deep cover of older rocks. These have cooled very slowly and therefore possess coarse grained crystals. Intrusive rocks, exposed at the surface have a coarsely crystalling texture. Examples are granite, diorite and gabbro.

Igneous rocks are also classified according to their mineral composition. As silica (SiO_2) is present in nearly all igneous rocks, the easiest classification is based on the percentage of this consituent in the rock. If a rock contains over 65 per cent silica it is classed as an acidic igneous rock. Due to the high content of white silica these rocks are light coloured. Examples of this group are granite, rhyolite and pegmatite. Rocks with silica content ranging from 52 to 65 per cent are known as intermediate igneous rocks. Diorite and andesite are two examples of this group. If silica content is between 45 and 52 per cent, the rocks are termed basic, and they are generally dark in colour. Gabbro and basalt are good examples of basic igneous rocks. Igneous rocks like peridotite have silica at percentages lower than 45, and these rocks are termed ultrabasic igneous rocks. Table III presents the classification of igneous rocks in summary form.

Texture is also used as a basis for classification of igneous rocks. The term texture in rocks refers to the size of the individual mineral grains, and this, as discussed earlier, depends on the rate of cooling of magma or lava. Texture is an easily recognizable characteristic, and together with colour, which indicates the minerological composition, is used in field identification of igneous rocks.

Table III - Classification of igneous rocks according to mode of occurrence and composition

Mode of occurrence	Composition			
	Acidic	Intermediate	Basic	Ultrabasic
Intrusive (Plutonic)	Granite	Syenite Diorite	Gabbro	Peridotite
Hypabyssal	Quartz porphyry	Porphyry	Dolerite	--
Extrusive	Rhyolite	Andesite Trachyta	Basalt	Augitite

Some common igneous rocks are described in the Table IV.

2.1.2 Occurrence in Sri Lanka

Only few types of true igneous rocks are found in Sri Lanka, of which, the commonest is dolerite. Other basic and acidic igneous rocks like gabbro, basalt and rhyollite have not been reported (Cooray, 1967).

Dolerite dykes are present in the eastern and western regions of the island (Fig. 2). Other igneous rocks one would encounter in Sri Lanka are granite, pegmatite and

Table IV - Some common igneous rocks (Modified from Mykura,1977)

Name	Colour	Mineralogical composition	Texture	Uses
Granite	Grey, reddish, white and black yellowish,rarely greenish or blue	Quartz, feldspar, mica, apatite, zircone, magnetite,sometimes amphibole, pyroxene, sphene, topaz,	Coarsely crystalline	Important building stone,road metal
Syenite	Grey, sometimes reddish	Feldspar, mica, amphibole, pyroxene, apatite, sphene, zircon, iron ore	Coarsely crystalline	Similar to granite
Diorite	Black and white black and grey	Feldspar, mica, pyroxene, amphibole, zircon, sphene, apatite, iron ore	Coarsely crystalline	Similar to granite
Gabbro	Grey and black brownish, green rarely reddish	Feldspar, augite, olivine, apatite, ilmenite, spinel sometimes hornblende	Coarsely crystalline	Similar to granite
Pegmatite	Variable colour	Quartz, feldspar, mica, amphibole, pyroxene, apatite, sphene, magnetite, zircon, ilmenite	Coarsely crystalline	Similar to granite
Basalt	Dark grey, black	Feldspar, olivine, augite pyroxene, leucite, mica, magnetite, apatite	Finely grained	Road metal concrete aggregate
Dolerite	Dark grey, black, greenish	Feldspar.augite, olivine apatite, ilmanite	Medium grained	Similar to basalt
Rhyolite	Grey, reddish, yellowish,blue green, brown	Quartz, feldspar, mica apatite, zircon, magnetite, sometimes pyroxene	Finely crystalline	Building purposes road metal

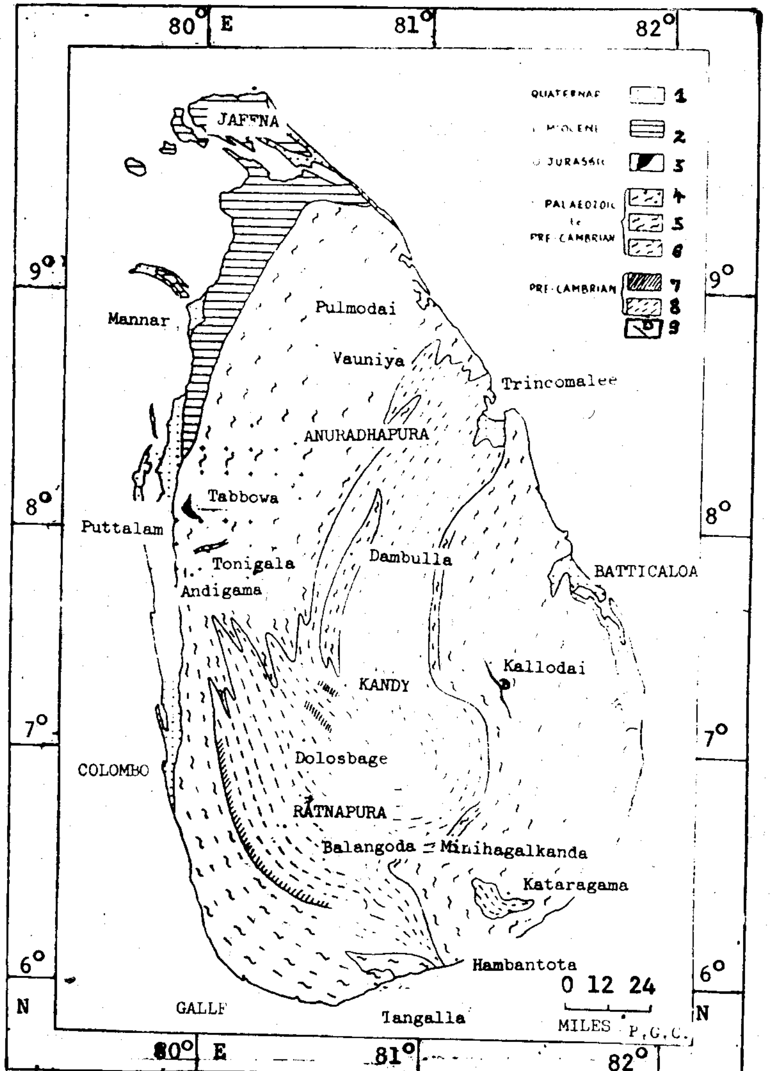

Fig. 2 - GEOLOGICAL MAP OF CEYLON (COORAY, 1964)

1. Gravels, sands, clays and alluvium, (Older and Younger Groups of N.W. Coast)
2. Limestone (Jaffna Limestone)
3. Arkose, feldspathic sandstone, silstone, and mudstone (Tabbowa Beds)
4. Pink granites, granite gneisses, and migmatites (Tonigala Complex, Kathiraveli Gneisses, Kirinda Gneisses)
5. Granitic gneisses and migmatites (Vijayan Series)
6. Granitic gneisses with charnockites, charnockitic rocks, and metasediments (Dambulla, Habarana migmatite belt. Transitional Zone, South-West Region).
7. Basic rocks: amphibolites and basic charnokites (Kadugannawa Gneisses, Sinharaja basic zone)
8. Metasediments and charnokites (Highland Series Complex)
9. Dolerite dykes

pumica. Pink coloured granites are present in the Tonigala and Ambagaspitiya areas. Granites are also found in Arangala and honey brown coloured zircone granites are present in Balangoda area. Pegmatites containing quartz, feldspar and mica are found in all parts of the island. Towards the south west part of the country, pegmatites containing thorianite, thorite, monozite, zircone, allanite and gem minerals are present. Acidic pumice rocks are found in Trincomalee and Kalkudah areas.

2.2 Sedimentary rocks

2.2.1 Properties and classification

As the name implies sedimentary rocks are formed by the sedimentation and subsequent consolidation of fragments, most usually the weathered fragments of rocks which could be igneous, metamorphic or even sedimentary. The first step in the formation of sedimentary rocks is the mechanical and chemical breakdown of already existing rocks which are exposed to the physical and chemical weathering processes at the surface. These weathered products are transported by flowing water, wind or glacier and are deposited. The eventual compaction and cementation of these loose deposits or sediments give rise to sedimentary rocks. Some of the cementing agents involved in this process are organic matter, silicate, clay minerals, iron oxides, silica and calcium carbonate. Some sedimentary rocks are formed by the accumulation of the exoskeletons of marine organisms like shells of molluscs, whereas some are formed by the precipitation of salts from aqueous solution.

Sedimentary rocks can be conveniently classified into three groups according to their origin.

1. Mechanical sedimentary rocks
2. Chemical sedimentary rocks
3. Organic or biogenic sedimentary rocks

Mechanical sedimentary rocks are composed of fragments broken from pre-existing rocks. They are further divided according to the size of the fragments (Table V).

Table V - Classification of sedimentary rocks according to the size of fragments

Diameter of fragments (mm)	Term used	Rock type
More than 256 64 - 256 4- 64 2 - 44	Boulder Cobble Pebble Granule	Rudaceous
1/16 - 2 1/256 - 1/16	Sand Silt	Aranaceous
Less than 1/256	Clay	Argillaceous

Rudaceous sedimentary rocks may have rounded or angular fragments. If the fragments are rounded they are termed conglomarates, and if angular they are known as breccia.

The shapes of the rock as well as its composition reveals the extent to which the rock has undergone weathering.

Examples of mechanical sedimentary rocks are sandstone, shale and siltstone.

Chemical sedimentary rocks are those formed by the precipitation of salts from aqueous solutions. Halite or rocksalt is a typical example of a salt precipitated directly from sea water or brine upon concentration, due to evaporation of water that keeps the salt in solution.

The organic or biogenic sedimentary rocks are formed mostly by marine organisms. The rocks are formed either by precipitating rock material, or by shells or other structures of marine organisms which use the calcium in sea water to build their shells. Coral reefs, coal and shell limestones are common examples of sedimentary rocks of organic origin.

Some of the common sedimentary rocks are described in Table VI.

2.2.2 Occurrence in Sri Lanka

Sedimentary rocks are present in various parts of the island. Small patches of sediments of Jurassic age (Table VII) are found in Tabbowa, Andigama and Pallama areas. At Tabbowa, the sedimentary rocks present are sandstones, arkoses, siltstones and mudstones, whereas at Andigama, black carbonsaceous shale with concretionary haematite are present (Cooray, 1967).

In the extreme north including the Jaffna peninsula, a large area is covered by sedimentary limestone of Miocene age (Table VII). In Arualkalu area (north of Puttalam), it has been found that these limestones vary from

Table VI - Some common sedimentary rocks (Modified from Mykura, 1967 and Foster, 1982)

Name	Colour	Mineralogical Composition	Origin	Texture	Uses
Sand stone	White, pale grey, yellowish red, brownish, greenish	Quartz with clayey siliceous limy or irony cement, sometimes mica, feldspar	Mechanical	Coarse, medium to fine	Building stone
Shale, mudstone, siltstone, etc.	Pale grey bluish grey black, purple red, green	Kaoline and other clay minerals, also quartz, mica, calcite, zircon	Mechanical	Very fine	for brick and manufacture
Crystalline, limestone, shell limestone, coral reefs	Pale to dark grey, white, brown, red, yellowish	Calcite, sometimes aragonite, dolomite, also clay, sand, iron oxide and bituminous material	Mostly biogenic	Crystalline, massive loose and porous	Building and ornamental stone
Coal	Black	Carbon	Biogenic	Fine	as fuel

Table VII - Geological time scale (Based on Raistrick, 1955).

