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MINERAL RESOURCES OF SRI LANKA

by

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FOREWORD TO THE SERIES

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

I must thank the Working Committee on Science Education Research of the Natural Resources, Energy and Science Authority, and in particular Prof. V. Basnayake who is the Hony. Director of the Working Committee for the work they have done to make this project a success.

R. P. Jayewardene
Director General

PREFACE

This small volume is the outcome of a project sponsored by the Natural Resources, Energy and Science Authority of Sri Lanka to provide supplementary reading material for Advanced Level science students. It deals with the economic mineral deposits of Sri Lanka. Minerals and metals have been of importance to man since pre-historic times and historical periods have been named after metals, such as the Bronze Age, the Iron Age and so on. Metals and minerals are obtained from the earth's crust which is the thin outer layer of the earth in which we live. Fortunately, this layer is not uniform and in places there are occurrences of metals and minerals useful to mankind. Where the concentration is sufficiently high, they can be worked profitably, and these give us our ore deposits. The minerals and metals must be extracted from the earth by mining.

In order to understand the nature, mode of occurrence and distribution of ore deposits, it is necessary to have some elementary knowledge of geology, which is briefly the science of the earth, and geological processes, and for this reason the volume has been divided into two parts. Part I deals with the earth's crust, the nature and classification of rocks and their modes of origin. It contains a brief outline of the geology of Sri Lanka without which there can be no proper appreciation of its mineral deposits. It also includes a chapter briefly describing the methods employed in exploration for minerals and mineral deposits. Part II deals with the economic mineral deposits (ore deposits). Since the book is meant essentially for students, over use of technical terms has been avoided except where they are strictly necessary and, as far as possible, they are defined in the text.

Since the volume deals with the economic mineral deposits of the Island, mention is made only of the deposits which are exploited or are awaiting development, or are of potential importance. No mention is made of those mineral occurrences which, by their very nature and from the present state of our knowledge, are only of academic interest.

A book of this nature is basically a compilation of available information from several different sources, chiefly from the Geological Survey, of which I had the privilege of being its head for over two decades. I have drawn freely from the work of former colleagues and from my own work, both published and unpublished. My grateful thanks are due to the Directorate of the Geological Survey, and in particular, Mr. L. K. Seneviratne, Director, and Mr. D. E. de S. Jayawardena, Deputy Director. My thanks are also due to the General Manager, State Mining and Mineral Development Corporation, and the Chairman, State Gem Corporation, for statistical data and other information.

L. J. D. Fernando

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PART I

Chapter I

INTRODUCTION

The Island of Sri Lanka (formerly known as Ceylon) is a pear-shaped island in the Indian Ocean lying immediately east of the southern extremity of Peninsular India between 5° 55″ and 9° 51″ of North latitude and 79° 41″ and 81° 53″ of East longitude. It extends 434 km (270 miles) from north to south and 225 km (140 miles) wide at its broadest point with a total land area of 65 600 square kilometres (25 320 square miles), or approximately 6.5 million hectares. The south-west quadrant of the Island is often referred to as the 'Wet Zone' because it is affected by the heavy rains during the south-west monsoon in the months of May to September, while the northern and eastern parts of the country are affected by the north-east monsoon, though to a lesser extent. These latter areas are commonly referred to as the 'Dry Zone'. The Wet Zone comprises roughly 25 per cent of the total land area, the balance 75 per cent comprising the Dry Zone. Much of the Dry Zone, where past civilizations prevailed, is under jungle, and irrigation of these dry areas is necessary for agriculture. The general elevation in the centre of the Island varies from around 760 m to 1 525 m (5 000 feet) with six mountains over 2 225 m (7 300 feet) with Pidurutalagala, the highest mountain, rising to a height of 2527 m (8 291 feet). Heavy rainfalls are experienced in the central hill country with rainfall of over 5 000 mm annually in certain parts.

The great majority of the rivers originate in the central hills and flow to the west, south-west and south coasts. The Mahaweli ganga, the longest river in the Island, 335 km from its source in the mountains to its outfall into the sea south of Trincomalee, flows in a northern direction and throughout the greater part of its course through the Dry Zone. This river is the basis of several major multi-purpose projects which are currently nearing completion. The Island can be roughly divided into two distinct regions - the coastal region and the Central Highlands. The coastal region is almost flat and the rivers flowing through this have reached their base level of erosion. On the western and southern parts of the Island, the coastal region is narrow but widens on the eastern side of the Island and expands into a great plain which occupies almost the entire northern half of the Island. These two broad units can be further sub-divided, particularly the Central Highlands, where a number of terraces or peneplains can be recognised. The topography in these is rugged and characterised by deep valleys and immature drainage patterns indicating block uplifts. The topography is in sharp contrast to that of the coastal plain.

The Crust of the Earth

The earth is a planet in the solar system with a circumference of approximately 40 000 km (25 000 miles). It is known that it is not homogeneous but has a layered structure, and geophysics teaches us

that the earth consists of a relatively light crust resting on a heavy molten interior. The central core consists of nickel-iron; it is intensely hot not merely due to residual heat but to some extent due to the spontaneous decay of radio-active elements. The increase in temperature with depth is a matter of experience in the development of deep mines. This temperature gradient varies in different parts of the world but in Europe it is reported to be about one degree C for every hundred feet of depth. The central core passes into an olivine-rich (magnesium-iron silicate) shell with a density of around 3.3 - 3.4 having the composition of peridotite. Above the peridotite shell is the 'crust', the lower part of which is mainly basaltic, while the upper part is a siliceous granitic layer some 15 to 20 km thick with a specific gravity of 2.77 to 2.80. This outermost shell is the only part of the earth directly visible to us in deep valleys and gorges, deep mines and in boring operations.

Divisions of Geological Time

Evidence from the measurements of the radio-activity of rocks and minerals in the earth's crust, supported by more recent evidence from the lunar landings, show that the Earth was formed as a solid body some 4 600 million years ago. In support of this figure, it may be useful to briefly review the methods employed in dating rocks. Rocks can be dated by four important methods:-

(*a*) By careful observation and recording the succession of layers, geological formations or strata in areas where they have not been violently disturbed; this method gives an age relative to the geological formation above and below. Thus a bed or stratum overlying another is clearly younger than the one beneath it;

(*b*) by identifying animal or plant remains (fossils) known to have existed for limited periods of time. This method is widely applied to rock formations less than around 570 - 580 million years, and obviously applies to fossil bearing sedimentary rocks. However, igneous rocks may be dated by their interlayering with sediments, or where they cut across sediments of known age. For instance, an igneous rock cutting across sediments of known age is clearly younger than the sediments;

(*c*) by radio-activity using the known rates of decay of certain isotopes of elements such as uranium, potassium and rubidium;

(*d*) by the magnetic orientation of certain minerals. It is known that magnetic poles wander and reverse periodically. Magnetite, and other iron bearing minerals, crystallise with their magnetic poles oriented in relation to the poles of the Earth which existed at that time. The method is useful in dating igneous rocks where radiometric methods are not applicable.

Based on these fundamental principles, the history of the earth is divided into four great divisions of geological time and the rocks comprising the earth's crust are divided into these divisions generally known as groups. The groups are further sub-divided into systems of strata representing periods of time, and the systems in turn to series of strata representing epochs of time. According to this system which is commonly adopted (though there are minor variations from this) the groups and systems comprising the earth's history are as indicated in Table I.

Not all of the systems and epochs are represented in every country, and breaks do occur, and one or more of the systems may be lacking. Such breaks indicate that an interval of geological time is unrepresented. For instance, as the study of stratigraphy was extended into distant lands, it was found that a particular geological system well developed in Europe may be poorly developed, ill-defined, or even completely absent elsewhere. Changes in the nature of geological formations and their faunas result from changes in the geological conditions, and such changes are not contemporaneous throughout the entire globe. The United Kingdom is an example of a country where the almost entire history of the earth has been well preserved, where the groups and systems and epochs are all represented in a comparatively small area. On the other hand, Sri Lanka, as we shall see, is an example of a country where the greater part of the geological column is absent, and most systems and epochs are completely unrepresented. (Table II).

TABLE I

STRATA AND DIVISIONS OF GEOLOGICAL TIME

Groups of Strata (Eras of Time)	*Systems of Strata (Periods of Time)*	*Series of Strata (Epochs of Time)*
Quaternary	**Recent**	
Cainozoic (Tertiary)	**Pleistocene**	
	Pliocene	
	Miocene	
	Oligocene	
	Eocene	Upper Eocene Middle Eocene Lower Eocene
Mesozoic (Secondary)	**Cretaceous**	Upper Cretaceous(Chalk) Lower Cretaceous
	Jurassic	Upper Jurassic Lower Jurassic Rhaetic
	Triassic	Keuper Bunter
Primary **Newer Palaeozoic**	**Permian**	Upper Permian Lower Permian
	Carboniferous	Coal Measures Lower Carboniferous
	Devonian	Upper Devonian Middle Devonian Lower Devonian
Older Palaeozoic	**Silurian**	
	Ordovician	
	Cambrian	Upper Cambrian Middle Cambrian Lower Cambrian
Precambrian **Proterozoic**		
Eozoic		

The Precambrian rocks are so named because they underlie the oldest fossiliferous rocks, to which Sedgwick gave the name Cambrian from their typical development in North Wales. The Precambrian represents a vast interval of geological time - far greater than all the time that has elasped since, and it is difficult to interpret the rocks and still more difficult to correlate them. Not only are the Precambrian rocks devoid of fossils but they have been intensely altered and converted into gneisses and schists. Vast areas of northern Canada, north Scotland and Scandinavia are formed of Precambrian rocks and these provide a more complete succession, but even so there are breaks of such enormous magnitude that it is difficult to establish a reliable correlation.

TABLE II

DIVISIONS OF GEOLOGICAL TIME IN SRI LANKA

	Groups of Strata (Eras of Time)	*Systems of Strata (Periods of Time)*	*Sri Lanka*
	Quaternary	**Recent**	Alluvial deposits; coral and shell beds; Laterite; gem gravels; beach mineral sands.
		Pleistocene	Red Earths Gravels and Laterites
	Cainozoic (Tertiary)	**Pliocene**	Absent
		Miocene	Jaffna limestones
		Oligocene	Absent
		Eocene	Absent
	Mesozoic (Secondary)	**Cretaceous**	Absent
		Jurassic	Tabbowa beds - grits, shales, arkoses.
		Triassic	Absent
Primary	**Newer Palaeozoic**	**Permian**	Absent
		Carboniferous	Absent
		Devonian	Absent
	Older Palaeozoic	**Silurian**	Absent
		Ordovician	Absent
		Cambrian	Absent
Precambrian	**Proterozoic**		**Highland Series South-Western Group Vijayan Series**
	Eozoic		

Chapter II

NATURE AND CLASSIFICATION OF ROCKS

Igneous Rocks

All rocks are aggregates of minerals - there are the essential minerals which help to classify and identify rocks; there are other minerals - the accessory minerals - present in very minor amounts and whose presence or absence does not affect the nature and classification of the rock type. Some rocks are formed from molten material within the earth's crust. This molten material is referred to as "magma" or as "rock magma". The magma consists of a complex mixture of oxides of various elements with various fluids, gases and water. Rocks formed in this manner by crystallisation, or at least by solidification, of molten material are known as *igneous rocks.* For instance, the lava flows of Vesuvius which are well known to most students are examples of igneous rocks, but greater than the lava flows are other rock masses which have crystallised from molten material but which have not reached the surface and cooled more slowly at various levels within the crust of the earth; examples of these are the granites. Magmas vary in composition and thus give rise to different types of rocks on solidification.

Granites are igneous rocks and as they contain much free or un-combined silica, they are classed as acid igneous rocks. Generally speaking, they are light in colour and light in weight with specific gravity around 2.7. On the other hand, the magma may be deficient in silica and such a magma may give rise to a rock known as a gabbro. Gabbros are also igneous rocks but although they contain silica in combination with other elements, there was not enough silica in the magma from which it originated for any of it to crystallise out as free silica, unlike in the granite. Gabbro is thus an example of a basic igneous rock; it is dark in colour and heavy with a specific gravity around 3.0. And in between the acid and basic rocks are a whole range of intermediate igneous rock types. Magma can thus be considered as the raw material from which all varieties of igneous rocks are formed, whether they are intruded into the earth's crust or poured out on the surface such as lavas.

As we have seen, igneous rocks can be classified on the basis of chemical composition; they can also be classified on their mode of occurrence. Those rocks which occur in large masses and which have cooled slowly at great depths have certain physical characteristics in common regardless of their chemical composition. By virtue of their slow cooling, they are completely crystalline, coarse in texture with well grown crystals, and commonly of even grain. These are the deep-seated or *plutonic rocks*. There are other rock types which result from the chilling of magmas poured out on the earth's surface; these are the *eruptive or volcanic rocks.* Lavas are examples of igneous rocks formed from magmas which are poured out on the surface of the earth from volcanoes.

While the type of rock depends largely on the composition of the magma, the physical conditions under which the magma cools also play an important role in determining the nature and the type of rock. For instance, high viscosity impedes molecular movement and tends to form innumerable small crystals instead of fewer and large ones. The viscosity depends to a large extent on the presence of fluxes - principally water and volatiles in the magma. An acid magma poured out on the surface of the earth cools rapidly and loses its volatiles and under such conditions a very fine grained rock, or even a glass, will result.

Due to the escape of gases and other volatiles, the lavas may also show a vesicular structure or contain cavities. Pumice stone, which is often washed up from the sea on the beaches of the north-east coast of the Island, is essentially a natural glass sponge. The sudden cooling and the escape of the gases has resulted in a glass with a spongy texture. But the very same magma crystallising at depth under a thick mantle of rocks will cool slowly allowing time for the formation of crystals, and the resulting rock will be coarse grained and thoroughly crystalline.

On the basis of the mode of origin, we have recognised two broad categories of igneous rocks - the deep seated or plutonic rocks such as granites and gabbros; and the eruptive or volcanic rocks such as lavas, each with its own distinctive characteristics. There is yet a third group intermediate between these two in its mode of origin. These are the "*hypabyssal*" *rocks*. Major intrusions such as granites often branch off and cut across pre-existing rocks; or they may spread laterally as sheets conformable with the pre-existing rocks along bedding planes. The cross-cutting types are known as dyke rocks and the sheet-like rocks as sills. They are all minor intrusions and like the other two great categories, they may be acid, intermediate or basic in composition. A generalised and simplified classification of igneous rocks is furnished in Table III.

The process of crystallisation of the magma results in an increasing concentration of volatiles in the residual magma, principally water and gases such as chlorine, fluorine and compounds of sulphur, phosphorus, boron and others. They have an effect on the crystallisation of the residual magma by greatly reducing its viscosity and thus promoting active crystal growth, while they also act as mineralizers. The rocks which form from this residual magma enriched in volatiles are thoroughly crystalline and very coarse grained and are called *pegmatites*. They occur as veins, dykes and irregular masses accompanying large intrusive masses. Besides the volatiles, the residual magma is enriched in certain rare elements such as tin, tungsten, tantalum, zircon, lithium, beryllium, molybdenum and many others, and these combine with other elements to form minerals of economic value. Thus pegmatites are essentially coarsely crystalline rocks, often carrying

TABLE III

CLASSIFICATION OF IGNEOUS ROCKS (SIMPLIFIED)

		Acid	*Intermediate*	*Basic*	*Ultra-basic*
		Alkaline	Calcic		
SiO_2	75 — 65%	65 —	55%	55 — 45%	45 — 35%
VOLCANIC	Rhyolite Obsidian Pumice	Trachyte Phonolite	Andesite	Basalt	
HYPABYSSAL	Micro-granite Quartz porphyry	Porphyry	Porphyrite	Dolerite	
PLUTONIC	Granite	Syenite	Diorite	Gabbro	Peridotite Serpentinite
PRINCIPAL MINERAL CONSTITUENTS	Quartz Orthoclase Felspar Muscovite Biotite Hornblende	Othoclase felspar Plagioclase felspar Biotite Hornblende	Plagioclase felspar Hornblende Augite	Plagioclase felspar Hornblende Augite Olivine	Augite Olivine Iron-ores.

minerals of economic value. The commonest of this type of rocks are the granite pegmatites which consist essentially of quartz and felspar but include accessory minerals such as muscovite mica, fluorite, topaz, beryl, cassiterite, tourmaline, spodumene, ilmenite and many others, and may be a source of one or more of these minerals and hence of economic importance. However, there are large masses of pegmatites which contain little else but quartz and felspar. Basic pegmatites are not common.

Sedimentary Rocks

The surface of the land is undergoing a constant process of change and destruction. Every shower of rain carries with it loose material and in times of flood the carrying capacity of streams and rivers is increased several fold and they turn turbid due to the amount of solid matter which they carry in suspension. In desert regions, an unfailing supply of sand is constantly whirled around by the wind; this acts as a sand blast and results in the wearing down of the rocks exposed to the blast. The general effect of the sand blast is to produce a conspicuous rounding and polishing of the surfaces exposed to it. In temperate regions frost action is dominant in winter. In cold climates or in mountainous regions above the snow-line, snow is consolidated into ice and moves as an ice stream or glacier. Moving ice can be a powerful agent of erosion. Moving ice carries with it a veritable cargo of rock fragments of varying sizes and shapes and other rock debris which act as powerful

tools of mechanical weathering. In such regions, the chemical factor in weathering is in abeyance but the mechanical agents are of great importance. Rocks of varying degrees of hardness are ground down to a more or less uniform plane or curved surfaces. Entire surfaces exhibit rounding, well marked striations and polishing except in the highest peaks where these effects are obliterated by frost action.

All these changes are included in the general term weathering and weathering includes all processes which result in the disintegration and decay of rocks. Weathering consists of a two-fold process—mechanical disintegration and chemical decay. Mechanical weathering is mainly due to the development or release of local stress resulting in strains and cracks not only in the rock masses as a whole but in the constituent mineral grains. Such strains are brought about by sudden or extreme variations of temperature, dampness or extreme dry conditions, and in temperate climates by the action of frost and ice. Chemical weathering includes all changes brought about by water and atmospheric agencies. Felspars (alkali-alumino-silicates) and ferro-magnesian minerals all undergo alteration. Some of the original constituents go into solution and may be removed, while some remain in a hydrated or oxidised state.

The loose products of the disintegration are transported by water, by streams, rivers and ice, and by wave action and deposited in lakes or other bodies of water or in the sea. With the passage of time, the products undergo compaction and consolidation, or they may undergo cementation, and are converted into rocks. These are the *sedimentary rocks* and examples of these are sandstones, grits, marls, shales and limestones. They form the greater part of the visible portion of the earth's crust and although they have varied origins they have some important characteristics in common. Since they are laid down in bodies of water over large areas, they are more or less horizontal in their original state. They show bedding or stratification and occur in regular layers one upon another and it is this stratification which provides the basis for the interpretation of the relative ages of rocks. These sedimentary rocks also contain the skeletal remains of plant and marine animal life which once inhabited the earth; these are known as fossils.

Among the great group of sedimentary rocks, three principal types can be recognised; fragmental or clastic rocks; organic and chemical. As the name implies, fragmental or clastic rocks consist of fragments of pre-existing rocks, igneous, metamorphic or even sedimentary, usually with grains of chemically resistant minerals such as quartz, ilmenite, rutile, sillimanite, staurolite, zircon and others. These fragments and grains may be held together loosely or cemented. The cementing material may be clay, which itself is a product of chemical weathering, or it may be siliceous, calcareous or ferruginous cements. Special names are applied to the resulting rocks depending on the nature of the cement; thus we can have a calcareous sandstone or a ferruginous sandstone. Organic sediments are as varied as the clastic rocks and include all rocks consisting predominantly of the remains of plants or animals. Those of vegetable origin are usually carbonaceous, and include coal beds, peat and lignite, while limestones are the best examples of rocks composed of animal remains. Depending on the nature of the fauna, we have such limestones as coral limestones, crinoidal limestones and others. There are other types; for example siliceous types, the best example of which is the diatomaceous ooze, which has use as an abrasive. Finally, the third type (the chemical) include beds of rock-salt, anhydrite, gypsum, potash and magnesium salts, and nitrates and borates. These sedimentary deposits result from the precipitation of substances in solution in enclosed seas by evaporation or chemical interaction with other substances. One of the best examples of this type is the Stassfurt deposits in central Germany in geological formations of Permian age. Besides rock-salt, other principal products from this deposit include the chlorides and sulphates of potassium and magnesium.

Metamorphic Rocks

Minerals which constitute rock masses do not always remain in the identical condition in which they were originally formed. In other words, minerals do not exist under all possible physical conditions and each particular mineral has a more or less definite field of stability governed by a set of physical controls. The most important of these physical controls are temperature and pressure. Some minerals have a wide range of stability, others have a very limited range and any changes in temperature and pressure, or both, render such minerals unstable. Given time, a mineral which is not in harmony with its environment will be converted into a new mineral which is more suited to the changed conditions. This elementary principle is the basis underlying the phenomenon of metamorphism and this gives us our third great group of rocks - the *metamorphic rocks*. Rocks of all types - igneous, sedimentary, and even metamorphic rocks existing under a given set of conditions of temperature and pressure come under a new set of physical conditions. Some of the component minerals are no longer stable in the new environment and give rise to a new assemblage of minerals suited to the changed conditions and a metamorphic rock results.

How are these changed conditions brought about? Temperature may rise as a result of deep burial; or it may rise due to the intrusion of a large plutonic mass of igneous rock. This results in an increase in temperature in its neighbourhood and the surrounding rocks are modified by heat; recrystallisation and other changes may take place, and this type of metamorphism is known as thermal or contact metamorphism. The other important physical condition is pressure; this may be of two kinds - uniform or hydrostatic pressure, and directed pressure or stress. Pressure varies at various levels in the earth's crust and changes in pressure can also result from deep burial. Stress is

of fundamental importance in metamorphism as among other things it controls the texture of the rocks. Stress metamorphism is developed in areas of mountain building where enormous pressures can arise. This type of metamorphism is referred to as regional or dynamic metamorphism and as the name "regional" implies, it affects va [illegible] ns, generally those subject to mountain building [illegible] ments, unlike in thermal metamorphism which is confined to the immediate neighbourhood of the igneous intrusion.

Thermal metamorphism produces compact, granular rocks, at times speckled rocks, commonly referred to as "hornfels". Where stress is active, the minerals re-arrange themselves more or less parallel with one another so that the stresses set up in their growth is equal to the external stress. Thus dynamic metamorphism gives rise to "foliated rocks". Such rocks are referred to as gneisses when they are coarse in grain and as schists when they are fine-grained. In all metamorphic rocks, and particularly in regions of intense dynamic metamorphism, high density minerals such as garnet, sillimanite, corundum and others are common. Apart from gneisses and schists, other examples of metamorphic rocks are slates, phyllites, quartzites and marbles (crystalline limestones).

We can look upon metamorphic rocks as systems constantly striving to adjust themselves to changes in the environment - an old assemblage of minerals or old structures giving place to a new mineral assemblage and new structures. Sometimes the old mineral assemblages and the old structures are not completely wiped out and relics of these may still be preserved, and if we can identify them and interpret them correctly, we can recount the changes which these rocks have undergone.

Chapter III

OUTLINE OF THE GEOLOGY OF SRI LANKA

The Island of Sri Lanka (Ceylon) with an area of 65 600 square kilometres (25 320 square miles) is essentially part of a "shield" area which includes Peninsular India. Since geologically remote times, the Island has neither been submerged by the sea resulting in the formation of newer strata, nor has it been subject to the violent upheavals which have led to the formation of the great mountain chains of the world such as the Himalayas. The main reason for this is that the Island along with Peninsular India is part of a segment of the earth's crust made up of an ancient crystalline complex sufficiently rigid to withstand crustal movements and thus has remained an inflexible land mass. The Island shares these characteristics with Peninsular India revealing a complete antithesis and a fundamentally different type of architecture to North India, which is built up of much younger sedimentary rocks, and which has been repeatedly submerged under the sea and subsequently elevated from the floor of the oceans to form land. The only major submergence of the Island was in Tertiary times when limestone sediments of Miocene age were deposited and subsequently elevated to form the north-western coastal belt of the Island, including the Jaffna peninsula, its off-shore islands and Mannar island.

The Island is a geologically recent fragment detached from the main South Indian peninsula, possessing a common geological structure and rock composition, which recent geological investigations have tended to emphasise. The Island shares this feature of ancient antiquity not only with Peninsular India but with other 'shield' areas of the world, such as the Canadian shield, parts of Siberia and Central Africa and parts of Australia which have remained impassive for geological ages. Amidst all the geological changes which have over and over again changed the face of the earth resulting in the redistribution of seas and lands, these shield areas have remained impassive, being only subject to limited vertical movements. The compressional mountain building movements so characteristic of geologically younger areas are absent.

PRECAMBRIAN

Over ninety per cent. of the surface area of the Island consists of rocks of Precambrian age (Archaean), the oldest rocks of the earth's crust, being the metamorphic derivatives of a very thick group of mixed sediments comprising mostly sandy, clayey and calcareous sediments. The only other geological formations represented in the Island are narrow belts of Jurassic sediments in faulted basins, strictly local in distribution in the north-west of the Island, in the neighbourhood of Puttalam; and a more widespread development of limestone formations of Miocene age, principally in the north-west coastal belt of the Island; and Pleistocene and Recent formations.

