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THE GRAPHITE INDUSTRY IN SRI LANKA

BY

N. P. WIJAYANANDA

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By

N.P. WIJAYANANDA*
Mine Geologist
Kahatagaha Kolongaha Mines
State Mining & Mineral Development Corporation
Dodangaslanda, Sri Lanka

August 1987

* Present Address : National Aquatic
Resources Agency,
Crow Island, Mattakkuliya, Sri Lanka

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FOREWORD TO THE SERIES

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

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

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

R.P. Jayewardene
Director General

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THE GRAPHITE INDUSTRY IN SRI LANKA

1 (a) Introduction and Historical Background

When someone says "Graphite", the first thing that comes to our mind is the Graphite pencil. The name graphite, was given by A.G. Werner in 1789 and is from the Greek word "to write" because the mineral was used for making pencils. Earlier names still in use are plumbago and black lead. But since the mineral contains no lead these names are singularly inappropriate.

This mineral was known to the world from very early times in history, and due to its soft character it leaves a mark when scratched on a hard surface. During early days graphite had been used to mark cattle and sheep.

The existence of graphite in Sri Lanka was known for a few centuries. The first record was in 1675 when the Dutch Governor Rykloft Van Goens in writing to his successor mentioned about the existence of Graphite in Sri Lanka. There is also evidence to say that during the Kandyan era, iron ore had been melted in graphite crucibles.

Trade in graphite, mainly for the pencil industry, seems to have been in existence from the 16th century. But it is only during the British time that this mineral was mined and exported, to be used in making crucibles for the casting of bomb shells and cannon balls. Graphite has been exported from Sri Lanka for the last 160 years, and in 1899 the mineral earned Rs. 2.2 million which was 22% of the total foreign exchange earnings at that time.

Before world war II there had been over 2500 graphite pits and mines located in the South West and Central Highlands in Sri Lanka, but now only two underground mines and a few experimental mines are in operation.

In 1974 Mr Rex A. Casinader did a study on the "Evaluation of the Graphite Industry in Sri Lanka" and has categorized the 1850 to 1973 period into three phases.

(i) The fledgling phase (1850s to 1870)
(ii) The prosperity and maturity phase (1870 to 1917)
(iii) The decline and selective phase (1917 to 1973)

(i) The fledgling state

From about the middle of the nineteenth century to early 1870's is a period during which graphite established itself as one of the minor export industries of the island. Among the factors contributing to the development of the graphite industry at this stage, was the growing demand for Sri Lanka graphite the high carbon content of which was by then well known. This quality graphite was particularly required by the crucible industry which was rapidly emerging in Great Britain and USA perhaps activated by the American civil war.

(ii) The prosperity and maturity stage

The period 1869 to 1918 may be characterised as a period of great activity for the graphite industry in Sri Lanka. This was the period that witnessed the scatter of nearly 3,000 graphite pit mines in the south-western quarter of the island, the crystallization of mining methods, viz the pit mines with mechanical aids ("mol pathal") and primitive pit mines operated manually (dabare pathal). It is a matter for conjecture whether some of the graphite mining methods were borrowed from traditional gemming methods and practices. Gemming had been going on in Sri Lanka from ancient times and by the mid 19th century when graphite mining was entering the fledgling stage, there was in active existence an established traditional system of gemming.

(iii) The decline and selective maturity

From 1917 to the present day the graphite industry slipped down from being one of the major exports of Sri Lanka. In 1912 some graphite which matched the quality of that in Sri Lanka, was discovered in Malagasy. This resulted in stiff competition, the Malagasy graphite being extracted at a lower cost. The Sri Lanka production declined slowly but inexorably, with some outbursts of revival during World War I and II.

The share of Sri Lanka, which was half the world trade in graphite prior to 1912, had fallen to less than 2 per cent in 1980.

(b) The State Mining and Mineral Development Corporation History

The State Graphite Corporation of Ceylon was established in 1971, after the nationalization of the graphite industry. On this occasion the three mines of Kahatagaha, Kolongaha and Walakatahena were grouped into a single entity, the Kahatagaha-Kolongaha Mine. The Bogala mine was already the result of the merger of several old small mines, producing from the same ore bodies. At first these two mines were the sole producing units of the new Corporation. The experimental graphite mine of Rangala was opened in 1973. The one at Ragedera was opened in 1976. The Corporation's name was changed to State Mining and Mineral Development Corporation (SM & MDC) in 1979. Exploration of new prospects for graphite have started from this time.

Production, Exports and Share of Customers

Production (in metric tons)

	1977	1980
Bogala	5,162	3,969
Kahatagaha - Kolongaha	2,932	3,155
Rangala	199	295
Ragedera	53	227

Exports (in metric tons)

Bogala (with the experimental mines)	5,749	3,929
Kahatagaha - Kolongaha (with the experimental mines)	3,020	2,367
	-----	-----
	8,769	6,566

Average price ex Colombo
Rs. per metric ton 5,057 13,049

Share of customers (per cent)

Japan	26.4	46.3
U.S.A.	19.2	20.2
U.K.	17.8	8.7
Others	36.6.	24.8

In 1978, 79 and 80, the Corporation has sold outside Sri Lanka 11,163, 10,933 and 6,566 tons respectively. Sales to the national market during the same period were in the range of 200 - 250 tons per year.

2. OCCUPATIONAL CULTURE AND THE LANGUAGE OF THE MINERS

As in any other industry, graphite miners have their own culture and specialized vocabulary. With the mechanization of the mines these are now changing.

In the early days there were two types of mines, the hand operated and machine operated. They were called "dabare pathal" and "mol pathal". Dabare is a manually operated contrivance used to lift graphite, rock and miners. When this dabare was subsituted by the hoisting machines called winches they were called mol pathal. The machine operated mines were first powered with steam and later with compressed air. Most of the mining activities now are mechanized and powered with electricity and compressed air.

The communication within tne mine was achieved with the help of two men, called "bakki - karaya" and "adikaraya". The "bakki - karaya" controls the movement of men, graphite and mine dumps, at the head of the shaft, and "adikaraya" supervises at the bottom of the shaft. In communicating verbally with one another, with the aid of a hollow P.V.C. pipe extending from the pit head to the bottom, they use phrases as "oy uda" means, means hey, you up there, "oy yata" hey you down there. When the adi karaya says "ariya" the elevator (lift) goes down and when he says "habesh" the elevator or the box moves up. Though now this communication system is changed to bells and intercoms, the old system is yet in use at some places of the mines.

The jargon of the graphite miners change from mining area to area. They have many common words as well as words restricted to particular mining areas.

Words used by the miners and their meanings.

Pathal kavi	- mine poems
Dabare	- contrivance
Vinchi	- winch
Miniran	- graphite
Kutti miniran	- lump graphite
Kota renu	- short grains
Talatu miniran or Potu miniran	- mica
Madulu miniran	- pulp graphite
Kiri miniran	- milk graphite
Tel miniran	- oil graphite
Gas illan	- steep veins
Roda illan	- veins closer to horizontal
Miniran geta	- graphite found in isolated lumps
Doruwa, vala	- shaft or well
Dona	- Tunnel
Doru	- pit
Listeka	- elevator
Gal donava	- tunnel in the rock
Miniran donava	- tunnel in the graphite vein.

Mukku wetta	-	a fixed ladder made on a shaft ora raise for the men to move about
Mattan	-	Level
Bamba	-	fathom
Dakku	-	trolley
Dakku karaya	-	trolley man
Kontarat	-	contract
Bas	-	head man of the gang
Kankanam	-	supervisor
Lin	-	down ward excavation
Mathekka habesh	-	lift with me
Mashima	-	drilling machine

Mining life is insecure and has a tragic quality similar to the one in sea going life. Mining all over the world has this quality which has made miners more superstitious and at the same time more disciplined.

The local miners believe that "Bahiravaya" looks after underground wealth. "Bahiravaya" seems to be a short made person with a big tummy. Annually the miners organize an almsgiving to thank the god and a "Bahirava pooja" for their safety at the mine.

3. GENERAL GEOLOGY

Geology is the science of the earth, its composition, structure and development, of the processes going on in its atmospheric, aqueous and stone envelopes. The earth consists of several different shells.

The atmosphere is the layer of air which envelopes the earth. Essentially it consists of nitrogen and oxygen with a small admixture of water vapour, carbon dioxide and certain rare noble gases, notably argon.

The hydrosphere is the aqueous shell which includes all natural waters - the waters of oceans, seas, lakes and rivers, which cover more than 70 per cent of the earth's surface, and also underground waters, suffusing the rocks of the earth.

The biosphere is the envelope of the earth which is the site of organic life.

The lithosphere is a stony envelope, the outer solid shell of the earth and is composed of rocks.

It is not easy to define precisely what is meant by rocks and minerals. Rocks are complex natural bodies composed of chemically and physically simpler bodies called minerals. As an example one can see that these terms rock and mineral are respectively closely comparable to the terms, mixture and compound used in Chemistry.

Advanced text books define a mineral as a substance having a definite chemical composition and atomic structure and formed by the inorganic processes of nature. The rocks are described as combinations of different minerals.

Geology mainly concerns itself with the study of the lithosphere. To gain an understanding of the structure of the lithosphere, the process going on in it and the history of its development, it must be studied in several aspects. The following subdivisions of Geology may be recognized.

1. Sciences that concern themselves with the constituion of the earth is called Geochemistry.
2. Sciences studying the processes occurring in the earth may be called Dynamic Geology.
3. Sciences studying the history of the development of the earth is called Historical Geology.
4. Sciences directly aimed at practical utilization of the earth's interior-Economic Geology.

Classed in the domain of geochemical cycle in the broad sense of the term usually are such sciences as Crystallography, Mineralogy and Petrology.

Crystallography - Nearly all minerals have a regularity of internal structure on the atomic scale which is often shown as an external regularity of form. Such forms are called crystals. Crystallography is the science of crystals their external form and internal structure. The majority of natural minerals are crystalline bodies; therefore, the study of their forms is useful in identifying them.

Mineralogy - Mineralogy is the science of minerals.

Petrology - Petrology is the science of rocks.

Basically the rock formations can be divided into three - the igneous, sedimentary and matamorphic. The igneous rocks are rocks formed due to volcanic activities. The sedimentary rocks are formed by the deposition of the sediments in the sea or in the lake. These sedimentary and volcanic rocks undergo changes due to change in pressure and temperature and such altered rocks are called metamorphic rocks. When sedimentary rocks change, it is called metasedimentary, and for altered volcanic rocks the term metavolcanic is used.

Other than a few isolated patches, the rocks found in Sri Lanka are sedimentary and metasedimentary. About 9/10 of the island is covered with metasedimentary rocks the rest being sedimentary (Fig. 1). The Jaffna peninsula and the coastal stretch from the peninsula to Puttalam are covered with sedimentary rocks, which are lime-stone. These lime-stones are 14 million years old and their geologic period is called Miocene. Except for a few patches the rest of the Island is underlain by metasediments. On age dating some of our metasedimentary rocks are found to be more than 2500 million years old. Thus all our metasedimentary rocks are of Pre-cambrian age.

