GRAPHITE

Proceedings of a seminar held on

20th July 1991, at Bogala Graphite Mine Premises

RESEARCH IS THE FOUNDATION OF KNOWLEDGE

Organized by *Natural Resources, Energy & Science Authority of Sri Lanka*

Sponsored by *Bogala Graphite Lanka Ltd.*

FOREWORD

As part of NARESA's activities, the Working Committees organize seminars at regular intervals for grant recipients and other scientists, in order to expose them to peers and specialists. These Seminars are generally of two types, Progress Review Seminars, where the grantees present the findings of research for critical review, and seminars focusing attention on specific scientific themes. This year's seminar, "Graphite" which falls into the second category, was organized to survey and review the current status of an important natural resource of Sri Lanka, and to disseminate the recent findings of research to the current and potential users of graphite.

The seminar which consisted of two sessions had five presentations in the first session. A guided tour of the Bogala mines was given to the participants in the second session.

I wish to thank the organizers, resource persons and participants for their contributions to the seminar and for their assistance to bring out this publication.

Dr R.P. Jayewardene

Director General

ACKNOWLEDGEMENTS

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Our thanks are also due to Mr M. Abeynayaka, Chairman, Bogala Graphite Lanka Ltd. and his staff at Bogala for their assistance in organizing this seminar successfully.

Our grateful thanks are extended to Bogala Graphite Lanka Ltd. for sponsoring this important seminar.

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HISTORY OF GRAPHITE

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INTRODUCTION

Graphite is the mineralogical name for one of the naturally occurring cristalline forms of carbon, the other varieties being diamond and charcoal. Although these materials are chemically identical, they differ largely in physical properties and this is mainly due to their different atomic arrangements. Graphite is a hexagonal mineral and it is opaque, soft, greasy to touch, and iron black to steel grey in colour. It conducts electricity and heat well but is extremely refractory. Other major properties are chemically inertness and very low in hardness which is between 1-2 according to the Moh's scale. Graphite receives its name from "Graphein" the greek word meaning to write. Once mistaken for lead, it was also called "Black Lead" and pencils made from graphite are still called "Lead Pencils". The name "Plumbago" is a commercial name used for graphite.

Graphite has appeared in the international trade since the 16th century after which time the mining industry was present mainly in Germany and Siberia. Subsequently, more and more countries began producing graphite and the occurrence of graphite in Sri Lanka had first been reported in 1675 by the then Dutch Governor Rycloff Van Goens. However, this became known to Sri Lanka as a mining industry as well as an important export commodity during the British colonial period. Graphite is one of the main minerals mined and exported by Sri Lanka over the last 175 years and it has been an important export commodity similar to Tea, Rubber and Coconut. Today, however, it is ranked a very low level among Sri Lanka's items of export in terms of value because its contribution to the national economy is less than 1%. Current annual production is around 9,000 M. Tons though it had been 20,000-30,000 M. Tons during the boom times i.e. 1st three decades of the 20th century. The highest ever graphite export was 33,411 tons reported in 1916, at a value of Rs. 22 million. The present national production is received from two large mines, namely Bogala and Kahatagaha/Kolongaha and a handful of small scale mines and the revenue is approximately Rs. 175 million. Moreover, it is noteworthy to state that Sri Lanka still enjoys a very high reputation as the world's best natural graphite due mainly to its extremely high purity, the purity being above 90% C.

BEGINNING OF THE INDUSTRY

Though graphite deposits were known to exist in and around the central and south-western sectors of the island, the first commercial exploitation had been reported in the Kalutara District in 1800, perhaps following the discoveries made by the Dutch. Subsequent to these discoveries in the west coast of the island, the mining industry had gradually expanded to the interior of the country. As stated by the then Ceylon Blue Book of 1830, there had been three graphite pits in Pasdunkorale with a production of 55 pieces. This indicates that Sri Lanka had been producing lump-grade graphite at the outset of the mining industry where other parts of the world could not produce lumps as such. This is also a rare advantage that Sri Lanka possesses in the international trade. By 1836 the number of mining pits had been increased to 28 with a production of 1175 "Bushels". Occurrence of graphite in the Sabaragamuwa Province was first reported in 1847 and until then the graphite mining was confined to the Pasdunkorale. Towards 1855 it had been further expanded into the interior of the country as mining had been reported in Harispattuwa in the Central Province. It had reached the Kurunegala District in 1861 and to date Kegalle and Kurunegala districts have become the most important regions for graphite mining. By early 1870 the British had introduced a policy on mineral rights and royalty for graphite having realised that it had become a major industry in the country.

BRITISH INTEREST IN MINING

It is most interesting to note that the graphite industry expanded largely during the colonial period, but their engagement in graphite mining was extremely limited, although the British were in possession of all the required facilities and technology. They almost from the beginning of their rule, exhibited an interest in the commercial exploitation of graphite deposits of the island in addition to export and import trading. However, the colonial Government in Sri Lanka did not have a direct participation in graphite trading, but they gave due engagement to the British entrepreneurs. It is quite peculiar however, that while the British had the complete control in the plantation industry and export trade, they were unable to gain a similar position in graphite mining though there is evidence to suggest that they made serious efforts to do so. The inability of the British to get into the local mining industry had also been described by a British Mining Engineer G.A. Stonier in 1903. According to him there were only 3 mines owned by the British miners in 1903. It was also believed that the local miners did not like the British entering the graphite industry so that they did not provide any assistance to them in this trade. This was reported by Septimus Morgan of Morgan Cruicibles who came to Sri Lanka in 1866 in search of graphite-bearing lands. But the natives were uncooperative to them in their search for graphite.

BOOM TIME

The first two decades of the 20th century were characterised as a period of great activity for the graphite industry of Sri Lanka. During this period the local industry was at its peak level owing chiefly to the heavy demand created by world war 1 and also because most parts of the world had yet to know about this strategic industrial mineral. For instance, the highest ever export tonnage was recorded as 33,411 tons in 1916 which was 35% of the world consumption. During this period there had been 3000 pits and mines in operation in all over the southwest and central parts of Sri Lanka. Among the factors contributing to the expansion of the graphite industry at this stage were the ability to export without processing due to the extremely high purity, low mining cost, large production from shallow pits and the high demand. As the local graphite does not need to go through expensive and time consuming upgrading process, it could be directly exported to the consumers from the mines. The graphite grade of the other producing countries was around 40%C. The graphite producing areas of Sri Lanka during this boom time were Bogala, Kahatagaha/Kolongaha, Madawachchiya, Vavuniya, Kurunegala, Kegalle, Ratnapura, Ruwanwella, Dompe, Mirigama, Kirindiwela, Padukka, Matugama, Ingiriya, Bulathsinhala, Agalawatta, Meegahathanne, Dumbara, Dodanduwa etc. (Fig. 1)

Very primitive mining methods had been used during the peak period of graphite mining owing to the prohibitive high capital cost, lack of technology & mining professionals and also due to the eagerness to earn quick money. A large number of shallow pits had been sunk in the weathered rock or top soil to produce graphite at a low cost in order to get rich quickly. This however caused extensive damage to the ore body and consequently deep seated reserves had not been tapped but left behind. Therefore there is no doubt that a very large reserve of graphite still remains in situ for exploitation. Major problems encountered in the early days of graphite mining were dewatering, haulage of material, drilling and blasting, ventilation, fixing etc. Most of the mining methods adopted were very primitive and the majority were pit mining operated entirely by manual means. Sometimes hand operated winches or winders ("Dabare") were used for haulage purpose. In these pits, when the miners were unable to tackle the problems of inherent ground water or side wall fixing, they were compelled to abandon the pit. On the other hand the systematic mines operated those days consisted of a vertical shaft and a series of horizontal galaries driven along the veins from the shaft at different levels. Developing another shaft or pit at some distance away and connecting them by galaries had improved natural ventilation. Dewatering had been done by an adit or using steam engins. Most of the graphite mining in mountain ranges had been done by developing a series of adits at different levels. In this type of adit mining, the problems such as ground water and ventilation do not arise. Miners were well experienced about the ventilation in pits or mines with the aid of their lamp or candle as it becomes flameless when there is insufficient oxygen in the tunnel.

DOWNFALL OF THE GRAPHITE INDUSTRY

Sri Lanka had been one of the leading suppliers of natural graphite to the world until 1920 and approximately Sri Lanka's share had been 20-35% of the total world production. This mineral became one of the important strategic industrial minerals particularly during world war 1 and as a result, the world came to know about this mineral and searched for it. This resulted in the discovery of many low grade (40% C) surface graphite deposits in various parts of the world. A typical example was the discovery of such deposits in the Republic of Malagassy which became a major graphite supplier later. Other contemporary producers who became major suppliers subsequently were Korea, Mexico and China. The most outstanding feature in this respect is that all these countries possess large reserves of low grade surface deposits from which graphite can be mined out with ease and at a low mining cost. The other advantage is that these mines can produce a very large out put. Consequently this provided a stiff competition to Sri Lanka's vein graphite. Vein graphite mining in Sri Lanka involves extensive labour, expensive deep mining methods and the inability to apply mechanized mining methods resulting in low production and high mining costs. This competition was acutely felt and created an unprecedented crisis in the graphite industry as a result of the drop in demand due to the increased supply of graphite to the international market.

The decline of the graphite industry (Fig. 2) created a response in the Government and as a result in March 1923, in pursuance of a motion in the Legislative Council by O.C. Tilakarathne, a plumbago industry committee was appointed, headed by H.W. Cordington and E.C. de Fonseka, Meedeniya, Sidney Seduwic, P. Fernando and D.S. Senanayake as members. The task of this committee was to study and recommend the measures that would improve the sinking industry. Later the Government implemented their recommendations and suspended the export duty on plumbago and import duty on explosives in 1925. These relief measures however, did not help to hold the collapsing industry. The main difference between the local and the foreign graphite mines is the nature of the deposits as described above. Later all of the small scale mining enterpreneurs of Sri Lanka were closed down and only a few large mines could survive due to their ability to withstand the challenge. Finally, the Sri Lankan contribution dropped to less than 1% in the world trade of graphite.

A second phase of boom in the graphite industry was noticed in 1940 but this also became temporary as it dropped again with the subsidence of tension of the world war 11. Thereafter, towards 1950, only three major mines of Sri Lanka i.e. Bogala, Kahatagaha and Kolongaha could survive from the sinking stages and all the other thousands of pits operated during this IInd world war were abandoned. By this time the other major suppliers like USSR, China, Mexico, Korea etc. were each annually producing over 75,000 tons. During the world war II the highest annual production of Sri Lanka was 27,734 tons recorded in 1942 and this was the 2nd highest ever exported tonnage from Sri Lanka.

MAJOR MINES OF SRI LANKA

Immediately after the IInd world war, thousands of pits, and mines which operated earlier dropped to a handful and a few years later only three major mines - Bogala, Kahatagaha and Kolongaha remained operative. These mines could withstand the challenge created by the other large producers of the world due to the fact that they (three local mines) had been developed to the level of large underground mines of Sri Lanka with modern machinery and labour added during the boom time. In the 1950's these mines were further improved technically with the assistance of mining professionals of local and foreign nationals. For instance, Bogala mine was mechanized up to international standards in 1960 and as a consequence the production was increased from 25% to 65%. Beginning of the Bogala Mine is not clear, but believed to be opened up in 1860's as a few scattered pits. Subsequently these pits had been developed as three separate mines extracting graphite from three major veins namely Karandawatta, Mahabogala and Punchibogala. Mahabogala was owned by A. Fernando alias "Kathonis Bass" and later in 1920 he annexed the Punchibogala to Mahabogala. Morever, in 1947, he had taken over the ownership of the Karandawatta mine as well and later all three mines were named as Bogala Mines and managed by the members of the Fernando family as Bogala Graphite Ltd.

It was believed that Kahatagaha and Kolongaha mines were also opened in 1860's as scattered pits in Maduragoda in the Kurunegala District. The Kahatagaha pits were then owned by Atigala Muhandiram and Kolongaha pits by H.L. de Mel Co. The Kahatagaha mine ownership later fell on the family members of the Artigala Muhandiram, namely Senanayake, Jayawardana and Kotalawala (all sons- in-law of Atigala Muhandiram). After 1940, and until the nationalization, the Kahatagaha and Kolongaha mines were managed by Sir John Kotalawala and H.L. de Mel Co. respectively. By the time Sir John had 65% of the shares of the Kahatagaha Co.

NATIONALIZATION AND PRESENT SITUATION

The next most significant event in the history of the graphite industry was the nationalization of the entire industry in 1970 including mining, processing and exporting. The existing three major mines - Bogala, Kahatagaha and Kolongaha (K/K) were taken over by a competent Authority and later the management was transferred to the newly formed State Graphite Corporation of Sri Lanka: Subsequently this name was changed to State Mining & Mineral Development Corporation of Sri Lanka in 1982 as the corporation was engaged in handling other varieties of minerals as well. Again in

1991 the government policy on controlling the nationalized industries was changed to a peopolization programme and as a result Kahatagaha/Kolongaha mines became Kahatagaha Lanka Graphite Ltd.; and the Bogala Mines became Bogala Graphite Lanka Ltd. Recently the Government has taken special interest to upgrade this industry and as a consequence several important concessions were given to the industrialists. As a government effort to boost this industry, the graphite export tax was reduced to 15% from 25% in 1986 and in 1991 the government has taken a further step to remove the export permit on graphite exports. Today most of the industrial and export regulations of the country have been amended and relaxed enabling the local or foreign industrialists to invest in new ventures like graphite based or mining industries. However, large scale graphite based industries are yet to be commenced in the country, although this raw material is available cheaply and plentifully for any major or small scale industry that could be set up in the free trade zones (FTZ) of Sri Lanka or any other specific parts of the country.

Today approximate annual production is 9,000 M Tons and chief contribution is from Bogala Mines (5,000 M. Tons). K/K mines (3000 M. Tons) and from a few small scale mines. However, this quantity can be easily increased up to 20,000 M.Tons if this industry is expanded as there are adequate reserves in this island.

Commercially speaking, there are three varieties of natural graphite in the world, namely amorphous, cristalline and flake of which the amorphous type graphite enjoys a large demand than the others in the International Market. Sri Lanka produces chiefly the amorphous and cristalline varieties, but the presence of flake graphite has also been reported in the island. The cumulative graphite production of Sri Lanka from the early days of the mining industry (1820) has gone up to 1.7 million tons from which the existing deep mines (Bogala, K/K), alone have produced more than one million tons. This explains how the balance production has been obtained from the thousands of shallow pits scattered in various parts of the island, mined during the world wars. Most of these deposits have been mined only upto a shallow depth ranging from 100-200 feet, leaving behind the better portion at deeper levels due to various technical problems discussed above. The gradual deepening of the K/K and the Bogala Mines has fortunately revealed the presence of most prolific portions of the ore bodies at moderate depths, without either having to carry out any investigations or having any prior knowledge of them. However, deepening of a mine has a limit as far as the mine's economy is concerned and as a result, meeting the demand cannot soley depend on vertical expansion. Therefore, it is high time to search for new deposits and develop the industry to meet the increasing world demand and to maintain Sri Lanka's position in the international graphite trade similar to that of tea, rubber and coconut. As mentioned earlier, it is suspected that a large tonnage must have been left behind at deeper levels in the early pit mining areas. Moreover, the recent investigations have established that the veins at shallow horizons are poor in quality as well as in vein thickness. As a consequence, it can be predicted that the occurrence of large graphite reserves of several million tons, in the island, still remain to be exploited. Further, it can be stated that there may be several fresh undisclosed deposits yet to be found as most of the existing deposits in the island have been exposed by the early prospectors. In the circumstances, it is now quite opportune to reassess the potential reserves in the country and to extract large quantities systematically.