The Precambrian rocks are all completely crystalline, hard with great strength and low porosities. They are also compact with strongly interlocking grains, and though they give an impression of massive texture, most of these rocks show on closer examination a well marked parallelism of some of the constituent minerals. This is particularly true of the micas and this commonly gives the rocks a banded appearance. Banding is also often due to fine veinlets of granitic material at times coarser in texture than the surrounding ground mass.

The Precambrian rocks comprise a great group of metamorphosed sediments (meta-sediments) and include quartzites, quartz schists, fine to medium grained acid gneisses and granulites, calc gneisses and granulites, crystalline limestones (marbles) and dolomites, sillimanite gneisses, and sillimanite-garnet-graphite rocks. They are all well bedded, indicating their original sedimentary character. Associated with these are granites and granitic gneisses. Another characteristic of this ancient complex is the presence of certain types of minerals, such as ilmenite, zircon, sillimanite, rare-earth minerals, thorium minerals and a host of precious and semi-precious stones, chief of which is corundum. On the other hand, oil and gas, coal (except in Gondwana formations), gypsum and anhydrite, rock salt, potash and sulphur are very rare.

On the basis of lithology, structure and field relationships, the Precambrian has been divided into three major units (Cooray, 1978).

They are:-
1. The Highland Series.
2. The Vijayan Series; and
3. The South-Western Group.

Associated with these are igneous rocks represented by relatively small granitic bodies and their satellite pegmatites and several dolerite dykes.

The Highland Series

The rocks classed under the Highland Series are all high grade metamorphic rocks and make up the central highlands, extending as a broad band, sweeping from the south-west coast to the north-east coast of the Island in the Trincomalee area. Its eastern boundary is along the foot hills of the central highlands in the Uva and Central provinces. On its western side the boundary is ill defined. The Series comprise a great group of metamorphosed sediments and include massive quartzites, quartz schists, fine to medium grained acid gneisses and granulites, crystalline limestones and dolomites, calc gneisses and granulites, sillimanite gneisses and sillimanite-garnet-graphite schists, the last rock type having the name khondalite. They are all well bedded indicating their original sedimentary character and the rock types such as quartzites and crystalline limestones can be traced more or less continuously for many miles along their strike.

A striking feature of the Highland Series is the close and intimate association of the meta-sediments with dark rocks known as charnockites and charnockitic gneisses, a fact first pointed out by the author in 1948 and later amplified by Cooray in 1962. The charnockites occur inter-bedded with the meta-sediments with no intrusive or cross-cutting relationships. They possibly represent volcanics but whatever their original nature, the charnockites and charnockitic gneisses have been exposed to the same high grade metamorphic processes which transformed the original sediments into their metamorphic equivalents.

The Vijayan Series

Except for the area occupied by the South-Western group of rocks, on either side of the Highland Series are rocks of the Vijayan Series. They are widespread and well developed in the low lands which form the eastern and south-eastern sector of the Island, and to the north and north-west of the Highland Series. The main rock types include biotite gneisses, hornblende-biotite gneisses, and migmatites (mixed rocks), at times inter-layered and generally containing microcline felspar (Fernando, 1948 and Cooray 1967). To the north and north-west of the Highland Series, the Vijayan rocks consist dominantly of pale pink or buff coloured granitic gneisses and these are best developed in the triangle formed by Puttalam-Nikaweratiya-Anuradhapura. Minerals such as garnet, sillimanite and rutile so common in the Highland Series are rare, while charnockites prominent in the Highland Series and the South-Western group are generally absent. The rocks are intimately mixed and folded together and the structure differs greatly from that of the Highland Series. Whereas the Highland Series is characterised by a prominent north-east trend, the strike trends in the Vijayan are characteristically irregular, though at times oriented east-west. Not only are there east-west trends, but often complete closure of the strike with outward dips suggesting the existence of dome structures.

The South-Western Group

Although a precise division of the Highland Series is not possible at present, the South-western group extending from a little north of Colombo to Matara in the south consists of a group of gneisses, granulites and schists which are of sedimentary origin as in the Highland Series. But the group shows significant differences from the Highland Series of rocks. Scapolite-wollastonite-diopside gneisses and granulites and garnet-biotite-cordierite gneisses are found as narrow bands and ribs in this area. Quartzites though occasionally present as narrow bands are not prominent, while charnockites in the region are coarse grained, exhibit a granitic texture and show intrusive relationships. There are also structural and mineralogical differences and all these differences warrant their separation as a separate group.

Intrusive Rocks

Coomaraswamy (1904) gave the name "Balangoda Group" to zircon-bearing granites and pegmatites found in the Balangoda district. Similar zircon-bearing rocks have since been found at Loluwa, near

Mirigama. The Tonigala granite so called from the type area, Tonigala, about 20 kilometres south-east of Puttalam on the Puttalam-Kurunegala road, is a hornblende granite with pink orthoclase felspar and microcline felspar. It shows intrusive relationships to charnockites and other rock types and is widely distributed in the Precambrian of the north-west of the Island. Only isolated outcrops are found elsewhere. Other granites include a hornblende-bearing granite at Arangala on the coast in the Alutgama area and the pink Ambagaspitiya granite which is well developed in the Yakkala area and its neighbourhood in the Gampaha district. In addition to these granites, there are a number of dolerite dykes in the eastern half of the Island. The largest and best known of these dykes is the Kallodai dyke which can be traced for about 100 kilometres running in a north-west - south-east direction. Dolerite dykes have also been located at China Bay, near Trincomalee, and in the Elahera area. On the western side of the Island, a dolerite dyke has been recorded at Jorsigoda, near Alutgama.

Pegmatites are widely distributed in the Precambrian; they are mostly quartz-felspar pegmatites carrying dark mica. The quartz-felspar pegmatite at Rattota, which is quarried as a source of felspar for the ceramic industry, is known to carry small amounts of fluorspar which is a calcium fluoride (CaF_2). Allanite-bearing pegmatites are common and have been recorded from several localities, one of the best known being the allanite-bearing pegmatite at Owella estate, Matale North district.

The stratigraphic relationship between the three broad divisions of the Precambrian is a matter which has attracted the attention of most geologists but on which there is no unanimity. However, recent work by the Geological Survey has thrown some light on the controversial problem. The Seruwila copper-magnetite deposit is found at the margins of the Vijayan and the Highland Series. Further, several bodies of serpentinite have also been identified in close proximity to this boundary. The presence of serpentinites is some evidence of a tectonic feature, usually a thrust contact. Recently a gravity survey of the Island has indicated a significant gravity low of approximately 25 milligals, which more or less coincides with the the eastern boundary of the Highland Series and the Vijayan (Hatherton, Pattiaratchi and Ranasinghe - 1975). The geological interpretation of the gravity low tends to support the view that the contact between the Highland and the Vijayan is a thrust zone and that the anomalies are consistent with the overthrusting of the Highland Series over the Vijayan.

JURASSIC (TABBOWA SERIES)

The Jurassic or Tabbowa Series are shallow water, non-marine sediments first described by Wayland in 1925 and named after the locality where the outcrops were first discovered. The beds occupy a small basin a few square kilometres in extent to the north and north-west of Tabbowa tank, a few kilometres east of Puttalam, and consist of loosely consolidated grits and argillaceous sandstones overlain by shale beds with inconstant bands of nodular limestones. These in turn are capped by massive grits and sandstones sufficiently resistant to form minor surface features which are clearly evident on the Puttalam-Anuradhapura road. The shales and mudstones are full of plant impressions and spores and these have helped to establish the age of the Tabbowa beds as Upper Jurassic or Upper Gondwana, (Sitholey, 1944). Subsequently, similar rocks were discovered by the Geological Survey at Andigama, where on the basis of recent work, the Jurassic rocks in this locality are found to occupy an area of around 38 square kilometres (15 square miles). Still more recently, yet another basin of Jurassic rocks was discovered at Pallama, a few kilometres north-east of Chilaw. The geological formations encountered in both these localities include a rapidly alternating succession of sandstones, arkoses and dense carbonaceous shales.

The formations at both locations, Andigama and Pallama, were drilled by the Geological Survey to depths of around 460 metres (1 500 feet). The drill holes confirmed that the formations persist with monotonous regularity indicating cyclic conditions of sedimentation. The preservation of these sediments is due to down faulting of the rocks into the Pre-cambrian. Core samples of the carbonaceous shales were examined in the laboratories of the Geological Survey of India and have yielded spores, pollen and cuticles and other plant remains. The microflora suggest an age from Middle to Upper Jurassic (Upper Gondwana). Similar rocks have been found in India but no workable coal seams have been recorded from these horizons.

MIOCENE (JAFFNA LIMESTONES)

The Miocene is best developed in the Jaffna peninsula where limestone outcrops are prominent and have been termed the Jaffna limestones. They vary from a cellular material in places to a massive highly fossiliferous, hard, compact rock with a resemblance to chert. The limestones are capped by thin layers of residual red soil of the "terra rosa" type. The beds are more or less horizontal and show little or no signs of disturbance. The thickness of the limestone beds is not known but is probably of the order of several hundred metres. A bore hole drilled by the Irrigation department in the vicinity of Pallai in the peninsula is reported to have met "basement rock" at a depth of 212 metres (700 feet), but as the hole was non-coring it has not been possible to establish this with certainty. At the margins of the peninsula, the limestones are overlain by coral of Recent age.

The Miocene limestones of the peninsula extend southwards along the north-west coastal belt to Puttalam on the west coast. Near its southern end, the limestones are well exposed and form minor topographic features such as Kudremalai, 68 metres (225 feet) and Aruakalu hill, 79 metres (260 feet), immediately north of Puttalam. While they resemble the Jaffna limestones, the lithology varies from pure limestones to siliceous limestones and calcareous sandstones. Outcrops of Miocene are also well exposed in the Parappukkadantan and Adampan area on the mainland, near Mannar Island. Several holes were drilled in this locality for cement raw material and two of the holes encountered siltstones, arkoses and mudstones, strongly reminiscent of the Upper Gondwana rocks of the Tabbowa area, below the Miocene. Besides the limestones on the west coast, a small outlier of rocks of Miocene age occurs at Minihagalkanda on the south-east coast of the Island.

PLEISTOCENE AND RECENT

Resting on the Miocene formations and at times directly on the crystalline rocks at several localities in the Island are a variety of consolidated and unconsolidated material consisting largely of laterites, gravels, sands and clays. These deposits belong to the Quaternary system. Gravels of Pleistocene age were first discovered by Wayland (1919) when he recognised certain deposits lying on the surface of the Miocene as "plateau" deposits. The Pleistocene consists of two formations - an upper "Red Earth" and a lower gravel deposit. The two formations are fairly well defined though locally they appear to merge into one another both laterally and vertically. The Red Earth varies considerably in thickness in the Puttalam region, where the maximum observed thickness is around 36 meters (120 feet). The sands comprising the Red Earth are brick-red in colour and consist predominantly of heavily stained grains of quartz and some fine ferruginous clay. The sands also contain small amounts of heavy minerals such as ilmenite, zircon, monazite and other mineral species.

The gravels are mottled and show various shades of red and brown in a grey clayey matrix. The gravel which consists mainly of quartz of varying sizes, at times a few inches across, is cemented by oxides of iron and clay material. The gravels are not always present and their distribution is patchy. Where the gravels are absent, the Red Earth lies directly on the Miocene or the crystalline rocks. Laterite is a mottled deep red, yellow, or reddish brown ferruginous earth showing vesicular structure. It is extensively developed in the Colombo district and along the south-west coast extending down to Matara and Tangalle. Inland, it thins out and as the elevation increases passes into lateritic soils. Other deposits of Quarternary age include residual and alluvial deposits, coral and shell formations, lagoonal and estuarine deposits, peat deposits, gem-bearing gravels and beach sands.

Chapter IV

MINERAL EXPLORATION

Mineral exploration may be briefly defined as the effort to find new economic mineral deposits or ore-bodies with the minimum cost and in a minimum amount of time. Though occasionally mineral discoveries are made by amateurs as a result of fortuitous circumstances, it is true to say that by and large the great majority of mineral deposits are the result of systematic exploration based on sound geological reasoning. With the exception of unexplored regions in remote parts of the globe and with the extension of geological work in the period since World War II, the changes of finding out-cropping mineral deposits of importance grow less and less. At the same time there was a growing realisation that the classical methods of the old-time prospector, though still practised with some success, were slow and time-consuming and had to give place to more advanced techniques and methods. The need was not merely for the development of techniques which were quick but above all for methods of exploration, which provided the geologist with supplementary tools, which enabled the extension of geological knowledge to depths which were not directly visible to him.

The development of these techniques and their subsequent refinement has been made possible by the close and active collaboration of geologists, physicists, chemists and engineers and provides one of the finest examples of the beneficial results which arise by close collaboration between different scientific disciplines. These techniques could not have been developed without such collaboration and this gave birth to geophysics and geochemistry.

Geophysical Prospecting

Geophysical methods are by far the most important of the techniques used in mineral exploration and have been developed to a high degree of perfection. Briefly, the technique depends on the fact that an ore-body differs from the surrounding rocks not only geologically but in its physical properties as well. An essential condition for the use of geophysical methods is that the ore-body should have suitable physical characteristics which can be measured and which distinguish it from the surrounding environment. What geophysical prospecting does is to detect and measure differences in physical properties - whether they be differences in magnetism, electrical conductivity, gravity, or even radio-activity. It should be noted that it is not absolute values that are detected and measured, but rather the differences or contrasts in physical values and it is this contrast which is of importance. Geophysical methods tell us little or nothing about the composition of the ore-body, and further the ores of many metals, since they lack suitable physical characteristics, cannot be located by geophysical methods. Examples of these are the ores of gold, silver, tin, zinc, lead, mercury, vanadium and others.

Ground magnetic surveys are carried out by the use of sensitive instruments known as "magnetometers" which measure the natural magnetism; there are several types of magnetometers, and they provide detailed information about the location of sub-surface magnetic materials, such as magnetite, the magnetic oxide of iron; pyrrhotite, a magnetic iron sulphide often found with copper and nickel, and other weakly magnetic minerals. An extension of the method is the use of air-borne magnetometers. The first air-borne magnetometers were developed during World War II as a means of detecting submarines. Air-borne magnetic surveys, where a recording magnetometer is carried in a plane flying at low altitude, is an efficient way of investigating large geologically little known areas at relatively low cost. They are therefore an important reconnaissance tool. Such surveys are also useful in the preparation of sub-surface geological maps as they provide information on the probable types of rocks underlying the area. For instance, igneous and metamorphic rocks are generally more magnetic than sedimentary rocks, while limestones and sandstones are almost completely non-magnetic. Dark coloured basic rocks are generally most magnetic. Magnetic data can also help to locate buried geological structures and hence of much use in oil exploration.

Gravity exploration is the simplest of the natural field measurements used in mineral prospecting. Heavy, dense bodies in the earth's crust show slight but detectable distortions in the earth's gravitational field. These distortions known as anomalies are measured by gravity meters which are essentially

highly sensitive spring balances. Shallow dense bodies show up much better but smaller bodies are more difficult to detect. Deposits of heavy minerals such as chromite and hematite have been discovered by this method. Gravity surveys are widely used to locate potential oil-bearing structures such as domes or anticlines, but gravity meters are very expensive and such surveys are costly.

Of all the physical properties of minerals, their electrical characteristics vary the most widely from highly conducting materials such as copper minerals or native silver to strongly insulating materials such as ceramic minerals. In electrical methods of prospecting, differences in the electrical conductivity of rocks and their associated mineral deposits are measured but the method has limited use. In the "self potential" method, use is made of the fact that an ore-body itself produces minor currents which can be detected at the surface by repeatedly inserting a probe or probes into the ground at fixed distances and measuring the voltages on a sensitive potentiometer. The method is not widely used in mineral prospecting though it has been commonly used in correlating sub-surface zones in oil prospecting.

In seismic methods of exploration the speed with which artificially created "earthquake" waves travel through the sub-surface layers is measured. The velocity of the waves is closely related to the geology of the area and by careful interpretation of the results, it is possible to obtain a picture of the sub-surface geology and its structure. The technique, however, is not generally used in detecting metallic ores but is extensively used in exploration for oil and in engineering sub-surface investigations. There is also the resistivity method where the resistivity of the geological formations is measured. This is usually done by using four probes or electrodes, two of which put current into the ground while the other two are used to measure the resulting voltage. Most resistivity surveys, however, are carried out in the search for ground water or highly resistant bed-rock, rather than in the search for mineral deposits.

Probably in no phase of mineral exploration is there a wider range of technical equipment and methods than in the search for radio-active minerals. Radiometric methods of exploration depend on the fact the ores of thorium and uranium are radio-active and in the process of natural disintegration emit certain particles - alpha and beta particles - and gamma rays. While the particles are stopped by barriers such as metal barriers or other dense material, the gamma rays on the other hand are extremely penetrating and can be detected by the secondary effects of ionisation caused by the radiation. In all exploration for radio-active minerals, the principal tool is the field ratemeter, either a Geiger Muller counter or a scintillation ratemeter. Both instruments measure gamma radiation but in somewhat different ways. In the Geiger Muller counter the ionising radiations produce secondary electrons, whereas in the scintillation ratemeter the radiations produce scintillations in a phosphor which are amplified with the aid of a photo-multiplier. The latter is thus far more sensitive than the Geiger Muller counter. The instruments are small and light-weight, and generally designed to be portable. Air-borne systems are also available though these have to be used in low flying aircraft, preferably around 100 m (300 feet).

It is thus evident that there are many techniques available in the realm of geophysical exploration, and these are commonly utilised where soils, overburden or a mantle of other earth covering material conceal the presence of sub-surface deposits. The techniques include the measurement of magnetic, gravimetric, electric, electro-magnetic, resistivity and radiometric properties. As we have seen, they rely on contrasts in physical properties to assist in the exploration procedures. The methods do not rely on colour, crystalline form, or even chemical composition but on physical properties. The choice of the particular method depends on the physical and other properties of the mineral for which the exploration is to be undertaken. For instance, if the exploration is for iron ore, variations in the magnetic field are measured using a magnetometer. Likewise for the investigation of radio-active minerals, either a scintillation counter or a Geiger Muller counter is used. The actual interpretation of the geophysical results depends on the known geology and this is important for valid interpretation, and a combination of geological knowledge along with the geophysical results is much more useful in understanding the sub-surface conditions. For geologically unknown areas, regional geological surveys, chiefly using a magnetometer over a large area, are a most useful preliminary in an attempt at mineral resource evaluation.

Geochemical Exploration

The technique of geochemical exploration is based on the study of significant traces of metals dispersed in soils (overburden) around an ore-body; or in the waters draining from a mineralised zone; or even in the vegetation growing on soils enriched in a particular element. The weathering of an ore-body will introduce distinctive elements into the soils capping such ore-bodies, or into the streams draining from such areas, and analyses of these soils or waters will show anomalous concentrations of the principal metal or metals comprising the mineralised zone. Geochemical prospecting concerns itself, therefore, with the examination of soils and the soil cover, stream waters and stream sediments, circulating ground water as in springs and even plant material. The geochemist must consider the known geology of the area and the nature of the deposit he is seeking; the climatic characteristics of the area; the nature of the surrounding rocks and the manner of their weathering; and possible interference by human agencies. Many of us are familiar with the methods of the old-time prospector in his search for alluvial gold where the tiny particles of gold are washed down stream from the parent rock. The prospectors attempt to locate the source by tracing the particles of gold upstream. Geochemical prospecting uses much the same philosophy but extends it to a wider range of materials.

For reliable geochemical surveys, a very large number of samples are required, whether soils or water, and the reliability of the method increases with the density of the sampling. As the concentrations are usually very small, usually of the order of 100 parts or less of the particular element in a million, reliable analytical techniques, which at the same time are quick and simple, are required in view of the large number of samples involved. Some of the methods are simple enough to use in the field, while instrumental techniques are used in the laboratory to which the field samples are despatched. Geochemical surveys have, however, only limited value without some background geological knowledge. The best results are achieved where geological information is available but geochemical methods are also used widely for reconnaissance purposes.

Geophysical Surveys in Sri Lanka

An air-borne geophysical survey covering an area of approximately 23 300 square kilometres (9 000 square miles) was carried out by the Hunting Survey Corporation of Canada (formerly the Photographic Survey Corporation of Canada) in 1958/1959 under the Colombo Plan Technical Co-operation Scheme. The area covered by the survey comprised mainly the south-west sector of the Island and two geophysical quantities were measured simultaneously - the earth's total magnetic field and radiation due to radio-activity. The general flying height was 160 metres (500 feet) above the terrain and the flight direction north-south. The original line spacing was set at a quarter of a mile and subsequently changed to half mile spacing in order to obtain greater coverage; the change in the spacing took place along a line just east of Galle. Two long profiles of a reconnaissance nature were also flown - the first in an east-west direction from Puttalam in the West to Vandeloos Bay on the east coast and the second in a north-north east direction from Kankesanturai in the Jaffna peninsula to the neighbourhood of Vavuniya in the mainland. Each profile consisted of four lines with one mile spacing. The latter profile was designed to provide, if possible, information of the relationship of the Miocene sediments of the peninsula to the crystalline rocks of the mainland. The main objective of the air-borne survey was to delineate areas for detailed work on the ground.

As regards the measurement of the magnetic field, the summarising report on the air-borne survey listed all anomalies with a value over 400 gammas, and there were forty such anomalies. Although no large deposits of magnetic ore were indicated, the aero-magnetic maps provide a great deal of information of value to the geologist undertaking field work in the area covered by the survey. The only significant anomaly of potential importance was the one centred around Panirendawa in the Chilaw one inch topographical sheet, and this will be described in dealing with iron ores. Subsequently, ground magnetometer surveys were carried out in several areas covered by the air-borne survey. When a comparison is made of the magnetic contours from the air and ground surveys, important differences are evident in the shape and form of the contours. A striking feature is the irregular and jagged appearance of the ground survey contours in contrast to the smoothness of the contours from the aero-magnetic survey. There are many reasons for this. In the first place, the ground survey is much nearer the magnetic source and will record small anomalies with separate magnetic crests, whereas at greater heights from the air these tend to merge and disappear. The aero survey is also a continuous record, whereas the ground survey is made up of a large number of independent observations at stations separated from each other. Further, ground observations are influenced to a much greater extent by extraneous features such as fences, rail tracks, pipes and other metallic objects.

Core Drilling

The discovery of a mineral occurrence or prospect using available geological, geophysical and geochemical methods and techniques is only the initial step in a long sequence of events before the occurrence can be developed into a viable mine. To become an ore-body of importance which can be exploited economically, the prospect has to pass one critical test. Can the prospect be mined economically in the prevailing conditions and in the next decade or two? To provide an answer to this important question, the authority responsible for exploration, whether it be a Government agency or a mining company, has to spend large sums of money to prepare a detailed geological map of the area surrounding the prospect; to drill the orebody, to delineate its exact boundaries and to arrive at reliable estimates of tonnages; to collect samples for laboratory examination; to establish quality and grade and variations in grade, if any. The agency may even have to carry out pilot plant tests on the treatment and refining of the ore to ensure efficient recovery. Added to all this is the important need to investigate and establish markets for the mineral products.

Where the ground is relatively soft and the minerals occur at or near the surface, say within three to five metres, the simpler methods of pitting and trenching are adequate, but where the deposits occur at depth and in hard rock, drilling is required and this is done using a diamond drill. The essential features of a diamond drill include an engine which provides the power; the chuck in which the drill rods are firmly gripped while being rotated; either a screw or hydraulic feed which imparts the rotational speed to the line of drill rods; and the cat-head for lowering and hoisting the drill rods and the casing. The drill is usually mounted on skids which enables it to be moved under its own power over rough terrain. Though not a part of the drill proper, the most important piece of accessory equipment is the core barrel and the diamond bit at the end of the barrel. The core drill is, therefore, a power driven machine which uses an annular bit studded with diamonds to produce a solid core of the geological formations penetrated. The core barrel is a double walled tube with the diamond bit at one end. The rotary movement and the pressure imparted to the drill rods enables the bit to abrade a ring in the rock formations leaving a cylinder of rock which projects into the barrel.

The core is removed by hoisting the barrel and removing the bit at the end of each run. The core varies from 18 mm (three-fourths of an inch) to 150 mm (six inches) depending on the size of the drill bit. Cutting is by abrasion and in course of time the diamonds lose their cutting edges. When this happens, a new bit has to be used while the old bit is sent for reprocessing. There are other types of drilling such as percussion drilling which involves repeated blows to make a hole using a sharp solid bit. This system provides only dust and small fragments and has only limited use.

The cores from each drill hole are carefully examined and logged. Core drilling not only confirms the presence of the mineralised area but delineates its approximate boundaries, and provided there is an adequate density of drill holes strategically placed, it is possible to arrive at a three dimensional picture of the deposit and realistic estimate of the tonnages available. The cores are also examined mineralogically and chemically assayed to establish quality and grade of the ore and its physical characteristics. Samples for such studies must be prepared with care and uniform procedures adopted in order to ensure accuracy. Once a three-dimensional picture is constructed, the final step is a feasibility report as a prelude to investment and the development of a mine. Essential features of such a report should include ancillary matters such as accessibility, transportation, availability of power and water, housing, and even the availability of labour.

PART II

Chapter V

CLASSIFICATION OF ECONOMIC MINERALS

There are around 2 500 minerals but of these only about 120 or so are of use to man and thus of economic importance. Basically, minerals can be classified into three broad groups - metals, non-metals and energy minerals; the last group includes coal, oil and gas. Metals can be further sub-divided into -

(*a*) iron and ferro-alloy metals. The principal ferro-alloy metals include manganese, chromium and molybdenum;

(*b*) non-ferrous metals, such as copper, lead and zinc;

(*c*) light metals so-called because of their low specific gravity such as aluminium, magnesium and titanium; and

(*d*) noble or precious metals so-called because of their high value such as gold, silver and platinum.

