Minerals, Rocks and their Economic Significance

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Earth' Crust

The Earth's crust is its uppermost thin layer of rocks. Like the skin of an apple in relative terms, it is extremely thin in comparison to the radius of the earth (~ 6371km). The crust is on average 5-8 km thick under the oceans and about 35 km thick in continental areas. Crust is mainly made of rocks and minerals. In most areas the top layer is covered with a thin film of soil or sediments which have been formed by weathering and degradation of rocks and minerals.

What is a Mineral?

A mineral is defined as a naturally occurring inorganic solid, that possesses an orderly internal atomic arrangement (structure) with a specified chemical composition or compositional range. "Naturally occurring" means that it has to be formed by natural geological processes and is not man made as in the case of steel or synthetic gemstones.

A mineral should be in a "solid" state within the normal temperature ranges of the earth's surface. According to this strict definition, water and liquid/gas hydrocarbons are not minerals. "Inorganic" means that the substance is not derived from organic material or by an organism. For example, coal and peat which are derived from plants or pearls formed by organisms are not minerals by this definition. However, in general use ground water and petroleum are considered under mineral resources.

"Specified chemical composition" means that all occurrences of that mineral have a chemical composition that is fixed or varied within a specific limited range. For example: the mineral halite (known as "rock salt" when it is mined) has a chemical composition of NaCl. It is made up of an equal number of atoms of sodium and chlorine.

"Ordered internal structure" means that the atoms in a mineral are arranged in a systematic and repeating pattern. The atomic structure of any part of a mineral is the same irrespective of location within the mineral mass or location.

Classification of Minerals

While most minerals are compounds of two or more elements, some minerals are made up of a single element. Gold, silver and copper are called native elements and occur in nature in relatively pure form. The vast majority of minerals are compounds or combinations of elements. For a given mineral these combinations are consistent. For halite, the chemical formula is NaCl or sodium chloride. Each sodium atom is combined with one chlorine atom. The formula for Quartz is SiO_2, silicon oxide. For every atom of silicone, there are two atoms of oxygen.

There are over 4000 known minerals on earth. Each one is a unique substance with its own chemical formula. Most of these are very rare. Earth crust is mainly made of about 20 common rock forming minerals. Oxygen (O) silicon (Si), and Aluminium (Al) are commonest chemical elements in the earth crust. Quartz (SiO_2) is the most abundant mineral in the crust. There are several mineral families called "Rock Forming Mineral Families". Within each family, again there are several minerals with chemical variation of mainly Fe, Mg, Ca, K and Na. These families are:

(1) Feldspar
(2) Pyroxene

(3) Amphibole
(4) Mica

Mineral Classification

Minerals can be classified based on a number of criteria such as compositional characteristics, structural and crystallographic characteristics, practical use and their geological affinity. Two such common classifications are given below:

Chemical Classification of Minerals:

- Native elements
- Sulphides
- Oxides
- Nitrates
- Phosphates
- Sulphates
- Halides
- Silicates

A Classification Based on Applications:

Energy Minerals	Metallic Ore		Industrial Minerals
Coal	Ferrous & Ferroalloy Minerals	Non-Ferrous Minerals	Non Metallic
Peat	Iron	Bauxite (Aluminium)	Asbestos
Uranium ore	Chromium	Copper Ore	Clays
Thorium ore	Cobalt	Gold	Gemstones
Thorium minerals	Manganese	Lead	Graphite
Petroleum	Nickel	Zinc	Phosphates
Petroleum	Molybdenum		Feldspar
			Quartz
			Mineral sand

Rocks

Rocks exist all over the earth crust, beneath the soil or sediment cover. In fact, rocks are composed of various combinations of minerals. In the simplest terms, rocks can be considered as aggregates of minerals. Depending on the physical conditions of formation (Temperature and Pressure) appearance and physical characters of the rocks can be very different. There are three major categories of rocks namely, igneous rocks, metamorphic rocks and sedimentary rocks. Igneous rocks are formed at high temperatures (900-1500oC) by volcanic processes at or near the earth surface or at depths by intrusion. Sedimentary rocks are formed at or near the surface under relatively low temperature/pressure conditions by surface processes. When an igneous rock or metamorphic rock is subject to additional pressure and temperature through burial and heating by igneous processes this third category of rocks named metamorphic rocks are formed. The process is called metamorphism.

