Natural Resources Series – No. 1

ECONOMIC GEOLOGY OF SRI LANKA

J. W. HERATH

NATURAL RESOURCES, ENERGY & SCIENCE AUTHORITY OF SRI LANKA

Natural Resources Series – No. 1

ECONOMIC GEOLOGY OF SRI LANKA

J. W. Herath

Natural Resources, Energy & Science Authority

47/5 Maitland Place

Colombo

F O R E W O R D

One of the activities of the Working Committee on Natural Resources of the Natural Resources, Energy & Science Authority is the publication of material pertaining to the natural resources of Sri Lanka.

The Committee noted the fact that, in some cases, information on a natural resource is not readily and easily accessible in a published form, even in the institution dealing with the resource. To remedy this situation the Committee suggested that information available in the different areas be collated and published as a series of manuscripts. A manuscript on a particular natural resource will contain up-to-date information on the subject and it should serve as a guide to those seeking information on the resource. It will be of special use to those interested in natural resource development.

In this series we are hoping to cover the fields of economic geology, water resources, climate, soils, land and land utilization, energy, and population and manpower. The Committee has selected experts in the respective fields to prepare these manuscripts. The manuscripts were examined by referees before being accepted for publication.

I wish to thank the Working Committee on Natural Resources and in particular the authors who prepared these manuscripts and the referees and editors for the work they have done to make this project a success.

Dr. R.P. Jayewardene
Director-General

Natural Resources, Energy & Science Authority,
47/5, Maitland Place,
Colombo 7.

PREFACE

The development of interest in the mineral resources of Sri Lanka has led to an increased demand from students for information on the subject The texts available hitherto have been those published by the Geological Survey Department of Sri Lanka on the Economic Minerals of the Island including Economic Bulletin No. 1 on the Mineral Resources of the Island. The present text is an attempt to supply information at a level suitable as an introduction for graduate students, for undergraduates in the various sciences, and possibly for senior school students who wish to learn something of the aims and achievements in this field of scientific study.

This text was prepared in response to a suggestion by the Working Committee on Natural Resources of the Natural Resources, Energy and Science Authority of Sri Lanka. This volume presents up- to- date information on the mineral resources of the country and on activities dependent on the available industrial minerals. The text is intended to be an introduction to the subject. If the reader concludes the text with a feeling that our knowledge of the economic minerals of Sri Lanka is incomplete at the moment, one of the objectives will have been achieved. There is still much to be learnt about our mineral wealth.

The topic "Water Resources of Sri Lanka" has not been dealt with in this book since it will be the subject of a separate volume in this series.

Although I have had personal experience of most aspects of the subject discussed, I have relied very much on the results and interpretations of others in order to present an adequate coverage of the subject. I am indebted to many geologists and to others in related fields whose works I have consulted in texts and journals in assembling the material for this book. In particular I wish to thank Mr. L.K. Seneviratne (Director) and Mr. D.E. de S. Jayawardane (Deputy Director), Geological Survey Department, for their help in the preparation of this book.

I should also like to record my sincere thanks to Mr. L.J.D. Fernando (Consulting Geologist and former Director of the Geological Survey Department) to whom NARESA referred the manuscript for comments and observations, for reading the text in typescript and making numerous detailed suggestions for its improvement, nearly all of which I was pleased to incorporate. I am also indebted to Mr. L.C.A. de S. Wijesinghe, Addl. Director General, NARESA, for kindly agreeing to edit the text before publication.

Writing this preface after the rest of the work has been completed, I feel a certain measure of satisfaction with the result, and I therefore should like very sincerely to thank the Natural Resources, Energy and Science Authority, whose idea it was that this book should be written, for having chosen me to do it.

Oceanography Unit
National Aquatic Resources Agency
Crow Island - Colombo 15
January 1985

J.W. HERATH

CONTENTS

CHAPTER I

INTRODUCTION

A study of the history of human civilization demonstrates man's urge to understand nature and to utilize the knowledge thus gained to meet his material needs. Early man of the 'Stone Age' gathered his food by hunting. As civilization progressed, man's relationship with nature underwent a major change in what anthropologists call the 'Neolithic Revolution'. Man discovered the domestication of animals, settlement of villages, manufacture of tools, and agricultural activity. Next came the 'Industrial Revolution' when the demand for raw materials increased enormously. We are now undergoing the 'Scientific Revolution', resulting from the union of science and technology for economic growth and advancement of knowledge. The 'Growth Syndrome' witnessed by this revolution is posing several challenges particularly as a result of the fast depletion of natural resources, mainly mineral and energy resources.

It is a truism that the physical needs of man are met by the products of two basic activities - agriculture and mining. An adequate supply of minerals is therefore essential for the maintenance and improvement of his standard of living. Mineral resources are, for all practical purposes, considered non-renewable. As a generalization, it may be said that the richer mineral deposits of the world have been, or are being, exhausted, and future needs for metals and minerals must be met from larger deposits of progressively lower grade.

Mineral deposits occur at various depths in the earth or at its surface, in various forms, and their importance to man for economic and industrial development is only too well known. The advancement of the human race has been largely based on minerals and their transformation into various metals and other products. Minerals pervade our lives and determine our country's progress. We need minerals for our travel, for commerce and industry, and even for our pleasure and relaxation.

Economic geology deals with mineral deposits - the mineral wealth in the very widest sense. The present alarming consumption of mineral resources and the exhaustion of the known mineral reserves means that new supplies must be discovered. This is where an invaluable service can be rendered by geologists. The geologist's part in this endeavour is to discover and maintain supplies of mineral raw materials without which no country can progress or enjoy a high standard of living.

This book attempts to give an account of the mineral resources of Sri Lanka, together with a brief account of the industrial activities dependent on minerals. In order to appreciate the occurrence, distribution and development of the materials described, mention is made of some aspects of the formation of mineral deposits and of mineral prospecting and exploration, and an account is given of the economic minerals. The physical features of the island including its geology are also discussed together with the need for National Geological Surveys.

THE EARTH

The earth is a planet in the solar system. The solar system consists of planets, moons and other bodies, including a central star, which is the sun, having a surface temperature of $6000^{0}C$. The planets and other bodies revolve round the sun, approximately in the same plane. This would also mean that they all formed together, and different parts of the solar system should therefore have similar ages. The oldest rocks from the moon record an age of around 4600 million years; meteorites (rock-like bodies or objects sometimes reaching the earth) have been dated at 4550 million years and the age of the earth's crust has been calculated as 4550 million years. These ages suggest that the solar system is about 4600 million years old. How exactly the solar system was formed is not yet clearly known.

The earth has a circumference of approximately 40,000 km (25,000 miles). In addition to its journey round the sun, it also rotates from west to east and makes one complete rotation every day. It is this rotation which gives us night and day. The earth also revolves round the sun once every year, and on the average it remains about 149 million km (93 million miles) away from the sun. Most planets have smaller bodies called moons which revolve round them. The moon (earth's satellite) revolves round the earth once every 27.3 days at an average distance of 384,000 km or 239,000 miles. The moon has no atmosphere and therefore no life forms.

The earth's interior has a layered structure. The outermost layer is the crust, and beneath this is the mantle and then the core. Scientists cannot study the interior of the earth directly.

The earth consists of air, water and land. We recognize these more technically as the biosphere which sustains life possible on our planet. The hydrosphere includes all the waters which cover roughly 71 percent of the earth's surface. The floors of the oceans are very irregular, similar to the surface of land, and they also include mountain ranges. The deepest ocean is the Pacific which is more than 10,700m (35,000 feet) below sea level south of the Mariana Islands. Of prime importance to the geologist is the lithosphere, the solid part of the earth which is composed of minerals and rocks. These comprise the continental masses and ocean basins. The continental rocky platforms cover approximately 29 per cent of the earth's surface. The highest point on the continents is Mount Everest in the Himalayas which is 8848 m (29,028 feet) above sea level. The deepest drill hole has reached a depth of 11,662 m (The Kolsky super deep well USSR - 1983). Studies on continental geology have suggested that the continents are not immovable, but are drifting fragments, shields or plates, derived from the break-up of an ancient supercontinent. The evidence for this has come from the way certain continents, now far apart, seem to fit together, and how geological structures and formations seem to join up across such a fit (Fig. I). The distribution of certain plants and animals in the past as well as ancient climatic zones could not be satisfactorily explained unless the theory of continental drift is accepted. These considerations suggested that South America, Africa, India, Antarctica and Australia were at one time united and formed what is now referred to as Gondwanaland, a southern super-continent. This super-continent eventually broke up in stages some 200 million years ago to form the present day continents.

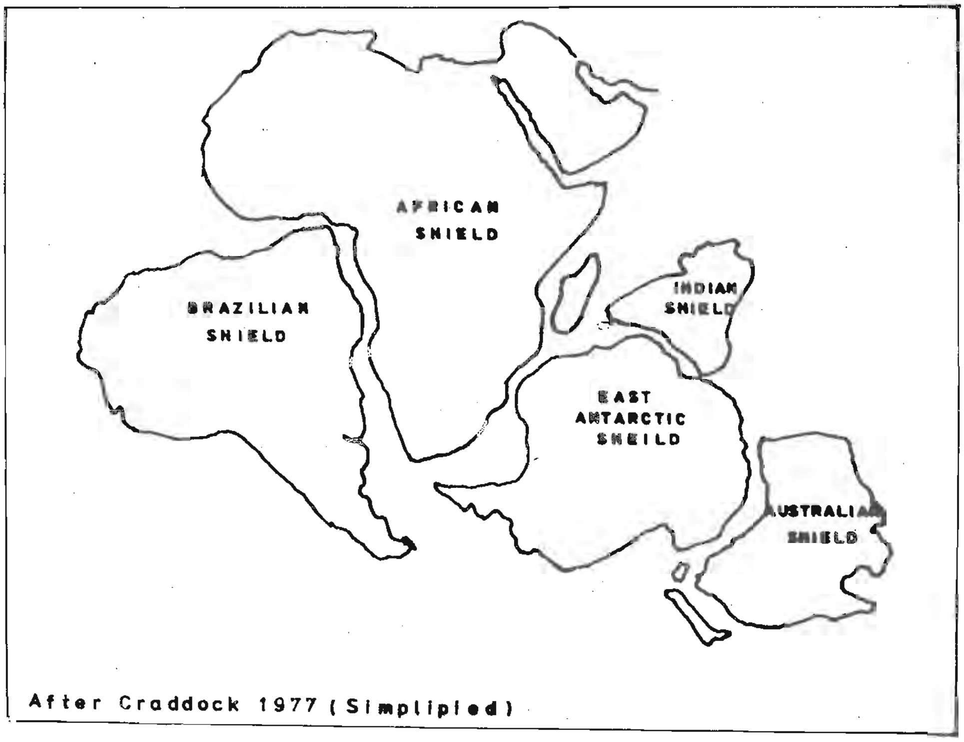


Figure 1. Tectonic Reconstruction of Gondwanaland before Fragmentation (Craddock 1977)

The theory of continental drift was developed in the late 1800's and because there was virtually no scientific evidence for the movement of the continents the theory was generally ignored. In the 1960's, however, extensive studies of the sea floor produced dramatic evidence that the continents and the rest of the crust had in fact moved about and are still moving. This new evidence led to the concept of plate tectonics (tectonics refers to the formation and structure of the earth's crust). Beneath the crust of the earth (6 to 25 miles thick) lies the mantle (1800 mile thick region of hot mineral matter) which is separated from the crust by a thin zone called the Mohorovicic discontinuity or Moho. Some distance beneath the Moho is a 120 mile thick layer of relatively weak mantle that earth scientists call the asthenosphere. The rigid portion of the mantle just below the crust is termed the lithosphere. The asthenosphere is believed to be weak due to the tremendous heat conducted from below, which brings the layer nearly to its melting point. It is believed that the lithosphere moves slowly about on the asthenosphere. This movement is the basis of the plate tectonic concept. It is believed that the lithosphere consists of a number of huge plates or sections that move about on the asthenosphere. The movement begins along a 40,000 mile long feature called the mid-ocean-ridge that lies beneath the world's oceans. Spreading of the lithosphere plates occurs when magma (molten material) is forced upward from the asthenosphere towards a weak area along the middle of the ridge. It appears therefore that the continents - and the earth's entire crust have been moving slowly over the face of the earth. The process continues today as can be seen from such phenomena as the widening of the Atlantic ocean, the northward sliding of coastal California and the continued upthrust of the Andes mountains.

FORMATION OF MINERAL DEPOSITS

The earth manifests many wonders of the world in which we live. We live on a planet whose continents and ocean basins are in a state of constant change. The earth's history is divided into a number of major eras. The oldest era (Azoic - without life) represents the earliest prehistoric period during which the crust was formed. No life forms are known from this era. The sequence and duration of the geological divisions are given in Table I. The general succession of geological formations present in Sri Lanka is also presented in this Table. It is seen that formations of rocks representing the Palaeozoic era are entirely absent in Sri Lanka. While the Miocene is well represented, only a very fragmentary part of the Mesozoic is seen in the Island. Pliocene, Oligocene, Eocene and Palaeocene formations have, however, been identified only in drill cores (petroleum exploration) from the Mannar area.

TABLE I

SEQUENCE AND DURATION OF GEOLCGICAL FORMATIONS

Era	Period	Epoch	Sri Lanka	Million Years Ago
CENOZOIC	QUATERNARY	RECENT	PRESENT	
		PLEISTOCENE	PRESENT	1
		PLIOCENE	....	
	TERTIARY	MIOCENE	PRESENT	10-25
		OLIGOCENE	....	
		EOCENE	....	
		PALAEOCENE	....	
				70
MEZOZOIC	CRETACEOUS		....	
	JURASSIC		PRESENT	135-180
	TRIASSIC		....	
				220
PALAEOZOIC	PERMIAN			
	CARBONIFEROUS		ABSENT	
	DEVONIAN			
	SILURIAN			
	ORDOVICIAN			
	CAMBRIAN			
				600
PRECAMBRIAN	PROTEROZOIC		PRESENT	1,000
	ARCHAEOZOIC			3,000
	AZOIC		....	3,000-6,000

The crust of the earth consists of minerals and these occur as solid masses of rocks. Mineralogy is one of the geological sciences concerned with the study of the earth's crust - the science of minerals. An important characteristic of a mineral is that it has a definite chemical composition and atomic structure and is formed by inorganic processes of nature. Rocks occuring in the earth's crust are composed of a mixture of various minerals. Rocks are, however, not homogeneous and have no definite chemical composition. Rocks of various origin are recognised: igneous, sedimentary and metamorphic.

Igneous or magmatic rocks are formed from molten magma or lava. The term magma is applied to the molten material while it still lies below the surface of the earth, and "lava" means molten material which is forced out of the earth's surface and which cools to form rocks. Molten magama originating at depth and moving towards the surface consolidates to form a variety of intrusive rock types. The most common igneous rock type is granite. The most widespread type of lava which consolidates on the surface is basalt which is volcanic igneous rock or a surface form of extrusive igneous rock that is commonly found in lava flows. A single magma cooling at different rates, may produce many types of rocks as different minerals crystallise out at different temperatures. This process gives rise to a large igneous body with zones of different minerals and different textures.

Sedimentary rocks originate at or near the earth's surface under much lower temperatures and pressures than the igneous rocks. Most of them are deposited in rivers, lakes and seas. The sediments producing these rocks have been formed by the destruction of the continents by erosion agents. These sediments are converted into rock by cementation and compaction. Sedimentary rocks have been classified into a variety of rock types such as shales, marls and sedimentary limestone.

Metamorphic rocks have a more complicated formation history. It is a modified sedimentary or igneous rock that has been subjected to high pressures and temperatures and to the chemical action of substances escaping from inside the earth. Such conditions originate at great depths. Under metamorphism, rocks lose many or all of their characteristics and they change in response to new environmental conditions, developing new structures and new minerals. Many types of metamorphic rocks are recognised, for example, gneisses, migmatites, marbles and quartzites.

Economic mineral deposits are geological bodies which may be mined to recover one or more minerals or metals and the term 'ore' is used for such deposits. Ores may yield a single metal or several metals and the worthless material which goes as waste is referred to as "gangue". All mineralization may be conveniently grouped into three main types: magmatic, sedimentary and metamorphic.

Magmatic Mineralisation

Most minerals are formed as a result of the solidification of the magma - a molten rock mass lying deep in the interior of the earth, which is frequently ejected to the earth's surface by volcanic eruptions. Volcanoes erupt on the land and on the floors of seas and oceans. Eruptions take the form of a succession of explosions, accompanied by discharges of solid material (volcanic ash and bombs) and effusion of lava. The lava may be thin, flowing out over great distances, or viscous and of low mobility. However, volcanic eruptions produce relatively small amounts of minerals, since the magma which reaches the earth's surface is largely devoid of its constituent gases and vapours (which play a major part in the mineralisation processes) and rapidly congeals to form what are known as effusive igneous rocks. A far greater number of minerals separate from the magma as it slowly cools in the depths of the earth, giving rise to intrusive or plutonic (deep-seated) rocks.

Magma consists of a multitude of constituents which are in mutual solution. Its predominant constituents are compounds of oxygen and silica,. but it also contains much aluminium, iron, calcium, magnesium, sodium, potassium, hydrogen, and carbon. In minute quantities, magma contains every known chemical element.

In addition to heavy refractory metals, the magma is saturated with gaseous, volatile substances: compounds of chlorine, fluorine and boron, hydrogen sulphide, carbon dioxide and superheated water vapour. This entire complex molten mass is in a state of equilibrium under the enormous pressure of overlying layers of the earth's crust. At times, certain zones and belts of the earth become the site of powerful mountain-building processes. The layers of the earth's crust begin to buckle, fold or split into enormous blocks. This causes the appearance of fractures, faults and fissures, and sometimes results in the formation of cavities. Through these fissures the magma is squeezed, as it were, to the surface from the depths of the earth.

As the magma approaches the earth's surface, its temperature and the external pressure drop. This disturbs the equilibrium between various constituents of the magma, and as a result they begin to differentiate and crystallise in a definite sequence. Some minerals differentiate almost simultaneously to form the igneous rocks. Volatiles of varying composition rise rapidly, contacting the enclosing rocks, penetrating the fissures, and transforming these rocks, producing in places considerable accumulations (beds, veins or pockets) of various minerals. Gold, tin, tungsten, molybdenum, copper, zinc, and other metal ores form in this way.

The main magmatic chamber continues to cool slowly and turns into an enormous mass of igneous rock, chiefly granite. This is accompanied by the separation of a hot residual magmatic melt rich in silica, sodium, potassium, aluminium and rare metals, which until then had been scattered in the magma.

This residual melt usually congeals to form veins of pegmatites which have large inclusions of feldspar, quartz, and dark and light mica; it may also contain cavities encrusted with crystals of precious stones. Pegmatite veins abound in various minerals - tin, beryllium, tantalum, niobium, lithium and other ores; sometimes they develop characteristic inclusions - intergrowths of quartz and feldspar minerals.

Magmatic processes do not stop at the formation of pegmatite veins. Water vapours from the cooling mass turn into hot aqueous solutions, which rise along fissures, sometimes travelling far from the place of their origin and carrying along with them compounds of gold, tungsten, copper, lead, zinc, antimony, mercury, and other metals. These solutions give rise to hydrothermal deposits, generally in the form of quartz veins impregnated with minerals containing the above mentioned metals.

This is essentially the pattern of the formation of minerals when the magma cools. It is known as magmatic mineralisation and is governed by the flux of energy from the hot interior of the earth.

This picture of mineralisation is, of course, much too simplified. However, one important circumstance should be borne in mind, namely, that in the magmatic process mineralisation proceeds gradually.

Some mineral associations are formed at great depth, within the cooling magma, right in the magmatic chamber; others are formed in a definite order at varying distances from the latter.

Veins containing feldspar, mica and ores of rare metals form at the greatest depth, sometimes in the cooling magmatic mass itself; the minerals of tin, tantalum, niobium, gemstones (tourmaline, beryl, topaz) and gold-bearing quartz veins form somewhat farther from the magmatic chamber. Closer still to the earth's surface come the minerals of tungsten, molybdenum, copper, zinc, lead and silver, which are deposited in a definite sequence by gases and hot aqueous solutions; farthest from the parental magma are the minerals of antimony, the golden-yellow compounds of arsenic, the bright red mercury sulphide - cinnabar, which are precipitated from magmatic waters when they become quite cool.This gradated or zonal development of magmatic mineralisation is of great practical significance because it makes prospecting and exploration easier.

The most essential indication by which magmatic rocks are classified is their silica content. By this indication they are divided into four groups: (1) acidic rocks-granitoids (more than 65 per cent of silica), (2) intermediate rocks-diorites (55 to 65 per cent), (3) basic rocks (40 to 55 per cent), and (4) ultrabasic rock (less than 40 per cent).

Rocks may also be classified by their colour. Acidic rocks are most often light pink or grey, intermediate rocks are dark grey, and basic and ultrabasic rocks are dark to green-black. This gradual darkening (from acidic to basic rocks) is due to the fact that, at the expense of silica, they contain increasing amounts of iron, which together with magnesium, gives them a dark colour.

The presence or absence of quartz is another indication for classifying rocks with a fair degree of accuracy. In acidic rocks the excessive silica segregates in the form of quartz, which is an important constituent of the majority of these rocks. Quartz is found in small amounts or not at all in intermediate rocks. Basic rocks, as a rule, contain no quartz.

Sedimentary Mineralisation

Everything created by orogenic processes is subjected to vigorous chemical and mechanical destruction.

The entire complex of the natural processes of mineral and rock destruction is called weathering.

The combined action of sharp temperature fluctuations, wind, water freezing in rock crevices, and plant roots penetrating into the rock mass, decomposes great blocks which gradually split into chunks, then into smaller fragments, and are finally reduced to detritus and sand.

In addition to mechanical destruction, magmatic minerals are subjected to chemical alteration, of which water is the principal agent. Saturated with atmospheric gases and acid salts, the water penetrates into countless cavities and fissures, and seeping through the minutest crevices infiltrate deep into rocks causing various complex changes. Practically all the minerals formed by magmatic processes, known as primary minerals, yield to the action of aqueous solutions. Feldspars are converted into a white clay called kaolin; iron compounds into iron ores; and primary copper, zinc and lead minerals of ore veins are oxidised into secondary minerals - carbonates, sulphates and phosphates. Only a few minerals, such as diamond, quartz, gold and platinum, resist weathering and separate from the host rock to accumulate in placer deposits.

The products of weathering seldom stay in place. Most are transported by wind, mountain streams, creeks and rivers, which continually carry them to the sea and other bodies of water, as suspended solid matter and as mineral solutes.

Surface or exogenous processes - mechanical and chemical destruction, dissolution, transportation and redeposition of mineral substances - go on continually, for years, centuries, for thousands and millions of years. Everything that is picked up by running water is transported to the lowlands and seas. Layers of loose sediments - sand and clays - are deposited on the sea floor. This is accompanied by the accumulation of the remains of marine organisms. This gives rise to thick masses of limestone, chalk, marls and diatomites. Such is the pattern of the second - sedimentary - type of rock formation.

As a result of the continuous secular movements of the earth's crust, the seas, with time, change their position; in some instances they are cut off as shallow lagoons and finally dry up, leaving salt deposits on their floors. The accumulated mass of diverse sediments is compacted and petrified. Thus, in addition to the rocks formed directly by magmatic processes, in the earth's crust there develop various sedimentary rocks, which not infrequently contain abundant traces and remains of animals and plants which once inhabited the earth. These remains are called fossils.

Metamorphic Mineralisation

Products of sedimentary origin do not remain at rest forever. As a result of crustal movements, they may find themselves in different conditions, sink to a lower depth, or come under the action of high temperatures and pressures.

These conditions touch off new chemical reactions, new processes of rock formation, which, in turn, give rise to new minerals. Thus, at a great depth, limestones are converted into marbles, and clays into hard clayey schist and roofing and other shales; loose sandstones turn into hard compact quartzites. Under certain conditions, magmatic rocks may also be altered into rocks of a different structure and composition (for instance, gneisses). All altered rocks are known as metamorphic (transformed); they often contain numerous important minerals, such as talc, corundum, mica, garnet, andalusite and iron ores.

PROSPECTING AND EXPLORATION

Geological prospecting and exploration concerns itself with the problems of discovering economic mineral deposits. Prospecting covers the whole range of work directed to locating valuable mineral deposits. Once promising areas are recognised, prospecting is immediately followed by exploration. Exploration involves investigations for determining the industrial importance of a mineral deposit, for example, the quality and quantity of the mineral and the natural and economic conditions in which it occurs. The quantity of the mineral is measured by the volume it occupies. The aim of exploration, therefore, is to ascertain the shape and dimensions of the deposit. Quality is determined by a study of the chemical and mineralogical composition and other technological properties.

In the discoveries of many mineral deposits, chance has played a significant role. Many mineral deposits have been located by the old-time prospector who went in search of outcropping or detrital minerals. Their discoveries were due to keen observation and were mainly based on surface evidence. As the geological sciences advanced, many new techniques have been perfected to locate surface and buried mineral deposits. These methods include aerial photography and geochemical, geophysical and drilling techniques. However, one of the prime needs for any systematic search for minerals by modern methods is adequate base maps such as those covering topography, geology and geophysics.

The Geological Survey of Sri Lanka uses topographic maps as the base for geological mapping, and the standard scales used are 1 inch = 1 mile (1:63,360) and 2 inches = 1 mile (1:31,680). All topographic maps are obtained from the Survey Department of Sri Lanka. The scope of geological mapping undertaken depends on the purpose for which the map is required. In some instances areas of interest may be mapped in great detail. Seventy four sheets (1:63,360) cover the entire island which is 25,332 square miles in extent (65,600 square kilometres). Each full sheet covers, approximately 480 square miles (1,240 square kilometres). Regional geological mapping is normally undertaken on the scale 1:63,360 although some areas in the south-west sector of the island have been mapped on the scale 1:31,680.

The systematic study and recording of regional geological data is the principal responsibility of state surveys. The main objective of geological mapping is to demarcate areas which are of interest from the point of view of mineral exploration. The application of modern techniques, aerial photography in particular, to the construction of geological maps has not only speeded up the process but has increased the reliability and usefulness of the products. Aerial photographs are used for the preparation of base maps upon which geological data are plotted, for the identification of geological formations and structures, and for locating rock outcrop and planning out traverses. The Island has been covered by air photographs (scale 1:40,000), and mosaics are also available. Sri Lanka has also access to landsat imagery. New air surveys are also being undertaken when required.

Systematic geochemical prospecting was first carried out in the U.S.S.R. in 1932 and has since been applied throughout the world in mineral exploration. Geochemistry concerns the study of chemical elements in the earth or the chemical processes which occur in the earth. The laws governing the combination of elements and minerals at various temperatures and pressures in the earth's crust form the basis of modern geochemistry. In brief, the basis of geochemical prospecting is that when mineral deposits are formed they give rise to an anomalous dispersion of some indicator material in the neighbourhood of the deposit. For example, in the search for concealed lead-zinc ore bodies, arsenic and antimony are very important indicator elements, in addition to Pb and Zn. A dispersion of this nature may offer a target which could be detected in superficial materials overlying a buried deposit.

Geochemical prospecting involves mainly the analysis of rocks, soils and waters for indicators and the choice of the indicator is normally governed by the metal being sought. A knowledge of the theories of ore occurrence, of geochemical data, of known mineral occurrences in the area, of behaviour of different elements under varying conditions, and of the theory and techniques of chemical analysis are pre-requisites for those engaged in geochemical prospecting programmes. In Sri Lanka, geochemical prospecting has been initiated and for a start, a series of stream sediments, soils and water have been investigated.

Geophysical methods are now virtually standard techniques both in the search for oil and for metalliferous ore bodies. This method may also be used as an aid to the interpretation of regional geology. If methods of geophysical prospecting are to be successful, there should be a significant difference in the physical properties (magnetic, electrical, electromagnetic or radioactivity) between the mineral deposit and the surrounding rocks or differences in density or rate of transmission of artificial earthquake waves.

The magnetic method is based on terrestrial magnetism and the instruments used measure particular variations in the earth's magnetic field. The most sensitive and most widely used instrument is the magnetometer; it is used in aerial surveys, where ground instruments measure the vertical or the horizontal components of the field, and air-borne instruments, the total field. The method is used in prospecting for magnetic iron ore, and in some fields for mapping geological structures by following magnetic marker beds. Aerial magnetometer surveys provide information about geology at depth, reveal unobserved differences in rocks, and show new major structures. A magnetic contour map is a permanent record of the effect of the rocks. It may be interpreted many times, with improvements on each interpretation, as more is discovered about the geology of the area.

In electrical methods of prospecting, the difference in the electrical conductivity of the rocks and the associated mineral deposits are measured. In the self-potential method the ore-body itself produces currents which are detectable at the surface by means of a sensitivity potentiometer. In recent years, the Induced Polarization (I.P.) survey technique has been used. This method relies on the actual earth polarization, and for it to be used successfully the presence of metallic particles are required. I.P. effects occur whenever an electrical current is passed through a volume of rock which contains electroionic conductors. Naturally occurring electroionic conductors include most base metal sulphides, some oxides and graphite.

Electromagnetic methods involve the generation of electromagnetic waves which would stimulate currents by induction in any conducting body and thereby produce a secondary induced field which can be detected at the surface and carefully measured. The method has found wide application in the search for ore bodies containing lead, copper sulphides and graphite.

Radioactivity methods are used in the search for uranium and thorium bearing minerals. The equipment used for the purpose includes the usual range of Geiger-Muller counters and scintillometer counters.

The different densities of rocks modify the magnitude and direction of the earth's gravitational attraction. An instrument of great sensitivity, the gravimeter, detects the slightest variation in gravitational attraction (the variation in weight). This type of geophysical surveying (the gravimetric method) has proved useful in structural studies and has been widely used in oil exploration.

In the seismic method of exploration, the speed with which artificial 'earthquake' waves travel through rock is determined. Waves travel more rapidly in crystalline rock than in unconsolidated materials. This method is also widely used in oil exploration.

In Sri Lanka, an air-borne geophysical survey was carried out covering nearly 23,310 sq. km.(9000 sq. miles) of the south-west sector of the Island. The earth's magnetic field and the radiation due to radioactivity were measured simultaneously. Lines of a reconnaissance nature were also flown across other parts of the island. The more important anomalies have been studied by field magnetometer methods, and magnetite deposits have been proved by drilling techniques. Ground electromagnetic (EM) and resistivity surveys have been used to locate near surface graphite deposits.

Extensive ground radioactive surveys have been carried out and seismic work is also undertaken. The Geological Survey is equipped with modern electro-magnetic, resistivity and seismic equipment including magnetometers of both the precision and reconnaissance types.

The results of geological, geochemical and geophysical surveys, when found promising, must generally be augmented by a programme of drilling before oil and other mineral deposits can be worked. This may take years as holes must be drilled down to the level of the deposit, and cores of rock extracted for examination. A diamond drilling programme is usually the final step in mineral appraisal prior to mining operations. The rapidly growing use of geophysical methods in ore search is resulting in a greater footage of diamond drilling to test the anomalies so revealed. Knowing where to drill is of course the key to successful mineral exploration and drilling is undoubtedly the cheapest method of testing a deposit at depth. Once an area of interest is noted detailed application of surface geology, geophysics and even geochemistry enable the selection of prospects and the definition of drilling targets.

Exploratory drilling is normally undertaken to prove the presence or absence of an economic grade of ore of acceptable width and follow-up drilling to delineate the shape, size and composition of the deposit, after the presence of an economic grade and width has been established in previous drilling operations. As diamond drilling is undertaken to test unknown conditions, it cannot normally be planned accurately. Samples taken during exploration are subjected to a series of tests, chemical, mineralogical and technological. The estimation of reserves which is the ultimate object comprises the determination of quantity, quality and grade and the distribution, and checking the reliability of the estimated reserves and the economic importance.

The tonnage and grade of ore that may be expected from a mineral deposit need very careful estimation with a degree of confidence, as this is the basis for any mining venture. In the classification normally used to describe ore reserves (U.S. Bureau of Mines), terms such as measured, indicated and inferred, are used. Measured ore is ore which is actually known or proved as a result of detailed investigations including sampling and extensive drilling; indicated ore would mean ore for which tonnage and grade are computed partly from measurements and partly from geological evidence, and inferred ore is ore for which estimates are based on geological knowledge and for which few or no measurements are available. Other factors which should be taken into account when assessing the economic value of a deposit include accessibility, transport facilities, hydrogeological conditions, availability of power, housing, medical facilities in the area under study and the distance to which the material is to be transported for treatment or use.

After a deposit has been located and the reserves are proved as economic, mining must be considered, and this activity involves development work, i.e. work associated with getting the material out of the ground. Mining methods may be surface or underground. Surface methods are much less costly than underground methods. Quarrying refers to removal of material from open pits and strip mining is used where a deposit is near the surface in horizontal beds. Open-cut mining generally involves working downward and outward in benches to considerable depths. Hydraulic mining is washing of loose surface material by strong jets of water. Dredging is a means of mining in placer or alluvial deposits. Underground mining is slow and requires ventilation and ground water control. A shaft is usually driven underground from the surface, and drifts (tunnels) are cut horizontally into the deposit and the mined material is hauled to the shaft and lifted to the surface. If the ore body is reached from the side of a hill the entry driven horizontally or on an incline is termed an adit or drift entry.

Once the material is mined, it may have to be processed; low grade ore may have to be concentrated near the mine. The methods employed may range from simple processes such as hand picking to remove unwanted material to complex milling and flotation processes. If further treatment is required, higher grade ore or concentrates are transported to favourable areas for smelting or other processes to extract the mineral.

Minerals are an exhaustible resource. Every mine is in time worked out or becomes too costly to operate. As a result there is a continual search for new areas and development of new mines. Mineral deposits are fixed in location; they occupy very small areas and the limited distribution of a particular mineral may lead to monopolistic development in contrast to forest or agricultural activities. Mineral deposits are costly and there is usually a large factor of chance in mineral search.

MARINE MINERAL RESOURCES

The potential of marine resources is well known. The ocean contains vast deposits of non-renewable resources such as building materials, minerals and hydrocarbons, and live resources such as fisheries. In recent years marine organisms have been used for drug extraction which is a new field. Although man has been aware of the vast mineral producing potential of the sea, the oceans and the seabed remain a relatively untapped source of industrial minerals. Marine research is expensive and necessitate teams of highly qualified men, specialized vessels and costly equipment. Nevertheless, it should be regarded as a highly profitable medium - and long - term investment.

Many developing countries have coast lines; in fact, a number of them are islands. These countries have assumed management responsibilities over an economic zone extending 200 nautical miles (370 kms) from the coast line. Within this area of sea and sea bed, occur resources of various kinds. If these resources are to be exploited, a marine science and technological capability has to be gradually developed within each country. A great potential therefore lies in developing marine resources. This development should be national and international in scope. Marine resources have to be exploited efficiently through marine science and technology. The application of marine science to development can only be undertaken by people trained accordingly. The failure to exploit the mineral deposits of the sea is largely due to a lack of information concerning the deposits and the lack of a fully developed technology for using the deposits. Another important factor is the enormous costs involved in their exploitation. However, there is also no pressing need, either economic or political, to exploit them at the present time.

The more developed countries were quick to perceive the importance of the ocean, whereas many developing countries have failed to do so. The result is that the marine science capabilities of developing countries remain at their initial stage of development. The geology of the continental shelves is mainly an extension of the geological features of the land. Survey methods appropriate for marine conditions obviously differ from those used on land but the purpose and objectives of the marine geology programme are essentially the same.

In regard to mineral resources, the sea can be divided into five regions: marine beaches, sea water, the continental shelves, surficial sediments and the hard rock beneath the surficial sea floor sediments. A variety of minerals are extracted from the first three regions of the ocean. Some minerals mined from marine beaches include the heavy minerals resistant to chemical weathering, diamonds(Southwest Africa), gold (Alaska), magnetite sands (Japan), shell sands (USA), ilmenite-rutile-zircon (Sri Lanka, Australia, India, USA, Brazil and other countries). In addition to common salt, bromine, magnesium compounds, and several other minerals are extracted from sea water.

Important minerals on the continental shelves include, phospherite, glauconite and calcareous shell deposits. Barium sulphate concretions have been dredged from about 1235 m off Colombo, (Jones 1887). The oil reserves of the continental shelves of the world have been estimated to be about equal to the resources of onshore areas of the continents. From an economic standpoint, manganese nodules are the most important on the floor of the three major oceans. Very little is known about the fifth region, that of the hard rock under the ocean floor sediments. These are the better known mineral occurrences of the seas as described by Mero(1975).

A great potential therefore lies in developing marine resources, and the application of marine science to development can only be undertaken by people trained accordingly. Recognizing the importance of the marine sciences, Sri Lanka has established a new organization (1981) named the National Aquatic Resources, Research and Development Agency (NARA), charged with the responsibility of carrying out and co-ordinating research, development and management activities on the subject of aquatic resources (living and non-living). The establishment of NARA also satisfies a long felt need for a National Oceanography Institute for Sri Lanka. NARA is perhaps an unique organization on account of its structure and scope of responsibility. The organization developed primarily as a response to developments in the Law of the Sea which brought to Sri Lanka (as in the case of many other developing countries) a vast extent of off-shore jurisdiction. A National Hydrographic Office (NHO) was also inaugurated in March 1984 to create in Sri Lanka an authority for hydrography. The (NHO) which functions under the umbrella of NARA forms the focal point through which all the available land and hydrographic expertise is channelled for a national hydrographic survey programme.

THE NEED FOR NATIONAL SURVEYS

One of the basic situations in a country's national and international policy is the desire for and utilisation of its mineral resources. Geological Surveys are organisations and institutions of geologists and technical specialists sponsored by national governments. Their purpose is to provide geological knowledge which will form the basis for national planning in the industrial and other relevant sectors and to provide information and advice on geological subjects to concerned institutions and the public. They were among the first national scientific bodies to be organized in many countries; e.g. Canada's Geological Survey was founded in 1842, India's in 1851, and Britain's in 1835, and others of the Commonwealth are among the oldest scientific organisations in the world. Because of the demands of the developing world, the functions and structures of surveys have changed greatly over the years. Surveys have been instrumental in the planning and execution of economic strategies. Field mapping which earlier assumed such an important role has been relegated to a more subordinate role with increased attention being given to geophysical and geochemical surveys, land classification, hydrogeology, pollution studies, and industrial mineral surveys. It is now not uncommon for a government geological survey to be wholly diverted into ad hoc local investigations of immediate importance.

Most surveys in many countries are now sufficiently diversified in their activities to be organised into a number of specialist divisions. The larger the survey, the greater will be the number of operational units. In the growth of institutions serving a large territory, two main patterns of operational structure have emerged. There is on the one hand, a large central headquarters complex which serves the entire country (as in Sri Lanka), and on the other, a relatively small headquarters occupied by the directorate and specialist services, supported by regional outstation offices in the districts. The question has often been posed, whether an earth science department, such as a geological survey, should be directly responsible to a Ministry or should operate under some organization as a research council or a development corporation. Most surveys are, however, responsible to a Ministry.

GEOLOGICAL SURVEY OF SRI LANKA

Our early knowledge of the geology and mineral resources of Sri Lanka is derived from the reports of the Mineral Survey directed by the Imperial Institute during the period 1903-1918. The Mineral Survey was established in 1903 on the recommendation of Professor W.R. Dunstan, then Director of the Institute, with the late Dr. Ananda Coomaraswamy as the first Principal Mineral Surveyor. The survey had as its main object the examination of mineral occurrences and the possibilities of developing the economic minerals of the island. The laboratory work in connection with the survey was carried out at the Imperial Institute. In 1922, the late Mr. J.S. Coates was appointed Government Mineralogist and in 1924 this post was combined with that of Salt Advisor, an arrangement which continued until the time of Coates' retirement in 1934. Little geological work was done during this period and only annual reports were published which contained occasional references to minerals. However, in the course of traverses over the Island, Coates gathered sufficient material for an outline of the "Geology of Ceylon" and his paper was published in the Ceylon Journal of Science in 1935.

Previous to the publication of Coates' paper, two important papers on the geology of Sri Lanka had appeared. The first of these, by Mr. E.J. Wayland, contained a description of the important discovery of rocks of Jurassic age at Tabbowa. The second was by the late Professor Frank Adams of McGill University, Canada, who spent two brief seasons in Sri Lanka in 1924 and 1926. He made some rather rapid traverses through the Island and published a monograph on the "Geology of Ceylon" in the Canadian Journal of Research (1926), the map accompanying this paper being the first geological map of the island. With the retirement of Coates, there was a break of nearly five years during which geological work was completely suspended. It was then decided to commence a geological survey of the Island and the department was re-organised in 1938 with the appointment of Dr. D.N. Wadia as Government Mineralogist. Preliminary geological mapping on the scale of 1 inch to 1 mile was begun and several sheets were completed. Systematic geological mapping may be dated from Dr. Wadia's appointment but the staff was very small and much of their time was taken up with advisory duties leaving little time for geological mapping. Limited laboratory and museum facilities were, however, available. In 1945, Mr. L.J.D. Fernando succeeded Wadia, and in 1971 Mr. D.B. Pattiaratchi assumed duties as Head of the Geological Survey Department. Four years later (1975), Dr. M.M.J.W. Herath succeeded Pattiarachi as Director. In 1979 Mr. D.J.A.C. Happuarachchi was appointed Head of the Survey and in 1983 Mr. L.K. Seneviratne succeeded him as Director of the Survey.

Reconnaissance surveys commenced in the early forties and a provisional geological map of the island was prepared. Detailed geological mapping was undertaken in 1954 and mapping commenced in the southwest sector of the island on the scale 1:31,680. During this period every effort was directed to geological mapping in an attempt to undertake mineral prospecting and exploration where necessary. With the availability of aerial photographs (1956) covering the entire island, there was an improvement in the pace of geological mapping, particularly since 1960.

Mineral exploration prior to 1958 was largely done by classical methods of pitting, trenching and augering. These methods are economical and do not call for any specialized skills and are useful where the ore body occurs at or near the surface, but are obviously of no use where an ore body occurs at depth. In 1958 the Department obtained diamond drilling equipment, mainly for use in mineral exploration. In the same year an air-borne geophysical survey was carried out and the earth's total magnetic field and radiation due to radio-activity were measured simultaneously. This survey was mainly confined to the south-west sector of the Island with line spacing of quarter mile and half mile and flying altitude, 500 feet above ground level. The results of the survey were presented in a series of contour maps. The aero-magnetic maps showed no large amplitude anomalies, the largest being 840 gammas. Ground follow-up work has, however, been undertaken and the occurrences of small iron ore deposits have been proved by diamond drilling investigations. A mineral resources map of the Island is available.

The geological mapping of the island has now been completed and a series of maps (scale 1 : 63,360) has been published, each map accompanied by either a memoir or an explanation. Other publications include, a mineral information series, economic bulletins and professional papers. An annual administration report is available in published form. For convenience, the results of the aero-magnetic survey have been prepared in the form of composite maps on the scale of 1:250,000 (4 miles = 1 inch), and the tectonic map of the island is also available as four composite maps and a single map - 1:500,000. A geological map of the island (scale 1:500,000 or 8 miles = 1 inch) has been published (1983). In the field or mineral exploration, cement raw materials (limestone and clay) have been investigated and reserves sufficient to operate two cement plants were proved in the Puttalam and Kankesanthurai areas. Economically valuable deposits of kaolin, fire clay, ball clay, quartz, felspar and dolomite have been proved and with these discoveries, most of the raw materials required for an expanding ceramic industry are now available locally. Very large deposits of glass sands and sizeable deposits of iron ore have been located; these are adequate to support the local glass and iron and steel industry. It was the work of the Geological Survey which first highlighted the economic importance and value of the Pulmoddai beach sand deposits, one of the greatest mineral assets of the country and one of the great mineral sand deposits of the world. Extensive clay investigations have been undertaken for the state brick and tile factories, graphite deposits have been located, peat deposits have been investigated; and in recent years the Survey discovered an economic deposit of apatite at Eppawela, a copper-magnetite deposit at Seruwila, and serpentinite bodies with traces of nickel at Uda Walawe.

These are a few of the more important investigations undertaken by the Department.

The principal functions of the Geological Survey Department are:

(a) geological mapping and preparation and publication of geological maps, economic bulletins, professional papers, memoirs, mineral information series and annual administration reports;
(b) mineral prospecting and exploration and appraisal of the island's mineral resources and giving advice on their uses and development.
(c) engineering geology and ground water studies;
(d) administration of the mining enactments and supervision of mining;
(e) mineral statistics; and
(f) research in the earth sciences and beneficiation studies of mineral raw materials for industrial purposes.

The Geological Survey of Sri Lanka has varied functions to perform when compared to other Geological Surveys of industrialized countries. In Sri Lanka, there are no private prospecting organizations, and up to about 1977, there were no private drilling companies. The state Geoligocal Survey had therefore to undertake the systematic study and recording of regional geological data and to advise on all geological matters, including mineral prospecting and exploration, engineering geology and ground water investigations. With the accelerated Mahaweli Development programme and the present day boom in building activity, a number of private drilling companies have been established in the island. They are mainly engaged in engineering geology and water supply investigations. Some drilling firms with foreign collaboration are also capable of undertaking other geological studies.

SUMMARY

The 'Growth Syndrome' witnessed by the Scientific Revolution resulting from the union of science and technology for economic growth and advancement of knowledge, is posing several challenges particularly arising due to the fast depletion of natural resources, mainly mineral and energy resources. The deposits of the world have been, or are being, exhausted and the future needs for minerals must be met from larger deposits of progressively lower grade. The geologists' responsibility is to discover and maintain efficient supplies of mineral raw materials without which no country can enjoy a high standard of living.

The earth is a planet in the solar system, and the age of its crust has been calculated as 4550 million years. It has a circumference of 40,000 km and it manifests the many wonders of the world in which we live. The earth's history is divided into a number of major eras. The oldest era, Azoic (without life), represents the earliest period during which the crust was formed. The crust of the earth consists of minerals and these occur as solid masses of rocks. Rocks are however not homegeneous and have no definite chemical composition. Rocks of various origin are recognised: igneous, sedimentary and metamorphic. Economic mineral deposits are geological bodies which may be mined to recover one or more minerals. Geological prospecting and exploration using modern methods concerns itself with the problems of discovering economic mineral deposits. After a deposit has been located and the reserves are proven as economic, mining must be considered and this activity involves getting the material out of the ground. Considerable attention has in recent years been given to the

potential of marine mineral resources. The oceans contain vast deposits of non-renewable resources including hydrocarbons and the live resources. Although man has been aware of the mineral production potential of the sea, the oceans and the seabed remain a relatively untapped source of industrial minerals. Recognising the importance of the marine sciences, Sri Lanka has established a new organization named the National Aquatic Resources Agency (NARA). Geological surveys are organizations and institutions of geologists and technical specialists sponsored by national governments. They were among the first national scientific bodies to be organised in many countries. Mineral surveys in Sri Lanka was first established in 1903. The present Geological Survey Department with its modern laboratories is fairly well equipped to carry out most geological investigations. In recent years, a few private drilling companies have also been established. These, however, are mainly engaged in engineering geology and water supply investigations. Mineral prospecting and exploration and the appraisal of the island's mineral resources, including advising on their uses and development, is the main function of the Geological Survey Department of Sri Lanka.

CHAPTER 2

ECONOMIC MINERALS

The development of a country is vitally linked with the development of its industrial and other minerals (Herath 1980). The deepest drill holes probe only a thin layer of the earth's crust. This layer which is accessible to us for study is found to be composed of a variety of minerals and rocks. These mineral raw-materials have undoubtedly played a major role in the development of many countries. Various systems of classification of minerals have been adopted. For the purpose of this book minerals are divided into four broad based groups: energy group, ferrous and ferroalloy group, non ferrous group and the non-metallic group. In the simplest of many classifications, non-metallic minerals other than fuels have been further classified in 3 groups according to their end usage: constructional minerals, process minerals and chemical minerals. In the first category occur the bulk aggregate construction materials of low value (limestone, clays, gravel and sand, gypsum and asbestos). The process minerals include a variety of industrial minerals used in the abrasive, ceramics, glass and other industries. The last category comprises the chemical and fertilizer minerals such as salt and phosphate. Table II is a list of some important minerals under the various groups, and the more important minerals from each group are briefly discussed.

It is extremely difficult to make an accurate assessment of the mineral resources of the world. A rough picture can, however, be obtained from the data available in the different countries. It is believed that 65 per cent of the known deposits of various kinds of minerals consists of low-grade ore, 5 per cent of high-grade ore and 30 per cent is of medium grade ore.