Source of information

1. Herath, J.W., 1980, Mineral Resources of Sri Lanka, Econ. bull. No. 2, Geo. Surv., Sri Lanka.

2. Economic Review, 1980, The People's Bank, Sri Lanka, V.6, No. 4.

3. Economic Review, 1987, The People's Bank, Sri Lanka, V. 12, No. 10

4. Personal Communication with miners

5. Documents preserved at Bogala and K/K mines.

FIGURE 1

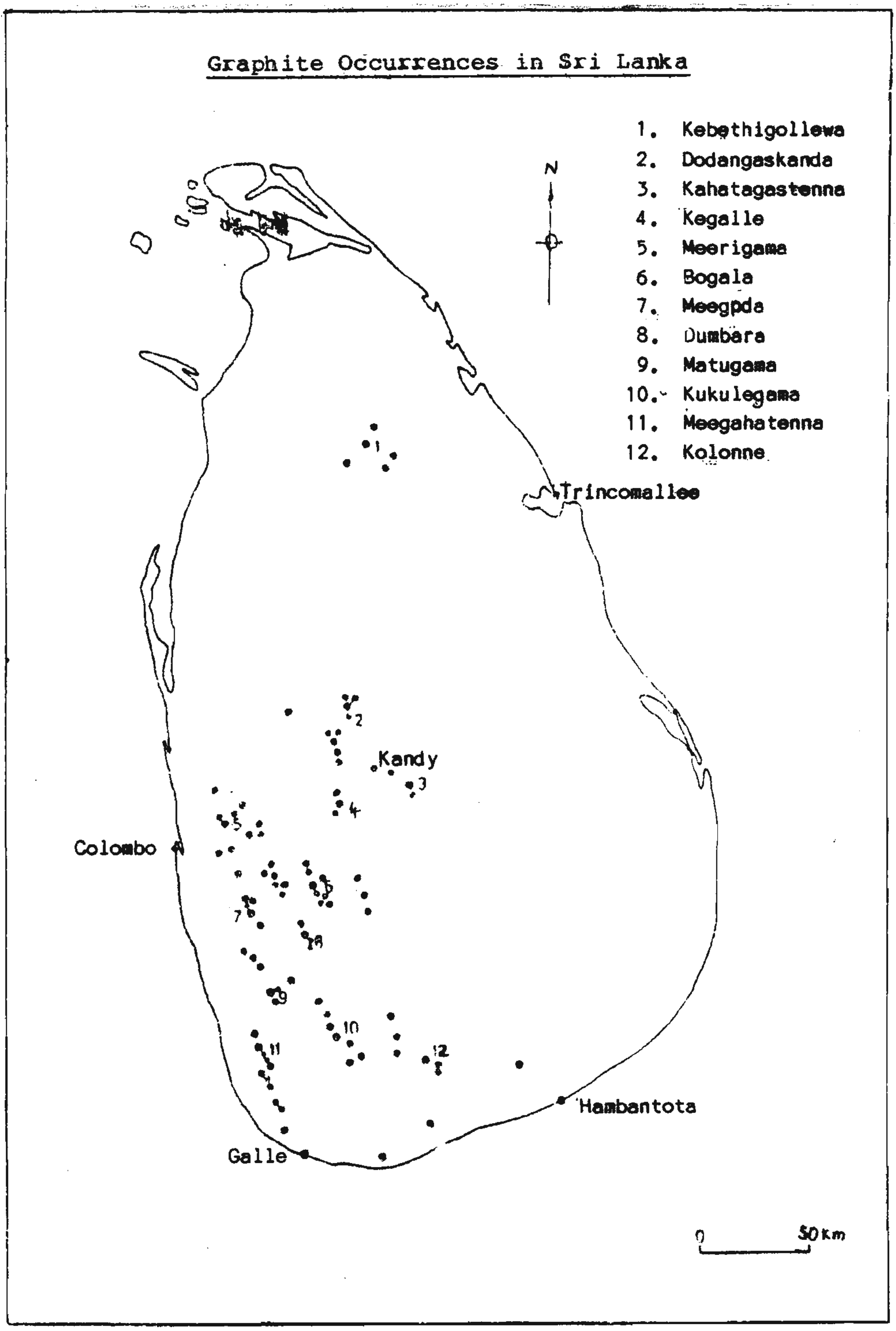
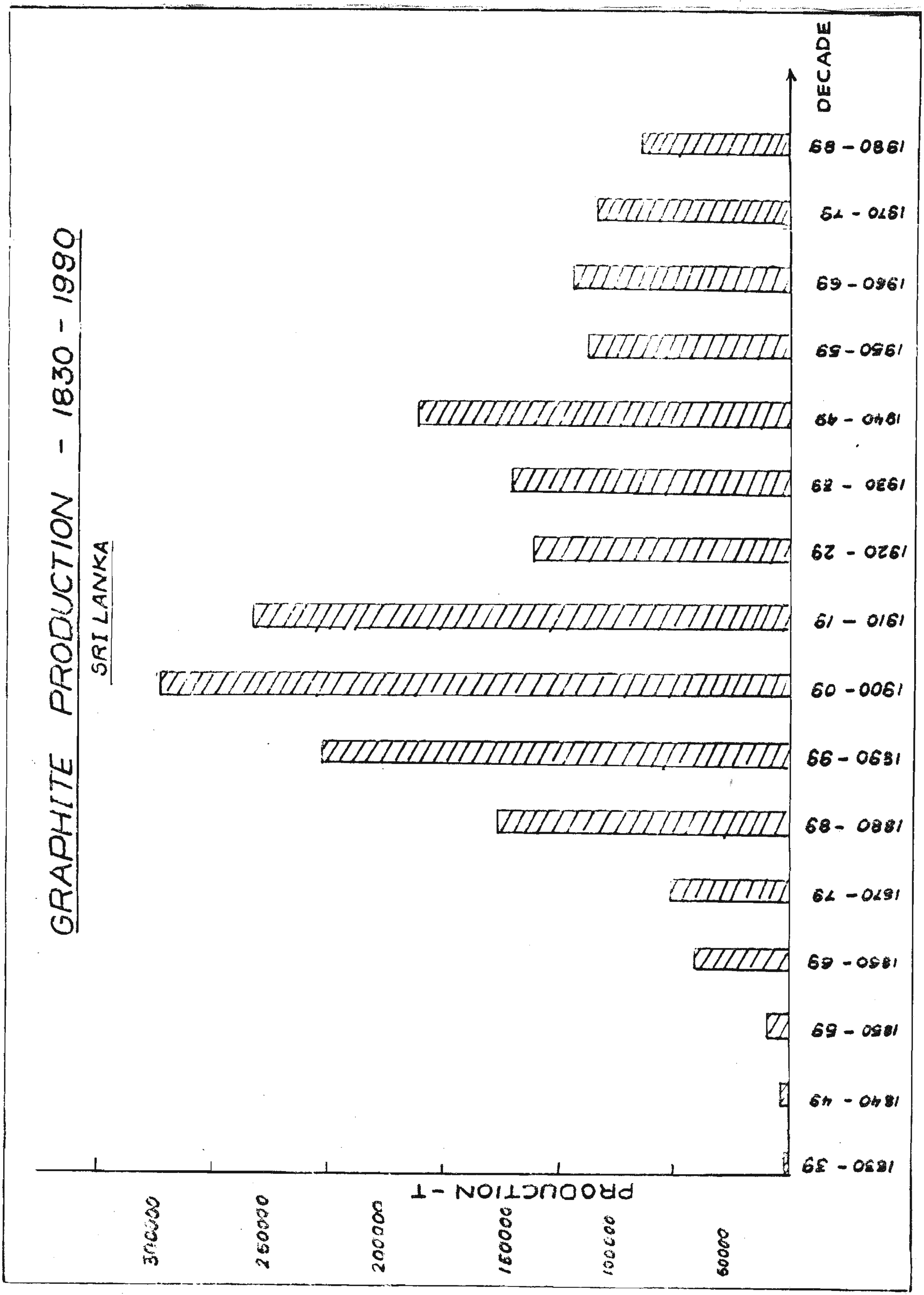

Graphite Occurrences in Sri Lanka
1. Kebethigollewa
2. Dodangaskanda
3. Kahatagastenna
4. Kegalle
5. Meerigama
6. Bogala
7. Meegoda
8. Dumbara
9. Matugama
10. Kukulegama
11. Meegahatenna
12. Kolonne
N
Trincomallee
Kandy
Colombo
Hambantota
Galle
0
50 Km

FIGURE 2


GRAPHITE PRODUCTION - 1830 - 1990
SRI LANKA
DECADE
1830 - 39
1840 - 49
1850 - 59
1860 - 69
1870 - 79
1880 - 89
1890 - 99
1900 - 09
1910 - 19
1920 - 29
1930 - 39
1940 - 49
1950 - 59
1960 - 69
1970 - 79
1980 - 89
PRODUCTION - T
50000
100000
150000
200000
250000
300000

GEOLOGY OF GRAPHITE

D.M.S.K. DINALANKARA

SYNOPSIS

Sri Lanka has some of the world's best natural graphite of vein type, the purity being 95-99% carbon. Other modes of occurrences are dissaminated flake graphite in country rocks and in form of vugs, lenses and pods which are commercially not important to Sri Lanka. Vein graphite is mined at Bogala, Kahatagaha, Ragedara and also from a few smaller mines located mostly in the south-west sector of the island. It is significant that most of the graphite occurrences in Sri Lanka reflect the association of a metamorphosed pelite - sandstone - limestone sequence and charnockitic rocks. Graphite bearing pelitic gneisses are the most common and appear to be the most prominent host rock. Formation of economic graphite deposits are tectonically controlled and they occur in the axial regions of anticliness and domes.

Vein graphite mineralization in the fissures has taken place repeatedly and the intrusion has been in fluid or semifluid state in association with silica rich hydrothermal solutions. As a result a single graphite vein is composed of several thin parallel bands of graphite containing a few gangue minerals chiefly silica, carbonates and sulphides, which are the main impurities of the ore.

INTRODUCTION

Sri Lanka has been a well known natural graphite supplier to the world since 1820. This reputation is mainly due to its extremely high purity, the purity being above 95% carbon. She produces two types of graphite namely amorphous and crystalline flake/needle. Current annual production is around 9000 M. Tons, exploiting mainly from three deep mines situated at Bogala, Kahatagaha/Kolongaha and from a few small scale shallow mines. Although the present contribution to the national economy by this commodity is considerably low, (less than 0.1%), it had been a major industry similar to the plantation industry in the early decades producing in the range of 20,000-30,000 MT of graphite per annum particularly during the two world wars. There had been around 3000 pits/mines during the past boom time, but over 90% of them were confined to under-developed shallow pits and adits. As a consequence, however, the early prospectors had discovered a large number of deposits scattered in the island particularly in the south-west sector. Owing to the fact that large number of deposits had been mined only to a limited depth, it is believed that substantially high reserves are still left behind at moderate to deeper levels in the island.

GEOLOGY OF SRI LANKA

Nine-tenths of Sri Lanka consists of precambrian metamorphic rocks. The metamorphic terrain is subdevided (Fig. 1) into the Highland series, the South-Western group and the Vijayan complex (Cooray 1978). The highland series is a NE-SW Trending linear belt consisting mainly of quartzites, marbles, calc gneisses, graphite shists, pelitic gneisses, granulites and charnockitic gneisses, formed mostly under granulite or upper amphibolite facies metamorphic conditions. These rocks are considered to be mostly of metasedimentary origin, although the charnockitic gneisses are thought to be of meta-igneous origin (Munasinghe & Dissanayake, 1980), but there is still much debate about their origin.

The rocks of the NNW-SSE trending South Western group are low pressure granulite facies metasedimentary rocks consisting of cordierite gneisses, scapolite-wollastonite gneisses, granulites and garnet-biotite gneisses and charnockitic gneisses.

The vijayan complex of rocks which are found on either sides of the Highland series are sub-divided into Western and Eastern units. The rocks of this complex are mainly granites, hornblende-biotite gneisses, migmatites and calc- silicate gneisses formed under amphibolite facies conditions.

Complex structural geological features have been formed in the vijayan complex while simple tectonic features are common in the Highland and the South- western groups. The Highland group displays a regional structural trend of NE-SW with major folds. The folds in the NE region are parallel, occasionally recumbent and frequently overturned to the East. In the central highland they display a double plunging synclinorium and anticlinorium type of fold systems (Fig. 1). In the Southwestern group the structural pattern is dominated by a series of parallel tight folds trending NW-SE to NNW-SSE and they are either upright or overturn to the West. Regional fractur lineaments have largely been developed in and around the central highland and most of them possess general trends of NW-SE and NE-SW. Minor scale fractures are abundant in the metasediments, and most of them are joints developed during the regional folding.

GRAPHITE OCCURRENCES

Graphite is widely distributed throughout the world. It occurs in many types of igneous, sedimentary and metamorphic rocks. Many occurrences are, however of little economic importance.. The more important are those found in metamorphic-hydrothermal deposits and in sedimentory rocks that have been subjected to regional or thermal metamorphism. Most, not all of the world's deposits of flake and crystalline graphite occur in metamorphic rocks of precambrian age associated mostly with marble, gneiss and schist. Vein graphite is also normally found in rocks similar to same rock types. Economic deposits of graphite include four main geological types.

1. Flake graphite dissaminated in metasediments

2. Deposits formed by metamorphism of coal or carbon rich sediments

3. Veins filling fractures and fissures in country rocks

4. Contact metasomatic or hydrothermal deposits in metamorphosed calcareous sedimentary rocks.

In Sri Lanka there are three main modes of graphite occurences, namely

a. disseminated graphite flakes in country rocks; (Fig.2)

b. vugs, lenses and pods; (Fig. 2)

c. Large vein graphite deposits (Fig.3)

It is interesting to note that all the above occurences in the island are confined to the Precambrian metasedimentary belts of the Highland and the Southwestern groups.

The disseminated flake graphite found in country rock is commercially not important to Sri Lanka as it's average content in the rock is 5 to 10%. At least there should be more than 20% graphite to be considered for commercial viability. Presence of disseminated flake graphite has been identified chiefly in the rocks of garnet-graphite gneisses, marble and some charnockites. Occurrence of a flake graphite deposit, containing 20% of graphite in the rock has been discovered by the author recently at Mitipola in the Ratnapura District. Presently, Canada is mining similar deposit containing 20% graphite in Quebec (Mining Magazine, July 1990). Major portion of the world's total production of graphite is derived from this type of graphite deposits and their average graphite content is 40%. Since these deposits are found at surface, they are known as surface deposits. These deposits can produce large quantities of graphite at a very low mining cost. However, they have to apply expensive processing techniques to upgrade the product over 90% C.

The second variety of, mode of occurence is rare in Sri Lanka. A few cses have been reported in Dumbar (Ratnapura), Bulathkohupitiya and Rangala (Hunnasgiriya).

The vein graphite is the most important type to Sri Lanka where as the entire graphite production comes from this source. This variety is rare in the other parts of the world. Consequently, Sri Lanka has a rare advantage in the international trade as only she can supply the high grade graphite in forms of lumps and chips where as other countries cannot do so. But, there are a few disadvantages such as; (i) veins are narrow, short and extending to deeper levels (Fig. 3); and (ii) mining cost is extremely high and low production capacity as it involves expensive underground mining methods. Occurrence of vein type deposits is abundant in the southwest quarter of the island, but only a handful of them are currently being mined. Presently active mining areas in the island are Bogala, Kahatagaha/Kolongaha, Ragedara, Mathugama, Bulathsinghala, Agalawatta and Dumbara (Fig. 1).

GEOLOGICAL SETTING :

All types of graphite occurrences in Sri Lanka are confined to the Precambrian metasedimentary belts of the Highland Series and the Southwestern group. One can infer that these occurrences reflect a metamorphosed pelite - sandstone- limestone sequence and charnockitic rocks. This type of rock units is common to graphite occurrences in some other parts of the world as well. Graphite bearing pelitic gneisses are the most common and appear to be the most prominent host rock. This is clearly seen in the pattern of distribution of economic graphite deposits, in the Highland series (Fig. 1). The deposits in the Highland series have been limited to scattered areas of Kurunegala, Kegalle, Vavuniya and Badulla, while in the Southwestern group there are NNW- SSE running belts of graphite deposits from Mirigama to Matara. The most common rock types which associate with graphite deposits are quartzite, charnockitic gneisses and pelitic gneisses consisting of garnet, biotite an sillimanite with or without cordierite and flake graphite may be present as and accessory constituent (Fig. 4). Further, veins of quartz and pegmatite are common in these regions.

Tectonically the majority of the graphite deposits of Sri Lanka are confined to anticlinal structures of close to tightly folded. It has also been observed that many of the ore-bearing antiformes have undergone complex deformation, developing refolds, local flexures, axial culminations and depressions (Fig. 5). These anticlines may be overturned or upright, but the most noteworthy feature is that they are always horizontal or gently plunging structures. Graphite bearing domes are commonly found in the Highland Group with a few occurrences in the Southwest group. Quite similar to anticlines, the graphite bearing domal structures too have similar fold characteristics. These domes are characteristically double plunging, approximately N-S trending, upright, close to tightly folded structures (Kahatagaha/Kolongaha, Rangala, Barigama, Kivulagala etc.). Further these domes are ellipsical to lensoid in outcrop shape with gradual thinning out at extremities. It is often observed that graphite bearing domes are local modifications of major anticlines, as in Rangala area (Fig. 5). This is a NNW-SSW trending long anticline, but as a result of culminations and depressions along the axis, two domal structures have been developed at two locations. Graphite is present in both domal structures except at points of axial depressions. Graphite occurrences in synclines are rare. A few examples are found at Siyambalapitiya, Bogala, Rangala and Ambalangoda. These synclines are also gently plunging, tight/open folds. It should however, be mentioned that most of these localities lie in close proximity to the graphite bearing antiformes or domes.

GRAPHITE VEINS

It is an outstanding feature that majority of graphite veins of Sri lanka possess common characteristic features. They can be classified as two structural types that are either normal or oblique to the axial plane of the aforesaid structures. Since most of the antiformes are approximately N-S trending, the preferred orientations of the veins are NWW-SWW, NEE- SWW and E- W. The presence of N-S veins is rare (Dinalankara, 1985). The dip of the veins is vertical to steep but southernly dipping veins are quite common. The strike lengths of the veins are in the range of 100-350 M and width of the vein varies between 1 c.m. to 50 c.m. The depth of the veins varies between 500 to 1000 m. In a single deposit, there may be a series of scattered parallel veins having above noted characteristic features, but only a few of them are minable. The minability entirely depends on the width of these high grade graphite veins. (Fig.6)

ORE GEOLOGY

Ore geology of the graphite veins of Sri Lanka appears to be common with slight variations in texture of the ore. In general appearence, a single vein is made up of a series of thin (2-10 cm) bands of graphite running side by side, paralle to each other (Fig.7).

The purity of the ore is controlled by the added gangue minerals and wall rocks. The wall rock contamination has occured during the graphite mineralization and is much pronounced in graphite mineralized in the fault zones. Detailed studies have revealed that purity of the ore changes systamatically from wall to the centre of the veins (Fig. 8). The major gangue minerals are silicates, carbonates and sulphides and their average contribution is quartz (60%), Iron minerals (20%), Calcite and dolomite (10%), feldspar minerals (6%) copper minerals (2%), mica (1%), and others (1%). Major iron minerals are magnetite, hematite, pyrite and phyrrotite. The copper minerals include mainly chalcopyrite with minor quantities of malachite and azurite. Major feldspar mineral is K. feldspar. Tourmaline may also be present in the graphite and pentlandite may occasionally found in association with sulphide minerals. Presence of siderite has been noticed in one of the mines in Kurunegala District (Ragedara).