According to the mineral assemblage, the rocks of Pre-cambrian age can be divided into three groups, called Highland Series, Vijayan Series, and the South West Belt (Fig. 1). The Highland Series runs across the Island and the Vijayan Series lies on either side of the Highland Series. The South West Belt is a small stretch at the south western part of Sri Lanka. There are controversies among Geologists on the boundaries between these lithological areas.

For more details about the Geology of Sri Lanka, the reader is referred to "An Introduction to the Geology of Ceylon, by P.G. Cooray, 1967 (Revised edition 1985), published by the National Museums Department, Sri Lanka.

4. (a) CERTAIN PHYSICAL PROPERTIES OF MINERALS

Minerals possess certain physical properties and the study of this is useful in identifying them.

The Colour of a mineral is often its most striking property. Unfortunately for purposes of identification, however, the colour of minerals varies very greatly. Even in the same species, specimens are found having different colours. The mineral quartz, composed of silicon dioxide, is commonly colourless or white, but it is also found with pinkish-yellow, green, brown and even black colours.

The Streak of a mineral is the colour of its powder and may be quite different from that of the mineral in mass. For instance, the mineral hematite is black but it gives a red powder. Streak is observed by producing a small quantity of the powdered mineral by scratching with a knife or file or by rubbing the mineral on a piece of unglazed porcelain or roughened glass called a streak plate.

The lustre of minerals differs both in intensity and kind, depending upon the amount and type of reflection of light that takes place at their surface.

Feel-Smooth, greasy, harsh or rough, are kinds of feel of minerals that may be used in their identification.

Hardness is one of the most important tests in the identification of minerals. This may be tested by rubbing the specimen over a tolerable fine-cut file and noting the amount of powder and the degree of noise produced in the operation. The less the powder the greater the noise, and harder is the mineral.

A soft mineral yields much powder and little noise. The noise and the amount of powder are compared with those produced by the minerals of the set used as standard examples for hardness test.

The scale in general use, and known by the name of Moh's scale of hardness, is given below. The intervals on this scale are about equal except for that between the minerals corundum and diamond which is estimated to be thirty or more times as great.

MOH'S SCALE OF HARDNESS

Hardness	Standard Mineral
1	Talc (Hydrous magnesium silicate)
2	Rock salt of gypsum (Hydrated calcium sulphate)
3	Calcite (Calcium Carbonate)
4	Fluorspar (Calcium fluoride)
5	Apatite (Fluo-phosphate or chloro-phosphate of calcium)

6	Feldspar (Aluminous silicates of potassium, sodium, calcium, or barium)
7	Quartz (Silicon dioxide)
8	Topaz (Aluminium fluosilicate)
9	Corundum (Aluminium oxide)
10	Diamond (Pure Carbon)

Window glass may be used in an emergency as a substitute for apatite and flint for quartz. The hardness test may also be made by endeavouring to scratch the specimens enumerated in the list with the mineral under examination. If for example, the mineral scratched feldspar but does not scratch quartz, it has a hardness between 6 & 7.

Hardness may also be tested by means of a pen-knife or even the finger nail, the former scratching up to about 6 1/2 , the latter up to 2 1/2.

(b) CHARACTERISTIC PROPERTIES OF GRAPHITE

Graphite has hardness between 1 and 2, and thus gets scratched when rubbed with a finger nail. The specific gravity is between 2.15 and 2.27 and varies according to the amount of impurities present. The lustre is usually bright, similar to that of metals, rarely dull or earthy. The colour is steel black to blue black and opaque. The streak is black and shining and feels cold like metal when handled. It is a good conductor of heat and electricity; extremely resistant to acid action and has a high fusion temperature, being one of the most important refractory substances known. It is combustible in air at a high temperature, leaving little ash.

Chemical Composition

The general run-of-the mine samples analyse 75-90 per cent carbon, but could be even more. Depending on the formation, the carbon percentage in a vein can also vary. Four samples collected from Ruwanwella, Kalutara and Galle districts were analysed by Wadia (1945) and the following results have been recorded.

	Sample 1	2	3	4
Fixed C	99.792	99.67	98.81	99.28
Volatile matter	0.158	0.108	0.90	0.301
Ash	0.050	0.213	0.283	0.415
Specific gravity	2.26	2.26	2.25	2.24

The composition of ash of Sri Lanka graphite may be represented by the following analysis

SiO_2	50.3
Al_2O_3	41.3
Fe_2O_3	8.2
CaO	]
	]Traces to nil
MgO	]

(c) SYNTHETIC GRAPHITE

Analysis of the crystal structure of graphite by means of X-ray shows that the atoms are arranged in layers (Fig. 2), which accounts for its scaly nature.

The synthetic graphite which is also known as artificial, manufactured or electrographite, is a carbon product which has been subject to a further stage of heat treatment at a temperature about 2400^{o}C. The graphitization process has the effect of altering not only the crystallographic structure but also the physical and chemical properties.

Synthetic graphite differs from its natural counterpart in a number of ways. Firstly, it is characterised by a high degree of purity and low crystallinity, whereas for natural graphite the reverse is usually true. Secondly synthetic graphite serves different markets, overlapping with the natural varieties in only a limited number of applications.

Testing for Carbon Percentage in Graphite

The purity of graphite or the carbon per cent in it is determined by heating a sample in a high temperature oven. Five hundred grams of fine powder graphite is weighed in a crucible and is heated upto 960^{o}C. The sample is kept at this temperature for three hours and allowed to cool. At this temperature all the carbon is oxidized into carbon dioxide and only ashes are left. On weighting the ashes the weight of carbon can be worked out and the per cent of carbon is determined.

5. (a) ECONOMIC MINERAL DEPOSITS

An economic mineral is a natural formation which is used in the national economy either in its natural state or following treatment.

An ore is a natural mineral formation from which it is technically and economically expedient to extract metals or other constituents.

Three groups of economic minerals are distinguished.

1. Metallic
2. Non metallic
3. Hydrocarbons

1. Metallic minerals are a source of metals.
2. The group of non-metallic minerals comprises minerals used either in their natural state (such as common salt, building stones etc.) or as raw materials for various industries such as graphite.
3. Hydrocarbons - coal, oil and natural fuel gases are non-metallic minerals but are classified separately in view of their great economic importance, and the specific features of their formation treatment and use.

A deposit is an accumulation of igneous sedimentary or metamorphic rocks containing an economic mineral and occupying a definite volume in the earth's crust.

A deposit is considered to be workable if it meets certain demands with regard to size and grade of the economic mineral. These demands differ for various economic minerals, and even for different deposits of the same mineral and depend on several factors such as:

(1) The general economic requirements
(2) Geological conditions such as the stability of the surrounding rock
(3) Value of the mineral
(4) Available mining equipment and possible mining methods.

Changes in the economic requirements and technologies may result in a change in the demands presented to minerals. Therefore, the concepts of economic minerals and deposits are relative ones. Some rocks which only recently had no economic uses have now become important economic minerals.

Economic minerals are vital to industry and to the national economy as a whole. Most important for economic development are coal, gas and oil.

Graphite, limestones, mineral sands are some of the economic minerals found in Sri Lanka.

Four forms of mineral bodies can be distinguished.

(1) Isometric, more or less equally developed in all three directions

(2) Tabular, extending mostly in two directions

(3) Pipe like, extending mostly in one direction

(4) Composite bodies are irregular deposits; they may be conceived as a combination of more simple, pipe like bodies with sheet like ones.

Graphite mined in Sri Lanka are tabular bodies extending mostly in two directions. These bodies are called veins. A vein is a body formed as a result of the filling of a fracture cavity by the ore. These veins exhibit great diversity of shape and dimensions, and may be tens or hundreds of metres long. The thickness of veins ranges from a few centimetres to metres and in some cases upto tens of metres.

(b) VIEWS ON THE ORIGIN OF SRI LANKA GRAPHITE

The origin of Sri Lanka vein type graphite has been the subject of much debate. Wadia (1945) postulated a theory that involved adsorption of limestones by an intrusive rock called charnockite resulting in the elimination of carbon in gaseous and volatile form. Erdosh (1970), carried out more detailed studies at Bogala mine and argued that vein graphite is the result of transportation of slippery graphite grains in a solid phase along grain boundaries down a pressure gradient. Silva (1974) showed that graphite mineralization is tectonically controlled.

Hapuarachchi (1975) regarded graphite as being of inorganic origin, having been formed by the carbon-dioxide derived from decarbonation of calcareous material. Recent studies have shown that the origin of graphite remains unresolved, though there is evidence to say the origin could be biogenic or inorganic. Dissanayake (1981) favoured an organic origin and also Mancuso and Seavoy (1981) proposed an organic origin and suggested it to be originated from a special variety of coal called authoxalite.

6. OCCURRENCE AND DISTRIBUTION OF GRAPHITE

The natural graphite can be classified into three groups on the basis of the physical properties and appearance.

(a) Flake graphite
(b) Vein graphite
(c) Amorphous graphite

(a) Flake graphite

Flake graphite consists of flat, plate like particles with varying sizes up to about five cms. They occur in a disseminated form through layers of regionally metamorphosed sedimentary rocks such as schists and gneisses. The flakes may also vary in thickness, toughness, density and shape from one deposit to another.

(b) Vein graphite

Vein graphite deposits are found in fractures or cavities in rocks. The form is massive and the size can vary from fine grain to coarse and flaky. The term ("amorphous") is sometimes used for fine grain vein graphite. But the proper term should be microcrystalline. The graphite veins exhibit a wide variation in the dimension such as width, length, thickness, etc.

(c) Amorphous graphite

The Amorphous graphite has a soft, black earthy appearance, in contrast to well crystallized graphites which have a striking metallic lustre. Most of the amorphous graphite deposits in the world are metamorphosed altered coal seams. The purity of this graphite depends upon the material before it was metamorphosed.

Graphite mineralization in Sri Lanka

The graphite ore district of Sri Lanka is confined to the central belt and extends over an area of more than 14,000 sq. kms. (Fig. 1).

The distribution of graphite occurrences inside this district is not uniform in character.

Three types of graphite occur in Sri Lanka. They are :-

(i) vein type
(ii) flake type
(iii) pegmatite and quartz vein type

(i) Vein type

This is the most important type of deposit in an economical sense. The veins often show a banded structure with fibrous or needle graphite at the margins arranged at right angles to the walls and with plates of foliated graphite at the centre. (Plate 1). They are usually well defined and there is little or no penetration of the well rocks (Plate 2).

This type consists almost entirely of graphite with little or no associated minerals.

Groups of parallel veins occur and these may be connected by transverse veins, sometimes blocks of country rock are found completely surrounded by graphite filled fractures. Individual veins vary greatly in width and may swell into wide pockets, often they thin out into mere stringers and the thickness of workable veins varies from some 10 cms upto 1m. The lenticular masses and pockets of graphite are included in this category. Their thickness can reach even upto 6 m as in the Mee vein in the Bogala mines. (Discussed later in the book).

The length of the veins along their strike is variable and the workable part can extend from a few metres up to 300 m. The general extension down the dip cannot be estimated. In the Bogala and Kahatagaha, Kolongaha mines the veins are still of economical value at depths of 370 and 610 m respectively. Most of the veins are with a high per cent of carbon content but in some cases the carbon content can be below 85 per cent.