Table II

CLASSIFICATION OF MINERALS

Energy-Group	Ferrous and Ferroalloy-Group	Non ferrous Group	Non metallic
COAL	IRON	ALUMINIUM	ASBESTOS
HYDROGEN	CHROMIUM	ANTIMONY	CALCIUM
NATURAL GAS	COBALT	ARSENIC	CLAYS
PEAT	MANGANESE	COPPER	CORUNDUM
PETROLEUM	MOLYBDENUM	GOLD	DIAMOND
THORIUM	NICKEL	LEAD	FELSPAR
URANIUM	SILICON	MAGNESIUM	GARNET
	TUNGSTEN	MERCURY	GEMS
	VANADIUM	PLATINUM	GRAPHITE
	TANTALUM	SILVER	GYPSUM
		TIN	MICA
		TITANIUM	PHOSPHORUS
		ZINC	QUARTZ
		ZIRCONIUM	SAND and GRAVEL
			STONE
		RARE-EARTH ELEMENTS	SULPHUR
			TALC
			SALT
			SILLIMANITE

After Bureau of Mines - U.S.A.

ENERGY GROUP

The energy content of a fuel is denoted by its calorific value which is the number of British Thermal Units (B.Th.U.) liberated by the combustion of one pound of the fuel. The B.Th.U. is the quantity of heat required to raise the temperature of 1 pound of water by 1^{o}F. Pure carbon has a calorific value of 14,137 B.Th.U. and hydrogen a value of 61,493 B.Th.U. Liquid and gaseous fuels with hydrogen contents up to 50 per cent by weight give out far more heat on combustion than solid fuels. The lower the oxygen content of a fuel, the better it will burn. The ideal fuel will therefore be pure hydrogen. It is believed that the majority of fuels come directly or indirectly from carbohydrates. Although petroleum is extensively used as a fuel, coal is probably the world's leading fuel material. Mineral fuels are solid, liquid or gaseous. Coals are solid fuels, and some like anthracite are almost pure carbon. Petroleum, the liquid fuel containing carbon and hydrogen, gives a whole range of fuels and lubricants. Natural gas occurs with petroleum deposits. Coal, petroleum and natural gas are the conventional fossil fuels. The new fissile fuels include uranium and, perhaps, thorium. The main sources of energy currently consumed in most countries are wood, coal, petroleum, natural gas and hydropower.

Nuclear power is perhaps the most immediately available new source of energy. As a result of the recognition that the conventional sources of energy will not suffice to meet the world-wide requirement even in the foreseeable future, the development of new sources of energy has for some time been one of the main goals of applied research. These sources include nuclear, solar and wind power, biomass conversion, tidal energy, ocean thermal energy, geothermal energy and hydrogen gas.

Coal is the greatest developed energy source, and the main industrial nations are those that are rich in coal. Coal is formed from vegetable material and is classified according to the degree of alteration from vegetation to fixed carbon. Peat is the first stage and is not considered a coal. Lignite contains the least fixed carbon. As compression of the formations increase, volatile matter and moisture are reduced resulting in the formation of higher grades of coal like bituminous and anthracite coal. Coke is specially prepared for smelting iron ore. Bituminous coal is heated in a reducing atmosphere, the coal becomes molten and the mass is made to solidify into a hard material made up of fixed carbon. World production of coal is now about 3,500 million tons and the main producing countries are U.S.A., U.S.S.R., China, Poland, Germany (FR), U.K., India, South Africa and Australia. World potential reserves of coal are in the region of 13,000 billion tons.

Petroleum is a fuel which is more accessible and one which is readily available. It is associated with sedimentary basins and its origin is connected with minute marine organisms in enormous quantities in shallow ocean bottoms. Slow decomposition of this material is believed to result in the formation of tiny droplets of oil. Increasing compaction of sediments forces the droplets out into porous earth strata like sandstone which are good reservoirs for the accumulation of oil. Useful quantities are formed when a trap structure exists for holding the migrating oil in a reservoir. Crude oil which is obtained from the earth is refined to produce fuel and a variety of other products. Petroleum reserves are concentrated in a few countries for example U.S.A., U.S.S.R., Venezuela, Saudi Arabia, Kuwait, Iraq and Iran. Together they produce nearly 70 per cent of the world's petroleum, the Middle East countries alone producing over 50 per cent of the world's requirements. World proved reserves of crude petroleum amount to over 600 billion barrels (1 barrel = 42 US gallons) and the Middle East countries are known to have one half of this reserve.

Natural gas occurs in association with petroleum and also in gas fields, and a commercial natural gas field is rich in methane the most stable of the petroleum hydrocarbons. Over 50 per cent of the world's reserves of natural gas are found in the U.S.A., U.S.S.R., Algeria and Iran. It is believed that the energy demands of the household and commercial sectors will be met increasingly by natural gas.

The harnessing of water power involves the construction of a dam across a river. Dams are primarily meant for irrigation purposes and are used to generate electricity only as a secondary function. The reservoir so created serves to store water and to create a suitable head for the operation of the turbines which are combined with a generator to provide the electric current. The power house is situated at the base of the dam. Electricity is not a source but a form of energy derived from available sources. The use of electricity in very large quantities is strikingly observed in the highly industrialised countries of the world.

Atomic power is perhaps the most immediately available new source of energy and it is likely to prove a major energy source in regions not endowed with normal fuels. The principal raw material used for nuclear power is uranium. The energy is derived from the central core or nucleus of the atom. Reactions involving the nuclei of the atoms which may release energy are of two types, fission and fusion.

In the fission process a large nucleus is induced to split into two or more smaller nuclei, and in the fusion process the particles of two light nuclei are rearranged to form a larger nucleus. The future for fusion power is not so clear cut since at the moment it is in the experimental stage. The heat liberated in the process is transferred from the reactor to the boilers where the steam that drives the turbo-generator is produced. Nuclear power stations already established use the fission chain reaction in U235. The world's first commercial nuclear power station is at Calder Hall (Great Britain), and it came into operation in 1956.

Other possibilities of opening up new sources of energy involve the use of marine phenomena. The energy of the tide can be harnessed and coverted to electricity. It is also possible to produce energy using the temperature difference between the surface water and the water at great depth in the ocean. The natural heat contained within the earth (geothermal energy) is also used as a source of energy when hot water or steam carries the heat from the rocks to the surface.

The generation of synthetic hydrocarbon fuels and the use of pure hydrogen as a fuel are areas which have attracted attention in recent years. The possibility of obtaining the fuel hydrogen by the electrolysis of water has been studied. Although the process requires large amounts of electricity, researchers feel that hydrogen could be used for heating and as a motor fuel. Hydrogen therefore may be a fuel of the future.

FERROUS AND FERROALLOY GROUP

Iron, the ferroalloys, and steel belong to this group. Iron is the greatest of all the metals. Materials used as alloys in steel making are termed ferroalloys and the main materials are manganese, chromium, nickel, cobalt, tungsten, molybdenum, vanadium and silicon. Steel, the most useful of all construction metals, is a product of iron, ferroalloys and carbon.

The chief iron minerals are hematite (Fe_2O_3) - 70 per cent iron, magnetite (Fe_3O_4) - 72.4 per cent iron, limonite ($Fe_2O_3.H_2O$) - 59 per cent iron and siderite ($FeCO_3$) - 48 per cent iron. Mined ores contain from 25 to 69 per cent iron. In iron ore, phosphorus, titanium and sulphur are particularly objectionable impurities. Precambrian metamorphosed sediments comprise a major part of the world's iron ore deposits. The taconite deposits of Minnesota in which magnetite is the principal mineral, the jaspilite deposits of Michigan in which hematite is the principal iron mineral, the hematite - magnetite ores of Krivoi Rog (U.S.S.R.), the banded iron formations (jaspilites or taconites) of the Pilbara region (Hamersley iron province) in Western Australia, and the hematite ores of Bihar are a few examples of commercial deposits of iron ore. World iron ore production is now over 900 million tons and the chief producing countries are U.S.S.R. (230), U.S.A. (85), and Australia (96).

Manganese is the most important ferroalloy. The important manganese minerals are pyrolusite (MnO_2 - 63.2 per cent Mn), manganite, psilomelane and rhodochrosite. Two types of deposits supply world requirements. These are bedded or sheet-like deposits of oxide ore overlying Precambrian rocks and basins of oxide beds in sedimentary rocks. Deposits of the first type are known in India, Africa, Brazil and Australia, and the second type occurs in the U.S.S.R., Gabon and Cuba. World production of manganese ore is over 24 million tons. The largest deposits of manganese occur in the Republic of South Africa, U.S.S.R. and Gabon. The only industral ore of chromium is chromite (chrome-spinellids). Chromium ores vary in the Cr_2O_3 content and contain from 18 to 62 per cent Cr_2O_3. The world's largest deposits are in the Bushveld Igneous Complex of the Transvaal in the Republic of South Africa where the reserves are estimated (in terms of chromium content) at 575 million tons. World production of chromite is around 8 million tons.

Most of the world's present day production of nickel comes from nickel sulphide minerals such as pentlandite and millerite, and from lateritic ores. Very often, as in the nickel deposits of the Sudbery District of Canada, the ores contain other valuable base metals, especially copper and cobalt. The nickel content of sulphide ores vary from 1.5 to 5 per cent. Nickel values from lateritic ores are generally less than 2 per cent. World nickel reserves are estimated at 65 million tons. The main resources are in Cuba, New Caledonia, Canada, Australia and U.S.S.R. Cobalt is produced as a by-product of other elements. The bulk of the production comes from the copper ores of the Congo (Kinshasa). Cobalt ore is found in Canada, Australia and Burma. In Canada cobalt is recovered from silver-arsenite ores and in Australia and Burma from lead-zinc ores. Cobalt also occurs in the metallic state in the Khovakshy deposit of the U.S.S.R.

The principal tungsten minerals are wolframite and scheelite. The chief sources of tungsten include wolframite-quartz veins and contact metamorphic deposits (contact between limestone and intrusive granite). The important producing countries are China, U.S.S.R., North and South Korea, U.S.A., Canada, Bolivia, Australia, Thailand, Brazil and Portugal. The principal mineral from which molybdenum is obtained is molybdenite (MoS_2). Large stock works of quartz-molybdenite and quartz-molybdenite-chalcopyrite ores are the main sources of the material. The main producing countries are U.S.A., U.S.S.R., Chile, Canada and Peru. The largest production of vanadium is from Carnotite of the Colorado Plateau where it is obtained as a by-product of uranium extraction and from roscoelite, a vanadium mica. In South-West Africa it is extracted from lead-copper vanadates and in Finland and South Africa from vanadium bearing titaniferous magnetites. The main producing countries are U.S.S.R., U.S.A., South Africa and Finland.

Silicon is not found in the free state but it occurs as silica ($SiO2$) which is widely distributed and is found in almost every country. These are distributed as deposits of quartz, quartzite, sandstone and silica sand. Silicon has long been considered a non-metal. However, in metallurgy the elemental crystalline form is known as silicon metal or metallic silicon. Silicon is widely used in the iron, steel and non-ferrous metal industries in the form of ferro-silicon metal. The largest use is as ferro-silicon in the production of iron and steel. Tantalum occurs always together with niobium. The alloys of tantalum and carbon are noted for their extreme hardness and are used to manufacture cutting tools and drills.

NON FERROUS GROUP

The non-ferrous minerals constitute a very important group and include a variety of minerals ranging from the major industrial minerals - copper, lead, zinc, aluminium, tin, magnesium, mercury and titanium, to the precious minerals - gold, silver and platinum. Copper metal is recovered from a variety of ores. Apart from native copper the principal ores are the sulphides chalcopyrite ($CuFeS_2$), bornite (Cu_5FeS_4) and chalcosite (Cu_2S), the oxide cuprite (Cu_2O), and the carbonates malachite ($Cu_2(OH)_2CO_3$) and azurite ($Cu_3(OH)_2(CO_3)_2$. Intrusive porphyries (copper-porphry type) account for a major portion of the world output of copper and include deposits like Bingham (Utah-U.S.A.), Kounrad (USSR), and El Teniente (Chile). World production of refined copper is around 8 million tons and the chief producing countries are U.S.A., U.S.S.R., Japan, Zambia, Canada and Chile. Lead and Zinc usually occur together in nature. The common lead ores are galena (lead sulphide) and cerussite (lead carbonate), and ores containing lead may also contain copper, gold, silver, zinc and other metals. The main lead producing countries are U.S.A., U.S.S.R., Canada, Australia, Mexico and Peru. World production of refined lead is around 4 million tons. Zinc is mainly extracted from sphalerite (ZnS, zinc blende). World production of refined zinc is around 6 million tons and the main producing countries are those mentioned for lead.

Bauxite ($Al_2O_3.H_2O$) and gibbsite ($Al_2O_3 .3H_2O$) are the aluminium ores of greatest economic significance. Australia dominates world bauxite production and the famous Gove, Weipa, Michell palteau and other deposits in that country account for one-third of the world reserve estimated at 15,000 million tons. Guinea in West Africa also has one-third of the world reserve, and the remaining third is found in Jamaica, Surinam and Guyana.The main tin ore minerals are the oxide cassiterite (SnO_2) and the sulphide stannite ($Cu_2Fe\ SnS_4$). The main tin producers are in South-East Asia and include Malaysia, Indonesia, China, Thailand and Burma. These countries produce over 60 per cent of the world's production. The deposits are mainly placer (alluvial), and cassiterite is the main ore mineral. Bolivia comes next in importance in the mining of tin ore; mining is done from vein-type deposits, and by-products include copper, silver, lead, zinc, molybdenum and tungsten. World smelter production of tin is around 198,000 tons. The main sources of magnesium are magnesium chlorides from carnallite deposits, magnesite, dolomite, and sea water (0.13 weight per cent magnesium). The supplies therefore can be considered as inexhaustible. The estimated world reserve of magnesite ores only, other than dolomite, is nearly 9 billion tons which includes only the major deposits like those of China (5,000 million tons) and North Korea (3,000 million tons).

Mercury or quick-silver is a metal that is liquid at ordinary temperatures. The only important ore is the sulphide, cinnabar (HgS). World production of mercury is estimated as 9 million kilogrammes. Almaden (Spain) and Idria (Italy) are the world's largest producers of mercury. Other producing countries are U.S.A., Canada, Mexico, Yugoslavia and Russia. Ilmenite ($FeTiO_2$) is the present source of 85 per cent of world titanium requirement. The other titanium mineral of commercial importance is rutile (TiO_2). These minerals are recovered from beach mineral sands. Ilmenite is also found as hard rock deposits. Grains of rutile, zircon, ilmenite, monazite, and other minerals tend to occur together as natural concentrations. Their original occurrence has been in the granite and other rock types of inland areas. Subsequent removal of the weathered products, mainly by rivers, has shifted the mineral grains to the coast and there wave action concentrates the heavy minerals. Australia is the world's leading supplier of mineral sands accounting for almost 95 per cent of all rutile, about 80 per cent of all zircon and about 25 per cent of all ilmenite and monazite produced. Titanium resources in inland rock deposits are also abundant. The largest market for titanium dioxide pigment is the paint, paper and plastics industries, and titanium metal is mainly used in the aircraft industry. Zircon occurs in syenite rocks and in placers. Zircon occurs also as gem stones. It is mainly used in the ceramic industry. The principal antimony ore is stibnite Sb_2S_3. Antimony is mainly used in antifriction alloys for bearings.

The principal minerals of gold are native gold and gold tellurides–calaverite, sylvanite, petzite and nagyagite. Gold is obtaind from gold ores and placers and as a by-product from ores mined essentially for copper and other base metals. The Republic of South Africa has the world's largest reserves of gold, and other countries of importance include U.S.A., U.S.S.R., Canada, Australia, Colombia, Southern Rhodesia and Ghana. World production of gold is estimated as 1.4 million kilogrammes. In addition to its widespread use for its monetary value, gold is mainly used in the jewellery industry. The chief silver minerals are native silver, argentite, pyrargyrite and proustite. Despite their great number, known silver minerals are rarely concentrated in deposits by themselves. Silver occurs mainly in dispersed form in complex gold and copper ores and in association with galena in lead-zinc deposits. Silver is therefore a by-product metal. Vein silver deposits proper occur in Mexico (Pachuca and El Oro). About 70 per cent of the total silver production is used for monetary purposes - as coin or bullion. The main producing countries are Mexico, U.S.A., U.S.S.R., Peru, Canada, Australia, Bolivia and Japan. The total world production of silver is 9 million kilogrammes. Platinum is more useful commercially and rarer than gold. Platinum usually occurs with other rare and chemically similar metals such as iridium, rhodium, osmium and palladium. The most common ore is native platinum. The bulk of production comes from the Merensky Reef in South Africa. World production of platinum group metals is approximately around 180,000 kilogrammes, and the main producing countries were U.S.S.R., South Africa, Canada, U.S.A. and Colombia. Arsenic is found in comparatively small quantities in hydrothermal deposits. The rare-earth elements are the source of rare-earth oxide (REO) used in a number of industries.

NON METALLIC GROUP

The non metallic minerals are numerous and they range from bulk commodities such as sand, gravel and stone, down to industrial diamonds and gemstones. Included in this group are common industrial minerals such as asbestos, mica, calcium, phosphorus, clays, felspar, graphite, talc, gypsum, sulphur, garnet and corundum.

Asbestos is a name applied to a group of fibrous minerals. The principal variety is chrysotile ($3MgO.2SiO_2. 2H_2O$). Other commercial varieties are amosite and crocidolite and of minor importance are tremolite and anthophyllite. The province of Quebec (Canada) has the largest asbestos mines and mills in the world. The U.S.S.R. is also an important producer. The Republic of South Africa, Southern Rhodesia, Swaziland, China, Italy and the U.S.A. produce substantial quantities. Mica is a group name for a number of minerals, for example, muscovite, phlogopite, biotite and lepidolite. Commercially, mica is classified as sheet mica and scrap and flake mica. The chief uses of sheet mica are in thermal and electric insulators. Most scrap mica is processed into ground mica which finds varied industrial use. The major producing countries are Brazil, India, U.S.A. and the Malagasy Republic. Exports of mica from India are over 33,000 tons (all grades).

Natural sources of calcium are limestone ($CaCO_3$), dolomite ($CaCO_3.MgCO_3$), marl, chalk, shell, coral, brine and certain other minerals. The largest consumer of limestone is the cement industry. Very large quantities of limestone and dolomite are used in blast furnaces and steel works. Other uses are for the production of lime, for agricultural purposes, and for the chemical and other industries. Calcareous materials occur in most countries. The world production of cement is over 600 million tons. Most of the phosphate deposits of the world are in igneous rocks as apatites, and in sedimentary rocks as phosphorites. The phosphorus industry is chiefly dependent upon fertilizer demands. Deposits of phosphate rock are fairly widespread. The main producing countries are U.S.A., U.S.S.R., and Morocco, which together account for four-fifths of the estimated world production of 125 million tons. Other producing countries are Christmas - Island, Tunisia, Togo, Senegal and Egypt.

Clays and clay minerals form one of the most widespread and widely used groups of inorganic industrial raw materials and they have an infinite variety of uses. The different industries require different grades of clay as regards plasticity, refractoriness, shrinkage, purity and other properties. By far the greatest quantity of clays consumed in most countries is used in ceramic production or in other fired materials. The clay types are kaolin, ball clay, fire clay, bentonite (montmorillonite), fuller's earth, brick clay, cement clay and other miscellaneous clays. The U.S.A., U.K. and U.S.S.R. together account for nearly 70 per cent of the recorded world output of kaolin. Other important producing countries are India, France, Germany (FR), Czechoslovakia and Spain. World production of kaolin or china clay is around 18 million tons. The U.K. is the world's largest exporter of china clay. Felspar is used mainly in the glass and ceramic industries. The principal felspars are orthoclase and microcline, albite and anorthite. The main producing countries are U.S.A., U.S.S.R., Germany, France, Italy, Norway, Japan, Sweden and Canada. The world production of felspar is around 3 million tons. Natural graphite is the mineral form of elemental carbon and is also referred to as plumbago. Graphite is mainly used as a refractory material and as a lubricant in the manufacture of a wide variety of products. Depending on the type, particle size and carbon content of graphite, several commercial grades are identified. The three principal types of natural graphite - vein, amorphous and crystaline flakes are identified on the origin and physical characteristics of the ore. The U.S.A. graphite deposits of Texas, Pennsylvania and Alabama contain less than 5 per cent of graphite. Other producing countries are Mexico (Sonora), South Korea, U.S.S.R., Austria, Sri Lanka, West Germany, China, Brazil, Canada and the Malagasy Republic. The last mentioned country has the largest known resource of flake graphite in the world. Estimated world production of graphite is over 500,000 tons, with South Korea being the largest producer. The mineral talc is a hydrous magnesium silicate. Talc has a variety of uses. It is used mainly in ceramics, paint, insecticides, paper, refractories and as a high quality filler. Talc occurs in vein-like bodies in serpentinized ultra-basic rocks, such as the Keryabino deposit (U.S.S.R) and the deposits in Virginia (U.S.A.). Talc also occurs as irregular deposits in dolomites. The main producing countries are Japan, U.S.A., U.S.S.R, France, China, India, Italy and Austria. The world production of talc and similar minerals is around 5 million tons.

Gypsum is a mineral with the composition $CaSO_4 2H_2O$. The largest deposits of gypsum have been formed as chemical precipitates from marine waters of high salinity. Moderate heating of gypsum yields a product known as plaster of paris, used for diversified industrial purposes. The U.S.A. is the leading producer and consumer of gypsum in the world. The main producing countries are U.S.A., U.S.S.R. Germany (FR), France, Canada, Italy and U.K. The world production is around 60 million tons. The principal uses of sulphur are in the making of sulphuric acid, fertilizers, pigments, explosives and pulp and paper. Sulphur occurs as native deposits associated with salt domes, as volcanic deposits and as deposits associated with anhydrite. The main producing countries are U.S.A, Mexico, South America (Chile), Italy, Japan, U.S.S.R, Canada, France, Spain and China. The world production is around 50 million tons.

Natural industrial garnet consists essentially of the variety almandine (iron-aluminious-silicate) which has desirable abrasive qualities. Garnet is mainly used as an abrasive in a number of forms in various industries. The U.S.A is the largest producer and consumer of garnet. The largest mine is the Barton Mine in New York where the garnet occurs in metamorphosed igneous rock. Garnet is also recovered from beach mineral sands. The main producing countries are the U.S.A., U.S.S.R., Spain, India, Australia and Argentina. The world production of garnet is approximately 30,000 tons.

Corundum is mainly used as an abrasive material in grinding wheels and as grinding and polishing grain. Transparent varieties include rubies and sapphires which are prized as gemstones. Emery is a natural mixture of corundum with magnetite and some haematite and spinel. The Republic of South Africa, Southern Rhodesia, U.S.S.R. and India have very large reserves of corundum. The U.S.S.R. is the largest producer.

Sillimanite occurs in large deposits as lenses and pockets in crystalline schists at Khazi hills and Pipra in India. Sillimanite is used in the refactory industry. The world's largest diamond deposits are located in South Africa. Diamond is mainly used as a gemstone.

SUMMARY

Economic geology deals with mineral deposits, the mineral wealth in the very widest sense. A knowledge of geology provides the key to locating economic mineral deposits. It provides a basis for all kinds of industrial and regional development. In particular, it constitutes the basic data required in the search and development of mineral resources which is essential to a country's economic development. It also provides a basis for assessing the magnitude of both known and potential resources in the formulation of policies governing competing demands for exploration and conservation. The science of prospecting and exploration concerns itself specifically with the problems of revealing economic deposits. It is well known that a very few (in some cases one or two) geological and mineralogical types of deposits supply the bulk of the world output of a particular mineral. The vast mass of the remaining ore discoveries of every possible genetic type have, in practice, usually no commercial significance. It is therefore important that every exploration geologist must be familiar with the commercial types of ore deposits, a few of which have been listed.

NA-24-2

CHAPTER 3

GENERAL GEOGRAPHY AND OUTLINE OF GEOLOGY

GENERAL GEOGRAPHY

Physical Features

The island of Sri Lanka, formerly known as Ceylon, is a tropical country within the latitudes 6^{o} and 10^{o} north and longitudes 79^{o} and 82^{o} east. It lies 32 km to the east of the southern most extremity of Peninsular India and has an area of 65600 km^2. It is 432 km long and is 229 km wide at its widest.

In the island two main physiographic divisions can be recognized:

1. The low lying coastal plain with little relief and traversed by rivers which have reached their base level of erosion in this region
2. The central highlands with immature drainage pattern and marked relief, abounding in numerous strike ridges, hills and mountains

Adams (1929) in his 'Geology of Ceylon' was the first to draw attention to the existence of three well defined plains of erosion (peneplains) cut in the rocky framework of the island. A characteristic feature of a peneplain which can exist at any level is that the hills, ridges and plateaus within them are all at the same general level. It is usually referred to as the erosion level.

The respective elevations of the 3 plains (see Fig. 2) are as follows:

First Peneplain - 0 - 30 m above sea level
Second Peneplain - 500 m above sea level (average)
Third Peneplain - 1200 m above sea level (average)

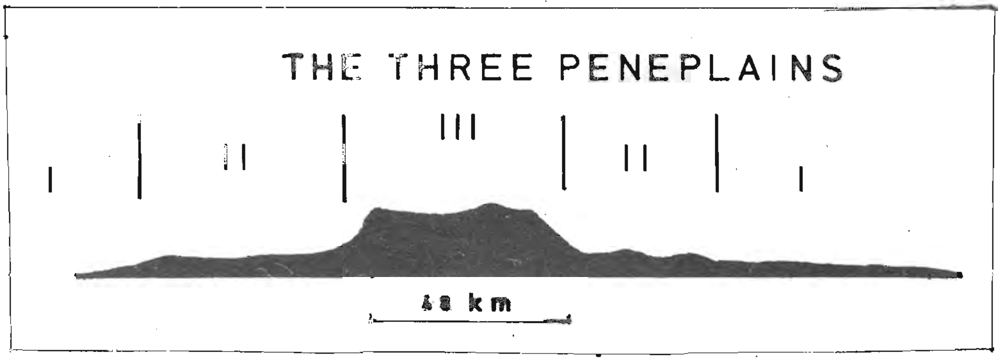


Figure 2. Respective Elevations of the Three Peneplains

The first terrace or lowest peneplain (coastal plain) surrounds the hill country on all sides. It is narrow on the western and southern margins but widens to the east, while to the north it expands into the great plain that forms the whole of the northern half of the island. The coastal plain is devoid of relief, and it rises inland to over 100 m above sea level. The only physical features are the erosion remnants which could be seen either isolated or in detached groups. The erosion remnants such as Sigiriya, Gunner's Quoin, Yapahuwa, Westminister Abey and others (See Fig. 3), have stood out against the levelling process over millions of years due to the resistant nature of minerals forming these rocks. Their present heights give us only an indication of the original height of the land, for even the erosion remnants themselves have suffered much levelling down. Because of the steepness of the sides of these rocks, remnants like Sigiriya and Yapahuwa have become famous in Sri Lanka's history as the sites of fortresses, palaces and temples. Some erosion remnants may rise up to 100m or more.

Rising steeply from the coastal plain is the second terrace or peneplain. It is best seen in the eastern and southern parts of the island. Inland from the coast the land rises gradually to about 100m until it reaches the foot of an escarpment generally about 300m high which separates the coastal peneplain from the middle peneplain. This escarpment is best seen in the Minipe and Kongala areas where

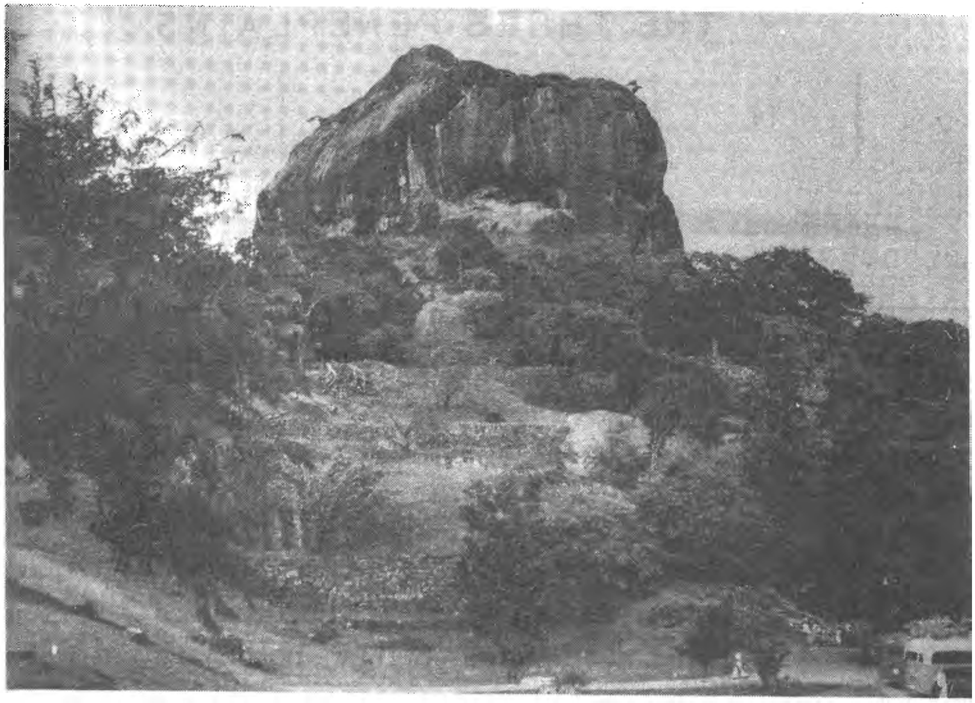


Figure 3. Sigiriya Rock - Isolated Erosion Remnant in Coastal Peneplain.

it forms a prominent physical feature. The main road from Minipe to Kandy climbs the escarpment in a number of hairpin bends to reach a region of parallel ridges all at a general level of between 760m and 1320m which is part of the middle peneplain. The Kongala escarpment south-east of Balangoda is also a prominent physical feature. In the western side of the island the railway line from Colombo begins to climb the west escarpment at Rambukkana and wanders thereafter as far as Nawalapitiya on the middle peneplain.

The highest peneplain is a complex one and is least like a peneplain. It rises from the second peneplain and forms the central highlands at a general altitude of about 1200 m. This terrace supports the highest mountains of the island, Pidurutalagala 2524m, Kirigalpotta 2389m, Totapala kanda (2357m) and Adam's Peak (2238m - Fig. 4). The scarp face of this terrace referred to as the 'Southern Wall of the Hill Country' (Cook,1931), is perhaps the most striking feature in the whole of the Island. It is best seen from the road between Balangoda and Bandarawela. A number of waterfalls like Diyaluma, Bambarakanda and Galagama drop over its edge. The general topography and drainage pattern of this third terrace are abrupt and juvenile and there is none of the physical features which are usually associated with Precambrian terrain.

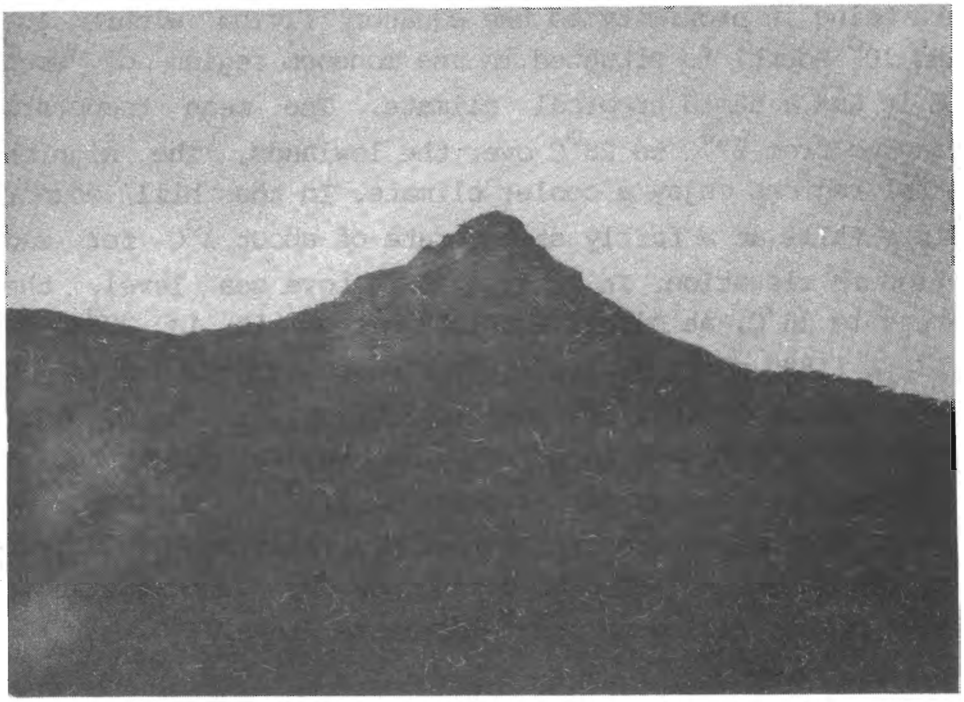


Figure 4. Adam's Peak - in Third Peneplain

Adams (1929) believed that the three terraces represented three successive stages of denudation brought about by successive uplifts of the country and that the terraces were erosion remnants after each period of base-levelling. On this view the coastal peneplain is the youngest and the third terrace the oldest.

On physical grounds Wadia (1945) rejected this view. He put forward the theory that the terraces are the result of successive block uplifts taking place on an already peneplained Precambrian terrain. According to him the coastal plain is the oldest and the third terrace the youngest. He also drew attention to the significa e of the ring of water-falls that surrounds the highest terrace nd suggested that the falls indicated important dislocations resulti in different uplifts of one part relative to another. It is not proposed here to discuss the theories concerning the origin of the three peneplains.

Climate

Sri Lanka being in proximity to the equator (lying within latitudes of 6° and 10° north) is situated in the monsoon region of south-east Asia and it has a humid tropical climate. The mean temperature is high, ranging from $27^{\circ}C$ to $28^{\circ}C$ over the lowlands. The highlands in the central regions enjoy a cooler climate. In the hill country the temperature falls at a fairly steady rate of about $1^{\circ}C$ for each 140 metres rise in elevation. In Kandy, 488 m above sea level, the mean temperature is $25^{\circ}C$, at Diyatalawa(1250 metres) it is $20^{\circ}C$, and at Nuwara Eliya (1890 m) it is $15.5^{\circ}C$. The mean temperature at Colombo during the coolest months, November to February, is $26^{\circ}C$. April and May are the warmest months in Colombo. In Nuwara Eliya the minimum temperatures are generally of the order of $7.2^{\circ}C$ (February) and may occasionally fall below freezing point. The relative humidity varies generally from about 70 per cent during the day to about 90 or 95 per cent at night, rising as the temperature drops.

The annual average rainfall varies from below 1270 millimetres in the arid parts of the north-west and south-east of the island to over 5000 millimetres at certain places on the south-western slopes of the hills. There are four rainfall seasons during the year with corresponding periods which may roughly be recognised as follows:

1. The South-West Monsoon period - May to September
2. The Inter-Monsoon period - October to November
3. The North-East Monsoon period - December to February
4. The Inter-Monsoon period - March to April

The division of the island into a Wet Zone and a Dry Zone with an Intermediate Zone between them is the most widely recognised climatic classification of the island. In Fig. 5 the rainfall patterns are shown clearly demarcating the Wet and Dry Zones.

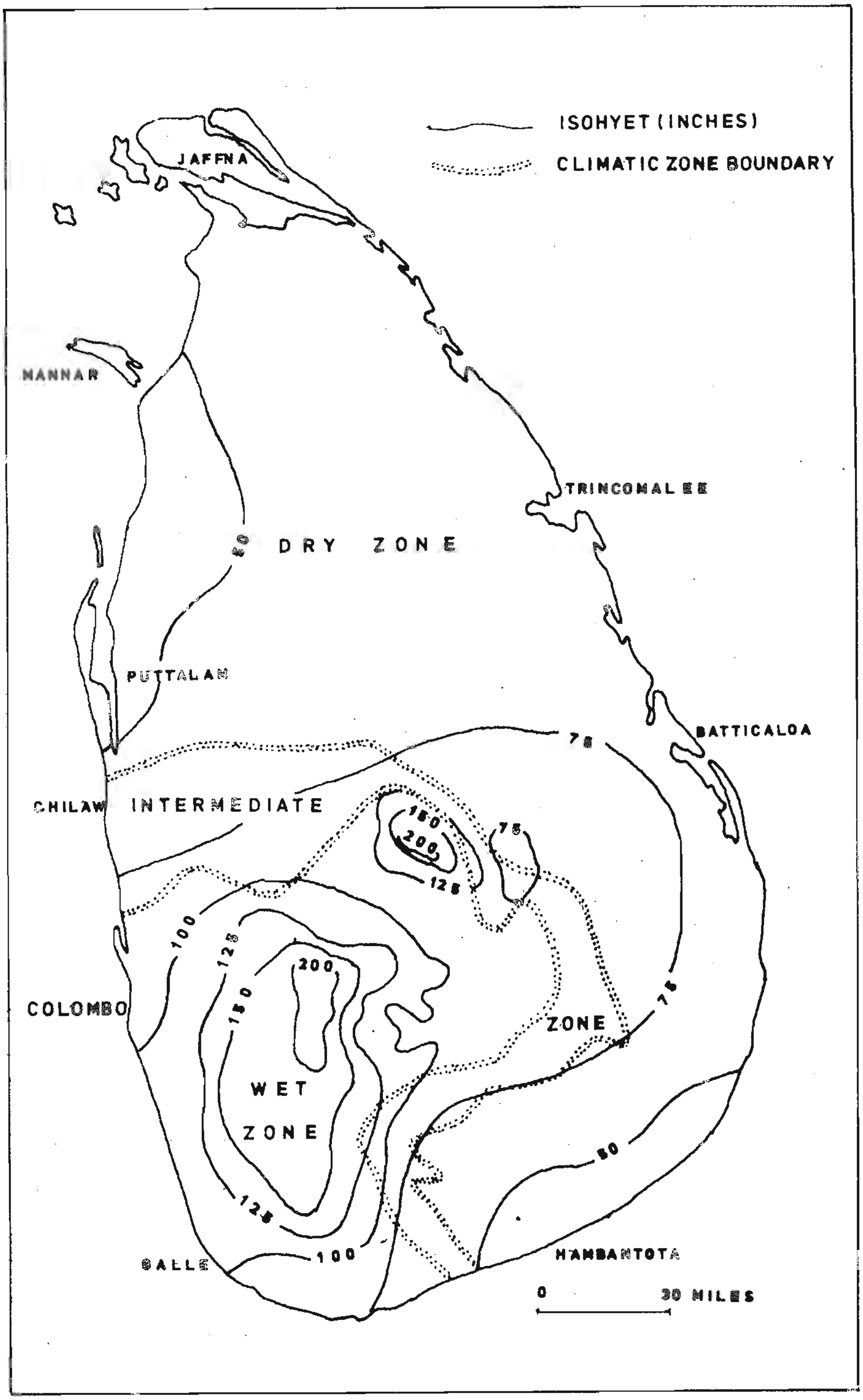


Figure 5. Rainfall Pattern and Climatic Zones

Drainage

The drainage pattern for the most part is radial. The upper reaches are mainly confined to the central hill country. The greatest problem of Wet Zone hydrology is that of flood control. Inundation of low lying areas is almost inevitable, and vast stretches of ground are subject to serious flooding during the wet seasons. This has resulted in the development of deep and extensive deposits of alluvial material along the lower reaches of the major river systems draining this region. In the Dry Zone it is a seasonal shortage of water which is a problem. Very few rivers rise in the Wet Zone and flow into the Dry Zone. The most important and the longest river, the Mahaweli Ganga, rises in the hill country and flows towards the north-east with its mouth near Trincomalee. The lengths of the principal rivers of Sri Lanka are given in Table III.

TABLE III

LENGTHS OF PRINCIPAL RIVERS

River	Length in Kilometres	River	Length in Kilometres
Mahaweli Ganga	335.0	Mahaoya	134.0
Aruvi-aru	164.0	Menik Ganga	114.0
Kala Oya	148.0	Kalu Ganga	129.0
Kelani Ganga	145.0	Kirindioya	118.0
Yan Oya	142.0	Kubukkun aru	116.0
Deduru Oya	142.0	Gin Ganga	112.0
Walawe Ganga	138.0	Nanu Oya	109.0
Maduru Oya	137.0	Gal Oya	108.0

Ceylon Year Book - 1983

Department of Census and Statistics

Population

The main concentration of settlement in the island is in the Wet Zone in the whole of the western, south-western and central hills.

The Dry Zone areas, for example in the north, north-central and east-central parts of the country, are not heavily populated. The population of Sri Lanka in 1901 was approximately 3.5 million, in 1953 the population was 8 million and in 1979 it was 14.5 million. At present (1985) the population is around 15 million.

Based on the 1981 census the mean density of population for the country is 586 persons per sq. mile. By far the highest density (in excess of 2700 persons per square mile) was recorded in the Western Province, and this clearly results from the largely urban character of this region. Other provinces with relatively high population densities are the Central, Southern and Sabaragamuwa Provinces with rates varying between 780 and 930 per sq mile.

In contrast, the Eastern, Uva, and North Central Provinces all record population densities below 300. Table IV is presented to show some districts with high population densities.

TABLE IV

SRI LANKA POPULATION DENSITY (1981)

(Some districts with the highest density of population)

District	Population	Area (in sq. miles)	Density (persons per sq. mile
Colombo	1,698,322	252.0	6742
Gampaha	1,389,490	540.0	2573
Jaffna	740,184	440.0	1682
Kandy	1,126,296	833.0	1352
Kalutara	827,189	620.0	1334

Department of Census and Statistics

OUTLINE OF GEOLOGY

The greater part of the island is made up of Precambrian crystalline rocks. The only extensive development of sedimentary rocks is along the north-west coast of the island which is built up of limestones of Miocene age. On the basis of lithology, structure and age the Precambrian rocks have been subdivided into 3 major units (Cooray 1978):

1. Highland Series
2. South-Western Group
3. Vijayan Series

Several dolerite dykes, small granitic bodies, and a series of pegmatites have been intruded into the Precambrian rocks. Two small occurrences of Gondwana sediments (Jurassic), the Tabbowa basin and the Andigama-Pallama basin, are located in the north-west of the island. The Miocene limestone formations are confined to the Jaffna area and to the north west of the country. Table V shows the succession of geological formations and principal mineral deposits of Sri Lanka, and Fig. 6 is a simplified geological map of the island.

Precambrian

<u>Highland Series</u>. Rocks of the Highland Series occupy the central highlands. The eastern boundary of the Highland Series is along the foot hills of the central highlands where a transitional zone lies between it and the Vijayan Series on the east and south-east. Enclaves of Highland Series rocks are found within the eastern Vijayan as at Kataragama and Buttala. The Highland Series comprises an extensive group of well-bedded rocks including quartzites, quartz schists, fine grained acid gneisses, granulites, calc gneisses and granulites, marbles, and the type khondalite, which is a sillimanite-garnet-graphite schist. These rocks extend in a broad band from the south-west coast (Welipatanwila area) to the north-east coast (Trincomalee area). One of the most striking features of the Highland Series is the close and intimate association of metasediments and charnockitic gneisses throughout the entire area. The two are conformably inter-banded (Cooray 1962). Whatever their original nature, the charnockitic gneisses have been formed in the course of the same high-grade metamorphism that gave

TABLE V

GENERAL SUCCESSION OF GEOLOGICAL FORMATIONS
AND PRINCIPAL MINERAL DEPOSITS IN SRI LANKA

Principal Geological Divisions		Principal Formations	Important Mineral Deposits	Others
Era	Period			
ANTHROPOZOIC	HOLOCENE (RECENT)	Recent residual and alluvial deposits, blown sand, coastal sandstone, coral and shell formations, beach mineral sands, gem gravels, peat, lagoonal and estuarine deposits	Kaolin, ball clay, refractory bond clay, residual and alluvial clay, silica sand, ilmenite, rutile, zircon, monazite, garnet, gem, coral, shell sillimanite, clay ochers.	Thorianite, thorite, baddeleyite-peat
CENOZOIC	QUATERNARY (PLEISTOCENE)	Laterites (may extend from Recent to Tertiary Periods), gravels, red earths.	Gem	Laterite, limonitic iron ore (low grade)
	TERTIARY (MIOCENE)	Limestone	Limestone	-
MESOZOIC	JURASSIC	Shales, Carboneceous shales and arkosic sandstone.	Shales	-
PALAEOZOIC	-	Abesnt	-	-
ARCHAEOZOIC	PRECAMBRIAN	Highland Series (metasediments) Vijayan Series (gneissic complex) Southwestern Group (gneisses and metasediments) Intrusives, (granites, dolorite dykes, pegmatites)	Marble, quartz, felspar, graphite, mica, apatite	Magnesite magnetite allanite cordierite, chert wollastonite sillimanite copper, serpentinite

(Modified after Herath 1980)

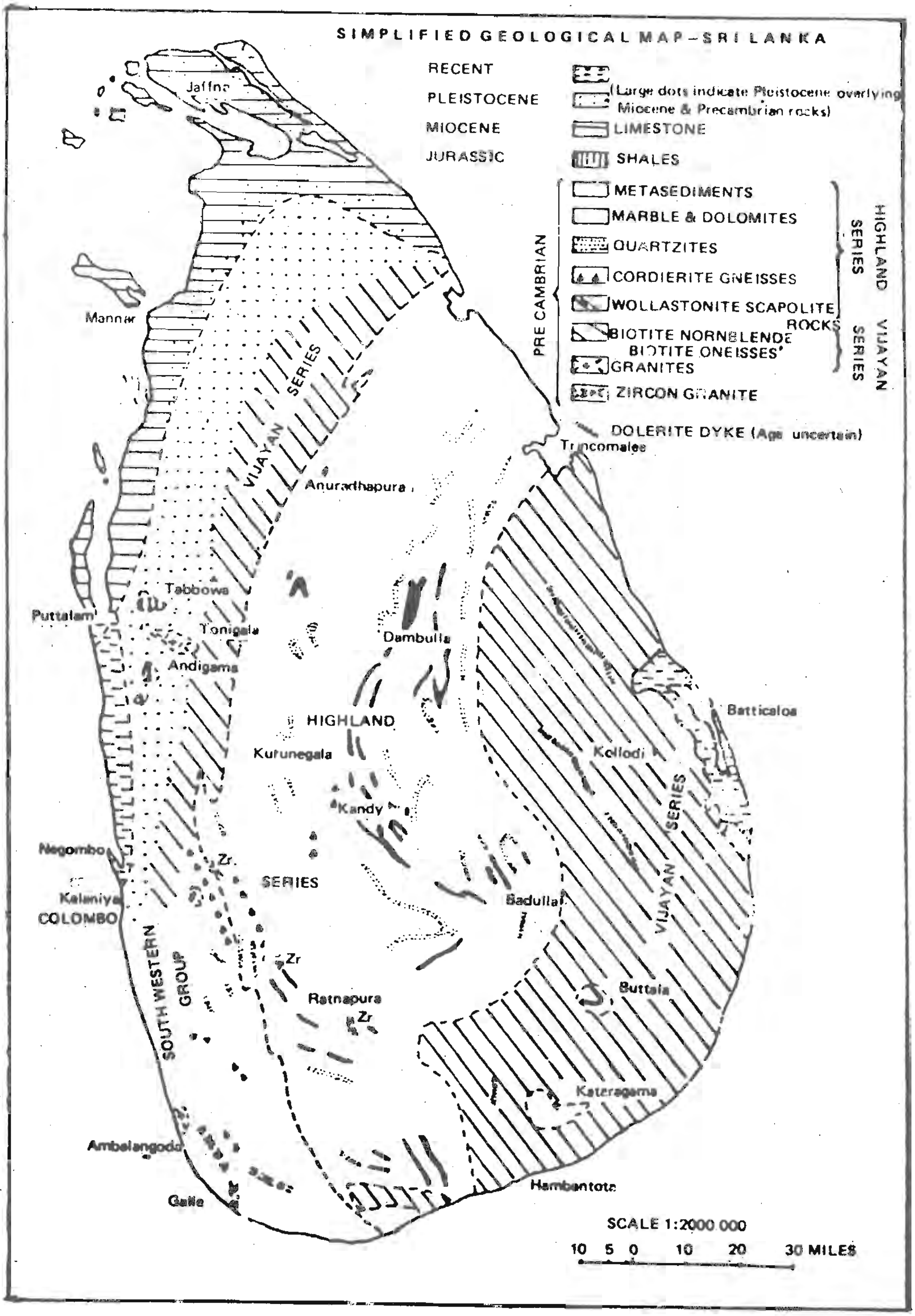


Figure 6. Simplified Geological Map of Sri Lanka

rise to the metasediments with which they are so closely associated. The only other prominent lithological type is in the Kadugannawa area where basic rocks are so developed that they have been given the special name of 'Kadugannawa Gneisses' (Coates 1935). The gneisses are black (see Fig.7), lustrous amphibolites or hornblende-plagioclase schists. Another group of amphibolite facies rocks, hornblende-biotite gneisses and migmatites, occur in the Kandy area restricted to large doubly-plunging synforms or "arenas" (Vitanage 1972).