The gangue minerals may associate with graphite in three forms such as pegmatitic bodies particularly in shallow veins, thin tabular veins in the ore and as disseminated fine grain particles in the ore. Most of the shallow graphite veins are low grade containing chiefly graphite, quartz and feldspar occcasionally changing in to pegmatitic with diminishing graphite. Graphite in these low grade shallow veins is always in coarsely crystallined flake form and sometimes appearing as radiating accicular structures. Thin veins or lenses of pure quartz, calcite/dolomite, pyrite or quartz/feldspar pegmatite are quite common in these ores. Randomly distributed country rocks in from of fine to very coarse particles in the graphite ore is found to a certain degree.

Chemical analysis of graphite samples from different localities show the presence of silica, iron, alumina, lime, potash, soda, magnesia, with minor amounts of copper, nickel, titania and volatiles derived mainly from the aforesaid gangue minerals. Comparis on of the variation of these elements with the ore grade clearly indicates the increase of SiO_2 with the decrease of ore grade (Fig. 9). Moreover, the iron content decreases with the increase of C% particularly above 85% C grade.

TEXTURE OF THE ORE

Vein graphite of Sri lanka can be texturally classified into amorphous, needle, flake and platy types of graphite. Basically all the graphites are microcrystallined to coarsely crystallined. Generally two or more of the above types of graphite may be found in one locality. For instance, Bogala mine consists of 65% of amorphous, 20% of coarse needle, 10% of flake and 5% of platy type of graphite while at K/K mines, the highest fraction belongs to the needle type. The amorphous graphite is fine grained, equigranular well compact aggregates and microscopically they are finely crystallined hexagonal flakes compact together forming a bee-hive like structure.

The needle variety is fibrous in texture and made up of 1-5 cm long thin (1-3 mm) needle shaped fibres (Fig.10) and they always prefer to crystallize perpendicular to any surface, like vein walls or foreign bodies in the ore (Fig. 8). Microscopically, cross section of a needle is rhombic shaped. The flake type is medium to coarse grained and generally found in book form. Thin veins of graphite occassionally show well developed zoning, containing the above noted types of graphite from wall to the centre of the vein such as bands of amorphous-needle-coarse needle-flake respectively. However, in most of the cases, this regular sequence is not seen due to the subsequent graphite intrution through the preformed veins from time to time.

WALL ROCK ALTERATION

There is no significant wall rock alteration in association with graphite veins but localized alterations may be seen occasionally. Visually, the affected area of the altered host rock is 1-3 cm in depth as indicated by well marked discolouration, change of grain size and texture and change of mineralogy (altered minerals). It is most common that gneissic texture of the metasediments have been replaced by fine grained granulitic texture as a result of recrystallization process. Kaolinization is also common in these areas and pinkish coloured alamandine garnets have been discoloured into dark brown. Presence of soap stones is a prominent feature in biotite rich wall rocks (K/K and

Bogala). Microscopically the depth of alteration can be traced up to 30-50 cm. with the identification of altered minerals. In this case, alkali feldspar has been partially altered to kaoline and most of the mafic minerals to chlorite and serpentine. This alteration can also be seen along the cleavages and minute fractures of some minerals and this probably indicates the affect of hydrothermal action in these areas. Moreover, silicification is considerably high in the wall rock bordering the vein.

It is remarkable that the graphite has migrated to the wall rocks from the vein and this migration is limited mainly to the altered wall rock zone. They occur particularly at grain boundaries of the coarse grained rocks, but thin section studies show their occupation in all the varieties of rocks especially in the grain boundaries, fractures and cleavages of minerals. Average concentration of graphite in these zones is 15%, but occasionally increases to 40-50% depending on the type of wall rock. Generally, coarse grain rocks, such as some granitic gneisses, marble and pegmaties tend to absorb much graphite from the vein. In some pegmatites, diffused graphite occurs even as small scale lenses and pods branching off from main veins when the pegmatite is cut by a graphite vein.

OTHER MINERAL VEINS

Apart from graphite, presence of variety of other mineral veins in the graphite bearing regions is quite common. They are thin (10-25 cm), Tabular, steeply dipping veins of pegmatite, quartz, sulphide (pyrite, chalcopyrite, phyrrotite), magnetite, carbonates (calcite, dolamite, siderite), tourmaline and mica (Fig. 11). Owing to their thinness and also due to chemical weathering these veins are not readily visible at surface, but in underground openings. It is interesting to note that these veins too follow the same orientations of graphite veins of the region.

Most of the pegmatites are vertically extending discordant veins and some are of discontinuous lensoid bodies. Their mineralogy is coarse to very coarse grained, equigranular quartz, feldspar and mica with minor quantities of garnet, pyrite, sillimanite, zircon etc. Quartz veins are composed of either pure quartz or quartz plus minor quantities of graphite, pyrite, feldspar, mica, calcite etc. Therefore, the vein quartz with above impurities appears to be resulting either from graphite- gangue assemblage due to segregation or quartz vein cross cutting graphite veins. Occurrence of calcite veins in graphite mines is frequently found and their distribution is somewhat greater in the vicinity of major graphite veins. some of the calcite veins carry graphite, quartz, feldspar etc.

DISCUSSION AND ORIGIN OF GRAPHITE

Sri Lanka vein graphite deposits are tectonically controlled and these tectonics can be classified as graphitiferous close to tightly folded anticlinal structures (Dinalankara, & Dissanayake 1988). Lithologically these graphite bearing structures possess a rock suite of quartzite- charnockite-pelitic gneiss with accessory graphite. It is believed that graphite reservoires have been formed at low pressure zones in these structures, preferably crest areas of antiformes during the regional metamorphism and deformation. Subsequently, they have migrated to the fractures under pressure, perhaps with the aid of hydrothermal solutions. This is evident by the association of afore said gangue minerals and veins of silicified nature and also the wall rock alteration. High silica content in graphite is also interesting to note in this respect.

Veins of quartz and quartz rich pegmatite are comparatively rich in graphite bearing regions and some of them carry graphite. Absence of graphite in those quartz and pegmatitic veins reported in other areas of the island reflect that they may not have been generated through graphite bearing zones. Similar observations have also been made in Indian occurrences by Krishan Rao & Malleswara Rao (1965) in which graphite transformation by quartz and pegmatitic veins picking graphite from graphite shists. Wadia (1943) and Cooray (1983) have described occurrence of graphite bearing quartz and pegmatitic veins localizing in shallow horizons in various parts of the country. Coats (1935) has observed systematic segregation of quartz and pegmatitic material from graphite towards the surface and similar veins have been observed by the writer in Rangala, Pussahena and Ragedara mines. These data reveal that the graphite and silicate material have migrated together in fractures and segregation of impurities has occurred at shallow levels with the change of P/T conditions. It should be stated here that graphite is a high temperature mineral. Moreover, presence of exsolution structures of unmixing silica and graphite has been noticed at some localities. In these structures, graphite is coaresly crystallined while silicates (Quartz + feldspar) are in form of a fine grain anhedral matrix. Edwards (1954) has suggested that these structures are common in narrow veins where temperature of the intrusives is well above the host rock and they are the best evidence of simultaneous deposition of high and low temperature solidifying minerals. He also states that the temperature in these areas should be in the range of 450^{o}-$500^{o}C$.

Perfect fibrous texture of graphite and their mineralization perpendicular to the vein with zoning suggests the migration of the ore in fractures has been in a form other than solid state. However, Philips (1974) suggests that the fibrous texture is a result of a tensile strain crystalization in which crystals under stress become elongated at right angles to the principle stress direction and in direction of maximum strain. However, this is less applicable to vein graphite as there are zoning of graphite with different type of graphite in a single vein. Presence of slickenside and "bent needle" graphite indicates the solid state movements but due to post mineralization movements. Fluid state of migration is supported by exsolution structures, segregration of gangue minerals from graphite, wall rock alteration and hydrothermal action. Gaseous state migration is less reliable as there are presence of large angular floated brecccia of wall rocks in isolated positions of the ore and it is noteworthy to state that in which needle graphite has crystallized, perpendicular to rock surface.

The association of vein graphite deposits with calcareous rocks has led some workers to believe that the CO_2 derived from decarbonation reactions was the source of carbon for the production of graphite (Hapuarachchi 1977). Based on the composition of the fluids under granulite facies condition and the role of these fluids in their transport through the crust, Katz (1987) was of the opinion that graphite is a direct consequence of granulite facies metarmorphism in the presence of CO_2 rich fluid. Fluid state mineralization is also favoured by Dissanayake (1981) and Dinalankara, (1986) but the source of carbon as organic matter that would have been preserved in the precambrian sedimentary basin. Erdosh (1970) however, favours solid state of mineralization as a result of flake graphite in the country rocks migrated into the fractures under pressure. Mineralization of graphite in fractures is pressure and temperature dependent. The formation of four graphite types in veins as described previously, has been controlled by the reducing temperature and also by the migration rate in the fractures. This is well exhibited by the graphite zoning in some veins from wall to the centre of the vein. When the migration rate of graphite - hydrothermal assemblage was high, rapid cooling, fast solidification, poor crystalinity of the minerals and also poor separation of graphite-gangue minerals have been resulted. The segregation in rapid cooling is evident by quantitative analysis of amorphous graphite (Bogala) and needle/flake graphite (K/K) where the former shows a high impurity content. In case of slow migration due to slow opening up of fractures, perfect crystalinity of graphite may result and also the low temperature gangue minerals may systamatically separate and concentrate towards the top of the veins. Lendis (1971) has shown that perfectly formed crystals of graphite may develop approximately above 400°C under a pressure of 6 kb and Grew (1974) suggests that it is largely temperature dependent and which is about 660°-690°C. As far as pressure is concerned it is believed that a substantially high pressure might have been developed in the veins by invading graphite hydrothermal assemblage. This is evident by diffusion of invading material into the wall rocks, minute fractures and cleavages of minerals. This pressure has also forced the development of fracture openings.

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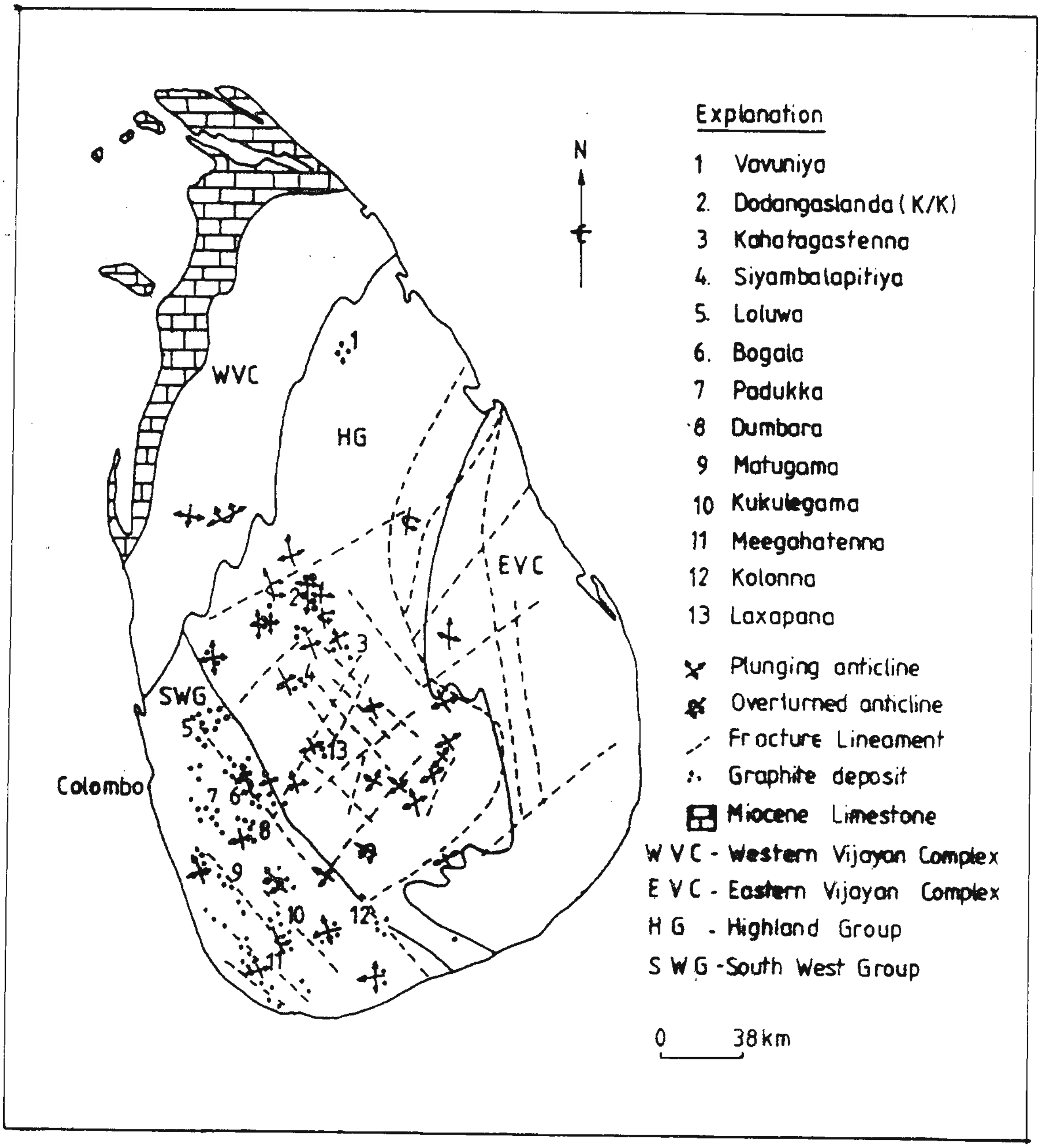
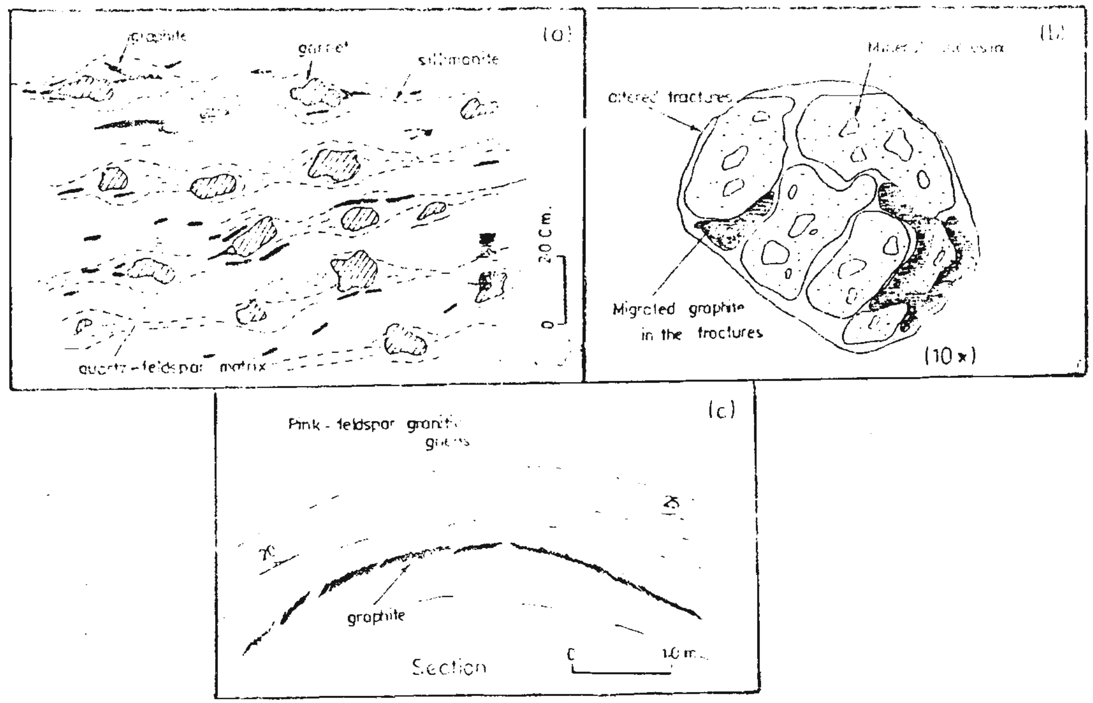
FIGURE 1