Era	Geological system	Approximate age of base of system (Million years)	Biological age
Quartenary	Recent Pliestocene	- -	Age of man
Tertiary (Cainozic)	Pliocene Miocene Oligocene Eocene	- 30 - 70	Age of mammals and modern plants
Secondary (Mesozic)	Cretaceous Jurassic Triassic Permian	110 140 180 220	Age of giant reptiles and amphibia
Primary (Palaezoic)	Carboniferous Devonian Silurian Ordovician Cambrian	280 310 340 400 500	Age of fishes, graptolites and trilobites
Archean	Pre-cambrian	1200	

pure limestones and siliceous limestones to calcareous sandstones and impure calcareous muds or marls (Herath et. al, 1961).

In addition a belt of unconsolidated recent deposits is present along the entire coastal belt. Coastal sandstones are found in the west coast of the island along Beruwela, Galle and Matara, while unconsolidated beach sands are present in the entire coastal belt around the country. Sand dunes are present in the north-west coast, from Chillaw to Kalpitiya. In several points off the coast of the island coral reefs are found, the best known places being Colombo, Mount Lavinia, Hikkaduwa and along the south-western coast. Patches of lagoonal deposits consisting of fine silt and clay are present in the coastal regions of the west, north-west and east of the country. In addition, alluvial deposits of sand and gravel have been found where rivers overflow their banks during periods of flood, (Fig.2).

2.3 Metamorphic rocks

2.3.1 Properties and classification

Metamorphic rocks are formed from igneous or sedimentary rocks which undergo physical and chemical changes. These changes may include recrystalization, change in texture and or minerology. The main agents of metamorphism are heat, pressure and shear. Three types of metamorphism have been recognized. They are:

1. Contact metamorphism
2. Regional metamorphism
3. Dynamic metamorphism

Contact metamorphism is the alteration of rocks that are in contact with molten magma. The changes are thus

Table VIII - Some common metamorphic rocks (Modified from Mykura, 1967 and Raistrick, 1955)

Name	Colour	Mineralogical composition	Texture	Uses
Gneiss	Grey, reddish white and black, yellowish	Quartz, feldspar, mica, pyroxene, apatite, iron ore, rutile, zircon	Coarsely crystalline	Road metal
Schist	Pale colours often grey	Quartz, mica, garnet epidote, rutile, calcite graphite, kyanite	Finely crystalline	of little use as building material
Phyllite	Dark grey greenish	Quartz, chlorite, rutile sericite, tourmaline, magnetite, albite	Finely crystalline	For roofing
Quartzite	White to yellowish, bluish	Quartz	Massive crystalline	
Slate	Pale grey, bluish grey, black, purple, red, green	Clay minerals, quartz mica, calcite, zircon, bituminous material	Fine	For roofing and pavement slabs
Serpentine	Bright to dark green, streaked and blotched with red	Serpentine, garnet, tremolite, talc	Massive	Ornamental stone
Marble	White to yellowish, bluish green, black, flesh coloured red and white	Calcite, dolomite, quartz, mica, talc, grossularite, diopside	Massive	Decorative building stone

limited to a narrow region that has been in contact with magma and were subjected to high temperature. Regional metamorphism refers to the changes taking place in a rock, chiefly due to the pressure of mountain building processes. This phenomenon occurs over a large area, and recrystallization may take place within the crust. Dynamic metamorphism is the change in rocks caused by movements like earthquakes. Rocks are broken by the movements into fragments and therefore this type of metamorphism is mainly mchanical.

Metamorphic rocks possess certain features which resemble igneous and sedimentary rocks. Some are coarsely crystalline, and some possess foliated structures with banded parallel layers. Some common metamorphic rocks are described in Table VIII.

2.3.2 Occurrence in Sri Lanka

The major part of the island consists of metamorphic rocks, particularly metamorphosed sedimentry rocks of Precambrian age (Table VII). In the central highlands of the country, and extending towards north-east up to Trincomalee, metasediments and charnockites are predominent. They are also found around Kataragama. These metasediments and charnockites consist of granulites, granulitic gneisses, schists, quartzites, intermediate and acid charnockites, calc granulites, calc gniesses, amphibolites etc. In addition granitic gniesses are present in the south-east, south-west, and the north-east of the country.

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CHAPTER 3
Rock weathering and soil formation

3.1 Weathering of rocks

Weathering is the breakdown and alteration of rocks exposed at the earth's surface. Reiche (1950) defined weathering as the response of materials which were in equilibrium within the lithosphere to conditions at or near its contact with the atmosphere, the hydrosphere and perhaps more importantly the biosphere.

The process of rock weathering begins with disintegration and decomposition in situ. The products of this process are unconsolidated material, which are resistant to further weathering, and this material at any stage may be removed either machanically or in solution, and redeposited elsewhere. At and near the earth's surface, these weathered material is subjected to special processes related to climate, topography (slope of the land) and the biosphere. These processes are known as the soil forming processes and the end product is a soil profile, comprising a sequence of layers or horizons.

Weathering and soil formation occur simultineously and at any point it is difficult to distinguish between the two processes. According to Ollier (1969), weathering means any alteration of rocks and minerals while soil formation is the production of layers or horizons in weathered material near the earth's surface.

Three main types of weathering may be distinguished, physical weathering, chemical weathering and biotic weathering.

3.1.1 Physical weathering

Physical weathering is the breakdown of material by mechanical methods which causes rock disintegration without appreciable changes in chemical composition. Due to physical weathering an existing rock is broken down to smaller fragments, which, due to increase in the surface area, facilitates the decomposition by chemical weathering.

The first step in physical weathering is the development of cracks in rocks due to erosion and earth movements. Once cracks are formed a number of forces, that would increase the width of cracks and cause rupture of rocks may work together. In temperate regions, frost is the main agent of physical weathering. Water that seeps into the tiny cracks in rocks, may expand due to freezing, breaking the rock into fragments. Rock disintegration would be more, with repeated freezing, and thawing than with steady low temperatures. Under some circumstances the growth of salt crystals from solution causes disintegration of rocks. The disruptive effect is similar to that of frost. Rock weathering due to salt growth mostly takes place in hot arid areas and in coastal regions. Temperature changes also may cause disintegration of rocks. A rise in temperature causes a rock to expand, and a fall causes it to contract. Alternate expansion and contraction due to repeated temperature fluctations may cause a rock to break up into smaller fragments. Thermal expansion and contraction of rocks due to fire is another cause of rock disintegration. This is common in forest areas where, for example, fires usually start due to lightening. Some other agents of physical weathering are plant roots, burrowing animals, wind and human activities.

3.1.2 Chemical weathering

The term chemical weathering refers to the changes in chemical composition, properties and texture of a rock as a result of the reactions between the rock and its environment. Simple inorganic compounds like water, CO_2 and O_2 are mostly responsible for chemical weathering. Thus under appropriate conditions, coarsely crystalline silicate rocks may be reduced to very fine clay minerals.

Some of the important chemical reactions involved in rock weathering are solution, oxidation and reduction, carbonation, hydration, chelation and hydrolysis.

Solution depends on the solubility of minerals that are present in the rock and the amount of water passing the surface of the rock. For example, rock salt or halite is very soluble, and therefore is found at the earth's crust only in arid regions. Apatite, on the other hand is sparingly soluble while the solubility of gypsum lies in between rocksalt and apatite. The presence of dissolved oxygen, carbon dioxide and humic susbtances increases the dissolving power of water. Rain water contains appreciable amounts of dissolved carbon dioxide as well as chlorides, sulphates and even SO_2 derived from the ocean and industrial activities, which increases its effectiveness in chemical weathering.

Oxidation and reduction are other chemical processes which take place during weathering. The terms oxidation and reduction mean the removal of electrons from the atoms, and addition to the atoms of some elements, respectively. Many rock forming minerals contain cations that are easily converted to another oxidation state such as Fe^{2+} to Fe^{3+}, and Cr^{2+} to Cr^{3+}. Oxidation usually occurs through the intermediate action of water in which oxygen is dissolved. Reduction generally takes place under water-logged anaerobic conditions.

Carbonation is the formation of carbonates and is due to the presence of carbon dioxide in the soil atmosphere. Carbonation is not a common process in 'in-situ' weathering.

Hydration refers to the association of water molecules to a mineral, often without actual decomposition or modification of the mineral itself. For instance, the mineral anhydrite ($CaSO_4$) may absorb water and turn into gypsum ($CaSO4.2H_2O$).

Chelation involves the holding of an ion, usually a metal, within a ring structure of organic origin. Chelating agents are formed by biological processes in soil. A complex structure is formed between the metal and the molecule of chelating agent.

Hydrolysis is a chemical reaction between mineral and water. The result is the replacement of the basic ions in the mineral by hydrogen ions. This is commonly regarded as the most important chemical reaction in rock weathering.

3.1.3 Biotic weathering

Weathering of rocks is largely controlled by biologic agents such as plants, animals, microbes and human beings. Plants contributes to the physical weathering of rocks by widening the cracks in rocks due to root growth. Burrowing animals also cause physical break-up of rocks. They may also mix the soil and increase its permeability, facilitating the entry of air and water, thus enhancing chemical weathering processes.

Biologic agents may be directly involved in chemical weathering. For example, the extreme acidity generated at the

root tips of plants can act as a powerful force in chemical weathering of rocks. Further, respiration of organisms releases CO_2, which increases the dissolving power of water due to formation of H_2CO_3. In addition pH of the soil may be changed, which also would affect the chemical weathering processes.

3.2 Soil formation

Parent material derived from rock weathering undergoes soil forming processes, and the ultimate product is a complete soil profile. Depending on the five factors of soil formation, i.e. climate, topography, time, parent material and biosphere, different soil forming processes may take place. Of these processes, the one that dominates would determine the type of soil formed.

Soils support vegetation which is the only source of food for man and animals, of timber and lumber for shelter, natural fibres for clothing and other purposes, and fuel and raw materials for some industries.

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CHAPTER 4
Properties of minerals

Minerals are identified by several physical properties. Some of the most important physical properties used in mineral identification are; colour, transparency, streak, luster, cleavage, fracture, hardness, specific gravity, structure and crystalline form.

4.1 Colour

Colour is the most easily observed physical property of a mineral. Generally the colour of a freshly broken surface is used for identifiction. Some minerals have a fairly constant colour which is diagnostic and they are known as idiochromatic minerals. A good example is magnetite, which is black in colour. For most minerals the colour is not a diagnostic property. Few minerals have colours that vary greatly due to impurities they might contain. They are known as allochromatic minerals, and quartz is an example which is colourless when pure and slightly coloured when impurities are present, as in rose quartz.