(ii) Flake type

Graphite occurs disseminated as small scales and flakes in several rocks such as crystalline limestones and gneisses. The amount of graphite in these is very small usually less than 1 per cent, and, although in some quartz - graphite - gneissic rocks it may rise to eight to ten per cent, this mode of occurence is not concentrated enough to be of economic value.

Artificial flake graphite is produced, at the present time under experimental form in Kahatagaha, Kolongaha mine. This "Flake graphite" results from a lamination of fine chips (o.5 to 1.7 mm size graphite) between two rollers running at different speeds. This process induces a reduction of the ash content of the feed material, together with the formation of flakes, whose aspect and uses are very similar to the one of natural flakes as produced in other countries.

(iii) Pegmatite and quartz vein type

Pegmatite is a rock which has mainly large quartz and feldspars. Sometimes these can be as large as few metres. Large pegmatites are mined for quartz and feldspars and sometimes for mica which also may occur in the pegmatite.

Graphite is also known to occur in pegmatites and quartz veins as flakes, patches and crack fillings. Usually these deposits are not considered to be of economic importance even in the actual mines where they are encountered in the mine workings.

7. SOME STRUCTURAL ASPECTS OF THE VEIN TYPE MINERALIZATION

The graphite veins normally follow a pattern and although the directions of the veins are variable in a given area, the majority of the veins tend to follow one or two directions.

7 (a) Graphite characteristics

Crystalline characteristics

The vein graphite is essentially crystalline in character. However, due to the size of the elemental crystals, some varieties have slightly different properties.

Crystalline graphite

In some veins mainly in Bogala, the size of the crystals is large, which is considered to be of good quality. In this case the graphite is called crystalline. The carbon content is in the range of 90-92 per cent.

Needle graphite

Mainly in thin veins either in Kahatagaha, Rangala or Ragedera Mines the graphite is found in the form of needles. (Plate I). These needles appear on the wall, and in the thicker veins, in the core too. On the walls, these needles are relatively short (± 10 mm) and in the core of the vein their length can reach several cms.

"Amorphous" graphite

It is not correct to use the term Amorphous for the Sri Lanka graphite. The graphite found in large blocks, from the thick vein of Bogala, under cryptocrystalline form, is usually called Amorphous, even if it is not at all Amorphous. The general property of the blocks is the same as that of Amorphous material, though the origin differs.

This graphite is generally very easy to grind and is used for the preparation of low grade powders, used in foundries.

7 (b) Ash Composition

Ash composition of graphite is its composition other than carbon. This may have a wide influence on its potential uses. It appears that the composition of ash varies widely between the two main graphites produced in Sri Lanka, ie. Bogala and Kahatagaha Kolongaha graphite.

The ashes of Bogala graphite are basically composed of silica (more than 90 per cent). The ashes of Kahatagaha Kolongaha graphite are composed of Silica and iron oxide in equal amounts. The ash composition is of prime importance in influencing the uses of the products. For example, Bogala graphite is less suitable than Kahatagaha Kolongaha graphite for the preparations of lubricants, due to the high silica content of its ash.

8. (a) EXPLORATION FOR GRAPHITE

The vein graphite deposits are confined to the Highland Series and South West belt of rocks, (Fig. 1), and most of the deposits are located in the South West belt. Thus the geological study helps to isolate the graphite bearing areas for detailed studies. Within these two belts the deposits have been exploited during the two world wars, the probable graphite bearing areas are already known. Once the probable area is isolated, a Geophysical method is used to detect the veins.

Since graphite is a conductor of electricity, an electric signal when passed through the earth strata, on encountering a graphite vein, will show an anomalous behaviour that could be picked up by a receiver. Based on this principle, an electro-magnetic instrument called an E.M. gun could be used successfully for detecting the graphite veins upto a depth of about 200 feet.

Very low frequency (V.L.F.) method is also used in detecting the graphite veins. V.L.F. signals are emitted for submarines from stations in countries as Australia, U.S.S.R., Japan, U.S.A., etc. When these waves strike a plane with a density difference, they get reflected and with a simple instrument the reflected waves can be detected. Since vein graphite is found in joint planes, the V.L.F. signals get reflected on the graphite veins. For this method, in Sri Lanka

generally we use the signals sent from Australia, as the veins lie in east west direction and Australia is south of Sri Lanka.
There is a limitation to the depth which these geophysical methods can be used. Since most of the deposits are already exploited, it is very important to check whether the graphite deposit exists within this limit.
Since mine dumps are found around these graphite deposits, the contamination from dumps may give an error in the readings. It is very important to take these factors into account in conducting these geophysical studies. Once the geophysical survey is completed if the anomalies of two geophysical methods overlap and these agree with the geology of the area, diamond drilling is carried out to confirm it.
The object of diamond core drilling is to obtain cores for analysis. Diamond drills powered with high pressure air are used at the mines and those powered with diesel or petrol engines are used in the field. The core barrel is at the lower end of a line of drill rods, and at the end of the rods is the drill bit. Drill bit is a small cylindrical barrel with diamond pieces mounted on one end and a screw thread on the other end. The rock core cut by the drill bit is collected in the core barrel which is usually five or ten feet long. Once the core barrel is filled it can be pulled out and the core samples can be collected from the core barrel.
According to the Americal system there are four types of core barrels with diameters 54.7 mm, 42 mm, 30.1 mm and 21.4 mm.

8. (b) RECENT EXPLORATION

Siyambalapitiya (Bogala District)

There are approximately 25 old pits and adits in a 400 x 120 m area. Good quality graphite can be seen on mine dumps on all the prospect. Diamond drilling was completed and in two drill holes good veins have been encountered.

Pussahena (Bogala District)

Pussahena is located 2.5 km south west of Bogala mine (Fig. 3). No graphite is visible on the surface but approximately 50 old pits and adits extend on a 330 x 680 m area. An adit tunnel was made to reach the veins at depth without much success.

9. BOGALA GRAPHITE MINE

The Bogala graphite mine is about 104 km north east of Colombo (Figs. 1 & 3). The mine is at an elevation of 150 metres above mean sea level.

The Bogala graphite mineralization is in the Highland series rocks and the main rocks are gneisses, quartzites, charnockites. This mine consists of three major and several minor subvertically dipping graphite veins (Fig. 4). Horizontal extension of the main veins is 130 m to 300 m with thicknesses varying from 0.28 m to 0.98 m and exceptionally several metres. Graphite quality is not constant in all veins. Total ore reserves are little more than 70,000 tons.

The mineralization is usually pure graphite with relatively litter other minerals as pyrite, chalcopyrite, calcite, quartz and feldspar.

The three veins have following parameters.

Vein	Striike	Length	Thickness	Attitude	Graphite quality
Kumbuk	N 65 W	130-250 m	0.28 m	straight	medium
Na	N 60 E	150-300 m	0.61 m	straight to wavy	good
Mee	N 50 E	120 m	0.98 m	wavy	good

Description of the Mine

At Bogala there are four shafts and a horizontal adit. This is unusual for a mine and the reason is that there were previously three mines which were united only in 1947. Only three of these accesses are presently used: the Alfred shaft, the ventilation shaft and the adit.

The deepest level of the mine is 205 fathoms (375 m) (Fig. 4). Access is through two shafts in series: the Alfred shaft from the surface to the 72 fathom level (132 m) and the number 5 shaft from 72 level to the 205 level (243 m).

Method of Tunnelling

Usual cross section of a tunnel	:1.4 m width x 1.8 m height
Depth of a drill hole	:1.5 m
Diameter of a drill hole	:32-35 mm
Number of holes for a blast	:25 - 30
Machines used for drilling	:Compressed air powered drilling machine mounted on a leg
Depth broken in a blast	:1.2 m±
Explosive consumption for a blast	:10 kg ± of gelatine 80%
Loading and tramming	:manual

Usual cycle of a blast:-

(a) Drilling of 10± holes and blasting of burncut

(b) Mucking of the burncut

(c) Drilling and blasting of the remaining holes

(d) Final mucking of the tunnel

Average advance of the tunnel per month (46 shift) is 7.90 metres.

Method of Mining

Cut and fill method

When a vein is established, it is divided into blocks, horizontally between the two adjacent levels (generally distance from 30 to 40 metres), and vertically between winzes generally 45 m apart and sometimes less (Fig. 5).

Each panel is stoped by cut and fill method. Slices 2.1 metres high are taken successively from bottom to top, and they are filled with waste rock, coming either from the development works, or from slope walls. (Fig. 5). On each slice, stopping begins near the winzes and progresses towards the centre of the panel.

The graphite vein is taken out first on a length of 0.75 metres, either by blasting if the vein is thinner than 0.30 metres, or by pick if it is thicker. Afterwards the walls are drilled and blasted to have a width of at least 0.90 metres. The rate of advance is approximately

3.60 metres per month, but sometimes it may reach upto 10 metres.

After the first slice above the bottom drift is mined out, a concrete floor of 0.3 metres thick is built; it will support the weight of the future fill.

Tramming is by wheel barrow, from the face to the winze. Material is dumped in the winze or hoisted to the upper level in a bucket moved by an air powered hoist. Near the top of each slice caps are anchored in the walls by hitches and logging is laid on them for building a floor which will be used for working on the next slice. The usual crew in a stope comprises ten men working two shifts.

Tramming

The mine car, which is called trolley, has a box which may be rocked for dumping. (Plate 3). Its capacity is about 0.7 tons of graphite or one ton of waste rock. Its weight empty, is about 240 kgs. Tramming is done mannually by two men. The trolley runs on rails.

Hoisting

The hoisting of the shafts is done by electrically powered hoist (lift).

The winzes

The winzes are equipped with air powered hoist (Plate 4) which move buckets having half the capacity of a trolley.

Drainage

There are water inflows coming on each level, not in large quantities but suffcient to make the air very humid and uncomfortable. On the average, the total water inflows in the mine are 150-200 cu. metres per hour.

The tanks are made at different levels. The water collected at a particular level is allowed to drain to the tank. The water from the lower level is pumped to the upper level using electric and compressed air powered pumps. This water is brought to surface by pumping in stages and drained out to a near by stream.

Ventilation

A naturally flowing air passage is planned for ventilating an under-ground mine. Fans are used at the dead end when it is needed to improve the naturally flowing air passage.

Lighting

Lighting is on a 220 V. A.C. current network. Some battery and carbide lamps are used.

Graphite Processing at Bogala Mine

A. Raw Graphite Production

The graphite coming mainly from the three veins Kumbuk, Na and Mee is extracted at an average monthly output of about 500 tons. It has been demonstrated that the average carbon content of the three veins is different, particularly Kumbuk has an average of 80 per cent and Na and Mee have an average of more than 90 per cent carbon.

B. Size Screening

1) The run of the mine is firstly screened on a grizzly (Plate 5) to separate the pieces bigger than 3 inches. These pieces with 3 inches and more are called 'slabs'. These 'slabs' are hand cured. 20 per cent of the slabs are 'Gal katu' with an average content of 45 to 55 per cent carbon. 'Gal katu' is a term locally used for the graphite pieces with rocks in it. The rock pieces in this graphite are removed by a process called flotation and are upgraded.