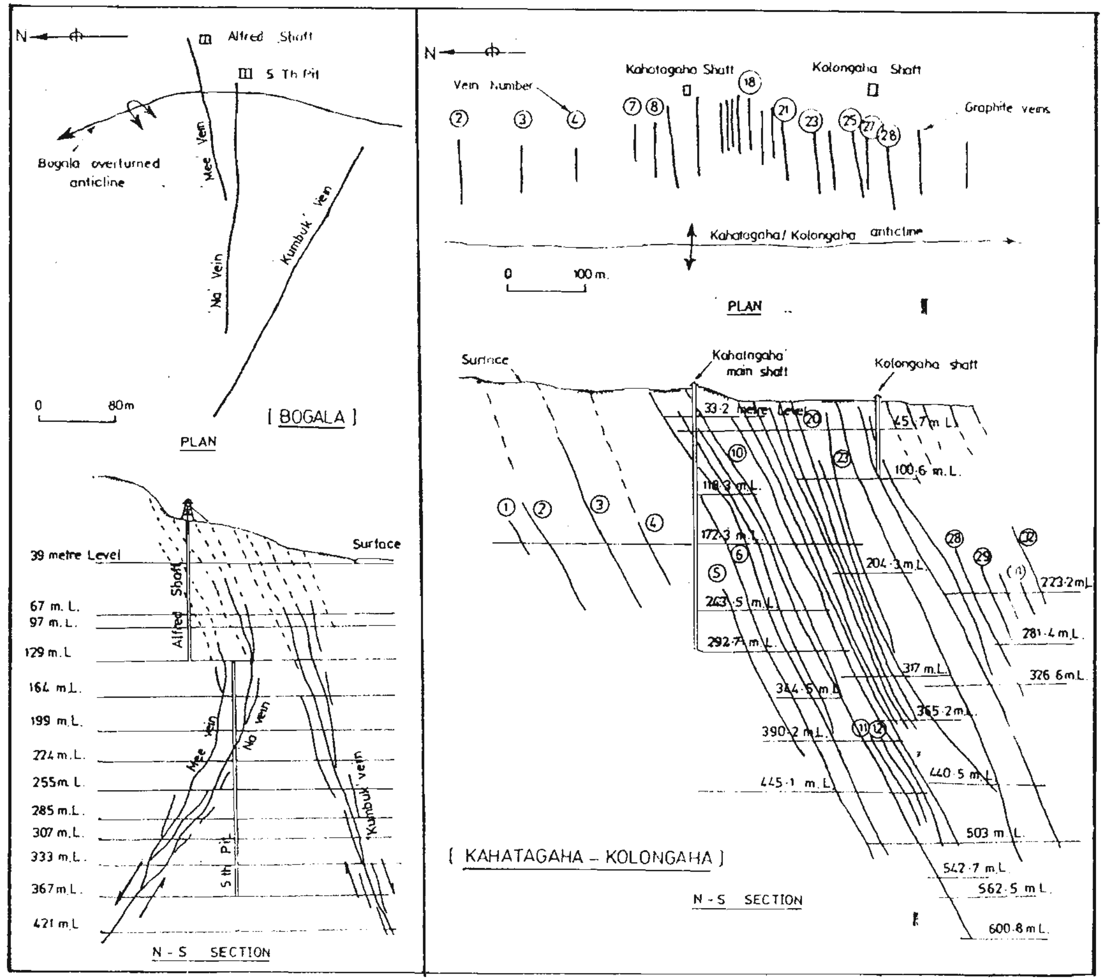
Graphite occurrences and Geology of Sri Lanka

FIGURE 2



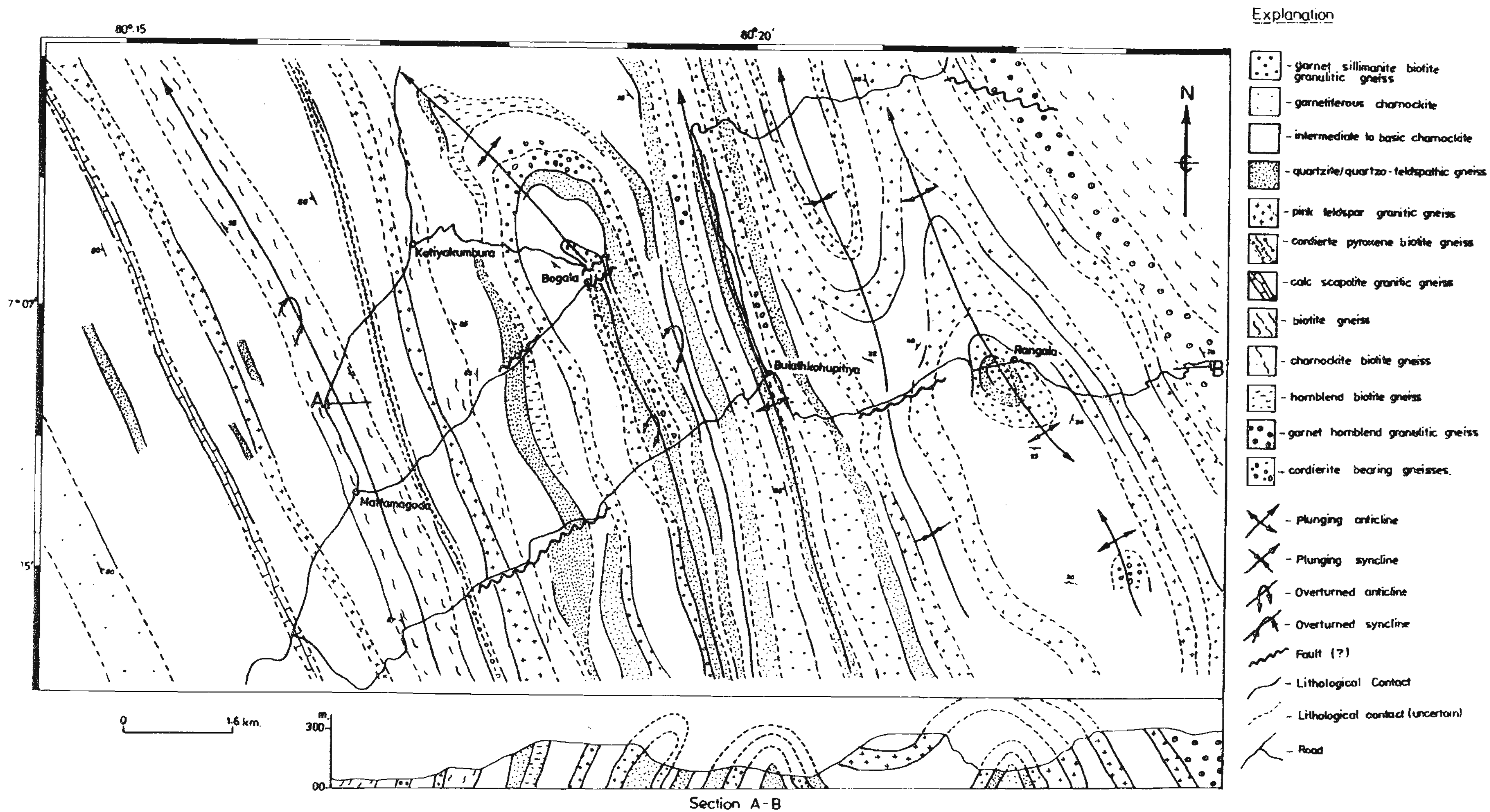
Modes of occurrences :- (a) disseminated flake graphite in Country rock (Khondalite), (b) Thin section showing graphite occurrences in minute fractures of a garnet crystal, (c) a lens-shaped graphite mineralized in foliation.

FIGURE 3



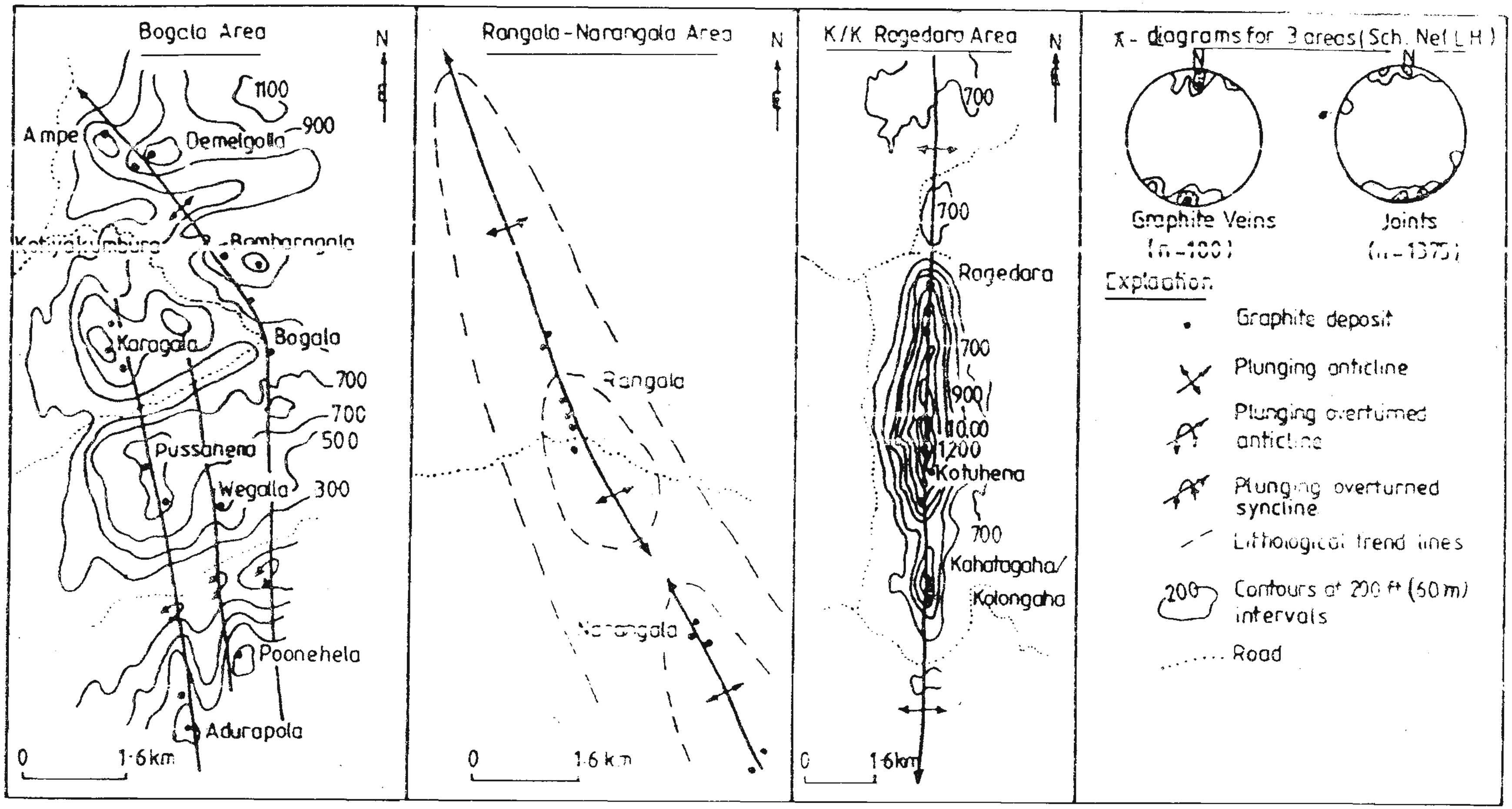
Plan and Section of Bogala and Kahatagaha/Kolongaha graphite veins.

FIGURE 4



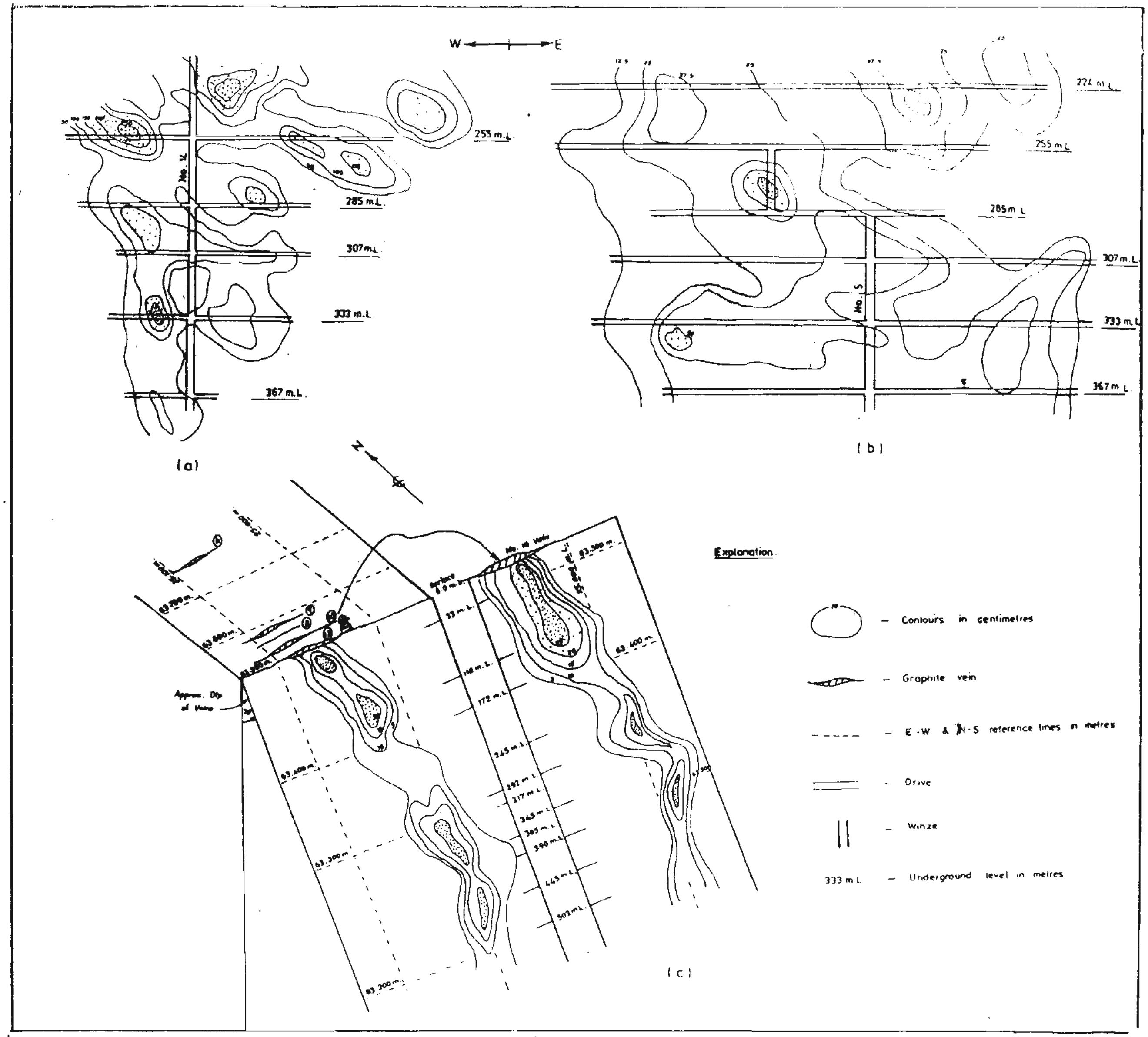
Geology of Bogala - Rangala Graphite bearing region.

FIGURE 5



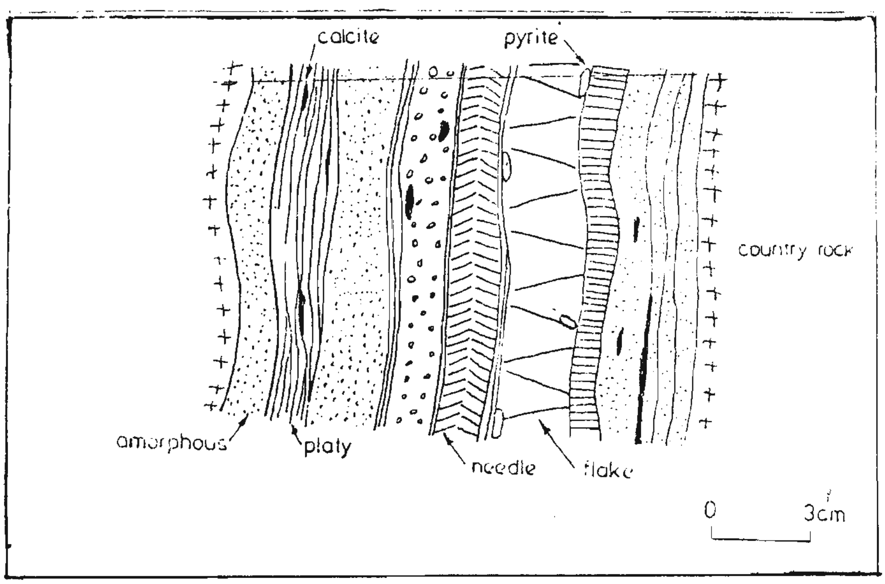
Anticlinal /domal structures showing refolding, local flexures (Bogala), axial culminations and depressions (Rangala & K/K) and graphite mineralization at axial culminations.

FIGURE 6



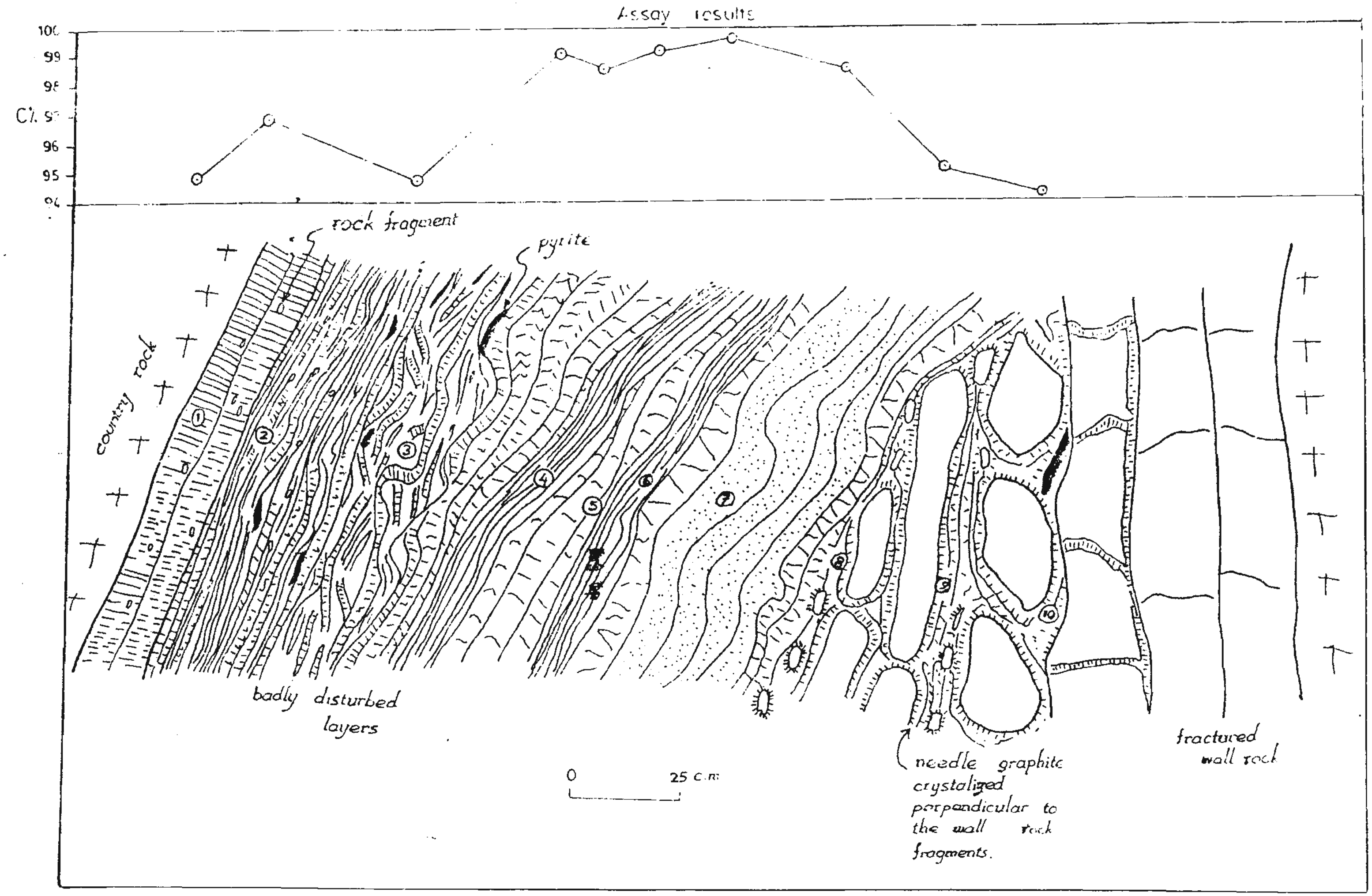
Variation pattern of vein widths of graphite veins:- (a) Mee vein (Bogala Mine) (b) Kumbuk vein (Bogala Mine) (c) No. 10 & 13 veins and block diagram of Kahatagaha ore body.