4.2 Transparency

Transparency is the ability of a mineral to transmit light. It is another easily observed property of a mineral. A good example of a transparent mineral is colourless quartz, through which objects can be easily seen. Translucent minerals transmit some light and objects are seen only indistinctly, through the mineral. Fluorite is an example of a translucent mineral. Minerals like graphite do not transmit light and are termed opaque minerals.

4.3 Streak

Streak is the colour of the powdered form of a mineral, and it is frequently used in mineral identification. Although the colour of the mineral may vary greatly, as in the case of haematite, the streak is often fairly constant. Streak is determined by rubbing the mineral on a piece of unglazed porcelain known as the streak plate. Colour of the streak in some minerals is quite different from the colour of the mineral. For example, the black coloured haematite and geothite have streaks of red brown colour, and yellow brown colour respectively. In some minerals the colour of the streak is the same as that of the minerals. Magnetite is an example which has a black streak and black mineral colour. It is obvious that minerals harder than the streak plate cannot form a streak.

4.4 Luster

The luster of a mineral is the appearence of its surface in reflected light. Luster can be divided as metallic and non-metallic. Non-metallic luster is further divided as adamantine, vitreous, resinous, greasy, pearly, and silky. Examples of each are given below :

Kind of Luster	Description	Example
Metallic	Appearence of metals	Pyrite
Adamantine	Appearence of diamonds	Cerussits
Vitreous	Appearence of glass	Rock crystal
Resinous	Appearence of resin	Copalite
Greasy	Appearence of oiled surface	Nepheline
Pearly	Appearence of mother-of-pearl	Talc
Silky	Appearence of fibrous structure	Asbestos

There are also varying degrees of luster. This refers to the intensity or quantity of light reflected by the mineral. To express the degree of luster the following five terms : splendent, shining, glistening, glimmering and dull, are used. In decreasing order of the quantity of light reflected they are :

Degree of luster	Example
Splendent	Micaceous haematite
Shining	Calcite
Glistening	Prochlorite
Glimmering	Flint
Dull	Chalk

4.5 Cleavage

Cleavage is the tendency of minerals to break along smooth, flat and definite surfaces. For example, if a piece of calcite is hit with a hammer, it will break into small fragments, with sharp straight edges and smooth flat surfaces where it is broken off. This property is common to many minerals, and it is used, when present, to distinguish such minerals. Because cleavage occurs along a direction of weakness, one cleavage will result in two faces of the mineral. Depending on the number of cleavage directions and the angle between them, there are six cleavage types, namely : basal, pinacoidal, prismatic, cubic, rhombohederal and octahederal; examples of which are given below :

Cleavage	Description	Example
Basal	One direction	Mica
Pinacoidal	Two directions, nearly at right angles	Feldspar
Prismatic	Two directions, not at	Amphibole

	right angles	
Cubic	Three directions, nearly at right angles	Halite
Rhombohederal	Three directions, not at right angles	Calcite
Octahederal	Four directions	Fluorite

As mica has one direction of cleavage a sheet of mica can be split into a number of thin sheets. The mineral halite possess a cubic cleavage, and if a piece of halite is struck with a hammer, some of the resulting fragments will resemble tiny cubes, while others will resemble blocks made up of cubes. Therefore, cleavage is a very conspicuous physical property and is widely used in identifying minerals.

4.6 Fracture

Fracture is the character of the surface obtained when a mineral breaks along a non-cleavage direction. Minerals with no cleavage, or with one or two cleavage directions, may break in another direction that does not leave a flat surface. Given below are the terms used to describe fracture of minerals together with their descriptions and examples.

Type of fracture	Description	Example
Even	Surfaces are flat or nearly flat	Lithographite Limestone
Uneven	Surfaces are rough	Serpentine
Conchoidal	Surfaces are curved with concentric curves	Obsidien
Subconchoidal	Concentric curves are very distinct	Rose quartz
Splintery	Mineral breaks into splinters	Tremolite

Hackly	Surfaces with spiky fragments	Copper

4.7 Hardness

The hardness of a mineral is its resistence to abrasion or scratching. It is an important property and can be easily determined and used in rapid recognition of minerals. A scale of hardness known as the Moh's scale consists of ten starting from the softest mineral (Number 1) to the hardest (Number 10). The figures 1 to 10 have no quantitative significance and the difference in hardness between successive grades is variable. The minerals used as standards are as follows :

1. Talc
2. Gypsum
3. Calcite
4. Fluorite
5. Apatite
6. Feldspar
7. Quartz
8. Topaz
9. Corundum
10. Diamond

Hardness is measured by scratching a fresh surface of an unknown mineral with minerals of known hardness. If a scratch is made on the unknown, then it is softer than the mineral used to scratch it.

The determination of the hardness value of a mineral is simplified by using a finger nail (hardness 2.5), copper coin (hardness 3), knife blade (hardness 5.5) and a steel file (hardness 6.5). This simplified procedure is of great importance since the majority of minerals are less than six in hardness.

4.8 Specific gravity

The specific gravity of a mineral is the ratio of its weight to the weight of the same volume of water. Many minerals with similar physical properties have different specific gravities, which helps in their identification. For example, celestite ($SrSO_4$) which has a specific gravity of 3.95 is easily distinguished from barite ($BaSO_4$), which has a specific gravity of 4.5 (Kraus- et.-at, 1959).

Specific gravity can be determined by weighing the mineral in air and in water.

$$\text{Specific gravity} = \frac{\text{Weight in air}}{\text{Weight in air - weight in water}}$$

The specific gravity of a mineral can be easily determined using a specific gravity bottle.

4.9 Structure

Minerals are either crystalline or amorphous. Amorphous minerals have no regular shape and occur in compact masses. There are many types of crystalline aggregates or amorphous masses of which some important types are given below :

Type of structure	Description	Example
Crystalline	Irregular grains or particles	Marble
Massive crystalline	Bounded crystalline Substances (Crystal aggregates)	Quartz

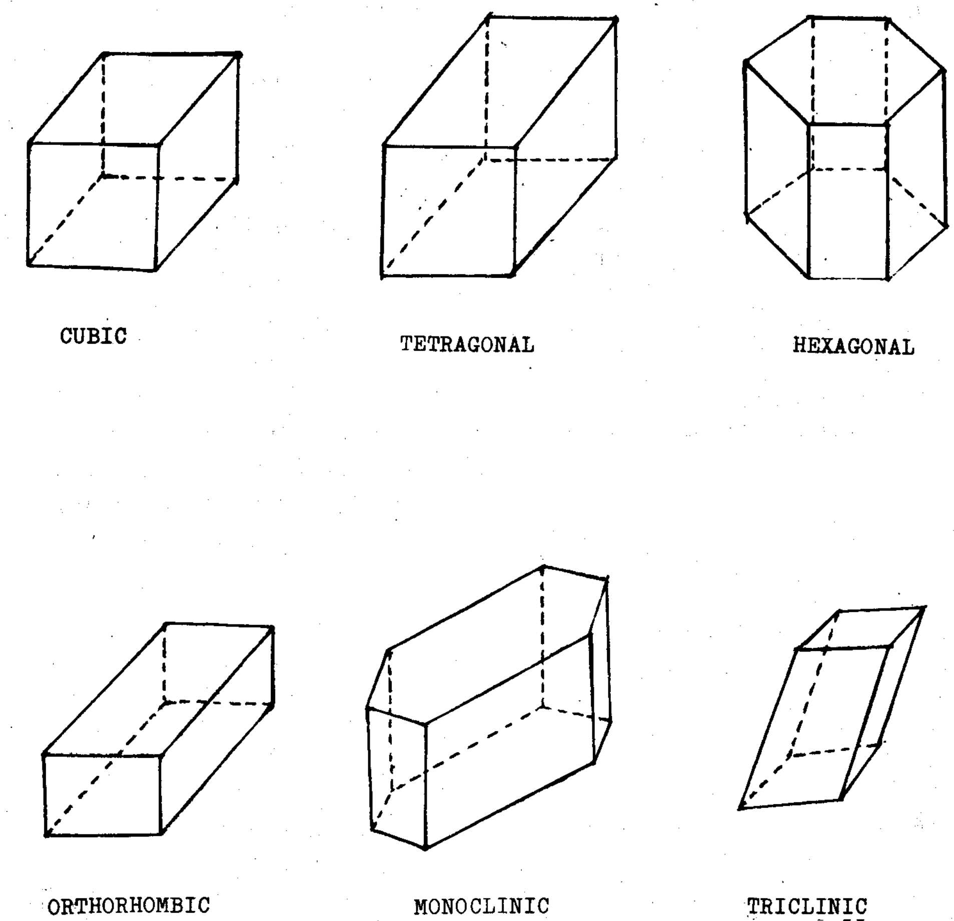

Fig. 3 - Crystal Systems

Granular	Closely packed coarse or fine grains	Olivine
Micaceous	Made up of very thin plates	Mica
Fibrous	Consist of slender fibres	Asbestos
Columnar	Made up of thick parallel columns	Tourmaline
Compact	Amorphous compact masses	Opal

4.10 Crystal form

All crystalline minerals form crystals with organized internal structures. The shape of the crystal can be used in mineral identification because generally a mineral has only one characteristic crystal form. The six crystal systems ; cubic, hexaganal, tetraganal, orthorhombic, monoclinic and triclinic, are shown in the Fig. 3 , giving common examples.

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CHAPTER 5
Rock-forming minerals

The minerals that constitute rocks are known as rock forming minerals. Although about 2000 minerals have been found in the earth's crust, there are only a handful of rock-forming minerals. These minerals can be conveniently classified into two main groups;

1. Silicate minerals
2. Accessory minerals

Silicate minerals contain silicon as an essential ingredient whereas accessory minerals do not.

5.1 Silicate minerals

In silicate minerals silicon and oxygen form a unit structure, known as tetrahedron unit, in which a silicon atom is surrounded by four oxygen atoms. These unit structures may combine to form paired structures, rings, chains or sheets as shown in the Fig. 4.

Atoms of other elements found in the earth's crust, such as, aluminium, iron, calcium, sodium, magnesium and potassium fit into spaces in these structures.