2) The pieces smaller than 3 inches are mechanically screened. The products are named as follows:

No. 1 OL grade : between 1 1/4 in and 3 in.
No. 2 OL grade : between 5/8 in and 1 1/4 in.

tab dust grade : smaller than 5/8 in.
The average carbon content of the tab dust is between 85 and 90 per cent. This product is sold as it is without any additional curing or after grinding and additional screening.

C. Curing

The slabs and the No. 1 OL are hand cured and sorted between the various carbon content categories.
ie. above 99 per cent, 97 to 99 per cent, 95 to 97 per cent, 92 to 95 per cent, 90 to 92 per cent, less than 90 per cent.
After curing, the products are dried on a hot plate, heated with wood. After drying, the different qualities and sizes are stored before packaging or further processing.

D. Milling

To follow the customers orders, all the grades manually cured are ground in a crusher and separated in vibrating screens. At the end of this processing the following sizes are produced.

bold chips : 1.7 mm to 5 mm
fine chips : 1.2 mm to 1.7 mm
dust : 0 to 1.2 mm

For some orders, no screening is made after crushing and is called chippy dust and sold as it is.

For special purposes, the products delivered from the crushing plant are treated in the powder plants called the Baby Raymond mills and cyclone separation equipment. This equipment produces two categories of powders.

(a) minus 200 mesh
(b) minus 100 mesh

High quality graphite (above 97 per cent carbon content), with very small size particles are produced in a plant called Micro Cyclomat. This is fed with chippy dust from the crushing mill and produce the following sizes.

less than 10 microns
less than 20 microns
less than 40 microns

Packing

The finished products are packed into jute bags, with additional bags according to the various sizes.

(a) The lumps and bold chips are packed in double jute bags.
(b) The fine chips and chippy dust are packed in double jute bags with inner polythene.
(c) The powders are packed in inner multiple ply paper bags, with inner polythene and outer jute bags.

10. THE KAHATAGAHA KOLONGAHA GRAPHITE MINES

The Kahatagaha - Kolongaha (K/K) graphite mine is situated 27 km north east of Kurunegala along the Kurunegala - Matale road. (Fig. 1) The mine area is about 220 metres above mean sea level. (Plates 6 and 7).

The mineralization is entirely of the vein type with a regular east west strike direction and southerly dip. The vein pattern is completely different to that in Bogala. The number is higher (more than 100 veins or veinlets) of which 32 have been mined or explored. The vein system can be considered as quite regular (Fig. 6). However, all veins do not develop continuously with depth while others appear only at lower levels.

Horizontal extension of the veins ranges between 20 metres and 150 metres with an average of 60 metres. The vein thickness averages 0.23 metres rising exceptionally 0.90 metres. The total reserves are about 25,000 tons.

Most of the K/K graphite ore is of high quality needle type and does not generally contain other minerals as pyrite, chalcopyrite, etc.

Description of the mine

On the location of the Kahatagaha/Kolongaha/Wala-katahena mines - named subsequently K/K mine-graphite extraction.

started in 1872 and until now more than 300,000 tons have been produced. The present mining complex is the result of the merger of three mines.

The deepest level of the mine is 2000 feet (610 m). Access is by two shafts; the Kahatagaha shaft which has a depth of 330 ft (101 m). (fig. 6). Below these depths, access is by a series of winzes equipped with small air powered hoists, moving loads of 400 kg ±.

Method of Tunnelling

Usual cross section	: 1.8 m width x 1.8 m height
Depth of a drill hole for blasting	: 1.75 m
Diameter of holes	: 32 - 35 mm
Number of holes per round	: 34
Depth broken	: 1.4 m
Explosive consumption per round	: 13 kg ± of gelatine 80 per cent
Loading and cleaning	: manual
Advance per month (23 shifts)	: about 5 m

Method of winzing

The method is as same as Bogala. The height of the winzes is 1.8 m. The width is 2.70 m.

Method of stoping

The generally observed small thickness of the graphite veins (23 cms on the average) and the strength of the walls determine the stoping method.

When a crosscut penetrates a vein, a gallery is driven which follows the strike. In a place where the thickness is larger a raise is opened and the stope is extended everywhere the thickness is sufficient to allow a man to crawl. Where the vein is too narrow, but still economic to mine out, a wall has to be mined to provide access and the resulting waste has to be trammed and hoisted, because there is no filling.

Stoping progresses are always from bottom to top of the panels. The workers place iron bars and ladders on the stope foot wall for climbing.

Tramming

The tramming is the same as Bogala Mine: 2 men per trolley. At the moment, there are six levels connected directly to the Kahatagaha shaft where trolleys are used. On levels which are not connected to a shaft, but only to a winze the trolleys do not leave their level. They are dumped in hoisting sub-stations where the muck is reloaded in wooden boxes which are hoisted in the winzes by small hoist.

Hoisting

The Kahatagaha shaft is equipped with a double drum hoist powered with an electric motor. The Kolongaha shaft is equipped with a compressed air powered hoist.

The cable way of two ropes is attached to the hanging wall of each winze, on which rolls a carriage moved by a hoist. Boxes are attached to this carriage. Two persons may be transported in a box, but the workers go to their work place by circulating on ladders.

Drainage

This mine is relatively dry. Nevertheless there is some water coming from the surface and from drilling, and it is enough to increase the natural humidity of the air. The water is pumped from level to level as in Bogala.

Ventilation

The ventilation systems of Kahatagaha and Kolongaha are completely separate. Both rely on natural ventilation.

In Kahatagaha the air is forced down to the bottom of the shaft and to a series of winzes. It goes up through other winzes and old workings, passes through the booster fan and finally escapes from the mine through the Bemmulla shaft. (Fig. 6).

Lighting

The workings are lit electrically. Moreover some battery lamps, candles, coconut oil lamps are used at stope ends and working places where the electrical lighting is not possible.

Processing of the Kahataga - Kolongaha Graphite

Graphite coming from the Kahatagaha and Kolongaha works, and also from Ragedera experimental mine, is mainly of the crystalline needle types. (Plates 1 and 2). The average monthly production of raw products is 300 tons. The carbon content of all the mined out veins is similar and generally very high due to the high level of crystallinity.

The run of mine is received from the mines and is screened into five different size categories:

Slabs more than 50 cm
Lumps 25 mm to 50 mm
12.5 mm to 25 mm
5mm to 12.5 mm
less than 5 mm.

The average carbon content of the less than 5 mm category is 90/92 per cent. This last product is not cured and is only screened in 3 size categories:

Bold chips	: 1.7 mm to 5 mm
Fine chips	: 0.5 mm to 1.7 mm
Dust	: 0 mm to 0.5 mm

or sold as it is, as chippy dust 90 - 92 per cent. The total amount of "less than 5 mm" represents approximately 35 per cent of the total production. All the screening operations are manually made on single stage deck screens, after breaking of slabs with hammers or hatchets.

Curing

On the four size of lumps, a hand curing is made by female workers with the help of some male workers for heavier works and operations on machinery. By hand curing on the lumps, the following qualities and quantities are produced.

97-99 per cent carbon	: 30 per cent of total production
95-97 per cent carbon	: 20 per cent of total production
90-92 per cent carbon	: 10 per cent of total production
Gal katu	: 5 per cent of total production

By experience the workers are able to say the carbon content of a graphite piece by visual assessment. But these products are checked by the mine laboratory for the carbon content.

Milling

When required, according to the specifications of the buyers, the less than 5 mm category is milled in the Mill called Baby Raymond Mill, which produces powder whose content is 85 per cent carbon and less than 200 mesh.

Flaking

For special uses, and mainly for foundry purposes, flakes are produced starting from fine chips (0.5 to 1.7 mm) with average carbon content of 90 to 92 per cent. The flaking is in fact a lamination of the crystals between two flat rollers turning at different speed and strongly joined.

The flakes are later screened on a vibrating screen. (Plate 8).

Packing

The bags are marked at the mine in accordance with the terms of contract ie: quality of graphite, number of order, shipping conditions etc. Additional bags are added according to the packed product. For powders, the bag is made on an inner multiple ply paper with inter polythene sheet and outer cover of jute.

For flakes, fine chips and chippy dust, the inner and outer bags are of jute with inner Polythene.

Only lumps and bold chips are packed in double jute bags. Once filled the bags are hand or machine sewed.

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11. THE EXPERIMENTAL MINES

Rangala Experimental Mine (Bogala District)

The Rangala experimental mine is located at six km. east of Bogala mine and is accessible by road (Fig. 3).

There are four main graphite veins in the Rangala mine with a general north 45 west strike dipping south west and many minor vein splits with a north 70 west strike. Their thickness varies from a few centimetres upto 0.75 metres. The graphite is mainly of needle high grade graphite.

The old mine workings were known in the area and a geophysical survey was carried out on it. Some geophysical anomalies were identified and diamond drilling was performed which detected graphite mineralization.

The mining work at Ragedera mine started in 1972. The adits form the main accesses to the vein system. This mine came into production in 1974. Rangala mine has no processing facilities and this graphite is sent to Bogala for processing.

Ragedara Experimental Mine (Kahatagaha - Kolongaha District)

The Ragedera experimental mine is located seven kms. north of Kahatagaha Kolongaha mine. The mineralization consists of a vein system striking E - W with a near vertical dip.

In the central part of the mine workings, there are approximately twelve veins. Their thickness varies from a few mm upto 25 cms. Only six of them are of economical value. The length of the vein is 15 metres maximum and they contain good quality graphite mainly of needle type. The mining method is similar to that of Kahatagaha Kolongaha mine.

12. EXPORTS - WORLD MARKET OF NATURAL GRAPHITE

World Supply of Natural Graphite

Total world supply of natural graphite was in the range of 525,000 tons per year by the late 70's. It grew significantly in the mid 70's from about 390,000 tons per year, at the beginning of the decade. Main producers are mainland China and U.S.S.R., whose combined production exceeds 35 per cent of the world production. Other important producers are North Korea, India, Mexico, the Republic of Korea and Austria. These contries produce essentially amorphous or low grade graphites, sometimes used for fuels.

Higher quality graphites are produced mainly by the Malagasy Republic, Norway, Brazil, West Germany and Sri Lanka. Among those producers Sri Lanka is the only one able to supply graphite under lumps and chips forms as all the other countries supply only crystalline flakes. The production of Sri Lanka which is rated as 10,000 to 11,000 tons per year, represents thus less than two per cent of the world production, but because of its unique form provides Sri Lanka with one of its best assets.

The Demand

The demand for natural graphite stems from many different industrial sectors, which have quite different requirements regarding the quality of the product, its carbon content, particle shape and size, ash analysis, refractoriness, and electrical conductivity. These requirements are not standardized by use, and, even for the same use, various end users may have different requirements, as they work in fact more on the basis of production recipes.

The State Mining and Mineral Development Corporation is the sole exporter of Sri Lanka Graphite. Other than the graphite from Bogala and Kahatagaha - Kolongaha mines, the experimental Rangala and Ragedera mines provide additional but smaller tonnages of saleable material. The Ragedara graphite is integrated with the Kahatagaha - Kolongaha production and the Rangala graphite has been sold as such since 1978.