FIGURE 7



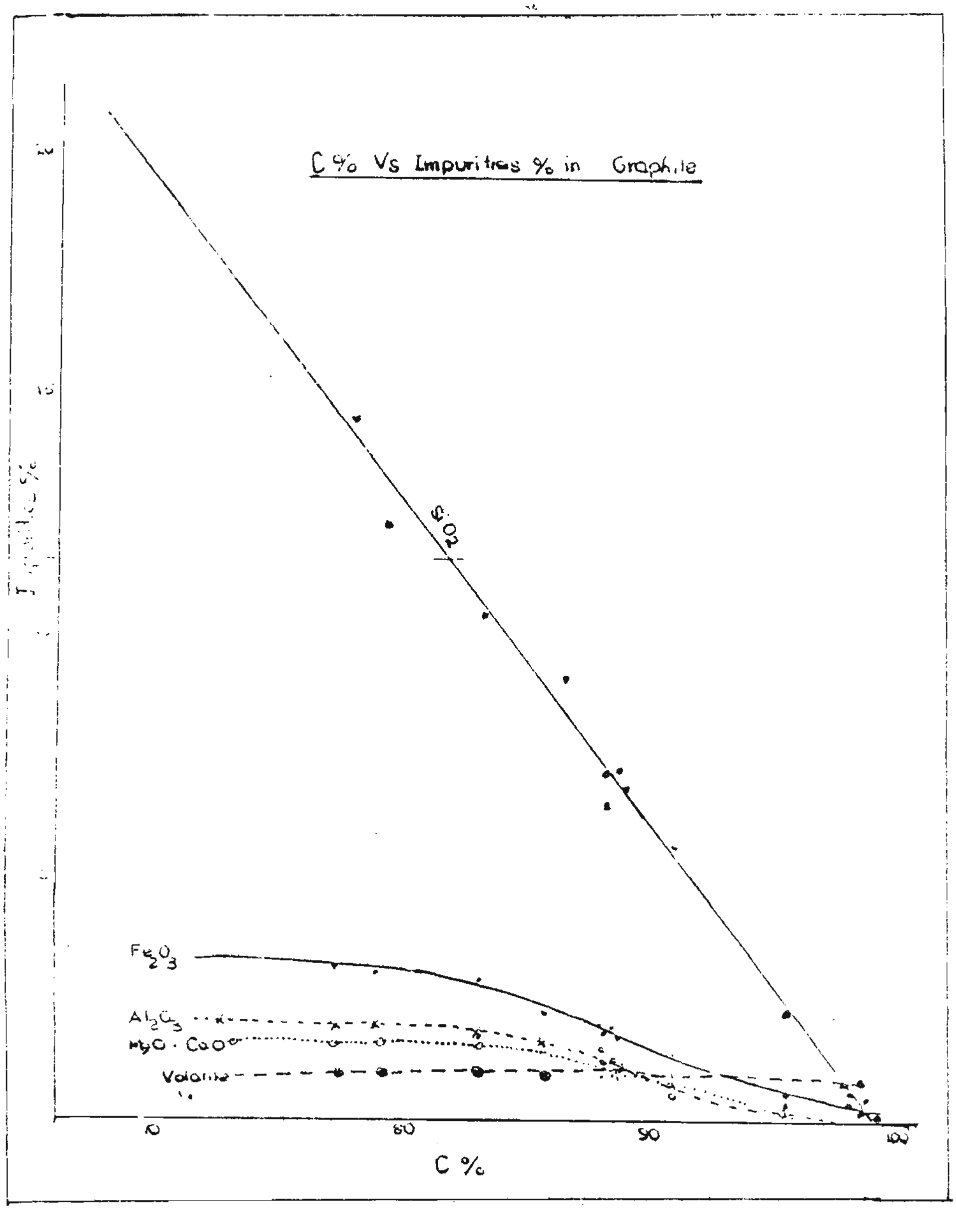
A graphite vein showing different types of graphite and bands running parallel to each other.

FIGURE 8



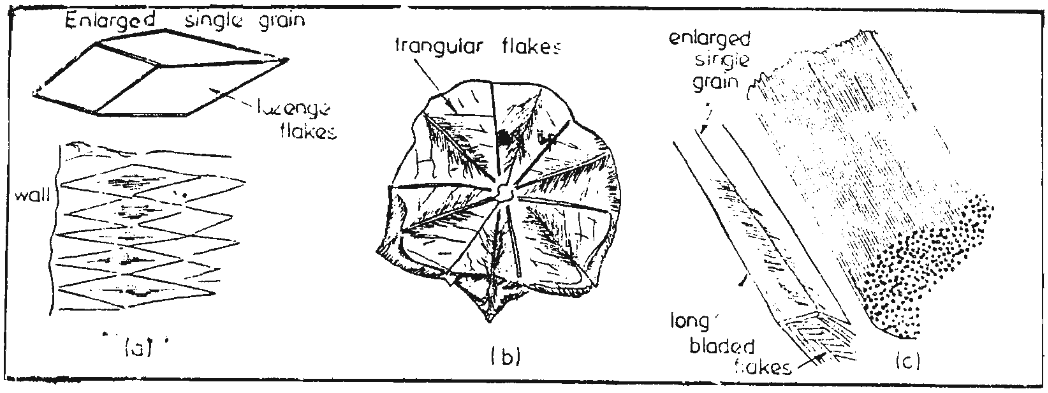
A section of a graphite vein (Bogala Mine) showing variation of the purity. Nos. 1-10 indicate the locations of samples taken for assaying.

FIGURE 9



Variation of impurities in graphite.

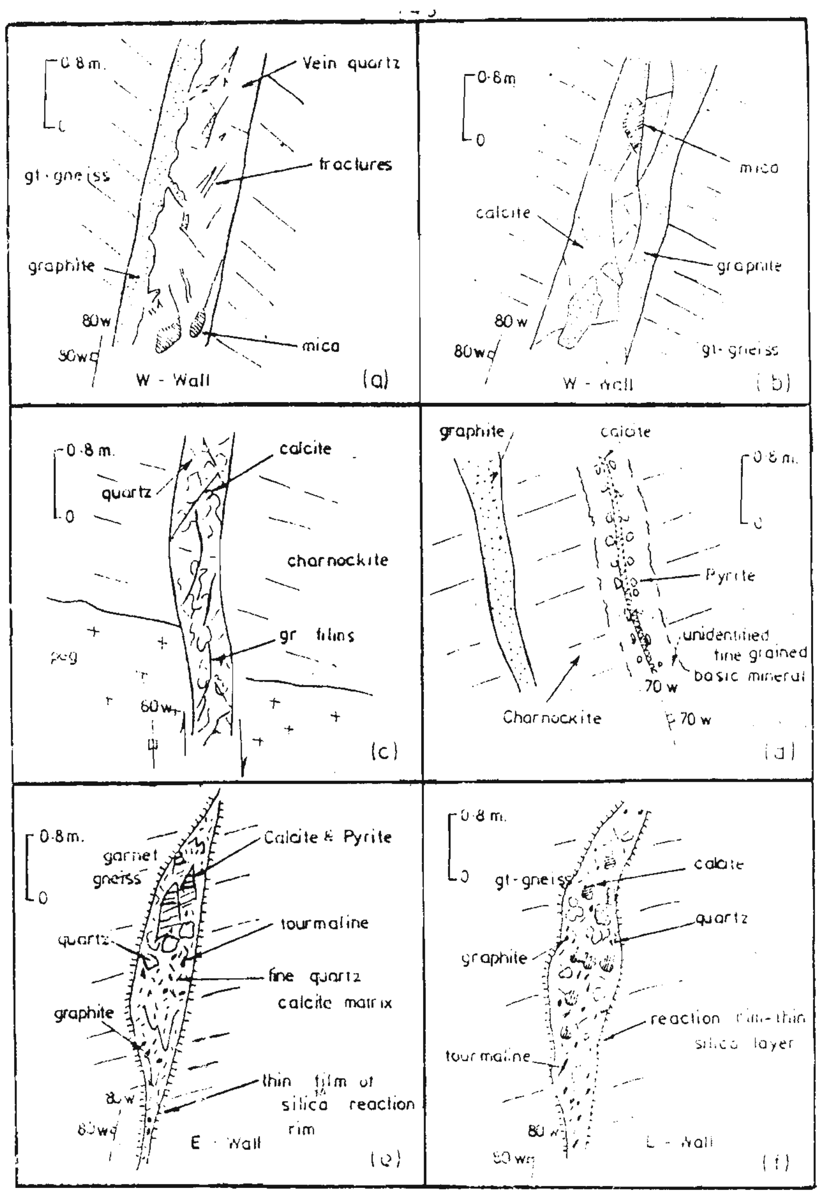
FIGURE 10



Diagrammatic view of graphite:-

(a) Wedge shaped needles or flakes. (b) tabular radiating or acicular flakes (c) Fine grained needles.

FIGURE 11



Some Mineral veins found in Bogala mine region

(a) Quartz vein. (b) Vein of calcite & graphite. (c) vein of calcite & quartz. (d) dyke of calcite, pyrite and basic minerals. (e) Vein of calcite, quartz, pyrite, tourmaline & graphite.

MINING OF GRAPHITE

N. GREGORY

DIRECT OPERATIONS :

Drilling of rock & ore

Blasting of rock & ore

Loading of rock & ore

Transport of rock & ore

Transport of men & material into and from mine

Erection of underground supports

INDIRECT OPERATIONS

Water and drainage management

Draining of gasses (coal mines)

Mine ventilation

Mine lighting

Mining is, extraction of valuable minerals, precious metal ores base metal ores from beneath the ground, ensuring maximum safety, at the lowest possible cost, and long term profitability. The mining involves drilling, blasting in order to break down the rock, loading and transport of the material to the surface. Mining has to be safe, therefore ground stability must be ensured, therefore the need for underground supports arise. Ventilation must be provided for the workmen.

Mining can be open cast as in Eppawela apatite mining or underground as at graphite mining at Bogala.

When an ore body is discovered, depending on the depth of it from the surface, ground conditions geometry of the ore body and economics of extraction by different methods, the mining method has to be decided, that is to mine by underground mining or surface mining. At Bogala the mineral deposit is of vein type. The ore body at Bogala consists of three major and several minor subvertically dipping graphite veins surrounded by high metampophic rock. The horizontal extension of the major veins is about 130 m to 300 m with thickness varying 0.28 meters to 0.98 meters and exceptionally several meters.

After the decision is taken to mine by underground operation, by what kind of access the ore body could be reached has to be decided. This could be done in many ways.

Access by

1. Shaft - Vertical or inclined
2. Adit
3. Ramps

At Bogala, access to the mine is by two vertical shafts in series. Two electrically driven winders drive the cages in these shafts which transport men & mineral to and from underground and underground transport is by mine cars - In mining operations the winders are used for hoisting material to and from underground. The winders are selected in considering the following.

1. expected capacity
2. the speed
3. pay load
4. depth

When a winder is choosen for a mine it should at least be used for about 15 to 20 years, as the mine grows deeper & deeper, the shaft capacity reduces, therefore planning for about 20 to 15 years ahead to keep the required capacity at that time is essential. It should have safety devices for the following.

1. over speed protection
2. protection against sudden power failure
3. protection against over winding
4. safety brakes & service brakes

At Bogala, for hoisting, two single drum hoist are used one at the surface and one at 72 fm. level. This is a case of multiple hoisting. The capacity of lower capacity shaft dominates if there is no production above the higher capacity shaft level.

The hoist rope is the most important component of the mechanical system. In selecting the required rope following are considered

HOIST ROPE :

Ratio of diameters of rope & drum

Required safety factor

Breaking strength of the rope

Depth of the shaft

Weight per foot of the rope

EXTRACTION OF THE ORE

When the access is made to underground it may be necessary to tunnel through the rock to reach the ore body. At Bogala Mines, rock tunnels are excavated from the shaft to intersect the three major graphite veins. The tunneling is a sequential operation where the activities are,

1. Drilling of rock
2. Loading the drilled holes with explosives
3. Blasting (Electric or fire)
4. Mucking (Removal of debris)

This is a cyclic operation.

There are different types of blasting patterns (designs).

1. Burn cut
2. Wedge cut etc.

The required type is decided for the job and blasting pattern is decided. This is done mathematically and adjusted to get the maximum pull out, good fragmentation, minimum vibration and damage to neighbouring areas by trial & error, good results in this area is achieved by the experience you have in rock blasting. Use of electric delay detonators gives good breakage and good fragmentation and vibration and damage could be controlled. There is a delay in milli seconds in blasting and each round fire after an interval of time.

Removal of debris is done manually at the mines but mechanical equipment could be made use of, the loaded trucks are hoisted to the surface or where it is required.

ROCK DRILLING & ORE DRILLING

I would like to take both together as it is the same process involved. There are many types of drilling machines.

1. Rotary
2. Percussion

Drilling Machine : Air leg type machine

Jumbo drills

These machines are normally operated by compressed air. The correct pressure of air and water is necessary. Water is used as the drilling fluid, it cools the drill bit and washes the rock particles which get out. Normally at the mines 5' or 3' holes are drilled in the rock, 30-35 holes for a tunnel face and for the ore body. Few holes are drilled if the ore is soft if large amount of explosives are used ore dilution will occur. The selection of drill bits depends on the hardness of the rock. In mining industry, many types of drilling machines are used. The machine should be maintained in good condition to get maximum efficiency.

EXPLOSIVES & BLASTING & ACCESSORIES

Type of explosives

Explosives

High explosives	Blasting agents	Special explosive	Blasting methods
T.N.T.	Anfo	Sesmic	
Dynamite	Slurries		Explosive agents
Gelatine	Emulsions	Permissible	Mechanical Methods
	Hybrid ANFO/ Slurry	Shaped	Water Jets
		Binary	
		Lox	
		Liquid	

The manufacture of explosives for civil use commenced in 1864, when Alfred Nobel set up his first company, Nitro Nobel to commercially exploit his invention of Dynamite. For rock and ore blasting the explosive used are dynamite or gelignite. The choice of explosive depends on the following.

1. High detonation velocity
2. Resistance to water
3. Handling safety
4. Loadability
5. Rock breaking characteristics

The other accessories needed for blasting are

1. Safety fuse
2. Plain detonators or electric detonators

3. Exploder

4. Bean hole connectors

5. Port fires

At Bogala S.L.9 G drilling machines, are used with integral drill steel for rock drilling. 80% gelatine and 60% gelatine are used with safety fuse and plain detonators for cross cutting and driving. In shaft sinking, electric detonators are used for safety reasons. Explosive consumption for cross cutting and shaft sinking is approximately 3 kg/cu. meter. For winzing and driving, only 1/3 of this is consumed.

With this background information, I would like to move on to the techniques applied at Bogala Mine to develop the ore body and extract the ore.

Development of the Bogala Mine is carried out from the completely concrete lined twin cage rectangular main shaft sunk from the surface to 130 m level. From this level sub shaft is sunk to 307 m. level and it is kept deepening. The working levels are spaced at 30-35 m. vertical intervals. The extraction is below 130m levels. Since the foot wall tunneling of the main drives were found to be expensive, the main drives were established in the graphite vein itself. By this system, the cost of the drives are recovered by the graphite extracted in the process. The roof of the main drives are timbered or concreted to hold back the roof graphite from coming loose. Below 130 m. all development work are in these main veins namely Na, Mee and Kumbuk, but at the 130 m. level over 1300 meter of cross cutting was carried out in order to intersect vein in northern and southern boundaries of the Bogala Mine. Developing the known veins involve driving 1.8 m x 2.0 m tunnel in the veins and winzing or raising 2.0 m x 4 m connection between main levels. These winzes or raises which are at 35 m interval distance along the drives has one ladder compartment and another hoisting compartment which is used as a haulage way and chute for graphite and waste rock.