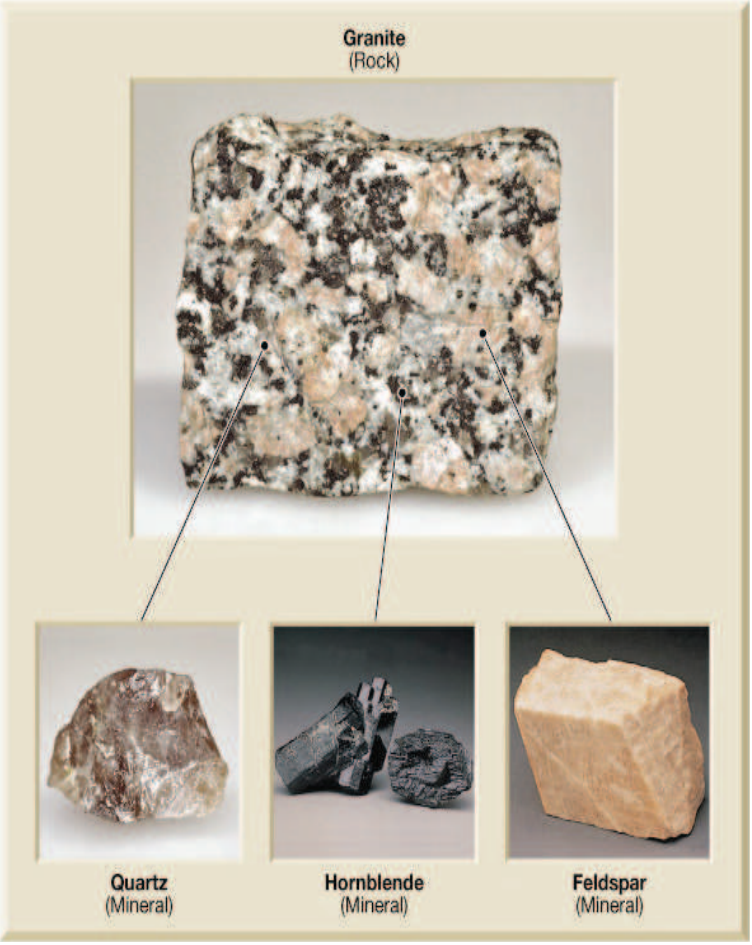
Economic Minerals and Mineral Based Industries in Sri Lanka

Sri Lanka is reasonably endowed with non-metallic minerals but not with metallic and energy minerals. The economic minerals of Sri Lanka include industrial minerals such as clays, mineral sand (ilmenite, rutile, zircon, garnet & monazite), silica (quartz), limestone, dolomite, apatite (phosphate rock), graphite, feldspar, mica and gemstones (see Figure, 2 Mineral Resources Map of Sri Lanka). No energy minerals are extracted yet on land or within the Exclusive Economic Zone of Sri Lanka offshore. However, the presence of hydrocarbons within western offshore area has been reported recently. Detailed exploration by CAIRN, India is in progress.

All mineral deposits in Sri Lanka except for graphite and gemstones are mined in quarries or surficial pits by open-cast method. The only underground working mines are for graphite which are located at Kahatagaha and Bogala. The Graphite mine at Ragedara has also been re-opened recently.

Except for a few involvements by the government owned companies such as Lanka

Phosphate Ltd. on Eppawala apatite deposit, Lanka Mineral Sands Ltd. for Pulmoddai mineral sand deposits, and Kahatagaha Graphite Ltd., the mineral industry of the country is now in the hands of the private sector.



Clay Deposits and Related Industries

Clay is the main ingredient in the body mixture of ceramic ware, wall tiles, bricks and tiles. Clay deposits of Sri Lanka include kaolin (kaolinite/ china clay), ball clay (a mixture of kaolinite, gibbsite, vermiculite and boehmite), and brick and tile clay (a mixture of kaolinite, gibbsite, goethite and vermiculite deposits). Kaolin (china clay) deposits mainly occur in the southwestern sector of the country. Well known kaolin deposits are in Meetiyagoda and Borellasgamuwa areas. Much of the deposit at Meetiyagoda has been exploited and the mining activities in Borellasgamuwa area are hindered by rapid urbanization. Ball clays are mainly found in flood plains of the southwestern sector. Main ball clay deposits are at Dediyawala in Kaluthara District. Surveys to find out new deposits are being currently conducted in the southwestern part of the country. One of the well established mineral industries in Sri Lanka is the ceramic industry. There are a number of local companies which produce high quality ceramic ware for export and local use.