The Bogala mine produces a wide range of carbon contents, from 80 per cent carbon to +99 per cent carbon. About 25 per cent of the production is the 97-99 per cent carbon grade. Bogala graphite is usually available in lumps, fine chips, bold chips, chippy dust and powder. Fine, ultra fine and micro-fine powder can be obtained from high grade graphite (more than 97 per cent carbon).

The Kahatagaha - Kolongaha mine products rate from 85 per cent to +99 per cent carbon. The mine throughout averages 90 - 92 per cent carbon and about 30 per cent of the total production is upgraded to 97 - 99 per cent carbon.

The major commercial forms for Kahatagaha Kolongaha are the chippy dust and the lumps. About 19 per cent of the shipments are powder products. Artificial flakes are also produced at this mine.

Customers for Sri Lanka Graphite

The present export market for Sri Lanka graphite concentrates on a relatively small number of customers most of whom are in Japan, United States, United Kingdom and Australia. Recently new outlets have been found in the Far East and some business has developed with countries of Eastern Europe. The State Mining and Mineral Development Corporation's customers can be divided into two groups.

a. Those who are end users of graphite
b. Those who are importers - processors

The latter play a dominant role in the traditional Sri Lanka markets, Japan, U.S.A. and Europe.

The U.K. Market

The United Kingdom used to absorb about 18 per cent of the Sri Lanka graphite but after 1979 it dropped. The State Mining & Mineral Development Corporation has three traditional customers in the United Kingdom - Arthur Branwell, T.S. Wilson and Wood Stock. All of them are importers and processors, exclusively dealing with graphites of various origins.

Japanese market

The Japanese market is the largest single outlet for Sri Lanka graphite. It absorbs about 50 per cent of the total exports. Not all the Sri Lanka graphite imported by Japan is used domestically, some tonnages are re-exported after processing. The Japanese market used to import low carbon graphite products, mainly chippy dust of 75 to 80 per cent carbon to 90 to 92 per cent carbon grades. It is current practice for the Japanese graphite importers to upgrade the imported materials and to process them into the form required by the end-use customers.

The U.S.A. Market

About 20 per cent of the Sri Lanka graphite goes to the U.S.A. which ranks second after Japan in the list of Sri Lanka graphite outlets. Sri Lanka sales of graphite in the U.S.A. essentially consists of high grade graphite in lump or powder form for which there are few substitutes and of which Chinese or Brazilian materials are not direct competitors.

The Australian Market

The Australian market ranks fourth among Sri Lanka graphite outlets after the U.S.A., Japan and United Kingdom. The Australian market was essentially oriented towards low grade Sri Lanka graphite products and the promotion of higher grades and powder has not been successful.

Other Asian Markets

The State Mining & Mineral Development Corporation made its first sales of graphite to Pakistan in 1976. It has five customers only one of which is an end-user. Other four are importers working with the Corporation on a commission basis. Most of the requirements are for 70 - 75 or 80 - 83 per cent carbon powder for the foundry industry.

Thailand

Thailand used to absorb about 500 tons of Sri Lanka graphite, mainly low grade powder for foundry industry. The increasing prices of the local graphite has discouraged most of the customers who have turned to other sources, specially China.

India

The State Mining and Mineral Development Corporation is a traditional supplier of Graphite to India. With an annual output of around 50,000 tons, India is a significant producer of Amorphous graphite, but it is lacking in high carbon crystalline grades which it imports mainly from Sri Lanka, Malagasy Republic, W-Germany and Japan. The Corporation has about 10 regular customers in India including dry battery manufacturers, and many crucible producers. The requirements are generally for 90 - 92 per cent carbon grades.

Singapore

The corporation gained a new customer in Singapore whose requirements are for 85-87 per cent carbon and 90 to 92 per cent carbon grades.

Other European Markets

Besides the United Kingdom, France and West Germany are regular importers of Sri Lanka graphite in Europe. In France there is only one customer and he is an importer - processor, and also acts as an agent. Sri Lanka graphite used to account for about 17 per cent of total French imports of graphite.

West Germany

The main importer is an industrial minerals merchant, whose traditional requirements are for 100 - 120 tons per year of 97 to 99 per cent carbon fine chips and powder for break linings.

Italy

The corporation made sales of a few tons of 97 to 99 per cent carbon lumps to an Italian buyer.

The Structure of Sri Lanka Graphite Sales

Virtually all the graphite production of Sri Lanka is exported, the domestic requirements are indeed very modest fluctuating in the range of 200 - 250 tons per year, ie: about 2 to 3 per cent of annual output.

Referring to the present production level and the State Mining and Mineral Development Corporation market structure, more than 50 per cent of the local graphite output goes to the foundry industry which mainly requires chips or chippy dust grading 85 to 87 per cent or 90 to 92 per cent carbon. The major customers for this use are located in the Far East and Australia. Dry-cell batteries are the second end-use sector for Sri Lanka graphite representing 27 per cent to 30 per cent of total markets. 97 to 99 per cent carbon powder is utilized by Union Carbide in U.S.A. and India while 80 to 83 per cent carbon chippy dust is bought by a buyer in Taiwan. About 12 per cent of the exports is intended for refractory producers in Japan, United States of America, United Kingdom and India; 97 to 99 per cent carbon lumps are preferred form for this use. Finally less than 5 per cent of the exported tonnages is used for lubricants, paints, pencils and other minor applications.

Considering the form in which the graphite is exported, lumps, chips and chippy dust are the main commercial sizes supplied to the market.

A significant feature of the market for Sri Lanka graphite is the differentiation made between Bogala graphite and Kahatagaha, Kolongaha graphite. Physical and chemical differences such as hardness, grindability and carbon content directly influence the suitability of the two graphites for different uses. For instance Kahataga, Kolongaha material is preferred by the refractory industry because it is rather flaky and the flux element content of ash is lower. But when the carbon content requirements of the user is less than 90 per cent, the origin of the graphite loses its importance. Thus the present distribution of sales between Bogala and Kahatagaha, Kolongaha materials cannot be entirely explained by their physical and chemical differences. Tradition still plays a dominant role, and some customers prefer Bogala graphite because they have always used Bogala graphite and their processes are perfectly adjusted to this kind of material.

About 50 per cent of the shipments to Japan, United States and United Kingdom were Kahatagaha, Kolongaha graphite. The Kahataga, Kolongaha mines also supply about 1/3 of the Australian requirements as well as 100 per cent of the Indian market.

Price Structure of Sri Lanka Graphite

Several factors are to be considered in understanding the price structure of the local graphite products.

(a) Chemical analysis of the product

(b) Physical form of the product

(c) Selling expenses

(d) Profit margin

Chemical Analysis

The quality of Sri Lanka graphite is exclusively linked to the carbon content of the product. In this respect, prices are arranged in eleven categories.

70-75 per cent carbon (C)

75-80 per cent C

80-83 per cent C

83-85 per cent C

85-87 per cent C

87-90 per cent C

90-92 per cent C

92-95 per cent C

95-97 per cent C

97-99 per cent C

+99 per cent C

Lower the carbon percentage, lower the price, and the price increases with the increase in carbon content.

The Physical form of the Product

Sri Lanka graphites are supplied in various particle sizes. The main ones being lumps (+10 mm), bold chips (-5 mm to +1.7 mm), fine chips (-1.7 mm to +0.5 mm), chippy dust (-5 mm) and powder (minimum 85 per cent minus 75 micron). (- means less than; + means more than).

No difference in pricing is made between lumps and chippy dust, nor between bold chips and fine chips, basically pricing takes into consideration three groups of particle sizes.

(a) lumps and chippy dust

(b) bold and fine chips

(c) powder

Special sizes such as hard or bright lumps, flakes, fine and micron powder also justify price differences.

Selling Expenses

Other than the production cost, a significant share of the corporation graphite price covers selling expenses. These are generated partly at the mines and partly at the Head Office. Selling expenses at the mines consists essentially of packing costs. Those at the Head Office include freight bureau charges, shipping and transport charges, sampling and analysis fees, promotion and advertising, cable charges and stamp duties. However, the largest component of the selling expenses is the export duty presently valued at 25 per cent of the FOB value of the exports.

The Profit Margin

The selling prices of the corporation graphite allow for a reasonable profit margin.

13. OTHER GRAPHITE PRODUCING COUNTRIES

Malagasy Republic

The Malagasy Republic (Madagascar) is a major producer of natural flake graphite. The graphite flake is found in between the minerals of the country rock. These graphite bearing patches, or the ore are found in layers that vary between three metres and thirty metres in thickness containing 3-10 per cent graphite, usually about two thirds is large flake and about one third is fine flake.

These deposits occur in belts of micaceous gneiss and schist over a distance of 500 miles throughout the eastern half of the Island. The main area of commercial importance extends from Tamatare to Marovintsy, a distance of around 70 miles. The reserves are estimated to be large.

Open cast mining is concentrated on the weathered upper parts of the deposits, where graphite which is resistant to weathering is found among the residue. This flake possesses uniform thickness, toughness and cleanness in addition to high quality. The annual production is around 20,000 tons.

Mexico

The most important deposits of amorphous graphite in the western hemisphere are found in

Mexico. These deposits were mined from 1891 and now has an average output of about 50,000 tons per annum.

Some of these deposits have been formed by the thermal metamorphism of coal seams and the others are hydrothermal veins. In some instances this graphite has a purity of over 85 per cent carbon.

U.S.A.

U.S.A. does not produce any graphite now. The last mine was closed down in Texas, in 1979 because it was no longer economically feasible to continue.

Canada

Flake graphite is found in Canada and only in 1980 the Company named Asbury Graphite de Quebec, opened a new mine at Notre Dame de Lous, 150 miles from Montreal.

West Germany

Crystalline graphite in seams, lenses and disseminated flakes in gneisses and schists is found near the Austrian border in West Germany. Only one working mine is found in West Germany which produces little over 10,000 tons of graphite per annum.
After complex beneficiation involving crushing and floating is completed, a 93 per cent

graphite concentrate is obtained and this is subsequently dried, milled and blended with imported graphite.

Austria

Amorphous type graphite is mined in Austria. Output has risen in recent years to around 40,000 tons per annum. Graphite formed by the metamorphism of coal seams occur in highly folded slates and limestones. The carbon content varies between 40 to about 88 per cent. Deposits are found in an area west of Vienna along the west bank of Danube.

Italy

Italy has been a small scale producer of amorphous graphite. The graphite content of the deposits, which can be upto five metres in thickness varies between 40 and 70 per cent.

Norway

It has been estimated that there are reserves of over one million tons of crude flake ore with 25 - 30 per cent carbon in the island of Senja north of the country, occuring as unweathered lenses in the mica schist country rock. An 88 - 90 per cent concentrate is obtained by crushing, grinding and flotation.

India

India is a large graphite producer for a number of years. The total reserves are about 180 million tons and most of them are amorphous. Production at the moment is confined to Andrah Pradesh, Bihar, Gujarat, Orissa, Rajastan and Tamil Nadu States.

Brazil

Brazil produces about 10,000 tons of flake graphite per annum. The graphite is mined using open pit form and crushed and concentrated as done in Malagasy Republic.