Silicate minerals are further divided into ten groups according to chemical composition. These are:

1. Silica group
2. Feldspars
3. Feldspathoids
4. Micas

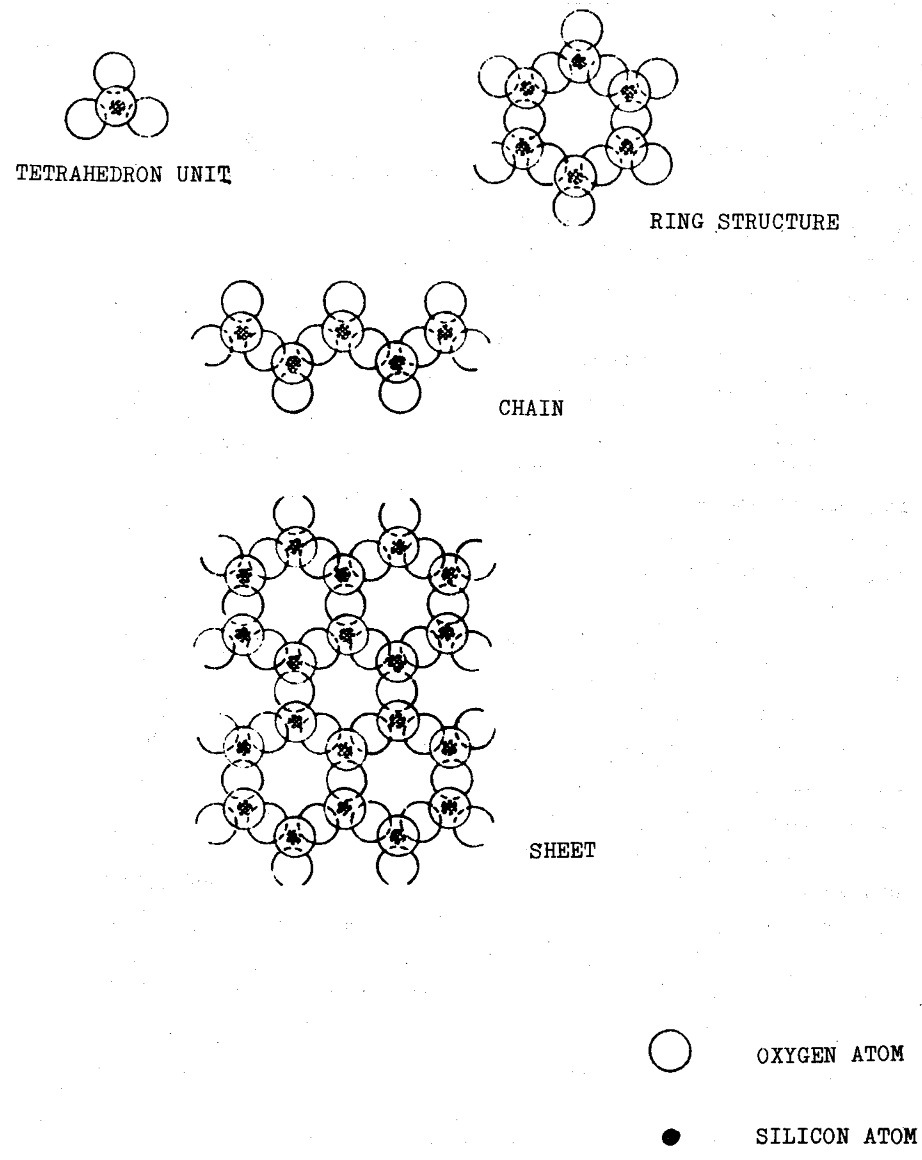

Fig. 4 - Silicate Mineral Structure

5. Amphiboles
6. Pyroxenes
7. Tourmalines
8. Olivine
9. Garnets
10. Other silicates

5.1.1 Silica group

Common minerals included in this group like quartz and opal contain SiO_2. The chemical composition of quartz is SiO_2 with no molecules of water of crystallization. It is of wide occurrence in many rocks. Quartz is colourless when pure, and coloured when impurities are present. The structure of quartz may be crystalline or massive. Amethyst and rose quartz are examples of crystalline quartz, while agate and flint are examples of massive quartz. Quartz is recognized by its hardness value of 7 and its lack of cleavage.

Quartz is present in all three types of rocks. In Sri Lanka quartz of many varieties are present throughout the country.

Opal, $SiO_2.nH_2O$, is not an abundant mineral, and is present in recent volcanic rocks. This mineral is however not found in this country.

5.1.2 Feldspars

Feldspars are the most abundant group of rock-forming silicate minerals. Feldspars are further subdivided into subgroups; (1) Potash feldspars, which as the name applies, essentially contain a high proportion of potassium and little of calcium and sodium, and (II) plagioclase feldspars which does not contain potassium but contains either sodium, or calcium or a mixture of both. The chemical formula of potash feldspars is $K_2O,Al_2O_3.6SiO_2$ and it may have a monoclinic or a triclinic crystal system, in which case they are termed orthoclase or microcline respectively. Plagioclase feldspars is termed albite, $Na_2O.Al_2O_3.6SiO_2$, if it contains sodium, and anorthite, $CaO.Al_2O_3.6SIO_2$, if calcium is present. Feldspars are distinguished from other minerals by the pinacoidal cleavage, light colour and the hardness value of 6.

Feldspars are present in all three types of rocks. In Sri Lanka it is of wide occurrence throughout the island.

5.1.3 Feldspathoids

This group includes two important minerals, leucite, $K2O.Al_2O_3.4SiO_2$ and nepheline, $Na_2O.Al_2O_3.4SiO_2$. The former is gray, white or colourless while the latter is reddish, grey, white or colourless. Nepheline is easily recognized by its greasy luster.

These two minerals are present in syenites and volcanic rocks. They are not common in the rocks of Sri Lanka.

5.1.4 Micasgroup

Three common types of mica have been identified according to their colour, namely ;

(i) Muscovite or white mica, $KAl_2(Si_3AlO_{10})(OH)_2$
(ii) Biotite or black mica, $K(Mg,Fe)_3(Si_3AlO_{10})(OH)_2$
(iii) Phlogopite or amber mica , $KMg_3(Si_3AlO_{10})(OH)_2$

Micas are distinguished by their perfect basal cleavage, and their micaceous structure.

These minerals are present in all three major types of rocks. In Sri Lanka, the most common type of mica is biotite which is present with muscovite in igneous and metamorphic rocks like granites, gneisses, pegmatites, schists etc. Phlogopite occurs in crystalline limestones and in some igneous rocks.

5.1.5 Amphiboles

The most common mineral of the amphibole group is hornblende, which has a chemical formula of $Ca3Na(Mg,Fe)6(Al,Fe)3(Si_4O_{11})_4(OH)_4$. This mineral is black or dark green in colour, and is distinguished by its prismatic cleavage with cleavage angles at approximately 60 and 120 degrees.

Hornblende is present in igneous and metamorphic rocks. Some rocks containing hornblende in Sri Lanka are granites, gneisses, charnokites and pegmatites.

5.1.6 Pyroxenes

This group includes minerals like enstatite, $Mg_2Si_2O_6$, hypersthene, $(Mg, Fe)_2Si_2O_6$ and augite, $Ca(Mg,Fe)_3(Al,Fe)_4SiO_3)_{10}$. Enstatite is a greyish coloured mineral and hypersthene may be greyish, greenish, yellowish, bronz, brown or black. Augite is a black coloured mineral.

Pyroxenes are present in igneous and metamorphic rocks like charnokites, gneisses and schists.

5.1.7 Tourmaline

The rock-forming tourmaline has a chemical formula of $NaFe_2Al_4B_2Si_4O_{19}(OH)$, and is black in colour. It is distinguished by its columnar structure.

In Sri Lanka tourmaline is present in gneisses and pegmatites.

5.1.8 Olivine

Olivine, $(Mg,Fe)_2SiO_4$ is olive green in colour, and is characterized by its granular structure. It is found in basic and ultrabasic igneous rocks. In Sri Lanka, however, this mineral is not of common occurrence.

5.1.9 Garnets

Rock-forming group of garnets include epidote and garnet. Epidote, $Ca_2(Al,Fe)_3(SiO_4)_3OH$ is green brown or light yellow brown in colour, while garnet, $Ca_2Al_2(SiO_4)_3$ may be red or brown coloured.

In Sri Lanka garnets are present in igneous and metamorphic rocks like charnokite, khondolite, gneisses and schists.

5.1.10 Other silicates

Zircon, $ZrSiO_4$, sillimanite, Al_2SiO_5 and some other minerals come under this group. Commonly zircon is brown or greyish in colour, but it may be red, yellow, blue or even colourless.

Zircon is present in igneous and sedimentary rocks. Pegmatites, gneisses, quartzites, charnokite, Tonigala granite, beach sands and miocene calcareous limestones are the main zircon containing rocks of Sri Lanka (Vithanage, 1957).

Sillimanite is present in metamorphic rocks of Sri Lanka, such as gneisses and schists. This mineral is white, brownish or greenish in colour.

5.2 Accessory minerals

Accessory minerals do not contain silicon as stated earlier. They can be further divided in to seven groups on the basis of their chemical composition, namely :

1. Elements
2. Oxides
3. Halides
4. Phosphates
5. Sulphates
6. Sulphides
7. Carbonates

5.2.1 Elements

The minerals of this group consist of only one single element, and not compounds, as in all other groups. But they may contain traces of impurities. Iron, which is present in basaltic rocks is an example for elemental minerals. This mineral is usually identified by the metallic luster, and the steel grey colour. But when oxidized it may be brown coloured.

Graphite is another mineral of this group, which contains only carbon. It is found in metamorphic rocks of Sri Lanka.

Diamond, which also contains carbon, is present in alluvial deposits probably derived from dark plutonic rocks. It has not been found in Sri Lanka.

5.2.2 Oxides

Magnetite, Fe_3O_4, haematite, Fe_2O_3, geothite, FeOOH, ilmenite, $FeTiO_3$, rutile, TiO_2 and spinel, $MgAl_2O_7$, are some of the common rock.forming oxide minerals.

Magnetite, the magnetic or black oxide of iron, possesses a black streak. It contains approximately 72 per cent Fe and is usually found in igneous and metamorphic rocks and in beach sands. Haematite has a bright red streak and is present in all three types of rocks. This mineral also contains around 70 per cent Fe. Geothite is black coloured with a brownish yellow streak, and is commonly found in ore deposits. These three oxide minerals are abundant in some rocks of Sri Lanka, namely, basic charnokites and pyroxene amphibolites, which leads to high magnetic intensity in areas where they are present (Hapuarachchi et. al, 1964).

Ilmenite is black or brownish black in colour with a black, brownish or yellow streak, and is present in basic igneous rocks. The titanium oxide rutile, which is a constituent of some plutonic igneous rocks and metamorphic rocks, is black or reddish in colour possessing a streak of light brown. These two minerals are present in igneous and metamorphic rocks of Sri Lanka particularly in the south west part of the country.

Spinel may be black, orange brown,red or blue in colour. This mineral is found in plutonic igneous rocks and metamorphic rocks of Sri Lanka.

5.2.3 Halides

The most common rock-forming minerals of this group are halite, NaCl, cryolite, Na_3AlF_6 and fluorite, CaF_2.

Halite is also known as rocksalt, and distinguished by its salty taste, and perfect cubic cleavage. This mineral is commonly found in dried lakes and sedimentary beds. Halite is usually colourless but may be sometimes white in colour.

Cryolite which is colourless or white is found in isolated deposits.

Fluorite may be colourless, black, white, brown or violet blue, and it is found with ore minerals or in sedimentary rocks. This mineral is distinguished by perfect octahedral cleavage.

5.2.4 Phosphates

The common rock-forming phosphate minerals are monozite, vivianite, strengite, variscite and apatite.

Monazite, $CaPO_4$ with ThO_2 and SiO_2 is yellow to reddish brown in colour. It is present in gneisses, granites and sands. In Sri Lanka monozite occurs in a number of granitic and gneissic rocks, which are concentrated by weathering in raised beaches, river terraces and river mouths (Cooray, 1967).