Development of graphite vein is complete with exposure of the ore body on all four sides to inform 35 m x 35 m block and then estimating the ore tonnage in these blocks, on the average vein width exposed on all four sides.

MINING METHOD

Most of the Bogala stopes are worked by the cut and fill method. When the vein width exceeds 1.5 m special stoping practices have been adopted.

About 90% of the working stopes are developed in the form of 35 m x 35 m square blocks with winzes/raises connecting the upper and the lower level drives at 35 m. intervals. The winze/raise connections are timbered and divided into two compartments, and for the ladder ways the other compartment is used as a ore chute. These stopes are, worked by cut and fill method.

Stoping is started from the bottom of the raise/winze connection by removal of a 2m high bench towards the other raise/winze connection. After the two bottom benches are removed from raise to raise, approximately 1/2 m thick sill concrete is cast insitu and waste rock is packed on this sill concrete. By this benching process, only graphite is extracted either by hand baring or with light blasts, precaution being taken to lay a jute mat on filling to prevent ore contamination. The broken ore in the stope in hauled into chute/holes by means of wheel barrows. Thereafter, the wall rock is blasted if working space is required. The waste rock obtained is used to fill stope. This process is continued to the upper level and no crown pillar is left.

When the vein width exceeds the width of the stop drift, long timbers or joined timbers are required for roof fixing. In wide veins, the extraction is carried out in two stages. One half of the graphite vein will be advanced and after removal of the graphite, this part will be filled with waste rock and other half will be extracted later.

When badly shattered or wide crushed graphite stopes are encountered upto a maximum depth of 12 meters, winzing type extraction is carried out. In this method vertical or inclined slices along the short wall of the winze are removed in section and the void of extracted slice is filled with waste rock after timbering. This method is used to cover very bad ground as it involves heavy timbering costs, and additional hoisting and handling problems.

TRANSPORTATION OF ORE FROM UNDERGROUND TO SURFACE

This is one of the most important considerations in the efficient operation of a underground mine. Often the determining factor between profit or loss is the quick removal of ore and waste from the working places to surface and the other function of the transport system is moving the supplies to underground working places with minimum interruption to the loading process. Transport of men rapidly but safely.

The following are used in general in mines.

Mine cars

Locomotive on track

Belt conveyers

Rubber tired haulage equipment

The choice of underground haulage system should be one that gives the smallest overall cost of ore removal during the life of the mine and having necessary safety requirements.

In selection of a haulage system these are also considered.

Road way type - soft, smooth, rail type, hard

Work area dimension

Roadway attitude

Type of hauler - load rails, cars or buckets

Power consumption - Electric, diesel, mannual compressed air

Ventilation - Specially for diesel powered system

Capacity - Requirement for mine capacity

Man power - Automatic systems and manual systems

The next important consideration is hoisting of material from underground (after haulage) to the surface.

- Hoisting of material in a cage or skip

- Sending supplies to underground

- Transport of men

TYPES OF HOIST AVAILABLE

a. Drum hoists

b. Friction hoist

Drum hoist can be single drum or double drum.

The ore and the waste rock transportation at Bogala mine could be broadly classified as follows.

a. incline hoisting in winzes

b. level transportation by mine cars

c. vertical cage hoisting of mine cars

Incline hoisting is carried out mainly at levels below 410 m level and in winzes. Ore from stopes are loaded into kibbles with bottom opening doors which are placed on trolleys, hand trammed to the inclined winze where it is hoked onto a hoisting rope and hauled to the upper level. This is then emptied into 3 1/4 mine 3/4 cars, hand trammed to shaft station and hoisted to the surface via sub shaft of depth 410 meters. In this shaft double deck cage operates which hoist two cars at a time. Once the mine cars reach the surface, they are hand trammed to a grizly pit for the seperation of the ore in to sizes over 3" and under 3".

UNDERGROUND DRAINAGE

Geographically, Bogala is situated in an area where the annual 500 mm rainfall is experienced round the year. It is observed that the country rock is weak and found to be permeable. Main underground pump stations and pumps are situated in levels 52 f, 72 f, 126 f, 205 f. %o-80 H.P. centrifungal electric pumps are used in these levels. 120 million liters/day is handled by these pumps. Objective of water pumping is efficient and safe working.

VENTILATION SYSTEM

Bogala Mine has a forced ventilation system operated by two 250 H.P. ventilation fans installed at the surface. This system along with the natural ventilation current, provides a reasonably cool working environment. Booster fan is used underground for efficient air flow. In the ventilation system the important functions are

1. Quantity of air blown in, depending on number of workmen

2. Air speed without disturbing the dust

3. Removal of polluted air

UNDERGROUND SUPPORTS

Types - concrete

steel

timber

rock bolts

Function -

keep the workings stable

Safe working

Roof control and stop roof falls

Filling of excavated areas

The essential elements of mining are extracting ore from the earth's crust and maintaining adequate stability in surrounding ground. Mining at Bogala requires timber, concrete, and steel supports to keep the mine stable and for safe working of the mine.

PROCESSING OF GRAPHITE

S. RAMAWICKREMA

OBJECTIVE OF PROCESSING

(a) It is to extract the values of minerals from the ore sent to the mill, economically. And also it is to balance all the financial cost and returns in such a way as to ensure the maximum profit from the operation. And also this is of two fold nature. That is technical and economic.

(b) It is to bring the marketable product or concentrate, in to the technical condition required by the customer, by removing or reducing unwanted constitutuents in the original ore to the specified percentages such as

i. particle size

ii. assay grade

iii. moisture content etc.

In the graphite industry it is to maximise the carbon recovery by using these principles. How it's being done in the graphite industry and why processing is needed to the 'Run of Mine' (what is coming out of the mine) could be explained as follows.

To have a clear view on this its better to know about the origin of graphite.

ORIGIN OF GRAPHITE

The chief mode of occurrence of graphite has been described by 'Wadia' as dissemination in crystalline rock, with embeded masas, veins and graphite pockets.

But vein type (Bogala deposit) is thought to be hydrothermal in origin. It occurs filling fissures, fractures, and cavities in ignoeous rock. The size of particle within the vein can vary from microcrystalline to coaser and flaky.

When consider the origin of graphite it occurs filling fissures, fractures, cavities, when this process takes place, rock particles mostly quartz and calsite are embedded in graphite veins as rock intrusions. This could be seen in the figure (1) clearly.

In the process of graphite extraction these embeded rock particles are extracted along with the graphite and comes to the surface as 'run of mine'. And also same rock particles which break due to blasting actions too get mined with graphite and comes to the surface. Therefore if we analyse the carbon content as it is, it is low and lies between 85% to 87% carbon. But by the processing activities it could be increased even up to 99 + % of carbon.

METHODS OF UPGRADING

1. Visual
2. Density
3. Physical and chemical
4. Electrical conductivity
5. Radioactivity
6. Shape
7. Texture

VISUAL

Manual or mechanised grading and picking by colour, luster, florescence, for removal of mine waste selected specimen minerals.

DENSITY

Exploitation of differing rates of settlement through fluids of solids of different gravities applied in jigging, dense media seperation shaking table work and classification.

PHYSICAL & CHEMICAL

Solvation of minerals by chemical methods from its gangue, modifing surface reaction as in froth-flotation etc.

Methods of ore treatment has to be chosen which is appropriate to a specific ore as well as to a set of principles. Since there are several types of ore complexes such as,

- massive
- intergrown
- Disseminated and
- vein type

Out of these complexes Bogala deposit could be considered as vein type complex.

In vein type complex mostly chosen methods of upgrading are visual, density and physical. Separations of values using these methods could be seen clearly.

Initial processing drawing

Crushing flow sheet and

Flotation drawing

Separation of value in this mine is done in three stages. That is

For 90% and above carbon grades, by using visual methods

For 70% carbon to 90% carbon grades, by adopting density methods

And for below 70% carbon grades, physical methods

Value adding to the minerals is done according to the buyers specifications. Most of the consumers (Buyers) are very particular on specification as they are professionals.

Eg. In Germany they use graphite in manufacturing brake liners. They insist for - 1.7 mm to 0.5 mm in grain size and 97% - 99% carbon.

In Japan they use graphite 80%-83% powders 300 # (mesh) as mould wash.

Benificiation works of Bogala mines clearly shown in the plant flow sheet.

FINANCIAL EFFECT OF UP GRADING AND BENIFICIATION

Financial gain with the effect of benificiation is clearly shown in the prising curve.

In 99 + grade

Eventhough the carbon content is high, selling price is lower than the 97/99 carbon grade of value added.

Higher carbon grades get lower price than value added product. Initial stages of the curve shows with the increase of carbon, price also increases propotionately. But it changes with the benificiation work.

GENERAL EFFECT IN THE WORLD MARKET

Eg. country : Japan

Imports to Japan and our share in the Japanese market is shown in the attached bar chart.

To increase share in the Japanese market, should produce more of 80/83% carbon grades by upgrading of low grades such as 40/45% carbon, by physical methods.

INDUSTRIAL USAGE OF GRAPHITE

Manufacturing of crusibles

Manufacturing of magnesia carbon refractory bricks

Brake liners

Carbon brushes (for heavy equipment)

Batteries

Pencils

Steel making

CONCLUSION

Adhering to correct processing patterns and correct benificiation work contributes a lot to financial gaining. And also it is very essential to maintain good standards for being in the worlds industrial market since it has to compete with other graphite producing countries such as China, Madagascar etc.

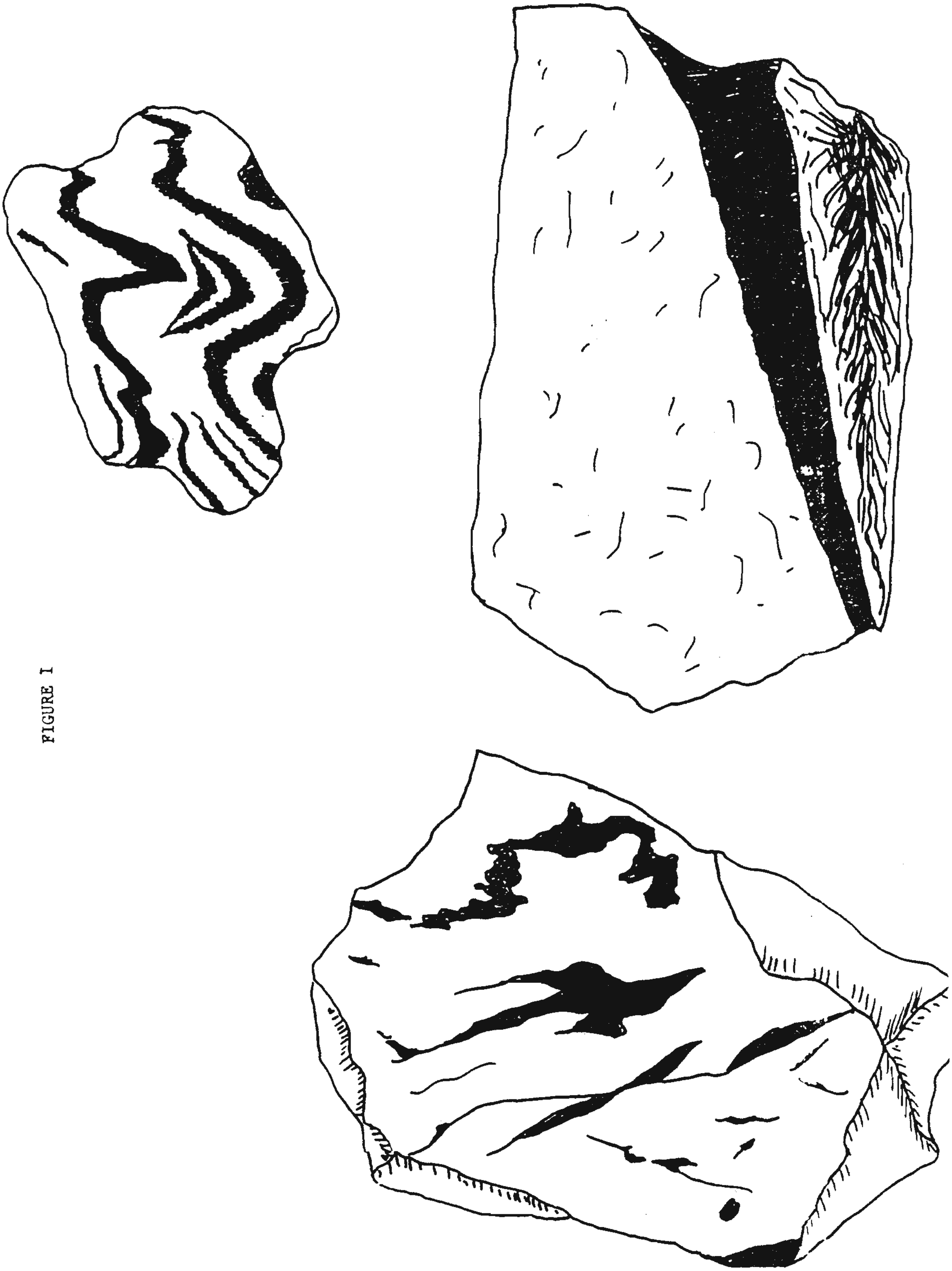
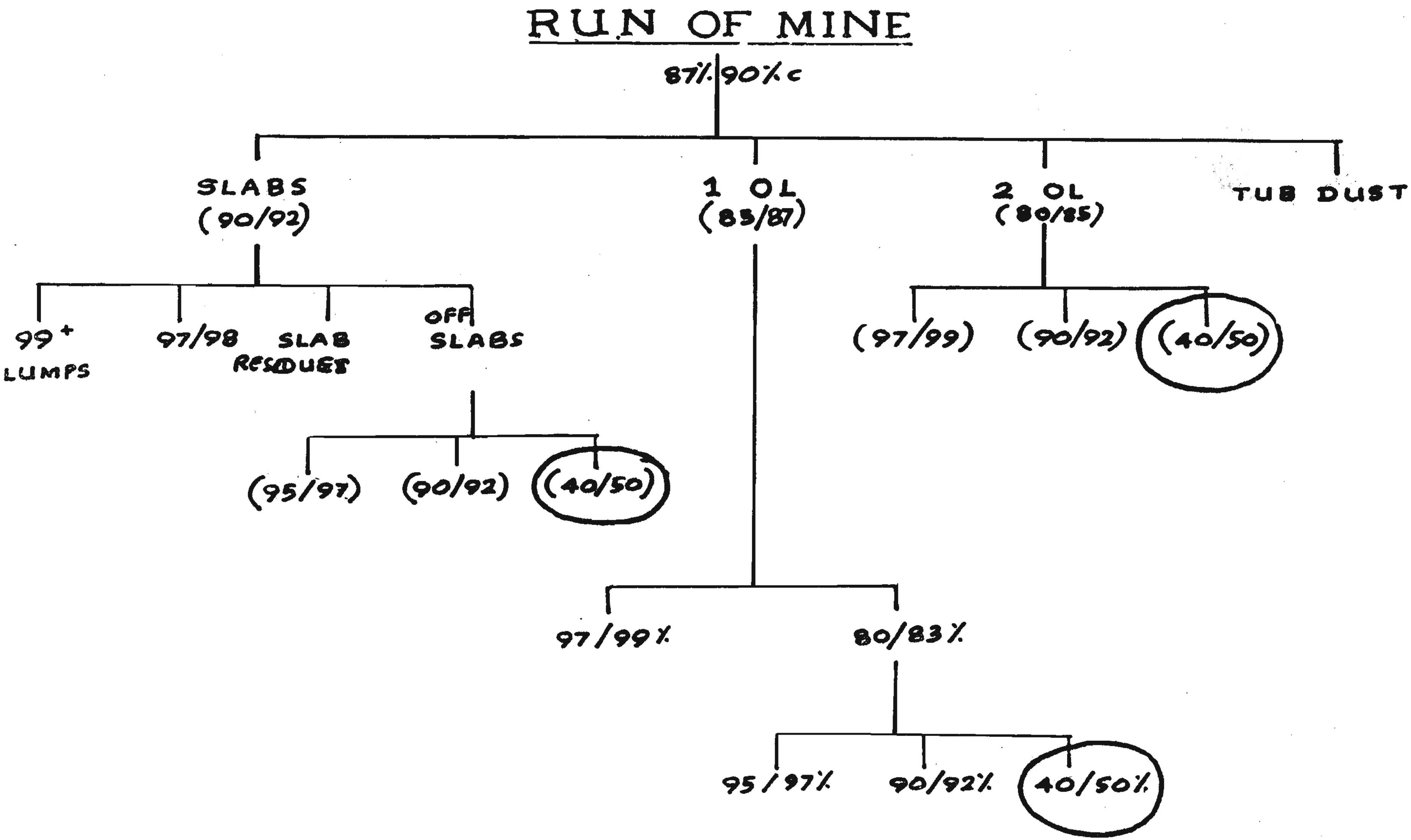
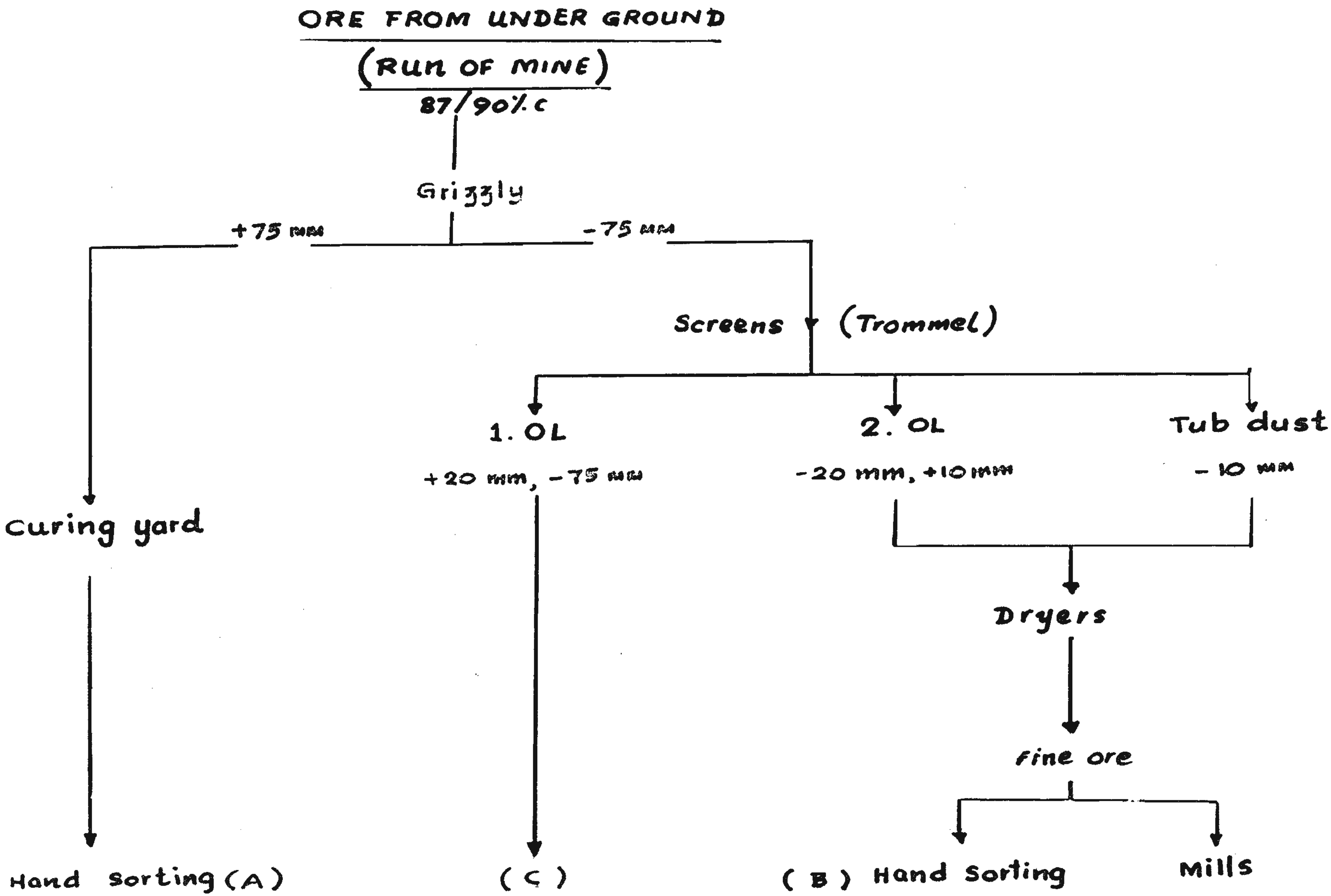