South Korea

South Korea has been a large producer of natural graphite for a number of years. The output is around 40,000 tons. The country is best known as a producer of amorphous graphite. Estimated reserves of amorphous graphite are between 2.5 to 3 million tons with an average 75 per cent carbon.

14. USES

Pencils

Though this is the most widely known application, the quantity used for the manufacture of pencils is small. The lead in the pencil is a mixture of carbon and clay. The hardness in the lead is changed by changing the proportion of the graphite to clay. Mostly the flake graphite is used in the manufacture of pencil lead.

Batteries

If you break a dry cell you can see a black rod at the centre of it. Graphite is employed in these rods to improve the conductivity. Impurities as the metallic elements and particle size and crystallographic orientation can have an influence on the quality of the cell. Usually fine ground graphite (below 200 mesh) is suitable. The carbon content of the graphite used is between 85 and 90 per cent. The quantity of graphite used in the manufacture of batteries is not substantial.

Crucibles

Graphite crucibles are used in the foundry smelting of steel, non ferrous and precious metals. The crucibles are widely used in our brass industry. The traditional clay graphite crucible is made with flake graphite, which is flexible and interlocking, and is generally able to withstand greater thermal stress and lasts longer than a crucible made with other varieties of graphite. The carbon content should be more than 85% and particle size large enough to allow good bonding with the other ingredients. The proportion of the ingredients will vary depending upon what the crucible is to be used for.

The clay graphite crucibles are used in brass and aluminium manufacture because they are resistant to oxidation. An average clay crucible employs between 40 and 50 per cent graphite.

Lubricants

Graphite is used in lubricants because of its properties of softness, low friction, inertness and heat resistance. Lubricants containing graphite are widely used in industry, mostly in areas of high temperature and/or high stress such as steel rolling and automotive application. About 10 per cent of graphite with size below 1 micron is mixed to the lubricant which usually is a mixture of oils, greases, alcohols and water. The graphite used here should be free of hard abrasive material and the carbon content is more than than 95 per cent.

Carbon Brushes

The requirements for different brushes vary very much and both synthetic and natural graphite are used accordingly. Sri Lanka graphite has been found to do well in difficult conditions such as low voltage applications in submarines and aircrafts. Brushes are usually made of graphite and bonding ingredients. The proportion of the graphite to the bonding agent depends on the end use of the brush. The graphite usually used is of 95 per cent carbon ground to 100 mesh, with low silica.

Paints

Graphite is used in the manufacture of anticorrosive paints. Low grade graphite with carbon content 50-55 per cent carbon, usually derived from amorphous deposits is used for paints.

Foundries

Low grade graphite dust usually derived from amorphous graphite with carbon content 40 to 70 per cent is generally used on foundry facings, to provide molds and cores with a smooth surface and to prevent metal castings from sticking.

Magnesite - Carbon Bricks

This is rather a new application and magnesite carbon bricks are employed in conjuction with water-cooled panels in electric-arc steel furnaces where it is replacing high fired magnesite bricks. It is possible to use all forms of graphite although flake is found to be the most suitable.

Other applications

For nuclear applications high purity graphite is needed. Thus synthetic graphite is generally used. Graphite, whether natural or synthetic, is employed in the manufacture of moderators and reflector blocks in nuclear fission reactors and has the ability to slow down, but not capture, neutrons produced in the fission reaction.

Graphite's diverse properties give rise to a wide variety of other applications which do not however consume very significant amounts. These include: drilling mud additives, heavy duty brake linings and clutch facings, explosives where graphite controls the burning rates of smoke-less powders by coating the powder grains and preventing excessive friction between the grains which might lead to preignition, shoe and stove polishes, television tube coatings, self lubricating mechanical parts such as bearings, sealing rings and gland packings.

15. FUTURE OF THE INDUSTRY AND CONCLUSION

Graphite has been mined in Sri Lanka for well over 100 years. Only two large mines and two experimental mines are in operation today, but in boom times such as during the last two world wars, thousands of pits of all sizes and depths were opened up all over the graphite producing areas of the island. Many of these small scale mines are worked by local miners or villagers without any sophisticated or even normally available equipment and technical support.

It appears that the abandoning of most of the old mines is mainly due to deficient economical and technical conditions rather than to disappearance of ore in depth. Graphite ore was generally discovered fortuitously during agricultural activities. There was no trace of modern and systematic graphite exploration till 1970 when the Geological Survey Department of Sri Lanka started sporadic inquiries about old mining areas.

There is a high probability of the existence of undiscovered economically profitable ore bodies, as

(a) The high number of graphite occurrences and old mines over a district covering 14,000 sq. kms.

(b) The persistence of some veins in depth as at Bogala and Kahatagaha, Kolongaha mines.

(c) The cause of abandoning of old mines was mostly due to technical, economical and social reasons.............

Greatly increased oil prices since the mid 1970's have led many end-users to return to natural graphite. Sri Lanka natural graphite of grades less than 90 per cent now faces severe competition from People's Republic of China, Mexico, Brazil and Madagascar, which have opened up new deposits.

The future for natural graphite appears to be confused at the present time. Consumers and their processing techniques have become accustomed to graphite from a particular source. Due to the recent world recession the demand for graphite had reduced and the prices invariably went down. The market for Sri Lanka graphite in the future would be influenced by the competition from other natural graphite producers, specially from China and Brazil, and competition from synthetic graphite.