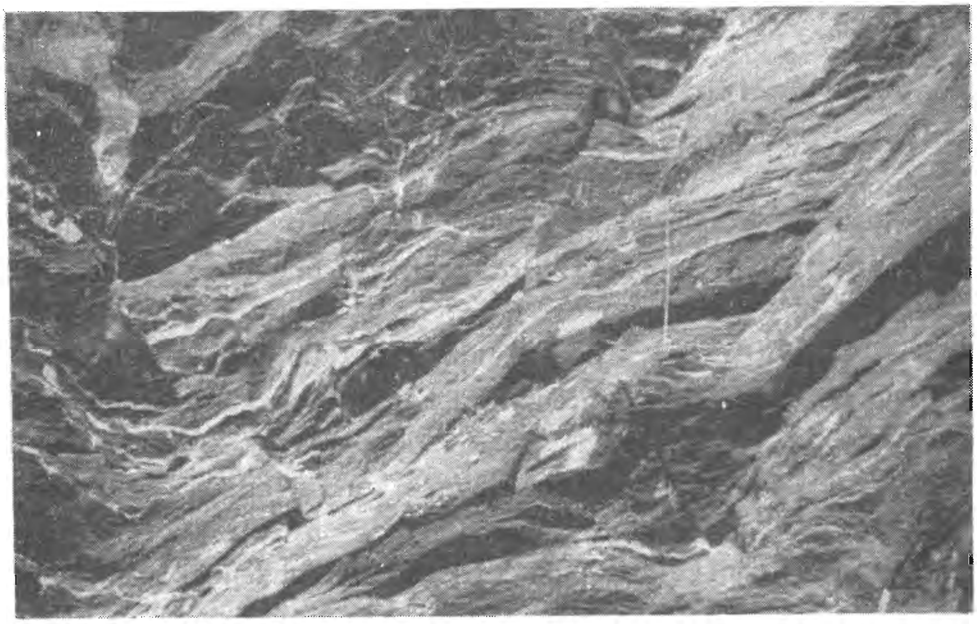


Figure 7. Kadugannawa Gneisses

Rocks of the Highland Series belong to the granulite facies of metamorphism. Closely associated with these rocks are assemblages characteristic of the amphibolite facies such as hornblende-biotite gneisses. It is believed that the Highland Series rocks have been subjected to polymetamorphism in the course of which some granulite facies rocks were retrogressively altered to amphibolite facies rocks.

South-western Group. This, like the Highland Series, is made up of schists, gneisses and granulites of metasedimentary origin. There are, however, significant differences between the two major units in terms of both lithology and metamorphic history, differences that appear to justify their separation (Cooray 1965). The main rock types are given below:

1. Thin persistant quartzites and quartz schists (unlike the thick quartzites of the Highland Series)
2. Narrow wollastonite calciphyres (unlike the thick marbles of the Highland Series)
3. Cordierite-bearing pelitic gneisses
4. Coarse grained intrusive hypersthene granite (charnockitic rocks)
5. Abundant granitic gneisses, augen gneisses and migmatites, including chert

The South-Western Group passes northwards into the western Vijayan by an increase in the proportion of granitic gneisses and migmatites.

Vijayan Series. On either sides of the Highland Series belt, except for the area occupied by the South-Western Group, are rocks of the Vijayan Series. They are mostly microcline-bearing quartzo-feldspathic rocks with layers and lenses of amphibolite and/or biotite. The main rock types include a variety of gneisses, migmatites and granitoid rocks including charnockitic gneisses. (Fernando 1948, and Cooray 1967).

It is not proposed here to discuss the stratigraphic relationships of the three Precambrian units. A good deal of controversy still remains about the sub division of the Sri Lanka Precambrian. What can be generally agreed is that the structures are everywhere complex.

The Seruwila copper magnetite deposit (discussed in Chapter 5) is at the margin of the eastern Vijayan and Highland Series. Serpentinite bodies observed in Sri Lanka are all confined to the boundary of the Highland Series and the eastern Vijayan (Fig. 6). A recent gravity survey of the country indicated a significant gravity low of an amplitude of approximately 25 milligals. This gravity low was also found to run along the eastern boundary of the Highland Series (Hatherton 1975). The geological interpretation of this gravity low shows that the contact between the Highlands and Vijayans is a thrust zone. These recent observations and findings reveal that the eastern boundary between the Highland and Vijayan Series stretching from Trincomalee through Uda Walawe to the Welipatanwila coastal area is a mineralized zone. A programme of work initiated by the Geological Survey Department proposes to study this zone in great detail. This boundary is about 25 km in width and 550 km long.

Intrusives

Dolerite dykes are present on the eastern and western side of the island, the former being prominent. The largest of these, the Kallodai dyke, can be traced for almost 100 km in a NW-SE direction. The Tonigala granite is located in the area between Puttalam and Galgamuwa in north-west Sri Lanka. Other granites include the Arangala hornblende granite in the Alutgama area and the Ambagaspitiya granite in the Yakkala area. Zircon bearing granites are well developed round Balangoda. Good exposures of zircon granite are also found at Loluwa neat Mirigama. Pegmatites are widespread in the Precambrian. An intrusion of carbonatite (apatite) was discovered at Eppawala in 1971.

Jurrasic

The Jurrassic or Tabbowa Series occupies a small basin a few square kilometres in extent. These are shallow water non-marine deposits of Upper Gondwana age. The main rock types are arkose, feldspathic sandstone, siltstone and mudstone. Fossil plant impressions in the siltstone and mudstone establish the stratigraphic position of the Tabbowa beds as Upper Gondwana or Upper Jurassic (Sitholey 1944). Two other occurrences of Jurassic sediments, south of Tabbowa, are at Andigama and Pallama. These deposits are composed of a fair thickness of carbonaceous shales, and contain fossils similar to those found at Tabbowa.

Miocene

The largest development of rocks of Miocene age occur in the north-west coastal belt of the island, extending from the Jaffna Peninsula in the north to Puttalam on the west coast. The limestone is best developed in the Jaffna Peninsula and is a highly fossiliferous, hard, compact rock, usually creamy in colour. In the Aruwakalu area, north of Puttalam, the lithology varies from pure limestone and siliceous limestone to calcareous sandstone and impure calcareous muds.

Besides the limestone in the west a very small outlier of rocks of Miocene age occurs at Minihagalkanda in the south-east coast.

Pleistocene and Recent Formations

Resting on the Miocene formations and crystalline rocks at several localities in the island are a variety of consolidated and unconsolidated material consisting largely of gravel, sands and clays. These deposits belong to the Quaternary system and among them are a number of economic mineral deposits.

Ferruginous gravel beds are mainly confined to the coastal plain from Negombo to Mannar. They have also been observed in other parts of the coastal areas of the island. In the western coastal area the gravel rests on limestone of Miocene age and is overlain by red earth deposits. The origin of the gravel is not known. Their distribution along the coastal belts indicate that these formations may be marine beach deposits formed when the Pleistocene sea swept over much of the present coastal area of the country.

Red earth formations are uniform in character and consist mainly of sand. They vary in thickness from a few metres to over 30 metres. They form prominent ridges parallel to the coast line. The quartz grains are well rounded, and their similarity to the dune sands suggests that the ridges once formed a barrier beach backed by sand dunes. Minerals present in these sands in negligible amounts include ilmenite, rutile, zircon, garnet and monazite. These constitute less than 5 per cent of the composition of the sands.

Terrace gravels occupy terraces that are a few metres above abandoned river courses in the Chilaw and other areas where they rest directly on the Precambrian rocks. They are thought to be fluviatile in origin.

Laterites are a mottled deep red, yellow or reddish brown ferruginous earth, showing vesicular structure. The thickest laterite occupies the high ground, 20 - 30m above sea level, between Negombo (north of Colombo) and Kalutara (south of Colombo). Inland it thins out, and with increase of elevation, passes into lateritic soils (Herath and Pattiaratchi 1963).

Other important deposits of the Quarterary system include residual and alluvial deposits, blown sand, beachrock (coastal sandstone), coral and shell formations, beach sands, lagoonal and estuarine deposits, peat deposits and gem gravel.

SUMMARY

The greater part of the island is made up of Precambrian crystalline rocks subdivided into three major units · Highland Series, South Western Group and the Vijayan Series. The rest of the island is composed of Miocene limestone and later sediments and two small basins of Gondwana (Jurassic) deposits faulted into the basement. The Highland Series consists of metasediments and closely associated charnockitic gneisses, metamorphosed under granulite facies conditions about 2100 million years ago. The South Western Group is characterised by the presence of wollastonite and cordierite bearing rocks. Coarse charnockitic rocks are common. The Vijayan Series is composed of migmatites and granitoid rocks, with scattered occurrences of metasediments and charnockitic rocks. The Vijayan rocks have been formed by the widespread granitisation and migmatisation of pre-existing Highland Series rocks under amphibolite facies conditions about 1250 $\pm$ 60 million years ago.

Several dolerite dykes and small granitic bodies have been intruded into the Precambrian rocks. A carbonatite intrusion has recently been identified (Eppawala apatite deposit). The Tabbowa beds are believed to be over 500m thick whereas the Andigama basin is over 350m in thickness. The Miocene occupies the north-western parts of the island and the Post Miocene formations include the red earths, laterites, beach rocks, and a variety of other sediments including gem gravel. The island is fairly rich in the non metallic group of minerals or the industrial minerals. The main mineral exports are graphite, gems, ilmenite, rutile, zircon and small quantities of mica. A number of industries have been set up using local mineral raw materials. In this connection the ceramic industry is worthy of special mention. Recent mineral discoveries include the Eppawala apatite deposit, the copper magnetite deposit at Seruwila and the Uda Walawe serpentinite deposits with traces of nickel. The boundary between the eastern Vijayan and the Highland Series is now recognised as a mineralised zone and the Geological Survey Department has plans to map this zone in great detail. The Seruwila copper-magnetite deposit and a few bodies of serpentinite constitute the only evidence available to assume that the boundary between the eastern Vijayan and the Highland Series is a mineralized zone. Much work therefore remains to be done before any definite conclusions could be made. This also applies to the origin of the mineralized zone. With the establishment of the Oceanography and Survey of Off-Shore Area Unit by the National Aquatic Resources Agency, the Marine Mineral Resources of Sri Lanka would also be investigated. A National Hydrographic Office has been established by the Agency.

CHAPTER 4

ENERGY MINERAL RESOURCES

In order to appreciate the development and distribution of energy mineral resources, other forms of available energy are also discussed. The pattern of use of primary commercial energy sources varies according to local abundance or shortage. Wood is the main fuel source in Sri Lanka. Since Sri Lanka has no known resources of fossil fuels, petroleum products and limited quantities of coal are imported. The Ceylon Petroleum Corporation is the sole importer and distributor of petroleum products and it operates a refinery at Sapugaskanda. This organization has also undertaken activities in connection with the exploration for oil in the country. Water power potential has enabled hydropower development. The existing electricity generating stations (hydropower and thermal) with a total capacity of around 430 MW(1983) generate nearly 1700 Gwh of electrical energy per year. Eighty per cent of the electricity generated is from hydropower. In 1968, the actual and potential economically viable hydropower resources of the Island were estimated at around 1600 MW of installed capacity capable of producing an average annual output of 6260 Gwh (UNDP-FAO-1969). However, the estimates are no doubt higher now since resources not considered to be economically viable 15 years ago could be viable today with the steep rise in the oil prices during the intervening period.

Approximately 50 million tons (wet basis) of low grade peat or 5 million tons (dry basis) have been proved to occur in the Muturajawala swamp north of Colombo. The deposit cannot be considered a promising one. Deposits of uranium have so far not been discovered. Promising areas for uranium exploration have, however, been identified for detailed investigation. Thorium minerals occur in the island, monazite being the most important thorium bearing mineral. Geothermal resources are limited. A number of hot springs have been identified but they cannot be considered as a potential resource for energy purposes. Figures 8 and 9 are presented to show the energy resources of Sri Lanka.

ENERGY CONSUMPTION PATTERNS

In Sri Lanka the total approximate energy consumption pattern is firewood - 60 per cent, petroleum products - 27 per cent, and hydro-electricity - 13 per cent (Fernando 1982).

The total energy consumption for the year 1979/1980 has been estimated at 10,000 Gwh (eletricity replacement) of which 1200 Gwh was produced by electricity, 2700 Gwh from oil products and 6100 Gwh by traditional fuels such as firewood and agricultural wastes. Traditional fuels therefore account for the major part of the energy consumed. Around 95 per cent of the households in Sri Lanka use firewood for cooking and about 85 per cent use kerosene for lighting. Nine per cent of the villages have access to electricity. Less than 2 per cent of the households use gas for cooking.

PETROLEUM

Petroleum resources in Sri Lanka have not been discovered up to now. The Ceylon Petroleum Corporation was established in January, 1961. It operates a refinery at Sapugaskanda with an installed capacity of 2,300,000 metric tons per annum, a blending plant and a candle factory. Besides other development projects, it is also responsible for exploring for oil. Excluding firewood, petroleum products are the most important source of energy, accounting for the major portion of the total commercial energy consumption in the Island. Table VI is presented to show the energy consumption in Sri Lanka from 1961-1981, and Table VII shows the projected oil products requirements for the decade 1980-1990.

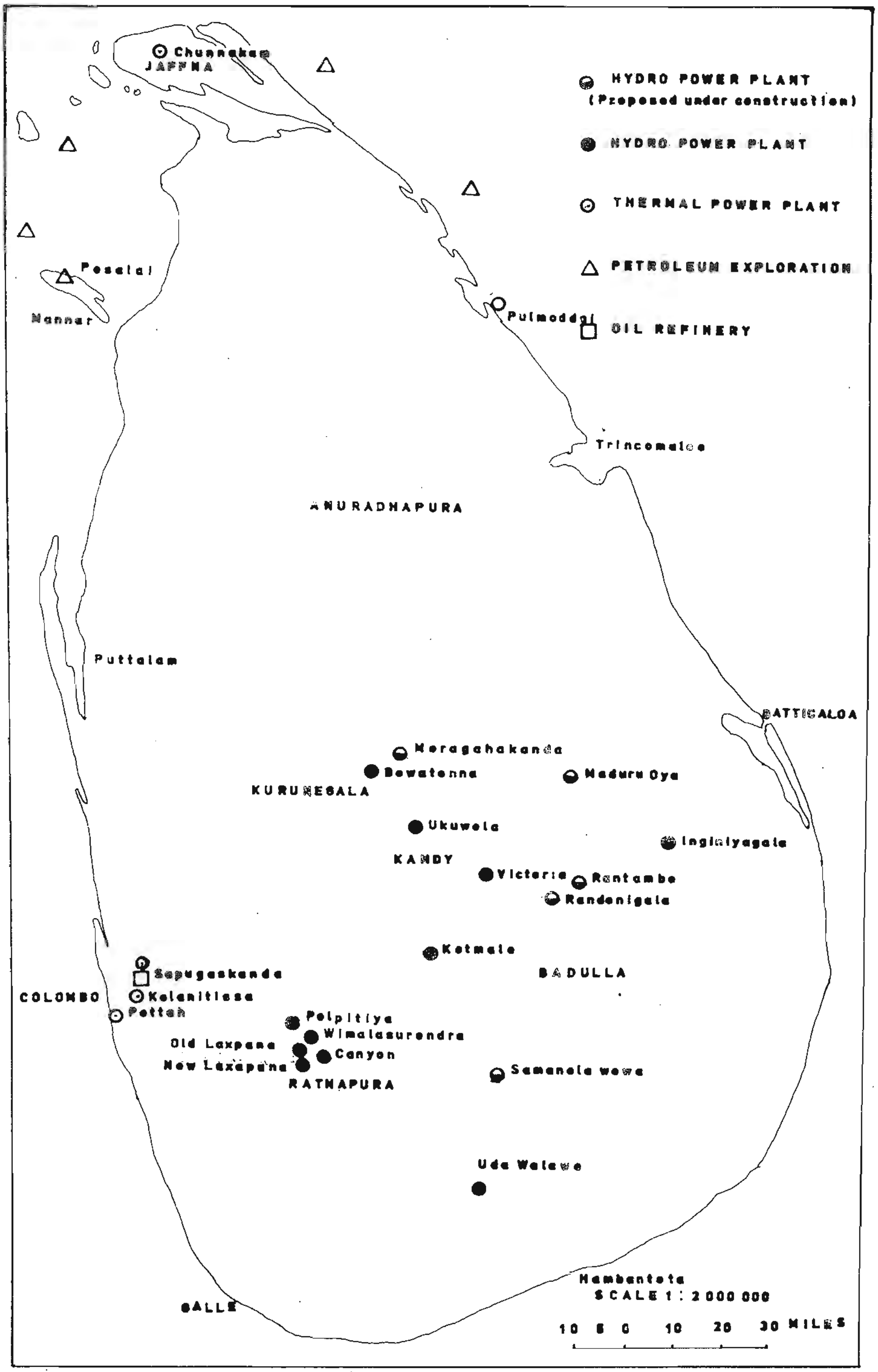


Figure 8. Energy Resources - Sri Lanka

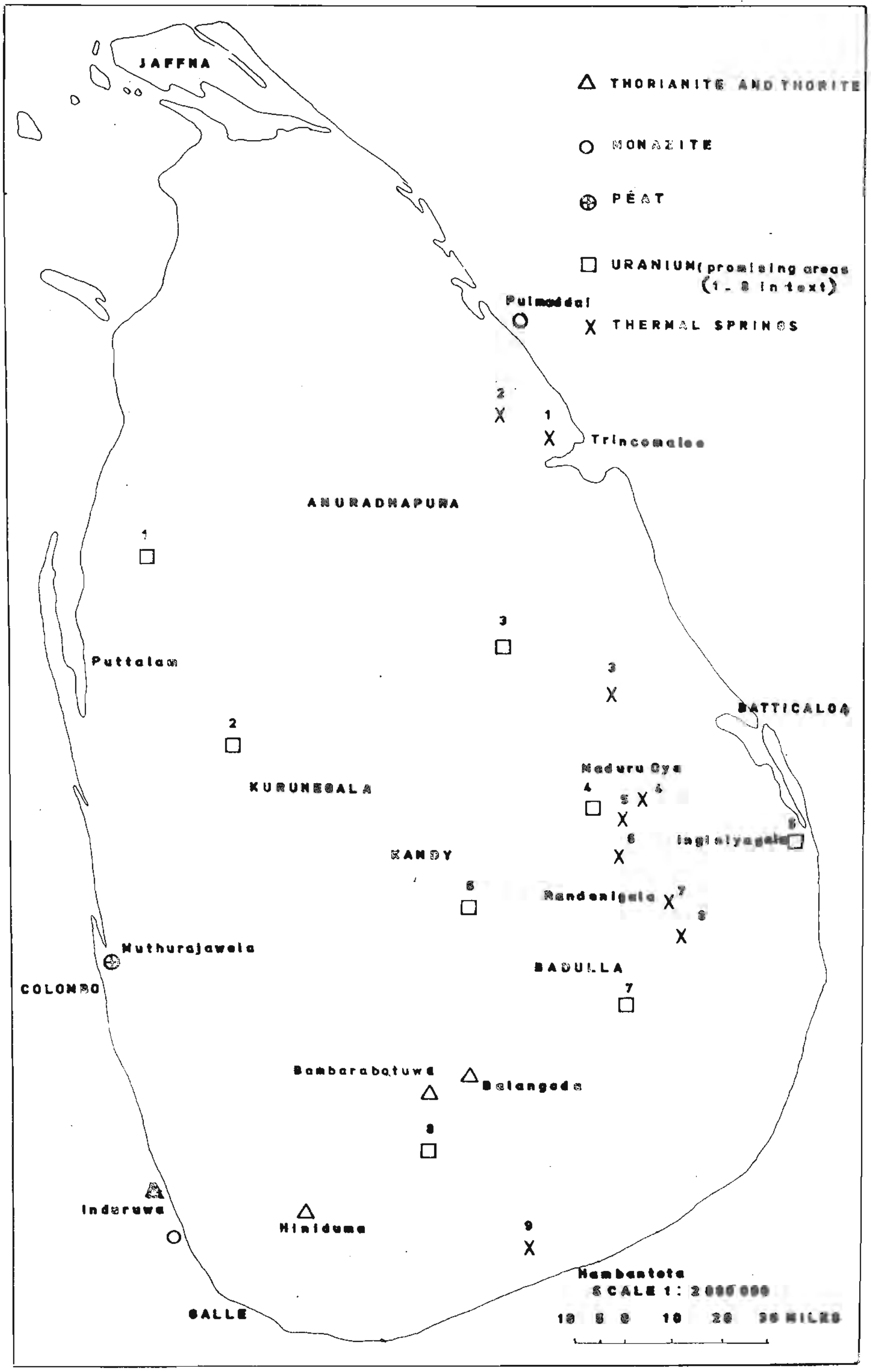


Figure 9. Energy Resources - Sri Lanka

TABLE VI

ENERGY CONSUMPTION IN SRI LANKA
1961 - 1983
(In Common Unit of Measure i.e. Gwh.e.r.)

Year	Electricity	%	Oil	%	Coal	%	Total
61	358.0	15.6	1674.6	73.0	261.37	11.4	2293.97
62	382.0	15.6	1809.3	73.8	261.56	10.6	2452.86
63	309.0	12.9	1821.6	75.9	269.06	11.2	2399.66
64	333.0	13.1	1879.5	74.0	327.19	12.9	2539.69
65	360.0	14.5	1860.3	75.1	256.31	10.3	2476.61
66	424.0	16.8	2034.9	80.8	57.94	2.4	2515.94
67	489.0	16.6	2237.4	75.8	229.69	7.6	2551.09
68	556.0	18.8	2319.9	78.5	78.37	2.7	2954.27
69	604.0	19.3	2464.5	79.0	49.68	1.7	3118.18
70	662.0	19.7	2679.0	79.6	22.69	0.7	3363.69
71	722.0	21.5	2612.4	77.7	24.75	0.8	3359.15
72	810.3	22.5	2772.0	76.9	21.57	0.6	3603.86
73	866.1	22.9	2891.4	76.6	18.0	0.5	3775.5
74	982.3	27.9	2295.3	71.7	12.19	0.4	3199.79
75	965.4	30.5	2196.9	69.4	3.75	0.2	3166.05
76	999.3	29.0	2440.8	70.9	1.87	0.1	3441.97
77	1040.6	31.4	2069.8	68.5	1.5	0.1	3311.9
78	1162.3	30.0	2682.3	69.3	24.18	0.7	3868.78
79	1298.3	30.7	2932.1	69.2	4.01	0.1	4234.41
80	1391.6	31.7	2993.8	68.2	5.09	0.1	4390.49
81	1503.1	31.1	3320.7	68.8	3.59	0.1	4827.39
82	1686.0	31.2	3646.8	67.4	77.79	1.4	5410.59
83	2114.4	30.3	4810.86	69.0	40.49	0.6	6965.59

Conversion Factor: 1000 tons of oil = 3 Gigawatt hours
1000 tons of coal = 1.875 Gigawatt hours
1 Million Kwh = 1 Gigawatt hour

Source: Ceylon Electricity Board, Ceylon Petroleum Corporation and Customs Returns.

After: Edwin Ranasinghe - Manager (Economics and Planning) Ceylon Petroleum Corporation.

TABLE VII

PROJECTED OIL PRODUCTS REQUIREMENTS
IN SRI LANKA
(1980-1990)
1000 metric tons

YEAR	Domestic Kerosene	Industr. (HD & PO)	Transport Auto Diesel	Petrol	Total
1980	188.9	156.4	401.4	88.1	840.8
1981	195.2	159.9	428.2	87.3	870.6
1982	201.7	163.7	450.0	86.5	901.9
1983	208.4	167.8	472.9	85.7	934.8
1984	215.3	172.5	497.2	84.8	969.8
1985	222.5	177.4	522.5	84.1	1006.5
1986	229.9	182.5	549.2	83.3	1044.9
1987	237.5	188.4	577.3	82.5	1085.7
1988	245.4	194.6	606.7	81.8	1128.5
1989	253.6	201.3	637.6	81.0	1173.5
1990	262.0	208.7	670.3	80.3	1221.3

After Edwin Ranasinghe Manager (Economics and Planning) Ceylon Petroleum Corporation.

The price of crude oil has been steadily rising over the years. In Sri Lanka, the price increases have not been immediately passed on to the consumer. However, over the past decade there have been sharp increases in the prices of petroleum products. In 1973 a gallon of super petrol was sold to the consumer at Rs.5.75, kerosene at Rs.1.32 and auto diesel at Rs.2.14. The retail prices now are petrol Rs.61.40, kerosene. Rs.29.97 and auto diesel Rs.36.98. As Sri Lanka has to continue to depend on kerosene (for household lighting), heavy diesel and furnace oil (industrial sector) and petrol (transport) the import of oil will continue to have a critical impact on the economy of the country. Off-shore investigations for petroleum have, however, commenced and there is some hope that Sri Lanka may discover oil in the future. The Corporation which divided the off-shore area into 13 blocks for the purposes of exploration work has now allocated most of these blocks to foreign companies to carry out exploration work on a production sharing basis. (Fig.8).

ELECTRICITY

The development of electrical power in Sri Lanka has been described by de Silva (1980). Electricity distribution was started in Sri Lanka in 1895 when Colombo was supplied with electricity from diesel engines in the Pettah Power Station. In 1929 the installed capacity was 2.4 MW and the demand was 1.9 MW. The Stanley Power Station was constructed next at Kolonnawa in 1929 with an installed capacity of 6 MW which was later increased to 9 MW. A further 3 MW was installed at the Pettah Power Station in 1939 and by this time the system peak demand was 7.8 MW.

The first hydropower station to be constructed was the Laksapana Power Station with an installed capacity of 25 MW. It was declared open in 1950. The installed capacity of this station was later increased to 50 MW and the work was completed in 1958. The Kelanitissa steam thermal station (50 MW) was completed in 1964, and in 1959 the next hydro power station at Norton Bridge (Wimalasurendra Power Station) with an installed capacity of 50 MW was completed. The hydro schemes utilized the water resources of the Kehelgamuwa Oya.

The next phase of development was based on the utilization of the water resources of the Maskeli oya and the first station was constructed at Polpitiya with an installed capacity of 75 MW. This station was commissioned in 1969. The new Laksapana Power Station (100 MW) was completed in 1974. Work on the Canyon Power Station (30 MW) on the Maskeliya Oya was completed in 1983. By this time other hydropower stations connected to the system were Inginiyagala in 1954 (10 MW) and Uda Walawe (6 MW) in 1968. The power available from these two small stations are seasonal (Fig.8). The Chunnakam (diesel) station (8 MW) was installed in 1959. In order to meet the expected energy shortfall in the immediate future, thermal plants with a total capacity of 170 MW have been installed at Kelanitissa and similar plants with a total capacity of 80 MW has also been installed at Sapugaskanda.

The Mahaweli Ganga development scheme will bring under cultivation about 650,000 acres of new lands and provide assured water for another 250,000 acres of partially cultivated land. The Master Plan envisages the construction of 15 reservoirs on the Mahaweli Ganga and its tributaries and the Maduru Oya. Eleven of these reservoirs are to include power stations. The total installed capacity of the main stations are assessed at around 500 MW in the Master Plan. It also provides for the future development of a number of hydropower stations in the upper catchment of the river giving an additional installed capacity of nearly 450 MW. The work was to be undertaken in 3 phases each consisting of a number of projects and spread over a period of 30 years.

Work on the first project in the Master Plan, the Polgolla - Bowatenne Diversion was inaugurated in 1970. The main features of the project are the construction of a dam across the Mahaweli Ganga at Polgolla and the diversion of water through a tunnel (7955 metres in length) to Ukuwela where a power station is operated with an installed capacity of 40 MW. From here the water flows to the Bowatenna reservoir. At this point there is another power station with an installed capacity of 40 MW. From here a part of the water is diverted to the Kandalana - Kalawewa Basin through a 6979 metre long tunnel. These complexes including the power station at Ukuwela were completed in 1976, and the Bowatenne power station was commissioned in 1981.

In the present accelerated programme of Mahaweli development which came into effect in 1977, the State has decided to take up the development of the first stage, to be completed in about 6 years. A number of reservoirs and hydro power projects are being constructed. The power stations will have a total installed power capacity of over 500 MW and irrigation development would cover 320,000 acres of new land. The main reservoirs are Victoria (first stage 210 MW), Kotmale (201 MW) and Randenigala (122 MW). Other reservoirs mentioned are Maduru Oya (8 MW) Moragahakanda (40 mW) and Rantembe (46 MW) (Fig.8).

The installed capacity and the annual energy output capability of the generating stations as at 1985 and the power stations under construction and those planned for development under the accelerated programme of Mahaweli development and the Walawe ganga project are presented in Table VIII. The predicted maximum power demand on the national grid (Ceylon Electricity Board study, 1981) for the period 1984-1996 is presented in Table IX.

The total hydropower resources of Sri Lanka (existing and potential) as estimated in 1968 are presented in Table X. As there has been no systematic basin by basin study under-taken so far, figures presented for hydropower resources (Table X) are subject to revision. The need to investigate all potential hydropower sites so as to examine their technical feasibility and economic viability has been emphasised from time to time. With a study of this nature it would be possible to draw up a master plan to develop the hydropower resources on a planned basis. In this connection the Ceylon Electricity Board has plans to undertake a survey of the hydropower potential of the country under a Master Plan study on the subject of energy in Sri Lanka.

Sri Lanka's electrical energy supply from hydropower resources will continue to expand sharply till about the year 1990. From there onward the development in this source of energy is expected to be slow.

PEAT

Peat is used as a fuel in many countries. The largest known deposit of peat in Sri Lanka is in the Muturajawela swamp, situated on the west coast, north of Colombo. The deposit covers an area of 34 sq. km with an average thickness of 4 metres. Investigations by the

TABLE VIII

SRI LANKA POWER STATIONS

(Existing - Under construction - those planned)

Existing Hydro	Power (MW)	Annual Energy Capability (Gwh)
*Kotmale	201	-
Victoria	210	-
Old Laxsapana	50	325
Inginiyagala	10	60
Uda Walawe	6	22
Wimalasurendra	50	105
Polpitiya	75.	355
New Laxsapana	100	410
Ukuwela	40	220
Bowatanna	40	135
Canyon	30	144
Existing Thermal	**Power (MW)**	**Annual Energy (Gwh)**
Sapugaskanda	80	-
Kelanitissa	170	-
Chunnakam	12	30
Pettah	08	02
Under Construction or Planned for development	**Power (MW)**	**Annual Energy (Gwh)**
Randenigala	122	-
Moragahakanda	40	-
Maduruoya	8	-
Rantambe	46	-
Samanalawewa (Walawe ganga)	120	-

Ceylon Electricity Board

*Presently available 67MW

Geological Survey Department have proved 50 million tons (wet basis) of peat in the area. Actual reserves are much larger. Drying is one of the serious problems of peat workings. The peat contains 80 - 90 per cent water, and this could be reduced to 10 - 15 per cent by slow drying over a period of 10 - 12 days. Table XI shows the results of analyses for type samples of peat. The material is of a low grade type and the formations are not of a uniform character. The deposits cannot at present be considered to be of value as an energy resource.

TABLE IX

PREDICTED MAXIMUM POWER DEMAND
ON NATIONAL GRID

YEAR	MAX. LOAD MW.
1984	657
1985	744
1986	808
1987	883
1988	961
1989	1046
1990	1139
1991	1242
1992	1352
1993	1472
1994	1602
1995	1744

Ceylon Electricity Board

(CEB Study in 1981)

TABLE X

HYDRO POWER RESOURCES OF SRI LANKA
(Including existing stations)

Location	Capacity (M.W)	Average Annual Output (Gwh.)
Mahaweli Complex	962	3380
Kelani Ganga	305	1450
Kalu Ganga	135	580
Walawe Ganga	126	680
Jasmin Complex	36	160
Other Minor Rivers	28	40
TOTAL	1592	6260

UNDP - FAO Report 1968
Ceylon Electricity Board.

TABLE XI

CHEMICAL ANALYSES OF MUTHURAJAWELA PEAT

Sample No.	1-A	3-A	8-C	10-E	13-A
Moisture %	78.34	82.22	83.52	79.39	70.69
Ash %	16.95	24.92	11.24	30.46	27.65
Volatile Matter %	56.07	44.01	51.22	42.69	46.25
Nitrogen %	0.86	0.43	0.92	0.70	0.73
Total Sulphur%	4.15	5.08	5.14	4.78	3.56
Fixed Carbon%	26.98	31.07	37.54	26.75	26.00

Ash content - range 10 to 30 per cent (Average 20)
Sulphur content - range 1 to 8 per cent (average 5)
Moisture - range 80 to 90 per cent
Nitrogen content - less than 1 per cent
Geological Survey Department
Colombo 2.

URANIUM AND THORIUM MINERALS

Uranium, the most important source element of atomic fuel, is found in the earth's crust in an amount estimated at around 0.0003 per cent. But it also occurs in concentrations of sufficiently high grade to permit economic extraction; these are the ore deposits. The principal ore mineral of uranium is pitchblende or uraninite. Along with a few other lesser known minerals, uraninite is a primary ore mineral. There are also a number of other uranium minerals, such as carnotite, autunite, torbenite, etc., and these are all secondary minerals derived from the break-down of primary ore minerals or formed by the precipitation of uranium - bearing solutions some distance away from the original source. The latter type of mineralisation is more widespread than primary mineralisation, and usually occurs in sandstone, shales and conglomerates.

Deposits of uranium have so far not been identified in Sri Lanka. In 1979 an island wide stream sediment survey was undertaken by the Geological Survey Department with assistance from the International Atomic Energy Agency (IAEA) to identify uranium mineralization. The survey which was continued in 1983 was a reconnaissance type geochemical exploration programme which helped to demarcate areas for future more detailed surveys. The promising areas are Kalaoya, Galgamuwa, Polonnaruwa, Rukam - Mahaoya, Kalmunai, Hanguranketa, Passara and Rakwana (Personal communication - Jayawardene - 1983). These areas are marked 1 - 8 respectively in Fig.9.

These areas are mainly composed of highly metamorphosed rocks. Rocks of Jurassic age (shales, sandstone and arkose) are confined to the Kalaoya area. The average uranium values obtained for the stream sediments are in the region of 30 ppm U_3O_8. However, values over 300 ppm have been recorded. Although anomalous areas have been demarcated detailed surveys to identify source rocks, followed by a programme of drilling and sample testing have to be undertaken to detect the presence of uranium ore. Uranium in hard rock formations should show high values for economic exploitation. In soft rock formations low grade ores could be exploited economically (30 - 500 ppm.). The Geological Survey has plans to undertake follow up work on systematic lines in the field of uranium exploration.

Thorium is a potential atomic fuel and is three or four times as abundant as uranium in the earth's crust. Unlike uranium, however, the principal thorium minerals are all primary minerals and not altered secondary minerals. In Sri Lanka, thorianite (the oxide of thorium) and thorite (the silicate of thorium) have been found in small amounts in detrital deposits, mainly in gravel deposits or in talus accumulations in the Bambarabotuwa, Medagama, Niriella, Malwela, Balangoda, Ratnapura, Pelmadulla and Mitipola areas, but none of these are of commercial importance.

The bulk of the world's thorium is from placer deposits, the most important mineral being monazite, the phosphate of the rare earths (cerium, lanthanum, etc.) with thoria. Monazite is found as an important constituent of the heavy mineral sands at several locations on the beaches of the island. The deposits on the west and south-west coasts of the island are seasonal deposits formed during the south-west monsoon. The most important of these seasonal deposits are at Kaikawela, near Induruwa, and Polkotuwa, near Beruwela. Both these deposits were worked by the Geological Survey for the recovery of monazite and zircon and small amounts of garnet. The Kaikawela and Polkotuwa deposits were of special interest as small amounts of fine grained thorianite were recovered from the processing of these sands. This was the first detection of thorianite in Sri Lanka beach sands. Monazite also occurs in other areas and in the beach sands which are processed at Pulmoddai. Over 500 tons of monazite could be produced per annum in the country. Table XII is presented to show typical analyses of monazite, thorianite and thorite.

It is believed that thorium utilizing nuclear reactors appears a possibility in the future. There would be a substantial market for thorium when successful thorium thermal and breeder reactors are developed. Thorium is also used in the manufacture of gas mantles, aircraft alloys, refractories and catalysts.

THERMAL SPRINGS

A survey of hot springs in Sri Lanka was undertaken by Fonseka et al (1969). At present they cannot be considered as a geothermal resource for power generation. Unlike in some other parts of the world, these springs do not appear to have any direct connection with volcanic activity. For instance in Japan with about 65 active volcanoes, there are very rich potential reserves of geothermal energy. At present Japan's geothermal power generation output amounts to about 250 MW. In Sri Lanka, hot springs are mainly located in the eastern parts of the country where dolerite dykes are well exposed (Fig.9). Nine springs have been identified and the waters from these springs record a temperature usually in the range $34^{O}C$ to $55^{O}C$ which is considered fairly low (Table XIII). These hot springs are of no economic importance at present.

TABLE XII

CHEMICAL ANALYSES OF MONAZITE THORIANITE AND THORITE - SRI LANKA

MONAZITE			
Constituents	Dondra	Ratnapura	Beruwela
Thoria ThO_2	9.51	10.29	8.65
Ceria C_2O_3	28.70	27.37	27.35
Lanthanum La_2O_3	28.56	30.13	31.08
Yttrium Y_2O_3	1.05	2.14	0.95
Ferric Oxide Fe_2O_3	0.10	0.81	0.15
Alumina Al_2O_3	1.31	0.17	0.78
Lime CaO	0.89	0.41	0.20
Silica SiO_2	-	1.03	1.60
Phosphorus pentoxide P_2O_5	28.91	27.67	27.50
Titania TiO_2	0.05	-	0.15
Total	99.08	100.02	98.41

Geological Survey Department
Colombo 2

THORIANITE AND THORITE		
Constituents	Thorianite (Kondurugala)	Thorite (Kondurugala)
ThO_2	76.22	66.26
C_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
Total	99.93	99.89

(Imperial Institute) London.

Dondra and Beruwela - Beach sand deposits
Ratnapura - Gravel deposits

TABLE XIII

LIST OF THERMAL SPRINGS IN SRI LANKA

LOCATION Number	Name	DISCHARGE Litres/hr	TEMPERATURE	TOTAL grams/litre
1	RANKIHIRIYA		-	-
2	KANNIYAI		42	0.220
3	GALWEWA		-	-
4	KAPURELLA	1200	55	0.870
5	MAHA OYA	approximate	54	0.990
6	MARANGALLA	minimum	47	-
7	WAHAWA		-	-
8	KIVULAGAMA		34	0.550
9	MAHAPELESSA		44	6.490

*See figure 9.

After Fonseka et al (10).

OTHER RESOURCES

Other resources include various agricultural wastes such as paddy husk, sawdust, straw and coir dust. Investigations are being carried out on the application of solar energy. Wind mills have been constructed for use in irrigation and for domestic purposes. Biogas units, mainly for domestic use, have been constructed in some rural households. The installation of mini hydro power plants is being examined. The production of alcohol for power is also being considered. Attention has been given by NARA to a study of the Trincomalee off-shore region which includes the Trincomalee Submarine Canyon. The availability of deep water (extending to a depth of 2,500 metres) in close proximity to the coast at Trincomalee and the existence of a suitable temperature gradient gives Trincomalee the ideal conditions for the location of Ocean Thermal Energy Conversion (OTEC) systems. Presently studies are underway to obtain further oceanographic data relating to OTEC. These studies may also throw light on the origin of the Eastern Mineralized Zone (boundary between the Highland Series and Eastern Vijayan) which could be traced as far as Trincomalee (Seruwila copper-magnetite deposit).

SUMMARY

Firewood still remains the most important source of energy in the rural areas, accounting for nearly 60 per cent of the Island's energy needs. At present only 25 per cent of the country is covered by forests. It is envisaged that plantation forests would cover about 5 per cent of the land area by about the year 2000. Attention has also been given to the production of charcoal in the country. Sri Lanka has no known oil resources, and crude oil is imported and refined. Limited quantities of coal are imported. The peat deposits in the island cannot be considered an energy source. This also applies to the known thermal springs. Monazite occurs in appreciable amounts. Although areas have been demarcated for uranium surveys, much work remains to be done in this field of activity. The total hydropower resources of Sri Lanka were estimated in 1968 at 1600 MW. Projects not considered to be economically viable in 1968 could be highly viable now with the rise in oil prices. When the Master Plan Study (to be undertaken by the Ceylon Electricity Board) on the energy problem is completed, a true picture of the hydropower potential in Sri Lanka would be available. The country's electrical energy will mainly be met by her hydropower resources till the late 1990's. According to power demand forecasts for the country, the probable demand on the national grid in the year 1990 is expected to be around 1140 MW and in the year 2000 it would be in the region of 2500 MW (9 per cent growth rate from 1992). Expecting hydropower to supply 1500 MW by the year 2000, there is still a large balance to be supplied from other sources. Revised figures for electrical energy demand in the near future are likely to show higher values than those mentioned here.

Indications are that the economically exploitable hydropower potential of the island at present (taking into amount the high prices of fossil fuels) would be in the region of 2500 - 3000 MW which is nearly double the hydropower potential (1600 MW) as estimated in 1968. However, hydropower development in the country after the turn of the century is expected to be slow. The immediate need therefore is to develop and introduce new sources of energy. Alternative sources of energy such as solar, wind and biogas are not

going to supply the large increases in energy demand that will occur in Sri Lanka around 2000 AD. They are mainly acceptable for rural application. Power from coal has to be introduced and even power from nuclear reactors may have to be considered in order to meet the large blocks of energy demands in the future.

CHAPTER 5

FERROUS AND FERROALLOY MINERAL RESOURCES

Although there are some occurrences of a few of the minerals falling into this group, only iron occurs as deposits of any economic value. The use of silicon (Silica) in alloy form (ferro-silicon) is firmly established in the iron and steel industry. Silicon metal is also used in aluminium casting which requires silicon additives. Sri Lanka has extensive deposits of high grade silica used mainly in the ceramics and allied industries. Silicon alloys and silicon metal are not produced in this country. Silica is described under the non-metallic group of minerals in Chapter 7.

Molybdinite is known to occur as a minor accessory mineral in some pegmatites, granites and graphite bearing veins. None of these occurrences are in sufficient concentration to permit economic extraction. Laterized serpentinite occurrences at Uda Walawe have been studied in detail (Dissanayake 1982). The serpentinite shows a nickel content of 500ppm (minimum) and 2 per cent (maximum) and it also shows the presence of cobalt (70 - 380 ppm), manganese (700 - 6300 ppm), and chromium (300 - 3100 ppm). The results of studies by the Geological Survey Department in the serpentinite outcropping areas at Welepatanwila (Ussangoda coastal area) indicate higher chromium values (over 2 per cent) than those recorded for the Uda Walawe deposits. Jayawardene (1982) reports the presence of Fe 32-37 per cent, Co 13-19 per cent and Ni 8-13 per cent in the mineral pentlandite from the copper-iron ore prospect at Seruwila, and the trace element data indicate the presence of vanadium. It is also stated that the ultra-basic rocks in the Seruwila area have comparatively high contents of chromium, manganese and zirconium. The above values have no bearing on the overall grade of the ore at Seruwila or Uda Walawe. However, the information is useful for future more detailed surveys in the eastern parts of the island.

IRON ORE

Iron in its various forms, steel pig iron, wrought iron, cast iron and various alloys, is the most extensively utilized metallic element of the earth's crust. Iron ore is a low value mineral product and can be produced economically only in large quantities. Mining and transport costs are critical. Hematite ores are the most utilized and many of the major hematite deposits of the world can be mined at a grade higher than 60 per cent iron. In estimating the actual importance of ore deposits, a problem arises as to what constitutes "Ore". This varies from place to place and from time to time. For example, if we take the case of iron, a large part of the ore mined in France has only 26 per cent iron, but material of this grade would not be considered as ore in India, as the latter has adequate reserves of high grade iron-ore to last hundreds of years.

There is an abundance of high quality iron-ore in the world and recent discoveries, particularly in Western Australia, Africa and South America have added substantially to the world's known reserves of high quality iron ore which are now estimated at over 300 billion tons. This non-European ore is highly competitive on account of its high quality. The Sri Lanka deposits of iron-ore are negligible when compared to the world's large deposits. The total known iron ore reserves in the island are in the region of 10 - 12 million tons. The importance of the iron ore, however, lies mainly in the fact that it can, given other favourable conditons, support a small scale local iron and steel industry. Slag heaps have been observed to be present at a number of localities where iron ore deposits occur in Sri Lanka. These mark the sites of ancient iron furnaces. This trade was probably active during the Portuguese Period (16th and 17th centuries). Local folklore is rich in legends pertaining to the iron and steel production activities of this period. In many instances the slag heaps contain hollow conical clay tubes, about 2 inches in diameter at the large end, which were probably used for casting steel. Coomaraswamy (1904) describes in the following words what was one of the last surviving furnaces at Hatarabage near Balangoda:

"The iron smelters are called Yamanhu. The furnace is sheltered beneath the thatched roof of a shed which is open on all sides; it is quite close to the house occupied by the smelter and his family, as was always the case, it being more convenient to collect and bring the ore to the furnace than to build the furnace near the ore".

The iron ore deposits of Sri Lanka fall into three broad categories (Fig.10):

1. Deposits of hydrated iron oxide (limonite and geothite) occuring at or near the surface (lateritic ores)
2. Magnetite deposits within iron formations
3. The Seruwila copper-magnetite type of ore

Hydrated Iron Oxide Deposits

The hydrated iron oxide type of ores are the massive highly ferruginous laterites rich enough in iron hydroxide (mainly geothite) to constitute iron ore. These are mainly concentrated in the south-west sector of the island, particularly in the Ratnapura district, and to a lesser extent in the Galle and Matara districts. The occurrence of iron ores of this type has been known for decades, and Wadia (1939) pointed out that the development of the Sri Lanka iron ores was economical in spite of the fact that the deposits were very small. In his preliminary report, Wadia gave a figure of 1.75 million tons for the reserve, and later he estimated the total reserves of surface ore at between five and six million tons.