Vivianite, $Fe_3(PO_4)_2.8H_2O$ may be colourless, blue or violet with a streak of white, which turns blue on exposure to light. This mineral is found in ore veins and sedimentary clays. Strengite, $FePO_4.2H_2O$, is deep pink in colour and variscite, $AlPO_4.2H_2O$ is light or emerald green in colour. These two minerals are generally present in clay rich rocks.

Apatite $Ca_5(F,OH,Cl)(PO_4)_3$ may be white, brown, green, blue or yellow in colour. Fluoro apatite of igneous origin was discovered recently at Eppawela, in the North Central Province of Sri Lanka.

5.2.5 Sulphides

The most common rock-forming sulphide mineral is pyrite, FeS_2. It has a distinctive brass yellow colour and a metallic luster, and is present in all three major type of rocks. This mineral is not common in Sri Lanka.

Molybdenite, MoS_2 and Cinnabar, HgS are two others examples of rock-forming sulphide minerals.

5.2.6 Sulphates

Anhydrite, $CaSO_4$ and Gypsum, $CaSO_4.2H_2O$ are two common sulphate minerals of calcium. They may be colourless or white in colour, and are present in sedimentary rocks.

Celestite, $SrSO_4$, barite, $BaSO_4$ and epsomite, $MgSO_4.7H_2O$ are examples of less common rock-forming sulphates.

5.2.7 Carbonates

Some important rock-forming carbonate minerals are calcite, $CaCO_3$, dolomite $CaCO_3.MgCO_3$, magnesite, $MgCO_3$ nd siderite, $FeCO_3$.

Calcite is colourless or white in colour, with a distinguishable rhombohederal cleavege. It is present in all types of rocks. In Sri Lanka this mineral is present in limestones, which is mainly found in the Jaffna Peninsula, in the extreme north of the country.

Dolomite is colourless, white, pink or brownish, and is commonly found in sedimentary rocks. Dolomite is also present in the Jaffna peninsula.

Magnesite, which is white or colourless has a rhombohederal cleavage. Siderite may be brown, white or grey in colour. These two minerals are found in sedimentary beds, but are not common in Sri Lanka.

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These occur mostly in low lying areas of the south western portion of Sri Lanka, sometimes in extensive deposits of over five meters, and in the Bolgoda and Dediyawela areas.

The uses of ball clay include manufacture of porcelain and fine earthen ware, bounding material for harder and less plastic clay in the manufacture of refractories and stoneware. Ball clay increases the plasticity of the raw mixture and the fluxing properties.

6.3.3 Clay Minerals in the Ceramic Industry

Ceramics is the art and/or science of making products and artifacts chiefly or entirely from earthy raw materials (except fuels and metallic ores), involving a high temperature treatment. The ceramics industry includes the manufacture of refractories for industry ; bricks, tiles, pipes, etc. for construction; and household utensils such as china and stoneware. Others include the manufacture of high voltage and high frequency insulators for industry and the production of artistic and decorative meterials with aesthetic appeal.

It is a common misconception that ceramics are manufactured chiefly from clays. In fact however, clays almost always, make up only a minority of any ceramic product. It is commonly less than 30 per cent of most ceramics, the remainder being finely ground quartz, feldspar, corundum, talc or other minerals. Clays are added to ceremic because of their plasticity, wet and dry strengths and because of the colour they impart when fired.

Clays used in ceramics are almost universally of the 1:1 silicate layer type and kaolinite is the dominant clay usually used. Lesser amounts of halloysite and dickite are vanadium which imparts beneficial properties, tellurium which offers frost resistance to lead in water-pipes.

As new minerals are discovered, they will draw the attention of technologists depending in their potential usefulness. Therefore the list of industrial minerals discussed below is by no means complete.

6.2 Graphite

Graphite is a form of crystalline carbon, and its mining is one of the most important industries of the island. It has been exported since 1821. Graphite is distributed mostly in six provinces, as follows :

1. Western Province - Botale, Kaluaggala, Kuligedera, Welihinda, Makkanigoda, Ellalamulla, Karasnagala, Migoda, Pannaluwa and Watareka, Botalawa, Meegahatenna and Pelawatte.
2. Sabaragamuwa Province - Kukulegama, Delgoda, Weddagala, Dumbara, Karandana, Kolonna, Wijeriya, Werahera, Arukgammana, Bopitiya, Indurana, Niwatuwa, Pusella, Siyamballapitiya and Bolagama.
3. Southern Province - Batapola, Ampegama, Tirawamaga, Magala, Kolawenigama, Uragaha, Kottawa, Hiniduma, Panangala, Deniyaya, Kolawenigama, Idandukita, Daramitiara and Hillageainna.
4. North-Western Province - Regedara, Mipitiya, Maduragoda and Naramana.
5. Central Province - Dolapihilla, Kahatagahatenna.
6. North Central Province - Kebitigollawa.

Graphite occurs usually in veins and in pegmatites, but may occur as flakes in other rocks as well. Because it is

inert it tends to be in its original position long after the rock weathers and other rock constituents have disintegrated, Due to its outstanding colour it can therefore be easily spotted in a soil profile.

Graphite is also known as plumbago when it exists in the massive state and as 'black lead' when it is amorphous. Sri Lankan graphite which enjoyed a world monopoly since the early days of its exploitation is reported to contain very little impurities (Geological Survey Department, 1970).

Graphite is used in the manufacture of a large number of important items such as dry batteries and electrodes, electric brushes, lead pencils, explosives, electrotyping, graphite crucibles and ladles foundry facings and moulds, lubricants, paints, stippere and nozzles.

6.3 Industrial Clays

Clays are secondly minerals because they have been formed due to the weathering of already existing primary minerals. Clay minerals are colloidal i.e. they have a fine particle size. Most clay minerals are crystalline in nature, while some are amorphous. These minerals are also known as layer silicate minerals since their atoms are arranged in layer lattice structures.

Clays are perhaps the oldest raw materials used by man. Most ancient cultures are described in part on the basis of their discovered artifacts, many of which are pottery and ceramics.

When wet, clay forms a coherent sticky mass which can be readily moulded and on drying it becomes hard and brittle retaining its shape, when heated to redness clays become still harder and water has little effect on it, thereafter. Thus it is not surprising that ancient clay utensils are being discovered in pre-historic sites frequently. Industrial clays in Sri Lanka are kaolin, ball clay, refractory clay, brick-tile and pipe clay.

6.3.1 Kaolin

This is the pure white clay composed almost entirely of kaolinite. It has a low plasticity, high refractoriness and burns into a white product. Our kaolin is of good quality and occurs as pockets in intensely weathered rocks as distinct layers or as lenses under surface soils or as alluvium. They are found mostly in the South-Western portion and Central Highlands of the island, formed from feldspars in the rocks of Pre-cambrian age that dominate the geology of these areas. In the Tabbowa basin kaolin occurs as bands of 'pipe clay'. The best known kaolin deposits are in the Nugegoda - Boralesgamuwa areas estimated approximately at five million tons, at Meetiyagoda and in the low lying plains north of the Kelani Ganga. The deposit around Iranamadu contains much iron as an impurity.

The kaolin refinery of the Ceylon Ceramics Corporation at Borelesgamuwa supplies raw material for the rubber and paint industries. Iron, which is an impurity in kaolin is responsible for the frequent discolouration of the product.

6.3.2 Ball Clay

This applies to a large group of sedimentary, plastic refractory, dark coloured clays which turn white or cream on heating or burning. They are tougher than and are more plastic than kaolin, and possess superior bonding powers and low refratoriness.

Knowledge on the properties, both physical and chemical, of the various clay minerals can be used advantageously in technology and industry. However, most clay and clay deposits are identified and described on the basis of their uses instead of on the basis of their physical and chemical properties and minerological composition, which while being unscientific, is also a definite disadvantage.

6.4 Mica

Mica refers to a group of complex aluminium silicate minerals which also may contain potassium, sodium, lithium and ferrous or ferric ion as the case may be. In addition manganese, chromium, barium, fluorine and titanium are found in traces or in small quantities.

The commercially important types of mica are :

1. Muscovite, white mica or potash mica
2. Phlogopite or magnesian mica (amber mica)
3. Biotite, black mica or ferro-magnesian mica and (black mica)
4. Sericite

Of these only the first three occur in Sri Lanka. The chief mica deposits occur at Badulla, Bokkawela, Haldummulla, Madumana, Madugoda, Madampe, Mariarawa, Pallekelle, Talatu-oya, Ulwita and Wariyapola.

Mining for mica in this country dates back to 1896, when the tea estates of Badulla and Haputale areas were the first to be exploited. Phlogopite occurs in the provinces of Uva, Central and Sabaragamuwa in association with crystalline limestones and their associated rocks, while muscovite occurs in quartz-feldspar - pegmatites. Biotite occurs in schists, gneisses and pegmatites. Pegmatites are the richest source of mica.

also used. Occasionally other clays find their way to ceramics when they occur as contaminants in kaolinite deposits. However, the high swelling and shrinkage exhibited by 2:1 layer silicates make them undesirable in most ceramics since they crack upon drying or firing. The fired colour of ceramics is generally due to the presence, intentional or otherwise, of impurities, such as iron-rich minerals, in the clay.

6.3.4. Clay Minerals in the Petroleum Industry

Clays are used in the petroleum industry in drilling muds. Most petroleum wells are deep, necessitating therefore the use of rotary drilling equipment. Earlier the bore holes were kept full of water to cool the drilling bit and to facilitate the upward movement of cuttings. But later it was found that the presence of mud increased the ease of removing cuttings from the hole since mud had a higher viscosity than water. This also made the cuttings less prone to sinking through the fluid. However, the presence of clay in drilling muds was soon found to have more benefits than the simple removal of cuttings. Clay suspensions were found desirable for their ability to seal underground strata encountered. Clay also keeps water from these strata entering the bore hole and the mud from escaping into porous, empty strata. In addition, the thixotrophic behaviour of some clays is advantageous because during equipment shutdowns the gel formation prevents the settling of the cuttings back down the bore hole.

Drilling clays are rated on their ability to produce a seal (called a 'filter cake') of low permeability and their yield (in barrels/ton) of a slurry of 15 centipoise viscosity. The 2:1 layer silicates rate highest in these two criteria and are used almost exclusively for addition to drilling muds in the USA.

A secondary use of clay minerals in the petroleum industry is their use as cracking catalysts. 'Cracking' is the process of breaking long chain saturated hydrocarbons into shorter chained olefins. This cracking was initially accomplished thermally without the use of a catalyst, but the addition of certain acid activated clays lowers the temperature needed for this process. Hence the term 'catalytic cracking'. The exact nature of the altered clay surface is not fully understood, but the surface produced is thought to be an amorphous alumino-silicate. Both 1:1 and 2:1 layer silicates can be altered to act as catalysts, and a completely amorphous material can be produced from aluminium and silicon solutions that function equally well. In future most cracking catalysts will probably be synthetically prepared in this way.