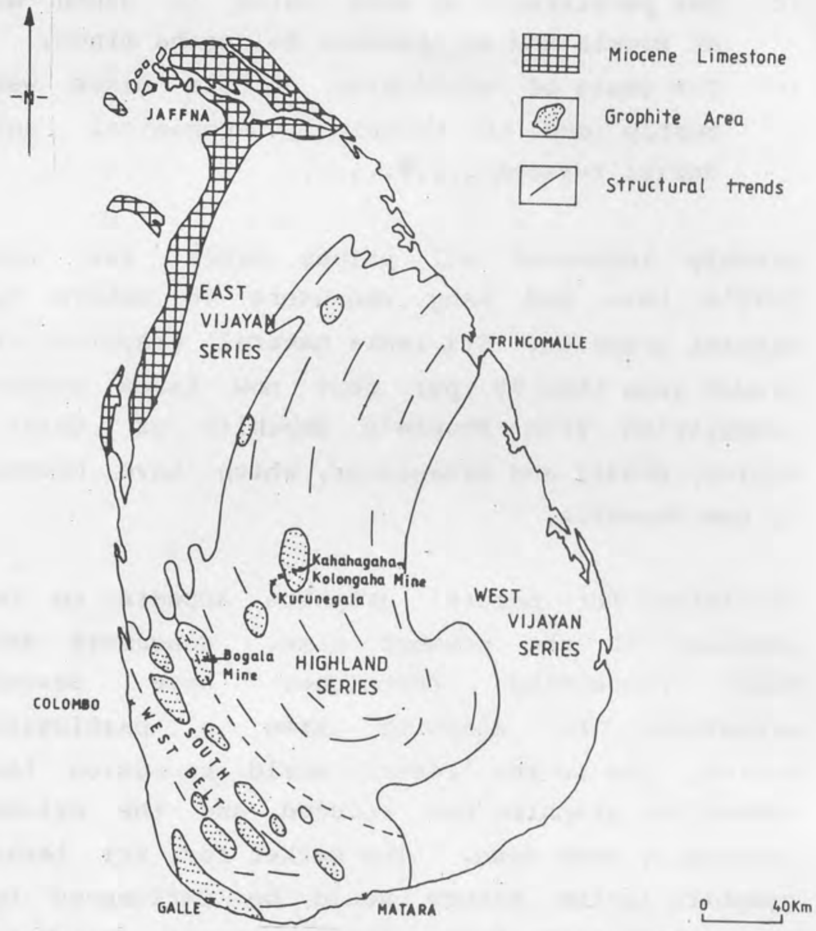

Fig. 1

General Geology map and graphite mineralizations in Sri Lanka

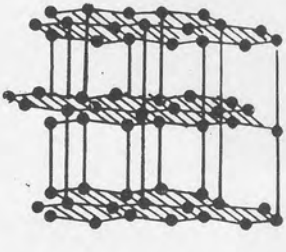

Fig. 2 The structure of graphite.
Layers of carbon atoms are shaded

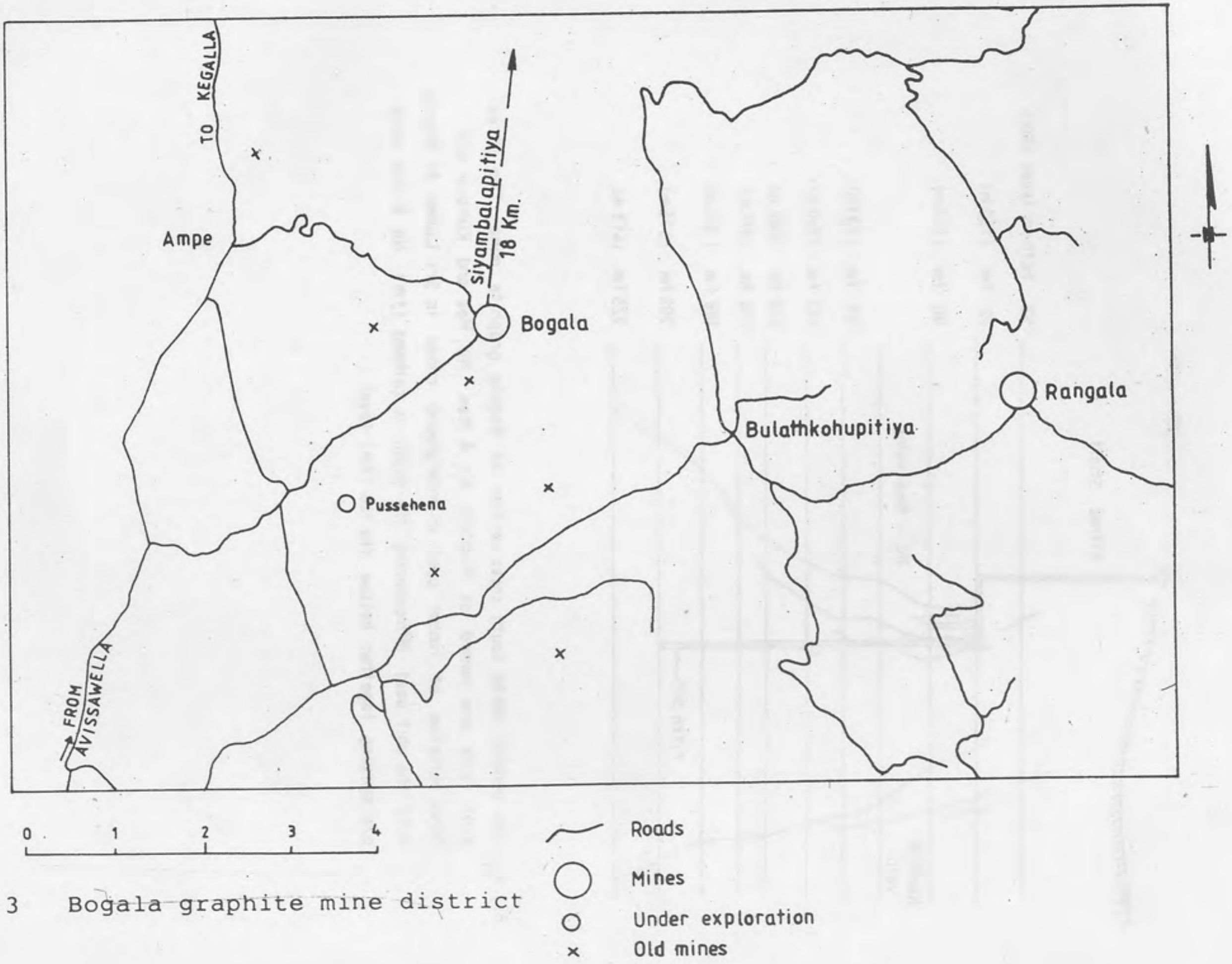

Fig. 3 Bogala graphite mine district

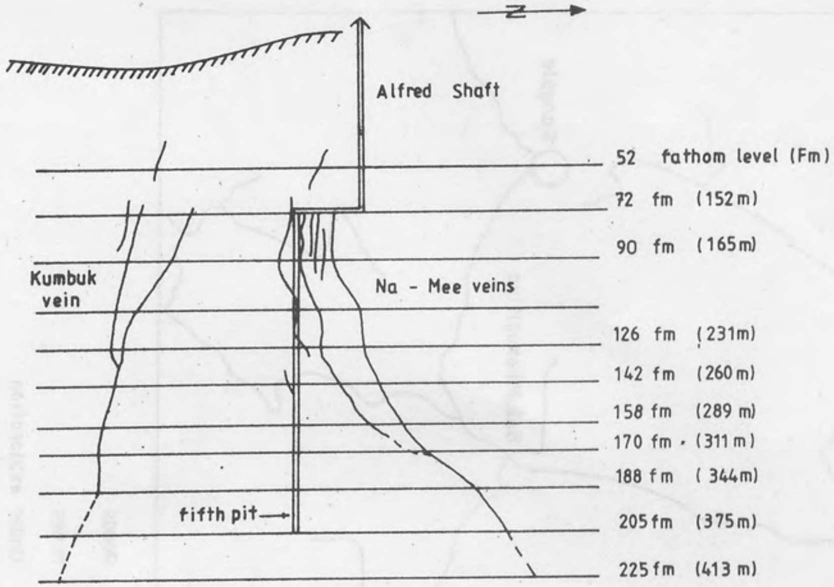

Fig. 4 . The general north south cross section at Bogala graphite mine, The three main veins are named as Kumbuk, Na & Mee. Na, Mee and Kumbuk are three varieties of timber used in underground mines in Sri Lanka. At Bogala mine the unit used in measuring the depth is fathoms (fm). Na & Mee veins are marging together bellow the 188 (fm) level.

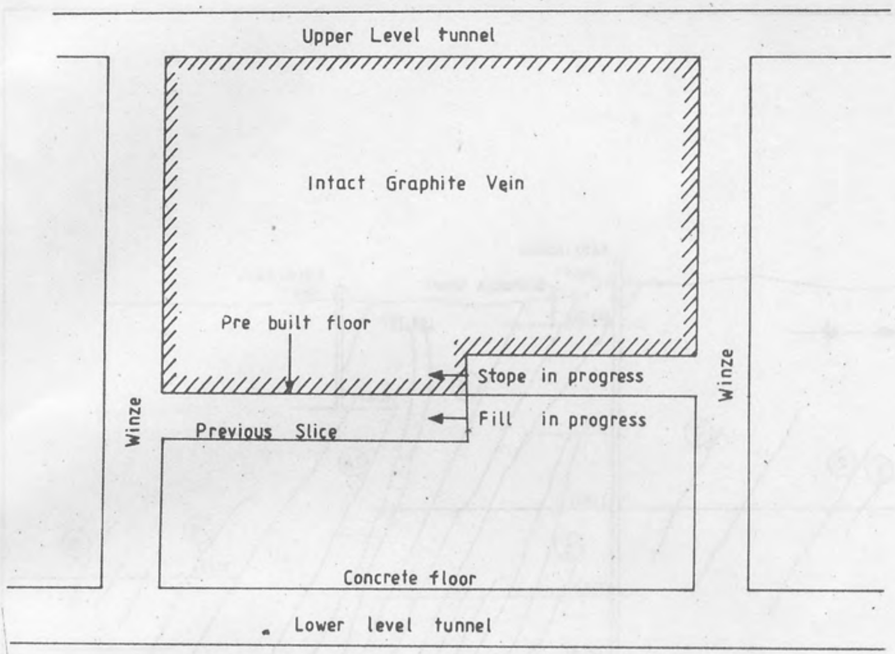

Fig. 5 Cut and fill stoping method used at the Bogala mine

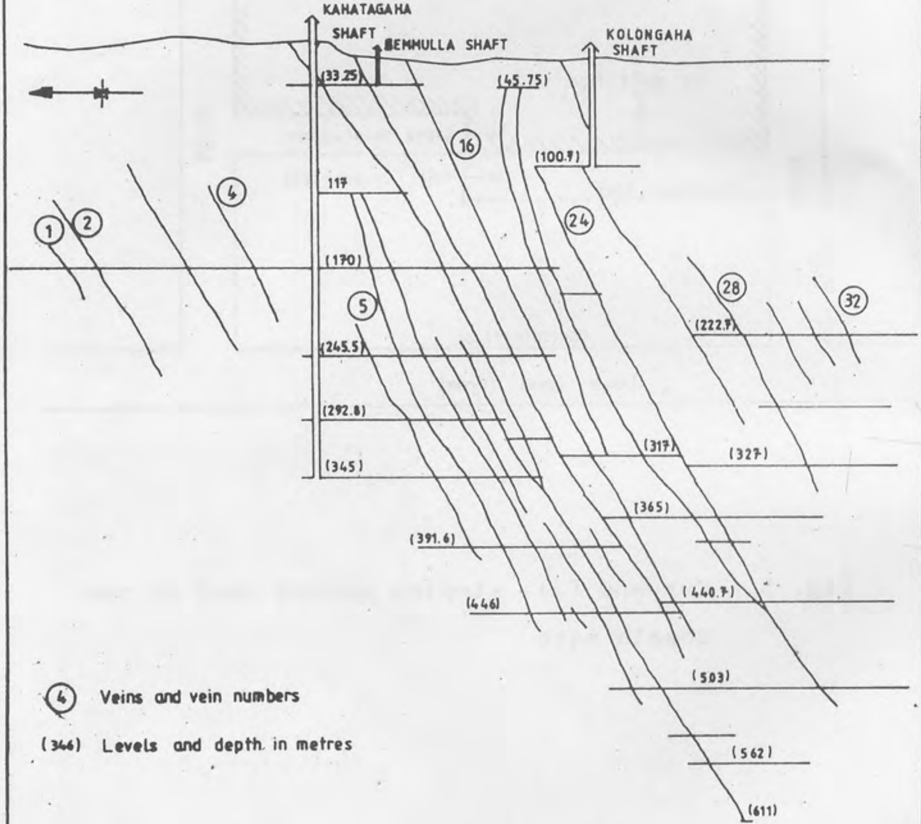

Fig. 6 The north south cross section at the Kahatagaha Kolongaha mine

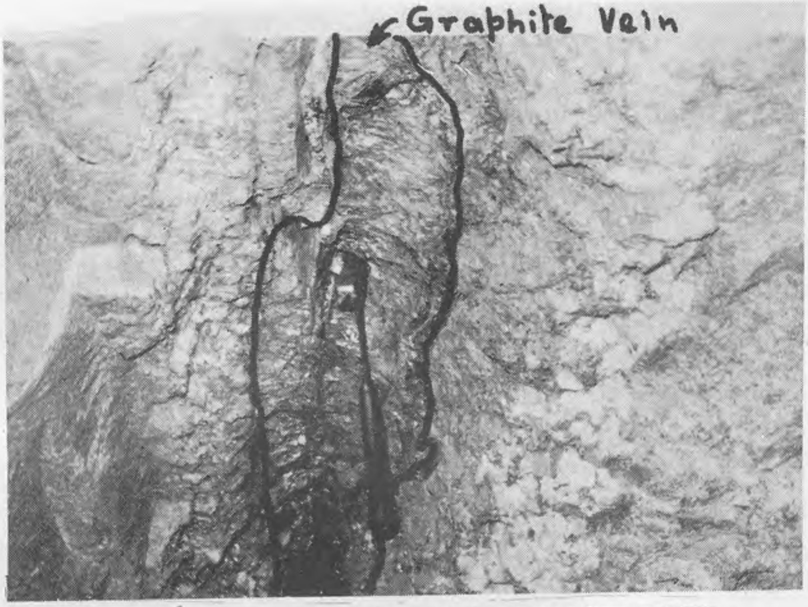

Plate 1 A graphite vein Ragedera mine, Malsiripura

Plate 2 A layer of needle graphite Kahatagaha Kolongaha mine

Plate 3 The Kahatagaha shaft Kahatagaha Kolongaha mine

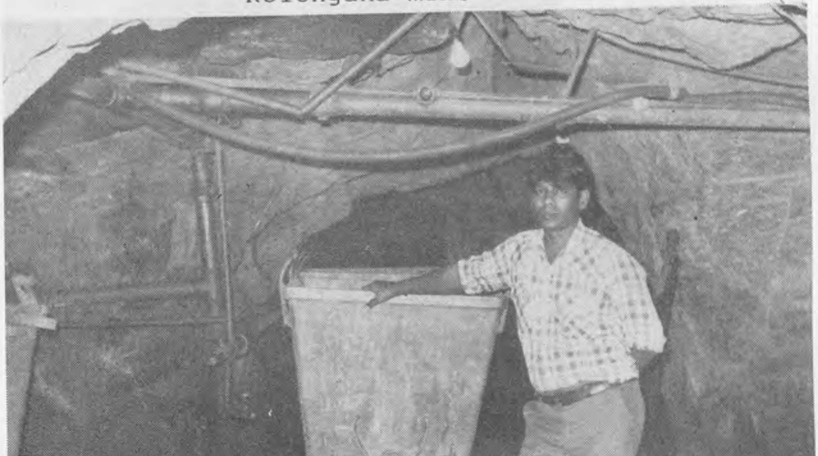

Plate 4 Adit entrance to Ragedera mine

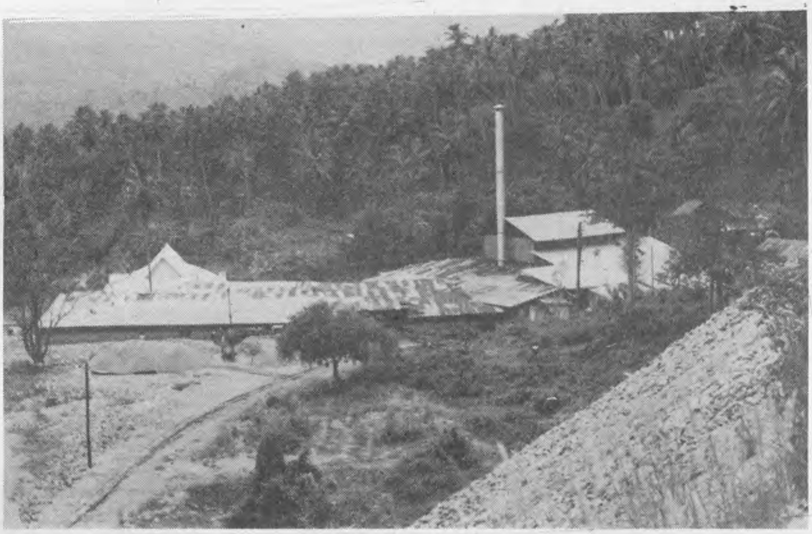

Plate 5 A view of the Kolongaha shaft. The tall chimney is of the old steam boiler which is not in use.