The non-metallic minerals are commonly referred to as "industrial" minerals because of their widespread use in industry and in construction. They are a very varied group ranging from sand, stone and gravel to ceramic raw materials such as quartz, felspar and kaclin;

limestone, dolomite and magnesite; fertiliser minerals of phosphates, sulphur and potash, to such diverse minerals as graphite, mica, asbestos and diamond. The early belief that industrial minerals are cheap and relatively of less importance is no longer valid. Because of their widespread use, their aggregate volume and value exceeds that of metals. It is also possible to identify a rare metal group which includes minerals of cerium, lanthanum, niobium, tantalum, hafnium and many others.

There is no sanctity about the classification outlined in the previous paragraph and other classifications are possible. For instance, minerals can be classified according to their origin. Some minerals are known to be associated with igneous rocks; examples of these are beryllium minerals, mica, ilmenite and chromite; others with sedimentary rocks and examples of these are limestones and dolomites; and yet others with metamorphic rocks such as graphite, sillimanite and talc. Some minerals may be formed in more than one environment. For example, titanium is found associated with igneous rocks and also with detrital or sedimentary rocks. Likewise, diamond is another example of a mineral found in both igneous as well as sedimentary environment. This simple genetic classification (igneous, sedimentary and metamorphic) though useful does not include many important groups of minerals formed later than the host rock, such as vein-type and replacement deposits. Nor does it include many minerals formed as a result of weathering and chemical change such as the clays.

Minerals can also be classified broadly on the basis of their principal use; for example ceramic raw materials (felspar, quartz and kaolin); or abrasives (diamond, corundum and garnet); fertiliser minerals (apatite and rock phosphates); refractory minerals (sillimanite, zircon, and certain clays) and so on. It will thus be evident that several methods of classification are possible depending on the criteria used. Despite minor limitations, the type of classification based on genesis combined with the mode of occurrence and association of the minerals is perhaps the most satisfactory, and this will be adopted in the description of the Sri Lankan minerals that follows. For example, ilmenite and rutile (titanium minerals), zircon and baddeleyite (zirconium minerals), monazite (phosphate of the rare-earth metals), garnet (the non-gem variety) and sillimanite (aluminium silicate) are all treated under 'Heavy Mineral Sands' as all commercially important sources of these minerals in Sri Lanka are the heavy mineral sands. They have a common origin and are invariably associated with each other.

In the description of the economic minerals, the following arrangement is adopted in the pages that follow-

(*a*) iron and ferro-alloy metals;
(*b*) non-ferrous metals;
(*c*) energy minerals;
(*d*) industrial minerals, including construction materials;
(*e*) heavy mineral sands;
(*f*) clay and clay materials; and
(*g*) gems.

In group (*b*) the chief non-ferrous metals are copper, lead and zinc. The only known copper deposit (Seruwila) is a copper-magnetite prospect in which the copper minerals are associated with magnetite, and is, therefore, described under group (*a*). Economic deposits of lead and zinc minerals are at present unknown.

The crustal layers are not uniform and there are local concentrations of metals and minerals useful to man. These are the mineral occurrences and where the concentration is adequate to work them economically, they are then classed as ore deposits. The distribution of minerals in the world is very uneven and not on a pro rata basis with population, and no country however large is entirely self sufficient in its requirements of minerals.

Chapter VI

FERROUS AND FERRO ALLOY METALS

Iron Ores

Iron is perhaps the most indispensable of all metals and can be regarded as the basis of all modern industry. Iron ore is a very plentiful mineral commodity, and with the possible exception of coal, is the commonest ore deposit with world reserves adequate to meet world steel making needs for many, many decades. At the current consumption of approximately 800 million metric tons a year, the known reserves would last at least two hundred and fifty years. Historically, most of the iron ore production of the world has come from low grade deposits near the main steel producing areas of Western Europe and North America. Examples of these low grade ores are the Jurassic iron ores from the Cleveland Hills in the Yorkshire district of England; the "minettes" of Lorraine in France; and the Clinton ores in the Appalachian States of the United States of America. However, the discovery in the last three decades of large deposits of high grade iron ore in non-traditional sources such as Australia, Africa, Brazil and India have completely altered the pattern of the industry.

There was a close bond between local sources of raw materials for making iron and steel and industrial growth in the 19th. century and the early part of the 20th. century. The ready availability of the raw materials, iron ore and coal, was largely responsible for the location of industrial centres and a major factor in the development of industrial nations. But today, the availability of local raw materials has no longer the same importance. Bulk carriers with attendant low cost transportation have broadened the raw material source areas, and international trade in raw materials on a large scale for the steel industry is a striking feature of the present day. Japan is perhaps the best example of this modern trend. The third most important producer of steel in the world, she imports over 90 per cent of the iron ore from countries as distant as South America, Australia and India.

Although there is a long list of iron-bearing minerals, three minerals only are important sources of the metal. These are magnetite, the magnetic oxide of iron having the formula Fe_3O_4 with theoretically 72 per cent Fe; hematite, a reddish ore having the formula Fe_2O_3 and theoretically with 70 per cent. Fe; and limonite, the hydrated oxide of iron with the formula $Fe_2O_3 . 2H_2O$ and containing around 58 per cent. Fe. To this list may be added the mineral siderite, which is a carbonate of iron, with the formula $FeCO_3$, but economically of lesser importance.

The iron ore deposits of Sri Lanka fall into two broad categories -

(*a*) scattered deposits of hydrated iron oxides (principally limonite) occurring at or near the surface; and

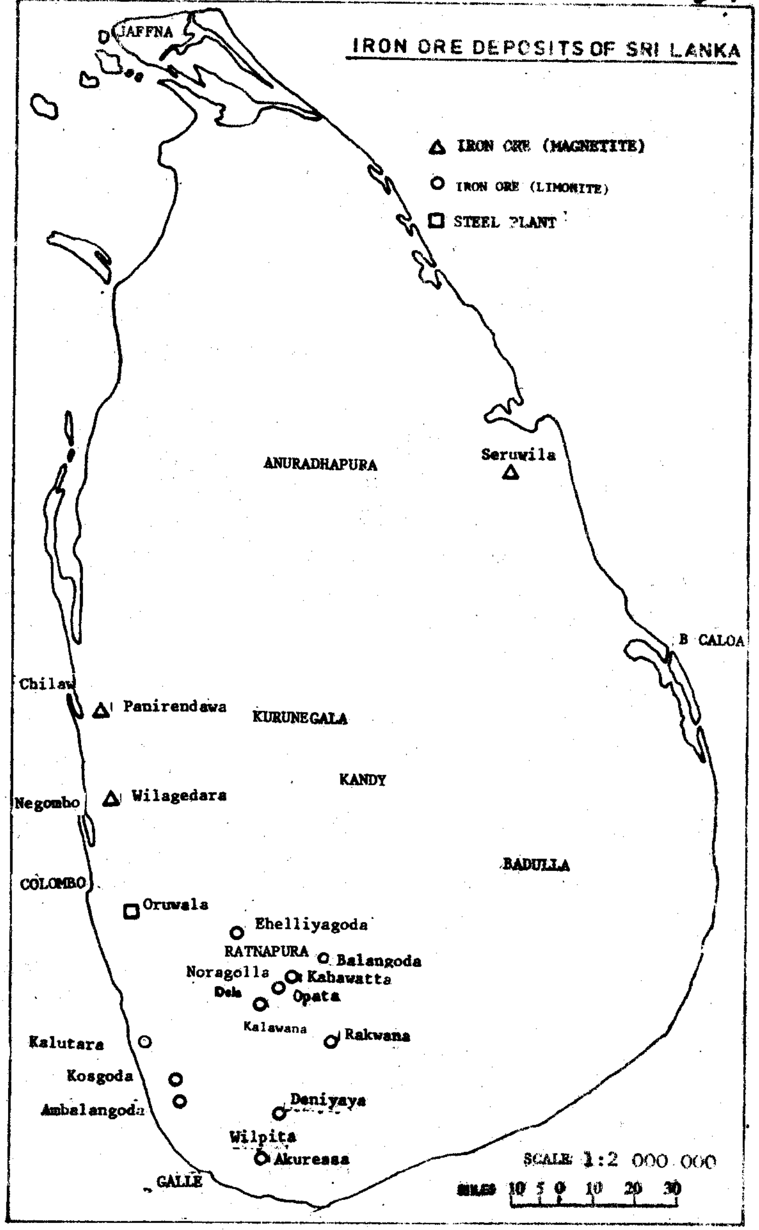
(*b*) magnetite deposits within iron formations in the Precambrian and occurring at some depth.

The Hydrated Iron Ore Deposits

The first type of deposit is concentrated mainly in the south-west sector of the Island, in the Western, Sabaragamuwa and Southern provinces with several deposits falling within the Ratnapura district. In all these cases the ore occurs largely as surface cappings and occasionally as embedded lenses or pockets. The cappings are not continuous but consist mainly of detached masses and boulders on the crests and slopes of small hills. The boulders and detached masses vary considerably in size, at times several feet across to small boulders only a few inches across. Generally the deposits have no extension in depth. Some forty to fifty deposits are known, principally in the Ratnapura district of the Sabaragamuwa province; the Galle and Matara districts of the Southern province; and the Kalutara district of the Western province (Fig. 1).

Individual deposits vary greatly in their estimated tonnages, from 10 000 tons to 150 000 tons. The density of distribution also varies, while in some there is a concentration of boulders, in others the boulders are sporadically distributed. Occasionally, very large masses are found, the best example being at Godakele, near Ambalangoda. The total reserves in all the deposits have been estimated at around 2.2 million tons. Some of the more important of the deposits are at Dela, Noragolla, Opata and Poronuwa in the Ratnapura district and Wilpita in the Galle district.

Fig. 1



The average iron content varies and is around 53 per cent. Fe. Besides these better grade ores consisting mainly of limonite, there are lower grade ores of the ferruginous lateritic type. These are markedly vesicular in appearance, have a lower specific gravity and contain clay and siliceous matter; the iron content in these is lower, generally from 30 to 42 per cent.

The Dela and Noragolla deposits were investigated by diamond drilling in 1958 and 1959 by the Geological Survey. The investigations revealed that there is no continuity of the ore bodies and no extensions in depth, and that they are in the nature of pockets and lenses with much barren ground in between. The mining of these limonite deposits does not present any major technical problems other than those arising from their scattered nature and the fact that most deposits are invariably in land supporting tea and and rubber in the Ratnapura district, and occasionally cinnamon cultivation in some of the deposits falling in the Galle district. The deposits are, however, too small and too scattered to be of any major economic significance.

Magnetite in Iron formations

In the second category are three deposits discovered in the past three decades by the Geological Survey by geological mapping and the application of geophysical methods followed by core drilling. The first of these is Wilagedera in the Chilaw district; the second at Panirendawa (1962) also in the Chilaw district; and the third at Seruwila (1971) in the Trincomalee district. The Wilagedera magnetite deposit discovered in 1959 is of interest as it was the first banded magnetite deposit discovered in Sri Lanka. Prior to this discovery only the hydrated iron oxide deposits of the south-west sector were known. Although the Wilagedara deposit is too small to have any economic significance, the occurrence is of considerable geological interest as the magnetite is associated with the mineral barytes (barium sulphate).

Panirendawa Magnetite Deposit

A second magnetite deposit of the Wilagedera type, that is a meta-sedimentary iron-formation in the Pre-cambrian complex, but on a much larger scale, was discovered at Panirendawa, five miles north-east of Madampe in the Chilaw district of the North-Western province. The iron-formations occur as thin intercalations in a succession of calc gneisses, quartzites, biotite gneisses and charnockites. The first systematic exploration of the area employing ground geophysics commenced in 1962 as part of the general ground follow-up work of the aero-magnetic anomalies revealed by the earlier air-borne geophysical survey of the south-west sector of the Island. This was later followed by diamond core drilling when twenty five holes were drilled with a total aggregate of 2 940 m drilled. The drilling showed that the iron-formation consists of bands of magnetite, which do not persist for any great distance, but pinch and swell in unpredictable fashion.

Because of structural deformation of the iron-bearing host rocks, the deposit is broken up into four separate blocks designated as A, B, C, and D (Fig. 2). Three of these (A, B and C) are small deposits, each

PANIRENDAWA IRON ORE DEPOSITS

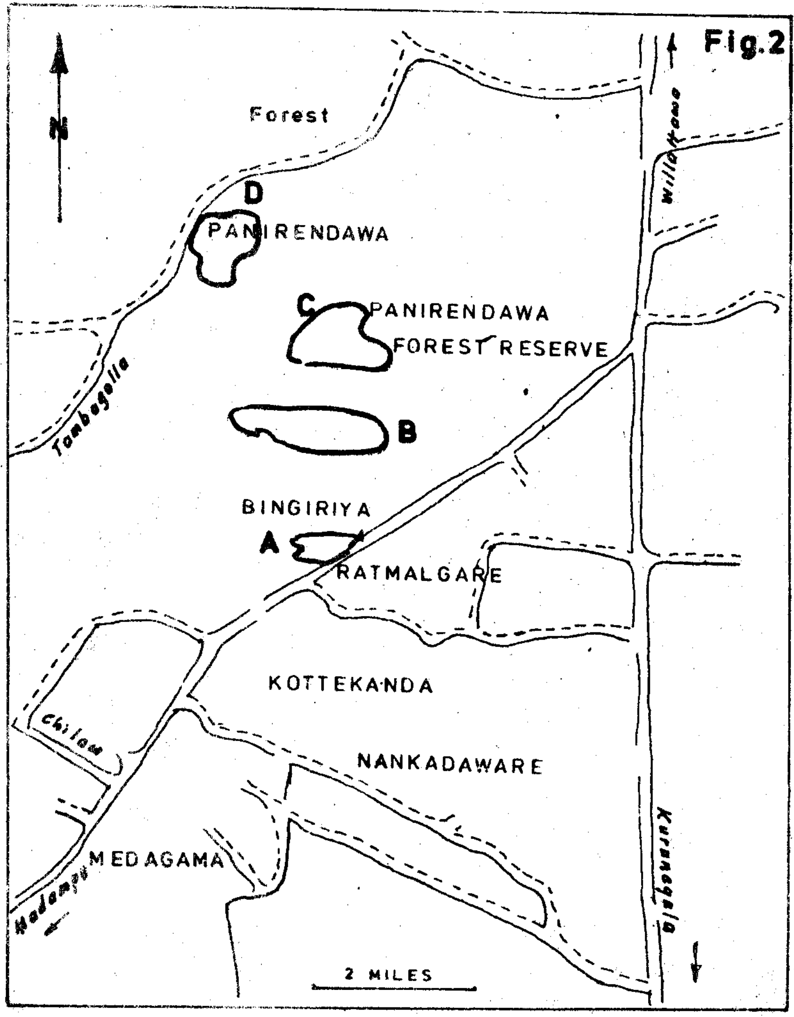


Fig.2

(After Herath, 1984)

with less than one million metric tons, whereas deposit D has a tonnage of over 3 000 000 m tons and has the best economic potential; the estimates are of tonnages up to a depth of 130 m. However, the deposit occurs at depths ranging from 30 m to 130 m. At such depths open cast mining methods cannot be applied and costly underground mining will be necessary. It is thus doubtful whether even deposit D can be mined economically. Table IV shows the tonnages of magnetite in the four structural blocks and analyses of the iron formation.

TABLE IV

ANALYSES AND TONNAGES OF IRON FORMATION - PANIRENDAWA

	A	*B*	*C*	*D*
Fe	52.10	48.20	53.50	51.10
SiO_2	17.90	19.20	18.0	19.80
MnO	0.50	0.43	0.85	0.39
TiO_2	Nil	Nil	Nil	Nil
Al_2O_3	4.90	5.29	4.78	7.41
CaO	1.88	0.74	0.22	0.08
MgO	1.30	0.72	0.64	0.30
S	0.31	0.39	Nil	Nil
P	0.033	0.039	0.069	0.057
Tonnage	981 980	981 328	852 530	3 537 421

Total Tonnage (A, B, C & D) 6 353 259

(After Kumarapeli (1964)

Geological Survey.

Seruwila Magnetite Deposit

The discovery of a deposit of iron ore with associated copper minerals at Seruwila, which falls near the boundary of the Trincomalee and Kathiraveli one inch topographical sheets, was made by the Geological Survey in 1971 during the systematic mapping of the north-east sector of the Island on the reconnaissance scale of 1: 63 360 (1 inch to 1 mile). Detailed mapping and ground magnetometer surveys of the mineralised area were undertaken in the following year and this was followed by a programme of core drilling a few years later. The area which is thickly forested is difficult of access and access during the investigations was from survey lines set out on a 20 m grid. The entire area is underlain by high grade metamorphic rocks of Pre-cambrian age. Charnockites and quartzites belonging to the Highland Series are the predominant rocks to the north-west of the area, while granites, granite gneisses and hornblende-biotite gneisses of the Vijayan Series are the predominant rock types to the south-east.

The drilling investigations revealed that the ore bodies containing magnetite and the sulphides of copper are lenticular in shape and concordant with the dip and strike of the host rocks; the lenses vary from one to ten metres in thickness. The host rock for the mineralisation is an ultra-basic rock with gabbroic affinities. The rock is highly weathered on the surface and contains secondary copper minerals. An account of the 'Geology and Tectonic setting of the Copper-Iron Ore Prospect at Seruwila' has been published by Jayawardena (1982). The author has categorised the mineralisation at Seruwila as follows -

(*a*) massive magnetite-sulphide ore;

(*b*) disseminated magnetite-sulphide ore; and

(*c*) trace mineralisation in the ultra-basic rock.

The massive magnetite-sulphide ore bodies vary in thickness from one to ten metres, are very coarse grained and contain magnetite, chalcopyrite (copper iron sulphide), pyrrhotite and pyrite. The disseminated ores are mainly composed of the same minerals while the gangue minerals include scapolite, tremolite, diopside and hornblende. The chalcopyrite is well developed in the massive ores unlike in the disseminated ore. From a careful study of the mineralisation and the associated rocks, Jayawardena is of the view that the ore mineralisation is along a deep seated thrust zone at the contact of the two major lithological divisions - the Highland Series and the Vijayan Series.

In view of the magnitude of the work involved, the Bureau de Recherches Geologique et Miniere (B. R. G. M.) of Paris was selected to assist the Geological Survey and to carry out further exploration work in 1979 on the basis of tenders; exploration work commenced in mid-1979. After a preliminary survey of the entirety of the Seruwila area and the work accomplished earlier, Arippu, a few miles south of Seruwila and at the south-eastern extremity of the Allai tank, was selected for further investigation and fifty holes were drilled in the area, the maximum depth being 120 m. Three million tons of ore with an average copper content of 1.06 per cent were proved in the area, while a further 1 200 000 tons of ore with a copper content of 0.32 per cent were proved in Kollankulam, north of Arippu. The ore assayed 41 per cent soluble iron. The total number of holes in the entire exploration programme was 76 with a total aggregate of 8 410 m drilled.

The estimates are up to a maximum depth of 120 m and it is possible that further ore reserves exist below this depth. But as in the case of the Panirendawa deposits, open cast mining is not feasible because of the depth of the ore bodies and underground mining will have to be adopted; this is not economically practicable with iron ores as they are a relatively low priced commodity. Secondly, the ore has to be crushed, milled and beneficiated and freed from copper before it can be used as a source of iron. As a source of copper, the deposits are far too small to justify their exploitation. Lastly, the ore is not in continuous bands or layers but as lenses which also involves high mining costs.

Although the proved iron ore deposits (Panirendawa and Seruwila) are of considerable geological interest, they are very small deposits by world standards. For instance, the Kiriburi deposits in the Bihar State in India have been estimated to contain over 300 million tons with an average grade of the lump ore of approximately 63 per cent. Fe after crushing and screening. To take another example, the Tom Price deposits in the Hamersley Range of Western Australia have been estimated to contain over 500 million tons of easily accessible ore averaging about 64 per cent. Fe. Many examples of this nature can be furnished from all over the world illustrating that the Sri Lankan deposits are very small, and their successful exploitation is a matter of great doubt. Major iron ore producers in the world are the Soviet Union, Australia, the United States, Brazil, Canada, the Peoples Republic of China, India and Sweden.

Ferro-alloy Metals

The chief ferro-alloy metals are manganese, chromium, molybdenum, vanadium, nickel and silicon; there are others but of minor importance. In most instances, ferro-alloy metals added to iron and steel are intended to provide special properties, such as increased strength or increased resistance to corrosion. A good example of this familiar to most students is chromium in stainless steel. Apart from titanium (ilmenite) and silicon (silica), which are abundant and described elsewhere in this volume, the ferro-alloy metals listed are not known to occur in the Island. Molybdenite, the sulphide of molybdenum, has been recorded from a few places in pegmatites as a very minor accessory mineral, while the discovery of a number of bodies of serpentinite raises hopes of the possibility of nickel. Generally speaking, the production of ferro-alloys requires large blocks of power and is a highly specialised industry in which the processes are largely trade secrets.

Chapter VII

ENERGY MINERALS

The so-called energy minerals are coal, oil and natural gas; they are the conventional fossil fuels and provide the greater part of the energy requirements of the world. Other types of non-mineral energy are wood, water power and solar energy. Of the energy minerals, coal out-ranked all the others but in the past four or five decades serious in-roads on the use of coal were made by petroleum. Coal is a mineral but is different from other minerals in that it is organic in origin. Coal can be loosely defined as a stratified rock formed from the accumulation and slow decay of vegetable matter, and it is universally accepted that all coal seams are derived from buried plant remains. Coal is abundant and widely distributed with economic and proved reserves put at 950 billion tons, while potential reserves are probably far in excess of this figure. It has been the back-bone of industrial life. Major world producers are the United States, the Soviet Union, the Peoples Republic of China, the United Kingdom, Poland, South Africa and Australia.

The great majority of coal beds of importance are found in the Carboniferous system in what are described as the Coal Measures, though some coal beds of lesser importance are found in later formations such as the Jurassic. During Carboniferous times there was a very heavy growth of plants, shrubs, ferns and other plants in swamps and bogs. The vegetation died and accumulated for geological ages and was compacted and gradually changed to peat, which is the first stage in the conversion of vegetable matter to coal. No coal deposits have been found in Sri Lanka, and as the Carboniferous system is totally absent, the chances of finding workable deposits of coal are extremely remote.

As regards oil, various theories of an inorganic origin were popular in the last century but all geologists and oil technologists are now agreed on an organic origin for oil. What is uncertain is the precise nature of the organisms which gave rise to the oil deposits. It is likely that both plants and animals have contributed their share. Microscopic plants such as algae and diatoms and other plant and animal remains, such as foraminifera and other marine animals, which were in great abundance in the oceans have contributed their share. Decay of the animal and plant remains, in an environment devoid of oxygen, has given rise to the production of hydrocarbons, and the rocks in which the oil is formed are known as "source" rocks. Due to compaction by the weight of the overlying sediments, the oil formed migrates and is stored in a porous rock such as a sandstone or a porous or cavernous limestone, and the rocks in which the oil is thus stored are known as "reservoir" rocks. Lastly, the oil formed would escape or disperse unless it is trapped by a geological structure sealed by what is termed a 'cap rock' such as an impervious bed of thick shale or clay. The simplest of all geological structures are anticlinal folds or domes. These essential requirements must be fully satisfied to result in an oil reservoir, and it is the function of geologists engaged in oil exploration to locate geological structures in potentially oil-bearing rocks.

Although oil is distributed in a number of geological formations belonging to the stratigraphical column (geological column), the most prolific horizons are formations belonging to the Tertiary. Other formations carrying economic deposits of oil are the Carboniferous and Cretaceous, and less frequently the Jurassic and Devonian. However, it is not the age of the geological formation that is of primary importance and oil fields depend on source rocks in large sedimentary basins with a great abundance of plant and animal life and the presence of suitable rocks into which the oil migrated and became entrapped. From this brief account, it will be evident that countries containing only rocks of Precambrian age have no possibility of discovering energy minerals such as oil and coal. The world's major oil producers are the Soviet Union, the United States, Saudi Arabia, Iran, Iraq, Venezuela, Kuwait and Nigeria, more or less in that order.

Peat

Investigations carried out by the Geological Survey in the early forties (at the time named the Department of Mineralogy) using manually operated augers proved a large deposit of peat in the Muthurajawela swamp, immediately south of the Negombo lagoon, and in its neighbourhood. Subsequently, in 1958/1959 a more detailed survey was undertaken. The swamp proper is bounded on the west by the Hamilton canal (constructed by the British) and on the east by the old canal (constructed by the Dutch). The peat deposits were then found to extend beyond the confines of the swamp proper in several areas towards Kelaniya and Hunupitiya. Such extensions form minor embayments in the high ground composed of laterite and lateritic earths to the east of the main swamp. The total area covered by the peat deposits is at least 34 square km (13 square miles) with an average thickness of about 4 m peat; the maximum recorded thickness in localised areas was seven metres. The total reserves have been estimated at around 55 to 60 million tons (on a wet basis) but the actual reserves are probably much larger.