An additional use of clay minerals in the petroleum industry is their use as clarifying agents. Certain contaminants in oils can be easily removed through the use of specially treated clays which adsorb the contaminants.

6.3.5 Clay Minerals in the Paper Industry

Clay minerals are also employed in the paper industry for 'pigment coating' of high grade writing paper, photographic paper, and other superior quality papers. This coating is composed of a suspension of white clay, usually kaolinite; a binder, usually starch or artificial resins ; and various pigments, such as titanium dioxide or calcium carbonate. The purpose of the coating process is to increase the surface floss and colour of the paper and to improve its 'printability' which describes its receptivity to ink and the speed with which the paper can be commercially printed.

In addition to this general coating use, the clay mineral attapulgite, is used in the manufacture of so-called 'carbon-free paper'. This paper consists of a layer of minute ink capsules sandwiched between two layers of this clay. When pressure is applied to the paper., as in writing or typing, the ink capsules burst, releasing ink. Thus a non-erasable mark is produced.

6.3.6 Miscellaneous clay mineral usage

Clay minerals are also used for purposes seldom known to most. Clays specifically kaolinite and attapulgite, are used in pharmaceuticals. Specially in the treatment of stomach disorders. Clays are widely used for their ability as binding agents, such as in the pelleting of fertilizers and mineral ores, and for the binding of foundry sand used in metal casting. In addition, certain clays are used for specific purposes due to their peculiar characteristics. For example, illite is used as an adsorbant for the removal of radioactive cesium from atomic waste materials. It is the only material known, so far, to be effective for this purpose. Attapugite is used as a filter because of its needle like structure and because it will not form an impenetrable filter cake. Clays, in addition, are used as organic clarifying agents in many industries; specially in the dye industry. They are also used as filler material in most agricultural sprays. In the rubber industry, kaolinite is added to rubber to increase its tensile strength and to increase its modulus of hardness.

Clays are more widely used than most of us realize. The many tasks to which clays are now put will probably soon be accomplished by synthetic substitutes much as amorphous alumino-silicates for cracking catalysts and resins for adsorbants and binding agents. However, industrial usage of clays will continue to be high in the future.

CHAPTER 6

Industrial Minerals

6.1 Introduction

Since man began to make regular use of the materials of the earth's crust he has searched for concentrations of rocks and minerals containing much needed materials. Such concentrations are ore deposits, masses of rocks which have got enriched in materials like metals (Fe, Ni, Au or Ag) or fuels (such as coal and oil) and nonmetalic substances such as phosphates or sulphur. Our industrial civilization depends on such materials.

The metals and most other materials used by man, except those that provide him food and clothing are obtained from the earth's crust. These occur as minerals, either separately, concentrated or mixed in rocks.

Industrial minerals have been contributing to Sri Lanka's economy. Mining activities in this country have been confined mainly to graphite, clays (including kaoline), mica, limestone, feldspars, rock phosphate, mineral sands and gemstone, (the latter has been discussed in detail in Chapter 7). These industries are controlled by the state sector, and all mining activity in the country is governed by the Mines and Minerals Law No. 4 of 1973, the authority of its implementation being the Ministry of Industries and Scientific Affairs.

Some minerals which are distributed only in trace amounts assume great importance, completely out of proportion to the amounts present in the ore, or to the quantities required. Examples of this kind are radioactive minerals, Good quality sheet mica has to be flawless with no inclusions or cracks, flat, clear and 'glasslike'. It is graded according to the area of the largest rectangle that can be separated from the sheet, the larger being the better and more expensive. The best grades are likely to occur at deeper depths.

Due to its property of not conducting electricity or heat, mica sheets or thin laminae are used for insulation in electrical appliances, in the computer industry, in electrostatic mercury tubes and in colour television. 'Scrap mica' finds uses in the manufacture of lubricants, fancy paints, rubber goods, moduled mica roofing papers, covering for steam pipes and for the decoration of all paper in the ground form. Muscovite is used in the manufacture of radio capacitors. Phlogopite, although much softer than the former, is superior in its heat resistance.

Inspite of many synthetic materials, mica is still superior for manufacture of electrical appliences.

6.5 Limestones

Limestones are rocks that contain $CaCO_3$ as its main ingredient, although some like dolomite contain $MgCO_3$ also in appreciable amounts.

Two types of limestones occur in Sri Lanka ; the sedimentary and the crystalline.

6.5.1. Sedimentary Limestones

Tertiary coral limestones of the Miocene age occur in the north-western coastal region ; chiefly in the Jaffna

Peninsula and in the Mannar and Puttalam districts. Sirimanne (1959) has described these limestones as varying from a somewhat cellular material full of coral to a massive rock containing gastropods. On complete weathering, it assumes a honey-combed appearance.

A small outcrop of Miocene limestone also occurs in the extreme south-eastern part of the island at Minihagalkanda. On weathering these limestones give rise to red soils, which were earlier referred to as the terra rosa' soils, due to the presence of traces of iron compounds in the original molluscan shell material from which they have been derived.

In addition to these, coral reefs of Quaternary age occur along the coasts. They are most prominant in the south-western region between Ambalangoda and Matara and along the northern and eastern coasts. These coral reefs are made up of loosely packed, stick or finger corals in association with blocks of heavy, massive corals.

6.5.2 Crystalline Limestones

Crystalline limestones of the Precambrian age occur mostly in the central and southern regions of the island, most prominently in the Kandy, Matale, Nalanda, Kandarawa, Ratnapura, Balangoda, Pelmadulla, Bibile, Badulla and Welimada areas, They occur interbedded with quartzites and garnetiferous gneisses in the highland areas and in the rocks of the Kataragama region.

In chemical composition these limestones vary from pure $CaCO_3$ to dolomite, with intermediate magnesian limestones. According to Fernando (1950), the magnesian limestones are more abundant than pure limestones.

6.5.3 Uses of Limestones

Limestones or their derivatives find uses in agriculture, in building construction and in the cement industry.

In agriculture, liming of soils is a very old practice, for maintaining soil fertility in humid regions. Lime increases microbial activity and thereby increases rate of decomposition of organic matter and availability of nitrogen and phosphorus in soils. In Sri Lanka coral limestone, slaked lime, dolomite lime, ground oyster and sea shells are the most common liming materials used, and responses to liming with several crops have been reported on acidic soils (Thenabadu, 1980).

High grade limestone is needed for the cement industry, and the sedimentary limestones of the north west coastal belt and the Jaffna Peninsula is suitable for this purpose. Cement clinker is an intermediate stage in the production of Portland cement, which is produced by heating lime, alumina, silica, and iron oxides in suitable proportions in rotary kilns to high temperatures. The hot clinker is then ground with a small proportion of gypsum after it cools, to yield finished cement.

6.6 Feldspars

Feldspars are a group of rock forming minerals as already described in Chapter 5. They are anhydrous silicates of aluminium combined with K, Na or Ca. Very rarely Ba may also be found in some feldspars. Orthoclase, microcline, anorthite and albite are the most important commercial varieties. Pink or salmon coloured microcline feldspars occur

in pegmatites at Rattota, Talagoda, Kaikawela, Namaloya and Koslanda, (Geological Survey Department, 1970).

The principal uses of feldspars are in the manufacture of glass, ie bottles, plate and window glass, opalescent glass and glassware for illuminating purposes (Jones, 1955).

The ceramic industry uses a very large quantity of feldspars, because it goes into the composition of the body of the ware. This mineral is also an important constituent of glazer used in chinaware, pottery and tiles, due to its property of fusing at a relatively lower temperature than clay, and forming a durable, transparent and hard glaze on cooling. High grade potassium feldspar is used in the manufacture of electrical insulators and artificial teeth. It is also required for making enamels for sanitary ware, household utensils and for coating sheet-iron.

Feldspars also find use as an ingredient in mild abrasive, scouring soaps, for roofing and cement surfacing. Attempts have been made in Sri Lanka and elsewhere to use feldspars as potassium fertilizer material, but the results of investigations here have not been encouraging so far.

6.7 Phosphates

Phosphates are indispensable for agriculture. No animal or plant can exist without this element. Plant available phosphorous is most likely to be deficient in nature, not because it is scarce, but because its minerals are insoluble, and therefore unavailable to plants.

Two principal varieties of phosphates are known :
1. rock phosphates such as phosphorite, phosphatic limestones,

guano and bone beds, and 2. apatite, which is the chief primary source of the element.

Rock phosphates occur frequently on oceanic islands or desert coasts as in Christmas Island, several islands in the Pacific ocean and along the coasts of Peru and Chile. This form of phosphate also occurs in beds of marine origin, usually interstratified with limestone, marls, sandstone or shales, and are most probably of organic origin, which were deposited in the ancient sea floors. The most important constituent of these rock phosphate is collophane, or collophanite, $Ca_3(PO_4)_2.H_2O$.

Apatite deposits at Eppawela in Sri Lanka, were discovered in the early seventies. Its phosphorus may not be readily available for short duration crops, but it could be used with perennial crops like tea, rubber and coconut.

6.8 Mineral Sands

Beach sands at several locations along the island's coast provide abundant quantities of ilmenite, monazite and zircon. These minerals remain almost unaltered when rocks containing them weather. They get carried to the sea by river waters and sorted out and concentrated due to the action of ocean waves. These concentrated deposits are black coloured due to the presence of ilmenite which is almost always associated with the other two minerals.

Pulmoddai, situated north of Trincomalee contains the largest and most important black sand deposit (containing about 75 per cent ilmenite, together with rutile and zircon). Hence the installation of the Mineral Sands Corporation at Pulmoddai. Other minerals of value in these deposits are garnet, spinel, magnetite, and quartz, with traces of monazite.

Black sand deposits also occur in some isolated locations on the west coast, at Induruwa, north of Colombo, Negombo, and Kudremalai point on the south west coast. But the ilmenite is less concentrated, varying from 10 to 50 per cent.

Monozite has been c l:cted from Induruwa, from as early as 1918 to 1922, where the black sands of the sea beaches contain up to 15 per cent of the mineral. An average figure for monozite in Sri Lankan beach sands is around 10 per cent. Other minerals present in these sands are ilmenite, zircon, rutile, garnet and tourmaline.

Thorianite is a heavy black mineral that contains mainly the oxides of thorium and uranium.

It occurs in several localities, and has been exported off and on, because the deposits soon get exhausted. It is fairly widely distributed in the Ratnapura district and may contain around 28 per cent U_3O_8 (Urania) and 63 per cent ThO_2. The per cent of U_3O_8 varies from about 11 to 35 per cent because samples of thorianite from different localties show different proportions of these constituents.

6.9 Salt

Rock salt deposits occur in some countries at depths of 1000 meters or more. In thickness these deposits may be as much as 100 meters and have invariably been formed by the evapouration of sea water along the littoral.

In Sri Lanka common salt is produced by solar evaporation of sea water in salterns at Hambantota, Puttalam, Elephant Pass, Palavi, Nilàveli and Mannar. The annual production depends on the weather and rainfall.