The ores occur 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 crest of hills, as for instance at Noragolla, or on hill slops as at Dela East. In some fields very large boulders of ore, several thousands of cubic metres in size, are found protruding from the soil (Fig.11). Generally they have no great underground extension in depth. The deposits are small, and forty to fifty scattered deposits of this type are known in the south-west sector of the island. Individual deposits vary widely in size from about 10,000 to 150,000

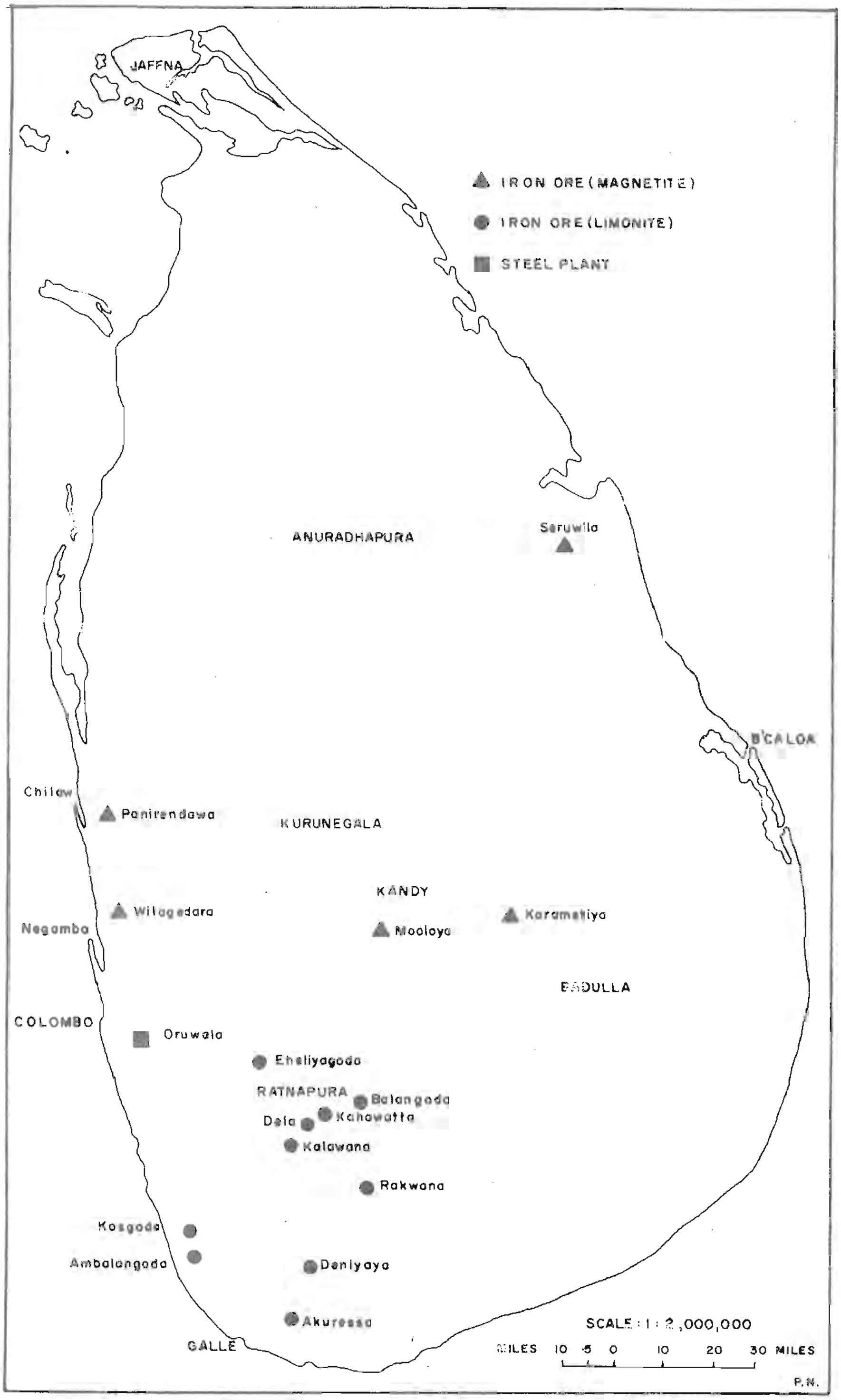


Figure 10. Iron Ore Deposits - Sri Lanka

tons. The most important of these deposits are at Dela, Noragolla, Opata and Poronuwa in the Ratnapura district and Wilpita in the Galle district.

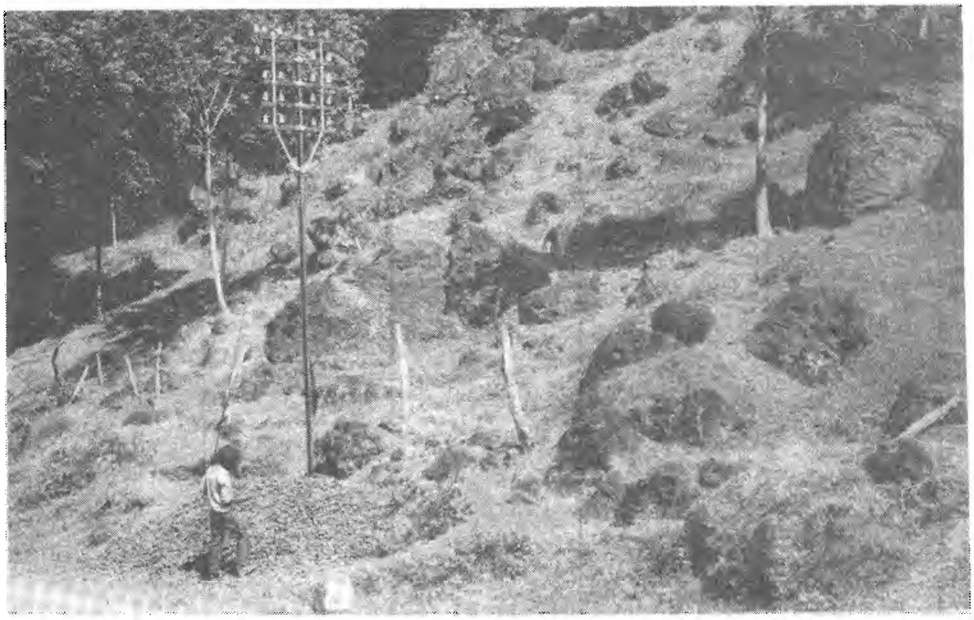


Figure 11. Boulders of Iron Ore - Dela Deposit

Besides the massive high grade ore averaging over 50 per cent Fe (Table XIV) there are lower grade ores which are also ferruginous lateritic types. These are markedly vesicular, have a lower specific gravity, and contain both clay and siliceous matter. These ores generally assay from 30 - 42 per cent Fe.

Diamond drilling investigations (1958) in the Dela and Noragolla deposits revealed that even at depth there is no continuity of the ore beds and that they are rather in the nature of pockets and lenses with much barren ground in between. With such uneven and sporadic deposits scattered over so many localities the accurate estimation of the quantity of ore is an extremely difficult task. Fernando (1958) in a report on the iron ore deposits of Ceylon estimates the iron ore reserves at around 2.2 million tons. This estimate has been given after a fairly detailed investigation of the ore deposits. Table XIV is presented to show the analytical data of some typicl samples of ore of the hydrated type.

TABLE XIV

ANALYSES OF IRON ORES - TYPICAL HYDRATED TYPES

Constituents	Dela	Noragolla	Ambalangoda	Deniyaya
SiO_2	6.57	4.25	13.16	11.58
Fe_2O_3	73.35	80.11	64.48	69.98
Al_2O_3	2.10	2.22	7.99	2.15
MnO	1.14	0.94	N.A.	1.03
TiO_2	Trace	Trace	N.A.	0.15
P_2O_5	1.62	1.75	0.09	0.87
CaO	0.14	0.11	N.A.	0.97
MgO	Trace	Trace	N.A.	0.01
S	0.17	0.19	N.A.	0.17
Loss on ignition	11.48	11.42	11.19	11.76
Total	99.51	100.59	96.91	99.67

After Kumarapeli (1964)

Geological Survey Department

The mining of the iron ore deposits will not present any serious problems other than those arising from the scatteed distribution of the ores. In most cases open cast methods will be all that is necessary to exploit the ore. With one or two notable exceptions, by far the great majority of the ore deposits occur on estates, mainly rubber and tea, and occasionally on cinnamon property. Although the

Sri Lanka iron ores are high-grade for deposits of this nature, the content of metallic iron is well below the amount normally preferred in modern blast furnace practice while the phosphorus content is comparatively high.

Magnetite Deposits

In the second category are the magnetite deposits discovered at Wilagedera in the Sandalankawa area (1959), at Panirendawa in the Chilaw area (1962), and the small occurrences on Mooloya Estate, Hewaheta, and at Karametiya. The only deposit of economic value is the one at Panirendawa; the others are too small to be of interest. Kumarapeli (1964) has given a detailed account of the Panirendawa magnetite deposit.

The Wilagedara magnetite deposit is of interest as it was the first bedded magnetite deposit discovered in Sri Lanka prior to this discovery only the hydrated iron ore deposits of the south-west were known. Although the deposit is too small to be of economic importance, it is of interest as the magnetite is associated with the mineral barytes (barium sulphate).

The Panirendawa deposit consisting of four closely related deposits (A, B, C, D) is situated 5 miles north-east of Madampe in the North-western Province of Sri Lanka. (Fig.12). The deposits are directly accessible from the Madampe - Bingiriya road. Except for a few bands of quartzites, the bedrock is everywhere concealed by a mantle of lateritic over-burden. Rock types in the surrounding areas include chrnockitic rocks, calc gneisses, cordierite gneisses, quartzites, biotite gneisses, migmatites and granite gneisses. The first systematic exploration of the area (geophysical work) commenced in 1962 as part of the general ground follow-up work of aeromagnetic anomalies of the south-west sector of the Island. Twenty five drill holes were also bored with a total footage of 2939 metres.

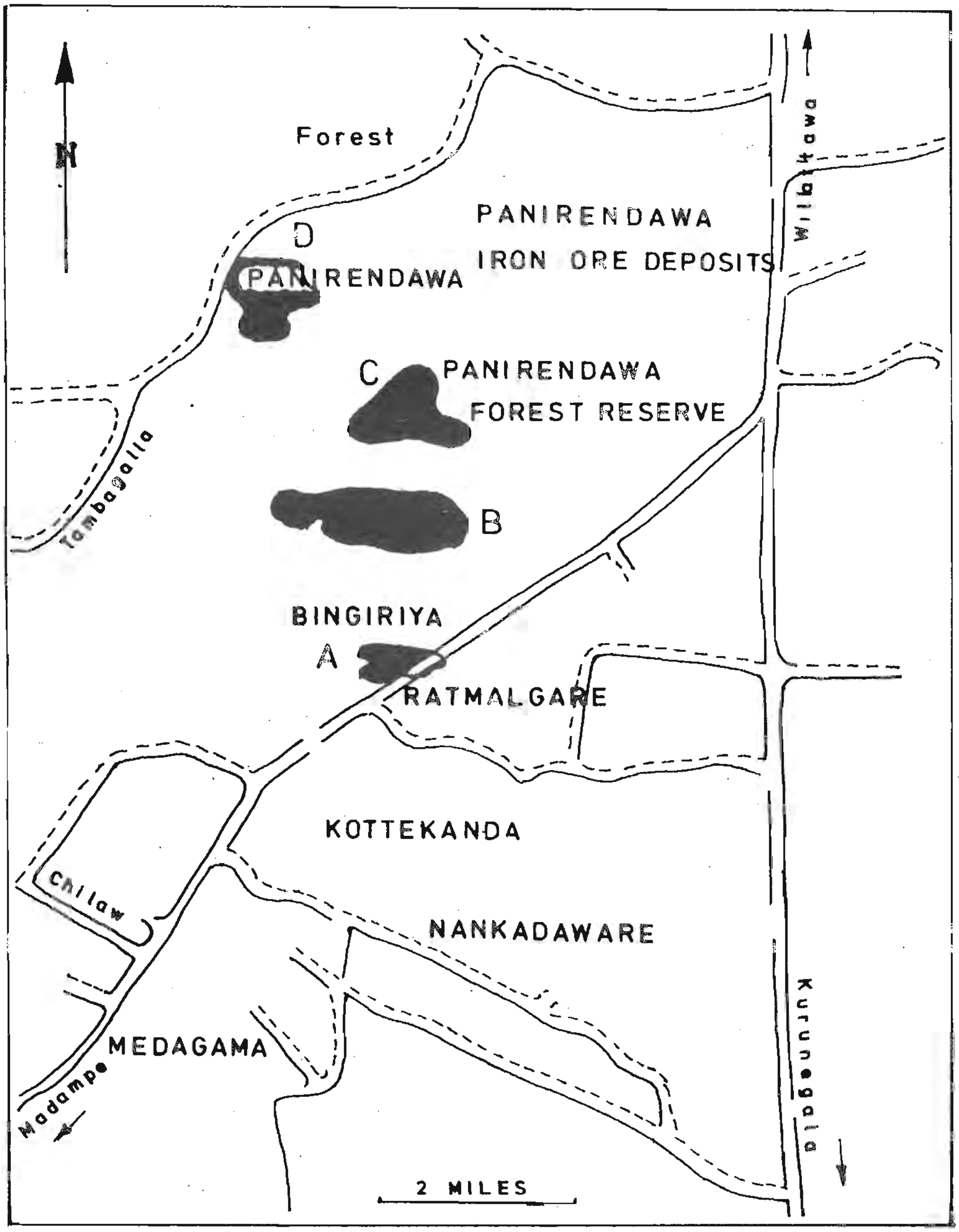


Figure 12. Panirendawa Iron Ore Deposit

The main rock type encountered in drilling operations is a calc-silicate gneiss. Within this rock is an iron formation consisting of two or occasionally three bands of magnetite rich rock. The maximum thickness of the iron formations intersected is approximately 15m, of which, bands of magnetite make up 12m. The iron formation does not persist in uniform thickness for any great distance, but seems to pinch and swell in unpredictable fashion. The banded magnetite at Panirendawa is a fine grained dense rock with a dark metallic grey to black colour. Thin parallel layers of light coloured silicate minerals, mainly potash felspar, gives the rock its black and white banded appearance.

The sampling of the deposit which was carried out by bore holes covered an area of about 260 hectares. Only a few drill holes were located in deposits B and C. Hence the estimates of tonnage and grade of deposits are less reliable than the corresponding estimates of deposits A and D. Magnetite estimated to occur at a depth greater than 130m from the surface has not been included in the reserve estimates. A maximum of 2.5m has been used as a cut off value in calculating the tonnages. Table XV is presented to show the estimates of tonnage and grade of the Panirendawa magnetite deposits.

TABLE XV

TONNAGE AND GRADE ESTIMATES - PANIRENDAWA
MAGNETITE DEPOSIT

	Tonnage	Fe	SiO_2	Mn	TiO_2	Al_2O_3	CaO	MgO	S	P
A	981,980	52.1	17.9	0.50	Nil	4.9	1.88	1.30	0.31	0.033
B	981,328	48.2	19.2	0.43	Nil	5.29	0.74	0.72	0.39	0.039
C	852,530	53.5	18.0	0.85	Nil	4.78	0.22	0.64	Nil	0.069
D	3,537,421	51.1	19.8	0.39	Nil	7.41	0.08	0.30	Nil	0.057
	6,353,259	51.2	18.7	0.54	Nil	5.59	0.73	0.74	0.175	0.049

After Kumarapeli (1964).

Geological Survey Department.

The value of an iron deposit is largely dependent on its suitability for mining by open pit methods. The Panirendawa magnetite deposit occurs at depths ranging from 30m to over 120m. Open cast mining has therefore to be ruled out. The magnetite deposit is broken into four structural blocks (A, B, C, D - Fig. 12). The deposits A, B and C have small tonnages (less than a million tons in each case). These deposits cannot be mined economically. The deposit D however, has a tonnage of over 3 million and is worthy of further examination to assess its economic potential. Kumarapeli (1964) has made a comparison of Panirendawa magnetite and the hydrated iron oxide deposits of the south-west sector of the Island (see table XVI). The discovery of the Panirendawa deposit marked the beginning of a new chapter in the history of exploration for iron ore in Sri Lanka. The Geological Survey was successful in identifying a banded iron deposit of the sedimentary type. Some of the largest deposits in the world are of this type and a 6m thick band extending over an area of three sq. km would yield a tonnage of over 50 million. The areas adjacent to this deposit in Panirendawa should therefore be intensively searched for other similar deposits.

The Seruwila Copper-Magnetite Deposit

The occurrence of copper-iron ore at Seruwila (N.E. Sri Lanka) the first base-metal find in the country, was discovered by the Geological Survey Department in 1971. The area is thickly forested and access during investigations was from survey lines set out on a grid of 20 metres. Drilling investigations have revealed that the ore bodies containing magnetite and copper sulphides are lenticular in shape and concordant with the dip and strike of the host rocks. The lenses of ore varied from 1 - 10 metres in thickness.

An account of the geology and tectonic setting of the copper iron ore prospect at Seruwila has been published (Jayawardane 1982 and 1983). The Seruwila area is underlain by high grade metamorphic rocks of Precambrian age. To the north-west of the area of mineralization, granulite facies rocks such as charnockitic rocks and quartzites are predominant and they belong to the Highland Series of rocks. To the south-east, granulites, granites and hornblende biotite gneisses are the major rock types and these belong to Vijayan Series. Detailed mapping of the Seruwila area has revealed that the ore mineralization is at the boundary of the

TABLE XVI

COMPARISON OF PANIRENDAWA MAGNETITE WITH IRON ORE DEPOSITS OF THE SOUTHWEST SECTOR

	PANIRENDAWA DEPOSIT	DEPOSITS OF THE S.W. SECTOR
1.	Occurs as part of a bedded iron formation at depths ranging from 100 ft to over 400 ft.	Occurs essentially as surface deposits, occasionally as embedded pockets or lenses
2.	Principal iron bearing mineral is magnetite	Iron bearing mineral is mainly geothite.
3.	Consists of four structural blocks with total tonnage estimated at 5.6 million. The largest deposit has a tonnage of 3.1 million	40 to 50 deposits make up a total tonnage of 2.2 million, individual deposits vary in size from 10,000 tons to 150,000 tons.
4.	Average grade 51.2% Fe, 18.7% SiO_2, 0.175% S, 0.049% P, but amenable to beneficiation to yield a plus 65% Fe concentrate.	Average grade 53.8% Fe, 7.25% SiO_2 0.51% P. Unlikely that this material will be amenable to beneficiation.
5.	Easily accessible	Easily accessible but scattered deposits.
6.	Has to be mined by costly under ground methods.	Can be mined by inexpensive open cast methods.
7.	Phosphorus content low - 0.049%	Phosphorus content high - 0.51%
8.	Has to be crushed, benefi-ciated and sintered prior to its use in the blast furnace.	The material is porous, there-fore, may be possible to feed it without beneficiation to the blast furnace.

After Kumarapeli (1964).

Highland Series and the Vijayan Series. Dolerite dykes are present in the area and magnetite outcrops have been observed to be present in the mineralized zone (Fig. 13). The host rock for minealization is an ultra-basic rock highly weathered on the surface with secondary copper minerals such as malachite and azurite. The host rocks appear to have gabbroic affinities that grade into monzonites. Scapolite forms an important constituent of the ultra-basic rock. Limestone has been mapped in the area and a coarse grained anorthosite is closely associated with the limestone. This is the first recorded occurrence of anorthosite in Sri Lanka. The regional strike of the area is N 50°E with steep dips of 70° - 80° to the north-west. There is evidence of isoclinical folding in the area.

SIMPLIFIED MAP SHOWING THE REGIONAL GEOLOGY AROUND SERUWILA AREA

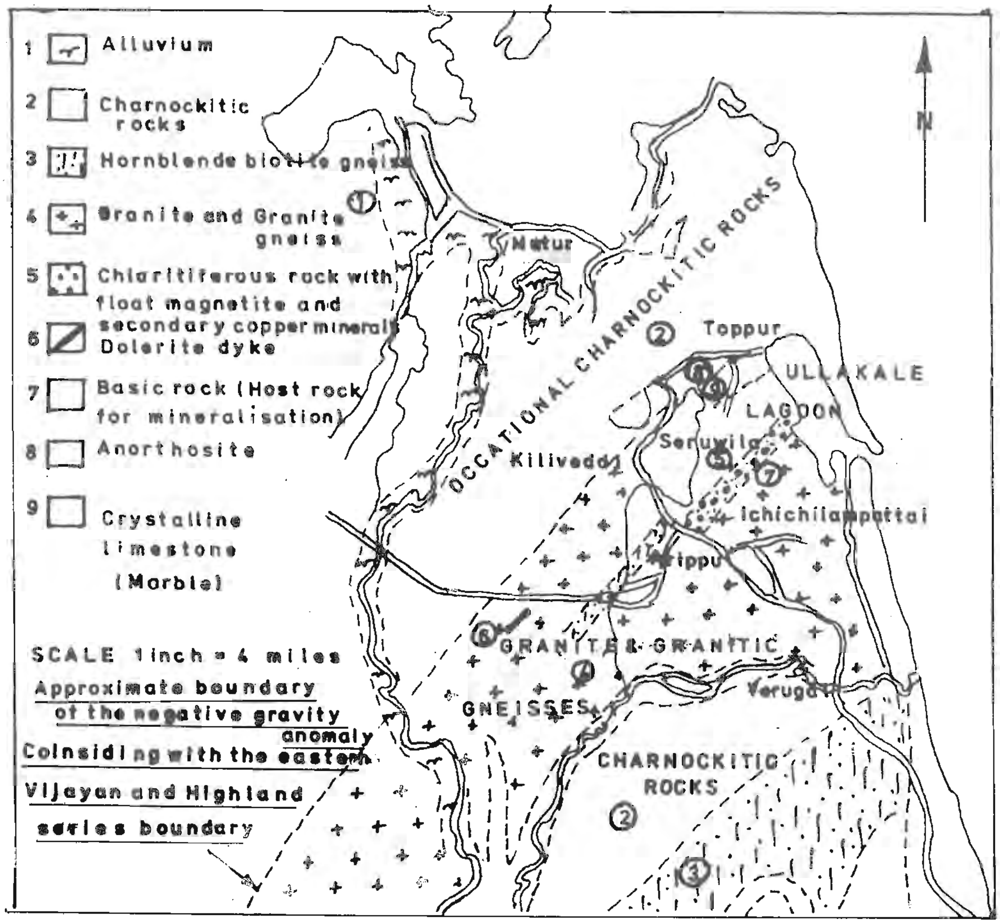


Figure 13. Simplified Geological Map - Seruwila Area

The massive magnetite sulphide ore bodies vary in thickness from

1-10 metres and are coarse grained with magnetite, chalcopyrite, pyrrhotite and pyrite. The disseminated ores are composed of magnetite, chalcophyrite, pyrrhotite and pyrite, and the gangue minerals are scapolite, apatite, tremolite, diopside and hornblende. Sulphides are also present in limestone (marble) and pentlandite has been identified in pyrrhotite crystals with the cobalt content of the pentlandite higher than the nickel content. Secondary carbonate veins also occur in the area with sulphide minerals, and vallerite has been identified in these veins. The secondary carbonate veins are present in the massive ores, disseminated ores, host rocks carrying ores and limestones. Two phases of mineralization have therefore been identified at Seruwila, an earlier phase of massive magnetite and sulphides and a later phase of secondary magnetite and sulphides.

It is now evident that the ore mineralization at Seruwila is along a deep seated thrust zone at the contact between the two major lithological divisions - Highland Series and Vijayan Series, (Jayawardane 1982).

The deep seated thrust is tentatively interpreted as an obducted ophiolite belt which has undergone a high degree of alteration and deformation due to the collision and overiding of the Highlands and Vijayan. The lithological characteristics and the tectonic setting at Seruwila are similar to a 'melange' from ophiolite belts in other parts of the world specially in Cyprus and the Red Sea. The work carried out so far indicates that the tectonic setting and the host rocks at Seruwila are definitely favourable for base-metal and possibly precious metal ore emplacement.

Investigations so far carried out have proved an ore reserve (Copper - magnetite ore) of 4 million tons. Of this reserve 40 per cent is iron (Fe) and 1.5 to 2.0 per cent copper. Table XVII is presented to show an analysis from each of the three types of iron ore deposits present in Sri Lanka. Open cast mining has to be ruled out at Seruwila as in the case of Panirendawa. The ore occurs at depth and has to be mined by costly underground methods. The ore has to be crushed, beneficiated and sintered; the copper minerals have to be removed prior to its use in the blast furnace. These processes are costly, and with world demand for iron ore continuing to decline it may not be economical to mine the type of deposit that occurs at Seruwila unless other valuable materials could be recovered as by-products.

TABLE XVII

ANALYSES OF IRON ORES - SRI LANKA

Constituents	Dela	Panirendawa	Seruwila
Fe_2O_3	80.11	73.21	94.66
SiO_2	4.25	18.70	0.86
Al_2O_3	2.22	5.59	3.34
MnO	0.94	0.69	0.02
TiO_2	—	—	0.12
P_2O_5	1.75	0.11	Tr.
CaO	0.11	0.73	—
MgO	—	0.74	—
S	0.19	0.17	0.70
Loss on Ignition	11.02	—	—
Total	100.59	99.94	99.70

1. Dela Limonitic type - average Fe content 53%
2. Panirendawa magnetite - average Fe content 50%
   Beneficiation possible - (to plus 65% Fe)
3. Seruwila magnetite - under investigations-benefication possible. (Tentative figure over 65% Fe).

Geological Survey Department,
Colombo 2.

The Ceylon Steel Corporation was established in 1961 for the purpose of implementing the steel project which involved the setting up of a rolling mill as the first stage. Thr rolling mill and a wire mill were commissioned in 1967. The rolling mill has a capacity of 72,000 tons per annum (3 shifts) and imported steel billets are fabricated in the mill to standard shapes to meet the requirements of the building industry. Cold twisted, high strength, ribbed tor-steel is produced for use in reinforcing concrete. The wire mill has a production capacity of 12,000 tons per annum. At present the steel project is only partly dependent on imported steel billets as the second stage expasion which makes use of scrap as raw material for the production of steel billets has been commissioned. The second stage process involves the melting of scrap in an electric arc furnace and producing billets by a continous casting process. The billets will provide the entire requirements of the rolling mill. When the plant is in full operation it is planned to produce about 35,000 tons of billets from the 2nd year of production. The Corporation has also plans to install a second arc furnace and a continuous casting unit when the demand for steel increases in the future. The third stage expansion to be undertaken will use locally available iron ore. This, however, would require a considerable amount of research and development on the suitability of the local ores for use in the industry. No techno-economic feasibility studies have yet been undertaken on the use of local iron ores for the manufacture of iron and steel. Research and development on the production of pig iron is being carried out by the Corporation. A steel foundary has been established for the manufacture of carbon and alloy steel, and a machine tools plant is in operation.

SUMMARY

Except for iron ore, economic mineral deposits of the ferrous and ferroalloy group are absent in Sri Lanka. Minor occurrences of some minerals belonging to this group (chromium cobalt, manganese, molybdenum, nickel and vanadium) have, however, been observed and these are only of academic interest. Three types of iron formations occur in the Island. The hydrated iron oxides (limonite and goethite

- 53 per cent Fe) are scattered deposits confined to the surface only and the reserves are estimated at less than three million tons. The Panirendawa type deposit (magnetite after beneficiation - 65 per cent Fe) occurs at depth and the reserves are not very large. The workable reserve is about three million tons and mining this type of ore may not be economical. The Seruwila copper-magnetite ore also occurs at depth (magnetite after beneficiation - 65 per cent Fe). The nature of the ore is such that it needs considerable processing before it could be used in industry. The third stage expansion of the steel project envisages the use of local iron ores. No investigations have however been undertaken on the three types of ore available to study their technological characteristics. Detailed studies therefore remain to be undertaken before a final decision could be taken on the use of local ores in the iron and steel industry of Sri Lanka. Further detailed surveys should also be undertaken at Seruwila and the area towards the south to assess the economic importance of the deposit with special reference to the presence of precious metals (gold, silver and platinum).

CHAPTER 6

NON FERROUS MINERAL RESOURCES

No important deposits of the base metals (lead and zinc) occur in Sri Lanka. The precious metals (gold, silver and platinum) are also absent. Mention has, however, been made in the historical records of the island of the presence of silver and gold in the country. Occurrences of gold have been reported from various parts of the island but they are of no economic value. The copper - magnetite deposit discovered at Seruwila is the largest single copper deposit so far located. There are indications of the presence of minor amounts of nickel, cobalt, silver and bismuth, and also, possibly, of zinc, gold and platinum at Seruwila.

Of the light metals, magnesium (magnesite and dolomite) and titanium (ilmenite and rutile) occurring as exploitable deposits, and aluminium as low grade ores (high alumina clays) are present in the island. Rare-earth elements are known to be present in the country; monazite being the principal source of these elements. Another probable source of rare-earth elements is allanite found in moderate amounts. Zirconium which is a metal of the new technology is recovered as the mineral zircon from the beach sands of the island. The copper-magnetite occurrence at Seruwila has been described (see Chapter 5).

DOLOMITE AND MAGNESITE

A number of minerals are used as raw materials for the production of magnesium metal or magnesium compounds. The main magnesium minerals are dolomite $CaMg(CO_3)_2$ containing up to 22 per cent magnesia

(MgO), magnesite ($MgCO_3$) with a theoretical magnesia content of 47.6 per cent, and brucite $Mg(OH)_2$ containing up to 69 per cent magnesia. Sea water magnesite is produced in many countries where other sources are not available. Sri Lanka has very large reserves of dolomite and minor occurrences of magnesite, and the possibility of producing sea water magnesia is also promising. Sea water with a magnesium content of 0.13 per cent by weight is an inexhaustible resource. Large deposits of dolomite are widely distributed throughout the world, and the world reserve of magnesite is estimated at 9.4 billion tons (China 5,000 million tons, North Korea 3,000 million tons and New Zealand 600 million tons).

Dolomite and dolomitic limestone deposits occurring in Sri Lanka are entirely confined to the belt of crystalline limestone (marble) deposits of Precambrian age. They occur interbanded with other rock types such as quartzites, charnockites and gneisses as discontinuous but well defined bands, some of which can be traced for many miles along the strike (Fig. 14). Most of the outcrops are found in low lying land. The only magnesite deposit of crystalline variety so far investigated occurs associated with dolomitic limestone in Randeniya, near Wellawaya. The map in Figure 15 shows the occurrence of crystalline limestone, dolomite and magnesite. It will be clearly seen from the map that these deposits cover a very wide area extending from as far north as Vavuniya, through the Kurunegala - Kandy area to the southern region near Ambalantota. Though the deposits do not appear to be continuous they nevertheless follow the regional strike of the country rock. The best known deposits occur in the Kandy, Matale, Nalanda, Habarane, Kanadarawa, Ratnapura, Balangoda, Badulla, Bibile and Welimada areas. Generally the deposits are of variable composition varying from a dolomitic limestone to a dolomite.

The dolomites are white in colour and the grain size ranges from rather coarse to fine. Large rhombs of dolomite are occasionally surrounded by smaller grains and this gives a texture resembling a porphyroblastic rock. Generally they are more or less impure due to the presence of various accessory minerals, the most common being fosterite and phlogopite with occasional diopside. Other accessory

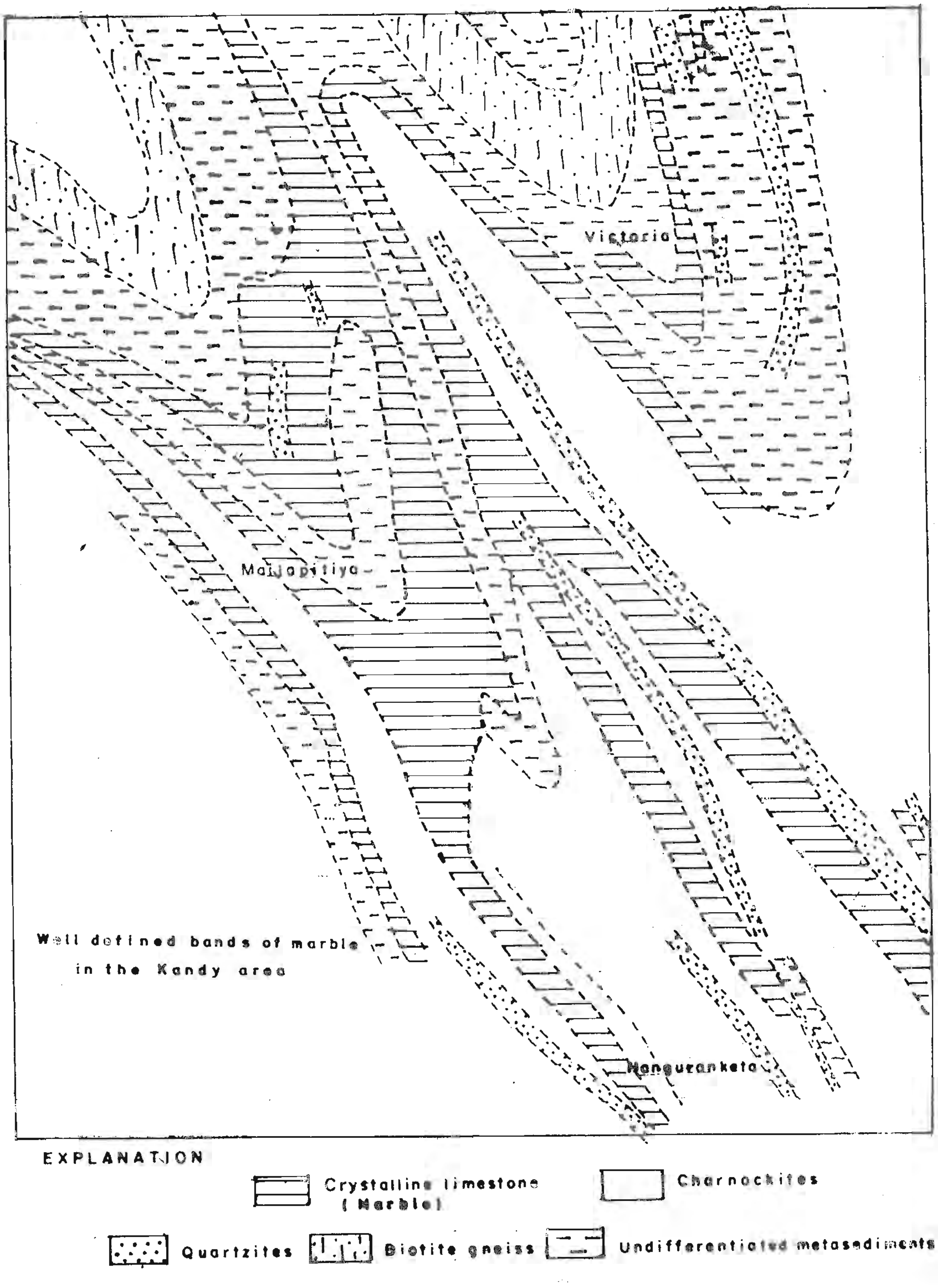


Figure 14. Well Defined Bands of Dolomite Limestone - Kandy Area

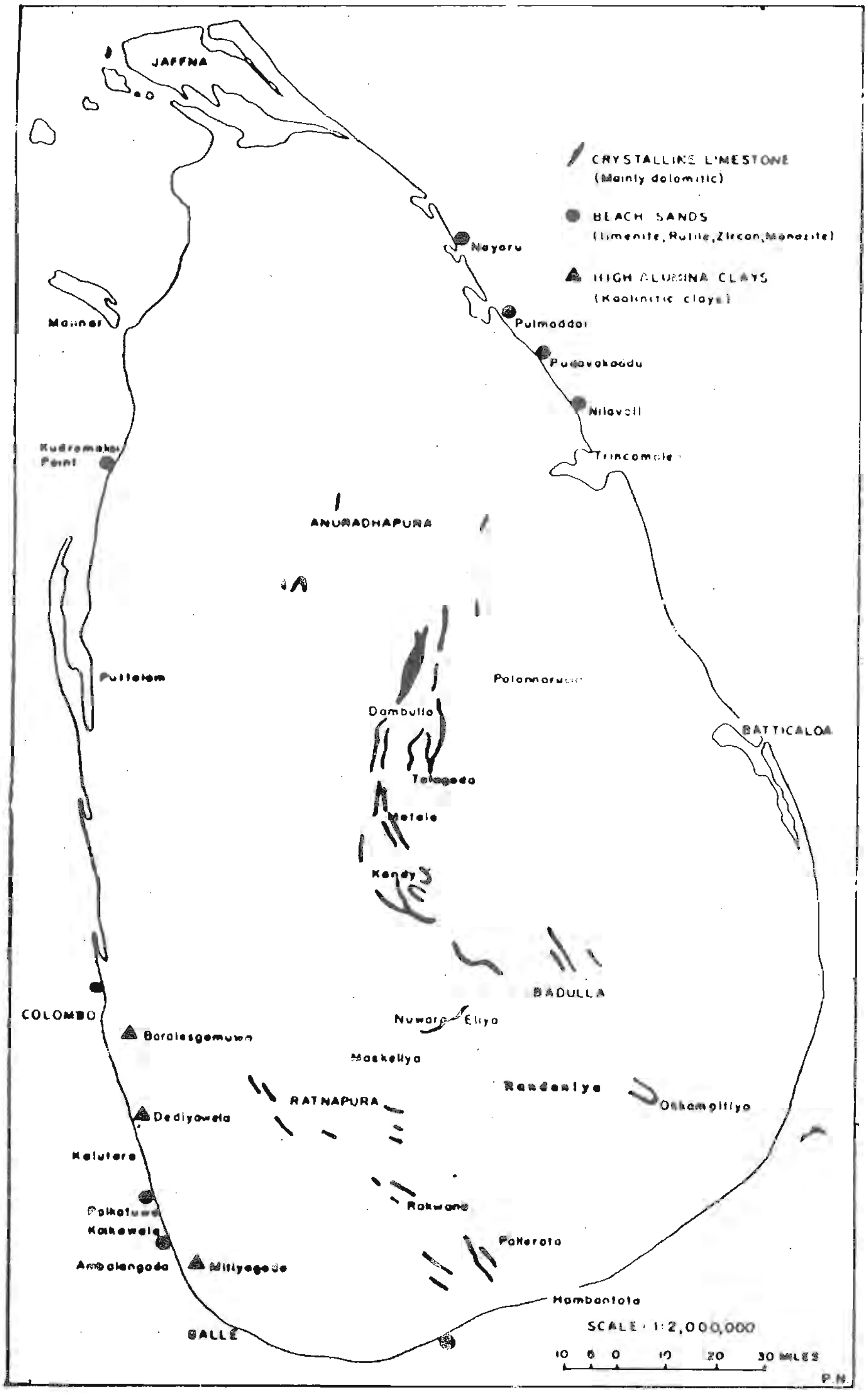


Figure 15. Non Ferrous Mineral Resources - Sri Lanka

minerals are apatite, spinel, pyrite, pyrrhotite, graphite, and rarely, sphene, chondrodite, serendibite and tourmaline. The silicate minerals may be uniformly distributed in association with other accessory minerals or may occur as distinct layers and clots which stand out on weathered surfaces. Serpentinization of fosterite may impart a pale green colour to the body of the rock resulting in the formation of green marble. Dolomitic limestones are chemically stable substances, and decomposition never occurs at ordinary temperatures. Decomposition can only occur at very high temperatures or through reaction with strong acids.

Table XVIII shows the typical composition of Sri Lanka dolomite, magnesite and dolomitic limestone. True dolomites have a composition CaO 30.4%, MgO 21.7% and CO_2 47.9% (theoretical). From the analyses given it is seen that some dolomite and dolomitic limestone in Sri Lanka may approach true dolomite in composition. However, an analysis of a large number of samples from various localities reveals that the magnesium content varies from a trace to over 20 per cent, and the majority of deposits examined showed an MgO content of 10 - 18 per cent. These deposits are termed dolomitic limestones. The majority of the so called dolomites are really dolomitic or magnesium limestones containing a smaller proportion of MgO than the theoretical 21.7 per cent although many of the deposits approach true dolomite in composition. Magnesite deposits are rare. A small occurrence of magnesite at Randeniya has been investigated.

Sea water magnesite is produced in many countries and is obtained by a simple chemical reaction. Sea water contains sulphates and chlorides of sodium, potassium, calcium and magnesium. If calcium hydroxide is added to sea water, the magnesium sulphate and magnesium chloride react with it to form magnesium hydroxide which is precipitated. The calcium hydroxide required for the process is obtained by calcining dolomite or limestone and slaking the latter with water to form the hydroxides.

$$\underset{\text{dolomite heated}}{CaMg(CO_3)_2} \text{ ——— } CaO + MgO \text{ ——— } + \underset{\text{water}}{H_2O} \text{ ——— } \underset{\text{slaked dolomite}}{Ca(OH)_2 + Mg(OH)_2}$$

TABLE XVIII

ANALYSES OF DOLOMITE, DOLOMITIC LIMESTONE AND MAGNESITE
SRI LANKA

Constituents	1	2	3
SiO_2	0.75	2.45	—
Al_2O_3	0.27	3.60	—
Fe_2O_3	0.05	0.80	—
CaO	31.01	33.10	1.27
MgO	21.78	12.15	46.50
CO_2	46.10	48.10	51.28
Total	99.99	100.20	99.06

NOTE 1. Type analysis for dolomites (Nalanda, Matale, Niriella, Kandy, Maratenna and other areas).

2. Dolomitic Limestones, Mgo content varies (10 to 18 per cent common).

3. Magnesite from Randeniya associated with dolomitic limestone.

Geological Suevey Department
Colombo 2.

The slaked dolomite is allowed to react with sea water in reaction tanks which are agitated. The precipitated magnesium hydroxide is then concentrated by settling, dried and calcined. The reaction may be represented by the equation:

$$\underset{\text{slaked dolomite}}{\begin{array}{l}Mg(OH)_2\\ Ca(OH)_2\end{array}} + \underset{\text{sea water}}{\begin{array}{l}MgCl_2\\ MgSO_4\end{array}} \longrightarrow 2Mg(OH)_2 + \underset{\text{(by products)}}{\begin{array}{l}CaCl_2\\ CaSO_4\end{array}}$$

The calcined $Mg(OH)_2$ contains approximately 97 per cent MgO. The possibilities of producing magnesia from sea water in Sri Lanka are promising.

Detailed investigations for detecting the presence of dolomite, dolomitic limestone and magnesite have been carried out in a number of localities. An investigation undertaken at Niriella proved a deposit of 150,000 tons of dolomite. However, more extensive, commercially valuable and easily workable deposits are present in many other parts of the Island, notably in the Matale - Nalanda areas. The deposit of magnesite at Randeniya was investigated by core drilling and tentatively estimated at 4,000 tons. From investigations made in the field, it can be said that Sri Lanka is well provided with dolomites and dolomitic limestones. If dolomitic limestone with a magnesia content between 10 to 20 per cent is taken into consideration together with the deposits of true dolomite, very large reserves are available in the Island. On the other hand, magnesite deposits are limited in extent, and the only known deposit is the one at Randeniya (Fig. 15).

Most of the dolomite mines are situated in the Kandy, Matale and Balangoda areas, and mining is by open-cast methods which involve drilling and blasting. No special processing is needed other than crushing to the required size. The cost of production varies. No magnesite mines are operated in the island.

Accurate records of present production of dolomite are not available, but is estimated to be around 10,000 tons a year. This material is largely used as crushed dolomite in agriculture and in the ceramics and allied industries. Dolomitic limestones are also mined in certain places for the manufacture of lime. The local requirements of dolomitic limestones in the future should be fairly large taking into consideration the rapid industrial development of the country.

Magnesite as such has up to recent times had little commercial use, but it is valuable for its magnesia (MgO) content. Magnesia has a high melting point, is chemically inert and is, therefore, suitable for many refractory purposes. Magnesite has in recent years become one of the most important ores of the metal magnesium. By heating magnesite to high temperatures dead-burned magnesite is produced, and this is the material generally used for refractory purposes. Dead-burned magnesite is used primarily for lining furnaces, particularly in the steel industry, for which purpose the burned magnesite is often pre-formed as bricks of various shapes. For refractory purposes the calcined magnesite should contain a minimum of 87 per cent MgO and should be as free as possible from zinc, tin, lead, sodium and any other volatile metallic impurities.

Caustic burned magnesite is used chiefly in the manufacture of oxy-chloride (sorrel) cement. The chief use of this cement is in the preparation of composition flooring, in which the calcined magnesite mixed with magnesium chloride and fillers form a resistant, non-slip, fire-proof and durable floor. Heat insulator coverings for boilers, pipes and buildings are also manufactured from magnesite cement. Caustic calcined magnesite finds various uses in the paper, rubber, glass, enamel and porcelain industries. Other uses are for medical purposes in the preparation of magnesia and epsom salts and as a base for fire resistant paints.

The uses of dolomite depend mainly upon its magnesia content and are in general similar to those of magnesite. Being cheaper and more abundant, it is used in preference to magnesite wherever it is possible to do so not withstanding its lower magnesia content and the presence of lime. Dead-burned dolomite obtained by calcining dolomite is used extensively for refractory purposes in basic open-hearth furnaces and in Bessemer converters. The most satisfactory dolomite for refractory uses should contain not more than 1 per cent SiO_2, 1.5 per cent combined Al_2O_3 and Fe_2O_3, and at least 38 - 40 per cent $MgCO_3$.

Dolomite is the raw material used to produce basic magnesium carbonate (magnesia alba) which is widely used in the manufacture of pipe and boiler covering and for general heat insulation. Dolomite is an important ingredient in glass manufacture and as a flux in various manufacturing industries. The crushed rock may be used as a fertilizer, also in paint, putty, and in the curing and fabrication of rubber. It is also used in the sulphide process of paper making. Dolomites make handsome building stones, and they can be used for kerbing and guttering, as pavement slabs, and as road metal and concrete aggregate. Dolomite could also be used as a source of lime.

ILMENITE AND RUTILE

The two principal mineral sources for titanium are ilmenite and rutile. Ilmenite is used mainly in the manufacture of titanium pigment, but rutile is used for making pigment, the titanium metal and other products. Rutile (TiO_2) is at least 95 per cent titanium dioxide whilst ilmenite ($FeTiO_3$) contains between 50 and 60 percent titanium dioxide. Two types of deposits contain titanium minerals of economic importance namely, rock and sand deposits. Australia is a leading producer of mineral sands which contain rutile, zircon ilmenite and monazite. Ilmenite resources in Canada, Finland and Norway, and about half of those in U.S.A. and the U.S.S.R. are in the form of rock deposits, while those of Australia, Sri Lanka (Ceylon), Sierra Leone, South Africa, India and Malaysia occur as beach mineral sand deposits. In beach mineral sands ilmenite and rutile normally occur in the same deposit, and other associated minerals are magnetite, zircon, monazite, garnet, sillimanite and other heavy minerals. Some sand deposits containing around 1 per cent of the mineral, rutile, are commercially workable because of their enormous extent (eg. the east coast deposits of Australia). Rock deposits which are workable have a TiO_2 content which ranges from 17 - 35 per cent, and they consist mainly of ilmenite.

The mineral ilmenite is relatively abundant, whereas rutile is in short supply. The price of rutile in world markets is over fifteen times that of ilmenite. This shortage and high price of rutile has long been recognized and the apparent and logical solution is the upgrading of the abundant and inexpensive ore (ilmenite) to produce a synthetic rutile. As a result of the rutile shortage, many processes have been developed the world over to upgrade ilmenite, and commercial plants have been established for this purpose. Fonseka (1973) has discussed in detail the processes used in upgrading ilmenite. The ilmenite upgrading processes developed so far can be grouped into three general categories:

1. Acid leaching of ilmenite in order to remove the iron oxides.
2. Electric arc furnace smelting for the production of pig iron and a slag rich in titanium oxides.
3. Reduction of the iron oxides contained in the ilmenite to either ferrous oxide or metallic iron followed by mechanical and or chemical treatments of the reduced ore. Most of the more successful processes for the production of a synthetic rutile are in this category.

Although the minerals ilmenite, rutile, zircon and monazite occur in the beach sands of Sri Lanka, it is only at certain points that the deposits are sufficiently concentrated for economic exploitation. Concentrated deposits are located at Pulmoddai north of Trincomalee, Kaikawela near Induruwa, Polkotuwa near Beruwela, Kudremalai point near Mannar, and near the mouth of the Kelani river (Fig.16). The Pulmoddai mineral sand deposit stretches from Vettilakerni to the mouth of the Kokillai lagoon, a distance of 7.4 kilometres. From the mouth of the lagoon, mineral sands of lower grade extend further northwards for about a kilometre. The average width of the depost is 60 metres. The deposit is estimated to contain 4 million tons of raw sand, and in certain places the composition was found to be as follows: ilmenite 70 - 72%, zircon 8 - 10%, rutile 8%, monazite 0.3% and sillimanite 1%. Recent estimates gave a figure of 79 per cent heavy minerals for the entire deposit. Of this 80 per cent is ilmenite (personnel communication - Fernando, L.J.D. - 1984). The Pulmoddai deposit is one of the best known in the world and its concentration of titanium minerals is unrivalled elsewhere (Wadia and Fernando 1945).

A coastal survey undertaken by the Oceanography Division of the National Aqautic Resources Agency covering the Kelaniya - Negombo area has revealed the occurrence of appreciable quantities of ilmenite near the mouth of the Kelani river. A current bedded sandstone (beach rock) of recent age forms a conspicuous feature of the coast north of Colombo. It is a coarse to medium grained rock consisting of ilmenite, quartz grains and shell fragments held together by a calcareous cement. The ilmenite is arranged in bands and consequently the beach rock has a banded appearence (Fig.17). The ilmenite content of the rock varies from place to place. At certain points the ilmenite content is so high that the rock is in effect an ilmenite rock and it has a specific gravity as high as 3.8. Other minerals present in the rock include monazite, zircon, garnet, magnetite and rutile. Similar current bedded beach rocks are exposed on the east coast and are well developed between Batticaloa and Arugam Bay. Figure 18 is presented to show a generalized cross sectional view of the beach about 2 kilometres north of the mouth of Kelani river. There are a series of ilmenite stringers at depth. The jigging action of the waves may have been responsible for concentrating the heavy minerals in certain zones of the beach. As in the beach sands of the Pulmoddai area ilmenite is the main heavy mineral present in the Kelani beach. At some points the beach sand contains over 75 per cent ilmenite. Other heavy minerals are present in negligible amounts and do not exceed five per cent of the bulk samples examined. There is no pattern whatsoever as far as the percentage of minerals in the mineral assemblages are concerned.