The peat bed is not uniform and there are minor intercalations of peaty clays and sandy clays; the base of the peat bed is usually sand and augering was not done below this layer. The peat consists essentially of (a) shrub and tree group; (b) reed and sedge group; and (c) humus peat (Fernando, 1962). The shrub and tree group consists of material derived from the roots, trunks, branches and the bark of trees and shrubs, while the reed and sedge group consists of grasses and reeds and other swamp vegetation. Peat of this group is light, fibrous and has a matted appearance. The humus type is mainly in the form of a slurry with finely comminuted plant remains; it is localised in distribution and its origin is uncertain, and this type of peat is well developed in the Kudahakapola field which is an eastward extension of the main Muthurajawela swamp. As with most peats from other parts of the world, the water content is high varying from 80 to 90 per cent. The ash content of the peat varies from 10 to 32 per cent; the volatile matter from 45 - 55 per cent., and the fixed carbon from 20 to 33 per cent., all calculated on a dry basis. One of the interesting features is the high sulphur content, which varies from 3.0 to 5.5 per cent. The material is low grade and the peat bed is not of uniform character, but in a situation where fossil fuels are unknown, the peat may have some potential value. Its use, however, will need further field and laboratory investigations.

One of the problems with peat is the very high moisture content (80 - 90 per cent.). Preliminary trials carried out by the author have shown that the moisture content can be reduced to 10 - 15 per cent. by sun drying in 48 to 100 hours; the wide variation in the drying time is undoubtedly due to the weather patterns - cloud, wind velocity etc. For the purpose of these trials, the peat was cut into blocks of the size of standard building bricks.

Uranium and Thorium

Uranium, the most important source element of atomic fuel, is found in the earth's crust at an average of 0.0003 per cent. or in other words three grams of uranium per ton of rock. Locally, it occurs in concentrations of sufficiently high grade to permit economical extraction and these are the ore deposits. The principal ore mineral is uraninite, the oxide of uranium, which is crystalline. Pitchblende is the amorphous variety of uranium oxide. Along with a few lesser known minerals, uraninite (or pitchblende) is a primary ore of uranium. There are a number of other uranium ores - carnotite, torbenite, autunite and these are all secondary minerals derived from the breakdown of the primary ore minerals, or formed by the precipitation of uranium bearing solutions. While the primary ores of uranium are quite inconspicuous in appearance, shades of black or dark grey, the secondary minerals display spectacular colours, in bright yellows, green and orange. Some of the most beautiful uranium minerals have come from the Shinkolobwe mine in Zaire (former Belgian Congo). The latter type of mineralisation, the secondary mineralisation, is more widespread than the primary ore mineralisation, and occurs largely in sandstones, shales and conglomerates. A good example of this is carnotite (potassium uranium vanadate, bright yellow in colour) which is found in the Jurassic sandstones of Colorado and Utah, and at one time an important source of uranium.

Uranium minerals have not been identified so far in Sri Lanka. In 1979, the Geological Survey with assistance from the International Atomic Energy Agency (IAEA) carried out a stream sediment survey to identify uranium mineralisation, and a number of areas have been demarcated for more detailed surveys following this preliminary reconnaissance survey. One of the areas earmarked for further exploration is the Galgamuwa area, where sandstones, shales and arkoses are known to occur. On the other hand, it is well known that Sri Lanka is a thorium province, the principal thorium-bearing mineral being the common monazite, which is described elsewhere under 'Heavy Mineral Sands.'

Thorianite

The most important thorium-bearing mineral in the Island is monazite, which is widely distributed, but this will be dealt with in the chapter on 'heavy mineral sands'. The other important mineral is thorianite. In 1903, Holland obtained from the streams of the Bambarabotuwa area in the southern slopes of the Peak Wilderness quantities of a heavy black mineral, some of which showed good cubic outline. The material was analysed in the Imperial Institute, London, and was found to be a new mineral, hitherto unrecorded, consisting mainly of thoria (ThO_2) with small amounts of uranium oxide (U_3O_8). The new mineral was named thorianite by Professor Dunstan, then Director of the Institute. Later investigations by the Mineral Survey in the early years of the century proved the presence of the mineral in several localities, and the deposits attracted considerable attention at the time. The more promising of the deposits were worked on a small scale and nine tons of the mineral were exported in the period 1904 - 1908, but the deposits were soon exhausted.

Later work by the Geological Survey in the early fifties proved the presence of the mineral in small amounts, in areas worked earlier as well as new areas. Small amounts of the mineral, similar in appearance to the thorianite from Bambarabotuwa are found in the Rada ela and the Denawaka ganga in the neighbourhood of Pelmadulla, the mineral occurring in patches where the heavy residues from earlier gemming operations were probably discarded. The thorianite is remarkably fresh and shows no rounding indicating that the mineral has not travelled far from its source. The Mineral Survey had also found the mineral at Maddegama, not far from Hiniduma in the Southern province, where it occurs in a pegmatite. The occurrence was worked on a small scale but the results were disappointing and the site was abandoned. A re-examination of the area by the Geological Survey proved small amounts of the unworked mineral, and a new occurrence was found at Bopagoda, about two miles from Maddegama. At this latter place, the mineral occurs on a hill slope and in the talus accumulation at the foot of the hill. As in the case of the other localities, the thorianite is fresh and shows good crystal form. The mineral was also recorded from Mitipola, near Eheliyagoda. Unlike in other areas, the Mitipola thorianite is sub-angular and heavily stained with iron oxides.

The specific gravity of the pure mineral varies from about 8.9 to 9.4, and has a dull or sub-metallic lustre. Penetration twins are not uncommon. On the whole, the deposits are small and low grade. A representative sample of thorianite from the Ratnapura district

on analysis gave the following result - ThO_2 62.6 per cent. and U_3O_8 28.52 per cent. Thorianites from different localities show varying proportions of thoria and urania, and in general the urania content varies from about 11 to 35 per cent. Some thorianite from Mitipola assayed 33 per cent. U_3O_8. Yet another thorium mineral is thorite - thorium silicate having the formula $ThSiO_4$; it has been recorded occasionally from the gravels of the Ratnapura district. Analyses of thorianite and thorite are shown in Table V.

TABLE V

ANALYSES OF THORIANITE AND THORITE

Constituents	*Thorianite* (*Kondurugala*)	*Thorite* (*Kondurugala*)
ThO_2	76.22	66.26
Ce_2O_3	8.04	7.18
La_2O_3		
ZrO_2	Traces	2.23
UO_3	12.33	0.46
Fe_2O_3	0.35	1.71
PbO	2.87	
SiO_2	0.12	14.10
CaO		0.35
P_2O_5		1.20
H_2O		6.40

Imperial Institute,
London.

The pilot plant studies carried out on seasonal concentrates of heavy mineral sands formed on the west coast have shown the presence of minor amounts of fine grained thorianite in the sands of Kaikawela, near Induruwa, and at Polkotuwa, near Beruwela. The Kaikawela thorianite assayed 66.5 per cent ThO_2 and 23.3 per cent. U_3O_8. All the available evidence indicates that the mineral is widely distributed though only in very minor amounts.

Chapter VIII

INDUSTRIAL MINERALS

Graphite

Graphite is the crystalline form of carbon; it is steel-grey to black in colour and characterised by its extreme softness and greasy touch. Its other unique characteristics include its high conductivity for heat and electricity; high refractoriness and its chemical inertness. The mineral is widely distributed in the Precambrian complex and the deposits fall into three main groups -

(*a*) graphite veins in the nature of fissure infillings;

(*b*) disseminated deposits in which the mineral occurs as small flakes and scales in a variety of crystalline rocks; and

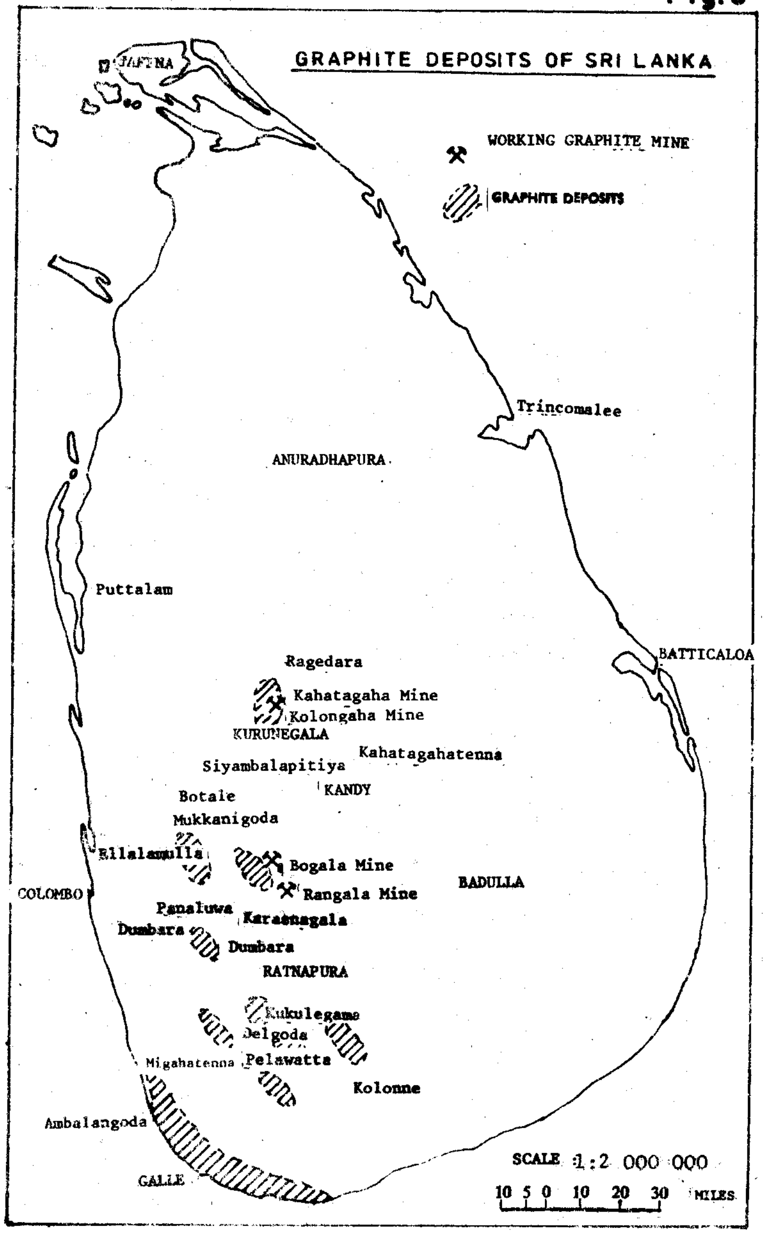
(*c*) in pegmatites and quartz veins where the mineral is sporadically distributed.

Mining is confined to the vein-type deposits which occur as fissure infillings in the metamorphic rocks of the Precambrian. The deposits occur in swarms of veins within narrow zones in structurally weak rocks such as the cores of anticlinal structures (domes) where fractures are common. The veins are generally well defined with sharp contacts with the country rock. Banded structure is common in the veins and they are characterised by a high degree of purity often consisting almost exclusively of graphite. Where other minerals are associated with the graphite, they include mainly quartz, calcite and pyrite. The veins vary greatly in thickness, from a few centimetres to a metre and more; at times, they enlarge into lenticular masses and pockets three to four metres in width.

The graphite veins are usually steeply dipping involving underground mining in hard rock with consequent high costs. They normally follow a structural pattern, and although the directions of the veins are variable in any given area, the major veins tend to have one or two identifiable directions. East-west trending graphite veins are common with off-shoots following joint planes and minor fractures in the host rocks. The deposits are mainly concentrated in anticlinal folds with a more or less north-south direction. The best known graphite occurrences are in the Western, North-Western, Sabaragamuwa and Southern provinces though minor occurrences are also found elswhere in the Central and North-Central provinces (Fig. 3).

The disseminated graphite occurs as small thin flakes and scales seldom over half a centimetre in diameter, and is found in a great variety of rocks such as crystalline limestones and dolomites, garnetiferous

Fig. 3



gneisses, acid gneisses and garnet-sillimanite gneisses and charnockites. The amount of graphite in these rocks is small and the disseminated deposits are not of economic importance. In pegmatites and quartz veins, the graphite flakes are usually larger and thicker but such occurrences are comparatively rare, one of the best known being the occurrence at Pussella, near Kegalle, where the mineral is found in a pegmatite associated with apatite.

The graphite industry which was entirely in the hands of Sri Lankans was nationalised in 1971, and following the nationalisation, the State Graphite Corporation was established in 1971 under the State Industrial Corporations Act No. 49 of 1957. The Corporation took over the running of three large mines previously operated by the Private Sector - Bogala, Kahatagaha and Kolongaha - which formed the backbone of the industry. The three mines, with their traditional mining communities drawn from their neighbourhood, formed the nucleus of the new Corporation. The main objectives of the Corporation included, among others, the mining, refining and processing of graphite; the manufacture of products of industrial value from graphite; and the sale and export of the mineral and its products. Subsequently in 1979, the Corporation was re-named the 'State Mining and Mineral Development Corporation' with expanded functions including the mining, processing and marketing of mineral commodities other than gem stones and mineral sands.

With the establishment of the Corporation, the three mines, Kahatagaha, Kolongaha and Walakatahena, situated very close to each other in the Kurunegala district of the North-Western province, were grouped together into a single mine and renamed the Kahatagaha-Kolongaha mine. This resulted in an improvement of the ventilation of the mines and rationalisation of the mining operations. The Kahatagaha-Kolongaha mine works a large group of south dipping veins; their horizontal extension ranging from 20 to 150 m with an average of 60 m (182 feet), while their thickness varies from 0.23 m to 0.9 m. The Kahatagaha mine is the deepest mine in Sri Lanka, the deepest level being 610 m (2 000 feet). Access is by two shafts - the Kahatagaha shaft having a depth of 345 m (1 130 feet) and the Kolongaha shaft 101 m. (330 feet.) Below the shaft bottoms, access to the lower working is by a series of winzes. The average monthly production of the combined units is 300 m tons.

The Bogala mine is situated in the Kegalle district about 80 kilometres north-east of Colombo. The terrain of the mine is rugged and the mine elevation is about 170 m. The vein system consists of three major veins with several steeply dipping minor veins in high grade metamorphic rocks. The horizontal extension of the major veins varies from 130 m to 300 m with thicknesses varying from 0.28 to 0.98 m, and exceptionally in places to several metres. The deepest level is 375 m (1 230 feet) and access is by two shafts in series - the first from the surface to the 132 m (432 feet) level and the sub-shaft from this level to 311 m (1 020 ft). The average monthly production is 500 m tons.

The Rangala graphite deposit was discovered by the Geological Survey at Siyambalawela in the neighbourhood of Bogala in the early seventies and development at this locality was started by the State Graphite Corporation in 1973. There are four veins of high grade graphite and access is by a system of adits. The experimental mine produces a few tons monthly. The Corporation also commenced development operations in the abandoned mine at Ragedara, Melsiripura, in 1976. Access is by an adit and one major level has been established which encountered a dense network of steeply dipping veins, most of which are of little economic importance. A second level has been established about 22 m below adit level and this has intersected some productive veins. The Ragedara graphite was reputed for its very high degree of purity assaying almost 100 per cent carbon.

Graphite possesses several notable properties and its importance in industry is based on one or more of its inherent qualities, such as its extreme softness; its ability to withstand very high temperatures; its inertness to a large variety of chemical reagents, and its ability to mix with liquids. Graphite is unequalled for many refractory uses and an important use of graphite is in the manufacture of crucibles for melting non-ferrous metals. Finely pulverised graphite commonly mixed with grease or oil finds extensive use as a lubricant, while considerable quantities, usually not of high quality, are used in graphite paints for the protection of metal surfaces from corrosion. Other uses include foundry facings, carbon brushes, dry cell batteries pencils (one of its more familiar applications), graphite electrodes and other miscellaneous uses. Sri Lankan graphite is an indispensable ingredient in carbon brushes for electric motors and other strategic electrical equipment and no other variety can be substituted completely for the Sri Lankan material. Graphite is soluble in molten iron and one of its important uses is in steel-making for increasing the carbon content of the steel, though other forms of carbon are also used for this purpose.

Sri Lankan production of graphite is very small, amounting to only about two per cent. of world production which is in the region of 500 000 m tons per annum. Nevertheless, the Sri Lankan material is of importance because of its high quality and because there is no substitute for it for certain uses. Other important producers are Korea, Mexico, Malagasy and Germany. Though all graphite is crystalline, the Trade recognises two broad varieties - 'crystalline graphite' or 'flake graphite' and 'amorphous graphite' - the term amorphous being applied to the crypto-crystalline variety in which the crystals cannot be recognised by the naked eye. While graphite from Sri Lanka and Malagasy are described as crystalline, the Korean and Mexican production is largely amorphous.

Almost the entire production of graphite is exported and the quantity used locally in small scale industry is negligible varying from 159 to 300 m. tons per annum. The local use is confined to the manufacture of dry cell batteries, pencils and in foundry use. Figures of production and exports are furnished in Table VI.

TABLE VI

PRODUCTION AND EXPORTS OF GRAPHITE
(1974 - 1983)
(In metric tons)

Year	*Production*	*Exports*
1974	10 261	9 622
1975	7 794	5 904
1976	7 964	7 893
1977	8 711	8 769
1978	10 675	11 163
1979	9 491	10 933
1980	7 124	6 566
1981	6 777	4 490
1982	8 257	3 024
1983	5 528	4 605

Authority: State Mining and Mineral Development Corporation.

The average price covering all grades works out at around Rs. 12 500 f.o.b., per m ton. The principal buyers are the United Kingdom, the United States of America and Japan.

Apart from gem mining, graphite mining is the oldest mining industry in Sri Lanka and the Island has long been known as a source of high quality graphite. The mineral has been mined for over one hundred and fifty years, enjoying a virtual monopoly in world markets in the latter part of the last century. The industry has passed through many vicissitudes with peak production coinciding with war years. For instance, the highest production ever recorded in the industry's long and chequered history was during the First World War, when in 1916 exports reached a figure of over 33 000 tons. Soon after, the demand fell sharply and the industry faced a serious crisis partly as a result of competition from Malagasy. Likewise in World War II when other sources of supply were lost, Sri Lanka was the main supplier of graphite to the Allied Nations and exports reached a peak of over 27 000 tons in 1941 and 1942 though the peak of the First World War was not reached. Apart from the three large mines, a large number of small mines, principally in the south-west sector, were worked with the favourable market created by the war. They were mostly shallow workings with a small production but with the end of World War II, nearly all of them closed down. A sharp fall in demand followed the end of the war, and the industry faced a crisis in the fifties and early sixties comparable with the depression of the early thirties.

To illustrate the vicissitudes the industry has passed through, the exports of the mineral for the period 1935 - 1946 are furnished in Table VII.

TABLE VII

EXPORTS OF GRAPHITE
(1935 - 1946)
(In long tons)

Year	*Exports*
1935	13 908
1936	13 514
1937	17 380
1938	11 782
1939	22 396
1940	23 819
1941	27 232
1942	27 734
1943	20 051
1944	12 264
1945	7 820
1946	8 032

Authority: Geological Survey.

Mica

The micas include a closely knit group of complex alumino-silicates with hydroxyl and other elements such as potassium, magnesium and ferrous iron; some rare varieties contain sodium and lithium, while part of the hydroxyl may be replaced by fluorine. The important varieties are —

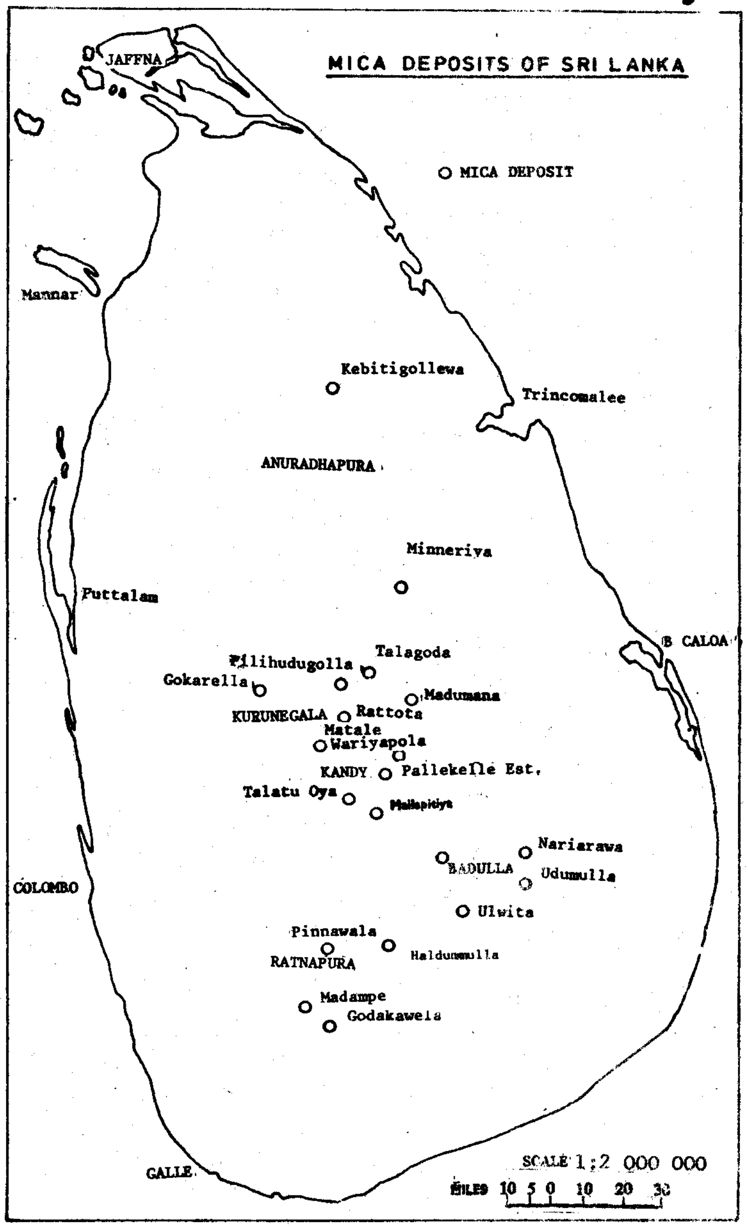
muscovite or white mica (potassium mica);
phlogopite or amber mica (magnesium mica);
biotite or black mica (ferro-magnesium mica); and
lepidolite (lithium mica).

Only muscovite and phlogopite have significant commercial value, and of the two, muscovite has by far the major importance. All micas are characterised by a perfect basal cleavage, which enables the mineral to be split into very thin sheets with a high degree of flexibility and elasticity, and by their pearly lustre. The micas generally occur in large crystals called "books", a good descriptive name for they can be cleaved into thin sheets in the manner of separating the pages of a book. The mineral occurs in pegmatites where they are commonly associated with quartz and felspar. Single books may attain large dimensions and muscovite plates ten feet in diameter have been found in India, while a single crystal found in North Carolina, U.S.A., is reported to have weighed almost two tons.

The chief type of mica found in the Island is phlogopite which is widely distributed in the Central, Sabaragamuwa and Uva provinces. The deposits are closely associated with rocks of the Highland Series, chiefly dolomites and dolomitic limestones, and occur along contacts of these rocks with pegmatites, or as irregular aggregates or vein-like masses in pyroxenites. The vein type deposits are inconstant and in the nature of pockets or lenses. Muscovite or white mica is rare in comparison, the best known locality being Pinnawela, near Balangoda; other muscovite-bearing pegmatites have been recorded from Mariarawa and Udumulla in the Passara district. Biotite or "black"mica has been recorded from a number of localities such as Kaikawela in the Matale district and from Polgolla in the Kurunegala district. Lepidolite, the lithium mica, pale lilac in colour, has been recorded from Kaikawela. In some pegmatites the mica may be segregated in zones more or less parallel to the walls of the pegmatite, while in others it is inter-mixed with other constituent minerals of the pegmatite.

In the past phlogopite mica has been mined from comparatively shallow workings at Naula, Wariyapola, Mailapitiya, Madumana, Talatu Oya, Pallekelle and Hanguranketa in the Central province; at Godakawela and Madampe in the Sabaragamuwa province; at Badulla, Haldumulla and Ulwita in the Uva province; and at Polgolla in the North-Western Province. In recent years there has been small scale mining for mica in the Kandy district, at Naula and Madugoda; and at Dutuwewa, near Kebitigollewa in the North-Central province. Small tonnages have been exported but the exports have been confined to scrap grades. (Fig.4)

Fig. 4



Mica has high di-electric strength and the ability to withstand high temperatures. It is, therefore, widely used in the electrical idustry for insulation and in electronic apparatus industries. Because of its heat resisting qualities, it is also used in the windows of furnaces, ovens and stoves, lamp chimneys and lamp shades. World production of mica can be divided into two main classifications - sheet mica and scrap or flake mica; the two types differ widely in their uses and in the form in which they are marketted. Books of mica of various shapes and sizes are cleaned of all adhering extraneous matter and then split into forms of suitable thickness, and flaws such as pin holes, cracks and inclusions removed. The edges of the resulting sheets are then trimmed using a sickle or knife to remove ragged and broken ends to facilitate further splitting for commercial use.

The mica sheets are then graded according to the area of the largest rectangle that can be cut from the sheet of mica, the larger the rectangle the higher the price. According to the Indian Standards, eight such grades are recognised - grade 7, the lowest with a rectangle under one square inch, and grade 1 with a rectangle area from 24 to 36 square inches. Grades in excess of 36 square inches are regarded as 'special grades' and fetch premium prices.