Feldspar

Microcline (K-feldspar) deposits occur mainly in Rattota, Thalagoda, Kaikawala in the Matale district and Koslanda area. Among these, the largest deposit is in Owella estate, Kaikawala. Feldspar is mainly used in the manufacture of glass, pottery, vitrified enamels and special porcelain. As important raw materials of the local ceramic industry, export of both clays and feldspar are not allowed.

Silica Quartz

Vein quartz deposits of high purity (SiO_2%>99.65) occur in many parts of the country. Significant deposits are found in Galahad, Opanayake, Rattota, Balangoda, Mahagama, Randeniya and Meegahakiwula areas. It is estimated that over 1,000,000 MT of vein quarts occur in these deposits. Currently, export of vein quartz is allowed subject to prescribed degree of value addition such as in the powder form or as crushed quartz. A minor percentage (~4%) is utilized locally in ceramic and allied industries.

Silica Sand

Deposits of inland silica sand are common and well known deposits occur in the Marawila, Nattandiya and Madampe areas. A very large deposit of silica sand occurs in the form of sand dunes in Ampan-Vallipuram areas. Major use of inland high purity silica sand is in the

glass industry. In addition, vast amounts of silica sand are excavated from flood plains and river beds to be used as fine aggregates. Use of dredged sea sand for construction purposes has been encouraged but still sea sand is mainly used as filling material.

Mineral Sand

Mineral sand is a mixture of refractory heavy minerals such as ilmenite, rutile, garnet, zircon, monazite together with some silica sand. Usually, the deposits appear as stretches of black sand along the beach or occur as raised beaches. In Sri Lanka, well known beach sand deposits are encountered at several points of northeastern and northwestern coastal stretches. Although the mixtures of these minerals are not uncommon, it is only at certain points they are sufficiently concentrated for economic exploitation. Well known deposits are at Pulmoddai, Nayaru, Koduwakattumalai and Tavikkalu. At Pulmoddai deposit 70-75% of the black sand is ilmenite, 8-10% is zircon, 6-8% is rutile and about 0.5% is monazite. Garnet concentrated sands are reported from Dondra Head and Hambanthota.

It is estimated that over 12,000,000 MT of mineral sand occur along the beaches and in raised beaches of the island. Currently, Lanka Mineral Sands Ltd. (former Ceylon Mineral Sand Corporation) has been extracting ilmenite and rutile using magnetic and gravity separation techniques. Minerals thus separated are exported without much value addition.

Limestone

Sedimentary limestone belonging to Miocene age extends from Puttalam to Jaffna Peninsula along the northwestern coastal belt of Sri Lanka. Limestone is well exposed at several places including Aruwakkalu, Mannar, Pooneryn and Kankasanthurai. Material exposed at these localities is mainly Ca CO_3 and is suitable for the cement industry. Currently limestone excavated at Aruwakkalu fulfills the Ca CO_3 requirement of the local cement industry. Export of limestone is not allowed.

Crystalline Limestone (Marble)

Chemically crystalline limestone (marble) is $CaMg(CO_3)$ with a variable CaO/MgO ratio. Magnesium rich varieties (dolomitic marble) are used as a fertilizer for long term crops, and for scrubbing powder, while calcium rich varieties are burnt to produce lime in place of coral based lime products. Thick bands of marble occur in the Highland Complex of Sri Lanka especially in Digana (Kandy), Mathale, Dambulla, Naula, Bakamoona areas and in the central highlands. Export of limestone is not allowed.

Apatite (Rock Phosphate)

A deposit of rock phosphate with proven reserves of 24,000,000 MT and another 15,000,000 MT of inferred reserves are located at Eppawala near Anuradhapura. Currently, this deposit is mined by a government owned company (Lanka Phosphate Ltd.), and crushed phosphate is produced for local phosphate fertilizer requirements of long term crops. The optimum utilization of this deposit could be possible only if the phosphate rock could be converted to soluble phosphate fertilizer such as Single Super Phosphate (SSP), Triple Super Phosphate (TSP) Di-Ammonium Phosphate (DAP) or Mono-Ammonium Phosphate (MAP). If this valuable phosphate deposit could be developed, large sums of money drained to overseas countries on fertilizer, could be saved.