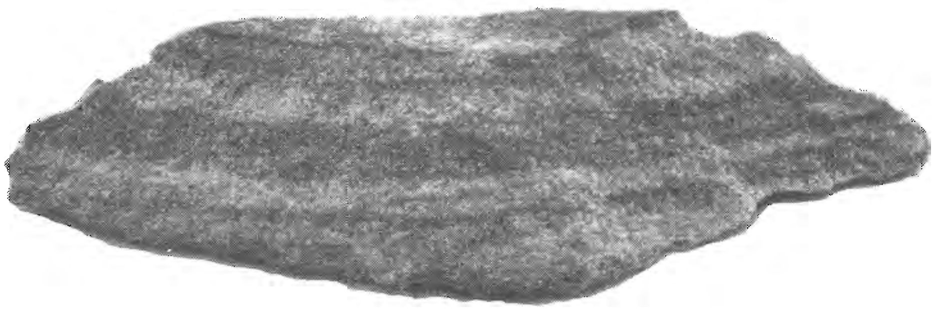


Figure 16. Beach Rock Showing Ilmenite Bands - Kelaniya Area

Figure 17. Ilmenite in beach - Crow Island area

The character of the deposits vary considerably and the mineral contents vary both with depth and within a few metres along the beach. Table XIX is presented to show the mineralogical composition of some sands from the Kelaniya - Negombo coastal zone and Fig.18 shows the ilmenite concentrations near Crow island where the beach is almost black in colour during certain seasons of the year. In recent years three very promosing deposits of heavy mineral sands have also been located at Nayaru, Koduwa-Kattumalai and Tavikkalu along the coastal stretch from Mullaitivu to Nilaveli (east coast) covering an are of approximately 360 hectares. It has been estimated that 500,000 to 700,000 tons of rutile, 350,000 to 500,000 tons of zircon and 2 to 4 million tons of ilmenite could be recovered from these deposits. Table XX is presented to show some typical chemical analyses of ilmenite and rutile from Sri Lanka. In 1981 Australia produced 1.2 million tons of ilmenite and 234,500 tons of rutile. World production of ilmenite in 1982 was around 5 million tons and rutile 400,000 tons. Titanium slag (around 80% TiO_2) is produced

TABLE XIX

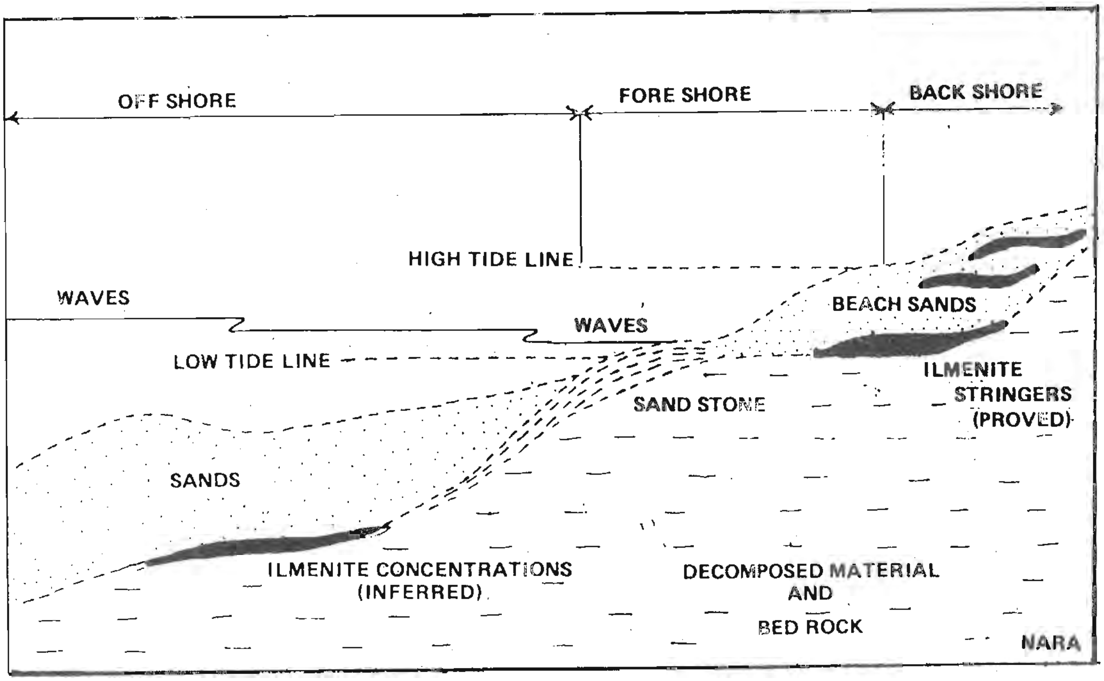
ANALYSES OF SOME BEACH SANDS

KELANIYA - NEGOMBO AREA

	A 1		A 2		A 5		A 7		A 9		A 11		A 13	
	0-40	40-60	0-54	54-107	0-46	46-82	0-40	40-89	0-47	47-72	0-44	44-67	0-51	51-103
Ilmenite	42	14.00	73.00	72.80	78.00	76.00	38.00	61.00	23.00	15.00	5.32	5.66	15.00	43.60
Quartz	44	73.30	12.60	8.23	6.50	6.82	53.50	32.00	76.30	76.96	85.60	84.44	80.60	52.80
Garnet	< 5	< 5	< 4	< 3	< 5	< 5	< 3	< 4	< 2	< 3.00	< 2	< 2	< 3	< 3
Monazite	4.12	3.10	0.92	2.76	1.64	0.74	-	-	-	3.90	-	-	-	-
Magnetite	1.23	12.00	4.00	5.32	4.34	3.10	0.64	1.54	-	0.22	5.40	5,30	-	-
Zircon	3.00	< 5	< 5	< 6	< 2	< 3	< 3	< 2	-	< 2	< 2	< 2	< 1	< 1
Rutile	-	-	1.38	1.02	1.24	3.00	-	-	-	-	-	-	-	-

	A 15		A 17		A 23		A 28		A 33		A 38		A 47	
	0.56	56-106	0-47	47-65	0-50	50-86	0-40	40-90	0-52	52-100	0-40	40-90	0-40	40-92
Ilmenite	46.64	56.80	65.50	67.60	12.60	14.80	35.80	37.00	42.50	38.00	26.80	32.00	13.25	15.65
Quartz	45.60	33.76	23.16	22.76	81.00	78.60	58.65	53.50	47.65	50.65	64.25	56.50	79.00	77.50
Garnet	< 3	< 3	< 5	< 5	< 3	< 3.00	< 2	< 2	< 5	< 5	< 3	< 3	< 5	< 5
Monazite	1.76	1.48	3.23	2.72	-	-	1.45	1.80	-	-	2.35	2.85	-	-
Magnetite	0.96	1.16	1.20	1.52	-	-	-	1.45	0.82	1.85	1.23	1.76	0.80	1.20
Zircon	< 2	< 2	< 2	< 2	< 5	< 5	< 2	< 5	< 5	< 5	< 2	< 5	< 2	< 2
Rutile	-	-	-	-	-	-	-	-	-	-	-	-	-	-

in Canada, South Africa and other countries and synthetic rutile is produced in Australia, India, Japan and Taiwan. In recent years the price and markets for titanium minerals remained depressed.



(After Herath 1983)

Figure 18. Generalized Cross Sectional View of Beach - Kelaniya Area

The Ceylon Mineral Sands Corporation was established in 1957 primarily for the purpose of exploiting the Pulmoddai deposit. The Corporation had established 2 plants, one at Pulmoddai for the recovery of ilmenite and the other at China Bay a few miles away from Trincomalee for winning of rutile and zircon. The Plant at Pulmoddai was equipped with several magnetic separators which were capable of extracting ilmenite from about 140,000 tons of raw dry sand each year. The tailings after the recovery of ilmenite were transported by sea to China Bay for extracting rutile and zircon. Ilmenite and rutile have been produced over the years for export only and Table XXI shows the quantities produced.

The Mineral Sands Corporation has now set up an integrated mineral sands complex at Pulmoddai by expanding its former production facilities and shifting the China Bay plant to Pulmoddai. The capacity of the integrated plant is 85,000 tons ilmenite, 14,000 tons rutile and 10,000 tons of zircon.

TABLE XX

COMPOSITION OF ILMENITE AND RUTILE CONCENTRATES - PULMODDAI

Constituents	Ilmenite	Ilmenite	Rutile	Rutile
TiO_2	52.53	51.21	97.53	97.35
Fe_2O_3	25.20	23.99	0.84	0.50
FeO	17.55	20.73	—	—
ZrO_2	1.42	—	0.82	0.91
SiO_2	1.20	—	0.61	1.07
Al_2O_3	0.98	—	—	—
Cr_2O_3	0.11	—	—	—
V_2O_5	0.04	—	—	—
MnO	0.68	—	—	—
Total	99.71	98.93	99.80	99.83

Geological Survey Department
Colombo 2.

In order to further increase the lines of production the Corporation has installed a Wet Gravity Upgrading Plant and a Wet Magnetic Separation Plant to increase the production of ilmenite and non magnetic tailings. The Wet Gravity Upgrading Plant is to upgrade the heavy mineral content to 95 per cent which will facilitate easy separation subsequently. The Wet Magnetic Separation Plant will separate the ilmenite and the non magnetic tailings. The latter is the feed stock for the Rutile-Zircon Plant which produces rutile, zircon and monazite. Unless the quantity of ilmenite produced is increased the amount of non magnetic tailings available will not be sufficient to feed the Rutile-Zircon Plant to maintain maximum production.

TABLE XXI

PRODUCTION OF ILMENITE AND RUTILE - PULMODDAI PLANT

PERIOD	ILMENITE (TONS)	RUTILE (TONS)
1964 - 65	47,302	----
1965 - 66	54,616	----
1966 - 67	45,234	----
1967 - 68	64,328	----
1968 - 69	75,986	1,999
1969 - 70	77,357	1,549
1970 - 71	93,212	2,070
1971 - (9 months)	67,954	2,055
1972	81,200	2,117
1973	93,005	2,216
1974	79,817	3,000
1975	63,000	3,062
1976	55,000	1,023
1977	34,100	1,000
1978	35,041	11,422
1979	55,370	14,677
1980	33,956	12,789
1981	80,011	13,301
1982	68,282	7,212
1983	80,486	8,093

1972-1983 figures for calender year

1964-1971 figures for financial year (October to September)

Geological Survey Department, Colombo 2

The capacity of the new complex would be to use around 220,000 tons per annum of raw sand to produce 150,000 tons ilmenite and 60,000 tons of upgraded non magnetic tailings. This will facilitate the working of the Rutile-Zircon Plant to full capacity. The increased production of ilmenite may eventually result in the production of synthetic rutile and titanium pigment. The Corporation has plans for establishing such a plant after a techno-economic feasibility study on the project is completed.

At present no titanium based industries have been established in Sri Lanka. Studies on the feasibility of industries which could be set up in the island based on these mineral raw materials should therefore be given high priority so that the country would obtain the maximum benefits from exploitation of these mineral resources.

The use of titanium metal is likely to expand due to its light weight and corrosion resistant properties. Ilmenite presently is the mineral source of nearly 85 per cent of world titanium requirements. Resources of rutile however are limited although the demand for rutile and titanium products are increasing at a much faster rate than for ilmenite. This has led to considerable research on developing methods to up-grade ilmenite (52 per cent TiO_2) to synthetic rutile (nearly 96 per cent TiO_2). The main use of rutile over the years is as a coating for welding rods and more recently as the source material for the manufacture of titanium pigments by the chloride process. Titanium minerals are mainly used in the manufacture of titanium pigment and metal. The largest market for titanium dioxide pigment is for use in surface coatings where it imparts whiteness, opacity and brightness to paints and it is also used in varnishes and lacquers. Titanium pigment is widely used in paper coatings and fillers and in the plastics industry. Titanium pigments and compounds are used in a wide variety of miscellaneous applications including rubber tyres, floor coverings, ink, porcelain enamels, wall coverings, upholstery material, artificial leather, oil cloth, coated fabrics and roof coatings.

BAUXITE AND NON-BAUXITIC CLAYS

Aluminium metal and alloys are used in many products. Aluminium ores are composed principally of the aluminium oxide minerals, gibbsite (trihydrate-$Al_2O_3.3H_2O$) and the monohydrates boehmite and diaspore. These materials are commonly referred to as bauxites. True bauxite material has so far not been observed in Sri Lanka. Alternative sources of aluminium, for example non-bauxitic clays (kaolin type clays) are widespread in most countries and the metal may in the near future be produced from such material.

Bauxites contain about 50 - 55 per cent Al_2O_3 (free aluminia), a small percentage of silica (around 3 per cent) and varying amounts of iron oxide. The reactive silica and titanium impurities must be as low as possible so as not to interfere with refining processes. Bauxites result from the decay and weathering of alumina bearing rocks, especially in tropical or sub-tropical climates where weathering processes are intense. These processes give rise to hydrated aluminium oxides by the solution and removal from the rock of constituents such as soda, potash, lime, magnesia and silica, leaving behind Al, Fe and Ti oxides and hydroxides (laterites). Leaching of silica is the most important factor during the transition from laterite to bauxite. The mobility of silica depends on the variation of pH, the soluble oxygen content of water, its temperature regime, the reactions of micro-organisms promoting the chemical weathering of the rock surface and most of all time itself which is a very important geological factor. The longer this complicated process lasts, the more silica is able to go into solution and to disappear from the complex resulting in the formation of bauxite.

Included in the Pleistocene deposits of the island are the red earths and gravels confined mainly to the north-west and the laterite deposits which are well developed in the south-west sector of th island. The red earths are old soils with a flat to undulating topography; they are highly sandy soils (over 95 per cent quartz), brick red in colour and occur to considerable depths with a distinct lack of horizon differentiation over the Miocene limestone deposts. Tests reveal that these red earths could be used as moulding sands. Laterites are extensively used for building (in the form of hand-cut bricks). The majority of the alluvial clay deposits contain varying amounts of lateritic material. The warm climate and abundant rainfall alternating with dry periods, are geologically favourable to the development of laterite and lateritic soils. The thickest laterite formations mainly found in the Wet Zone are particularly in the stretch between Negombo and Kalutara. Laterite is not developed in the Dry Zone.

The laterites overlie a variety of rock types and are largely developed in situ. In addition there are secondary laterites but their recognition is difficult unless good sections are available from surface to bed-rock. However, some of the evidence available such as rounded quartz pebbles underlying a layer of laterite indicates a secondary origin. In the south-west lowlands, laterites appear to have been more extensively distributed in former geological periods than in the present day. Absolute certainty as to the identify of the rock which has given rise to a particular laterite deposit is not always possible as outcrops of rock may be rare. Moreover the Pre-Cambrian complex is composed of a variety of rock types which show considerable variation both along and across the strike, and thus makes the problem even more difficult.

The laterites and lateritic soils of the island are classified into three broad groups (Fig.19) on the basis of differential thermal curves as follows (Herath, 1963):

1. Massive highly ferruginous laterites rich enough in iron hydroxide (mainly goethite) to constitute low grade iron ore.
2. Laterites with a vesicular appearance and widely used as a building material (gibbsite-kaolinite, or gibbsite and/or goethite-kaolinite mixtures).
3. Lateritic red earths - relatively rich in gibbsite together with geothite and kaolinite. Soils mainly associated with the intermedite slopes and the highlands.

The typical laterite is usually separated from its parent rock by a considerable thickness of intermediate decomposition products. The laterite layer may vary in thickness from a few metres to 12 metres or more. The lower beds are soft lithomarge-like material whilst the upper layers are harder and compact and suitable for use as building material. In the uppermost layers iron oxides get segregated to form surface ferruginous crusts. Some lower zones may show pockets of ferruginous material in the kaolinite layers. The laterite layer is usually found close to the surface, but in some areas the laterite may be buried under varying thickness of later sediments that conceal the lateritization surface. The skeleton of the cellular laterite is composed of quartz grains, iron and kaolin whilst the cavities are filled up with clayey matter and quartz. In the top-most layer the ferruginous material breaks down to form modules of limonite. Sometimes this fragmental material moves down slope and in its new surroundings may overlie fresh rock, clay or other soil

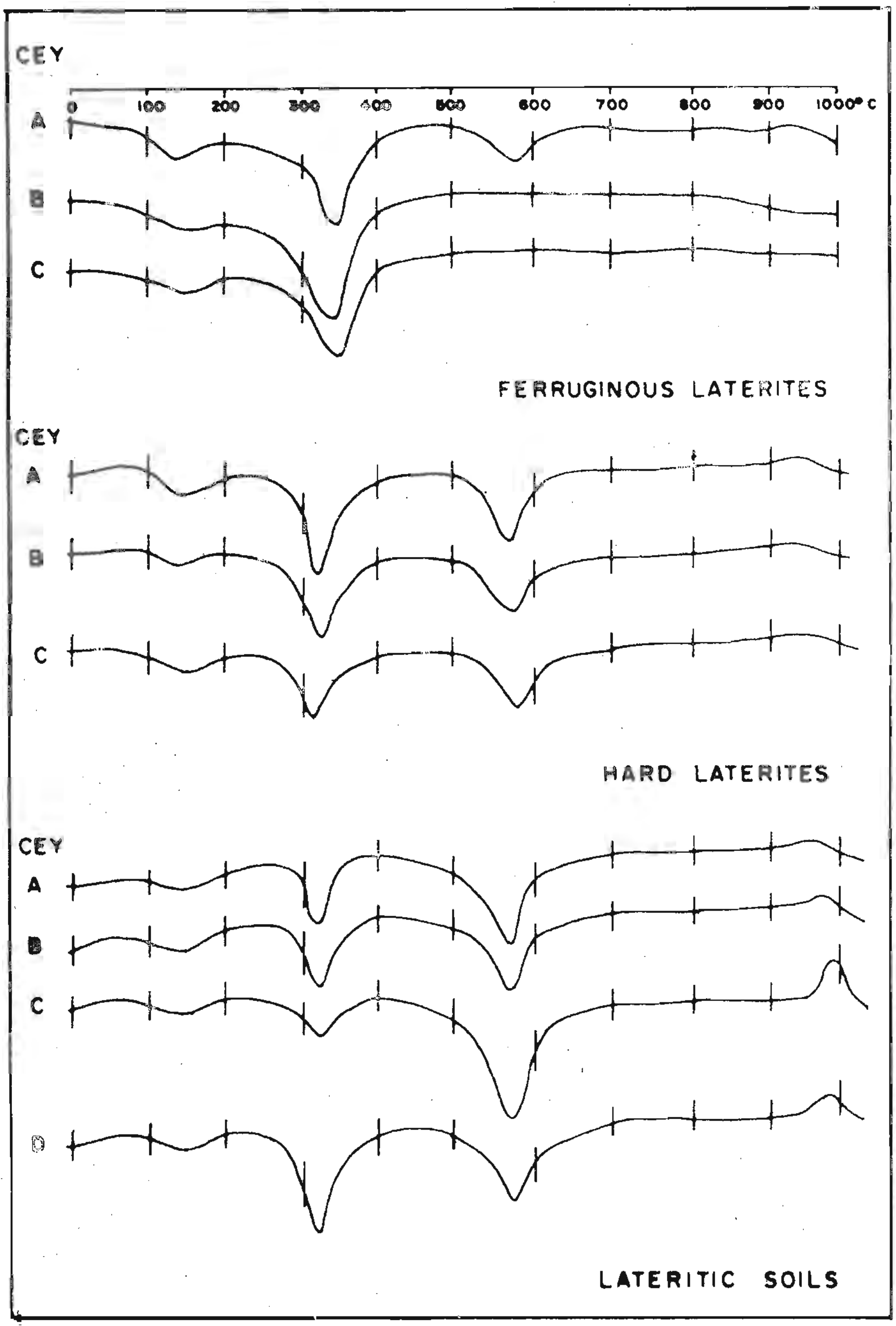


Figure 19. D.T.A. Curves for Lateritic Material

materials. Variations from the typical laterite profile have been observed. The hard laterite layer is normally absent in low lying areas, while sometimes the soft laterite layer is also missing. In certain parts the soft lateritic material has been almost entirely converted into kaolinite (See Fig.20). Where the hard laterite layer is used as a building material the over-burden is first stripped and the laterite is cut into blocks by hand. Although many houses, especially in the south-west sector of the island, are recorded as built of 'stone' the material used was largely laterite. It is also fairly certain that many houses recorded in the recent census as 'brick' are in fact of laterite (unburnt lateritic blocks). Lateritic material is also used for colour washing buildings (specially the yellow ochres locally named 'samara'). The porous nature of laterites is a highly favourable factor for recharge of ground water. The lithomargic clay below the laterite acts as an impervious stratum and helps in building up the groundwater storage capcity of the laterites. It is observed that the laterites of Sri Lanka including the ferruginous varieties are not of any great commercial importance.

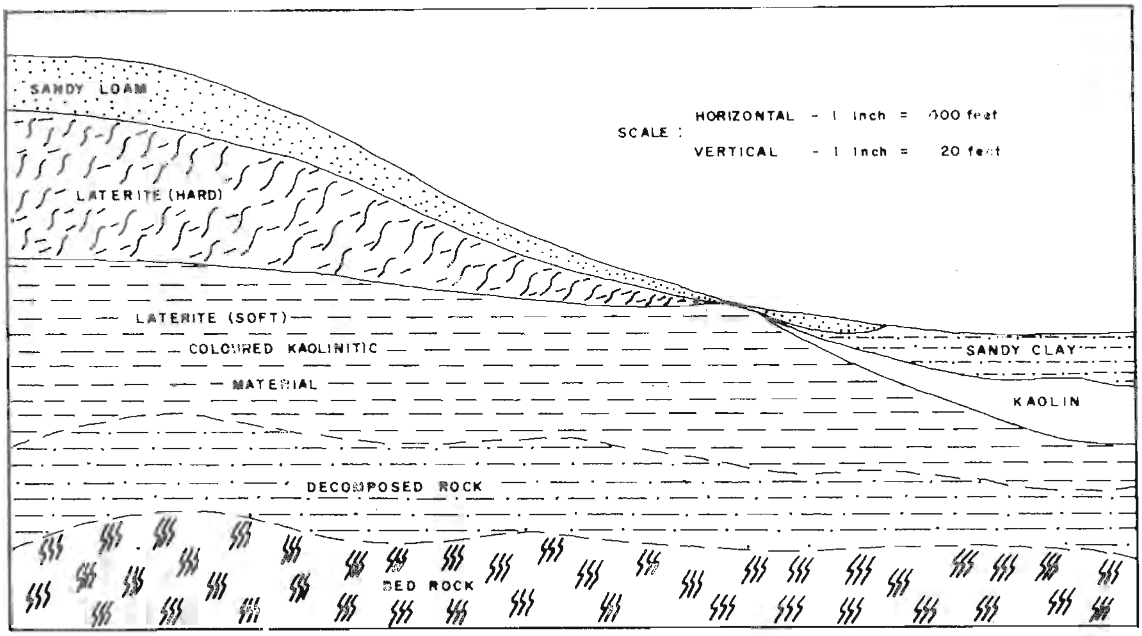


Figure 20. Cross Sectional View of Lateritic Formation - Boralasgamuwa Area

World production of Bauxite is in the region of 80 million tons. The main producing countries were Guinea, Jamaica, Australia, Surinam Guyana and U.S.S.R. The Jamaican bauxites are composed of both trihydrate and monohydrate minerals and contain 50 per cent Al_2O_3, 1 to 2 per cent silica and upto 30 per cent iron oxide, while the Surinam deposits are composed mainly of gibbsite and contain over 50 per cent Al_2O_3, up to 15 per cent silica and 5 to 15 per cent iron oxide. Production of bauxite from Weipa and Jarrahdale (Australia) was in the region of 27 million tons (1982), and Australian reserves which are now known to be in the region of 4,500 million tons are the largest of any country in the world. Alumina (Al_2O_3) is the intermediate product between the naturally occurring ore, bauxite, and the metal aluminium. Over 90 per cent of the world production of alumina is used to make the metal, while the balance is used as an abrasive and refractory. Production of alumina involves a complex chemical process requiring large scale plants and heavy investment, and practically all the alumina that is produced is made by the Bayer process or modifications of it. The conversion of the alumina to the metal aluminium is by the Hall process, where the alumina is reduced to the metal electrolytically. This requires enormous amounts of power. Cheap power is threfore, of the utmost importance and a key criterion in determining the feasibility of establishing an aluminium industry. These are the reasons why the production of aluminium takes place largely in countries very distant from the source of the ore. World aluminium production in 1982 was about 17 million tons.

Although laterites are extensively developed in the south-west sector of the Island they do not approach bauxite in composition. They are mainly ferruginous laterites containing up to about 10 per cent free Al_2O_3 which occurs as the mineral gibbsite ($Al_2O_3.3H_2O$). Table XXII shows the chemical composition of some laterites from Sri Lanka. They are mainly kaolinitic clay materials with a small percentage of gibbsite (less than 15 per cent), considerable amounts of geothite ($Fe_2O_3.H_2O$) and appreciable quantities of silica. Dry Zone lateritic material is devoid of gibbsite, they are ferruginous laterites.

A considerable amount of research has been carried out in various parts of the world on the utilization of kaolinitic clays for the production of aluminium. Kaolinitic clays are widespread in Sri Lanka and some clays contain up to 35 per cent Al_2O_3 (Fig.18). The alumina is combined with silica to form kaolinite ($Al_2O_3.2SiO_2.2H_2O$) and does not occur as free alumina as in Bauxite (gibbsite). Although techniques to produce alumina from such materials have been studied the processes have not been perfected. However, some countries have installed plants to produce alumina from kaolinitic clay materials. The by-product of the process is portland cement.

TABLE XXII

CHEMICAL COMPOSITION OF LATERITES - SRI LANKA

Constituents	WET ZONE		DRY ZONE*	
	Colombo	Colombo	Batticaloa	Batticaloa
SiO_2	34.31	37.22	39.25	40.69
Al_2O_3	19.05	25.12	23.12	16.19
Fe_2O_3	32.58	24.76	23.13	30.88
TiO_2	1.27	1.61	0.51	1.21
MnO	0.32	0.28	0.26	0.19
P_2O_5	—	—	0.12	0.15
CaO	0.33	0.28	0.82	0.38
MgO	0.89	0.48	1.19	0.66
K_2O	1.26	1.25	1.23	0.17
Na_2O	0.86	0.92	2.03	0.57
Loss on ignition	8.76	8.21	8.32	8.62
Total	99.63	100.13	99.98	99.62

*In the Dry Zone it consists of a surface crust of ferruginous material; not true laterite

Geological Survey Department
Colombo 2.

RARE - EARTH ELEMENTS

The rare-earth elements comprise a series of 15 closely allied elements from atomic number 57 to 71. This group of elements has been named rare-earths because they were considered to be scarce although it is now realised tht this group of elements as a whole is actually more abundant than many better known and commonly available elements. Analyses of rare-earth ores, metals and compounds are usually reported in terms of the rare-earth oxide, frequently abbreviated to REO.

Monazite is the principal mineral source of the rare-earth elements found in Sri Lanka. Allanite has also been observed in certain places. The mineral monazite is recovered as a by-product in the mining of beach mineral sands for the recovery of ilmenite, rutile and zircon. The composition of monazite from Sri Lanka is presented in Table XII. The pecentage of contained REO in the monazite, (cerium, lanthanium and yttrium oxides) is normally around 55 per cent. The Pulmoddai beach sands of the Island contain up to 0.3 per cent monazite, and approximately 500 tons of monazite per annum could be processed from the 220,000 tons of raw beach sands mined to rocover ilmenite. Monazite concentrates occur also at other places in the island. A minor deposit of allanite occurs at Owella Estate (Matale) and the material contains 15 to 20 per cent rare-earth elements. The chemical analyses of this allanite is shown in Table XXIII.

One of the major uses of the rare earths is in the manufacture of misch metal for the production of lighter flints and welding gas igniters. Cerium and mixed rare-earth oxides are used in the polishing of various types of glass, in the glass and ceramic industry and in the television industry.

Monazite and bastnaesite are the two principal sources of rare-earth elements and the countries with appreciable reserves are those where beach mineral sands occur. Bastnaesite a fluo-carbonate mineral contains up to 75 per cent REO and is mined in the U.S.A. Countries producing REO in concentrate include the U.S.S.R., India, Australia and Brazil.

TABLE XXIII

CHEMICAL ANALYSES OF ALLANITE - SRI LANKA

Constituents	Owella – Matale East		
	1	2	3
SiO_2	32.70	30.88	30.61
Al_2O_3	16.40	13.76	17.46
Fe_2O_3	5.10	4.44	6.01
FeO	10.73	12.08	10.38
TiO_2	0.30	0.88	1.21
MgO	1.02	0.76	0.95
CaO	8.90	13.56	11.45
MnO	0.51	0.20	0.30
ThO_2	3.18	1.54	1.98
U_3O_8	0.07	0.05	0.05
Ce_2O_3	6.38	8.30	7.04
La_2O_3 –			
Y_2O_3	7.66	8.36	7.38
P_2O_5	1.44	0.70	0.71
H_2O^+	5.35	4.75	3.95
Total	99.76	100.26	99.48

Geological Survey Department
Colombo 2.

ZIRCON AND BADDELEYITE

The principal source of the element zirconium is zircon. Two zirconium minerals, zircon ($ZrSiO_4$) and baddeleyite (ZrO_2) are marketed commercially. However, zircon is by far the more important mineral. Zircon is recovered from beach mineral sands like ilmenite, rutile and monazite. In Sri Lanka zircon is a widely distributed mineral in the igneous rocks. It is an original constituent of some granites and occurs in massive form in some pegmatites. The best known localities for zircon granites are Massena Estate near Balangoda and Loluwa near Mirigama. The mineral is also a notable constituent in the heavy residues left after washing of gem gravels in various parts of the island. The primary deposits of zircon are of no commercial importance. The island is, however, rich in beach mineral sands, and zircon is obtained as a by-product in the treatment of these sands for the recovery of ilmenite and rutile. Although zircon is not produced in large quantities at present, about 8,000 tons of zircon per annum is obtained from the Pulmoddai beach mineral sands. Baddeleyite has been recorded from the heavy mineral sand concentrates formed seasonally off the coast at Polkotuwa as a minor constituent of the monazite-rich sands, and a few tons of the mineral were produced in the processing of these sands for the recovery of monazite by the Geological Survey Department. Table XXIV is presented to show the chemical analyses of zircon from Sri Lanka.

TABLE XXIV

CHEMICAL ANALYSES OF ZIRCON - SRI LANKA

Constituents	China Bay (Concentrate)	China Bay (Concentrate)	Induruwa (M.P.S. Concentrate)
SiO_2	32.49	32.41	32.27
ZrO_2	66.40	66.43	66.12
Fe_2O_3	0.18	0.16	0.41
TiO_2	0.73	0.61	0.68
HfO_2	0.17	0.20	0.11
Al_2O_3	0.08	0.06	0.15
V_2O_5	0.02	0.02	—
Total	100.07	99.89	99.74

Geological Survey Department
Colombo 2.

Zircon is mainly used for facings on foundry moulds and for refractory bricks. The oxide is used as an opacifier and a pigment in enamels and glazes in the manufacture of ceramic products. Zirconium metal is of industrial importance in chemical processing equipment. Zirconium compounds are also widely used in industry and they are prepared from zirconium oxide.

SUMMARY

Although historical records of the Island mention the presence in Sri Lanka of a number of minerals which are listed in the non ferrous mineral group, no economic deposits have so far been discovered except for the presence of a copper deposit at Seruwila which is associated with magnetite. The majority of dolomites in Sri Lanka are dolomitic or magnesium limestones containing a smaller percentage of MgO than the theoretical 21.7 per cent found in the dolomite. Rocks approaching the composition of true dolomites are, however, present in a number of localities within the Highland Series. Only a single deposit of magnesite has been observed and ths is of no economic value. The beach sands of the island are rich in ilmenite, rutile, zircon, monazite, garnet and many other minerals. Pulmoddai beach sands are considered to be one of the richest deposits of the world and the sands contain over 70 per cent of the less expensive mineral ilmenite. The Mineral Sands Corporation which exports beach mineral sands has now completed an expansion programme which will enable the procesing of 220,000 tons or raw sands per annum to produce 150,000 tons of ilmenite and 60,000 tons of non magnetic tailings. The production of synthetic rutile and titanium pigment are areas in which the Corporation has shown interest. Sri Lanka is devoid of bauxite. The country is, however, rich in high alumina clays used in the refractories industry. Laterites are of no commercial value except for building purposes. Monazite is the principal source of the rare-earth elements found in the country. Allanite is also present. The Pulmoddai plant is capable of producing about 500 tons of monazite per annum. Zircon is another important mineral recovered from the Pulmoddai sands.

CHAPTER 7

NON METALLIC MINERAL RESOURCES

Sri Lanka is fairly rich in the non metallic group of minerals. These minerals range from bulk commodities as sand, gravel and stone, down to the precious gem stones which are measured in carats. The demand for this group of minerals in Sri Lanka has increased rapidly over the years due to an effort made to broaden the base of the economy by establishing manufacturing industries. The principal non metallic minerals that occur in the island are graphite, mica, industrial clays, silica, felspar, garnet, limestone, apatite, gemstone, cordierite, sillimanite and wollastonite, and sand, gravel and stone. Salt is also produced on a large scale by evaporating sea brines.

GRAPHITE

Graphite is one of the naturally occurring crystalline forms of carbon. Its chief characteristics are its black colour, metallic lustre, extreme softness, high conductivity of heat and electricity, high refractoriness and chemical inertness.

The mining of graphite in Sri Lanka and its export have continued since 1821, and in the early days the country enjoyed a virtual monopoly in the world markets. The graphite mining industry is one of the oldest mineral industries of the island. The highest exports of graphite have been in the war years, for example 33,410 tons in 1916 and 27,734 tons in 1942. Table XXV is presented to show the exports of graphite during 10 year periods from 1830 and the annual exports for the past 4 years.

TABLE XXV

EXPORTS OF GRAPHITE FROM SRI LANKA

PERIOD	QUANTITY(tons)	PERIOD	Quantity(tons)
1830-1839	1629	1930-1939	121651
1840-1849	4384	1940-1949	162268
1850-1859	9543	1950-1959	88852
1860-1869	40422	1960-1969	84425
1870-1879	62027	1970-1979	83303
1880-1889	127859		
1890-1899	230589	1980	6759
1900-1909	273538	1981	4671
1910-1919	237289	1982	3196
1920-1929	111740	1983	4873

After Casinadar (1974), Herath (1980), and the State Mining and Mineral Development Corporation

Up to about the early 1870's graphite was recognized as one of the minor export industries of the island. There was a great demand for quality Sri Lanka graphite particularly by the crucible industry which was rapidly emerging in Great Britain and the U.S.A. The period 1870 to 1919 may be characterised as one of great activity for the graphite industry of Sri Lanka (Casinadar 1974). This was the period that witnessed the opening up of nearly 3000 graphite pits and mines in the south-western quarter of the island. A survey carried out by the Geological Survey Department in 1974-1975 in the Meegahatenna area revealed the presence of nearly 108 abandoned mines within the area covered by the survey. These mines had been worked from the year 1870 onwards, and 10 mines were said to be over 70 metres in depth, with the deepest being 250 metres. The growth of the graphite industry during this period was stimulated by the expansion of the steel industry in the industrialized countries. From about 1920 to the present day, except for a boom period during the war years, the graphite industry slipped steadily down from the position of being one of the major exports of Sri Lanka, and only those mines that were rich in high grade graphite deposits and competently managed continued mining and trading activity.

Graphite occurs in the island in veins, pegmatites and disseminated flakes in the country rocks. The vein type graphite is mainly confined to fracture or joint systems in the folded metasedimentary rocks. Only the vein type deposits are exploited. The reserves of graphite in the island are estimated to be very large, but due to the nature of the deposits (vein type), it is not possible to estimate the quantities available. The veins normally follow a structural pattern, and major veins tend to follow one or two directions. East-west trending graphite veins are common with off-shoots following the joints and minor fractures in the surrounding rocks. The graphite deposits of the island are mainly concentrated in anticlinal structures generally trending in a north-south direction. The best known areas of graphite occurrence (see Fig.21) in the various provinces are as follows:

Western Province - Botale, Kaluaggala, Kuligedara, Welihinda, Makkanigoda, Ellalamulla, Karasnagala, Migoda, Panaluwa and Watareka, Botalawa, Meegahatenna and Pelawatte.

Sabaragamuwa Province - Kukulegama, Delgoda, Weddagala, Dumbara, Karandana, Kolonnana, Wijeriya, Werahera, Arukgammana (Bogala), Bolagama, Bopitiya, Indurana, Niwatuwa, Pussella, Siyambalapitiya, Siyambalawela(Rangala).

Southern Province - Ratapola, Ampegama, Tiranagama, Magala, Karandeniya, Uragaha, Kottawa, Hiniduma, Panangala, Deniyaya, Kolawenigama, Idandukita, Daramitiara and Hillageainna.

North - Western Province - Ragedara, Mipitiya, Maduragoda (Kahatagaha - Kolongaha) and Naramana.

Central Province - Dolapihilla, Kahatagahatenna

North Central Province - Kebitigollawa

The State Graphite Corporation was established in 1971 and it took over the running of the graphite industry. The Corporation was re-named the State Mining and Mineral Development Corporation (SMMDC) in 1979. At present the Corporation operates two main mines, Bogala and Kahatagaha - Kolongaha.

With the vesting of mineral rights in the State under the provisions of the Mines and Minerals Law which came into effect in 1973, a lateral expansion programme at higher horizons in each of the three

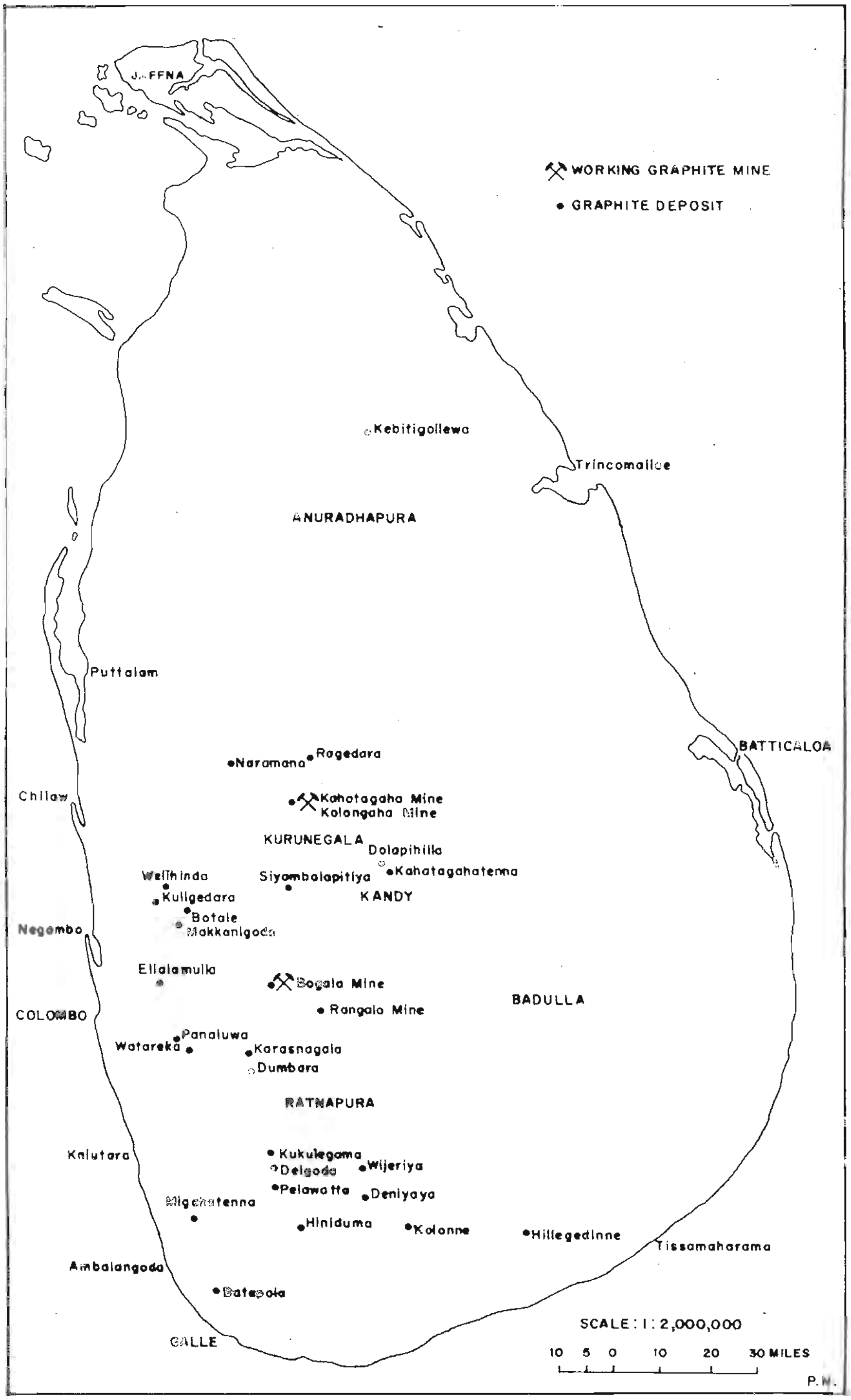


Figure 21. Graphite Occurrences in Sri Lanka

operating mines met with success as graphite deposits of economic widths were intersected. Shortly after nationalisation the Kolongaha and Kahatagaha mines which are situated close to each other have been connected underground. This has considerably improved the ventilation of the two mines. The rationalization of haulage together with improvements in mining techniques have further resulted in an improved working environment for the miner underground. Electrification of the mines has been completed. The Walakatahena workings (an abandoned mine) located between Kahatagaha and Kolongaha has been brought to operation once again. In the Kahatagaha - Kolongaha area graphite is associated with pegmatites. When the graphite veins are in close proximity to the pegmatites, the host rock identified as garnet-biotite gneisses, shows alteration to calc granulite. An alteration of this nature is not apparent when the pegmatites and graphite veins are far apart (Wijayananda and Jayawardane 1983). These veins show a consistent structural conformity along the joint-dip planes and this relationship has been developed as an effective tool in exploration for productive graphite veins in Sri Lanka.

The main graphite mineralization in the Kahatagaha-Kolongaha area is confined to a dome with an axial trend that runs north-south (See Fig. 22). The mineralization occurs mainly at the centre of the dome which is composed of garnet-biotite gneisses with occasional charnockitic rocks.

The Rangala graphite deposit was discovered by the Geological Survey Department at Siyambalawela in the neighbourhood of Bogala. The SMMDC commenced initial exploration work to determine the extent of graphite mineralization at Rangala with a view to developing it into a working mine. Exploration operations in the abandoned mine at Ragedera (Melsiripura) has also being undertaken by the Corporation. The Ragedara graphite is known to assay almost 100 per cent carbon and is unique for its purity, and it could undoubtedly be used in a number of industries. Other promising areas investigated by the Geological Survey Department and the SMMDC include Meegahatenne and Dumbara in the Sabaragamuwa Province. The Meegahatenne area could be classed as the richest graphite bearing ground in Sri Lanka. No

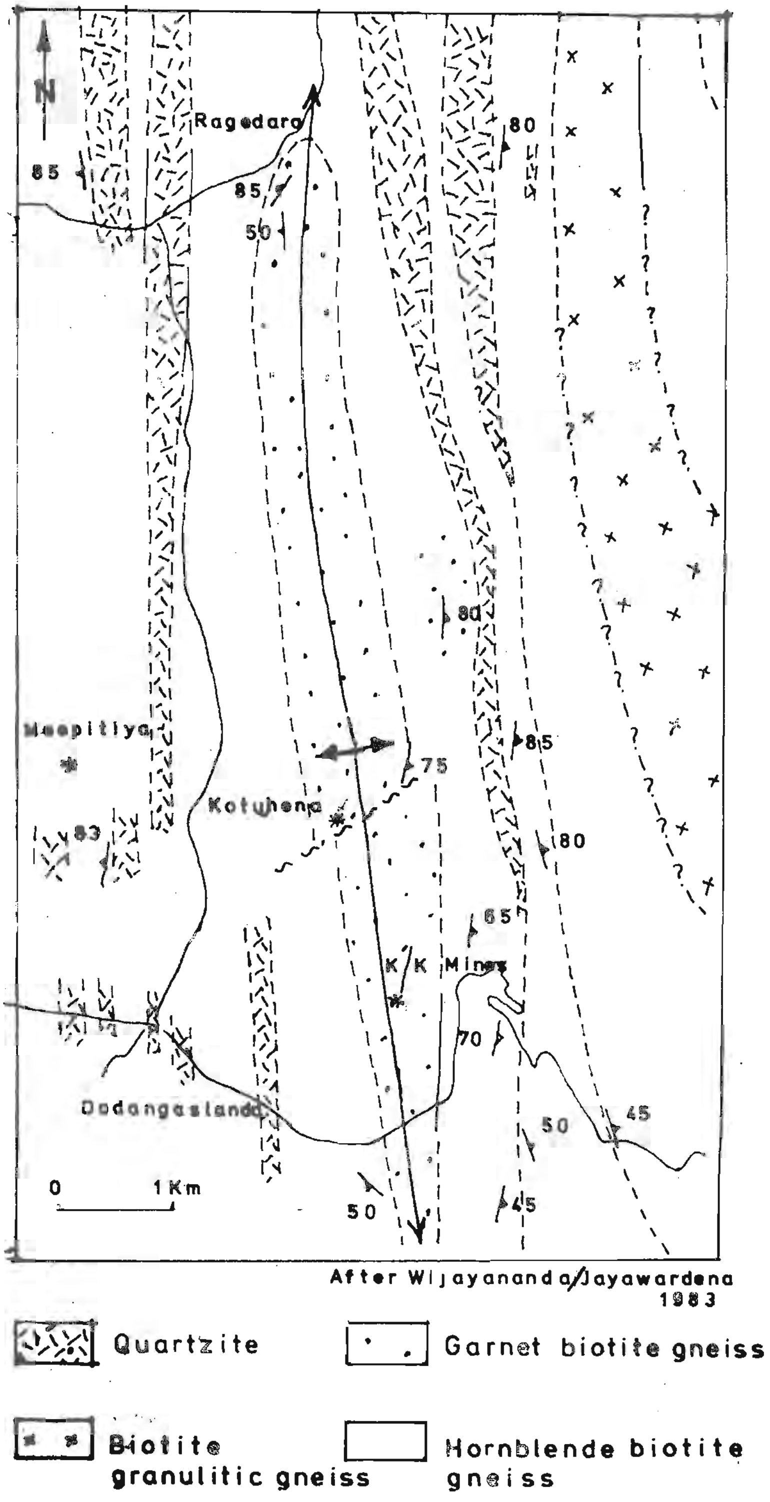


Figure 22. Geology of the Country around Kahatagaha - Kolongaha Mines

working mines were observed during recent investigations in the Meegahatenne area which is noted for its flake graphite.

The origin of the vein-type graphite has been the subject of much debate and is one which is unresolved. Recent researches favour an organic origin for graphite (Dissanayake, 1981). Graphite mined in Sri Lanka from vein type deposits is generally high in carbon content, (over 90 per cent carbon). The graphite is classified into a number of grades for export purposes, depending on particle size (lump, chip and dust), carbon content and structure (bright large lump-BLL, hard large lump-HLL, and slaty). Grades over 95 per cent carbon are common. All graphite material is crystalline and the term 'amorphous' graphite is normally used for microcrystalline varieties of graphite. Crystalline flake graphite is graphite which occurs disseminated throughout its containing rock, and the Malagasy Republic widely exploits this type of material. Although the island has some of the world's best graphite deposits with high carbon contents, graphite based industries have so far not been established except for the pencil industry which uses negligible quantities of graphite and the cottage crucible industry which produces a limited number of graphite crucibles. There is therefore plenty of opportunities for the further development of graphite mines in Sri Lanka and for the establishment of graphite based industries in the country.