Salt is one of the indispensable minerals needed for seasoning and preserving food, and in the manufacture of many chemicals like soda ash and caustic soda. It is also used for the production of chlorine, as at Paranthan, which is used extensively for bleaching pulp, paper and textiles, for sterilizing water, manufacture of hydrochloric acid and chlorination processes in metallurgy.

6.10 Quartz

Quartz (SiO_2) is one of the commonest minerals in rocks and the most abundant oxide in the earth's crust. Well-shaped crystals of quartz occur in rock cavities. These are referred to as rock crystals and may be of various colours such as rose-red or pink : rose quartz, purple or bluish violet; amethyst etc. They are used in cheap jewellery and for making optical glass. The most important use of quartz crystals is in the electronic industry.

Silica occurs in many forms and in various degrees of purity, as vein quartz, quartz sands, sandstone, quartzite, flint, trydimite, and chalcedony. Some of the semiprecious stones belonging to this group are amethyst, opal, and agate.

Vein quartz deposits of high purity with almost 99 per cent SiO_2 occur in several parts of the country, the best known being around Pelmadulla, Opanaike, Pussella, Rattota and Ratnapura. Vein quartz is used for the manufacture of pottery, sanitary ware and glass products.

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CHAPTER 7

Gemstones

7.1 Properties of Gemstones

Gemstones or precious stones are rare minerals possessing certain specific properties which other minerals do not usually possess. Only about 100 of the known minerals have these properties to the required degree to be recognized as gemstones. These properties that determine the value of a gemstone are beauty, durability and rarity.

The beauty of a gemstone depends upon its colour, transparency, brilliancy, luster and fire. Colour, transparency and luster have been already described in Chapter 4 in the description of the properties of minerals. Brilliancy of a gemstone is mostly a result of light entering the gem being refracted internally and returned to the eye of the observer. Minerals with higher indices of refraction are exeedingly brilliant. A good example is diamond, which has a refraction index of 2.42. Fire of a gemstone is the sparkle or the flashes of colour which can be observed, in certain colourless and light coloured minerals. It is caused by the dispersion of white light passing through the mineral and being broken up into its spectral colours. In most cases these qualities are best seen when the mineral is cut and polished. Some gemstones such as red diamonds possess all these qualities to a marked extent, whereas the beauty of some gemstones depends only upon one or more of the above mentioned qualities. For example, ruby, which is almost lacking in fire, is valued for its excellent colour, luster and transparency. The beauty of water-white diamonds which is devoid of colour is due to its luster, brilliancy and fire.

Durability is another important property of a gemstone. To be usable as a gem, a mineral must be hard, preferably harder than quartz, which has a Moh's hardness value of 7. If a mineral lacks durability, even though it possesses other good qualities of a gemstone, it may be hardly usable. Thus, durability is an important property and therefore plays a prominent role in the classification of gemstones. The gemstones like diamond, ruby, emerald and sapphire which are classed as distinct precious stones possess a higher hardness value than quartz.

The value of a gemstone is also determined by its frequency of occurence, the rarer the stone, the greater will be its value.

7.2 Gemstones of Sri Lanka

It is wellknown throughout the world that Sri Lanka is one of the countries that produces a variety of gemstones. Sri Lanka produces no less than the 40 out of the 60 popular varieties which enter the contemporary gem market. Rubies, amethysts, sapphires, moonstones and topaz are some of the most popular Sri Lankan gemstones. With the exception of diamond and opal, almost every kind of precious stone is found in Sri Lanka, from alexandrite to zircon.

In Sri Lanka gem minerals are concentrated in a comparatively restricted area, and the concentrations are localised. The gemming areas of Sri Lanka are shown in the Fig. 5, comprises about 200 ha. The most important and the best known gem bearing area is the Ratnapura district of the Sabragamuwa province, most actively gemmed areas being the neighbourhood of Eheliyagoda, Kuruwita, Ratnapura, Pelmadulla, Kalawana and Rakwana (Perera et. al, 1976, Wadia and Fernando,

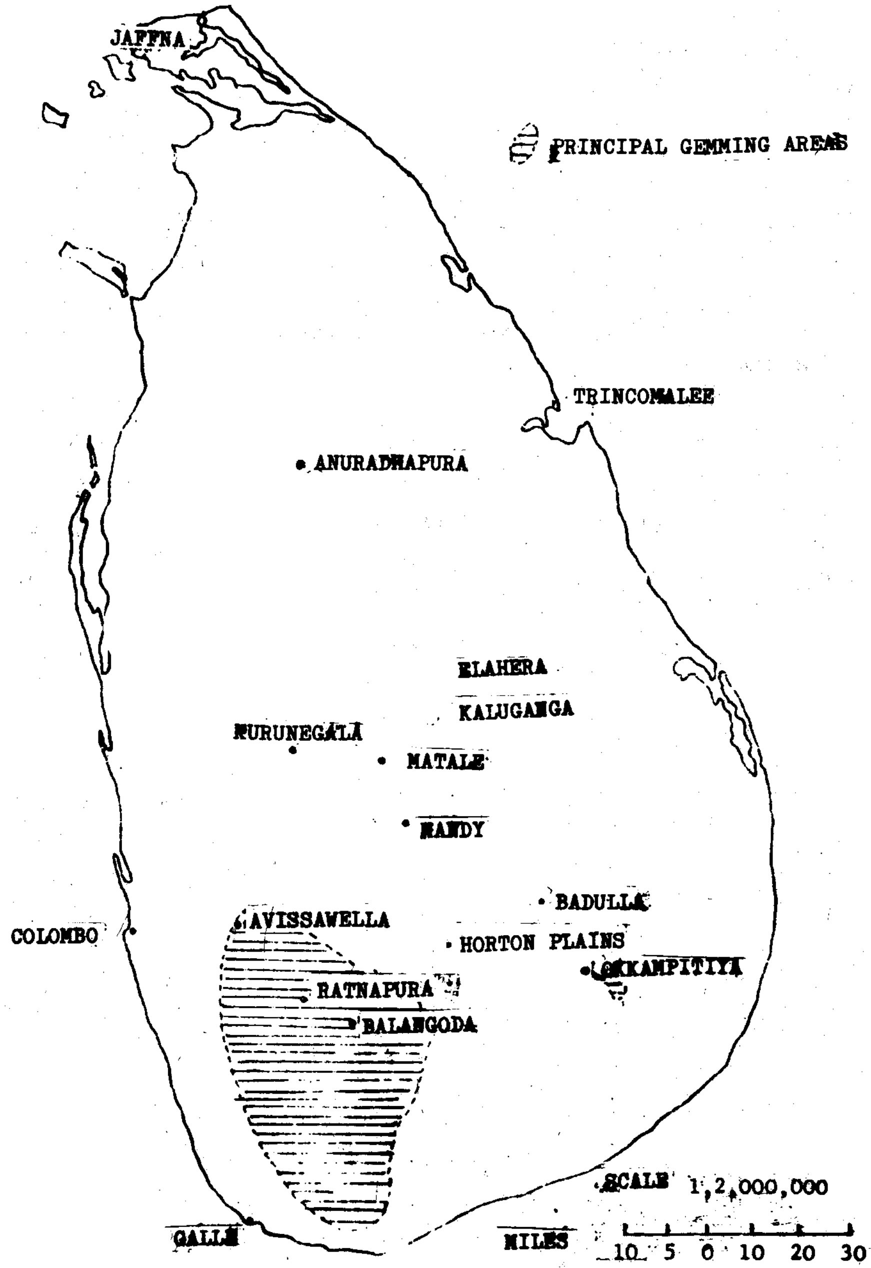

Fig. 5 - GEM BEARING AREAS OF SRI LANKA

1945). During the last few years new gem bearing lands have been found in the Okkampitiya and Elehara areas. Some gems have also been found in the Nuwara Eliya, Maskeliya and Kandy areas.

Practically all gemstones found in Sri Lanka are now obtained from alluvial deposits of rivers, that have drained regions of gem-bearing crystalline rocks (Dahanayake et. al, 1980). In the south-west of the island, centered around the Ratnapura valley, the gems are found in alluvial deposits that have accumulated to a thickness of about 40 feet (Katz, 1972). Overlying these gem gravels are auccessions of boulders, sand, clay and mud. The Elahera gem deposits also occur as alluvial and as residual formations (Silva, 1976).

Gemstones found in Sri Lanka include the following (Geological Survey Department, 1970) :

Corundum -Sapphire, star sapphire, yellow sapphire, white sapphire, ruby and star ruby
Chrysoberyl - Alexandrite and cat's eye
Beryl - Acquamarine
Topaz - White topaz and yellow topaz
Tourmaline - Black, pink, rose red, and blue
Garnet - Pyrope, alamandine and grossularite
Spinel - Deep red, green and violet
Zircon - Red, orange, brown and yellow
Quartz - Rock crystal, amethyst, rose quartz, smoky quartz and quartz cat's eye
Feldspar - Moonstone and amazon stone
Cordierite - Iolite
Kornerupine - Yellow or brown

In addition, new mineral species such as sinhalite and sphene have been found in the gem gravels of Sri Lanka, and therefore, there is every reason to expect that other new minerals will be found, in the future.

7.2.1 Corundum

The mineral corundum, which has a chemical formula of Al_2O_3 is very common and is the hardest of gems found in Sri Lanka. Ruby and sapphire are two colour variations of the same mineral, corundum. The term ruby is used when corundum is red in colour, and the term sapphire is used for a gem corundum of any colour other than red. Thus, sapphire may be blue, violet, yellow, white or pink, of which, the blue sapphire is the most popular. Red colouration in ruby is due to the presence of chromic oxide, while the blue colour in blue sapphire is due to iron and titanium.

Ruby and sapphire exhibit a vitreous luster. Some have a starlike effect when viewed in reflected light and this property is known as asterism. Ruby and sapphire possessing this property are termed star ruby and star sapphire respectively (Sahama, 1982). The corundum gem varieties have a hardness of nine on the Moh's scale, and thus rank next to diamond in this property.

Corundum of many colours, blue, violet, yellow, white, green, pink and red are found in the south-west part of the island (Webster, 1975). Blue sapphires and star sapphires of inestimable value, were recently discovered in the Laggala - Pallegama area.

7.2.2 Chrysoberyl

Chrysoberyl, $BeAl_2O_4$, may be of two varieties, alexandrite and cat's eye, and both are highly prized gemstones.

Alexandrite is emerald green in colour in daylight and blood red in artificial light. The variation in colour is due to differential absorption of the two kinds of light. Cat's eye chrysoberyl is yellowish green or brownish yellow in colour, with a silky luster. In cabochun-cut cat's eye, light appeers concentrated in a band across the stone, showing the cat's eye effect. Other gem species also may show cat's eye effect but chrysoberyl cat's eye is the most valuable.

The hardness of alexandrite and cat's eye chrysoberyl is 8.5 on the Moh's hardness scale. Chrysoberyl gems, therefore are the third hardest, among the gem minerals.

Sri Lanka is the principal source of alexandrite and chrysoberyl cat's eye. Large pieces of alexandrites have been found as pebbles in the gem gravels of Sri Lanka.