Graphite

Graphite mining in Sri Lanka dates back to the time of the 1st World War. There was a great demand for Sri Lankan graphite both during the periods of 1st and 2nd World Wars mainly because of its high purity. A large number of shallow pits and few major mines were in operation during these periods. Of these, only Kahatagaha and Bogala Mines are in operation at present. There is a potential for the establishment

of graphite based industries such as crucibles, carbon brushes, refractory bricks, electrodes, paints and lubricants. Unfortunately, bulk of the graphite mined in Sri Lanka is exported in raw form.

Iron Ore

There are three (03) known metamorphic iron ores and few scattered supergene deposits in Sri Lanka. Metamorphic deposits are at Panirendawa near Chilaw, Seruwila and Buttala. These deposits are very small in size in comparison with iron ores in other parts of the world. However, in view of increasing demand for iron there is revived interest in these occurrences.

Gemstones

Sri Lanka has long been renowned for its gemstones. Perhaps nowhere in the world are so many gem varieties as occurring within such a small area of land. A variety of gem minerals from corundum, chrysoberyl, beryl, topaz, tourmaline, garnet, spine and quartz families are found in alluvial or colluvial deposits or in-situ. Rare stones such as Sinhalite, Ekanite and Taaffeite are perhaps unique to Sri Lanka. Traditional gem mining area was Sabaragamuwa (Rathnapura) but Okkampitiya, Elahera, Horton Plains and many other areas within the Highland Complex of the country are also now known for occurrence of precious and semi-precious stones.

Mica

The main types of mica found in the country are phlogophite, biotite and muscovite. Important commercial types are phlogopite and muscovite. Phlogopite mica is found in the areas of Thalagoda, Madumana, Talathu-Oya, Badulla, Maskeliya, Madugoda, Udumulla, Naula, Haldummaulla and Kebithigollawa. Sheet mica is mainly used in electrical appliances and in the electronic industry. Scrap mica is usually ground and then used as a filler in plastics and paint industry.

Hard Rocks Suitable for Dimension Stones and Construction Material

Recent rapid infrastructure development in the country has created a great demand for road metals, rock boulders and rock aggregates. Since most parts of the island are underlain by high-grade metamorphic rocks there are numerous hard rock exposures that could be harvested for dimension stones or quarry material such as road metals or rock boulders. Since haphazard quarrying could lead to many environmental and social issues, such activities have to be monitored and regulated. However, this industry has managed to supply sufficient quantities of construction material required for the development efforts and earn valuable foreign exchange by export of value added products.

Mineral Production and National Economic Development

Many of the world's richest countries have benefited greatly from minerals extraction. Australia, Canada, Finland, Sweden, and the United States, for example, have all had extensive mineral industries and used them as a platform for broad-based industrial development. In more recent years, a number of developing countries also have achieved minerals-led development. For example, Chile, whose copper production accounts for 35% of world output, is now among the group of 'high human development' countries (ranked 39th by UNDP). Here, too many of the rewards have been reaped locally: the mining capital of Antofagasta is relatively prosperous and in recent years unemployment has been falling despite the arrival of immigrants from other regions. Africa can also provide positive examples. One of the most successful mining countries has been Botswana, a major producer of gem diamonds that has also had one of the world's highest economic growth rates. But some other countries with mineral development seem to have been considerably less successful.

There are a number of ways of deciding which countries qualify as "mineral economies":

Minerals output can be set against gross domestic product (GDP), or the dependence of foreign-exchange earnings on mineral exports can be considered. In 34 nations, mainly developing and transitional economies, mineral exports of metals, ores, and fuels (including oil) represented 25% or more of total merchandise exports in 1999. Another indication of minerals dependency is the proportion of government revenue that comes from mining. However, any country that wishes to translate mineral wealth in the ground into human development for its people faces stiff challenges. These include:

- Creating and sustaining mineral wealth while protecting environmental quality and other social and cultural values;
- Sharing the surpluses or economic rents from mineral production equitably among different levels of government, local communities, and mining companies;
- Converting non-renewable resources (mineral wealth) into renewable ones by investing in physical and human capital, and doing so in a way that also helps protect the interests of future generations;
- Maintaining a stable economic environment while coping with the exchange-rate impact of mineral exports, fluctuating international commodity prices, and the demands for structural adjustment; and
- Dealing with the impact of the mining sector on crucial issues of governance, in particular corruption, regional tensions over how revenue is shared, and human rights.