FIGURE I

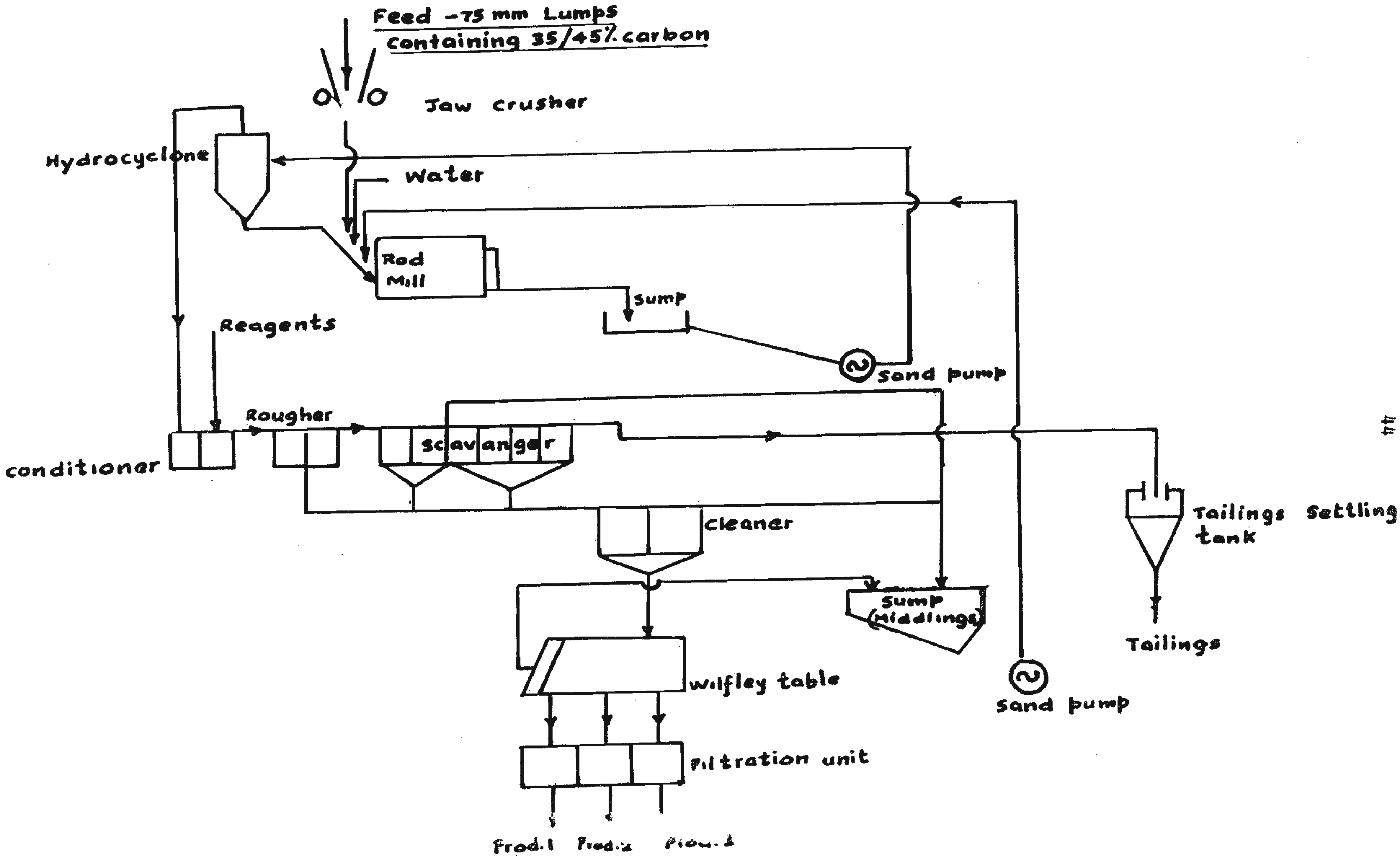
LAY OUT OF INITIAL PROCESSING WORK
(HAND CURING)