Higher grades of graphite are used for crucibles and lubricants and dust grades are used for foundry facings and polishes. Graphite is used in dry cells, as a refractory material in steel making (to increase the carbon content), in electrical work and in a variety of other industries. Substantial quantities of graphite are also used in atomic reactors as a moderator but only synthetic material is used for this purpose at present. If the natural graphite can be purified to the rigid standards required for this particular use, it could create a large demand for the mineral in future.

MICA

The name mica is applied to a group of minerals of a complex of aluminium silicates with potassium and hydroxyl, magnesium and ferrous iron, and in some varieties, sodium, lithium and ferric iron. Mica is characterized by excellent basal cleavage and by a high degree of flexibility and elasticity. The important commercial types of mica are muscovite (potash mica) phlogopite (magnesium mica) and, less frequently, biotite (ferro-magnesium mica) and sericite. Commercial mica is broadly classified as sheet mica (block, film and splittings) and scrap and flake mica. Sheet mica, because of its ability to withstand high temperatures, its high di-electric strength and its electrical insulation capability, has found wide use in the electrical and electronic industries. Most scrap and flake mica are processed into ground mica which finds varied industrial use.

Sheet mica consists of flat sheets of mica mined from books or veins of mica. These sheets are trimmed by hand to remove ragged edges, loose scales and other imperfections. Sheet mica is further processed and is specified as sheet, block, film and splittings based on thickness. Splittings are thin leaves or sheets of mica with a thickness not exceeding 0.0012 inch. Built-up mica is a fabricated mica product composed of splittings held together by a binder. Scrap and flake mica consist of material that is below specification for use as sheet mica and is normally used by mica grinders, to produce ground mica or micronized mica.

The main types of mica found in the island are phlogopite, muscovite and biotite. Phlogopite is widely distributed in parts of the Uva, Central and Sabaragamuwa Provinces associated with crystalline limestones and other rocks. Muscovite mica occurs in quartz-feldspar-pegmatites at a number of places while biotite mica is widely distributed in the gneisses and pegmatites of the island. The principal known deposits of mica (Fig. 23) are in the Talagoda, Madumana, Wariyapola, Pallekalle, Talatu-Oya, Badulla, Maskeliya, Madugoda, Mariarawa, Udumulla, Naula, Ulwita, Haldummulla, Madampe, Mailapitiya and Kabitigollawa (Dutuwewa) areas. Two types of

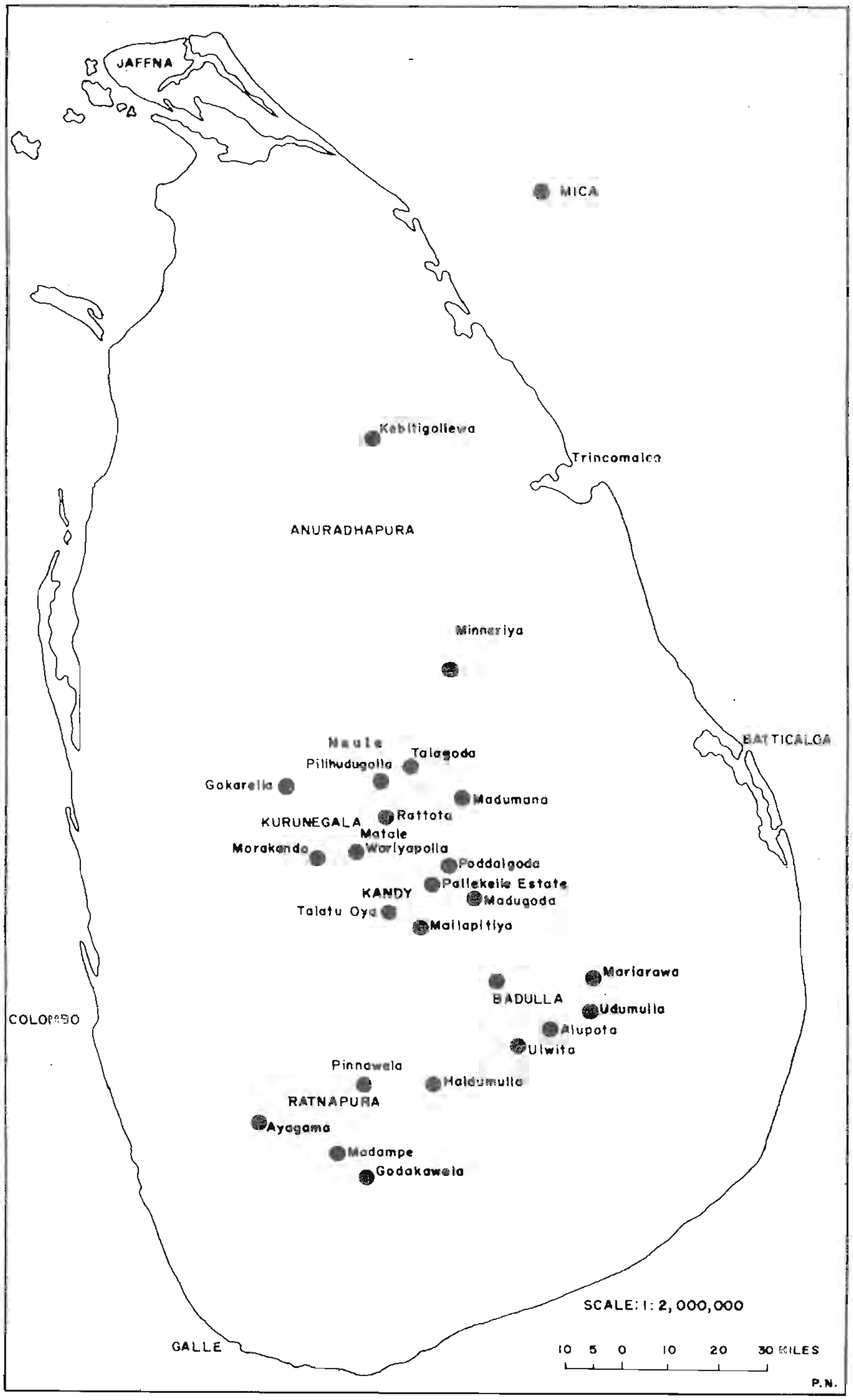


Figure 23. Mica Occurrences in Sri Lanka

deposits are known to occur, a pegmatite type deposit and a normal vein type of deposit. Mining of pegmatites for mica is sometimes not economical due to the sporadic occurence of the mica. If, however, two or more minerals are mined from pegmatites, for example, mica, quartz and felspar, mining becomes economical. Vein type deposits are more economical for exploitation purposes.

The mica industry in Sri Lanka dates back as far as 1896 when mining was carried on in the Badulla and Haputale districts. During the second World War mica mining was encouraged by the State and although the prices paid were favourable very little mica was offered for sale. Mica mining in Sri Lanka has so far been confined to shallow depths, and invariably, weathered material is obtained which would only be classed as scrap mica. Sheet mica is graded according to the size of clear materials (without imperfections) that can be cut from it. The Indian standards show eight grades for sheet mica and the areas mentioned range from 1 square inch to 48 square inches. In Sri Lanka the mica obtained so far is of the lower grades. It has been revealed that with deeper mining good grades of sheet mica could be obtained. The average annual production of mica is around 100 tons. Annual production figures of over 300 tons have also been recorded (1979-370 tons). Exports of mica from the Island have continued but in small quantities.

In recent years the systematic development of the mica industry has been considered and as a first step the promising mica deposits have been studied and a few places selected for detailed investigation with a view to commercial exploitation. The development of the mica industry is at present a function of the State Mining and Mineral Development Corporation, and steps have already been taken to establish a sound mica industry in the island.

Sheet mica is mainly used in electrical appliance manufacture and in the electronic and electrical industries. As an electrical insulator both muscovite and phlogopite are used. Dry ground mica is used for a variety of purposes such as filling for various types of plastics, floor coverings, gramophone records and paints. It is also used for dusting purposes and for lagging steam pipes and boilers. Wet ground mica is used mainly for decorative work, in wall-paper, printing, and in the rubber industry.

Vermiculite is the name applied commercially to hydrated micas. When heated, vermiculite expands into cellular granules occupying up to 16 times the original volume. This expanded material is suitable for use as an insulating medium. The weight per cubic foot of vermiculite is commonly about 5 to 8 lbs. Mica approaching the composition of vermiculite occurs at some places in the island.

INDUSTRIAL CLAYS

The term clay has no genetic significance. It is used for material that is a product of weathering or sometimes of hydro-thermal action, or for material deposited as a sediment. In general the term clay implies a natural earthy fine grained material, which develops plasticity when tempered with water. A soil is a material composed of clay and non-clay minerals, and even with a high clay component, it may not be fine grained or of sufficient plasticity to be termed a clay material. Clay minerals are formed as alteration products of primary rock minerals by weathering process or by the action of hydrothermal solutions. The nature of the clay mineral formed depends upon the mineral composition of the parent rock and upon the physio-chemical environment in which the alteration takes place. A soil or clay material is frequently a mixture of various clay mineral types and other resistant primary minerals.

The main clay minerals are kaolinite ($Al_2O_3 2SiO_2 2H_2O$; Al_2O_3-39.50%, SiO_2-46.54%, H_2O-13.96%), montmorillonite and the micaceous clay minerals. Associated with the clay minerals there are a large number of accessory minerals which have an important influence on the properties of the clays in which they occur. They include the hydroxides of aluminium (gibbsite, boehmite and diaspore) and the oxides and hydroxides of iron, quartz, felspar, mica, pyrite, rutile, ilmenite, monazite, zircon, tourmaline, garnet, calcite, dolomite and many other minerals. Organic matter is present in some clays. Clays may also contain alkali salts and other impurities.

Two main types of clay materials are recognised-residual clays and sedimentary clays. A clay material found at its site of formation from the parent rock is called residual. These deposits are usually formed by the percolation of ground water through the rock mass aided by other weathering agents. There are some clay deposits that are so deep down below the surface that it is unlikely that they would have been formed through the action of ground water, and most of these deposits are probably of hydrothermal origin.

Sedimentary clays are by far the most common and include a variety of deposits. Their nature is determined largely by the mode of transportation and deposition. They can be classified as follows:

1. Fluviatile - formed by sedimentation along the course of a river.
2. Estuarine or deltaic - deposited at the mouth of a river.
3. Lacustrine - deposited in a fresh water lake.
4. Marine - deposited in a sea.
5. Aeolian - transported by air.
6. Glacial - transported by large masses of ice and deposited either as moraines or as boulder clay or till.

These processes of transportation and deposition have been in progress for millions of years. Since clay may be formed from rocks of diverse character it is natural that they should differ considerably from one another as regards their mineral consitutents and other properties. However, they have a common feature in that they are hydrated silicates of aluminium or magnesium.

Clays are variable materials and possess a wide range of properties which make them useful for many industrial applications. Any one deposit, however, possesses certain characteristics which largely govern its particular value in industry. The assessment of these characteristics is important and such properties enable clays to be classified into different types.

China clay or kaolin is the name given to clays which form the basis of high quality domestic pottery and which is known to consist mainly of the clay mineral kaolinite. Raw china clay is usually refined to obtain a kaolin of high purity suitable for industrial purposes. Ball clay is a term applied to a large group of sedimentary plastic clays usually dark in colour but burning to a white or cream body. The ball clays represent the finest-grained transported clays and they are distinguished from kaolin by their greater toughness and plasticity, better bonding power and lower refractoriness. Ball clays are used chiefly for china and fine earthenware and as bonding material for less plastic clays in the manufacture of refractories and stoneware. Fire clays possess a remarkable resistance to heat and are termed refractory clays. As such, they find use in industries where high temperatures are involved such as metal smelting. The steel industries are the largest consumers of refractories for the lining of furnaces. By definition a good refractory clay is one which will withstand a temperature of about 1,600°C or more. The essential requirements in such materials are that they should be free from minerals which will melt or flux such as mica, felspar, calcium compounds, and iron oxides and hydroxides. They should, however, be rich in alumina. Building clays are slightly refractory. The ideal clays are those which vitrify sufficiently at a temperature of 950-1100°C to form hard bricks without excessive shrinkage or deformation. These coloured clay materials with a low refractoriness occur as residual or alluvial deposits and are used in the manufacture of structural ceramics, for example, bricks, pipes and a variety of other products.

Since the dawn of civilization man has recognised that clay could be made plastic with water, moulded and then made durable by the action of heat. On this phenomenon has been based the science and technology of the industry of ceramics. The word 'Ceramic' is derived from the Greek word 'Keramikos' which literally means 'earthern'. The oldest ceramic raw material was undoubtedly clay. Clay still remains the main ceramic raw material. Other materials, some of which may contain little or no clay, are also processed for the manufacture of a vast range of products requiring high temperatures for their manufacture. These products include structural ceramics or heavy clay products (bricks, pipes and tiles), refractories, pottery, industrial ceramics and abrasives, glass, glazes and enamels, and cements, limes and plasters.

The type of clay mineral that may occur in a clay material affects the ceramic behaviour. It is well known that kaolinite clays are the least plastic and the most refractory; montmorillonite clays are the most plastic and the least refractory and the hydrous mica clays are of intermediate plasticity and low refractoriness. Sri Lanka could be divided into three clay mineral provinces based on the frequency distribution of clay and associated minerals in the alluvial and residual soils (Fig. 24). The constitution of clay material from the various provinces may be listed as follows (Herath 1973, Herath and Grimshaw 1971):

Group I: Wet zone clay mineral province:

(i) Mainly Kaolinitic Clay (china clay)

(ii) Kaolinite - gibbsite - boehmite clays with mixed layer mineral and vermiculite (ball clay)

(iii) Kaolinite - gibbsite - goethite clays with mica, mixed layer mineral and vermiculite (brick and tile clays)

Group II: Dry Zone Clay Mineral Province:

Kaolinite - montmorillonite clays devoid of gibbsite but with calcareous material (brick and tile clays).

Group III: Intermediate Zone Clay Mineral Province:

Kaolinitic clays relatively low in gibbsite and montmorillonite.

The Clay Mineral Provinces closely follow the climatic zones of the island (Wet, Dry and Intermediate Zones), and this feature points out to the fact that climatic conditions have determined the nature of clay mineral development in Sri Lanka. A notable feature of clay mineral development is the progressive increase in the proportion of montmorillonite from Wet to Dry Zone, the progressive increase in the proportion of gibbsite from Dry to Wet Zone, and the progressive disappearance of calcareous material from Dry to Wet Zone. The proportion of gibbsite present is a highly diagnostic character, and the classification can be entirely based on this feature. Figure 25 is presented to show differential thermal analyses (DTA) curves for china clay and ball clay from the Wet Zone area and Fig. 26 shows characteristic D.T.A. curves for brick and tile clays from the three Clay Mineral Provinces. D.T.A. is a method of determining the temperature at which thermal reactions take place in a material when

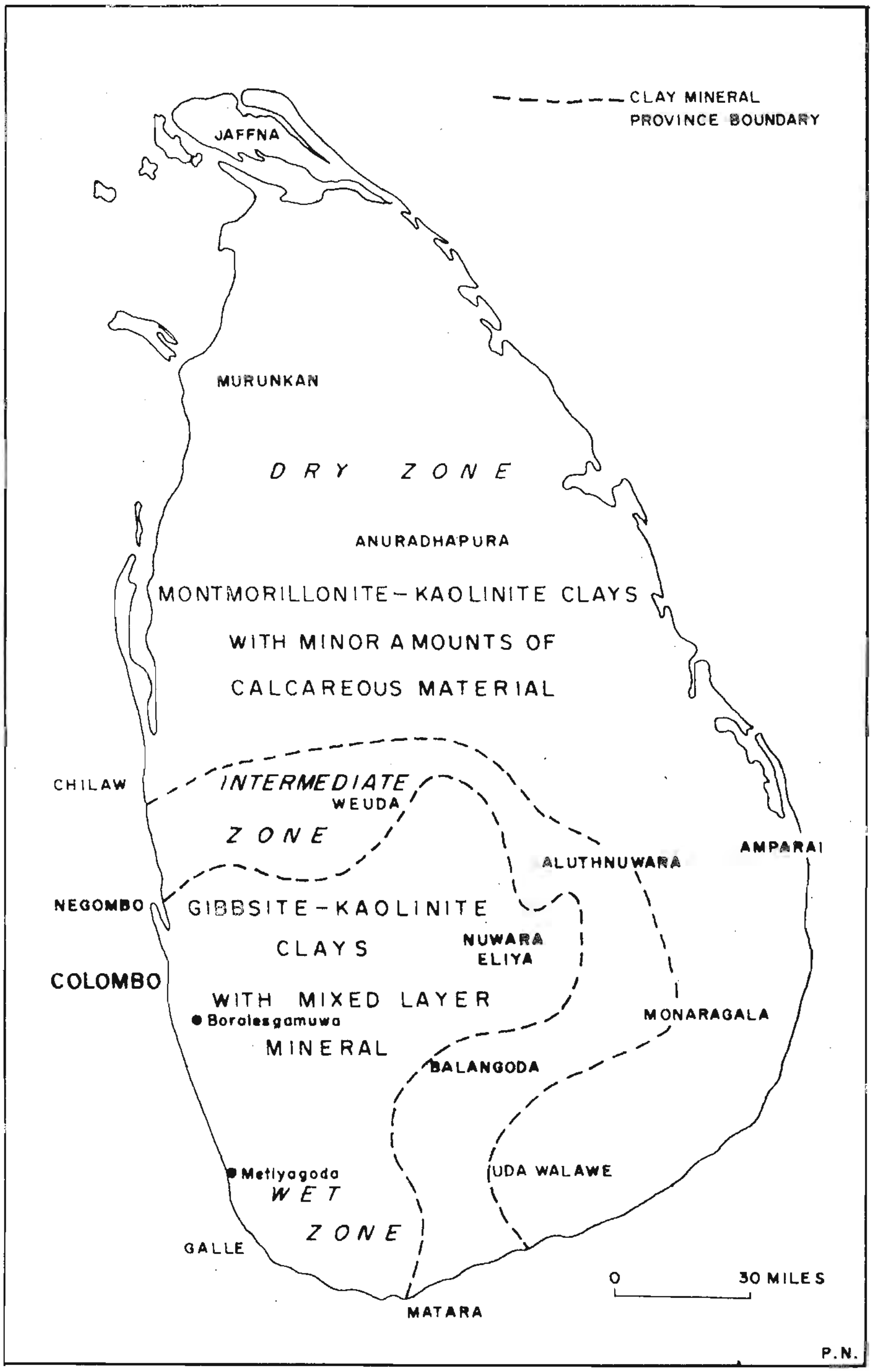


Figure 24. Clay Mineral Provinces - Sri Lanka

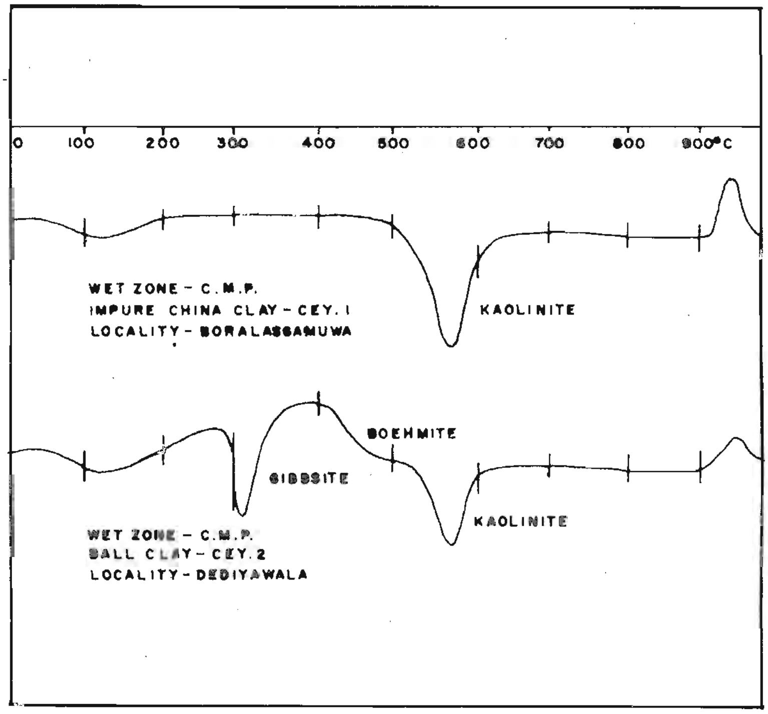


Figure 25. D.T.A. Curves for China Clay and Ball Clay - Sri Lanka

it is progressively heated. In the case of clay minerals D.T.A. at first shows charateristic endothermic reactions due to dehydration and loss of crystal structure, and later shows exothermic reactions due to the formation of new phases at high temperatures.

The occurrence of China clay or kaolin in the low lying areas around Colombo has been known for a long time. The reserves available at Boralesgamuwa are estimated to be well over a million tons (Herath 1963). No detailed investigations have been undertaken to prove the estimated reserves of raw kaolin. Other deposits occur in the deep residual weathered zones of the central highlands and in other areas, specially in the lowlands of the south-west sector (Meetiyagoda area). Clays which approach ball clay in composition are known to occur in the flood plains of rivers and are confined to the south-west sector. The best known deposits of ball clay occur widespread in the Kalutara area. The proved reserves in this area amount to over 500,000 tons, although the actual reserves are probably very much larger. The Dediyawala clay could also be classed

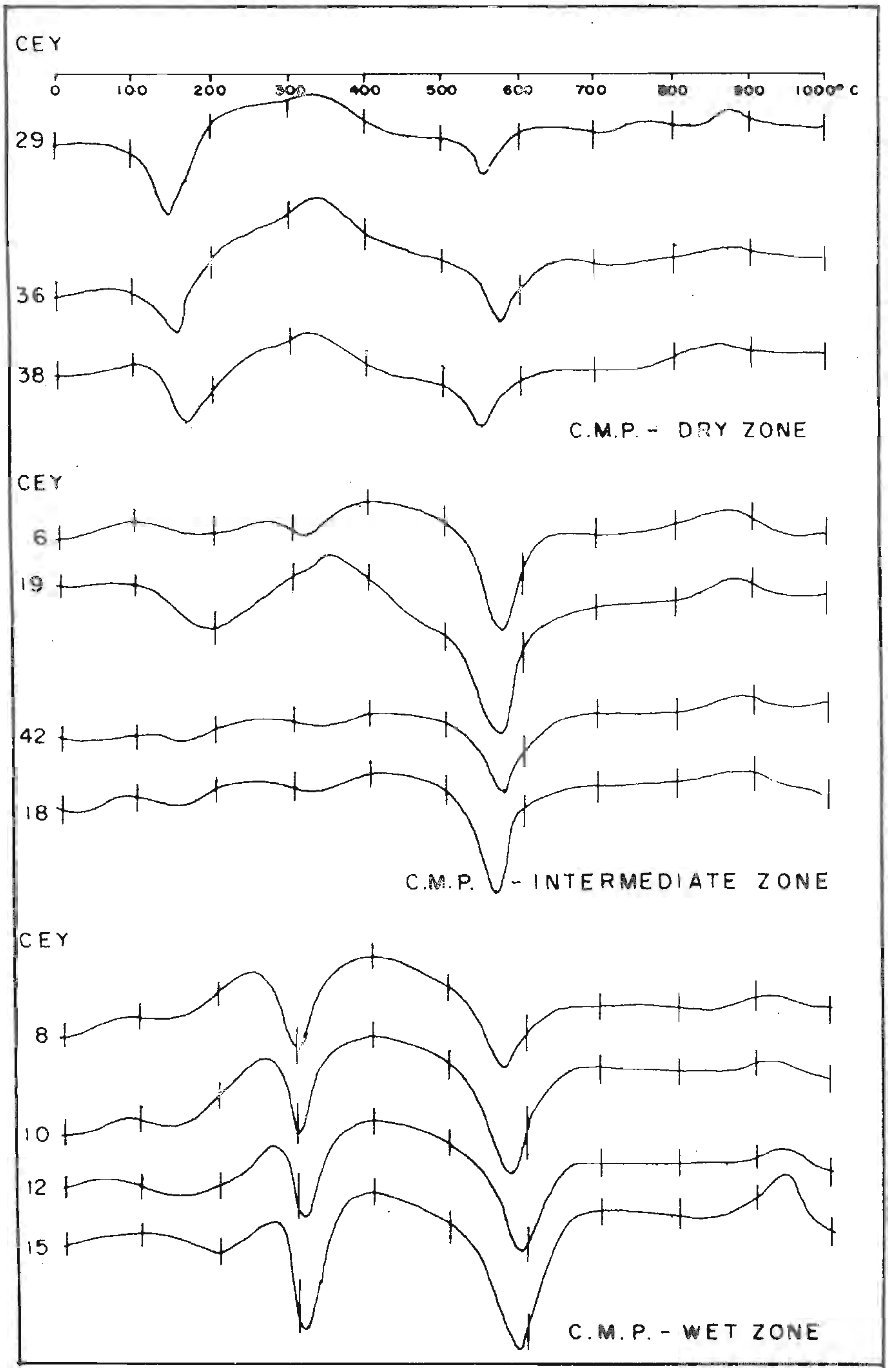


Figure 26. D.T.A. Curves for Clays from the Clay Mineral Provinces - Sri Lanka

as a refractory bond clay or a fire clay (fusion point 1,700^{o}C). The Dry Zone Clay types are ideal for the manufacture of expanded clay aggregate for concrete, and very large reserves of cement clays are available in the Murunkan and other areas. The alluvial clay deposits used for the manufacture of structural clay products vary considerably in character. The Jurassic shale in the Andigama area is a source of raw material for the manufacture of heavy clay products including refractories. The Pleistocene red earths have been found suitable for use as foundry moulding sands, and laterites are mainly used as a building material (bricks) - (Herath 1973, Herath and Grimshaw 1968 and 1972).

China clay is mined from the Meetiyagoda and Boralasgamuwa clay fields and is refined for use in the ceramics industry. The rational analysis of samples of china clay (impure and refined) are presented in Table XXVI. The chemical analyses of different types of clay materials are listed in Table XXVII, and Table XXVIII shows the mineralogical composition of the same clay materials. Clay materials can seldom be termed pure. The impurities present in them are important in determining their properties. Their examination may become difficult even when using modern experimental methods. Table XXIX is presented to show the mineralogical classification of the industrial clays of the island and Table XXX gives the characteristic physical properties of the clay materials. It is seen from the results presented that most of the ceramic properties may be predicted with a knowledge of the constitution of the clay materials.

Besides being used in the manufacture of ceramic products, clays and clay materials are also used in the manufacture of a large number and range of non-ceramic products. For example, refined kaolin or china clay is used as fillers and coatings for paper, as fillers and extenders for paints, and as fillers for rubber, textiles, oil cloth, toilet and tooth powder, soaps, and gramophone records. Kaolin is also used in soft polishing, medicines, pharmaceuticals, cosmetics and many other products. Coloured varieties of kaolinitic clays (clay ochers) contain varying amounts of iron oxides and hydroxides. In Sri Lanka these clays occur as lateritic clays.

'Samara' a yellow ocher is a common variety. Clay ochers are used for paints, ceramic stains and for a number of other purposes.

TABLE XXVI

RATIONAL ANALYSIS - IMPURE CHINA CLAY

CONSTITUENTS	PERCENTAGE	MINERAL	PERCENTAGE
SiO_2	70.54	Kaolinite	46.50
Al_2O_3	20.92	Mica	8.20
TiO_2	0.43	Quartz	45.00
FeO	–	Ilmenite	.23
Fe_2O_3	0.18	Iron Oxides	
K_2O	0.96	and Hydroxides	.13
Na_2O	0.22		
MgO	tr.	Total	100.06
CaO	–		
H_2O^-	0.40		
H_2O^+	6.49	RATIONAL ANALYSIS	
		(mica convention)	
Total	100.14	IMPURE KAOLIN	
		(CEY.1)	

RATIONAL ANALYSIS - WASHED CHINA CLAY

CONSTITUENTS	PERCENTAGE	MINERAL	PERCENTAGE
SiO_2	47.58	Kaolinite	97.00
Al_2O_3	38.89	Mica	.70
Fe_2O_3	0.42	Quartz	1.80
FeO	–	Ilmenite	.20
TiO_2	0.42	Iron Oxides and	.30
K_2O	0.06	Hydroxides	
Na_2O	0.02		
MgO	tr.	Total	100.00
CaO	tr.		
H_2O^-	0.51		
H_2O^+	11.96	RATIONAL ANALYSIS	
		(Mica Convention)	After
Total	99.86	WASHED CHINA CLAY	Herath (1973)
		(CEY. 1a)	

Since about nine-tenths of the island is occupied by Precambrian crystalline rocks, the island, except for some Jurassic shale, is devoid of true consolidated clays, upon which so much of the ceramic industry of the world is based. However, the surface of the island

TABLE XXVII

CHEMICAL ANALYSIS OF CLAYS - SRI LANKA

	CEY.1	CEY.1a	CEY.2	CEY.8	CEY.20	CEY.6
SiO_2	70.54	47.58	49.10	46.12	48.40	45.12
Al_2O_3	20.92	38.89	31.10	25.26	20.27	29.95
TiO_2	0.43	0.42	2.39	1.11	1.05	1.13
FeO	-	-	0.61	0.46	0.64	0.96
Fe_2O_3	0.18	0.42	0.16	9.73	8.85	9.10
MgO	tr.	tr.	0.62	0.90	1.27	1.14
CaO	-	tr.	tr.	0.76	1.41	0.68
K_2O	0.96	0.06	0.84	1.49	0.83	1.32
Na_2O	0.22	0.02	0.23	0.63	0.52	0.46
H_2O^+	6.49	11.96	11.79	10.72	9.17	8.61
H_2O^-	0.40	0.51	2.05	2.48	7.53	0.94
Total	100.14	99.86	99.69	99.66	99.94	99.26
Group	1-i	1-i	1-ii	1-iii	II	III
Al_2O_3/ SiO_2	.296	.815	.649	.547	.418	.570

After Herath (1973)

CEY.1 = Unwashed kaolin
CEY.1a = Refined Kaolin-without chemical treatment
CEY.2 = Ball Clay
CEY.8,20,6 = Brick and Tile Clays

Geological Survey Department,
Colombo 2.

TABLE XXVIII

MINERALOGICAL COMPOSITION
OF SRI LANKA CLAYS

MINERAL	PERCENTAGE				
	Cey.1	Cey.2	Cey.8	Cey.20	Cey.6
Kaolin	43	40	>20	> 30	> 40
Montmorillonite	–	–	–	< 20	< 10
Mica	8	–	–	< 8	< 13
Mica – interstratified mineral and vermiculite	–	–	<25	–	–
Vermiculite – interstratified mineral	tr.	< 10	–	–	–
Calcareous material	–	–	–	< 5	–
Quartz	46	23	24	15	12
Gibbsite	–	< 13	<15	–	< 5
Goethite	<.50	<.20	<12	< 8	<10
Ilmenite	<.50	<2.50	< 1	< 1	< 2
Boehmite	–	< 5	–	–	–
Felspar	<.10	–	–	> 3	–
Monazite	<.20	–	–	–	≤10
Organic matter	tr.	<2.50	tr.	present	tr.
Absorbed water	.40	2.05	2.48	7.63	4.79
Mineral Group	I-i	I-ii	I-iii	II	III

After Herath (1980)

has remained above sea level for the greater part of its geological history and this has resulted in a long period of intense weathering and erosion, with subsequent laying down of considerable amounts of alluvium in the intermediate slopes and the coastal regions. Sri Lanka has therefore to depend mainly on the unconsolidated alluvial clays along the lower reaches of the major river valleys for the raw materials used in the structural clay products industry. These deposits are not of a uniform character. A scientific assessment based on a carefully planned programme of field investigation is therefore essential to disclose the extent and quality of the clay materials. A temporarily high water table and liability to flooding is a problem in many parts of the island. Many deposits, if they are to be properly utilized, must be worked to depths much below the apparent water table. This is not the normal practice, and a large area of land goes to waste due mainly to unsystematic and imperfect mining in most areas. Accurate records of the quantity of raw materials mined by the cottage industry are not available. Assuming that approximately 500 million units are produced by the cottage industry about 1300 acre feet of clay are required per annum. The modern brick and tile industry (private and public) consumes about 270 acre feet of clay for the manufacture of 90 million units per annum. The total annual requirements would therefore be in the region of 1500 acre feet. At an average working depth of 2.5 m this will involve a land use of approximately 200 acres per annum. The reclamation of such mined land needs careful consideration. The total value of various clays used in industry is considerable and amounts to more than 80 million rupees annually.

Sri Lanka is well provided with ceramic raw materials. The cottage industry manufactures about 500-600 million bricks per annum. Unglazed tiles of the mangalore pattern are being made in over 50 modern factories; the Ceramics Corporation also operates about 12 tile factories and together they produce over 75 million tiles per annum. Earthenware pipes and floor tiles are also produced. The State operates a series of pottery centres. Two kaolin refineries are operated by the Ceramics Corporation which produce nearly 7,000 tons of refined kaolin per annum. This Corporation also operates two ceramic factories, one at Negombo and the other at Piliyandala. These factories produce over 7,000 tons of ceramic ware and the products include domestic crockery, sanitary-ware, wall tiles, mosaic tiles, elecroceramics and miscellaneous ornamental and fancy ware. A factory manufacturing porcelain ware (Lanka Porcelain Limited) mainly for export is situated in Matale. A refractories factory at Hanwella, a second kaolin refinery at Meetiyagoda, a ball clay plant near Kalutara, and a modern lime plant at Hungama have also been established. A wall tiles plant (Lanka Wall Tiles Limited) mainly for export is situated at Balangoda (Herath 1978). A floor tile plant is to be established by Lanka Wall Tiles Limited near Hanwella.

TABLE XXIX

MINERALOGICAL CLASSIFICATION OF SRI LANKA CLAYS

Mineral Group	Minerals Invariably Present	Others
Group I - Wet Nos. Cey. 2,8,9, 10,11,12,13,14, 15,80,82.	kaolinite, gibbsite, goethite, quartz and ilmenite	Montmorillonite halloysite mica interstratified minerals (biotite/vermiculite) vermiculite boehmite iron oxides other primary resistant minerals
Group II - Dry Nos. Cey.20,22,28, 29,31,33,35,36,38.	kaolinite, montmorillonite, felspar, quartz and ilmenite	geothite iron oxides mica calcareous material other primary resistant minerals
Group III - Intermediate Nos. Cey.3,4,5,6, 16,17,18,19,42,83.	kaolinite, Quartz and ilmenite	mica gibbsite goethite iron oxides montmorillonite other resistant primary minerals

After Herath 1973

The mid seventies may be considered as the height of the expansion of the Sri Lanka ceramics industry. In recent years a second porcelain factory has been established (1982-1983), at Dankotuwa. Fig. 27 shows the location of ceramic and other factories in the island. The Corporation has also re-structured its research and development facilities and has established a modern research facility to cater to the entire ceramic industry of Sri Lanka.

TABLE XXX

CHARACTERISTIC PHYSICAL PROPERTIES OF SRI LANKA CLAYS

	Properties	*Wet Zone I*	*Intermediate Zone III*	*Dry Zone II*
General	Mineralogy	Kao. Gib. Goe. M.L. Min.	Kao. Minor Gib. and Mont.	Kao. Mont. and Lime
	Clay — 2 microns	Range 12—49 Average 24	Range 24—57 Average 40	Range 40—65 Average 52
	Moisture (%)	Range 1.62—3.80 Average 2.52	Range 2.75—3.39 Average 3.63	Range 4.00—6.48 Average 5.23
	Total Cation, E.C.	Range 6.8—10.8 Average 9.4	Range 12.3—26.8 Average 17.6	Range 32.5—52.2 Average 40.2
Dry	Atterberg Plasticity Index	Range 9.7—19.4 Average 13.3	Range 20.4—38.4 Average 23	Range 41.3—49.0 Average 46.6
	Workability	Short to Normal	Normal	Excellent
	Bulk Density (gms. per cc.)	Range 1.38—1.61 Average 1.45	Range 1.55—1.81 Average 1.72	Range 1.80—1.97 Average 1.85
Wet	Weight Loss (%)	Range 13.5—29.3 Average 20.8	Range 16.0—31.2 Average 24.5	Range 21.4—24.5 Average 23.3
	Bulk Density (gms. per cc.)	Range 1.38—1.64 Average 1.46	Range 1.55—1.83 Average 1.73	Range 1.93—2.15 Average 2.07
	Volume Contraction (%)	Range 13.1—27.0 Average 19.8	Range 15.4—33.2 Average 26.8	Range 25.3—33.3 Average 29.4
	Stability Cracking	No Cracks	No Cracks	No Cracks to Fine C.
	Compressive Strength lbs./sq. in	Range 224—545 Average 353	Range 520—832 Average 666	Range 537—1052 Average 795
Fired-1050°C	Weight Loss (%)	Range 17.4—42.8 Average 32.0	Range 28.9—40.7 Average 34.5	Range 27.4—36.2 Average 33.3
	Bulk Density (gms. per cc.)	Range 1.39—1.68 Average 1.54	Range 1.92—1.98 Average 1.94	Range — Average above 2.00
	Volume Contraction (%)	Range 23.2—30.9 Average 27.5	Range 22.5—29.2 Average 32.8	Range — Average above 33.0
	Colour Hardness	Cream to Brick Red Soft to Fairly Hard	Pink Brown Hard to Very Hard	Light to Dark Brown Very Hard
	Stability Cracking	No Cracks to Badly C	Fine Cracks to Bad C.	No Cracks to Extreme Cracking & Bloating
	Water Absorption (%)	Range 16.2—28.5 Average 22.4	Range 7.1—14.9 Average 12.2	Range — Average around 5.0
	Compressive Strength/lbs./sq. in	Range 434—963 Average 629	Range 2460—4910 3283	Range — Average above 5000
	Refractoriness	High	Intermediate	Low

HERATH (1970)

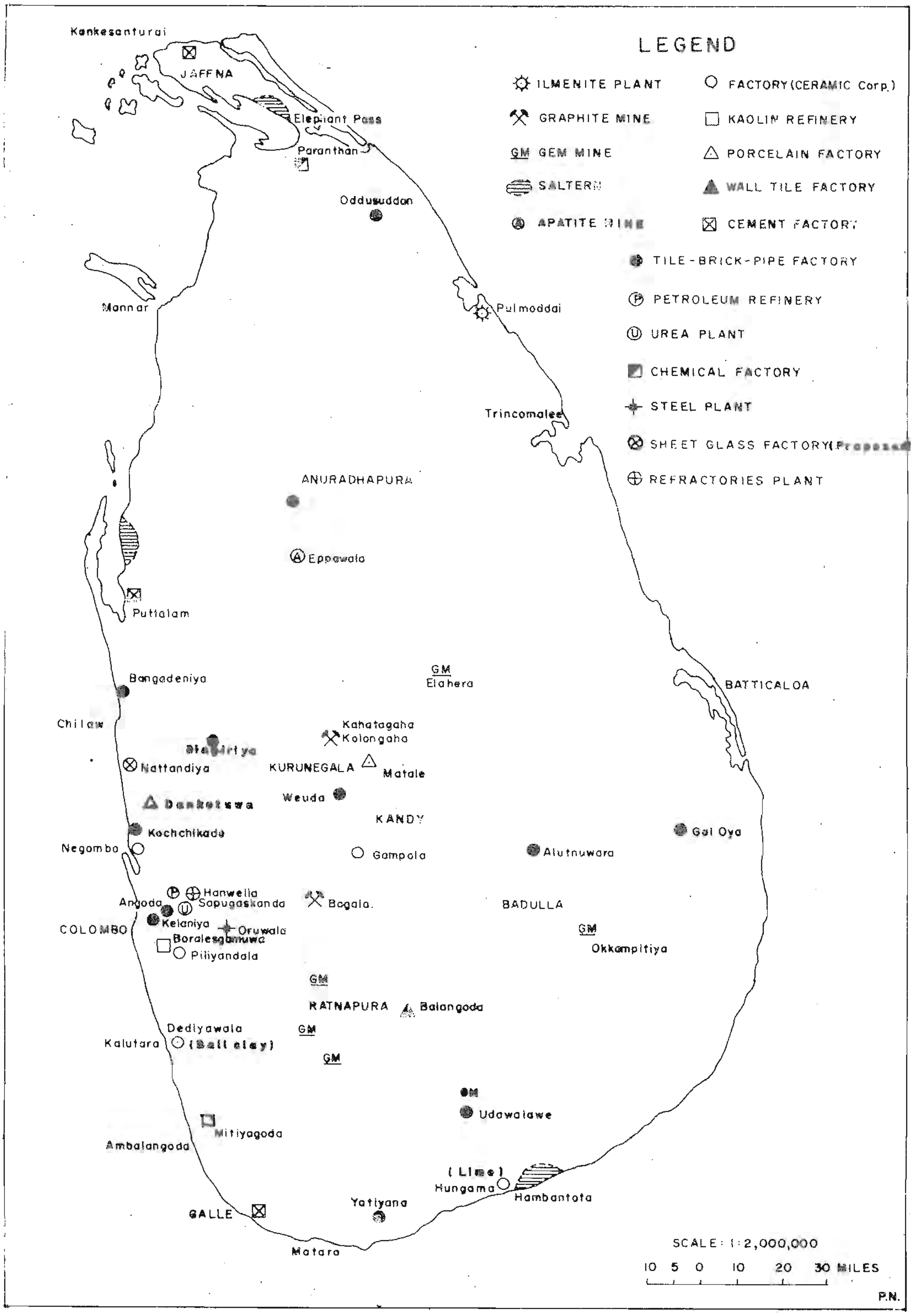


Figure 27. Location of State Industrial Units

SILICA

Silica (SiO_2) is the most abundant oxide in the earth's crust and occurs both as free silica and combined with other elements and compounds. Free silica occurs in nature in many forms and in many degrees of purity such as vein quartz, quartz sands, sandstone, quartzite, flint, trydimite, opal, agate, and chalcedony. Some varieties of quartz such as amethyst, opal, jasper and agate are valuable as semi-precious stones. In Sri Lanka silica occurs as vein quartz, silica sand and quartzite.

Vein quartz deposits of extreme purity (over 98.8 per cent silica) are found in many parts of the island. The best known deposits occur in the Opanaike, Pelmadulla, Pussella, Rattota and Ratnapura areas (Fig. 28). Table XXXI is presented to show the locations of deposits of vein quartz that have been observed during the course of geological surveys conducted by the Geological Survey Department of Sri Lanka. Vein quartz normally occurs on the surface as very large boulders and may in some places cover an area of about 4 hectares. They do not seem to extend in depth. Recent surveys carried out by the Geological Survey Department have proved deposits of vein quartz of commercial importance, and the reserves at present are estimated to be in the region of 800,000 tons. Vein quartz is mined for use in the ceramic and allied industries.

Deposits of silica sand are widespread in the island and the best known deposits occur in the Marawila-Nattandiya and Madampe areas (Fig. 29). A large deposit of silica sand also occurs in the Ampan-Vallipuran area. Three deposits have been recognised in the Madampe-Nattandiya area: the Madampe deposit in the north, the Kudawewa deposit in the middle, and the Marawila-Nattandiya deposit in the south. The length of the combined deposits, stretching for eight to ten kilometres, greatly exceeds the width, which in places is not more than a few hundred metres. The total area covered by the silica sand deposits has been estimated at approximately 1000 hectares.

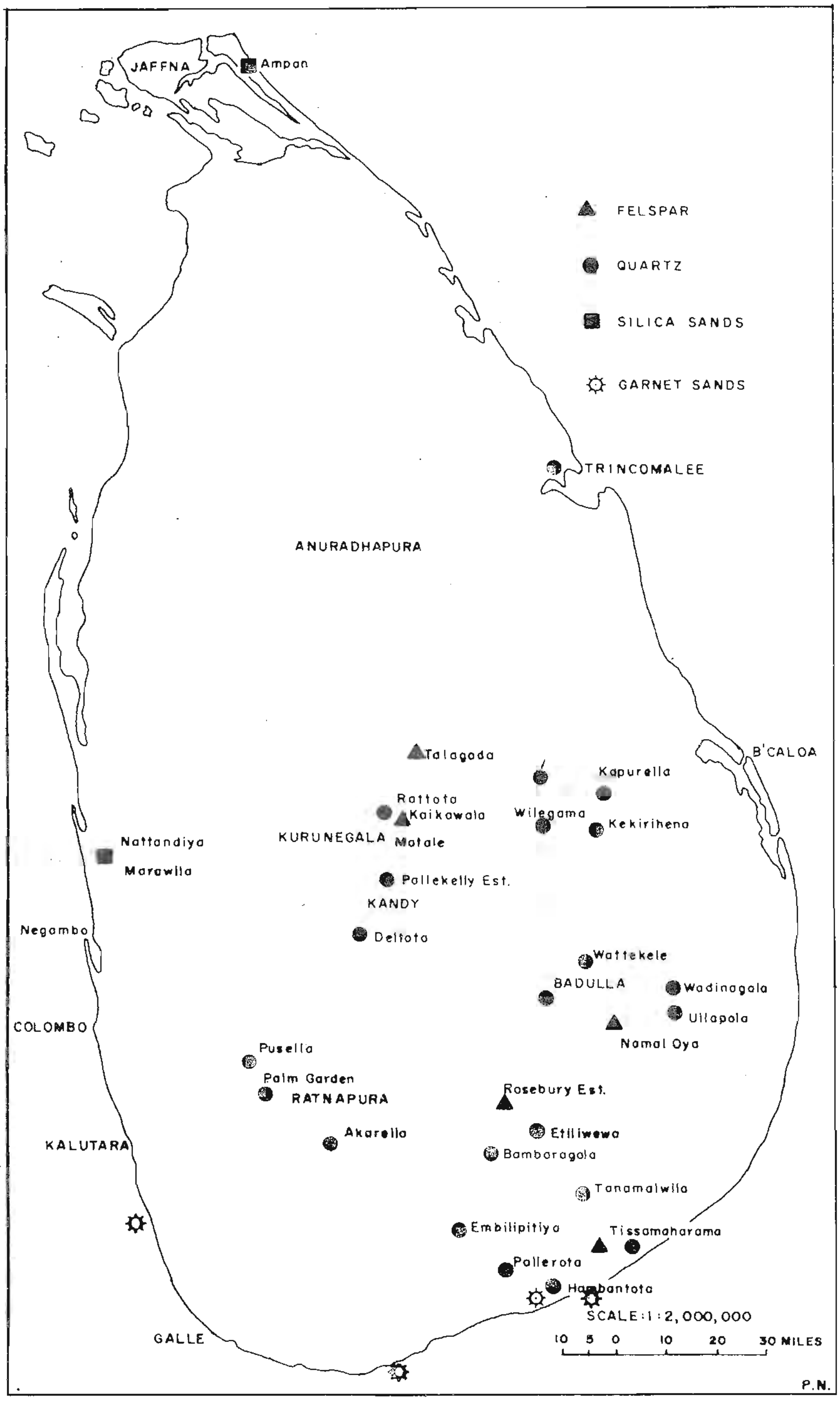


Figure 28. Occurrences of Felspar, Vein Quartz, Silica Sands and Garnet - Sri Lanka

NA-24-4

TABLE XXXI

LOCATIONS OF VEIN QUARTZ

SHEET	LONGITUDE Degs.	Mts.	LATITUDE Degs.	Mts.	LOCATION
Ambalantota	80	58	06	11	Pallerota
Anuradhapura	80	41	08	12	Nawakkulum
	80	15	06	53	Boraluwa
AvissaWella	80	15	06	53	Getahetta
Buttala	81	08	06	37	Kirindi Oya
	81	07	06	40	Kirindi Oya
Hambantota	81	11	06	18	Niyandagala
	81	08	06	17	Urapitissuwala
	81	08	06	10	Mahalewaya
	81	14	06	11	Embilikala Kalapuwa
	81	08	06	08	Pitawake
	81	16	06	11	Baminiya wewa
	81	20	06	13	Kirinda
	81	22	06	15	Palatupane
	81	24	06	16	Palatupane
Haputale	80	52	06	36	Kalugaha
	81	06	06	46	Ritigala
Hatton	80	39	06	57	St. Clair
	80	38	06	53	Ottery
Horowpatana	80	45	08	53	Ihala Kubukgollawa
Kandy	80	40	07	13	Galaha
	80	42	07	10	Deltota
	80	42	07	09	Pattiyagama
Kurunegala	80	40	07	31	Gurubibile
	80	40	07	30	Koswana
Maha Oya	81	20	07	30	Kekirihena
	81	10	07	31	Kekirihena
Nuwara Eliya	80	58	06	53	Kodemegama
	81	01	07	03	Moragolla
	81	01	07	02	Idemegama
Puttalam	79	54	08	02	Sellankandal
Ratnapura	80	26	06	34	Karawita
	80	27	06	30	Dela
	80	23	06	44	Ratnapura
	80	20	06	48	Pussella
	80	36	06	36	Opanaike
	80	39	06	35	Akarella
Timbolketiya	81	00	06	19	Suriyawewa
	81	05	06	20	Udamattala road
	81	05	06	25	Weberagala
	81	03	06	26	Podiwewa
	81	01	06	29	Dunga Ara
	81	00	06	31	Tunkema Wewa
	80	58	06	32	Hambegamuwa
Tirukkovil	81	34	07	17	Bakiniatta Aru
	81	34	07	08	Kivulagama
Vakaneri	81	11	08	05	Kandakadu
	81	12	08	04	Sinnakallu
	81	10	07	59	Tirumunatur
	81	12	07	57	Salambadimadu Kulum
	81	11	07	52	Dewagalla
	81	16	07	57	Singara Kulum
	81	24	08	04	Uppu Allan
	81	29	07	57	Mylankarachchan
West Minister Abbey	81	31	07	02	Ullapola

Geological Survey Department
Colombo 2.