Capturing Mineral Wealth

The existence of mineral deposits is no guarantee of economic development. Whether deposits turn out to be a blessing or a curse will largely depend on governments, on the quality of their institutions, on their capacity to manage these resources. Some governments have tried to maximize their incomes through higher taxes and royalties and by limiting the repatriation of profits. They also imposed various controls on what the corporations could import or export, and required that companies employ a certain proportion of national staff. When this did not yield the desired results, there were mandatory joint ventures with national companies, caps on the percentage of foreign ownership. However, it was clear that some of these measures were not bringing the desired results. Some state mining companies, rather than contributing to the national budget, became a drain, as subsidies were required to keep them afloat. Many governments acknowledged that state ownership and public-sector management were failing to deliver anticipated social and economic benefits, and that over-regulation was discouraging investment. Last three decades saw much economic liberalization and a greater belief that the best option was to allow the private sector to take the lead in spearheading development.

Post Mining Responsibilities

In the longer term, many mineral-intensive economies must also plan for the time when minerals run out. Prudent governments will consider the best ways to use their earnings for productive investment. Broadly there are two options. The first is to make investments that will produce a measurable financial return. These could include real estate or financial assets such as stocks and bonds. The second option is to invest in assets that produce less measurable return. This could involve physical infrastructure, for example, as well as human development in the form of skills development and health and education services.

Most poor or developing countries are likely to choose this approach. In any case it is extremely important to recognize early in project planning that there will be terminal costs, what these will be, and how they will affect a government's obligations.

Terminal costs are numerous, diverse, and sometimes very large. Examples might include:

- Sudden increase in unemployment and other social costs as a region is faced with relatively high unemployment
- Need to pay to maintain roads, telecommunications, electrical supply, or other infrastructure which were previously done by mining companies
- Need to look after rehabilitation and post rehabilitation maintenance work

There needs to be some clear agreement on the role of national government.

Export and Import of Minerals and Mineral Based Products – Sri Lanka

Major mineral exports of Sri Lanka are mineral sand, quartz, graphite and mica. Export income from these minerals for the year 2011 is given in the Table 1. Major mineral based products that earn foreign exchange are ceramic tableware, porcelain tableware, wall tiles, floor tiles and ornamental stones. The earnings through export of these items in 2011 exceeded rupees 4/5 billions. Although Sri Lanka has a well-established cement industry, country still has to import nearly 50% of its requirement. The total cement consumption during the year 2011 was about 5,000,000 tonnes. Despite the fact that there is a large rock phosphate deposit at Eppawala, country still spends billions of rupees on fertilizer imports.

In consideration of spending on other imports on mineral raw material and mineral based products it can be concluded that there is a large deficit in mineral export trade. In order to improve this situation, export of value added products in place of raw materials and development of existing mineral deposits should be encouraged.

Table 1: Production and Export Data for Sri Lanka Minerals (2011)

Mineral Commodity	Total Production (tonnes)	Export (tonnes)	Local Use	Foreign Exchange Earned (Rs. Value in millions)
Mineral Sand (ilmenite, rutile & zircon)	65566	80750	Negligible	1992
Graphite	3357	3324	Negligible	450
Mica	2927	2927		131
Vein Quartz	34903	33354	1500	1114
Gemstones	9154 (thousand carats)	9154 (thousand carats)		10027
Dimension Stones	6247	6247	---	180
Sea Sand	86200	14250	Bulk locally used	21
Feldspar	53337	0	Used in local industry	Save valuable foreign exchange for raw material export
Kaolin & Ball Clay	63000	0	Used in local industry	
Silica Sand	58355	0	Used in local industry	
Calcite	14674	0	Used in local industry	
Limestone	1231209	0	Used in local industry	
River Sand	7046431 (m3)	0	Used in local industry	
Dolomite	195000	0	Used in local industry	
Apatite	58254		Locally used	
Salt	87256	0	Locally used	

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