7.2.3 Beryl

Beryl, $Be_3Al_2Si_6O_{18}$, occur in three colour varieties, emerald; which is green in colour, acquamarine ; which is blue to seagreen in colour and golden beryl : which is golden yellow or yellowish green in colour. Of these gemstones, only acquamarine is found in Sri Lanka. Since it is a much more widespread gemstone than emerald, it is less valuable. Acquamarine is a transparent gem with a hardness value of 7.5.

In Sri Lanka, some very large stones of acquamarine have been found in the low country, that comes from the pegmatite granites higher up in the Maskeliya and Talawakelle region (de Silva, 1927).

7.2.4 Topaz

The chemical formula of topaz is $Al_2\ (F,OH)_2\ SiO_4$ where the percentage of fluorine and hydroxyl vary greatly. It has a hardness value of 8 on the Moh's scale, and its refractive index varies between 1.62-1.63. Many coloured varieties of topaz have been identified, in addition to the colourless topaz, pink topaz and pale yellow topaz, deep yellow topaz, pale blue topaz, pink topaz and pale green topaz. Of these varieties pale yellow topaz and colourless topaz occur abundantly in the gem gravels of Sri Lanka. The deep yellow topaz and light green topaz may occur as rarities (Gunaratne, 1969).

7.2.5 Tourmaline

The name tourmaline has been derived from the Sinhala word 'Toramalli'. Chemically tourmaline is a complex borosilicate of aluminium with alkali metals. Alkali metal present in the mineral is used as a basis for classification of tourmaline minerals, and the varieties are elbait, schorl, dravite, buergerite, liddicoatite, tsilaisite, and uvite. The variation in colour is used as a basis for classification of elbait tourmaline gems. Elbait tourmaline occurs in almost all colours, of which the most common are deep green, deep red, blue, rose red, brown and black. The reddish varieties are frequently called rubellite; and the black , schorlite; the dark blue , indicolite and the green , Brazilian emerald. Tourmaline has a hardness of 7 to 7.5 according to Moh's hardness scale.

In Sri Lanka tourmaline of black, pink, rose and blue colours have been found in alluvial deposits. The calcium rich tourmaline variety ; uvite, is present in the Uva province in the south-east part of the country, (Dunn, 1977).

7.2.6 Garnet

Garnet gemstone group consist of six varieties depending upon the chemical composition, and they are, grossularite ; $Ca_3Al_2(SiO_4)_3$, pyrope ; $Mg_3Al_2(SiO_4)_3$, spessartite ; $Mn_3Al_2(SiO_4)_3$, alamandine ; $Fe_3Al_2(SiO_4)_3$, uvarvite ; $Ca_3Cr_2(SiO_4)_3$ and anhydradite ; $Ca_3Fe_2(SiO_4)_3$.

The metallic radicles determine the colour of the stones, thus each variety is different in colour. The most common garnet gems are pyrope, which is red, and alamandine, which is purplish red. Less common varieties are grossularite, which is pale olive green, spessartite which is brownish red to orange and andradite which is brown to brownish green in colour. Hardness of these gemstones range from 6 to 8 depending on the variety.

Garnets are found in every part of the island. Of the varieties of garnets, pyrope, alamandine and spessartite are common gemstones occuring in Sri Lanka.

7.2.7 Spinel

Spinel has a chemical composition of $MgAl_2O_4$ where magnesium may be partially replaced by iron, zinc or manganese, and the aluminium by ferric ion and chromium. Spinel occurs in all colours, but the common are red, red brown, greyish blue, yellow, purple and brownish black. Pure green spinels are very rare. Based on the colour, there are many varieties of gem spinel. Ruby spinel is the name given for the deep red transparent variety. It is the most popular gem spinel. Baeas ruby is rose red to pink in colour, and rubicells is yellow to orange red. Violet to purple variety is known as alamandine spinel, while the blue variety is termed sapphirine. The iron bearing grass green variety is known as chlorospinel.

Spinel gemstones have a Moh's hardness value of 8. Luster is vitreous and the stones may be transparent to semi-transparent.

In Sri Lanka spinel of great variety of colours are found as water-worn pebbles in the gem gravels (Webster, 1975).

7.2.8 Zircon

Zircon, $ZrSiO_4$ has been known to occur in almost all colours. Colourless varieties are also found. The most common colours are red, orange, yellow, brown, green, blue and purple. Depending on the colour many varieties of zircon have been described. Hyacinth is the term applied to the clear transparent red brown variety. Jargon includes zircon of most of the other colours. Matara or'matura diamond' is the colourless zircon found in the Matara district of Sri Lanka (Kraus et. al, 1959).

Zircon has a hardness value of 7 to 7.5, and a refractive index of 1.93 to 1.99. Thus, the refractive index is the highest next to diamond. Zircon gem varieties like Baddeliyaite (Fletcher, 1892) are common in the sands and gravels of Sri Lanka.

7.2.9 Quartz

This group of gemstones consist of the largest number of varieties with attractive colours. Chemically, quartz is SiO_2, but it may contain impurities in the form of metallic oxides and the numerous colours in which quartz occurs is attributed to these.

The hardness of quartz is 7 in the Moh's scale and its refractive index varies between 1.54 and 1.55.

The varieties of quartz differ widely in their luster, transparency and colour. Only the transparent and semitransparent varieties are classed as gemstones. The many varieties of quartz are most conveniently classified as crystalline quartz, compact quartz and chalcedony, of which only crystalline quartz is known to occur in Sri Lanka.

Crystalline quartz is vitreous and occurs in crystals or crystalline masses. This group includes many varieties based on colour and structure. Rock crystal, amethyst, rose quartz, smoky quartz and quartz cat's'eye are the commonly found varieties of quartz in Sri Lanka.

Rock crystal is colourless and transparent. Because of this it stands prominently among other colourless stones. Quartz with various shades of purple or violet are termed amethyst. The distribution of colour in amethyst is often patchy, showing colourless portions alternating with portions of violet colour. Amethyst pebbles found in Sri Lanka are some of the finest known. Rose quartz usually occurs as large irregular masses and is semitransparent to opaque. The colour may vary from pink to rose red becoming paler on exposure to light. Smoky quartz may be smoky yellow, dark brown or even black in colour. The black variety is not considered as a gemstone. Distribution of colour in this stone is often not uniform. Cat's eye quartz is characterized by the inclusions of minute asbestos fibers arranged in a parallel pattern, which produces the cat's eye effect. This mineral is never transparent, and the colour may be white, olive green, leaf green, brown yellow or brownish red. In Sri Lanka cat's eye quartz of all shades of colours are found ; green and grey being the most common.

Quartz frequently occurs as microscopically minute grains, and aggregates of such grains are generally referred to as compact quartz. Both compact quartz and chalcedony quartz are not encountered in Sri Lanka.

7.2.10 Feldspars

Chemical formula of feldspars may be expressed by $MAlSi_3O_8$ or $MAl_2Si_2O_8$, where M may be potassium, sodium, calcium or barium. Moonstone or adularia is a potash feldspar, and it occurs usually in white or colourless crystals. This gem variety may be transparent or slightly cloudy. Amazanstone too is a potash feldspar and is bright green in colour. It is transparent to translucent and possesses a vitreous luster. Moonstone and amazonstone have a Moh's hardness value of 6, theerefore their durability is comparatively low.

The most important source of moonstone in Sri Lanka, where the mineral occurs in peculier adularia - leptinyte, dykes at Weeragoda, near Ambalangoda and in Dumbara and in the Kandy district in the Central province (Webster, 1975).

7.2.11 Cordierite

Cordierite, $Mg_2Al_3(AlSi_5O_{18})$ is found in many colours. Some of the common colours are light to dark smoky blue, dark blue, violet, grey, colourless, green and yellow. Its hardness value is between 7 to 7.5. The mineral may be transparent to translucent. Transparent varieties from Sri Lanka, which are referred to as iolite are used as gemstones. Iolite bearing rocks are found in the south-west part of the island (Hapuarachchi, 1968).

7.2.12 Other gems of Sri Lanka

Other gem minerals found in Sri Lanka include Kornerupine (Koveraar and Zwaan, 1977), sinhalite (Bank, 1977), diopside (Bank, 1977), sillimenite (Gubelin, 1979). enstatite, andalusite, (Webster, 1975), sphene (Gunawardene and Hanni, 1981, Zwaan, 1981) and ferroaxinite, (Hanni and Gunawardene, 1982).

7.3 Other Important Gemstones

7.3.1 Diamond

Diamond is the most valuable gemstone of all. It is composed of the single element, carbon, which is in a very pure state. It therefore is similar to graphite and to coal in composition. Diamond possesses outstanding properties for which it is highly valued. It has the greatest hardness, of all gemstones, with a Moh's hardness value of 10. It has a very high refractive index of 2.42 to 2.43, and therefore is exceedingly brilliant. Also it has a very great light dispersion, which produces the brilliant flashes of spectral colours known as fire. The known coloured varieties are bluish white, yellow, brown, red, green, blue and black. The different colours are due to the impurities that may be present. Diamond has a highly perfect octahederal cleavege.

There are three forms of diamond, gem variety diamond, bort and carbonado. The gem variety diamond is highly transparent. colourless and most of them are free from flaws. Bort diamond is used in industry in a wide variety of cutting and grinding operations. Carbonado is more valuable than bort. It is grnerally opaque and the colour may be black or gray.

Diamond is often found in extinct volcanic vents. In the Kimberely district in South Africa diamonds are known to occur in the original rock in which they are formed. Alluvial diamond deposits are found in the other parts of the world, such as India, Brazil and Venezula.

7.3.2 Emerald

Emerald is a beautiful, grass green variety of beryl, and chemically it is beryllium aluminium silicate. This gem mineral has a hardness of 7.5 and refractive index of 1.57 to 1.50. The most valuable emeralds are found in Columbia (South America) Urals, Austria, Norway, and North Carolina (U.S.A.).

7.3.3 Opal

Opal, $SiO_2.nH_2O$ is commonly found in all parts of the world. However, the gem varieties are rare. The principal gem varieties of opal are fire opal, white opal and black opal.

Fire opal is orange yellow to red in colour. It is semitransparent to transparent and may show a play of colours. The main locality for this variety is Mexico. White and black opal comes mainly from Central Australia.

7.3.4 Jade

Jade, $NaAlSi_2O_6$, includes two varieties, nephrite and jadeite. Nephrite, which is bright to dark green in colour is the more common of the two. Other colour varieties of jade are white, yellowish, reddish and bluish. Hardness of this gem mineral is 6.5 - 7 and the refraction index is 1.66.

Jade occurs in Burma, southern China, Tibet, Mexico and South America. It is considered to be one of the most highly prized stones found in the earth.

Most of the gems discussed in this Chapter have been known for a long time. Although they are non-essential minerals, they play a significant role in the economy of the world. They have been eagerly sought after for personal adornment and ornamentation, from the earliest times. In addition, some people believe that certain gemstones bring luck to its wearer, and they have recognized birthstones for each month. The birthstone for the twelve months are as follows: garnet for January, amethyst for February, bloodstone for March, diamond for April, emerald for May, pearl for June, ruby for July, peridot for August, blue sapphire for September, opal for October, topaz for November and torquoise for December.

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