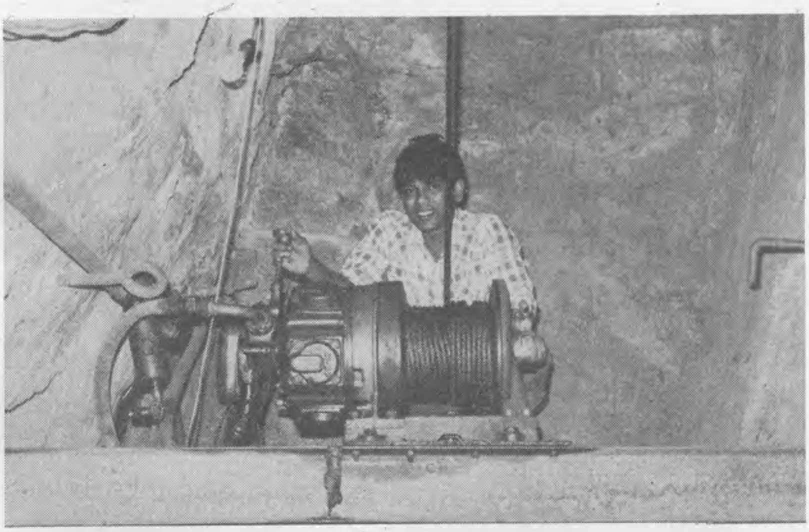

Plate 6 A compressed air winch. Ragedara mine.

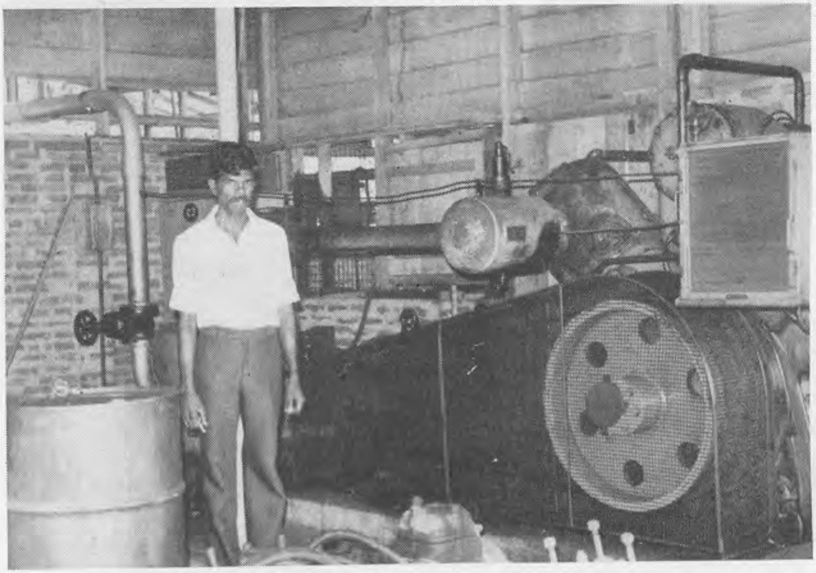

Plate 7 Air compressor operated by an electric motor

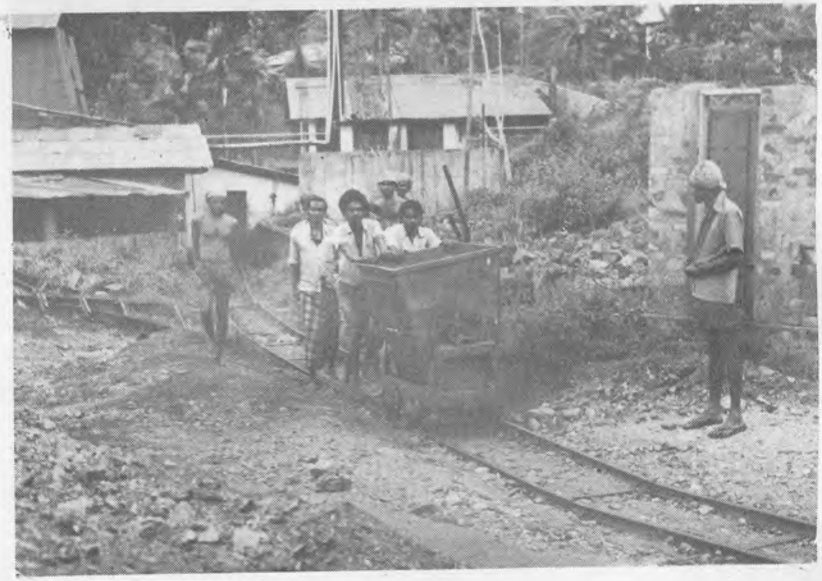

Plate 8 A trolley pushed by the mine workers.

Plate 9 Hand screening of graphite Kahatagaha Kolongaha mine

Plate 10 Screening of graphite flakes using vibrating screen. Kahatagaha Kolongaha mine

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17. GLOSSARY

Adit	-	Horizontal passage (entrance) to the mine
Anomaly	-	An anomaly is a departure from the predicted value of the earth's natural field at a particular point on its surface. Eg. magnetic anomaly, gravity anomaly etc. Also refer geophysical exploration.
Anticline	-	An arch - shaped fold of the stratified rocks in which the younger strata remain at the top of the succession.
Antiform	-	An arch - shaped fold of the stratified rock in which the direction of younging of the strata is not known.
Burn cut	-	Tunnel blasting is done in two stages. First about 1 1/2 feet x 1 1/2 feet opening is made closer to the centre of the tunnel face to make the free face for the second blast. This opening is called burn cut.
Calcite	-	Mineral with composition of calcium carbonate.

Chalcopyrite	-	Mineral with compostion of iron copper sulphide.
Charnockite	-	A rock with blackish greasy appearance.
Compressed air	-	High pressure air. Compressed air is produced by machines powered with fuel or electricity. This air is pumped into a closed tank and brings up the pressure. (Plate 9).
Cross cut (tunnel)	-	A tunnel developed at approximately right angles to the strike of the ore body.
Crystal	-	A homogeneous chemical substance having at least potentially, a definite geometrical form. In speaking of a crystal it is often implied that part at least of the geometrical form is realized in the specimen, and in chemistry and mineralogy the term is sometimes defined in this sense; but in geology generally a crystal implies having essential crystal character, whether or not any of its proper faces are developed.

Crystalline - Having the essential crystal character. (Depending on a regular atomic structure).

Diamond drilling - The object of diamond drilling is to obtain cores for analysis of rock, minerals etc. The core barrel is at the lower end of the line of drill rods, which is operated by a machine, and holds the core when drilling and brings the core to the surface after each completed "run" (operation).

Dip (of the graphite vein) - The inclination of the graphite vein. Primarily it is a vertical angle measured (down wards) from the horizontal plane in the direction of the greatest slope.

Drill hole - Drill holes are made using compressed air powered drilling machines. Explosives (gelatine) is loaded into these holes for blasting.

Feldspar - Most abundant group of rock-forming minerals in the earth's crust, of which it provides nearly two-thirds. The chief constituents are alumino-silicates of the alkali metals.

Foot wall - The lower side of the vein, opposite hanging wall. See description under hanging wall.

Fracture - A crack in rocks resulting from deformation.

Gal katu - This is a term used by the local miners. When a vein is extracted sometimes pieces of wall rock comes with the graphite. This graphite is chipped out and used. The rock piece with graphite is called Gal katu.

Geophysical Exploration - The basis of any geophysical exploration method is the ability to measure some difference in the physical properties of the object being sought from the corresponding property of the surrounding rocks. The most useful properties are: (a) Density (b) Magnetic properties (c) Electrical properties (d) Elastic properties along with the density (e) Radioactivity (f) Temperature differences. The difference must be large enough to influence instruments at or near the surface. This difference is called an anomaly.

Gneiss - Metamorphic rock derived from igneous or sedimentary material coarsely laminated or banded.

Grain	- Constituent particles in a rock. A mineral particle particularly a small, hard, more or less rounded.
Hanging wall	- The upper side of the vein. The fracture in which the ore lies, is all the way environed and bounded by two walls of stone, which are generally parallel to each other, and include the breadth of the vein so that when the miners dig down the roof or the hanging wall is over their heads.
Hoist	- Elevator (lift) used at the mine.
Limestone	- Sedimentary rock composed mostly of calcium carbonate.
Mesh size	- Specific size of graphite particles. These are sorted using a utensil with network or perforated bottom

through which the particles can pass while coarser matter is retained.

Metamorphic rock - A metamorphic rock which was originally of the kind or type included in the name metasediment or metasedimentary rock is the metamorphosed sedimentary rock. Meta igneous is the metamorphosed igneous rock.

Metamorphism - Any change in the characteristics of consolidated rocks due to natural stresses such as heat or pressure.

Mica - A group of silicates with very finely spaced cleavage planes that allow easy splitting into thin transparent or translucent sheets.

Microcrystalline The crystalline nature visible only under the microscope.

Micron - The millionth of a metre.

Mine dumps - Mine waste.

Mineral	-	A naturally occuring crystalline substance with a definite chemical composition and a regular internal structure.
Mucking	-	Removing the blasted rock.
Pre-cambrian	-	Geological time is classified into different periods. Pre-cambrian is the period more than 600 million years.
Pyrite	-	Mineral with composition iron sulphite.
Quartz	-	Mineral with composition silicon dioxide, SiO_2
Quartzite	-	A rock mainly composed of the mineral quartz.
Raise	-	Upwardly constructed excavation.
Refractory	-	Any substance which withstands high temperature, generally more than 1600^0C.
Rock	-	An aggregate of minerals.

Run of the mine -	Produce of the mine.
Schist -	A group of foliated rocks which splits easily into thin laminae parallel to layers of constituent platy minerals.
Sedimentary -	Formed by accumulated deposition of waterborne fragments or organic debris, or by precipitations from solution. Sedimentary rocks are formed in the ocean, lakes and river beds etc.
Shaft -	A vertical or inclined opening, giving access to and serving the various levels of a mine.
Stoping -	Excavating (usually upwards) with in underground ore body.
Stratified rock -	These are rocks in which the original layering can be recognized.
Strike of a graphite vein-	The direction at any point on the surface of the graphite vein

		or that of a horizontal line drawn on the surface of the vein.
Trammed	-	Transport using four wheeled trolley on rails.
Tunnel	-	A nearly horizontal underground passage.
Ventilation shaft	-	A shaft used in carrying air for ventilation.
Winze	-	An opening like a small shaft, sunk from an interior point in the mine.