The mica industry in Sri Lanka dates back to the eighteen nineties when mining was carried out on a small scale in the Badulla district. During the Second World War mica mining was encouraged by the State and the Geological Survey (at that time known as the Department of Mineralogy) purchased mica on behalf of the Anglo-American Mica Mission based in India. Despite favourable prices and advice given by the Geological Survey on the mining and preparation of the mica for the market, the quantities offered were small, less than ten tons in the period 1942 - 1944 and confined to the lower grades. One reason for this was that the books of mica were badly flawed and warped, heavily stained and often contained inclusions, all of which make the mineral unsuitable for industrial use. However, mining was confined to shallow depths and with deeper mining it is likely that better grades of sheet mica could have been obtained.

India is the world's largest producer of muscovite mica from the State of Bihar and the Nellore district of Madras, and in the past has supplied some70 per cent. of the world total of sheet mica. The great amount of hand labour required in producing and preparing block mica for the market gives countries with low wages, such as India, a great competitive advantage over those with high wages. Brazil is also an important producer of muscovite, while Canada and Malagasy are important producers of phlogopite mica. Because of the sporadic nature of the mineral, mica deposits are notoriously unsatisfactory for mining purposes. Apart from the presence of pegmatites, which may or may not carry mica, there are few indications to help the exploration geologist in his search for deposits of the mineral.

The mica mined at Dotuwewa, near Kebitigollewa, is a vermiculite, and is probably an alteration product of phlogopite. A few hundred tons of this material have been exported in recent years principally to Japan. The mine had reached a depth of around 22 m when work was stopped due to a change in quality and the lack of demand. The United States is the world's largest producer of vermiculite.

Although there is a specific mineral called vermiculite, the name is applied commercially to a number of closely related minerals which are essentilly hydrated silicates of aluminium and magnesium and which have the property of exfoliation. When heated, the mineral loses water and expands into a cellular aggregate which is several times the original volume. The main use of vermiculite is as an insulating medium for thermal insulation of roofs, ceilings and walls. It is reported that a ton of vermiculite can cover an area of over 1 100 square feet up to a depth of three inches and provide thermal insulation equivalent to a five foot brick wall! In addition to its use for insulation for domestic and commercial structures, loose vermiculite is used for packing refrigerators, incubators, ovens, thermal jugs and in other industries and competes with cork and mineral wool. Mixed with Portland cement, it can be poured in place or pre-cast into light weight, fire-proof slabs for roofing and partitioning walls.

LIMESTONE

Geologically the term limestone is applied to rocks of sedimentary origin which consist predominantly of calcium carbonate ($CaCO_3$). The theoretical composition of a pure limestone is - 56.1 per cent. CaO

and 43.9 per cent. CO_2. In actual practice the limestones contain various impurities such as silica, oxides of iron, alumina, magnesia and clay material. Thus we can have siliceous limestones, ferruginous limestones and other types depending on the nature of the main impurity. The great majority of limestones are of organic origin being composed for the most part of the altered remains of animals and plants which possess a calcareous shell or skeleton. Limestones display great variations in composition, appearance, colour, texture and porosity. Crystalline limestones or marbles are limestones in which the carbonate minerals have crystallised under heat into a dense crystalline form, while 'Chalk' is an extremely fine grained material consisting essentially of micro-organisms of marine origin.

The limestone deposits of the Island fall into three broad categories -

(*a*) sedimentary limestones of Miocene age;

(*b*) crystalline limestones (marbles) of Precambrian age; and

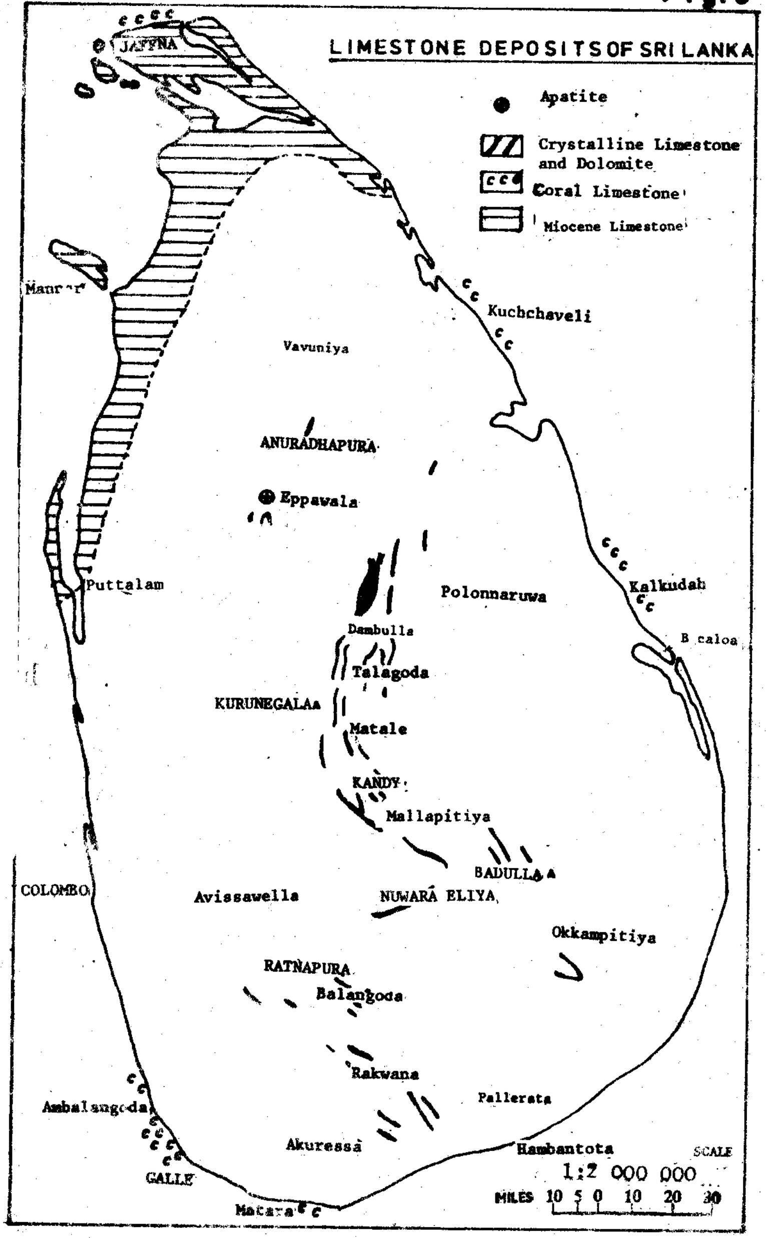
(*c*) coral limestones mainly in coastal areas and of Recent age.

The sedimentary limestones of Miocene age are best developed in the Jaffna peninsula, where they occur as hard, compact rocks with a $CaCO_3$ content of well over 95 per cent. These same limestones extend along the north-west coastal belt to Puttalam on the west coast. North of Puttalam they form a low series of hills running roughly in a north-south direction from Aruakalu hill in the south to Kudremalai in the north. The limestones in this region are interbedded with siliceous limestones (Fig. 5).

The crystalline limestones or marbles are prominent members of the Highland Series of rocks and are closely associated with quartzites and other rock types of the Highland Series. They occur as well defined bands which can be traced for many miles along the strike, though at times they are discontinuous. Most of these crystalline limestones carry varying amounts of magnesia (MgO) and they range from pure limestones through dolomitic limestones to true dolomites; the magnesian varieties are more abundant. Often the marbles are impure due to the presence of various silicate minerals. At times the silicate minerals are found in layers and this gives the marbles a banded appearance. Where they are free from silicates and other minerals, they form large masses of pure white marble which are too coarse in grain to be of importance for sculpture and carving.

The coral limestones are found at various points on the coasts of the Island, principally along the south west coast from Ambalangoda to near about Matara. The deposits consist largely of loosely packed finger or stick coral with some massive varieties. They are not of great economic importance but are extensively quarried in the region of Ambalangoda and Hikkaduwa

Fig. 5



LIMESTONE DEPOSITS OF SRI LANKA

as a source of lime for building purposes. Other areas where coral limestones are found are the Jaffna peninsula where they overlie the Miocene limestones, in the Trincomalee and the Kuchchaveli area on the north-east coast, and at Kalkudah on the east coast. Though of high purity and at one time thought to be suitable for use as raw material for the local cement industry, they are not extensive enough to justify their exploitation on a large scale, and in addition their mining causes severe sea erosion as at several points on the south-west coast.

The chief use of limestone is in the cement industry. Portland cement is made by burning properly proportioned raw materials containing essentially lime, alumina, silica and oxides of iron in rotary kilns. Theoretically a large number of raw materials are available for providing these essential constituents, but in actual practice two raw materials are used - limestone and clay. The former provides the lime, and the latter the alumina, silica and iron oxides. If the raw materials are not of the required specification in respect of these constituents, a third and even a fourth component may be added to the two major raw materials, for instance silica or alumina or both, to make up deficiencies. The clinker produced by burning the raw materials is cooled and then ground with a small proportion of gypsum to produce the finished Portland cement. The Cement Plant at Kankesanturai obtains its requirements of limestone from the quarry adjoining the Plant while the Puttalam Cement Plant obtain its limestone requirements from Aruakalu situated about 25 km from the Plant. The two Plants require over a million tons of limestone annually for cement manufacture.

Another important use of limestone is in blast furnaces in the Steel Industry. For every ton of pig iron produced in the blast furnace, the charge into the blast furnace includes 0.4 tons of limestone (depending on the quality) apart from the other raw materials. Other important uses are in the glass and paper industries and as the starting raw material for the production of lime (CaO) for use in several industries such as sugar, the chemical industries and water purification. It is also used in the building industry and for the manufacture of bleaching powder and calcium carbide.

DOLOMITE

Dolomite is the double carbonate of calcium and magnesium having the formula $CaCO_3.MgCO_3$ (theoretically 54.35 per cent. calcium carbonate and 45.65 per cent. magnesium carbonate). Dolomites are normally associated with limestones and they can be regarded as limestones partly transformed by hydrothermal alteration where calcium is partly replaced by magnesium. Limestones often contain small amounts of magnesia (MgO) and those with magnesia from 5 to 18/19 per cent. are referred to as dolomitic limestones, while those with over 18/19 per cent. magnesia are classed as dolomites. Theoretically, dolomites contain 22 per cent. magnesia. Analyses of dolomites and dolomitic limestones are furnished (Table VIII).

TABLE VIII

ANALYSES OF DOLOMITES AND DOLOMITIC LIMESTONES

	1	2	3	4
CaO	31.01%	30.62%	30.39%	33.10%
MgO	21.78	21.38	21.49	12.15
SiO_2	0.75	0.26	0.65	2.45
Al_2O_3	0.27	0.19	0.90	3.60
Fe_2O_3	0.05	0.23	0.26	0.80

1 — Ross Estate, Matale.
2 — Nalanda, Matale North.
3 — Niriella, Ratnapura district.
4 — Dolomitic limestone.

The Island has very large reserves of dolomites and dolomitic limestones entirely confined to the Precambrian and widely distributed in the Kandy, Matale, Matale North, Habarana, Ratnapura, and Badulla districts where they occur interbedded with other rocks of Precambrian age such as quartzites, garnet gneisses and charnockites (Fig. 5). Where free from silicate minerals, they are white in colour and their texture varies from coarse to fine, and at times. very coarse with large recognisable rhombs of dolomite. Quite commonly they contain accessory minerals such as forsterite (magnesium silicate), phlogopite mica, apatite, chondrodite, spinels, flakes of graphite and other minerals. The impurities may be uniformly distributed throughout the rock mass, or found in layers, or even as clots irregularly distributed in a white ground mass. Serpentinization of the forsterite may impart a green colour to the rock giving rise to a green marble e.g. Rupaha marble in the Nuwara Eliya district.

The main use of dolomite is as a refractory and it was first used as a refractory in the linings of basic Bessemer steel-making vessels, but its most important bulk use in the past century was in open hearth furnaces. Since open hearth furnaces have virtually disappeared, dolomite has lost some of its importance but is now used in electric arc furnaces. Apart from its refractory use, dolomite finds important use as a flux and as a slag conditioner in the iron and steel industry. In the uncalcined state, dolomite is often used as a blast furnace slag where it can make up to 10 per cent. of the limestone charge. In the light calcined state, it may make up to 25 per cent. of the total lime addition to the furnace.

Dolomite is also used in the manufacture of tar-bonded bricks and blocks. Bricks made up of dead-burned dolomite are ceramically bonded (i.e. fired) or bonded with tar or pitch (i.e. unfired). Magnesia is also one of the minor ingredients in the glass industry to give enhanced chemical resistance and lustre, and limestone and dolomite are added together to the batch in appropriate proportions. Another important use of dolomite is in agriculture where it is used as a soil conditioner and as a constituent of fertilisers to correct magnesia deficiency. Deposits of hard, compact dolomite have been used for centuries as a source of building blocks, and some of the buildings in the ruined cities of Sri Lanka have been built of this material.

Apart from its refractory use, dolomite is also the raw material for the production of magnesia from sea water. This involves the use of lime or dolime (CaO. MgO) to precipitate magnesium hydroxide from sea water. The precipitate is filtered and the magnesium hydroxide filter cake fired in rotary kilns to yield a a high purity magnesia. The possibilities of producing magnesia from sea water locally is worthy of consideration. In recent years, dolomite has also found important use as a filler. For this purpose, the dolomite has to be very pure, exceptionally white, and free from deleterious impurities such as iron and manganese.

MAGNESITE

The mineral magnesite is the carbonate of magnesium ($MgCO_3$), and occurs in nature in two commercially important forms - one compact and 'amorphous' and the other crystalline. The only known magnesite deposit in Sri Lanka is of the crystalline variety and is found at Randeniya, near Wellawaya, where it is associated with dolomitic limestones. The crystalline magnesite deposits have originated as a result of the replacement of dolomite or limestone by magnesia-rich solutions arising from an igneous source. The Randeniya deposit is a small, local occurrence and on the basis of drilling investigations carried out by the Geological Survey is estimated to contain about 4 000 m tons; the deposit is only of limited importance.

In addition to being a source of the metal magnesium, magnesite is a valuable refractory mineral. Dead-burned magnesite, prepared by prolonged heating of the mineral to high temperatures to expel the carbon dioxide, is employed as a basic lining capable of withstanding high temperatures in furnaces. Caustic calcined magnesite resulting from heating magnesite to 1 000°C retaining part of its carbon dioxide is used in making strong, quick-setting cement by mixing it with magnesium chloride. The cement becomes hard and tough and is extensively used for durable and fire-proof floorings in hospitals, kitchens and offices. Magnesium metal is used in making castings for aircraft engines and in some optical instruments such as microscopes. The metal is also used in a multitude of ways where lightness and strength are required, in tools, machinery and vehicle parts. A recent use for magnesium metal is in the Kroll process for the production of titanium metal on a commercial scale. Important producers of magnesite are the United States, the Soviet Union, Austria, Canada and India.

SILICA (QUARTZ)

Quartz, the oxide of silicon (SiO_2), is the most abundant oxide in the earth's crust and occurs both as free silica and combined with other elements as silicate compounds. Free silica occurs in nature in a great variety of forms and in varying degrees of purity such as silica sands, sandstones, quartzites, vein quartz, flint, chert and tridymite. Some varieties of quartz, such as amethyst, opal, jasper and agate are valued as semi-precious stones, while clear, colourless quartz crystal suitable for frequency control in electronic communications has important use in several industrial applications. The demand for this last type inspired one of the most important raw material searches of World War II. Quartz is commonly associated with felspar and is an invariable major constituent of pegmatites. In Sri Lanka, quartz occurs in pegmatites, as quartz veins, quartzites and as silica sands.

Vein quartz of a high degree of purity, often over 98.5 per cent. silica, are found in several parts of the Island, and the best known deposits are in the Pusella, Pelmadulla, Opanaike and Balangoda areas of the Sabaragamuwa province; in the Galaha and Deltota areas of the Central province; and in Rattota in the Matale district. Normally the vein quartz occurs on the surface as boulders of varying sizes and the veins can be traced by the presence of these surface boulders. Reliable estimates of the tonnages are not available but there is little doubt that they are of the order of several hundreds of thousands of tons. Quartz is also found commonly associated with felspar in pegmatites; good examples of these are at Rattota and Talagoda.

Extensive deposits of silica sands (glass sands) aggregating several million tons are found as isolated deposits on the coastal plain in accessible locations. The best known of these deposits is the Marawila-Nattandiya-Madampe deposit about 64 km (forty miles) north of Colombo in the North-Western province. A smaller deposit occurs at Ekala astride the Jaela-Minuwangoda road about 24 km (15 miles) from Colombo. Outside the western sea-board, a small localised deposit occurs at Chavakachcheri in the Jaffna peninsula, while extensive deposits are found along the eastern margin of the peninsula as a dune formation, extending in a south easterly direction from Ampan, near Point Pedro, to Vallipuram in the south (Fig. 6). The deposit at Chavakachcheri is too small to be of economic importance, while the Ampan deposits are pale brown in colour due to surface staining of the individual quartz grains, requiring pre-treatment with acid to remove iron staining to make the sands suitable for glass manufacture.

The silica sand deposits of the Marawila-Nattandiya-Madampe area occur as more or less irregular deposits with a slight north-south extension. Three deposits are recognisable -

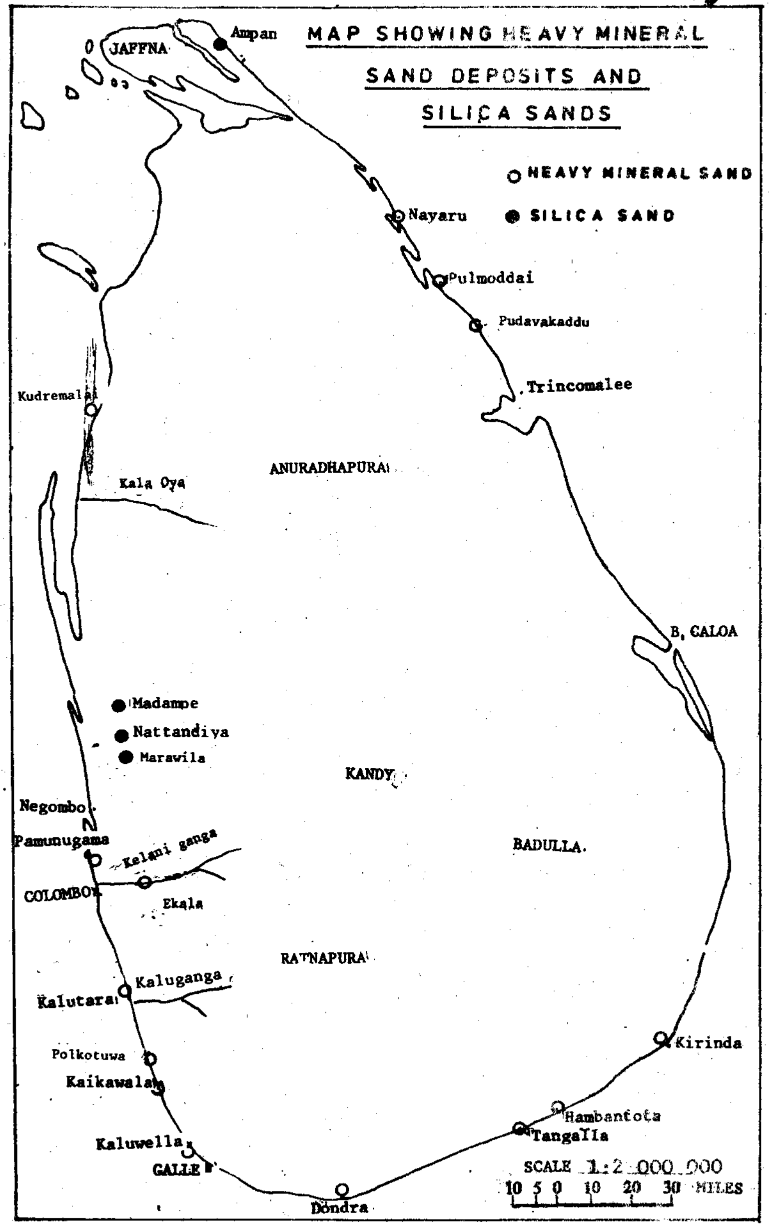
(*a*) the Madampe deposit in the north;

(*b*) the Kudawewa deposit in the centre; and

(*c*) the Marawila-Nattandiya deposit in the south.

The length of the combined deposits stretching for eight to ten km greatly exceeds the width, which in some places is not more than a few hundred metres. The total area covered by the sand deposits has been

Fig. 6



estimated at approximately 1 000 hectares (2 500 acres). The deposits consist of loose, unconsolidated sands varying in colour from white to buff, steel grey to dark grey, brown to dark brown and black. The thickness of this layer is generally from one to two metres though locally this depth may be exceeded. Values begin from the surface and there is no overburden. Invariably below the white sands is a lightly indurated 'hard-pan', dark brown to black in colour, which consists of quartz grains cemented with organic matter and some clay. The total reserves of glass sands in the combined deposits has been estimated at around 6 000 000 m. tons.

For the manufacture of glass, the silica sands must satisfy two important requirements. The first and most obvious requirement is that the sand should be as pure as possible and free from impurities which will discolour the glass or diminish its utility. Secondly, to be suitable for glass making the sands should consist predominantly of grains of more or less uniform size without extremes in size as this evenness of grain ensures even melting. The Marawila-Nattandiya-Madampe sands assay over 98 per cent silica and are suitable for ordinary quality cheap glass, and can be upgraded by conventional methods of processing to make the sands suitable for the manufacture of sheet glass. As regards particle size, on an average only about 50 per cent. of the naturally occurring sands fall within the grain size suitable for glass making, while the balance consisting of coarse and very fine sizes are of little value though they may find some minor use in other industrial applications. The silica sands from the Nattandiya area are used in the local glass industry.

Quartzites, though well developed and a prominent member of the Highland Series of rocks, are not of the required purity for glass manufacture or the ceramic industry. Quartz is also used in the manufacture of ferro-silicon which is widely used in the iron and steel industry. Vein quartz of adequate purity is used in the ceramic and allied industries, while other uses of quartz are in the manufacture of refractories, as moulding sands, abrasives and a variety of other industries. Fragments of colourless quartz crystals are utilised for making fused quartz in the construction of lenses, chemical equipment, and for the finest elastic fibres for use in highly sensitive physical apparatus.

Selected clear crystals of quartz cut parallel to their length into thin wedge-shaped plates (quartz wedges) are valuable accessories for investigating the optical properties of rock-forming minerals under the petrological microscope. But the most fascinating use of quartz crystals is in radio and telephone instruments. When sections of quartz crystals cut in a particular direction are subject to pressure, they develop positive and negative electrical charges on the opposite sides of the plate. Quartz is thus piezo-electric and this valuable property has resulted in the extensive use of the mineral in radio, telephone and

electronic applications. For this particular use the crystals must satisfy certain rigid specifications - clear, colourless crystals of a minimum size, showing good crystal outline, free from inclusions and untwinned. In view of the great demand for material of this quality during World War II, a search was made by the Geological Survey but material satisfying these rigid requirements was not available except in very minor amounts. Brazil still remains the most important source of quartz crystals for this purpose.

FELSPAR

The name felspar is a general term used to designate a closely allied group of minerals consisting essentially of alumino-silicates combined with the alkali metals - sodium, potassium and calcium - in varying proportions. The felspars are the commonest rock-forming minerals, being the chief constituent of most varieties of igneous rocks. The most important commercial varieties are orthoclase and microcline, both potassium aluminium silicates, and albite, the sodium aluminium silicate. Albite is one end member of a complete isomorphous series known as the plagioclase felspars (also known as the soda-lime felspars), the other end member being anorthite, the calcium aluminium silicate. Although so common in nature, most workable deposits of felspar are confined to coarse pegmatite veins where the felspar is associated with quartz. The felspar usually occurs in sufficiently large crystals and masses to permit easy separation from the other minerals with which it is associated.

Felspar-bearing pegmatites are common in various parts of the Island but the great majority of these are too small to be of any economic significance. The best known deposits are at Rattota, Talagoda, Kaikawela, Namaloya and Koslanda. Perhaps the best known deposit of felspar is in Owella estate in the Matale district. The felspar occurs in a large mass of pegmatite discovered by the Geological Survey in the sixties. Subsequent core drilling carried out by the Survey showed that the pegmatite extends to more than 200 m (656 feet) from the surface. Some of the quartz associated with the felspar is colourless and water-clear with a very high degree of purity. The pegmatite also carries minor amounts of fluorspar (calcium fluoride). Though no precise estimates of felspar are available, it is estimated that the reserves must be in the region of over three million tonnes. Open-cast mining of the deposit is carried out by the Ceylon Ceramics Corporation and the felspar is used in the Corporation factories and in the glass industry. In the ceramic industry the felspar forms part of the body of the ware and is also an important constituent of the glazes on chinaware, pottery, tiles and other similar products. High grade potash felspar is used in electrical porcelain insulators and for artificial teeth, while minor uses of the mineral are as an ingredient in scouring soaps, mild abrasives and in poultry grit.

APATITE

Phosphate rock is a natural rock containing one or more phosphate minerals, usually calcium phosphate. There are two varieties of natural phosphates - apatite which is a mineral with a definite chemical composition and 'rock phosphate', or 'phosphate rock' such as phosphorites, phosphatic limestones, phosphatic shales and guano beds which have no definite chemical composition. Apatite, the most common calcium phosphate, also contains CaF_2 or $CaCl_2$ and the chemical formula can be written $Ca_5(PO_4)_3F$ and $Ca_5(PO_4)_3Cl$ or $3Ca_3(PO_4)_2.Ca(F, Cl)_2$, the first half of the latter formula, being the tri-basic calcium phosphate. Theoretically, the fluorapatite contains 42.3 per cent. P_2O_5 and the chlorapatite 41.0 per cent.