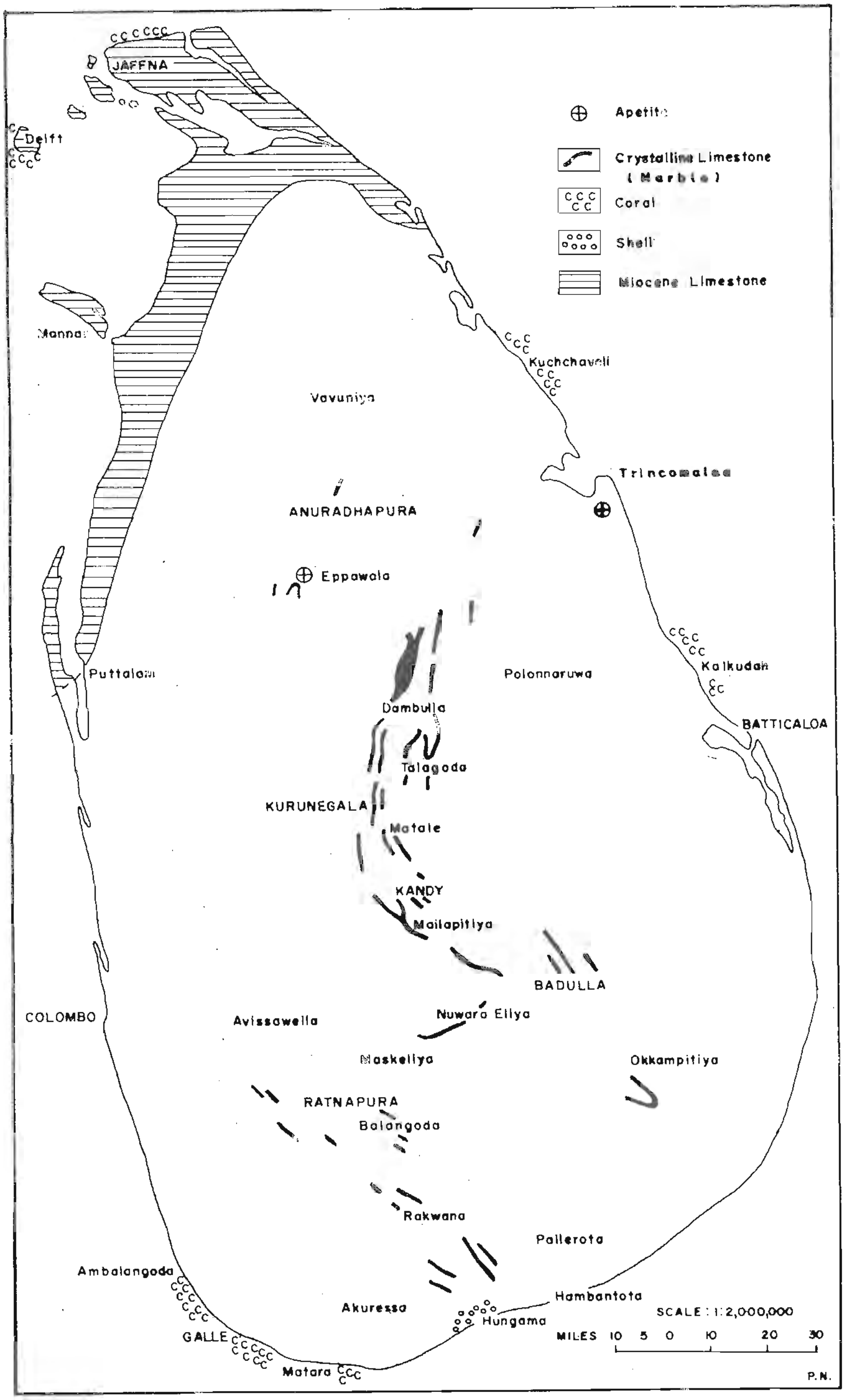


Figure 29. Occurrences of Calcareous Material - Sri Lanka

The average thickness of the silica sand is about a metre and no over-burden occurs. The total reserve of silica sand in these deposits is in the region of 6 million tons. Chemical analyses show that the silica sand samples examined contain over 98 per cent SiO_2, less than 1 per cent Al_2O_3 and less than 0.50 per cent Fe_2O_3 and TiO2. The sands are fairly well graded. The silica sands in the area are at present mined for use in the glass and ceramic factories. It is also proposed to establish a sheet glass factory in the island, (See Fig. 27). The sands are normally associated with heavy minerals but these occur in minor amounts, and objectionable impurities could be removed by beneficiation.

A deposit of silica sand also occurs in the Jaffna peninsula extending from near Vallipuram in the north to Ampan in the south (Fig. 28). The deposits which are well developed sand dunes cover several hundreds of hectares. The reserves available could be classed as very large.

Quartzites are well developed in the island and they occur mainly in the highland areas. The pure quartzites are generally coarse, granular, or massive whitish rocks in which no foliation or bedding is visible. In the felspathic varieties kaolinised felspar is present which often is stained and give the whole surface of the rock a brownish appearance. Quartzites are not utilized for any local industry in the island although the pure varieties may be considered for use in the ceramics and allied industries. Very good quartzites suitable for industry occur in the Balangoda area. Chert which is a finely crystalline siliceous material occurs at various points in the island. It could be used as an ornamental stone. Chert deposits are common in the Ambalangoda area.

High quality crystal quartz is used in precision instruments. Electronic grade quartz crystal occurs in Brazil. The use of silicon (SiO_2) in alloy form, primarily ferro-silicon, is firmly established in the iron and steel industry. One of the largest uses for silica sand is in making glass for which purpose both chemical composition and grain size are important. Silica is widely used in fibre glass manufacture and in the ceramics and allied industries.

Silica is used in refractories, building products, abrasives, moulding sands, fillers and a variety of other products. In Sri Lanka silica is mined (vein quartz and silica sand) mainly for use in the glass and ceramic industry and for use as a moulding sand and abrasive material.

FELSPAR

Felspar is a general term used to designate a group of closely related minerals, consisting essentially of aluminium silicates in combination with varying proportions of potassium, sodium and calcium. It is the principal rock-forming material, and the main species are orthoclase or microcline ($K_2O.Al_2O_3.6SiO_2$), Albite ($Na_2O.Al_2O_3.6SiO_2$) and anorthite ($CaO.Al_2O_3.2SiO_2$). Albite and anorthite are the end members of a continuous compositional series known as the plagioclase felspars. The potash and the soda varieties are of commercial importance.

Microcline felspar (potash felspar) occurs in pegmatites in various parts of Sri Lanka, such as Rattota, Talagoda, Kaikawela, Namaloya and Koslanda (Fig. 28). In Sri Lanka felspar is chiefly used in the ceramics and glass industries and mining of felspar is carried out in the Matale area. The largest deposit of felspar is in Owella Estate (Kaikawela), and the Ceylon Ceramics Corporation has commenced mining this deposit. Drilling investigations carried out by the Geological Survey Department revealed that the Owella felspar is an extensive and commercially valuable deposit. A number of drill holes put down in the area showed that felspar occurs to more than 200 metres from the surface. Weathered felspar occurs to a depth of about 12 metres and from this point downwards hard felspar is encountered. At depths the felspar occurs with other minerals such as quartz and mica. Fluorspar has also been observed to be present. The chemical analysis of felspar is presented in Table XXXII. The reserves available at Owella are fairly large and may be estimated to be over 3 million tons. The deposit is worked at present and supplies felspar to a number of industries. Felspar also occurs at other places, and deposits in the Talagoda area have been worked for a number of years. The Talagoda deposit does not appear to be promising for large scale mining of felspar. Table XXXIII is presented to show the locations of some felspar deposits which have been identified during geological surveys.

TABLE XXXII

COMPOSITION OF FELSPAR - SRI LANKA

Constituents	Owella	Talagoda	Koslanda
SiO_2	64.15	64.67	65.02
Al_2O_3	18.74	18.35	18.92
Fe_2O_3	0.06	0.10	0.08
TiO_2	tr.	-	-
CaO	0.35	tr.	tr.
MgO	0.04	-	-
Na_2O	2.80	0.20	0.34
K_2O	13.67	16.65	16.05
Total	99.81	99.97	100.41

Geological Survey Department
Colombo 2.

Felspar is used principally in the manufacture of glass, pottery, vitrified enamels and special porcelain. Less important uses include its employment as a flux or binding agent and as an ingredient in scouring soaps and in artificial teeth. For high class products it is generally considered that felspar should not contain more than 0.01 percent iron oxide and that for most varieties of colourless hollow ware the limit is about 0.03 per cent. These limits make it desirable that every effort should be made during the dressing of the felspar to remove iron bearing minerals or iron staining. In Sri Lanka climatic conditions are such that iron staining is very common

TABLE XXXIII

LOCATIONS OF FELSPAR PEGMATITES

SHEET	LONGITUDE Degs.	Mts.	LATITUDE Degs.	Mts.	LOCATION
Aluthgama	80	05	06	18	Medakubura
	80	06	06	11	Mitiyagoda
	80	08	06	08	Tiranagama
Anuradhapura	80	27	08	13	Puliyankulam
	80	21	08	11	Payudikulam
Buttala	81	08	06	37	Kirindi Oya
Elahara	80	45	07	11	Talagoda
	80	45	07	47	Puswellagolla
Hambantota	81	10	06	16	Hemagodagala
	81	08	06	12	Keligama Wewa
	81	07	06	07	Hambantota
	81	10	06	10	Udamalala
	81	10	06	13	Tangalla
	81	15	06	15	Near Hospital
	81	16	06	16	Polgahawelana
	81	16	06	15	Gangarama
Haputale	80	46	06	35	Kiriwanagama
	80	47	06	42	Weralugasmankade
	80	52	06	34	Taniangama
	80	54	06	35	Pokunutenne Wewa
	80	56	06	34	Dalukgala
	81	03	06	34	Balaharuwa
	81	06	06	44	Wellawaya
	81	06	06	48	Kiriyagolla
Hatton	80	39	06	53	Melton
Kalaoya	80	09	08	08	Wirapokuna
	80	09	08	11	Diwulgahawewa
	80	10	08	19	Milagaspitiya Wewa
Kalmunai	31	43	07	24	Puliyankulam
Kurunegala	80	40	07	33	Pallatenne
	80	39	07	30	Kaikawela
	80	41	07	31	Rattota
Marichchukaddai	80	05	08	22	Maradanmaduwa Wewa
Nilgala	81	09	07	17	Kudalunuke
	81	11	07	18	Kitulewela
	81	11	07	17	Rerupitiya
Nuwara Eliya	80	53	06	56	Alutwela
	80	56	06	52	Mirahawate
Padawiya	80	57	08	44	Navatkulam
	80	57	08	40	Karakgehewa
Ratnapura	80	42	06	43	Pidiligannawela

Rukam	81	10	07	50	Mahaulpota
	81	12	07	46	Aralaganvilla
	81	10	07	44	Ulpottegama
	81	11	07	42	Elewakumbura
	81	23	07	39	Nela Ela
	81	24	07	39	Nela Ela
Timbolketiya	80	55	06	32	Indurugaswewa
	80	55	06	26	Weeraketidigane
	80	59	06	25	Nikara
	81	00	06	20	Weliwewa
	81	05	06	20	Ranawaranawewa road
	81	01	06	27	Angunakolapelessa
Tirukkovil	81	34	07	14	Aligalge Tank
	81	32	07	12	Dematapitiya
	81	32	07	14	Bokutuwe Kandure
	81	35	07	08	Kivulagama
	81	39	07	10	Madane Aru
	81	44	07	09	Ambalamoya
	81	46	07	17	Ponnamveli Kulum
	81	49	07	11	Ammal Kulum
	81	49	07	06	Koraikalapukulam
	81	40	07	15	Muwangalawewa
West Minister	81	36	06	50	Hitigalarana
	81	45	06	59	Neugal Aar

Geological Survey Department
Colombo 2.

in felspar deposits and care has to be taken to remove these stains before the felspar is processed for industrial use. With the expansion of the ceramic industry it is important to locate good quality felspar deposits in order to maintain efficient supplies of raw material to industry.

GARNET

The name garnet is used to designate a group of silicate minerals where the minerals have similar physical properties but widely different chemical composition. Their only use other than as gemstones is as abrasives. Natural industrial garnet consists essentially of the variety almandite (iron aluminium silicate) which has desirable abrasive qualities. Almandite has a hardness of 7.5 to 8.0 and a chemical composition - $Fe_2O_3.Al_2O_3.SiO_2$. For commercial use garnet is normally crushed, ground and graded to various screen and micron sizes depending on the intended end use.

Garnets are chiefly found in metamorphic rocks, particularly schists and gneisses. The proportion of garnet present varies considerably, and it is generally not economical to treat rock with less than 10 per cent garnet. The U.S.A. produces very large quantities of garnet from metamorphosed igneous rocks for use as abrasive material. Garnet also occurs as alluvial deposits which have resulted from the weathering of parent rocks. In Sri Lanka garnet is a widespread mineral in the gneisses and granulites and some rocks contain nearly to 10 to 15 per cent garnet. However, recovery from rocks is not being carried out, and the garnet that is produced comes from the beach mineral sands. The beach sands of the southern coastal areas of Sri Lanka are rich in garnet and very large reserves are available for commercial exploitation. The beach sands in Dondra and Hambantota have been investigated in detail. The Dondra sands contain 9 to 24 per cent garnet. The Hambantota garnet sands are mainly concentrated in sand dunes and contain up to about 20 per cent garnet (Fig. 28). Kirinda is also an important locality for garnet sands. Small quantities of garnet sand have been produced in the pilot plant belonging to the Geological Survey from the heavy mineral sand concentrates of the Kaikawela and Polkotuwa areas. Garnet, however, is not produced at present in commercial quantities and the prospects for establishing a plant to produce garnet are promising especially in the southern parts of Sri Lanka where the beach sands are rich in garnet.

LIMESTONE

Geologically, the term limestone is applied to rocks of sedimentary origin which consist predominantly of calcium carbonate ($CaCO_3$). If they contain the double carbonate of calcium and magnesium, they are known as dolomites ($CaCO_3.MgCO_3$). Limestones range in chemical composition from almost pure calcium carbonate (such as the Miocene limestones of the Jaffna Peninsula) through magnesium limestones and dolomitic limestones to dolomites. Where the limestones are crystalline, they are referred to as marbles, eg. the Precambrian marbles of the Highland series. Chalk is a very fine grained material consisting of microscopic marine organisms, and whiting is finely ground calcium carbonate. Iceland spar is the name given to the water clear variety of the mineral calcite ($CaCO_3$). Coral and sea shells are also sources of calcium carbonate. Quicklime or calcium oxide (CaO) is produced by heating calcium carbonate, and hydrated lime ($Ca(OH)_2$) is the product of the reaction of quicklime and water.

The limestone deposits of the island fall into four main groups (Fig. 29):

1. Sedimentary limestone deposits of Miocene age (over 95 per cent $CaCO_3$).
2. Crystalline limestone (marble) deposits of Pre-Cambrian age ($CaCO_3$ variable).
3. Coral limestone deposits along coastal areas (over 95 per cent $CaCO_3$).
4. Shell deposits along coastal areas (over 95 per cent $CaCO_3$).

Sedimentary limestone deposits of Miocene age are best developed in the Jaffna peninsula where they occur as a hard compact limestone with a calcium carbonate content well over 95 per cent. These deposits which extend to great depths extend as far as Puttalam in the north-west coastal belt of the island. The overburden (red-earths) at some points (Aruwakalu Hill area) may be over 30 metres thick. The chief impurities in the limestone are varying amounts of clay and silica and traces of magnesia. Two cement factories producing nearly 650,000 tons of cement per annum are operating in the area using Miocene limestone as raw material. The two cement plants have an installed capacity of 940,000 tons per annum. The analyses of various types of limestone are presented in Table XXXIV.

TABLE XXXIV

CHEMICAL ANALYSES OF CALCAREOUS MATERIAL - SRI LANKA

Constituents	Shell (Hungama)	Coral (Akurala)	*Miocene (Puttalam)	Crystalline Precambrian (Kanadarawa)
SiO_2	1.15	2.00	0.82	-
Al_2O_3	0.41	3.40	0.52	-
Fe_2O_3	0.33	0.50	0.08	-
CaO	54.89	51.50	54.20	45.72
MgO	0.02	-	0.70	0.79
Loss on Ignition	43.15	42.70	43.68	-
Total	99.95	100.10	100.00	-

* Siliceous varieties are common in the Puttalam area.

Geological Survey Department
Colombo 2.

The crystalline limestones or marble are confined to the central hills and are associated with quartzites and other metamorphic rocks. They are generally found as narrow well defined bands which can be traced for many miles along the strike. In general they are more or less impure owing to the presence of various silicate minerals. In chemical composition the crystalline limestones vary from pure limestone through magnesium limestone to dolomites. The magnesium varieties are more abundant. Pure limestone deposits have been observed only at a few points (Kanadarawa), and these deposits are not of any commercial value.

The coral limestone is found at various points along the coast of the island, but these deposits are not of great importance. The best known coral beds are found along the south-west coast stretching from Ambalangoda to near Matara. The deposits consist of loosely-packed finger or stick coral with heavy blocks of massive coral. Coral deposits are also found overlying the Miocene limestone at the margins of the Jaffna peninsula. Other areas where coral beds have been recorded are Kalkudah, Kuchchaveli area and Delft island. The coral material is fairly pure limestone. Coral mining off-shore has caused serious sea erosion at several points along the coast.This activity has now been banned by the State. Coral is used for lime manufacture by the cottage industry located at several points along the coast.

Extensive deposits of sea shells occur at Hatagala (Hungama). These deposits stretch parallel to the coast and extend for about 3km and are approximately one to two km in width. The shells occur to a depth of 2 to 3 metres from the surface and are mixed with clay matter, silt and other impurities. The Hungama shell deposits have been worked over the years and it is estimated that the reserves are in the region of over a million tons. Chemical analysis of washed shell material from this deposit gives a $CaCO_3$ content of over 98 per cent. Large quantities of this material are transported to Colombo and other towns for the manufacture of lime. A modern lime plant has also been established in the area.

Limestone is principally used in the industry, in blast furnaces and steel works and in agriculture. Lime is used as a metallurgical flux, in the manufacture of alkali, glass, paper and calcium carbide; in water and sewage purification; in soil stabilization; and in the building industry in finishing lime, masons lime and mortar. Other industries using lime include textile and ceramics, the manufacture of bleaching powder, sugar, varnish and carbon dioxide, leather dressing, and the manufacture of sand lime bricks. Whiting is used in paints, rubber, ceramics and putty. Precipitated calcium carbonate is also manufactured from lime. Lime in one form or other is used in a number of other industries.

The Miocene limestone is the only locally available raw material for cement manufacture and this industry consumes large quantities of it. The Geological Survey Department has carried out extensive surveys over the Miocene limestone formations on several occasions to estimate the available reserves. With the expansion of the cement industry which now has production figures of 700,000 to 800,000 tons per annum, the Miocene limestone formations may have to be eventually reserved solely for the production of cement. The proved reserves at Kankesanturai and Aruwakalu are in the region of 100 million tons.

APATITE

Phosphate rock is a commercial term for a rock containing one or more phosphate minerals, usually calcium phosphate. Phosphate rock occurs as phosphatized limestones, sandstones, shales and igneous rocks. The majority of the known deposits are found in igneous (carbonatites) and sedimentary (phosphorites) rocks. The major phosphorus minerals of most phosphate rocks are in the apatite group and can be represented by the formula $Ca_5(PO_4)_3(F.Cl,OH)$ - for example fluorapatite, CaO 55.5%, P_2O_5 2.3%, F 3.8%, and chlorapatite, CaO 53.8%, P_2O_5 41%, Cl 6.8%. Phosphorus is one of the three major plant food elements, and phosphate rock is principally used for the production of fertilizer. Chemical analysis is usually reported either as per cent phosphorus pentoxide (P_2O_5) or as per cent tricalcium phosphate $Ca_3(PO_4)_2$ also known as B.P.L. (bone phosphate of lime). 1.0 per cent tricalcium phosphate is equivalent to 0.458 per cent P_2O_5 and 1 unit of phosphorous (P) is equivalent to 2.3 units of P_2O_5.

In recent years a considerable amount of phosphate exploration has been carried out in various parts of the world and the discoveries made have amply demonstrated the importance and value of applying basic geological methods to the complex problem of locating new phosphate deposits. Marine phosphorite deposits provide the bulk of the world's production of phosphate rock and, in general, can be mined more economically and are less difficult to process than apatite deposits of igneous origin. In addition, most existing fertiliser and chemical plants are designed to use sedimentary phosphate. This is particularly so of the plants in the Asian and Far East regions which obtain practically all their requirements of phosphate rock from relatively distant sources of supply, chiefly Tunisia and Florida.

In Sri Lanka, phosphate rock (apatite) was discovered by the Geological Survey Department in April 1971, at Eppawala (Fig. 30) which is situated in the north-central province (Kekirawa-Talawala Road) about 240 km from Colombo. The deposit is estimated to occupy an area of 7 sq. km The phosphate rock which is of the carbonatite type occurs in the form of a breccia on 6 hills rising to a height of 190 m above mean sea level (Kiriwelhena Hill). A detailed account of the Eppawala Carbonatite Complex has been given by Jayawardena (1976).

It is believed that the emplacement of the carbonatite complex had taken place along a deep fracture in the Precambrian crystalline basement. The apatite bearing crystalline limestone (carbonatite) is well exposed and the surrounding country rock includes granite gneisses, charnockitic rocks, marble, thin quartzites and biotite gneisses which belong to the Highland Series (Fig. 30). Drilling investigations undertaken by the Geological Survey Department have revealed that the deposit extends in depth to 125 m or more from the surface. Initial studies reveal a leached zone (apatite in a matrix of iron oxide - the phosphate rich ore zone) up to about 60 m followed by fresh carbonate rock with apatite. The apatite is

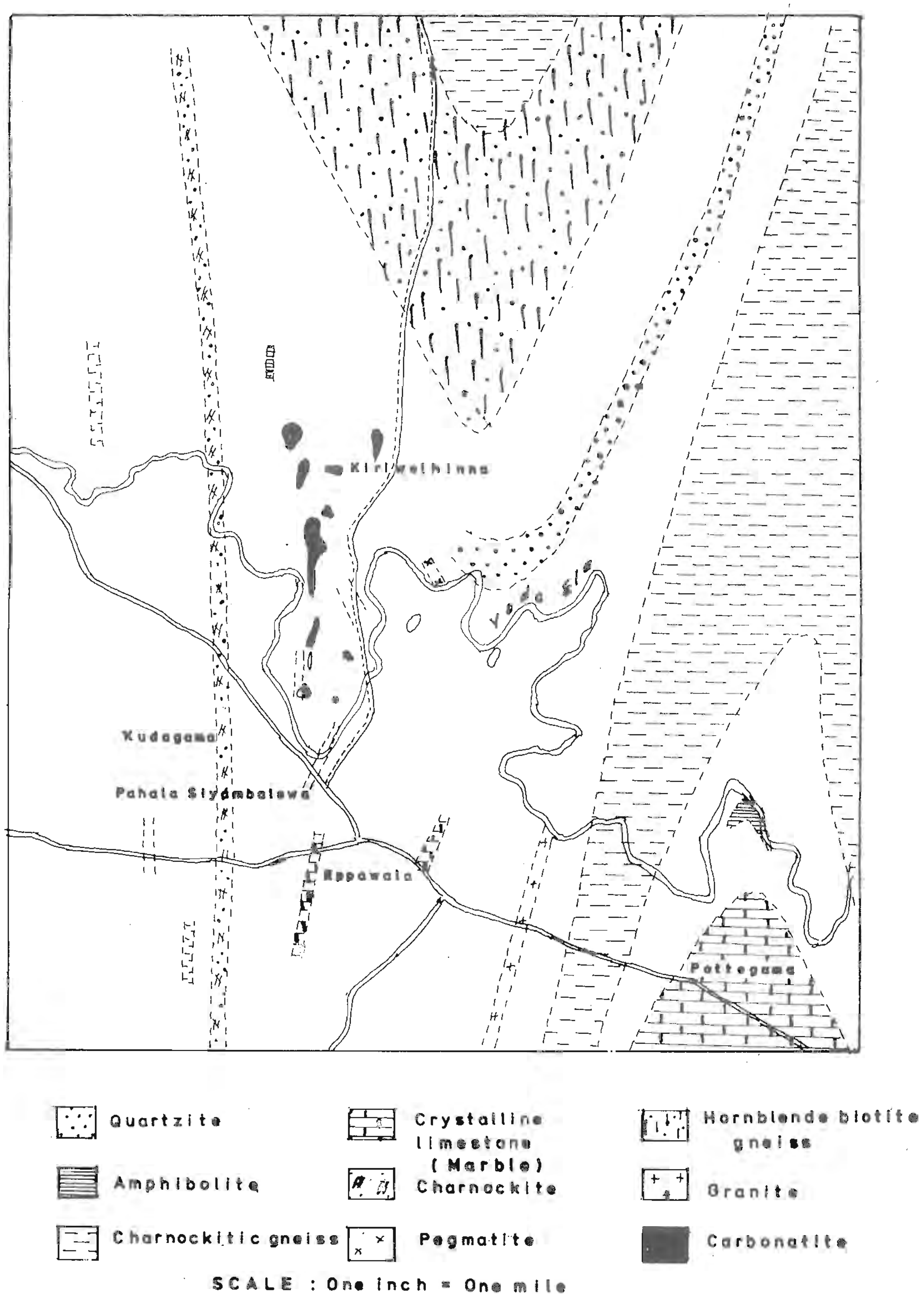


Figure 30. Geology of the Country Around the Apatite Deposit -Eppawala

classed as a chlorine-rich fluorapatite. The average P_2O_5 content is 35 per cent or more for the phosphate rich ore zone. Samples containing 39 to 40 per cent P_2O_5 content are not uncommon. The fresh carbonate rock at depth contain less than 10 per cent P_2O_5. Drilling investigations proved about 25 million tons of ore. Taking into consideration that the apatite occurs to great depths and covers a very wide area the inferred ore reserve may be in the region of 60 million tons. Table XXXV is presented to show the chemical analyses of the apatite from the phosphate rich ore zone.

TABLE XXXV

CHEMICAL COMPOSITION OF PHOSPHATE ROCK
(APATITE) - SRI LANKA

Constituents	Phosphate rich ore zone		
	EP/I/P	EP/2/P	EP/3/P
SiO_2	0.50	0.30	0.60
Al_2O_3	0.95	2.23	7.05
FeO	0.70	0.70	0.54
F_2O_3	3.72	2.30	7.70
TiO_2	0.78	0.78	0.60
P_2O_5	36.60	36.04	33.00
CaO	52.30	51.60	43.63
MgO	0.20	0.23	0.29
SrO	0.66	0.65	0.60
BaO	0.13	0.26	0.62
MnO_2	0.09	0.08	0.19
F	2.40	2.43	1.74
Cl	0.88	1.04	0.98
ThO_2	0.02	0.03	0.01
H_2O^+	1.46	2.65	3.60
Total	101.39	101.32	101.15
Less O for Cl and F	1.23	1.34	1.08
Total	100.17	99.96	100.07

MINERALOGY - Apatite (primary) insoluble, Francolite (secondary apatite) partly soluble, Martite (secondary iron) Rutile and goethite.

Geological Survey Department,
Colombo 2.

The Eppawala phosphate rock (apatite), even when finely ground, does not provide much available P_2O_5, and its use as a fertilizer is therefore limited. The rock consists principally of tricalcium phosphate which is insoluble and therefore cannot be used by plants. By acidulation a large proportion of the material can be converted into the monocalcium phosphate (superphosphate), a soluble form which could be absorbed by plants. Superphosphate could be produced by mixing sulphuric acid with finely ground phosphate rock. The mixture reacts to form superphosphate with 16 to 20 per cent available P_2O_5. Triple phosphate is a much more concentrated fertilizer which contains from 45 to 50 per cent available P_2O_5. Triple phosphate is made by the action of phosphoric acid on the phosphate rock. The largest consumer of sulphuric acid is the superphosphate industry. A number of research institutions have been engaged in studies connected with the utilization of the Eppawala apatite rock for the manufacture of both thermal and water soluble phosphatic fertilizer. The main drawback in manufacturing water soluble fertilizer is the inherent chemical character of the rock. The contents of chloride, iron and aluminium in the Eppawala apatite are high, and they cannot be removed economically by any physical beneficiation method. Detailed studies on the characterization of this rock were undertaken by the International Fertilizer Developement Centre in Alabama, USA, in 1979 as part of a research programme to assess the Eppawala rock for the manufacture of high analyses and thermal phosphate fertilizer. The mineralogical composition of the Eppawala apatite is listed in Table XXXVI. The high apatite content indicates that the rock is a high grade ore. It is seen that apatite occurs in two distinct varieties - a coarse crystalline chlor-apatite and a francolite type apatite (carbonate apatite). A secondary phosphate mineral, crandalite, is also present. A complete chemical analysis of a representative sample of Eppawala rock is given in Table XXXVII.

Although the Eppawala apatite is a high grade ore (36 per cent P_2O_5) it is not suitable for conventional acidulation processes for the manufacture of high analyses phosphatic fertilizers such as di-ammonium phosphate, triple or superphosphate. The high chloride content (average 1.1 per cent), and high R_2O_3 content

TABLE XXXVI

THE MINERALOGICAL COMPOSITION OF EPPAWALA PHOSPHATE ROCK (BRECCIA)

MINERAL COMPONENT	MODAL PERCENTAGE
Chlor-Apatite (coarse crystalline)	45.50
Francolite (Carbonate Apatite)	41.50
Crandalite (Hydrated Aluminium Phosphate)	5.10
Goethite and Hematite	4.60
Ilmenite	1.30
Quartz	0.80
Wad (Manganese Oxide)	0.70
Wavellite (Hydrated Aluminium Phosphate)	Trace
Total	99.10

After - IFDC studies 1979, Alabama - USA.
SMDDC

TABLE XXXVII

CHEMICAL ANALYSIS OF EPPAWALA PHOSPHATE ROCK (BRECCIA)

CONSTITUENT	WT. PER CENT
CaO	48.5
P_2O_5	36.4
Cl	1.1
F	2.6
CO_2	1.2
Na_2O	0.14
MgO	0.20
Al_2O_3	1.90
Fe_2O_3	4.80
SiO_2	0.80
MnO_2	0.67
TiO_2	0.66
SrO	0.38
BaO	0.15

Trace elements detected are - Cr, Cu, As, U, Cd, V and Hg.
After - IFDC studies 1979, Alabama - USA.
SMMDC

(Fe_2O_3 + Al_2O_3; average 7–8 per cent) are the major drawbacks in the utilization of this ore. The high chloride content gives rise to serious corrosion problems in plant and machinery and the high R_2O_3 content retards the filtration process during conversion of the rock to phosphoric acid by reacting with sulphuric acid. The international standards acceptable are less than 0.05 per cent chloride and less than 4 per cent R_2O_3.

Beneficiation studies have revealed that there is no practical method of beneficiating the Eppawala rock for acidulation and thereafter for the manufacture of phosphatic fertilizer by conventional technology. Due to the unsuitability of this rock as a feed material in acidulation, its suitability for direct application, specially for perennial crops, was studied. The Central Agricultural Research Institute of Sri Lanka carried out field trials with ground Eppawala rock in comparison with imported phosphate rock. The citric acid solubility of the Eppawala rock is about 2 per cent and that of the imported material is about 6 per cent. The Eppawala rock ground to a particle size of 100 mesh BSS was found suitable for direct application in tea plantations and in most of the rubber plantations. The rock, therefore, is crushed and ground, and approximately 15–18 thousand tons of the material is supplied to the Fertilizer Mixing Industry. This amount would be doubled in the near future.

There are a number of methods available for the manufacture of phosphate fertilizer. Many of these, however, cannot be applied to the Eppawela rock phosphate as it is a deposit without parallel in the world. The main types of fertilizer which could be manufactured include the Rhenania type phosphate, Fused Magnesium Phosphate and High Analyses Phosphatic Fertilizers. For the manufacture of the Rhenania type phosphate, phosphate rock, soda ash and silica are mixed and sintered at temperatures between 1000–1200^{o}C, and the apatite is converted into a product with varying amounts of P_2O_5. The sintered product is in the form of granules, and the total P_2O_5 content in the final product is around 26 per cent. Fused magnesium phosphate fertilizer could be produced by the fusion of Eppawala rock with serpentinite (available in the Uda walawe region) in a furnace at a temperature of about 1400^{O}C and then quenching the molten material in water. The final product is magnesium phosphate. The process has been known for over 30 years and it is adopted in a number of countries including Japan.

Both types of fertilizer mentioned are now considered to be uneconomical to manufacture on a commercial scale due to the high energy costs in producing fusion temperatures of 1200-1500^{O}C. Thermal phosphates are not water soluble but soluble in citric acid. These therefore have limited application and their effectiveness as a fertilizer is dependent on the pH of the soil.

High analyses phosphatic fertilizers include Single Super Phosphate (SSP), Triple Super Phosphate (TSP), and Phosphoric Acid (PA). Single Super Phosphate is manufactured by a rock-acid reaction in a mixer. The main drawback in its manufacture on a commercial scale is its low P_2O_5 content adding up to higher transport costs in comparison with a product like TSP which has, on an average, 50 per cent P_2O_5. The TSP is produced by reacting phosphoric acid with phosphate rock and denning and curing the product. Results obtained with the Eppawala rock have been very promising, the P_2O_5 availability in the product being in the region of 91.1 per cent.

Recent studies by a foreign firm have been successful in identifying a method that might prove commercially acceptable for overcoming the high chloride and R_2O_3 content in the Eppawala apatite and thereafter converting the rock to phosphoric acid by the conventional wet processes. The process does not require any physical beneficiation thus utilizing the entire rock for acid production (Jayawardena 1983). In this connection, the state intends to identify a foreign collaborator for the overall development of the Eppawela apatite deposit.

Most marine phosphate deposits have been classified broadly into geosynclinal and platform varieties. The phosphorite lithofacies was first recognised by Russian Geologists during the early 1930's (Kazakov 1937). The frequent association of phosphorite with black, carbonaceous or bituminous shales of mudstones, cherts (or other siliceous sediments), as well as with various carbonate rocks provides an effective aid to phosphate exploration. This assemblage characterises geosynclinal phosphate deposits. The platform phosphorite lithofacies comprises sandstone, carbonate sequences, calcareous shales, siltstones and evaporites. Some deposits are associated with glauconite and arenaceous - clayey sediments. Indirect prospecting techniques have also been used in phosphate exploration.

The most useful of the indirect methods depends upon the uranium content of phosphate rock which in marine phosphorites ranges from 0.005 to 0.02 per cent. Phosphorite together with certain black shales is thus significantly radioactive compared with most other sedimentary rocks.

The only large fertilizer complex in the island is the urea plant situated at Sapugaskanda. The nitrogenous fertilizer is manufactured from Naptha obtained from the Ceylon Petroleum Corporation. The island's demand for urea is about 150,000 tons per annum.

GEMS

Sri Lanka has long been renowned for its gems. In the scriptures, reference is made to gems being brought from Ceylon to the Court of Solomon. The 'Mahawansa', the great historal record of the island, refers to the singular reputation of the island for its gems. Several Greek writers of the first and second centuries refer to the reputation of Sri Lanka for its precious stones. From about the fourth century to the eleventh century the Arabs and the Persians exercised a great influence over the trade of the island. The Venetian traveller Marco Polo, in the thirteenth century, visited Sri Lanka on his homeward journey from China and in his book he mentions the gems of the island. He also records that he found the Moors, the descendants of the Arabs, in undisputed possession of the gem trade of Sri Lanka. It is also believed that Sinbad's Valley of

Gems in the Arabian Nights is probably the Ratnapura Gem fields. Sri Lanka has therefore been reputed for its gems since early historic times.

The main gem bearing area of Sri Lanka which has been known for centuries comprises a series of parallel ridges separated by longitudinal valleys and situated in the Sabaragamuwa Province (Fig. 31). To this day the main gemming fields in the island are confined to this area which covers nearly 1500 sq. km. The areas in the vicinity of Avissawella, Ratnapura, Rakwana, Pelmadulla and Balangoda have supported the most actively worked gem pits in the island for a number of decades. This region has supplied to the market some high-priced blue sapphires, star sapphires and cat's eyes. Ratnapura (meaning city of gems) is the main centre of the gem

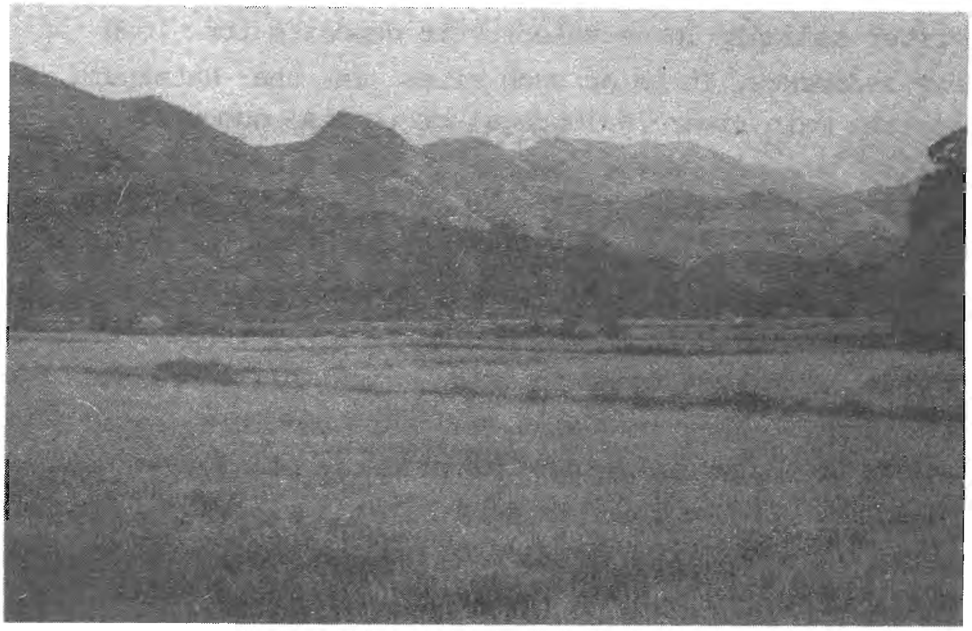


Figure 31. View of Gem Bearing Valley from Ratnapura-Pelmadulla Road

industry. Outside the main gem bearing area there are isolated gemming grounds of which Okkampitiya and Elahera are noteworthy. Other areas include Nuwara Eliya, Horton Plains, Hatton, Kandy, Matara, Hambantota, Uda Walawe and many other localities throughout the Precambrian of the island.

The Sabaragamuwa catchment basin (drained by the Kaluganga) comprises an area of over 4500 sq. km. The region is composed entirely of Precambrian rocks which are deeply dissected by a valley system. The main rocks exposed include garnet - sillimanite - graphite schists, quartzites, marbles, dolomites, garnet granulites, gneisses of various types, charnockitic rocks, and pegmatites. It is interesting to note that quartz of very high purity (99% SiO_2) occurring in the form of veins is confined to this area and is of economic value. The quartz, milk white in colour, occurs on hill slopes in the form of very large boulders. The Ratnapura region receives the highest rainfall in the island (320 - 508 cm) and is subjected to severe flooding during the wet seasons (See Fig.6).

When a river suddenly loses velocity it deposits its load of coarse and heavy sediments. It is at such sites in the Ratnapura valleys, either in the main river (Kaluganga) or in its numerous tributaries, and usually in old river channels and flood plains that the gemstones are found today mixed with gravel in the alluvial deposits.

The precious stones of Sri Lanka, with the exception of the moonstone (Meetiyagoda), some tourmalines, corundum and a few garnets which have been found in situ, are all obtained from old alluvial deposits. They represent the indestructible residual debris brought down from the high ground as products of degradation of the rocks. They may also be found embedded in gravel layers and sand in the beds of ancient rivers, in valley bottoms, in the beds of abandoned tributaries, in alluvial terraces and in talus accumulations at the foot of hills. All gem minerals are undoubtedly a part of the rocks of the country in the vicinity of which they are found provided they have not been transported for great distances. Fig. 32 is presented to show the principal gemming areas in the island. These are the better known areas but gems have also been found in many parts of the island in Precambrian terrain.

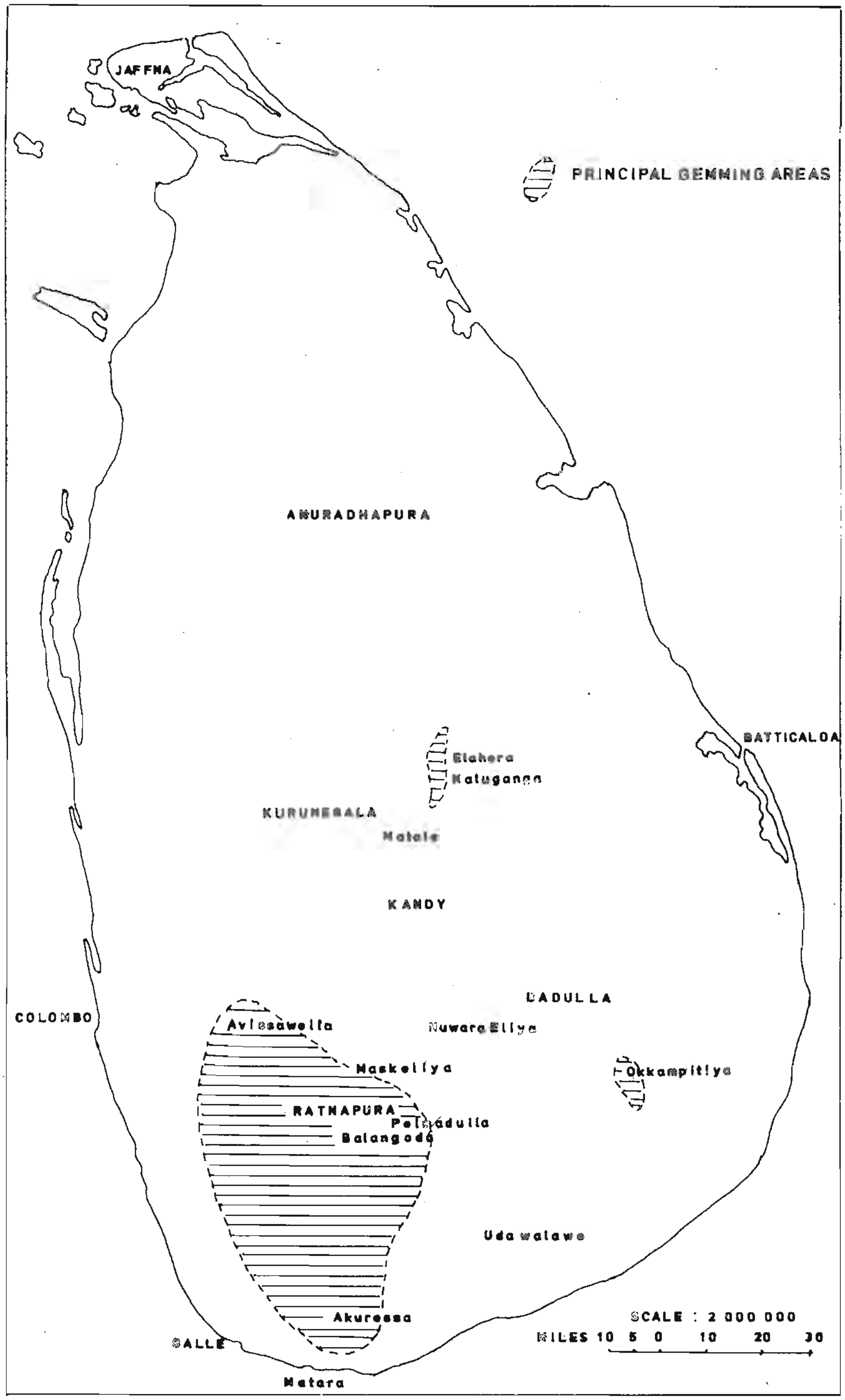


Figure 32. Main Areas of Gem Bearing Gravel - Sri Lanka

The succession of formations observed in the gem fields differs according to whether the deposition of alluvium took place in flood plains, in wide flat bottomed valleys, as residual gravel on hill slopes, as fan type gravel occurrences at foot hills, or as gravel stretches in abandoned hill streams. Gravel formations with gem material have also been observed in decomposed material overlying concealed pegmatite dykes. In the succession of formations in a typical gem pit three categories may be recognised (Fig:33):

(i) Superficial layers of soil, either lateritic or peaty, overlying sandy and clayey material. The clayey material

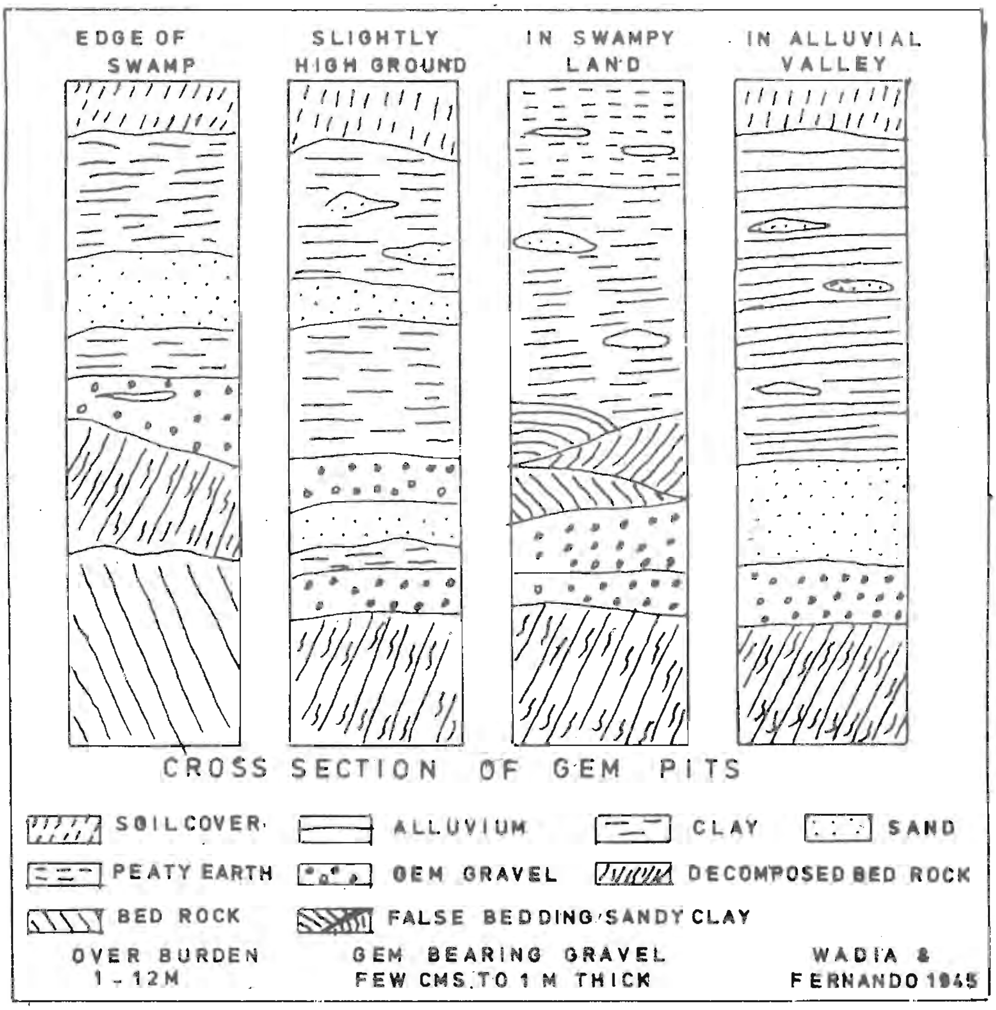


Figure 33. Succession of Formations in a Typical Gem Pit - Sri Lanka

is in parts kaolinized. The thickness of this formation which is virtually the overburden varies considerably and is in general 1 - 2m thick.