The mineral apatite occurs as a constituent of acid igneous rocks but only as an accessory mineral. It also occurs in pegmatites and reference has already been made to the occurrence of the mineral in the Pussella pegmatite. Apatite is also found in small amounts as small blue grains and crystals in metamorphic rocks especially in crystalline limestones and dolomitic limestones of the Highland Series. Perhaps the best known deposits in the world are the very rich apatite deposits of the Kola peninsula in the Soviet Union where the apatite is associated with nepheline syenites.

All land animals contain calcium phosphate in their bones and excrement and this explains the accumulation of phosphates where animal life is particularly abundant and relatively undisturbed. Phosphorite is a variety of natural phosphate resulting from the accumulation of organic remains and the droppings of enormous flocks of birds on desert or oceanic islands. The guano of commerce is deposited by birds congregating in these islands. The calcium carbonate of the rocks is replaced by phosphates to form a mixture of calcium phosphate and unaltered calcium carbonate. The best known of this type of deposit is Nauru in the Pacific and Christmas Island in the Indian Ocean. Phosphate beds are also found in marine beds of all ages, particularly those belonging to the Tertiary. These beds also derive their material from animal life. The phosphate rich minerals may occur as concretions or nodules or in a disseminated form. Phosphate beds are mined on a large scale in Morocco and along the frontiers of Algeria and Tunisia where the beds occur in the lower Eocene. These deposits are among the most productive in the world and large tonnages are exported.

In Sri Lanka, apatite (phosphate rock) was discovered by the Geological Survey in 1971 at Eppawala in the North Central province associated with carbonatite and this was the first recorded occurrence of carbonatite in the Island. Eppawala is situated in the south-western quadrant of the Anuradhapura one inch topographical sheet and is about 192 km from Colombo via Talawa. The carbonatite complex consists of six elevated hillocks with a general elevation of 60 m above the general level of the surrounding country. The apatite bearing crystalline limestone (carbonatite) is well exposed and the surrounding country rocks consist of granitic gneisses, charnockites, marbles, biotite gneisses and thin bands of quartzites of the Highland Series.

Each block consists of a 'leached zone' (apatite. in a matrix of iron oxides) at the top, rich in apatite. This zone extends downwards to a depth of around 60 m and rests on fresh carbonatite with apatite, magnetite and spinel. The average P_2O_5 is 35 per cent., at times higher, for the phosphate rich ore. Drilling investigations carried out by the Geological Survey in the northern half of the deposit has proved 25 000 000 tons of apatite, while the southern half of the deposit, though not investigated in detail, is reported to contain at least 15 000 000 tons inferred reserves. A detailed account of the deposit is contained in the Geological Survey Economic Bulletin No. 3 (Jayawardena 1975). The main use of apatite is as a fertilizer as a source of phosphorus. The Eppawala apatite has a very low solubility and for this reason it is not generally suitable for direct application to soils. This is a characteristic which it shares with crystalline apatites of igneous origin. Marine phosphorite beds provide the bulk of the world's production of phosphate rock; they are more economical to mine and less difficult to process than crystalline apatite. Another disadvantage of the Eppawala material is the high chlorine content of the apatite which causes problems of corrosion. The manufacture of soluble super-phosphate involves the use of large amounts of sulphuric acid and hence the dependence of the phosphate industry on an abundant and cheap supply of sulphuric acid. The manufacture of fused magnesium sulphate is another possibility. This is done by fusing the apatite rock with a magnesium silicate rock such as serpentine and then quenching the melt. Not only calcium and phosphorus but also magnesium and silica are rendered soluble. There are other processes also available and these will have to be carefully evaluated and field trials carried out with different crops and in different soil conditions, to ascertain the most suitable process.

SAND, STONE AND GRAVEL

The sand, stone and gravel industry is essentially a local industry depending on local use and not on foreign trade, though small quantities of sand and metal for construction have been exported to the Maldives for decades. It is largely labour intensive and not mechanised except in special areas serving very large construction projects such as the giant dams for irrigation and hydro-power. Because of the low price of the commodities, it is not generally regarded as a key industry; yet it is essential for every type of construction project, whether buildings, roads, railroads, paving, dams or industrial buildings. Sand is also used extensively for concrete blocks and other concrete products. Because of their low value, metal and aggregate cannot bear high transport costs and as a result markets must be found within economic distances.

Definitions of sand and gravel are not easy because there are wide variations in definition among different authorities, but a commonly accepted one is that sand is an unconsolidated, granular material resulting from the mechanical break-down of rocks, generally finer than quarter inch and coarser than 200-mesh, whereas gravel is also unconsolidated, often water borne, coarser than quarter inch and up to three to four inches. Commonly, sand consists essentially of grains of quartz while gravel consist of quartz and other resistant silicates. Unlimited quantities of good quality sand are available in the lower reaches of our major rivers. Sand is used mainly in the building industry and large quantities are obtained from the Maha oya, the Kelani ganga, Kalu ganga and the Deduru oya, where the sands are excavated from the river beds. Excavation is seasonal and confined to the dry months of the year. Some degree of mechanisation could be profitably introduced by employing portable equipment to streamline the operations.

Gravel may consist of a single mineral, commonly quartz, or rock material, and is available in great abundance in the streams and rivers draining the central highlands; the gravel is assorted and of widely varying sizes, and generally well rounded. This is a striking characteristic of transported gravel unlike residual gravels which are angular or sharp-edged. Gravel is also available from the gem pits in gemming areas, rounded quartz being by far the commonest constituent. But these operations are small scale and the output from individual gemming centres is limited. Quartz gravel is also available from the Pleistocene formations, but the gravel is lightly cemented with clay material and hydrated iron oxides, and needs washing and grading using a trommel, which in its simplest form is a power driven drum with perforations.

We have already seen that over 90 per cent. of the surface area of the Island consists of Precambrian rocks. They are thoroughly crystalline, hard, with great strength and low porosity; they are also compact with strongly interlocking grains. The properties required for good road metal and aggregate are compactness, great strength which implies resistance to abrasion, and resistance to weathering. Based on these characteristics, charnockites, granites, granite gneisses, biotite gneisses and granulites provide excellent material in great abundance to supply any possible requirements for metal and aggregate for many decades to come. Outcrops of these rocks are widespread and most metal and aggregate is obtained from quarries or shallow pits or hillside excavations in these rock outcrops. The great majority of these operations are small and only a few of them are partly mechanised. In a situation where labour is plentiful, most workings depend on human muscle rather than on mechanical means such as power shovels, compressors, conveyors and dumpers. Statistics of production are not maintained by most operations but the quantities are clearly very large.

Laterite is a mottled deep red, reddish-brown or yellow ferruginous material showing vesicular structure. Laterites are best developed in the south-west sector of the Island and some of the best exposures are in the Colombo District. They overlie a variety of rock types of Precambrian age, commonly charnockites and granitic gneisses. Most laterites are regarded as *in situ* weathering of the underlying rocks and the genetic connection between the two is clearly seen in some exposures in and around Colombo, Ragama and in the neighourhood of Matara, where the banding of the gneisses is seen surviving in the residual laterite. Similarly, blocks or boulders of the unaltered granites and charnockites are seen enclosed in the laterite. The laterite layer may vary in thickness from a few metres to 12 metres and more.

In the typical laterite profile, there is commonly a 'cap-rock' consisting of nodular ironstone (limonite nodules). At times, the cap-rock is absent, and at other times the nodules move down slopes and come to lie on fresh rock, clay or other soil material. The nodular layer is followed by hard cellular laterite immediately below which is a softer vesicular zone, both of which are quarried and provide the local 'cabook' which is widely used as a building stone. The zone immediately above the altered rock is generally soft, rich in clay material, and resembles lithomarge-like material. Laterite is extensively quarried in the suburbs of Colombo for use as building stone. The quarries are open-cast pits with stable vertical sides. The laterite is normally cut into blocks 14" x 7"×4". The blocks are stored for seasoning and drying before use.

Chapter IX

HEAVY MINERAL SANDS

When we talk of heavy mineral sands we think of our beaches and shore lines and other related features such as dune formations. In their physical composition, most beaches are made up of several minerals of varying sizes and shapes which have resulted from the break down of rocks, mixed with shell fragments of marine animals.

By far the commonest of these minerals is the ubiquitous quartz but there are others which are not so common and of much higher specific gravity such as limenite, rutile, zircon, monazite, magnetite, garnet, cassiterite (oxide of tin), sillimanite and many others. These are the so-called heavy minerals, all with specific gravity in excess of 2.8, and they represent like the gems, the hardest and most resistant minerals to abrasion and chemical change.

All of these minerals are found in very minor amounts - the accessory minerals - in the granites and gneisses and the rocks of the Highland Series. They are set free by the mechanical disintegration and chemical decay of the parent rocks. Because of their chemical resistance they remain unchanged and because of their higher specific gravity they are concentrated by the natural sorting action of the waves, and are concentrated in bands or lenses more or less parallel to the long direction of the beach. These deposits are easily recognisable because of their colour, commonly black due to the predominance of ilmenite; and at times pink due to the predominance of garnet. Modern and ancient beaches are one of the most important sources of minerals such as ilmenite, rutile, zircon, monazite and others, and the beaches of Sri Lanka are rich in sands containing these minerals.

ILMENITE AND RUTILE

Titanium is widely distributed and it is estimated that it is the ninth most common element in the earth's crust, and the fourth most abundant structural metal being exceeded only by iron, aluminium and magnesium. Though widespread, only two ores of titanium are of commercial importance - they are ilmenite and rutile - the former being the double oxide of iron and titanium ($FeO.TiO_2$) and the latter the pure oxide (TiO_2). Ilmenite is black in colour while rutile is reddish brown. Ilmenite is the major raw material for the production of titanium pigments and prior to World War II, India was the world's biggest producer of the mineral and supplied British and American consumers with all their requirements.

Commercial deposits of ilmenite fall into three categories —

(*a*) massive 'hard-rock' deposits where the ilmenite is commonly associated with magnetite or hematite. The ore has to be crushed and then concentrated. Good examples of such deposits are the Sanford Lake deposits in the Adirondack mountains in New York State; the Allard Lake deposits in the Province of Quebec in Canada; and the Tellnes deposits in south-western Norway. Similar deposits are also found in Finland and the Soviet Union;

(*b*) beach sand deposits, often referred to as 'black sands', in which ilmenite is associated with other heavy minerals such as rutile, zircon, monazite, garnet, sillimanite, staurolite and other minerals. Such deposits are found in Australia, Brazil, India, South Africa, Sri Lanka, Sierra Leone and in the United States; and

(*c*) deposits associated with alluvial tin as in Malaysia and Nigeria; these are only of minor importance.

The main use of ilmenite is in the production of titanium pigments and over 90 per cent. of the world production is used in the manufacture of pigment. The process involves the digestion of the finely ground ilmenite with concentrated sulphuric acid, followed by hydrolysis, the hydrolysed product filtered, washed,

and calcined to produce the oxide titania (TiO_2). The process involves the use of large amounts of acid and results in vast quantities of effluents the disposal of which causes severe problems. The main use of rutile is as a coating in the welding rod industry.

Around 1960, du Pont successfully developed the 'chloride process' for the manufacture of titanium pigments. This process uses rutile as the starting raw material and chlorine. The titanium tetrachloride produced is purified and made to react with oxygen to produce titanium dioxide. The new process has caught on particularly in the United States where chloride based plants have replaced many of the older sulphate plants. It was claimed that the pigment produced by the chloride process was superior to that produced by the older sulphate route, but the great advantage of the new process was that there was no undesirable effluent, while the chlorine was re-circulated.

Besides the production of titanium pigment by the chloride process, rutile is also the starting material for the production of titanium metal. Commercial production of titanium metal is based on the Kroll process or modifications of it. The titanium tetrachloride produced by the chlorination of rutile is reduced to the metallic state using magnesium in an inert atmosphere of helium or argon. The reduction is effected in a sealed vessel containing the inert gas and purified magnesium metal. The temperature of the vessel is raised to around 850°C and the purified tetrachloride is fed continuously into the vessel. When the reaction is complete, the product is a mixture of titanium sponge, unused magnesium and magnesium chloride which has not been drained off during the reaction. The sponge is purified by leaching or vacuum distillation or by a combination of both. The purified sponge is next converted into ingots in electric arc furnaces.

While ilmenite occurs as rock and sand deposits and both types are extensively mined, all the rutile is recovered exclusively from sand deposits. While the world reserves of ilmenite, whether as sand or rock deposits, are considerable, the reserves of rutile are limited, and despite mining developments in the world, Australia still retains its pre-eminent position as the principal source of rutile accounting for over 90 per cent. of world production. With the advent of the chloride process for pigment manufacture and the increasing use of titanium metal, there has been a strong upsurge in the demand for rutile and strong pressures on Australian producers, who have been compelled to work lower and lower grade deposits to meet the demand. With the threat of depleting reserves in Australia, much money and research has been devoted to finding a suitable substitute material for the natural rutile. Since ilmenite is also an ore of titanium and is readily available, it was the obvious starting point to produce a material to replace natural rutile.

To produce a substitute for natural rutile starting from ilmenite meant the elimination of iron from the ilmenite and there are two main lines of development by which this could be achieved -

(*a*) chemical processes; and

(*b*) metallurgical processes.

The iron in the ilmenite exists both in the ferrous and ferric states and in all of the chemical processes the first step involves the reduction of the ferric iron to the ferrous state and the subsequent leaching of the reduced ilmenite by acids under regulated conditions, resulting in the production of a new material simulating the rutile - 'synthetic rutile' and assaying over 92 per cent. TiO_2. Several processes have been developed for the production of synthetic rutile but basically they all conform to this pattern though details vary, such as the type of acid used and the method for the reduction process.

The metallurgical process produces a high titania slag by smelting. Apart from the Soviet Union, until recently the entire supply of titania slag for the pigment industry came from the Quebec Iron and Titanium Corporation of Canada utilising the hard rock ilmenite deposits assaying around 42 per cent. TiO_2. The slag commonly referred to as 'Sorel slag' and assaying approximately 72 per cent. TiO_2 found wide acceptance in sulphate process plants, as the use of slag had the advantage of reducing the requirements of sulphuric acid and in turn the problems of the undesirable effluents. Using ilmenite from sand deposits assaying 52 - 54 per cent TiO_2, or higher as a result of partial alteration, it is possible to produce a slag by smelting which assays over 90 per cent. TiO_2, suitable for chlorination for the production of titanium pigments or the metal. Analyses of some ilmenites from different sources are furnished in Table IX.

TABLE IX

ANALYSES OF ILMENITES

	Pulmoddai	*Indian*		*Australian*
		A	*B*	
TiO_2	53.21	60.60	54.20	54.02 - 55.20
FeO	20.50	9.25	26.60	21.00 - 24.50
Fe_2O_3	22.07	24.18	14.20	16.00 - 19.00
Al_2O_3	0.32	0.96	1.25	0.80 - 1.00
MnO	0.90	0.39	0.40	1.30 - 1.50
MgO	0.72	0.89	1.03	
CaO	0.10			
Cr_2O_3	0.10	0.12	0.07	0.03 - 0.03
V_2O_5	0.20	0.15	0.16	0.10 - 0.15
ZrO_2		0.90	0.80	
P_2O_5		0.21	0.12	0.02 - 0.05
SiO_2	0.89	0.40	0.68	0.20 - 0.80

A — Quilon ("Q" Grade).
B — Manavalakurichchi ('MK' Grade).
Australia - West coast deposits.

Analyses of rutile from Pulmoddai and Western Australia are furnished in Table X. The manufacture of titanium dioxide pigments by the sulphate route requires costly plant, large quantities of sulphuric acid, abundant supplies of water, large blocks of power and special location. The last is of great importance because of the need to dispose of waste effluent products and as the operation results in considerable air pollution. With the chloride process the cost is even higher and the process itself highly sophisticated though the effluent problem is eliminated. The phenomenal growth of the titanium pigment industry can be attributed to the high opacity of the titanium pigments, their high covering power and chemical inertness. About 80 per cent of the titanium pigments is used in the paint, enamel and lacquer industries and the balance in paper, rubber, floor coverings and other miscellaneous industries.

TABLE X.

ANALYSES OF RUTILE

	A	*B*
TiO_2	97.20 %	96.30 %
Fe_2O_3	1.29	0.37
FeO		0.23
MnO	n.a.	0.003
MgO	n.a.	0.015
CaO	n.a.	0.02
Al_2O_3	0.11	0.26
Cr_2O_3	0.14	0.20
V_2O_5	0.03	0.44
P_2O_5	trace	0.07
Nb_2O_3	n.a.	0.15
ZrO_2	0.52	0.70
SiO_2	0.65	0.61

n.a. — not analysed.
A — Rutile from Pulmoddai
Analyst: Fonseka, Geological Survey.
B — Rutile from Western Titanium N.L.
Western Australia (typical analyses).

Titanium metal because of its lightness and great strength is widely used in the aircraft industry, the chemical industry and in other non-defence uses. Traditionally, the aircraft industry has been the biggest consumer, but the aero-space programme of the major powers now consumes an important part of the metal production. Because of its high corrosion resistance, it is widely used in desalination plants and in other applications where resistance to chloride attack is necessary. Any major expansion of titanium production - whether pigment or metal - must be based on ilmenite or its derivatives such as synthetic rutile or high titania slag. For some considerable time, titanium metal will be used mainly for military purposes and in space programmes.

ZIRCON AND BADDELEYITE

Until recently the metal zirconium was considered to be a rare element; actually it is more plentiful than nickel, lead and zinc. The principal ore of the metal is zircon which is a silicate of zirconium ($ZrSiO_4$), theoretically containing 67.2 per cent. ZrO_2. It is colourless, but more commonly pale yellow to brownish yellow, or even reddish brown. Zircon is widely distributed as an accessory mineral in granites as for example in the Balangoda granites and the granite at Loluwa, in charnockites and other rocks belonging to the Highland Series, but commercial concentrations are restricted almost entirely to beach sands, where the mineral is commonly associated with ilmenite, rutile, monazite and other minerals.

Zircon is obtained largely as a co-product of rutile mining and to some extent as a co-product of ilmenite. Australia is the world's largest producer of zircon accounting for over 75 per cent. of the world's output, all of it from deposits of heavy mineral sands. Other important producers are the United States, Brazil, South Africa, India and more recently Sri Lanka. Sri Lanka is a potential major producer and with judicious development should within a few years outstrip Brazilian and Indian production.

The bulk of the zircon production is used for foundry purposes and as a refractory. Zircon is chemically inert, a good conductor of heat, and has a high melting point and is, therefore, an outstanding refractory. As a foundry sand, zircon is superior to silica sands. Other uses of zircon include the use of the mineral in the ceramics industry as an opacifier; in the production of zirconium chemicals used in leather tanning, water proofing and other uses, and zirconium metal for alloys in nuclear power reactors. Foundries continue to be the greatest consumer, with refractory and ceramic manufacture also requiring significant quantities.

Baddeleyite is the pure oxide of the metal zirconium (ZrO_2). The mineral is named after a Mr. Baddeley, an English planter in the Rakwana district in the closing years of the last century. He was a collector of mineral specimens which he sent to the Imperial Institute, London, for identification. In one of the parcels of stones from the gem gravels of the Rakwana area were specimens suspected to be zircon but which on investigation and chemical analysis turned out to be the pure oxide of zirconium. It was a new mineral which had not been previously recorded. The mineral was rare and only known to occur in the gem gravels of the Ratnapura district. Many years later in the sixties, the author detected traces of baddeleyite in the heavy mineral sands formed seasonally at Beruwela. A flow-sheet for the recovery of the mineral was developed by the author and a few tons of the mineral of a high degree of purity were produced in the sixties as a by-product of monazite production at the Mineral Processing Plant of the Geological Survey. The product assayed over 97 per cent ZrO_2, the chief impurity being traces of cassiterite (tin oxide). Like zircon, the baddeleyite is non-magnetic but has a higher specific gravity varying from 5.8 to 6.0 (Zircon - specific gravity 4.2 - 4.7). The mineral is fine grained, dark in colour with a resinous lustre. The entire production was exported. The only other countries producing baddeleyite are Brazil, and South Africa from the Palabora deposits. The Sri Lankan product is of a higher purity than the baddeleyite from both countries. Analyses of baddeleyite are furnished in Table XI.

TABLE XI

ANALYSES OF BADDELEYITE

	A		*B*
ZrO_2	98.90%	ZrO_2	98.86%
Fe_2O_3 FeO	0.82	Fe_2O_3	0.21
CaO	0.06	TiO_2	0.41
SiO_2	0.19	Insolubles (Zircon)	0.31
Loss on Ignition 0.28			

A — Polkotuwa, Beruwela.
Analyst: Fonseka, Geological Survey, 1964.
B — Balangoda,
Analyst: Blake, Imperial Institute, London, 1907.

SILLIMANITE

Sillimanite is the silicate of aluminium ($Al_2O_3.SiO_2$). Sillimanite, kyanite and andalusite have the identical chemical composition but differ in crystal structure and their physical and mineralogical properties. On heating to high temperatures in a furnace, they are converted wholly or partly to mullite ($3Al_2O_3.2SiO_2$) and silica. The mineral mullite rarely occurs in nature. Sillimanite is a frequent constituent of metamorphic rocks such as gneisses and schists. The mineral occurs in a variety of rock types in Sri Lanka and appreciable amounts are present in the garnet-sillimanite-graphite schists and in sillimanite gneisses which are well developed in the Central Highlands. Sillimanite is also a minor constituent of many of the heavy mineral sands of the Island. Though there is no production of the mineral in the plant belonging to the Ceylon Mineral Sands Corporation, the Pulmoddai deposit contains about one half to one per cent sillimanite and is a potential source of the mineral. Its main use is as a refractory. India possesses the world's largest known deposits of sillimanite in the Khasi hills of Assam.

GARNET

Apart from its use as a semi-precious stone, garnet is also used as an abrasive because of its hardness (hardness 8 on Moh's scale) and its sharp fracture. Although most types of garnets are used as gem stones when they are clear and transparent, almandine (the iron garnet) is the one most commonly used as an abrasive. Garnet is a common constituent of most metamorphic rocks - schists and gneisses. In Sri Lanka, garnet is a common mineral in most gneisses and granulites which may contain up to 10 per cent. garnet, but these primary occurrences in the rocks are of no commercial importance. However, the mineral is invariably present in the heavy mineral sands of the south-west and southern coastal areas, and in some of these the garnet may so increase in content that it imparts a pink or red colour to the sands. Examples of such pink beaches are found around Tangalle, Hambantota and Kirinda, in which the garnet varies from around 10 to 25 per cent.

Around Hambantota, the garnet sands are mainly concentrated in sand dunes in which the garnet is around 20 per cent. though there is much variation. They are potential sources of the mineral but because of the low value of garnet they can be exploited only where garnet is a by-product of the refining of other heavy minerals. Small quantities of garnet have been produced in the Mineral Processing Plant belonging to the Geological Survey at Kalutara as a by-product of the processing of heavy mineral sands from the west coast for the recovery of monazite and zircon. The garnet has been sold locally for abrasive use.

MONAZITE

The flint that yields the spark in the familiar pocket lighter is an alloy of cerium, and the chief source of cerium is the mineral monazite which is essentially a phosphate of cerium and other rare earths such as lanthanum and others with varying amounts of thoria (ThO_2). The mineral is thus feebly radioactive. In the early years of this century the bulk of the world's supply of the mineral came from the famous beaches of Travancore in south-western India, where the mineral has been concentrated by natural agencies with other minerals such as ilmenite and zircon. In Sri Lanka, the primary sources of the mineral in the granitic gneisses are of no importance and the only sources of commercial importance are the heavy mineral sands. Small amounts of the mineral, less than one per cent., are present in the Pulmoddai sand deposit and a semi-processed monazite has been produced and small tonnages exported in recent years. The Pulmoddai deposit is capable of producing around 500 tons per annum.

Monazite is also an important constituent of heavy mineral sand deposits on the west coast of the Island, being of the order of 0.5 to 2 per cent., but unusually high percentages are found at Polkotuwa, near Beruwela; Kaikawela, near Induruwa; and at Kudremalai on the north-west coast. In these deposits, the concentration of monazite may rise up to 15 to 20 per cent. and higher (Fernando, 1954). Mineralogical analyses of the Beruwela sands are furnished in Table XII. The concentrates from Beruwela and Induruwa have been processed in the Mineral Processing Plant of the Geological Survey and several hundred tons of high purity monazite assaying over 65 per cent. rare earth oxides, including thoria, were exported in the late fifties and the sixties. The deposits are not worked at present due to the problem of severe sea erosion.

TABLE XII

MINERALOGICAL ANALYSES OF BERUWELA HEAVY MINERAL SANDS

Date of Collection	*Monazite*	*Ilmenite*	*Non-Magnetics*
17.06.49	11.25%	67.15%	21.50%
7.08.50	14.68	63.65	20.92
18.06 52	14.18	65.32	19.94
17.07.53	5.44	70.74	23.46
06.05.54	13.24	64.20	22.28
12.05.54	9.12	70.72	22.48
04.06,54	7.76	66.20	25.96
18.06.54	10.52	68.00	21.20
25.06.54	4.80	69.88	25.24

Note: 1. Light fraction removed by flotation prior to magnetic separation.
2. Non-magnetics include principally zircon and garnet.
Authority: Fernando (1954)

Monazite was also the main source of thoria for the once popular incandescent gas mantles. Cerium and its salts have many other applications as in the ceramics industry, tanning and in the manufacture of optical glass. Large quantities are also used in making electrodes for electric arc lamps. Monazite has now acquired an energy use as most commercial thorium is obtained from monazite. The use of thorium as a source of energy depends on the fact that when thorium-232, the naturally occurring isotope of the element, is subject to bombardment by neutrons it is converted into fissionable uranium-233.

For many years, India was the world's chief source of monazite but in 1948 India placed an embargo on the export of monazite. Brazilian production, which used to be important in the early years of the century, had declined but came into its own with the Indian embargo but this was short lived as Brazil followed the Indian example. Monazite thus became a critical mineral commodity and an active search for alternate sources commenced in the fifties. Australia became an important producer of monazite as a by-product of ilmenite and rutile production, while a new ore-field was discovered in the Cape Province of South Africa. Unlike other sources, the South African monazite is a heavy brown mineral unlike the golden yellow of the Sri Lankan mineral, and, more important, is derived from a bed-rock reef, whereas all other sources are from sand deposits. Malaysia produces small amounts of monazite as a by-product of tin mining. Deposits were also discovered in the United States.

The thoria content of the Sri Lankan monazite is high varying from 8 to 10 per cent thoria (ThO_2), and in this respect is similar to the Indian monazite from the beaches of Travancore. The thoria content of Australian monazite, also from sand deposits, is lower and varies from 4 to 5 per cent., while the Brazilian monazite assays 6 per cent. thoria. The South African monazite from rock deposits assays 4 per cent thoria. For non-energy purchases where the mineral is used as a source of cerium and the other rare earths, it is usual to purchase monazite on the basis of guarantees for the total rare earths. Analyses of monazite from Sri Lanka are furnished in Table XIII.

TABLE XIII

ANALYSES OF MONAZITE

Constituent	*Beruwela*	*Dondra*	*Indian*	*Brazilian*
ThO_2	8.65	9.51	9.50	6.50
U_3O_8			0.35	0.17
$(RE)_2O_3$*			58.60**	59.20**
Ce_2O_3	27.35	28.70	27.20	26.80
La_2O_3	31.08	28.56		
Y_2O_3	0.95	1.05		
Fe_2O_3	0.15	0.10	0.80	0.51
Al_2O_3	0.78	1.31		
CaO	0.20	0.89		
TiO_2	0.15	0.05	0.20	1.75
P_2O_5	27.50	28.91	29.10	26.0
SiO_2	1.60		1.45	2.20

* Total rare earths (Ce, La and Yt)

** includes ceria (Ce_2O_3)

The Pulmoddai Mineral Sand Deposit

The largest and best known of the heavy mineral sand deposits is at Pulmoddai, 34 miles north of Trincomalee on the north-east coast of the Island. The deposit extends from Vettilakerni at its southern end to Kokkilai lagoon in the north, a distance of 7.4 km with an average width of 150 m. The average depth of the mineral sands is two metres with a maximum recorded depth of 3.5 m in a few places. The deposit consists of the foreshore; a raised beach with typical beach vegetation such as species of Spinifex and Ipomea and generally above high-water mark; and a back-shore forested area. The sands in the raised beach are clean and can be fed direct into the processing plant after prior screening to remove shell fragments and other beach debris, whereas the sands from the forested area have a thin film of iron oxides and/or organic matter and need prior scrubbing. Although comparatively small by world standards (Australia and India), the Pulmoddai deposit is unique in its concentration of heavy minerals, and the main beach has the astonishing composition as follows -

Ilmenite	..	75 per cent.
Rutile	..	10 per cent.
Zircon	..	8 per cent.
Monazite, Sillimanite and other heavies	..	2 per cent.

A survey of the deposit by the author in 1971 proved a tonnage of 3.72 million tons of mineral sand in respect of the entire deposit with an overall heavy mineral content of 79 per cent with the following composition -

Ilmenite	..	64 per cent.
Rutile	..	8 per cent.
Zircon	..	6 per cent
Other heavies	..	1 per cent.

The estimate does not include the mineral sands below the low-water mark for which no estimate is available; nor does it include mineral sands north of the mouth of the Kokkilai lagoon. The sands north of the lagoon are much lower in grade and in 1952 the writer estimated the area to contain 360 000 tons but further checking of this will be required to establish exact reserves and grade.

Extension surveys carried out by the Geological Survey in 1978/79 have proved heavy mineral sand deposits at Nayaru, north of Pulmoddai, and at Pudawakaddu, about ten miles south of Pulmoddai. The latter location is the more promising and has been estimated to contain 4.3 million tons of mineral sand in an area of approximately six square kilometres (2.3 square miles), with an average heavy mineral content of 17.7 per cent., as against the overall average of 79 per cent. for the Pulmoddai deposit. The rutile and zircon content are much lower than at Pulmoddai and average 0.64 per cent. rutile and 0.46 per cent. zircon. Because of its low grade, the ore will need pre-treatment in a Wet Mill to upgrade the sands prior to processing.

The West Coast Deposits

Besides the Pulmoddai deposit and other deposits on the east coast, there are several deposits of heavy mineral sands on the west and south-west coasts of the Island commencing from Kudremalai Bay on the north-west to Kirinda in the south. In nearly all of these deposits ilmenite is the major constituent giving the sands a black colour. Exceptions to this are the most southerly deposits around Tangalle, Hambantota and Kirinda where the sands are red due to the predominance of garnet. Concentrations of over 80 per cent. ilmenite have been recorded at Dondra and at a little fishing village called Vellaimundel, north of the Kala oya. Mineral sands occur along the coast north of the Kelani ganga and stretch for a distance of a few miles up to Pamunugama with barren stretches in between. The heavy mineral content varies from 8 to 15 per cent. while it rises to over 80 per cent during the south west monsoon. Similar sands are also found north of the Kala oya up to Kollankanatta and for about a mile north of the Kalu ganga. Heavy mineral sand concentrates are also formed at Kaluwella, immediately north of Galle, and at Dondra; at the latter place the deposits are more extensive than at Kaluwella. (Fig 6).

Nearly all of these deposits are seasonal and the highest concentrations are found during the south-west monsoon (May - September) with concentrations of over 80 per cent heavy minerals. Wave action of high energy and wave turbulence which are common during the monsoon months have combined and given rise to the formation of clean concentrates of a high degree of purity, which are easily recognisable because of their colour - black, red or even yellow, the last where monazite is abundant. Next in importance to ilmenite in the west coast deposits are zircon and garnet, whereas rutile is comparatively rare. Another feature of the seasonal deposits is that they show greater variety in their mineral make-up than the deposits on the east coast. For instance, small traces of fine grained thorianite (the oxide of thorium) have been detected in the sands from Kaikawela and Beruwela, while baddeleyite (oxide of zirconium) has been recovered from the Beruwela deposit. It is the first record of these two minerals in beach sands although they were known earlier from the gravels of the Ratnapura district. Cassiterite (tin oxide) has also been detected in very minor traces in the Beruwela sands.

The Ceylon Mineral Sands Corporation

The Ceylon Mineral Sands Corporation was established in 1957 under the State Industrial Corporations Act primarily for the purpose of mining and processing the Pulmoddai mineral sands and marketing the refined mineral products. Although the original intention was to establish the processing plant at Pulmoddai, as a result of a later decision two plants were in fact established - a magnetic installation at Pulmoddai for the recovery of ilmenite and a by-products plant at China Bay for the recovery of rutile and zircon. The non-magnetics after the recovery of ilmenite were transported by sea from Pulmoddai to China Bay a distance of about 70 km. The magnetic installation had a capacity of 120 000 tons of raw sand. Trial production commenced in 1961 and the export of ilmenite commenced in 1962 with a modest tonnage of 3 000 tons. The production of rutile and zircon commenced at China Bay in the late sixties but production was well below designed capacity because of difficulties experienced in transport of the feed-stock to the China Bay plant by sea, the losses incurred in transport and handling, and the lack of adequate supplies of water for processing of the by-products.

Following this experience, it was decided to establish an expanded and integrated plant at Pulmoddai with a capacity of 120 000 tons of raw sand plus 25 000 tons of non-magnetic tailings accumulated from earlier operations at Pulmoddai. The integrated plant was commissioned in 1978 with a planned production of 85 000 tons ilmenite, 12 000 tons rutile and 6 000 tons of zircon. When the accumulated tailings were exhausted, the magnetic installation was to be expanded to

provide the necessary feed-stock to work the rutile-zircon plant at designed capacity. This expansion was effected in 1984 by the installation of a Magnetic Separation Plant using wet magnetic separators. The capacity of the new complex is around 220 000 tons of raw sand with an expected yield of around 130 000 tons ilmenite, 14 000 tons of rutile and 8 000 tons zircon. Exports of minerals for the period 1964 - 1983 is furnished in Table XIV. Except for sales of small quantities which are bagged in paper sacks, all minerals are exported in bulk direct from the Pulmoddai plant in vessels lying off-shore at Pulmoddai. However, shipments can be effected only from April to September during the non-monsoon months. The value of the mineral exports is furnished in Table XV.

TABLE XIV

EXPORTS OF MINERAL SANDS

(1964 1983)

(Metric tons)

Year	*Ilmenite*	*Rutile*	*Zircon*
1964/65	38 380		
1965/66	50 575		
1966/67	40 399		
1967/68	55 580		
1968/69	72 546	02	
1969/70	80 800	2 830	
1970/71	81 413	1 110	
1971	75 303	910	
1972	83 862	3 338	15
1973	85 638	2 815	124
1974	85 672	2 372	42
1975	50 630	3 278	30
1976	52 259	2 376	41
1977	41 211	199	
1978	37 145	9 318	02
1979	30 478	14 623	3 202
1980	36 680	12 208	2 142
1981	41 465	5 270	4 735
1982	46 975	15 411	141
1983	30 673	12 321	11 555

Note 1 — Prior to 1977 production of rutile at China Bay. Reduced production in 1977 due to dismantling of China Bay Plant.

2 — From 1978, production at the expanded and integrated plant at Pulmoddai.

Authority: Ceylon Mineral Sands Corporation.

TABLE XV

VALUE OF MINERAL EXPORTS — PULMODDAI (in rupees)

Year	*Ilmenite*	*Rutile*	*Zircon*
1972	6 561 247	4 263 794	4 692
1973	8 066 105	3 738 530	47 820
1974	10 809 532	4 842 661	64 294
1975	8 152 245	11 121 258	116 085
1976	11 198 635	2 922 043	136 329
1977	7 938 839	562 919	
1978	9 049 103	677 772	2 457
1979	7 834 773	49 388 433	1 959 599
1980	9 863 879	56 016 133	1 425 709
1981	13 934 904	32 253 199	4 926 198
1982	15 272 308	74 728 215	348 270
1983	10 889 671	57 047 506	16 923 823

Authority: Ceylon Mineral Sands Corporation.

The Mineral Processing Plant Kalutara

The Mineral Processing Plant was set up at Kalutara in the early fifties with the immediate objective of taking advantage of the premium prices which prevailed at the time for monazite following the embargo on the export of the mineral from India. The raw material for the recovery of monazite was the heavy mineral sands formed seasonally at Beruwela and Induruwa. The initial equipment consisted of a High Intensity Magnetic separator and an old-fashioned Wind Table of Indian manufacture. However, the main objective in setting up the Plant was to provide facilities for the investigation and study of mineral

sands, which are one of the most valuable assets of the Island, on a pilot plant scale, and the development of flow-sheets for the recovery of the minerals. Further equipment was added later; these included a Humboldt Cross-belt magnetic separator; a Carpco High Tension separator; a Kipp-Kelly Air Float separator and a Kipp-Kelly 5-deck Multigrader. The additional equipment greatly expanded the scope of the Plant and enabled studies to be undertaken which were not possible earlier.

Among the more important achievements of this Plant are —

(*a*) the production of monazite of a very high purity (nuclear purity) purely by dry methods;

(*b*) the production of commercial grade zircon without employing wet processing;

(*c*) the discovery of thorianite during pilot plant tests on beach mineral sands from Kaikawela and Beruwela;

(*d*) the detection of baddeleyite in the mineral sand concentrates from Beruwela, and the development of a flow-sheet for its recovery.

(*e*) the production of a high quality commercial grade baddeleyite superior to the baddeleyite from Palabora in South Africa and the Brazilian production.

In carrying out these pilot studies and investigations, the conventional methods of mineral processing are employed such as gravity, magnetic and high tension (based on electrical conductivity) combined with screening where necessary. Any one of these methods or a combination of methods may be used to achieve the desired objective. The physical properties of the heavy mineral sands on which these methods are based are shown in Table XVI. The Plant has also provided facilities for carrying out trials for the development of flow-sheets for the Ceylon Mineral Sands Corporation and for the testing of equipment for the Corporation prior to the placing of firm orders.

TABLE XVI

SOME PHYSICAL PROPERTIES OF COMMON BEACH SAND MINERALS

Mineral	*Specific Gravity*	*Magnetic Susceptibility*	*Electrical Conductivity*
Monazite	5.2 - 5.4	Moderate	Low
Zircon	4.2 - 4.7	Very low	Low
Baddeleyite	5.8 - 6.0	Low	Low
Ilmenite	4.4 - 5.0	Very high	High
Rutile	4.2	Low	High
Garnet	3.7 - 4.2	Moderate	Low
Tourmaline	2.98 - 3.2	Low	Low
Sillimanite	3.23	Low	Low
Quartz	2.65	Very low	Low

Chapter X

CLAYS AND CLAY MATERIALS

Clays are hydrated aluminium silicates often containing small proportions of impurities. They are the result of weathering, or are sometimes formed by hydrothermal action, and occur in numerous mineral forms with a wide range of properties which make them useful for many industrial applications. In appearance, clays are very fine grained earthy material and are important constituents of most soils. Two broad categories of clays are recognised on the basis of their mode of occurrence. Clay materials which are formed in the identical position of the parent rock are referred to as residual clays, while those that are transported and deposited elsewhere are referred to as sedimentary or alluvial clays. The latter are by far the more common. No two clays are exactly alike and it is seldom possible to substitute one for another without considerable experimentation. For most industrial uses, chemical composition is relatively unimportant and it is the physical properties of clays that are critical. While the greater part of the clay consumed by industry is in the ceramics industry, large quantities are also utilised as a filler in the paper and rubber industries, as a refractory in the cement industry, and in heavy clay products such as brick, tiles and pipes.

The main industrial clays of Sri Lanka are kaolin or 'china clay', ball clay, refractory clays, brick and tile clays and other miscellaneous clays. Large quantities of clay are used in cement manufacture, the clay providing principally the silica and alumina and possibly small amounts of iron oxides. The cement plant at Kankesanturai obtains its requirements from Murunkan in the neighbourhood of Giant's Tank, while the Puttalam Cement Works gets its requirements from the Ralmadu-Achchamulai clay field in the flood plain of Kala oya. The latter deposits were investigated by the Geological Survey in 1959/60 and since they are alluvial clays detailed sampling was necessary to define the limits of the clay field and to detect vertical and lateral variations. 144 auger holes were drilled with a total aggregate depth of 540 m. (1 772 ft.). Plastic and sandy clays suitable for cement manufacture were proved to a depth of 1.8 m and the reserves adequate for a 200 000 - ton cement plant for forty years.

Kaolin or China clay, so called because samples of it were originally obtained in the 18th. century from China, is a pure white clay consisting predominantly of the mineral kaolinite (hydrated aluminium silicate) characterised by low plasticity and high refractoriness. All the china clay deposits of the world are the product of the decomposition of felspars in granites or granitic rocks. This alteration may be effected in several ways but the two commonest are (a) by downward percolating waters charged with carbon dioxide or organic acids, and (b) by hot ascending gases and vapours, chiefly carbon dioxide or steam arising from a deep seated acid, igneous source. The well known deposits of china clay in Cornwall and Devon in England of unsurpassed quality were formed *in situ* by ascending gases and vapours resulting in the alteration of the felspars of granites.

The largest known kaolin deposit in Sri Lanka is the Boralesgamuwa deposit in the low lying coastal plain south-east of Colombo. The kaolin occurs in layers and lenses with an overburden of one to four metres of surface soil or peaty alluvium, while the thickness of the kaolin layers varies from a little over a metre to around six metres. The reserves at Boralesgamuwa have been estimated at well over a million tons (Herath, 1963). The main use of kaolin is in the ceramics industry, and for such use the significant properties include plasticity, dry and fired colour, dry and fired strength, dry and fired shrinkage and vitrification range. A smaller deposit of kaolin is found at Metiyagoda, about 9.5 km from Ambalangoda. In parts the clay is stained and not up to the quality of the Boralesgamuwa material. Kaolin is also known to occur at Iranaimadu in the Northern province where the clay occurs as a bed underlying three to four metres of laterite. The clay at this location is heavily stained and not suitable for the ceramic industry or as a filler. Smaller occurrences are known from Watawala and Nuwara Eliya where the kaolin occurs as lenses and bands; they are mainly residual deposits formed by the *in situ* weathering of felspar-rich rocks.

The term 'ball clay' originated in England, where on account of its soft, pliable nature, it was mined from open pits in the form of balls weighing about 12 to 15 kg. Like kaolin, ball clay consists chiefly of kaolinite and other aluminium silicates. It is plastic, refractory and of sedimentary origin. Clays approaching ball clays are known to occur in the flood plains of the major rivers confined to the south west sector of the Island, and the best known deposits are in the Kalutara area in the flood plain of the Kalu ganga, where over half a million tons have been proved by the Geological Survey, principally around Dediyawala. The actual reserves are probably very much larger and extend to other parts of the flood plain. Ball clays are used chiefly in the ceramics industry and are an important ingredient in whiteware. They act as a plasticizer and a bonding agent. Ball clays differ from kaolin in their greater toughness and plasticity; they have better bonding power but lower refractoriness.

Refractory clays are clays capable of withstanding high temperatures and an essential requirement in such clays is that they should be free from minerals which will melt or act as a flux such as alkalis, compounds of calcium, iron oxides and others. Good refractory clays should be able to withstand temperature of 1600°C and above. The fusion points of material such as kaolin and the Jurassic shales have been found to be in the region of 1600° - 1715°C and they can be regarded as refractory clays. Most industries

that involve operations at high temperatures rely on fire-clay refractories for lining their furnaces. One of the largest consuming industries is the iron and steel industry but other important ones are cement, glass and various metallurgical industries. The Island is, however, well supplied with abundant reserves of high quality refractory materials other than clays, such as graphite, zircon, sillimanite and dolomite, and there is thus a promising potential for a good refractory industry.

We have already seen that the greater part of the surface area of the Island consists of Precambrian rocks. As a consequence of the great preponderance of crystalline rocks and their widespread distribution, the Island is almost entirely devoid of consolidated clays, mudstones and shales, which are a common feature of the geological formations of most countries and on which the ceramic industry largely depends. The only exception to this is the Jurassic shales but these are very limited in their distribution. Sri Lanka has thus to depend almost exclusively on the unconsolidated alluvial deposits for its requirements for the brick and tile industry. Being a stable land mass throughout the greater part of its geological history, the Island has been exposed to the unrelenting forces of atmospheric agencies resulting in the gradual break-down of the crystalline rocks. The weathered products are transported by streams and rivers and deposited in their lower reaches. Periodical uplifts have resulted in fresh cycles of erosion and thus the alluvial deposits have been replenished from time to time. Large alluvial deposits are thus restricted to the lower reaches of the major rivers and it is these deposits that provide the raw material for the local brick and tile industry. By their very nature, these alluvial deposits are not of a uniform character over wide extents and show a great deal of variation. For instance, good beds of clay may be inter-layered with sandy clays and even sands; or there may be lenses or pockets of sand or other sandy material in the clay formations. A carefully planned programme of systematic investigation is thus necessary to define the extent of the clay deposits, their quality and variation, if any. Extensive clay deposits occur in the lower reaches of the Maha oya, Kelani ganga and the Kalu ganga and are exploited for the commercial production of bricks and tiles. The local cottage brick and tile industry is carried on according to traditional methods which have remained more or less unchanged for decades. Most of these units operate on lenses and pockets of clays and sandy clays found near the surface. There is no quality control and rarely do they utilise good clays lying at greater depths.

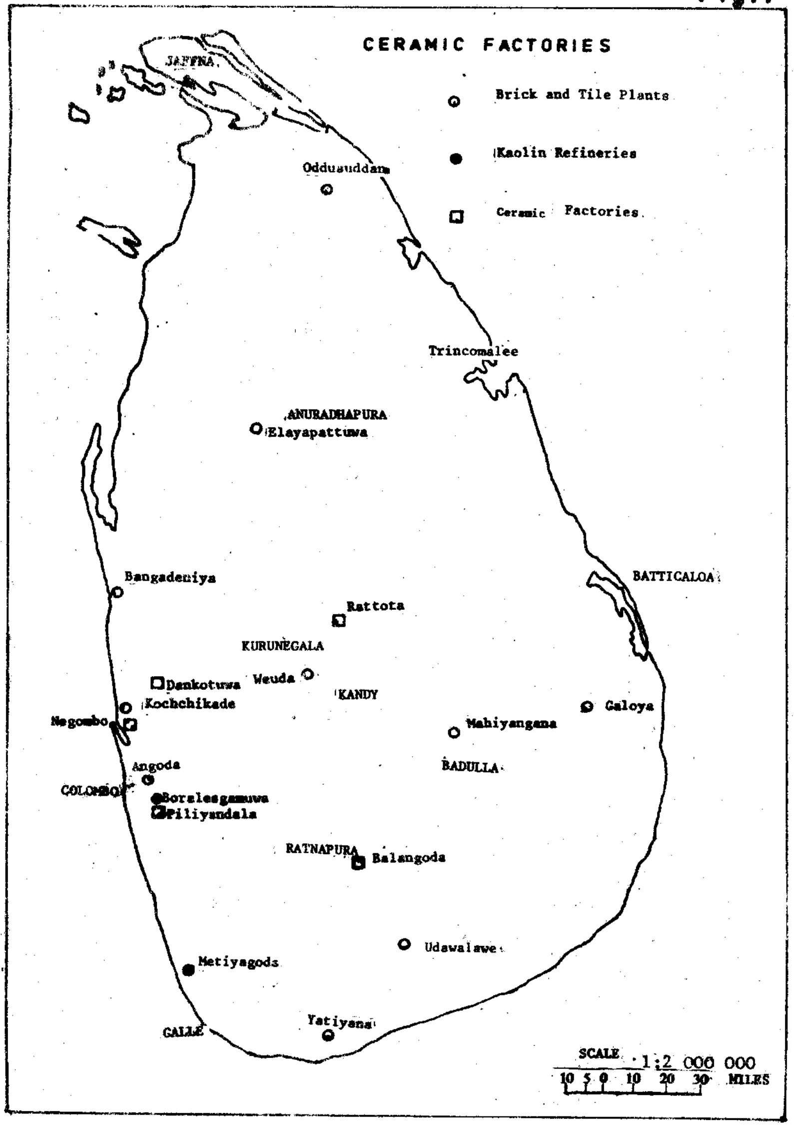
The first factory to manufacture Mangalore roofing tiles was set up by an enterprising Ceylonese at Ambatale in 1925 and this was followed by others, mainly in the Kochchikade area. The establishment of a tile factory at Irakkaman by the former Gal Oya Development Board marked the entry of the Public Sector into the tile industry. In 1959, the former Ceylon Carpentry Corporation was re-named the National Small Industries Corporation and its activities expanded to include the manufacture and sale of bricks and tiles. The new Corporation established five factories - at Bangadeniya in the Puttalam district; Yatiyana in the Matara district; Weuda in the Kurunegala district; Elayapattuwa in the Anuradhapura district; and Mullaitivu in the Vavuniya district. In 1965, the Corporation took over the tile factory constructed at Mahiyangana by the Land Development Department with aid from the Federal Republic of Germany. At the time this factory was one of the most modern, its special feature being the tunnel kiln which ensured the production of evenly burnt tiles of high quality.

Later in the seventies, the brick and tile factories came under the control and management of the Ceylon Ceramics Corporation, which then proceeded to establish factories in Bingiriya and Udawalawe. In addition, the State took over two factories belonging to the private sector - the first at Kelanimulla belonging to Ceylon Potteries and the second the Noorani Tile Works at Kochchikade. Herath (1975) has estimated the total clay requirements for the brick and tile industry covering the private and public sectors as well as the cottage industry at 2 360 acre feet. At an average working depth of 2.5 m this will involve a land utilisation of approxiately 120 hectares (300 acres) annually. The reclamation of such land used as a source of clay needs careful consideration. Most clay workings stop when water is encountered though in some localities good quality clays suitable for the industry are available at greater depths.

The Ceylon Ceramics Corporation

The Corporation has played a major role in the development of the ceramic industry in Sri Lanka. In addition to the brick and tile factories, two kaolin refineries are operated by the Corporation - at Boralesgamuwa and Meetiyagoda - with a combined production of 7 500 tons annually. The entire production is utilised in the local ceramic and paper industries. The Corporation also operates two ceramic factories - Negombo and Piliyandala - the former producing crockery and the latter crockery, wall tiles and sanitary ware. Lanka Porcelain Limited, a subsidiary of the Corporation, produces high grade tableware for export at its plant at Rattota, while Lanka Wall Tiles Limited, also a subsidiary of the Corporation, produces wall tiles and mosaic tiles for export markets. The most recent project is its actory at Dankotuwa which produces high grade tableware also for export markets. In addition, the Corporation is responsible for the mining and processing of the ball clay deposits at Dediyawala. The location of the kaolin deposits and the factories based on the clay deposits are shown in Fig. 7.