(ii) A layer or several layers of pay-gravel usually of lenticular shape. This is the gem bearing gravel. The miner refers to it as the 'illam'. The illam layer is a few cm to about a metre in thickness and may be encountered at shallow depths (3m) or at depths of up to 12m or more.

(iii) The next formation is the decomposed rock which is normally kaolinized and micaceous. The decomposed material is termed the 'Malawa' by miners. In pits where more than one 'illam' or pay-gravel is struck, the lower ones are the more prolific in gems. All gem pits should theoretically end work on striking the 'malawa' layer or decomposed rock.

Apart from their economic value as the carrier of the principal gems the 'illam' gravels are highly interesting from a petrological and mineralogical point of view. Once the gems are recovered after washing, the gravels are discarded. This discarded material is termed 'Nambuwa' by the miners, and up to recent years light coloured corundum sometimes in crystal form (semi transparent corundum), were discarded. The earlier discarded corundum is termed "Geuda" locally, and certain types are now collected and heat treated to enhance the blue colour. The most abundant constituent of gem gravel is quartz in well rounded pebbles. The gem miner has come to regard these quartz pebbles as an infallible guide to the presence of gemstones in the field and uses this association in his search for pay-gravel. Besides quartz and the ornamental stones, including a variety of rare gem minerals, the gem gravel contains a number of grains and crystals of the rare earth minerals - compounds of thorium, uranium cerium, yttrium, niobium titanium, beryllium, zirconium and others. In regard to the content of gems in the pay gravel, there is a notorious uncertainty; some pits may draw a blank while others, perhaps only a few metres away, may yield very highly priced gems.

No detailed work has been attempted on the origin of gems in Sri Lanka. Adams (1929) considered that they are the constituents of the associated crystalline rocks. Katz (1972) states that the Ratnapura-type deposits were derived from cordierite gneisses and associated rocks. Wadia and Fernando (1945) and Coates (1935) advocated a pegmatitic origin for some of the gem varieties. Dahanayake (1980) considered that most of the gem varieties in the Ratnapura and Elahera areas are found associated with garnetiferous gneisses and skarn-type marble deposits.

Deraniyagala (1958) studied a number of fossils embedded in the gem-gravels of the Ratnapura area and his work indicates a Pleistocene age for the majority of the Ratnapura gem gravels. Wadia and Fernando (1945), however, state that the gem gravels do not all belong to the same age since erosion of gem bearing rocks proceeded continuously through succeeding geological ages. Zircons from Sri Lanka gem gravels have been dated at 560 million years. This however, does not mean that the gem gravels were formed during this period. Only a few instances are known of raw gem-stones occuring in rocks. There is, however, no doubt regarding the pegmatite habitat of topaz, tourmaline, beryl, chrysoberyl, amethyst, sphene and zircon, and most of these minerals, some approaching gem quality, have been extracted from this source. In several Ratnapura fields, gems are found under conditions which point to their being not far removed from the source of origin, but as the rocks are buried under a deep mantle of decomposed material they cannot be examined from pits or trenches. The majority of the rare-earth minerals that are known have come to light from their association with gem gravels. Their habitats are unknown. It is therefore logical to assume that weathering has exposed deeper parts of the mountain folds of the Island where mineralization has taken place. This is the result of millions of years of sub-aerial weathering of the highly folded landmass which must have been very different in appearence from what we see now. This weathering process in previous geological ages has exposed pegmatite veins and rocks containing a number of minerals of gem quality. These outcrops of pegmatite material including rocks have been subjected to a renewed process of weathering through countless ages, and the gradual sorting action of the water has resulted in the deposition of gem gravel and sands which have subsequently been sealed by a covering of alluvial deposits as in the Ratnapura valleys.

The commonly used mining methods where only manual labour is employed, although primitive, are time honoured and belong to ancient Sinhalese tradition. They involve little capital outlay and are quick and efficient. Three methods are used to recover the gems. They are: Placer mining, Gemming by pits, and Gemming of river beds by dredging.

Placer mining: When the pay-gravel is in superficial soil deposits within about 2m of the ground surface, the land is worked by open cast mining after clearing the surface. The material obtained is sorted out and washed in the usual manner in running water or in improvised sluices.

Gemming by pits: When the overburden is of considerable depth the most common method is to sink pits. The size of the pit is normally 3 - 5m square, divided into 2 chambers by a partition, one for working and excavating the gravel and the other for de-watering the sump (Fig.34). In some of the deeper pits, lateral drifts are also driven in all directions from the bottom of the shaft. The gravel is washed in shallow baskets made of rattan or wicker. Very few pits use mechanised contrivances. However, in recent years, a high degree of mechanisation has been introduced in some mines. This is the most popular method of gem mining in the Sabaragamuwa mining area.

Gemming of river beds by dredging: Gemming in beds of rivers is less common and requires the assistance of experienced dredgers (Wadia and Fernando 1945). An obstruction is put up across a stream to increase the flow of water at a selected spot. Long handled showels up to 40 feet or more in length are employed by six to eight men to drag the river bed at a point upstream of the dam till the illam layer is exposed after some weeks' work. The overburden is carried away by the agitated water and the coarse sand and gravel (illam) is raked up and allowed to collect in a low ridge. This partly sorted illam is then removed from the water in baskets to the bank of the stream and the usual process of gem washing carried out.

Figure 34. View of a Gem Pit - Pelmadulla

The gemming season is normally from December to May, the drier part of the year. Under the existing mining law a licence to mine must be obtained from the State. No licences are issued for prospecting for gems. Applications for lease of gemming rights are granted on permits and the payment of an annual fee. Sometimes gemming rights are given after calling for tenders from the public, a reserve price or upset premium being fixed before hand. Seldom are gemming rights in Sri Lanka leased on a royalty or rent basis. The actual work of mining in a property is carried out on a remarkable system of co-operative sharing of labour, expenses and profits. The output of the gem pit is distributed as follows:

Ground rent of owner	.. 20 per cent
Leasee's or Licence-holder's share	.. 10 per cent
Financier's share	.. 35 per cent
Diggers share	.. 35 per cent

In certain instances 10 per cent of the financier's share goes for the purchase of a water pump and a further 10 per cent for timber. This system of sharing is unique in a highly uncertain business. It has maintained the gemming industry in a healthy state for centuries and has checked over production. The system of tenure under which land is held in Sri Lanka makes mechanical, large scale operations unworkable in practice.

All mineral deposits that are mined are a constantly diminishing asset. This is true of the gem gravels of Sri Lanka. Exhaustion of gravels at a number of points is an indication that the Ratnapura gembeds will not be everlasting and that their extinction is only a question of time. New areas have, however, been found. In fact the entire Precambrian of Sri Lanka could be searched for gem gravel. Table XXXVIII is presented to show the main gem varieties in the gem gravels of Sri Lanka and Table XXXIX is a list of the rare gem minerals of the island as listed by Zoysa (1983).

Gem cutting in Sri Lanka up to recent years was done by machines of primitive construction operated by hand. No mechanical or electrical appliances were employed. During the past 5 to 7 years modern and up-to-date machinery has been introduced to the gem cutting industry and today machine cut gems of a very high quality could be obtained in the island.

In the period 1963 - 1968, 60,000 to 196,000 carats valued at Rs. 1.3 to Rs. 4 million were exported annually. The value varied with the quality of the stones exported each year, but these figures are perhaps not accurate as, in addition to exports, it is well known that gemstones are taken out of the country by illicit methods. The value of illicit exports has been estimated by various authorities at hundred to two hundred million rupees a year. The gemstone has two features, a very low weight and volume and a very high value, and these make it attractive to the smuggler. The problem of the illicit flow of gemstones is not peculiar to Sri Lanka and in certain other countries it is estimated that at times smuggling may account for as much as 75 per cent of the gemstones leaving a country.

TABLE XXXVIII

SRI LANKA GEM VARIETIES

Mineral	Gem Varieties
Corundum	Star Sapphire, ruby and star ruby, Yellow, Blue, Green, Orange, Pink and White Sapphire.
Chrysoberyl	Alexandrite and Cat's Eye.
Beryl	Aquamarine - Colourless, Pink, Yellow
Topaz	White and Yellow topaz. Blue green violet and red topaz (pale tints).
Tourmaline	Black, pink, rose-red, blue, brown, green varieties.
GARNET Pyrope Almandine Grossularite	Pyrope - deep red to black. Almandine - deep crimson, red to violet. Grossularite - honey yellow to brownish yellow, also known as Hessonite or cinnamon stone
Spinel	Spinel - deep red, green, violet.
Zircon	Brown, Green, Blue, red, orange and yellow varieties.
Quartz	Rock crystal, amethyst, rose quartz, smoky quartz, citrine (yellow) cat's eye quartz and star quartz.
Feldspar	Moonstone and amazon stone.

(After Herath, 1980).

TABLE XXXIX

OCCURRENCE OF RARE GEM VARIETIES IN SRI LANKA

Mineral	Star Varieties	Cat's Eye types	Colour change types
Garnet	X	–	X
Corundum	X	–	X
Spinel	–	–	X
Zircon	X	X	X
Andalusite	–	X	–
Apatite	–	X	–
Diopside	X	X	–
Enstatite	X	X	–
Euclase	–	X	–
Fibrolite	–	X	–
Ekanite	–	–	X
Kornerupine	–	X	–
Scapolite	–	X	–
Other rare minerals present include morganite, Axinite, Danburite, Epidot, Iolite, Peridot, Sinhalite, Sphene and Taaffeite.			
(After Zoysa 1983)	X occurs in Sri Lanka.		

With a view to developing the gem industry of Sri Lanka, the government established the State Gem Corporation in November, 1971. The Corporation now handles the issue of permits for gemming and buys cut and uncut gems. All exports of gemstones from the Island have to be channelled through the Corporation. A modern gem testing laboratory has been established, and the Corporation has already made a significant contribution towards establishing a s[illegible] gem industry in the island. In 1971 gem exports from the Island were valued at Rs. 3.5 million . In 1978, 7 years after the establisment of the Corporation, gem exports were in the region of Rs. 600 million. This indicates the increasing confidence owners of gems were beginning to have in the Corporation.

SILLIMANITE, WOLLASTONITE AND CORDIERITE

Sillimanite is a silicate of alumina ($Al_2O_3.SiO_2$) with a theoretical composition of Al_2O_3 63.1% and SiO_2 36.9%. Kyanite, sillimanite and andalusite have the same chemical composition but differ in crystal structure and physical properties. On heating to around 1500^oC all the above minerals undergo conversion to mullite ($3Al_2O_3.2SiO_2$) and vitreous silica, and in the calcined form they are used in refractory products. Sillimanite occurs in a variety of rock types in Sri Lanka. Appreciable quantities of sillimanite are found in the garnet-sillimanite-graphite schists which are well developed in the central highlands. Sillimanite also occurs in the beach mineral sands, and the Pulmoddai sands contain up to 1 per cent sillimanite. When the Pulmoddai project becomes fully operational, over 200,000 tons of raw sand would be treated annually for the recovery of rutile, ilmenite and zircon, and about 500 - 600 tons of sillimanite could be recovered annually from this deposit. At present sillimanite is not produced in Sri Lanka. Sillimanite is mainly used in the refractories industry on account of its ability to withstand high temperatures. The material could also be used in the ceramics industry. Sillimanite is found in quantity in India, South Africa and Australia.

Wollastonite is a fibrous calcium silicate with the theoretical compostion SiO_2 51.70% and CaO 48.30%. In Sri Lanka wollastonite-bearing calc gneisses occur in the Ambalangoda and Galle areas. The wollastonite occurs as segregations of coarse wollastonite crystals in the calc gneisses. Although these rocks are distinctive they are limited in extent and cannot be considered to be of commerical value at the moment. Wollastonite has a high fluxing action to bring down the maturing point of ceramic bodies and can be used in low temperature once-fired products. Wollastonite is chiefly used in once-fired wall tiles. It is also used as a filler in paint, rubber and paper. Deposits of wollastonite occur in U.S.A., U.S.S.R and Finland.

Cordierite ($2MgO.2Al_2O_3.5SiO_2$) is a rare mineral. Cordierite bodies are used in the ceramic industry and the development of synthetic cordierite is achieved by using the raw materials kaolin, talc and alumina. In Sri Lanka cordierite occurs in appreciable quantities in the gneisses in the Gampaha and Avissawella areas. However, cordierite is not extracted from these rocks.

SALT

Sodium chloride (NaCl) commonly called kitchen salt is the commonest salt in sea water. The mineral salt, called halite, is characterised by its easy solubility in water, its distinctive taste, cubic cleavage and its crystal form. Salt is recovered from a variety of deposits: sea water, saline lakes, bedded salt deposits, and salt domes. In Sri Lanka salt is extracted from sea water by solar evaporation. The salt producing pans or salterns are located in three main regions and the State owned salterns are as follows:
Northern region - Elephant Pass, Kurunchativu, Kallundai, Irupalai.
Western region - Palavi, Mannar, Puttalam.
Southern region - Hambantota Maha Lewaya, Palatupana.

The National Salt Corporation operates the State owned salterns and a considerable amount of modernisation and improvement work has already been undertaken by the Corporation. The local demand for salt is in the region of 120,000 tons per annum and around 130 - 150 thousand tons are manufactured at present.

The Corporation also exports small quantities of salt to Africa and the Maldives. About 6,000 tons of gypsum are also produced. This material is supplied to the Ceylon Cement Corporation. An Epson salt plant is being established at Hambantota with a capacity of 1000 tons per annum. The product magnesium sulphate is sold to the Ceylon Fertilizer Corporation for use as a fertilizer. Although small quanitities of refined salt are produced by the Corporation, it has plans to establish a refined salt plant with foreign collaboration with an annual production of 20,000 tons which would be mainly for export. Salt is also supplied to the Paranthan Chemical Corporation for the manufacture of Caustic Soda and Chlorine.

The Corporation has commenced production of iodised salt to cater to the requirements of local hospitals and health centres. Possibilities also exist for the export of this product. The manufacture of P.V.C. is another project proposal by the Corporation. Other projects proposed include the establishment of a soda ash plant, conversion of gypsum to plaster of paris and chalk, and recovering magnesium sulphate from bitterns.

STONE, SAND AND GRAVEL

In the very earliest epochs, in what is termed the 'Stone Age', man used hard stones and from them fashioned their rough domestic tools and their weapons of war. In time, stone gradually gave place to metals. In Sri Lanka as in most other countries the value of stone had been recognized and there is evidence of stone work which goes back many centuries. Dimension stone and the magnificant carvings on stone are to be seen today in the remains of ancient ruined cities of the island.

In the present day, stone in various forms and sand are extensively used in the building industry all over the world. Stone which is specially cut or shaped for use in buildings and for other construction purposes is called dimension stone. Stone which is broken into required sizes is used in the construction of buildings and crushed stone is used as concrete aggregate and road-stone. In Sri Lanka the reserves of stone and sand are large and laterite is also used as a building stone and very large reserves are available.

Over nine-tenths of the Island is occupied by Pre-Cambrian Crystalline rocks, and except for a limited occurrence of Jurassic shales, the rest is covered by hard Miocene limestone. Granites, gneisses of various types, limestones and dolomites, and quartzites and charnockites are common rock types which are extensively developed in most parts of the country. The stone industry is one of the oldest industries in the country. Stone is used in Sri Lanka for building purposes, as road metal and as aggregate in concrete. Dimension stone and polished slabs are turned out in limited quantities. Grinding and pounding equipment is also turned out from stone for domestic use. Accurate estimates are not available as to the amount of stone consumed per annum but the quantities are very large. Stone is employed for building, engineering, roads and paving, and decoration and monuments. A variety of fresh rock is available in Sri Lanka for most purposes.

Very large quantities of sand are used in the building industry. Most of the sand is obtained from rivers which drain the Island. Good quality sand is available in unlimited quantities in the lower reaches of the major river systems. Accurate estimates of the amount of sand consumed are not available. The sands are mainly composed of quartz (over 90 per cent). Accessory minerals present include mica, ilmenite, rutile, garnet, monazite and other resistant primary minerals. Although little or no recognition is given to the sand, gravel and stone industry, it is one of the largest mineral based industries of Sri Lanka with a turnover valued at over 300 million rupees.

The composition of some minerals present in Sri Lanka are listed in Table XXXX.

SUMMARY

The non metallic minerals form an important group, and a number of industries have been set up using these mineral raw materials. Graphite, mica, gemstones and minor quantities of salt are exported. Graphite has been mined and exported since 1821. The reserves of mica are not very large. Clay materials in the flood plains of lower reaches of major river systems of the island and in other areas are being exploited by the cottage brick and title industry and the modern industry. Kaolin and ball clay are processed for use in the ceramics industry and silica and felspar are other raw materials that are mined. Large reserves of silica sands are available in the island for the glass industries. The Miocene limestone is mainly used in the manufacture of cement. There is also a proposal to set up a phosphate industry in the country, using the Eppawela apatite

TABLE XXXX

COMPOSITION OF SOME MINERALS IN SRI LANKA

Mineral	*Formula*	*Composition*
Kaolinite	Al_2O_3-$2SiO_2$-$2H_2O$	Al_2O_3 39.50, SiO_2 46.54 H_2O 13.96
Montmorillonite	(MgCa) C-Al_2O_3-$5SiO_2$ nH_2O	(variable)
Phlogopite	K_2O-$6MgO$-Al_2O_3-6 SiO_2-$2H_2O$	(variable)
Biotite	K_2O-6 (Mg. Fe)O-Al_2O_3 $6SiO_2$-$2H_2O$	(variable)
Muscovite	K_2O-$3AL_2O_3$-$6SiO_2$-$2H_2O$	K_2O 11.8, Al_2O_3 38:5, SiO_2 45.2 H_2O 4.5
Vermiculite	$22MgO.5Al_2O_3.Fe_2O_3.22SiO_2$ $40H_2O$	(variable)
Goethite	Fe_2O_3-H_2O	Fe_2O_3 85.50, H_2O 14.50 Fe content 59%
Magnetite	Fe_3O_4	FeO 31, Fe_2O_3 69. Fe Content 72.4%
Gibbsite	Al_2O_3-$3H_2O$	Al_2O_3 65.38, H_2O 34.62
Boehmite	Al_2O_3-H_2O	Al_2O_3 85, H_2O 15
Diaspore	Al_2O_3-H_2O	Al_2O_3 85, H_2O 15
Limestone	$CaCO_3$	CaO 56.1, CO_2 43.9
Dolomite	$CaCO_3$-$MgCO_2$	CaO 30.4, MgO 21.79, CO_2 47.90
Magnesite	$MgCO_3$	MgO 47.6, CO_2 52.4
Apatite	$Ca_3(PO_4)_2$	—
Fluorapatite	$Ca_5(PO_4)_3F$	CaO 55.5, P_2O_5 42.3, F3.8
Cholrapatite	$Ca_5(PO_4)_3Cl$.	CaO 53.8, P_2O_5 41, Cl.6.8
Quartz	SiO_2	SiO_2 100
Felspar (Microcline)	K_2O-Al_2O_3-$6SiO_3$	Al_2O_3 18.40, SiO_2 64.7, K_2O 16.9
Cordierite	2MgO-$2Al_2O_3$-$sSiO_2$	MgO variable (around 10%-Sri Lanka)
Sillimanite	Al_2O_3-SiO_2	Al_2O_3 63.2, SiO_2 36.8
Zircon	Zro_2-SiO_2	ZrO_2 67.2, SiO_2 32.8
Baddeleyite	ZrO_2	ZrO_2 100
Ilmenite	FeO - TiO_2	TiO_2 variable around 53% - Sri Lanka)
Rutile	TiO_2	TiO_2 100
Monazite	(La Ce) PO_4	Thoria content variable (9 - 10% - Sri Lanka)
Wollastonite	CaO-SiO_2	CaO, 51.7 SiO_2 48.3
Graphite	C	(variable) upto 99% Sri Lanka
Garnet (almandine)	$Fe_3Al_2(SiO_4)_3$	FeO 43.3, Al_2O_3 20.5, SiO_2 36.2

deposit. The Hambantota beach sands and sand dunes are very rich in garnet, the raw sand containing over 20 per cent of the mineral. The sands if processed to recover garnet could yield several tons per annum. Cordierite and wollastonite although present in the island cannot be considered deposits of economic value. Sillimanite could, however, be obtained form the Pulmoddai beach sands for the refractory products industry which has already been established. Very large quanties of sand, gravel and stone are used in the building industry and in various development projects. The non metallic mineral exports of Sri Lanka have had a positive impact on the economic development of the country through its contribution to the development of many industries.

CHAPTER 8

TOWARDS A MINERAL POLICY FOR SRI LANKA

The mineral system can be defined as a series of activities that begin with the location of resources in the ground and end with final consumption. Activities include the exploration for and the discovery of minerals, the extraction and processing, and the sale of the final product. The mineral system has a positive impact on the economy. It generates income and employment directly and indirectly. Even in a developing country like Sri Lanka the mineral system gives an impetus to the economic development of the country.

Mineral policy is the sum of government decisions and actions that influence the mineral system, and the ways in which the system itself affects the economy and society in general. Mineral policy covers more than the laws and regulations that directly influence mineral exploration, extraction and processing. Other policy elements include export-import permits, regional development funds, pollution control laws, taxation and social development programmes.

Sri Lanka is not a major world mineral producer. Mineral related activities, however, have profound effects on the lives of many Sri Lankans. The country is fairly rich in the industrial minerals or the non-metallic group of minerals. The first base-metal find in Sri Lanka is the recent discovery of the copper-magnetite deposit at Seruwila. There are also indications of the presence of precious metals in this mineralized zone at Seruwila. These, however, have to be proved with further detailed investigations. The serpentinite deposits at Uda Walawe (with traces of nickel) is of interest and worthy of detailed investigation. Future geological surveys may therefore have to be undertaken in the eastern mineralized area (the boundary between the Eastern Vijayan and the Highland Series). The discovery of the Eppawala Apatite deposit is also a major mineral find of recent years. The value of mineral commodities produced in Sri Lanka in the year 1982 was in the region of one billion rupees

The mining industry including the mineral based industrial units (mainly public sector industries) together with the cottage mineral industries (brick and tile, lime, and others) employ around 30,000 persons.

Sri Lanka will continue to depend on other nations for crude oil supplies and for supplies of coal for energy purposes, these being two important mineral raw materials which have to be imported. In the future, international factors will also have an impact on Sri Lanka's ability to derive increased benefits from minerals such as graphite and ilmenite and even gems, the bulk of which are exported. Such factors include the emergence of large trading blocs, resource-procuring strategies of other nations, international corporations, and increased competition from other producing nations. World demand for minerals, however, is expected to increase substantially in the years ahead. Based on these demands Sri Lanka can also increase her mineral output for export purposes and for expansion of the present and future mineral based industries. However, policies of Sri Lanka Governments will have a major influence on how this potential is realized.

Sri Lanka has established a number of mineral based industries operated by the public sector. The majority of these industries use local mineral raw materials, mainly the non-metallic minerals, and special mention may be made of the ceramic industry of Sri Lanka which has established itself utilizing every possible ceramic raw material of the island, and its products are of very high international standards. No industry based on local raw materials can, however, prosper unless the reserves and potentialities of the raw materials used are known and fully understood and the problems associated with their behaviour and use are solved. If the industries, established or proposed, are to progress, research and development facilities should be available. Industrial research and industrial development are not independent but inter-dependent. Efficient and continuous research along with quality control in the various stages of production are vital factors in achieving the goal of increased production and higher quality.

... policy should first seek, whenever possible, to increase ...versification and growth of the national economy based on minerals. This would involve not only increased mineral processing but also more mineral-based manufacturing prior to export and strengthening ties with other sectors of the economy.

Where increased mineral processing and mineral based manufacturing are not feasible, desirable, or economic, and the unprocessed mineral has to be exported, mineral policy should ensure that the country obtains the best possible terms for the export.

Under certain circumstances, it may be desirable to control the rate at which economic diversification or increased financial returns are sought from minerals. For example, mineral policy should seek conservation for future use or stretched-out-development where there is a possibility of depletion. Whatever direction mineral policy may take in the future, the first consideration must be to assure an adequate supply of minerals, whether from domestic or foreign sources, to meet the country's needs. The overall balance and emphasis of policy will change over time. Mineral policy must, however, maintain its general goal of obtaining for the island, the best benefits from minerals.

A geological survey obviously has a very important role to play in the search for mineral wealth. The nature of this role is determined largely by the local political and economic environment, and may range from the provision of background information to stimulate and support the activities of the private sector to a major direct involvement in prospecting.

Very large amounts of capital are required for the development of a mine and the exploitation of minerals. The risks of failure are high and revenues derived from mining and the export of minerals fluctuate sharply. Mining should therefore be accorded a special status in relation to other economic development projects, and this has been recognised in many countries, including developing countries. This recognition is embodied in their mining codes or mining enactments. Quite apart from the direct costs in the development of a mine and its ancillary facilities for treatment and processing of the ores, there is also the important matter of the cost of utilities. These include power, adequate supplies of water, ports and handling facilities, and their costs can be very much more than the cost of the mine and the processing plant. Mining therefore requires massive capital and the financial returns from such investments are not assured. Although exploration expenditure generally amounts to only a small part of total project cost, it constitutes the high-risk component of the project, and in most cases the expenditure is incurred without a proven viable deposit.

The extent, rigor and cost of preproduction activities in mineral resource development are far greater than those required for the development of other industries. This means that there has to be extremely large capital investment coupled with high attendant risks, and this has led to the industry being dominated by corporate giants capable of spreading risks over large geographic and commodity areas.

Up to very recent years there have been no private prospecting companies in Sri Lanka and the Geological Survey Department has been responsible for all activities connected with mineral exploration in the island. With the coming into operation of the new Mines and Minerals Law of 1973, the absolute ownership of all minerals is vested in the Government of the Republic of Sri Lanka, and the granting of prospecting and mining licences is the responsibility of the Director, Geological Survey. With the operation of this act there has been a rationalization of mining and also increased mineral production, with more revenue accruing to the State from mining rents and royalties. The implementation of this law would also help in the conservation of the island's mineral wealth and initiate mining activities for the benefit of the nation as a whole.

Mineral sector development in any country constitutes only one element of total national development and must therefore be structured to fit into the framework of the total economic plan. As a first step in formulating a national mineral policy a country must decide whether to develop its mineral sector on the basis of a private, public, or mixed system. In the case of State run mineral development (as in Sri Lanka), success will depend wholly on the effectiveness with which the State can plan, commit financial resources, provide managerial and technical expertise, and secure markets. Development under the private sector approach depends for its success on more detailed consideration of the respective responsibilities, privileges and obligations of private companies and the government.

Modern mining and processing methods have become so capital intensive that countries like Sri Lanka cannot expect to bring a sizeable project into operation on their own. Sri Lanka has therefore to decide whether it is able and willing to attract private capital (foreign or domestic) and the mining laws and the fiscal policies should be such as to encourage investment in mining and mineral exploration. Mineral legislation should provide the administrative framework for this purpose. In addition to the normal mining code, legislation should include a special taxation regime compatible with existing investment codes and social legislation. The taxation regime is perhaps the most important element of any national mining policy for it constitutes an important means for achieving many policy objectives.

It has been stated as a matter of policy that it is the Government's intention to create and maintain a favourable investment climate in order to encourage the private sector - both local and overseas based companies - to accelerate in partnership with the Government, the development and exploraton of Sri lanka's mineral resources. For example, the State has plans to develop the Eppawala apatite deposit (phosphate rock) for the manufacture phosphate fertilizer. This development programme is one of the biggest industrial development programmes to be launched by the State and would be undertaken in association with a foreign collaborator. The Ceylon Petroleum Corporation which divided the off-shore area into 13 blocks for the purposes of exploration work has also allocated most of these blocks to foreign companies to carry out exploration work on a production sharing basis.

Finally, it may be stated that the terms which any Government can offer or negotiate with concession holders depends primarily on how much competition for prospecting rights actually exists in the country. This will depend on the geological environment and the mineral potential of each country.

SUMMARY

Sri Lanka is fairly rich in the non-metallic group of minerals and a series of industries have been established based on mineral raw materials. These are mainly in the public sector. It is expected that the mineral policy in future will be reshaped to place greater emphasis on increased economic diversification and better financial returns from mineral development. Research and development by the state industrial research organizations, private and public sector industry, and universities should play a key role in mineral industry development in the country. The State should also frame the necessary laws to obtain the maximum benefits from available mineral raw materials. The mining laws and fiscal policies should be such as to encourage investment in mining and mineral exploration by attracting private capital (foreign and local).

CHAPTER 9

SUMMARY AND CONCLUSIONS

Geological surveys are a feature of government science and technology in practically every country in the world, and governments have generally found it necessary to establish a body to advise on mineral resources. But the geologist's and politician's views on how this can be done have frequently been in conflict. Governments usually seek quick answers to most problems and have not always taken kindly to the scientist's insistence on systematic progress. This is, however, not to say that a Geological Survey may ignore its primary economic responsibility to the State. The traditional function of the Sri Lanka Geological Survey is not yet complete; as much of the country remains to be mapped in adequate detail. Meanwhile new horizons are opening. Environmental geology, urban development, the geology of the continental shelf and slope, the integrated study of mineral provinces and mineralized zones or belts and the ever expanding application of geophysics and geochemistry and even satellite imagery are among the newer interests of the Geological Survey, including Quaternary geology a subject which is becoming an important area of activity and interest. It has been said that a nation's mineral wealth is not only a function of the original endowment, but also depends on the effectiveness with which such minerals as it might possess are sought for and developed. Substantial benefits can therfore accrue to Sri Lanka from a properly structured and administered Geological Survey Department.

In considering the island as a whole it is concluded that Sri Lanka is in possession of a number of non-metallic mineral raw materials upon which a series of industries have been established. Minerals on the ground represent resources which, depending on the market conditions and the technology of the time, may or may not be of economic value. Mineral deposits are considered an exhaustible resource; however, experience has shown that as our geological understanding and our exploration techniques have improved so has the extent of known mineralization been enlarged.

As mineral resources are consumed, new deposits are usually found, and the rate at which their discoveries are made will depend on the stock of minerals in the earth's crust which is unknown. It is well known that processing adds greatly to the value of mineral products. For example, processing bauxite to aluminium may increase its value twenty fold, similarly ilmenite if upgraded to synthetic rutile may also increase its value fifteen fold or more. On this evidence most governments have realized that they should process their minerals where possible before export. A further advantage would be to establish local industries based on processed mineral raw materials and their by-products. However, a cause of gross dissatisfaction among the developing countries is the heavy concentration of mineral processing facilities in the developed regions. Although there is great scope for mineral processing and the establishment of mineral industries in the developing countries, progress will be slow, because the major impediment is transfer of technology and capital, rather than access to markets.

In Sri Lanka, as in all other countries, the search for new mineral deposits is being continued. It is, however, left to the industrialist to intelligently and economically to exploit the deposits that have already been discovered. No country is fully self-sufficient in mineral resources. In order to make available more comprehensive information on the mineral resources of the island the Geological Survey should modify its mapping programme by adopting a multidisciplinary approach. The end product will be basic geological, geophysical and geochemical information, largely in map form, on an islandwide basis. A compilation of all data relating to known mineralization should be attempted since this will enable an initial comprehensive assessment of Sri Lanka's mineral potential. Inspite of many pressures to undertake ad hoc programmes of work, a certain amount of long term research in the form of systematic geological map sheet revision must be undertaken. A mineral index should prove very useful to provide quick retrieval of all information on mineral localities as well as on operations pertaining thereto if any. Mining legislation is at present incomplete and this needs to be remedied, and royalties should be collected on minerals mined. It is, however, envisaged that in future most surveys would be confined to the eastern mineralized zone (boundary between the Eastern Vijayan and Highland Series) which has been identified by the Geological Survey Department. It is expected that the value of Sri Lanka mineral production would increase substantially during the remainder of this century. This is bound to have an important economic impact throughout Sri Lanka. The nature of this impact will depend on how future decisions affect the rate and pattern of mineral development and utilization. At present the value of mineral commodities produced per annum in Sri Lanka is in the region of one billion rupees (Tables XXXXI and XXXXII). State corporations and to some extent other establishments with foreign collaboration will take a major role in the mineral industry (mining and utilization of minerals). The government (Geological Survey Department) will solely be responsible for exploration and development activities. The exploration phase of the mineral industry initially requires access to relatively large areas of land as in the copper-magnetite survey at Seruwila. Assuming that mineral development is an acceptable use of land in most instances the State will expect this development to proceed with minimum disturbance to the environment when mining activity is undertaken. When processing of minerals is chosen and mineral based and certain other industries are established the problem of pollution has to be considered. Although technology offers the promise of nearly pollution-free processes at all stages they have to be commercially proven. Until then, governments will be faced with choosing between industrial activity and environmental protection.

Sri Lanka's mineral exports cannot be considered as substantial. The major mineral exports from the country include gems, graphite and mineral sands (ilmenite, rutile and zircon). Small quantities of salt and mica are also exported. Sri Lanka at one time was a leading

TABLE XXXXI

SRI LANKA — PRODUCTION OF MINERAL COMMODITIES — 1978

Commodity	*Quantity (Long Tons)*	*Value S.L. Rupees*	*Producer*
Ilmenite	33,041	8,085,133	Ceylon Mineral Sands Corporation
Rutile	11,497	31,725,396	Ceylon Mineral Sands Corporation
Zircon	3,295	2,081,325	Ceylon Mineral Sands Corporation & Geological Survey Dept.
Monazite	18	61,250	Geological Survey Department
Garnet	2	800	Geological Survey Department
Limestone	974,894	7,019,236	Ceylon Cement Corporation
* Dolomite	7,000	360,000	Private Sector
Apatite	3,420	1,991,447	Mining & Mineral Development Corporation
Graphite	10,506	22,132,574	Mining & Mineral Development Corporation
Mica	140	336,085	Mining & Mineral Development Corporation
Felspar	3,160	347,000	Ceylon Ceramics Corporation
Quartz	803	77,000	Ceylon Ceramics Corporation
* Silica Sand	200	20,000	Private Sector
Salt	149,825	25,020,775	National Salt Corporation
Gems	—	526,411,326	State Gem Corporation
Kaolin	5,541	4,136,000	Ceylon Ceramics Corporation
Ball clay	2,309	1,518,000	Ceylon Ceramics Corporation
Clay (cement)	103,232	4,645,440	Ceylon Cement Corporation
Brick & Tile Clay	143,520	968,760	Ceylon Ceramics Corporation
* Brick & Tile Clay	280,000	1,940,000	Private Sector
* Brick & Tile Clay	1,300,000	5,200,000	Cottage Industries
* Stone	1,500,000	60.000,000	Private & Public Sector

* Accurate figures not available (estimated)

Note : Coral, shell, sand and gravel not taken into account.
Total value of mineral commodity — Rs. 700,000,000. (Approximate)

TABLE XXXXII

SRI LANKA-PRODUCTION AND VALUE OF MINERAL COMMODITIES-1982

Commodity	Quantity (Long tons)	Value (S.L. Rupees)	Producer
Ilmenite	68,262	27,224,000	Mineral Sands Corporation
Rutile	7,212	41,610,000	Mineral Sands Corporation
Zircon	5,789	11,578,000	Mineral Sands Corporation
Monazite	304	409,000	Mineral Sands Corporation
*Garnet	2	4,000	Geological Survey Department
*Silica Sand	500	125,000	Private-Public Sector
*Quartz	2,000	500,000	Ceramics, LWL, LPL, Private
Apatite	13,993	10,627,972	SMDDC
Limestone	1,615,901	59,580,514	Cement Corp.
*Dolomite	9,000	2,250,000	Private-Public
Salt (common)	176,437	74,103,540	Salt Corp.
Mica	291	1,435,524	SMMDC
Graphite	8,803	61,843,998	SMMDC
Felspar	2,923	906,000	Ceramics Corp.
Clay (cement)	62,591	1,741,202	Cement Corp.
Kaolin	8,206	13,000,000	Ceramics Corp.
Ball Clay (raw)	8,554	1,539,000	Ceramics Corp.
Ball Clay (refined)	737	734,000	Ceramics Corp.
*Brick-Tile Clay	1,820,000	54,600,000	Cottage Industry
*Brick-Tile Clay	378,000	12,040,000	Public-Private
Gems	———	400,000,000	State Gem Corp.
*Stone	2,000,000	200,000,000	Private-Public
*Sand (river)	3,000,000	120,000,000	Private-Public

* Accurate figures not available (estimated)

Total value of mineral commodities Rs. 1,102,577,750 (comparative figures for 1978 and 1973 are Rs.700 million and Rs. 250 million respectively).

exporter of graphite and an attempt to regain this position is worthy of consideration. A systematic survey of graphite occurrences in Sri Lanka should be carried out and promising deposits should be located. Abandoned graphite mines in the country should be studied. Mining by the private sector should be encouraged. Small-scale mining could be introduced. The development of graphite based industries should also be studied. The only graphite based industry in the island is the cottage crucible industry and the pencil and other minor industries. The establishment of local industries based on processed beach mineral sands should be considered.

A mobile plant could be operated to process beach mineral sands from small deposits formed during the intervals between the two monsoons. Minerals such as sillimanite, monazite and garnet in the beach sands should also be recovered. The exploitation of garnet sands in the Hambantota and Devinuwara beaches should be undertaken. A factory for the processing of this mineral could be set up at Hambantota. Sand dunes in this area contain over 20 per cent garnet and can profitably be processed. This activity could be undertaken by the Mineral Sands Corporation. Sillimanite as a refractory material is becoming increasingly important and monazite is the principal mineral source for rare-earth elements used in a variety of industries. The ceramic industry in the island has expanded very rapidly from the early 1970's. It is essential that detailed surveys should be undertaken to locate ceramic raw materials to maintain mineral supplies to the expanding ceramic industry. Special mention may be made of kaolin and felspar. The Meetiyagoda kaolin deposit will in the near future be exhausted. Surveys should therefore be undertaken in the region to locate a sizeable deposit of kaolin which could keep the factory at Meetiyagoda in operation. Investigations should be undertaken to study the Andigama shales as this raw material (consolidated clay) is ideal for the manufacture of floor tiles and other structural clay products including stone-ware items. High alumina clays should be studied for their suitability for the manufacture of alumina and the by-product, portland cement. Although the copper-magnetite deposit at Seruwila has been studied in some detail a proper evaluation of the surrounding region needs consideration.

The establishment of a phosphate industry in Sri Lanka with foreig collaboration to make use of the Eppawala Apatite deposit is alread under consideration. More use should be made of the silica sands, the pure quartzites and vein quartz which occur at various points in the island. The establishment of a sheet glass industry in the island may be considered. The newly established National Aquatic Resources Agency (NARA) is another step forward in the mineral exploration and development programme of the country. The Oceanography Unit of this institution has already plans to carry out off-shore surveys late this year (1985). The increasing demand for mineral raw materials in the near future for local industries and for export purposes calls for an intensive mineral resource development programme in the country. The time lag between the start of exploration and the commencement of commercial production can be considerable; on an average it could be more than 10 years and often as much as twenty years. The mining industry is extraordinarily complex because of the physical characteristics of mineral resources, their heterogenity and nonrenewability, their uncertain and often remote occurrence, and the nature of the requirements for processing. The extent, rigor, and cost of preproduction activities in mineral resource development are far in excess of those required for the development of other industries. The world has become aware of the importance of natural resources for the survival of civilization. It is therefore necessary to respond to the challenges of the mining industry by providing adequate investments for the acquisition of knowledge and the improvement of operational capacity.

At present the mineral resources of the island are exploited without any long term plans by various state organizations engaged in utilizing the industrial minerals. Reliable reserve estimates of most minerals are not available and the long term requirements of minerals by the industry are not known. The impact of large scale mineral expansion programmes on the environment needs careful study at the very initial stage of project development. The early initiation of an effective programme for the compilation of a Mineral Resources Inventory for Sri Lanka will help in a realistic assessment of the mineral resource potential of the country. This task cannot be achieved unless the Geological Survey Department is expanded and the institutional facilities are improved.

REFERENCES

Adams, F.D. (1929) - The Geology of Ceylon. Canadian J. of Res., Vol. I, Canada.

Casinadar, R.A. (1974)- The Evolution of the Graphite Industry in Sri Lanka (1929-1973). Ceylon Studies Seminar, Series No. 7, Serial No. 5, Sociology Department, University, Colombo. 1-27.

Coates, J.S. (1935) - Geology of Ceylon. Ceylon J. Sci., Vol. 19B, 101-187.

Cook, E.K. (1931) - The Geography of Ceylon. London.

Coomaraswamy, A.K. (1903-1908) - Administration Reports, Mineralogical Survey of Ceylon. Geological Survey Department, Colombo.

Cooray, P.G. (1962) - Charnockites and their Associated Gneisses in the Precambrian of Ceylon. Quart. Journ. Geol. Soc., London, Vol. 118, 239.

Cooray, P.G. (1965) - Geology of the area around Aluthgama. Memoir No. 3, Geological Survey Department, Colombo.

Cooray, P.G. (1967) - An introduction to the Geology of Ceylon. Natn. Mus. Dept., Colombo.

Cooray, P.G. (1978) - Geology of Sri Lanka, GEOSEA III. Bangkok, Thailand, 701-710.

Craddock, (1977) - The Evolution and Fragmentation of Gondwanaland. 4th Internal. Gondwana Symosium, Calcutta, India, 1-16

Deraniyagala, P.E.P. (1958) - The Pleistocene of Ceylon. Ceylon National Museum Pub., Colombo.

De Silva, L.W. (1980) - Development of Electrical Power in Sri Lanka. Seminar on Energy in Sri Lanka, SLAAS, Colombo.

Dissanayake, C.B. (1981) - The Origin of Graphite of Sri Lanka. Organic Chemistry, Vol. 3, 1-7.

Dissanayake, C.B. (1982) - The Geology and the Geochemistry of the Uda Walawe Serpentinite. Sri Lanka, J. Natn. Sci. Coun., Vol. 10, No. 1, 13-34.

Fernando, G.B.A. (1982) - The Energy Situation in Sri Lanka and the Need to Develop Alternatives to Oil Imports. Progress, Vol. 2, Issue 3, Ministry of Plan Implementation, Colombo.

Fernando, L.J.D. and Wadia, D.N. (1944) - Gems and Semi Precious Stones of Ceylon. Records of the Department of Mineralogy, 13-44.

Fernando, L.J.D. (1948) - The Geology and Mineral Resources of Ceylon. Bull. Imp. Inst., London, Vol.46, 303-325.

Fernando, L.J.D. (1958) - Iron Ore Deposits of Ceylon. Department of Mineralogy Ceylon, Unpub. Report, Colombo.

Fonseka, J.P.R. et al. (1969) - Mineral and Thermal Waters of Ceylon. International Geo. Cong. Vol. 19, 5.

Fonseka, J.P.R. (1973) - A Review of the Processes Used in Upgrading Ilmenite. Proc. Inst. of Chem Ceylon, 2nd Annual Ses., 11-15.

Hatherton, et. al. (1975) - Gravity Map of Sri Lanka, 1:1,000,000. Sri Lanka Geological Survey Department, Prof. Paper, No. 3, Colombo.

Herath, J.W. (1963) - Mineralogical Composition of Some Laterites and Lateritic Soils of Ceylon. Indian Mineral., 4, 36-42.

Herath, J.W. (1963) - Kaolin in Ceylon. Eco. Geol., 58, 769-773.

Herath, J.W. (1973) - The Ceramic Scene in Ceylon. International Ceram. 22, 103-105.

Herath, J.W. (1973) - Industrial Clays of Ceylon - Geology, Mineralogy and Appraisal for Ceramics and Other Industries. Eco. Bull., No. 1, Geological Survey Department, 1-113, Colombo.

Herath, J.W. (1978) - Sri Lanka Mineral Resources and Industries. GEOSEA 111, Bangkok, Thailand, 711-717.

Herath, J.W. (1980) - Mineral Resources of Sri Lanka. Eco. Bull., No. 2, Geological Survey Department, 1-72.

Herath, J.W. and Grimshaw, R.W. (1968) - The Ceramic Industry in Ceylon. J. Brit. Ceram. Soc., 5, 436-446.

Herath, J.W. and
Grimshaw, R.W. (1971) - A General Evaluation of the Frequency Distribution of Clay and Associated Minerals in the Alluvial Soils of Ceylon. Geoderma 5, 19-30.

Herath, J.W. and
Grimshaw, R.W. (1972) - Light Weight Aggregate from Ceylon for Use in Structural Concretes. Spolia Zeylanica, Vol. 32, 129-135.

Herath, J.W. and
Pattiaratchi, D.B. (1963) - Geology, Composition and Mineralogy of Ceylon Laterites. Cey. Geog., 17, 11-20.

Herath, J.W. and
Senanayake, A. (1983) - The Kelaniya - Negombo Coastal Zone and its Geological Resource Potential. Symposium, Geology of Sri Lanka (Abstracts), 23, Peradeniya.

Jayawardane, D.E. De S., (1976) - The Eppawala Carbonatite Complex in North West Sri Lanka. Eco. Bull., No. 3, Geological Survey Department, Colombo.

Jayawardane, D.E De S. (1982) - The Geology and Tectonic Setting of the Copper-Iron Ore Prospect at Seruwila North East Sri Lanka. J. Natn. Sci. Coun. Vol. 10, No. 1, 129-142.

Jayawardane, D.E. De S. (1983) - The Utilization of the Eppawala Rock Phosphate for Manufacture of Phosphatic Fertilizer. Symposium, Geology of Sri Lanka (Abstracts), 41, Peradeniya.

Jayawardane, D.E. De S. (1983) - Geology and Ore Mineralogy of the Copper - Magnetite Prospect at Seruwila, Sri Lanka. Symposium, Geology of Sri Lanka (Abstracts), 37, Peradeniya.

Jones, E.J. (1887) - On Some Nodular Concretions obtained by trawling of Colombo in 675 fathoms of Water. J. Asiatic. Soc., Bengal, 56, 209.

Katz, M.B. (1972) - On the Origin of the Ratnapura-type Gem Deposits of Ceylon. Econ. Geol. Vol. 67, 113-115.

Kazakov, A.V. (1937) - The Phosphorite Facies and the Genesis of Phosphorites (English Translation). Trudy nauch. Inst. Udobr. Insektofung, No. 142, 22.

Kumarapeli, P.S. (1964) - A Report on the Panirendawa Magnetite Deposits. Geological Survey Department, Unpub. Report, Colombo.

Mero, J.L. (1975) - The Mineral Resources of the Sea. Elsevier, Holland, 1 - 20.

Sitholey, R.V. (1944) - Jurassic Plants from the Tabbowa Series in Ceylon. Spolia Zeylanica, Vol. 24, 3-17.

Vitanage, P.W. (1972) - Post Precambrian Uplifts and Regional Neo-Tectonic Movements in Ceylon. 24th International Geo. Cong. (Montreal), Vol. 3, 642-654.

Wadia, D.N. (1939) - A Preliminary Report on the Iron Ore Deposits of Ceylon. Internal Report, Department of Mineralogy Records (Unpublished).

Wadia, D.N. (1942) - Report on the Iron Ore Deposits of Ceylon. Department of Mineralogy Records (Unpublished).

Wadia, D.N. (1945) - The Three Superposed Peneplains of Ceylon. Ceylon Department of Mineralogy Records, Prof. Paper No. 1, 25-32.

Wadia, D.N. and Fernando, L.J.D. (1945) - Ilmenite, Monazite and Zircon - Gems and Semi-Precious Stones of Ceylon. Prof. Paper No. 2, Geological Survey Department, 1-44.

Wijayananda, N.P. and Jayawardane, D.E. DE S. (1983) - Some Aspects of the Geology of Graphite Mineralization in Sri Lanka with Special Reference to the Kahatagaha-Kolongaha Area. Inst. Min. Met., Trans. Sec. B, Vol. 92, B93-B98.

Zoysa, E.G.G.(1983) - Unusual Gem Materials of Sri Lanka. Symposium, Geology of Sri Lanka, (Abstracts) 15, Peradeniya.