Fig.7



Chapter XI

GEMS

When we talk of gems it is necessary to know what exactly we mean. Excluding some gems of organic origin, such as coral and pearl, all other gem material consists of coloured varieties of minerals possessing certain special properties which distinguish them from other mineral species. The first and most important of these is that the mineral has to be rare. For however beautiful it may be, a stone that is common and available in abundance cannot be classed as a gem. Secondly, to be classed as a gem the mineral has to be beautiful and this beauty may manifest itself in colour as in the precious ruby, sapphire and emerald; or lustre, what is termed "fire" as in the diamond. The optical properties that cause brilliance and fire are the index of refraction and dispersion. Thirdly, the mineral has to be hard and durable. Hardness may be defined as the resistance to scratching and abrasion, and Moh's scale of hardness is commonly used as a measure of the hardness of minerals. The scale consists of ten minerals arranged in order of decreasing hardness starting with diamond 10, corundum 9, topaz 8, quartz 7 and so on. The great majority of gems have a hardness of 7 and over. It is because

of this last property of hardness and durability, with resistance to chemical change, that gem material is preserved throughout geological ages.

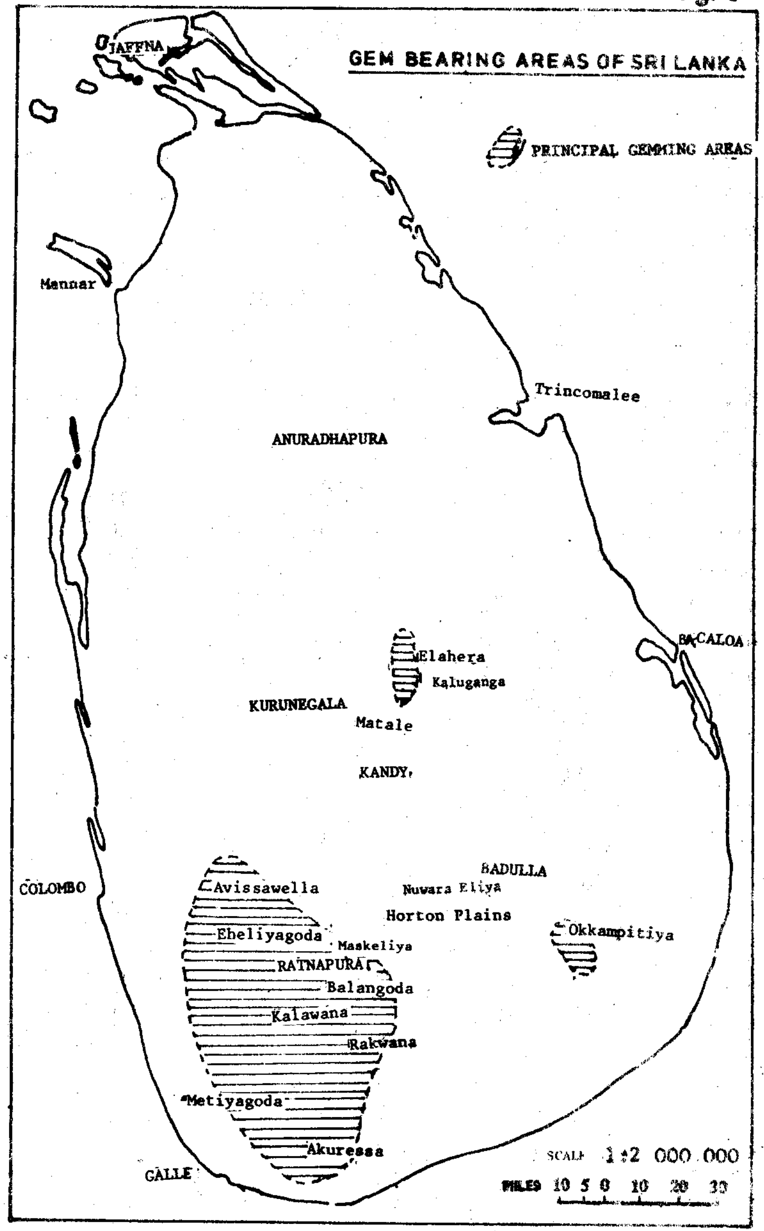
Gem material falls into two broad categories - precious and semi-precious varieties. Sapphires and rubies, including their star varieties, and cat's eye which is a variety of chrysoberyl are commonly regarded as precious stones, while gem material such as beryl, topaz, garnet, zircon, spinels, tourmaline, quartz and moonstone fall into the second category.

The best known and most prolific gem producing area in the Island is the Ratnapura district of the Sabaragamuwa province, the most extensively gemmed areas being the neighbourhood of Eheliyagoda, Kuruwita, Ratnapura, Pelmadulla, Balangoda, Kalawana and Rakwana. The Sabaragamuwa catchment drained by the Kalu ganga, the major river in the area, has an area of approximately 4 500 square kilometres. It is also of interest that this region is an area of heavy rainfall, and is subject to serious flooding during the wet seasons. Smaller extensions of the Sabaragamuwa gem fields are found in the Western and Southern provinces. All these areas are the traditional gem areas where gem mining has been going on for centuries. But mining activity in the past three decades or so in the upper reaches of the Menik ganga in the neighbourhood of Buttala and Okkampitiya in the Uva province, and still more recently in the Elahera area in the Matale North district of the Central Province, indicate that the gem bearing areas are not confined to the south-west sector of the Island (Fig. 8). Further prospecting operations in these new regions are likely to reveal gem bearing gravels though they are unlikely to be as extensive or as prolific as the Sabaragamuwa gravels. Other locations which have produced some stones in the past are the Nuwara Eliya basin, the Horton Plains, Maskeliya and the Kandy district.

With the exception of moontones, which are obtained from partly altered pegmatites, near Ambalangoda, all other gem material is obtained from alluvial deposits of rivers and streams, or in abandoned channels, draining regions containing gem bearing crystalline rocks. The gem material is thus of secondary origin, occurring as worn fragments or rolled pebbles in gravel beds inter-layered with beds of sands and clays. The gem material in the gravel beds represent the chemically inert material brought down during past geological ages by the action of streams and rivers and deposited in the low lying valleys and swamps and preserved during transport and the rolling action of water due to their superior hardness. Other minerals of non-gem variety which possess similar characteristics are associated with the gem material in the gravels; examples of these are ilmenite, thorianite, baddeleyite, geikielite and others.

The gravels are thus formed by the action of running water in streams and rivers and laid down in their beds or in their flood plains. During times of heavy floods, the carrying power of the streams is increased several fold and the load of heavy material

Fig. 8



is carried further away, whereas in the dry seasons the carrying power is limited and deposition takes place much nearer the source of the material. Sudden drop in velocity for any reason has the same effect and results in deposition; this commonly happens when a mountain stream falls into a slower moving main stream. Further, deposits laid down in one geological age may be eroded and deposited elsewhere in another geological age. As a consequence of the capricious behaviour of streams and rivers, the gem bearing gravels do not have any great lateral extensions. Rather they tend to occur as pockets, lenses and streaks in layers of sands and clays with much barren ground in between and the gravels are strictly local in their distribution.

The depth, character and composition of the gem gravels vary considerably from place to place and even in a particular location, but one thing they all have in common is the presence of rounded pebbles of ubiquitous quartz varying from half inch to several inches. The overburden capping the gravels consists of layers of sands, sandy clays, ferruginous sands, clays and peaty clays. The thickness of the gravel beds also shows much variation from a few centimetres to a metre and more. Their depth also varies, from shallow depths less than three metres to twenty metres and more. The gem bearing layer is known as the "illam" and it generally rests on the decomposed rock which is normally highly kaolinised. The altered rock base is referred to as the "malawa" by the gem miners. In several locations, more than one gravel layer is present and where this is so, the lowest layer is the most prolific in gems. The pits are stopped when the altered rock is encountered.

Methods of Gem Mining

Depending on the mode of occurrence of the gem bearing gravels, three principal methods of mining are employed; they are —

(*a*) surface placer mining;

(*b*) gemming by pits; and

(*c*) gemming by dredging river beds.

Where the pay gravel is in superficial soil layers within a few feet from the surface, as for example in dry 'deniyas' or in the bottom slopes of relatively high undulating ground, the land is worked by open cast mining (quarrying) after the removal of any vegetation. The gravel which is rarely thick or extensive in such occurrences is excavated and washed in running water in a nearby stream or in improvised sluices, resulting in the removal of the light materials such as sands and clays leaving the heavy residues from which the gem material is hand picked by the experienced miner.

Where the overburden of sands and clays is thick and the gravels occur at some depth, the commonest method of extraction is by sinking pits. Their depth varies with the depth of the gravels from five to twenty metres and more. The shaft is divided into two chambers by a partition in the centre, one for excavating and bringing up the gravel from the bottom and the other for de-watering the sump. When the gravel from one chamber is excavated completely, it is then used for de-watering and excavation of the gravel commences in the other chamber. The sides of the shaft are propped up with rough logs or planks to prevent caving in of the loose soft strata. The illam is brought up in baskets by relays of workers until a fair sized dump is accumulated at the pit-head; it is usually covered with bracken. De-watering is commonly by the use of buckets, though some of the larger pits use pumps for this purpose. When the gravel has been completely excavated, mining is stopped and washing of the gravels commences. The gravel is washed in large, shallow wicker baskets in a nearby water course such as a channel or in a small pond made artificially. At each turn of the basket, a portion of the rim is depressed below the water surface and in the same movement some of the light materials such as clay and sand are swept over the rim by centrifugal force. Experienced miners show a high degree of skill in washing and succeed in removing all the light material leaving only any gem material present as well as other heavy minerals such as ilmenite.

The great majority of pits are simple shafts without any lateral galleries or headings. Where the bottom of the shaft is above the ground water table, adits or tunnels are driven along the illam layer but they do not extend far because of the problem of ventilation. At times adjoining pits are interconnected by tunnels. In some of the deeper shafts where the cost of excavation is high, lateral drifts are driven in all directions from the base of the shaft so that as much gravel as possible is collected through a single shaft. This is by far the commonest method of gemming and in

heavily gemmed areas the ground is riddled with pits and connecting tunnels. In the early years of the century, Coomaraswamy commented "a gemmed out deniya should be seen to be appreciated; the place is turned into a rabbit-warren of pits and tunnels, and if the illam is good every pound of it has been excavated and washed".

The third method of gemming in river beds is less common and calls for more arduous and prolonged operations. A low, temporary, brush-wood dam is built across a stream to increase the flow of water at a selected spot. Long-handled shovels up to twelve metres or more in length with mammoty heads at the ends are employed by six to eight men to drag the river bed at a point upstream of the temporary dam. The men standing in a row across the stream scoop out a hollow by removing the sand and exposing the illam layer in the river bed. The overburden of sand and silt is carried away by the agitated water and the coarse material and the gravel comprising the illam is raked up and collected in a low ridge. This partly sorted illam is next removed in baskets to the bank of the stream and the gravel washed in the usual way. This method of gemming can only be employed when the gravel occurs at shallow depths.

The methods of mining employed are simple, almost primitive, using only manual labour and with the exception of pumps no mechanical means are used. They involve little capital outlay and are time honoured methods which are quick and reasonably efficient and particularly suited to the nature and mode of occurrence of the gem bearing gravels. Besides, mining is seasonal and normally extends from December to May as most of the gem bearing lands are flooded or partly submerged during the wet season. With sporadically distributed gravels, the use of mechanical means of excavation or dredging is not feasible. Some degree of mechanisation has been introduced in recent years for the washing of the gravels, such as the use of jigs, but these have not been entirely successful.

Deraniyagala (1958) from a study of the bones and teeth of terrestrial mammals and some fossil wood in a fair state of preservation came to the conclusion that gravels were of Pleistocene age. Wadia and Fernando (1944) had earlier pointed out that the gem material does not belong to any particular age as erosion of the parent rocks proceeded continuously throughout the geological ages. Zircons from some of the gem gravels have given ages around 560 million years, though this does not imply that the gravels are of this age. Although a Pleistocene age is likely for the majority of the gravels, it is certain that not all the gravels belong to this age, or for that matter to any particular age. It is far more likely that the concentration of gem bearing material has gone on for past geological ages with each new cycle of erosion even from the earliest Pleistocene and extending to sub-Recent times.

The Gem Varieties

Sri Lanka has long been known as a source of precious and semi-precious stones. In the Scriptures, there is a reference to gems being brought from Ceylon to the Court of Solomon. The great historical record of Ceylon, the Mahavansa, refers to the singular reputation of the Island for its gems. Although the early history of the Island is clouded in some obscurity, there is little doubt that rumours of the wealth of the Island, at times no doubt exaggerated, had reached the Western world and several Greek writers refer to the reputation of the Island for its gems. Ptolemy, the Greek astronomer of the second century, refers to beryl and sapphire as products of Ceylon. His information, particularly about the coastal belt of the Island, is surprisingly accurate and has given rise to conjecture as to the source of his information. It is probable that his informants were sailors who had actually visited the Island. Even in these early times, Ceylon had attained some importance in view of its geographical position. The reputation of the Island for its gems was also known to the Chinese and records exist in historical works to show that Chinese vessels called at Ceylon from the fourth century onwards for trade. The records mention that "pearls, crystal and gems were the most eagerly sought after" and that the gems consisted of "rubies, sapphires, carbuncles and topazes of four distirct tints". In the thirteenth century, Marco Polo, the Venetian traveller, who visited Ceylon on his home-ward journey from China, refers to the gems of the Island, and records that he found the Moors, the descendants of the Arabs, in undisputed possession of the trade in gems.

Despite centuries of gem mining, Sri Lanka is still one of the most important gem producing areas of the world and the most important source of sapphires, spinels and zircon. Corundum, which is the oxide of aluminium ($Al_2 O_3$), is the most important gem mineral in Sri Lanka. Second in hardness only to diamond, corundum includes sapphire (blue) and ruby (red), but also includes other colours such as yellow, pink and colourless varieties. The most highly prized stones are the royal or corn-flower blue, and the price for a flawless, deep blue stone may be as high as US $ 5 000 per carat. Sri Lanka also produces star varieties of both ruby and sapphire which exhibit a six-rayed star in a dome or cabochon form.

It is interesting to note that some of the finest sapphires were produced in Kashmir where the deposits lie in a small valley in the north-west Himalayas at an elevation of around 4 570 meters (15 000 feet). Because of the inaccessibility of the mine and the severity of the climate there has been no production in recent years. Other areas producing sapphires are Cambodia, Thailand, India and Australia though the stones are of poorer quality. The most notable locality for rubies and for some sapphires is the district around Moguk in Upper Burma, where the rough gems are found in extensive gravel deposits as in Sri Lanka. Zircons and spinels are also recovered from these deposits.

Chrysoberyl - beryllium aluminium oxide ($BeO. Al_2O_3$), is another of the highly prized gems of Sri Lanka. There are two varieties - alexandrite and cat's-eye - both of which exhibit unusual properties. Alexandrites have the property of changing colour depending on the nature of the light; in daylight they appear green and red in artificial light. They are

only found in Sri Lanka and in the Ural Mountains of the Soviet Union. Cat's-eye chrysoberyl displays an optical phenomenon somewhat reminiscent of the star sapphire and a bright line or band of light appears across the surface of the stone when it is cut cabochon. The position of the band alters as the stone is rotated and it is this striking phenomenon suggestive of the eye of a cat that has given the name to this stone. Sri Lanka is the main source of this gem variety. Most people are familiar with two of the beryllium minerals - the beautiful grass-green, transparent, highly prized precious stone, emerald, and the pale blue or greenish-blue, semi-precious aquamarine. The former has not been recorded in Sri Lanka, but the latter is found as a fairly common constituent of the gem gravels. The typical home of beryl is in granite pegmatites, where in rare cases the crystals can attain enormous dimensions A crystal in Maine in the United States measured 5.5 metres (18 feet) long and weighed 19.6 m tons. Similar crystals almost as large have been reported in the Namaqualand in South Africa; these are exceptional occurrences and not of gem quality. The distribution of beryl in pegmatites is sporadic and deposits containing beryl can be worked only when other minerals such as felspar and mica are the major products. Other sources of gem quality beryl include Brazil and Columbia.

Though the name garnet is loosely applied to a single mineral, the name includes a number of closely related species crystallising in the cubic system. They are complex aluminium silicates varying widely in chemical composition and thus exhibit a variety of colours. The best known are pyrope, red in colour, and almandine varying from crimson to violet-red. Other garnet gem varieties include spessartite and grossularite in varying shades of yellow-brown to brownish-red and brownish-orange, while andradite yet another variety is green. Garnet is a common constituent of several types of igneous and high grade metamorphic rocks. Besides Sri Lanka, other productive areas of the gem variety include India, Malagasy, Tanzania, Brazil, and the Soviet Union.

When transparent, the mineral zircon, a silicate of the metal zirconium, serves as a gemstone. It may be colourless but more often is brownish, or reddish-orange or yellow in colour. These coloured varieties are generally known as hyacinth, while the colourless and smoky varieties are often referred to as 'jargon'. By heat treatment some of the coloured zircons can be changed to blue. Topaz is a a fluor-silicate of aluminium in which part of the fluorine is replaced by hydroxyl. When perfectly pure, topaz is clear and colourless but most have pale colours in varying shades of yellow and brown, and occasionally pink. The mineral occurs in the gem gravels of the Ratnapura district as colourless water-worn pebbles which at times attain a considerable size; it has also been recorded from pegmatites in a number of localities. Flattened, colourless and water clear, sub-rounded masses have been recorded from the Owella area in the Matale North district. The most valued topaz is from Brazil.

Although the true spinel is a magnesium aluminate with the formula MgO. Al_2O_3, the name is given to a group of closely related minerals crystallising in the cubic system and having the general formula $R''O.R'''O_3$ where R'' is magnesium, ferrous iron or zinc and R''' is aluminium, ferric iron or chromium. The mineral is variable in colour from a deep red to other shades of red, orange, yellow, green, blue and black. The magnesia spinel is the deep red transparent variety and is often referred to as 'spinel ruby.' Ceylonite is the iron rich variety of spinel and varies in colour from green to black. Spinels are common in the gem gravels and are often found as perfect octahedra which are generally opaque and hence of no value as a gem. Spinels are also found as small grains often showing good crystal form in crystalline limestones and dolomites of the Highland Series but are too small to be of value as gem material.

Quartz is the oxide of silicon (SiO_2) and is common in the gem gravels. Where the mineral is water clear and colourless, it is popularly known as rock crystal and is employed in cheap jewellery and also for making optical glass. Amethyst is the clear purple or violet variety; rose quartz the pink; citrine the yellow; and cairngorn the smoky variety of quartz, this last variety being named after the mountain in Invernesshire where it is chiefly found. Well shaped crystals showing hexagonal prisms terminated by pyramidal faces are found in pegmatites and in rock cavities. One of the most important sources of crystal quartz is Brazil.

Other gem varieties include tourmaline which displays a remarkable variety of colours and is a common constituent of the gem gravels, though most of it is opaque and non-gem variety; andalusite, which is an aluminium silicate, and found occasionally as water-worn masses in the gravels; cordierite, which is a hydrated magnesium aluminium silicate with ferrous iron replacing part of the magnesium, the so called "water sapphire" of jewellers; and apatite, which is a calcium phosphate with fluorine, the gem variety of which varies from a blue to a bluish green, but is not common. Other rare gem varieties include kornerupine and ekanite. Special mention must be made of moonstone for with rare exceptions, moonstone is the only gemstone obtained from primary deposits of the mineral. Moonstone is a variety of orthoclase felspar with a characteristic bluish white or milky opalescence on account of which the mineral has attained some value. This optical phenomenon is due to an intergrowth of orthoclase and albite felspar resulting in internal reflection and giving a 'schiller' effect. The stone is usually cut cabochon. In the early part of the century, moonstone was obtained from the Dumbara district of the Central province where the mineral was found in acid granulites and gneisses belonging to the Highland Series.

Several pits were in existence on Rajawela estate at Haragama from which good quality moonstone was recovered; other pits were situated at Talatu-oya and these provided almost the entire world's supply

of moonstone at the time. The pits were shallow, rarely exceeding ten metres, and supplies were soon exhausted. Subsequently, moonstone was found at Metiyagoda, near Ambalangoda, and this is now the sole source of the mineral. The moonstone occurs in a partly kaolinised pegmatite in a swamp. Hand borings have shown that the pegmatite underlies the greater part of the swamp with an overburden of peat and clay, and the moonstone is recovered from pits.

Pearl is a gem material formed by a biological process and strictly speaking is not a mineral. There are few gems more beautiful than the pearl and pearls have been highly prized from pre-historic times. The finest pearls are found in the Persian Gulf off the Island of Bahrain, while another major occurrence is in the Gulf of Mannar which separates Sri Lanka from India. The Sri Lankan pearl banks have been known from the earliest times and reference is made to the export of pearls from Ceylon in the writings of the early Greeks and Pliny records Taprobane as "the most productive of pearls of all parts of the world". The most profitable series of fisheries from the banks in the Gulf of Mannar were in the first decade of this century but there have been no pearl fisheries since the mid-twenties. It is possible that the pearl beds have been impoverished by wasteful methods of collection and possibly by excessive tonnage of silt brought down by rivers discharging into the Gulf following the opening up of land for cultivation. With the great popularity of pearls, it is not surprising that experiments have been undertaken to stimulate artificially the growth of pearls in the marine organisms responsible for them. These experiments were successful particularly in Japan and culminated in the commercial production of cultured pearls by Mikimoto in the early twenties. The cultured pearl industry is now a major industry in Japan, and natural pearls have become relatively rare.

The Gem Mining Industry

Under the Mining Laws of Sri Lanka, the State is the sole owner of all minerals whether found on the surface or beneath it, and no person can mine or otherwise exploit gems without the authority of a licence. Licences to prospect for gems are not normally issued unlike in the case of other minerals, and the right to gem on a defined area of land or stream reservation is sold by tender or auction, a reserve price being fixed beforehand. Gemming rights are not normally leased out on a royalty and/or rent basis unlike in the case of non-gem minerals. Once a licence is issued for gemming, the actual mining of the property is carried out on a remarkable system of co-operative sharing of labour, expenses and profits, and the output of the venture is distributed as follows -

Ground rent for the owner of the land ..	20 percent.
Lessee or licence holder's share ..	10 percent.
Financier's share ..	35 percent.
Miner's share ..	35 percent.

Thus each individual engaged in gemming gets a share. This system of sharing is unique in mineral economics and has been the mainstay of the gem industry where the risks are high.

Until recently gem cutting was entirely by primitive machines operated by hand and no mechanical or electrical appliances were utilised. In recent years modern machinery has been introduced to the gem cutting industry and machine cut gems of good quality are now readily available. Exports of gemstones from Sri Lanka in the sixties and early seventies show considerable variation, from 60 000 to 196 000 carats with values ranging from 1.3 to around five million rupees. The variation in value is accounted for by the quality of the stones exported but the figures are unreliable as it is widely recognised that gemstones are taken out of the Island by illicit means.

With the exception of diamond, it is very difficult to assess the real economic importance of gems as an earth resource. There are many reasons for this. In Sri Lanka, as in many other countries, most gem deposits are small and not suited to mining on a large scale employing highly mechanised methods. Mining is not generally carried out by large companies with vast resources at their disposal, but rather by individuals or small groups of miners. Illicit mining is also rampant. Accurate production and export figures are thus not available. Much of the rough stones as well as cut stones leave the Island through illegal channels and this is true of some other gem producing countries as well. Official figures are, therefore, largely meaningless.

The State Gem Corporation

The State Gem Corporation was established in November 1971 by an Act of Parliament - No. 13 of 1971. It functions under the Ministry of Finance and its chief activities are the administration, control and the development of the gem industry. Licences and permits for gemming are now issued by the Corporation and all exports of gemstones have to be channeled through the Corporation. A modern Gem Testing laboratory has been established by the Corporation and its services are also available to the trade. Exports of gems which were almost negligible in the period before the setting up of the Corporation have shown a spectacular increase, and even making an allowance for the reduced value of the rupee, the export figures reveal the substantial gains achieved from the setting up of the Corporation and the increasing confidence of the producers and the trade in the Corporation. Peak export figures of over Rs. 600 000 000 were achieved in the years 1980 and 1981. The Corporation also turns out jewellery for export but this is relatively insignificant. Statistics of gem exports for the period 1972 - 1983 are furnished in Table XVII.

TABLE XVII
GEM EXPORTS — 1972 - 1983

	Private Rs.	*Corporation Rs.*	*Total Exports Rs.*
1972 -	8 828 888	6 667 496	15 496 384
1973 -	127 993 993	24 987 186	152 981 179
1974 -	116 981 191	15 953 257	132 934 448
1975 -	178 307 418	10 643 065	188 950 483
1976 -	278 357 572	8 790 138	287 147 710
1977 -	242 934 217	10 928 131	253 862 348
1978 -	442 467 681	82 583 244	525 050 925
1979 -	449 548 207	45 201 478	494 749 685
1980 -	598 296 058	65 402 843	663 698 901
1981 -	624 065 249	8 442 449	632 487 689
1982 -	385 894 043	7 456 446	393 350 495
1983 -	510 122 461	1 399 799	520 522 260

Authority: State Gem Corporation.

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