CRUSHING FLOW SHEET

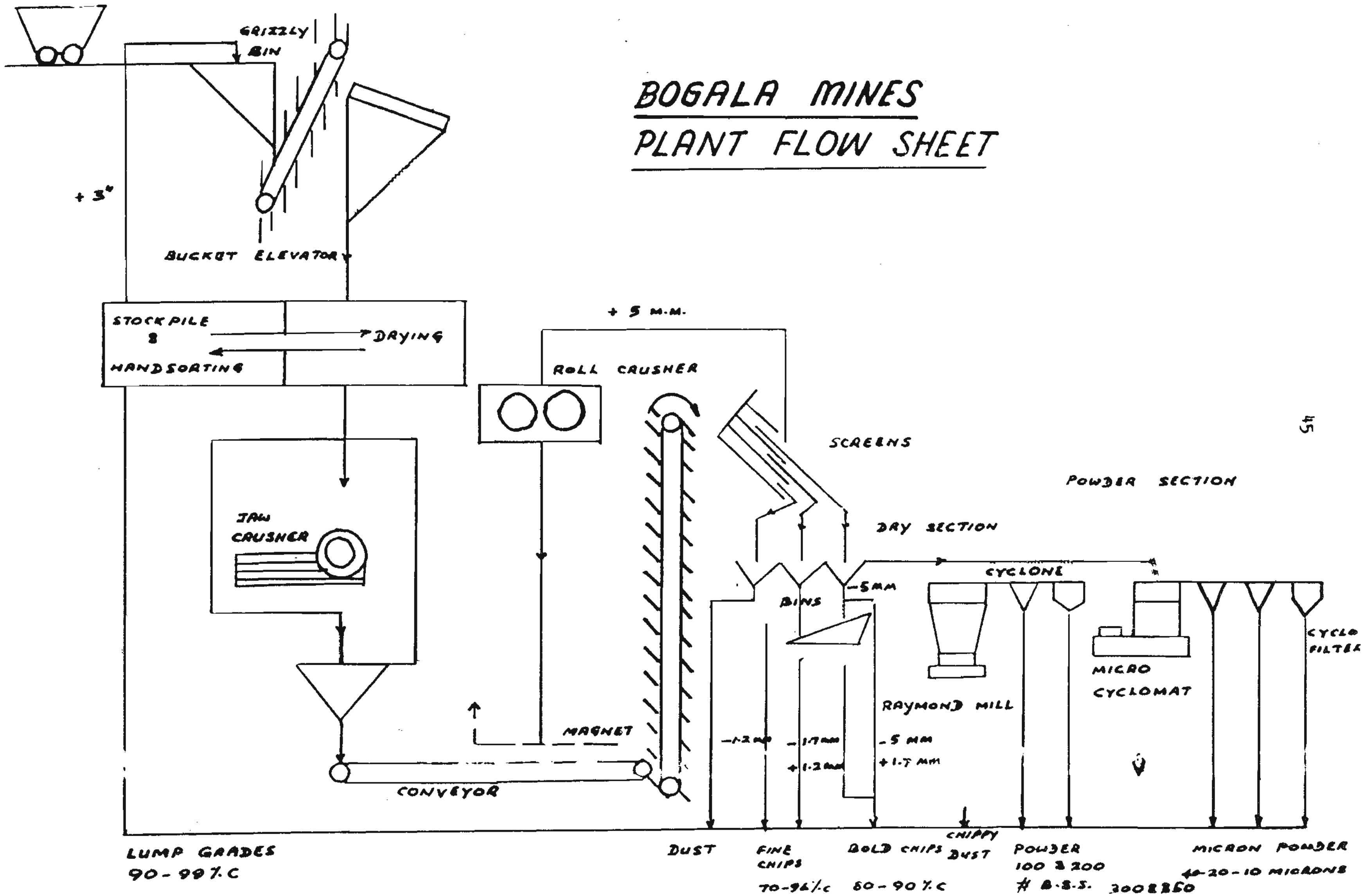


Flotation Plant

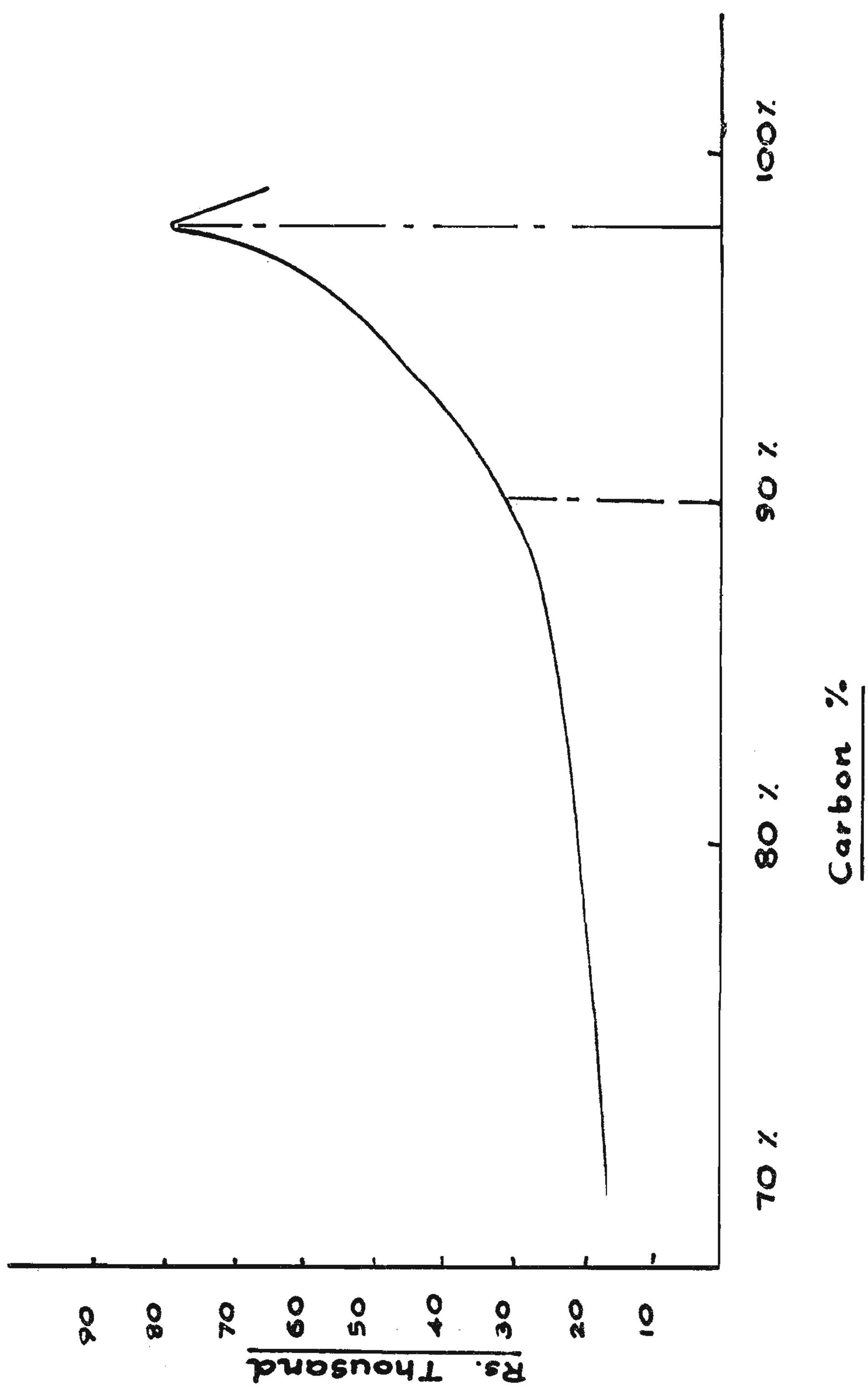


Carbon 85/90%c Particle size 70% -100#

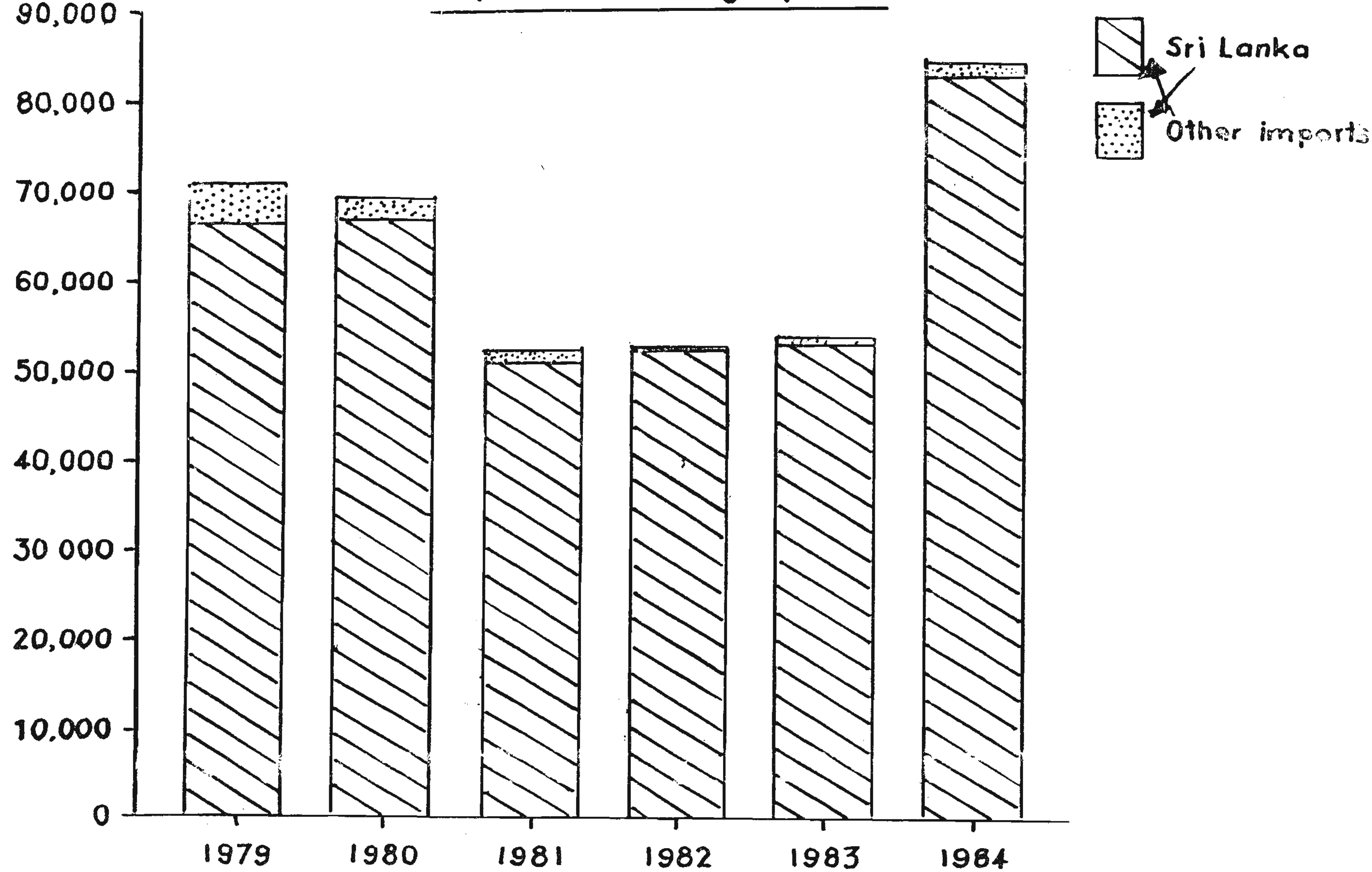
BOGALA MINES
PLANT FLOW SHEET

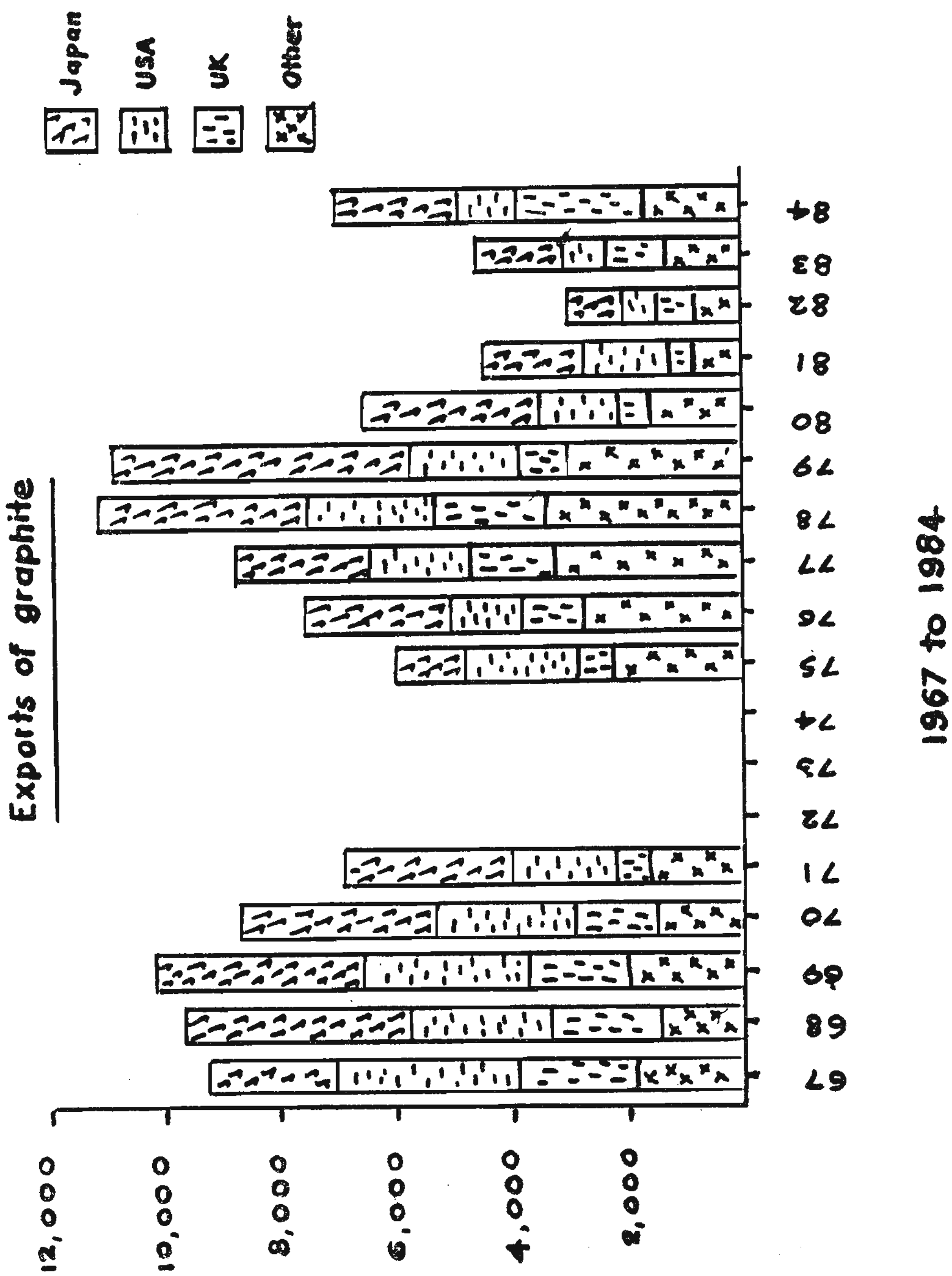


Approximate Selling prices of Various Carbon grades



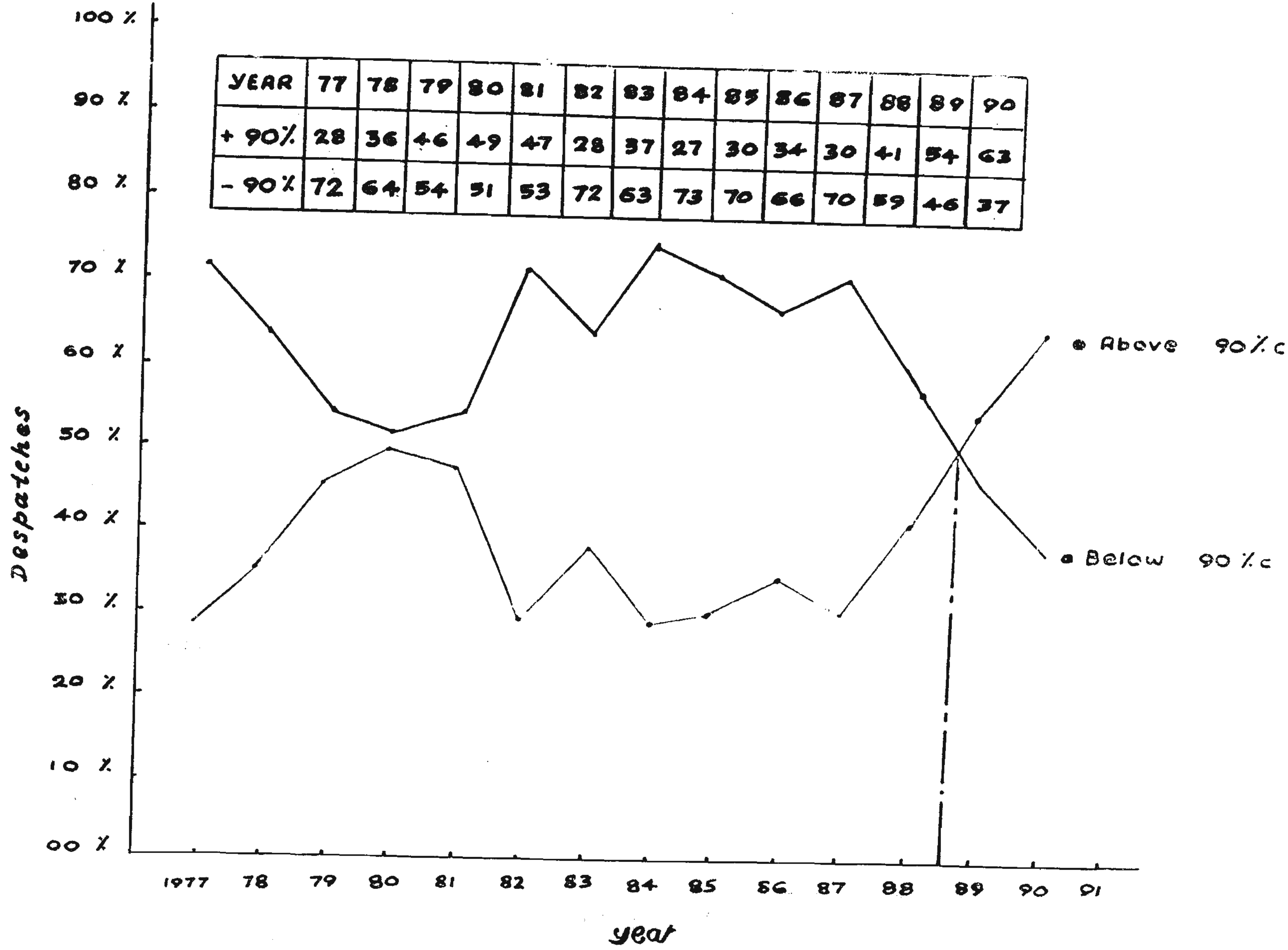
Imports of all graphite (JAPAN)



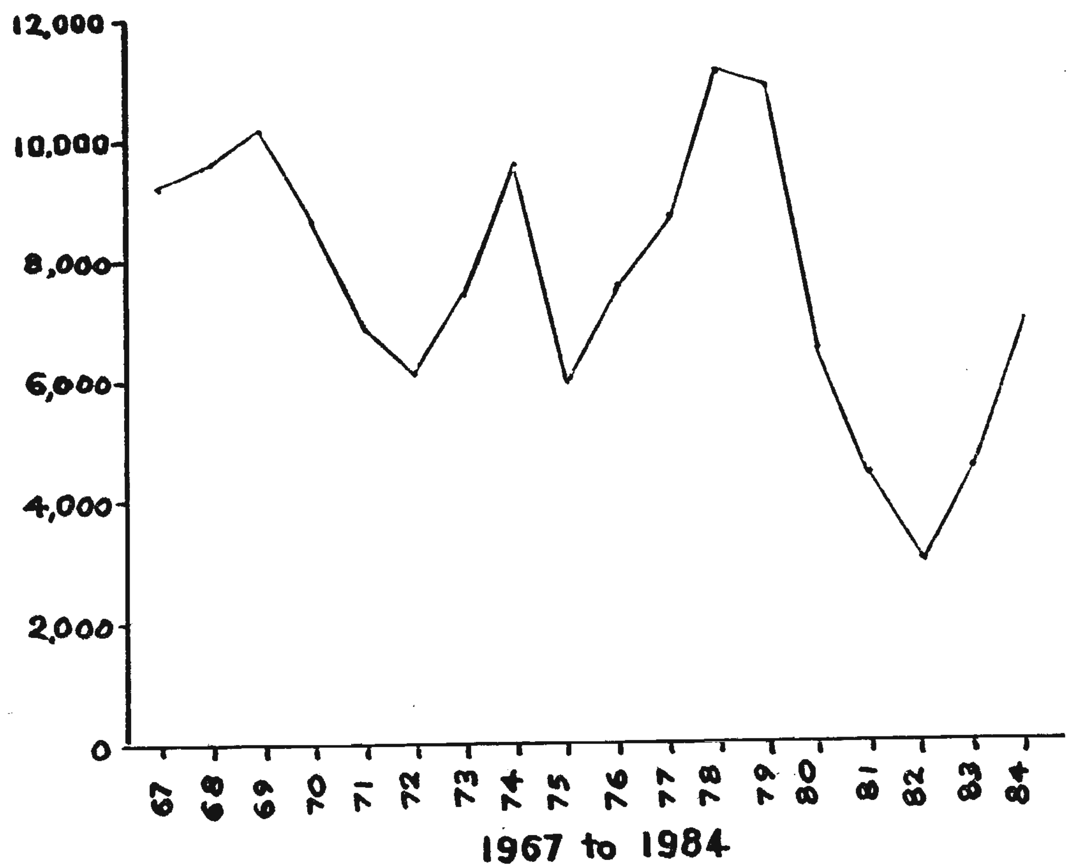

Exports of graphite
1967 to 1984
Japan
USA
UK
Other
12,000
10,000
8,000
6,000
4,000
2,000
67
68
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84

Cumulative despatches percentages Of above 90% & below 90% grades

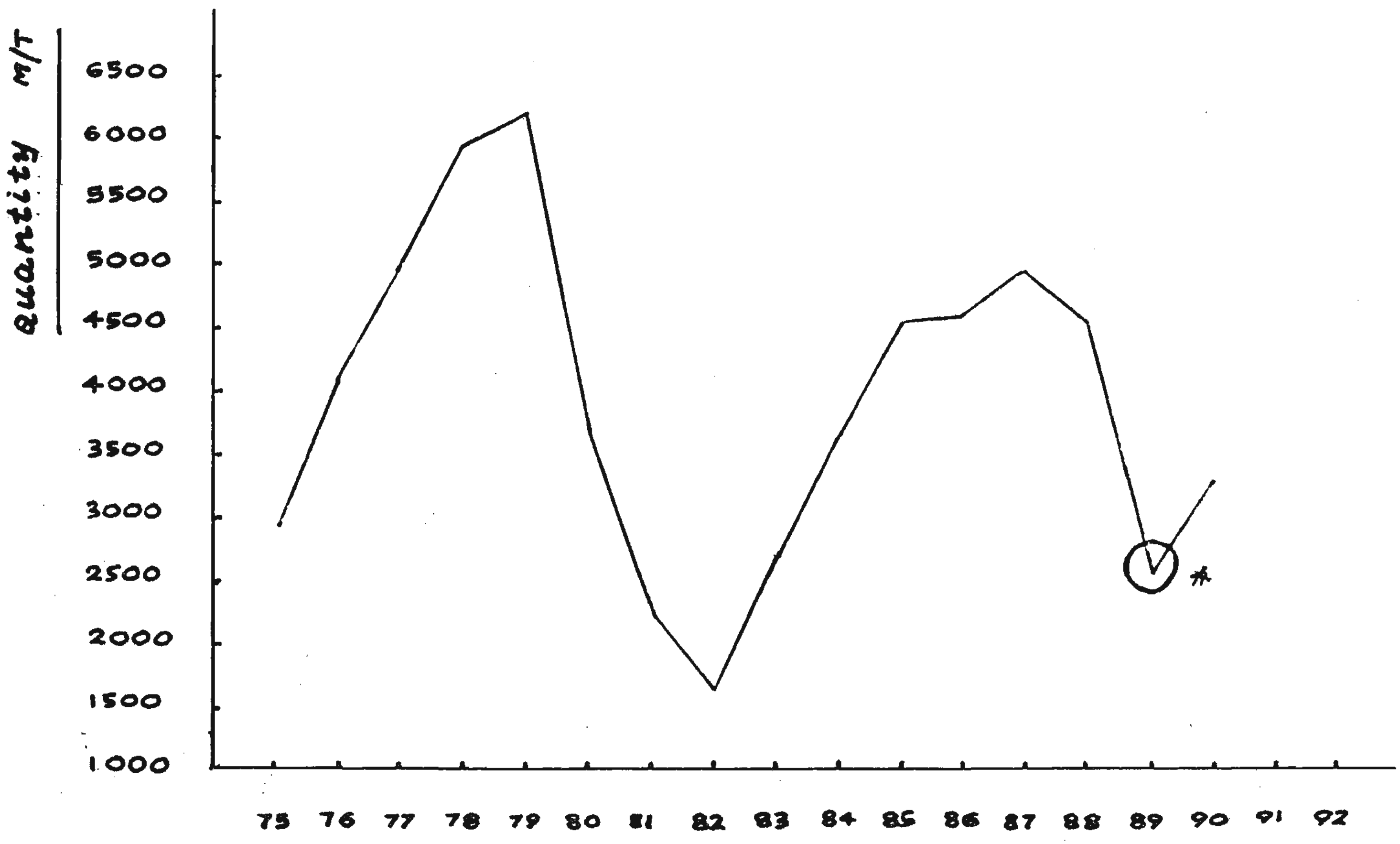
YEAR	77	78	79	80	81	82	83	84	85	86	87	88	89	90
+ 90%	28	36	46	49	47	28	37	27	30	34	30	41	54	63
- 90%	72	64	54	51	53	72	63	73	70	66	70	59	46	37



Sri Lankan exports



Mill's despatches from Bogala Mines



* Low production due to countries prevailed situation.

YEAR	TONNES
1975	2964.2
1976	4193.6
1977	4973.5
1978	5986.8
1979	6249.6
1980	3703.7
1981	2268.4
1982	1642.9
1983	2730.6
1984	3656.5
1985	4545.9
1986	4617.7
1987	4944.6
1988	4524.5
1989	2598.0
1990	3316.5

MARKETING OF GRAPHITE

S.M. ABEYWICKREMA

DEFINITION

Achieving objectives & goals of the organisation by satisfying customer needs and wants.

What are the objectives and goals of a commercial organisation? Main objective is maximization of profits. This could be done only by satisfying customer needs and wants.

If you offer a poor quality product the customer will refuse it and you will end up with losses. If you offer a good product at a high price, you are not competitive and then again you will end up with losses. Therefore, it is essential that we know our 4 P's in marketing. They are :

Product

Price

Place

Promotion

As we have discussed the basic things in marketing now let us get onto marketing of graphite.

PRODUCT

Sri Lankan graphite is known as the best in the world. At present, we market nearly 30 grades of graphite. It varies from 99% carbon to 75% carbon. It also varies according to the particle size. The standard particle sizes are :-

-325 mesh (Fine powder)

-200 mesh (Powder)

+ 10 mm (Lump)

-5 mm (Chippy dust)

-5 mm + 1.7 mm (Bold chips)

-1.7 mm + 0.5 mm (Fine chips)

-10 + 60 mesh (Flakes)

-40 + 100 mesh (Flake type)

As you know the technology is developing fast and we need to develop new products to cater to the changing needs of our customers.

PRICE

Unlike any other product, the actual international prices of graphite are not published anywhere in the world. However, there are few journals like Industrial Minerals & Mining Journal, published in the U.K. and the Chemical Marketing Reporter published in the U.S.A. These publications give some idea of the prices, but comparison is not possible due to difference in quality and the vast range of prices given.

The Roskill Publication on 'Economics of Natural Graphite' has stated that graphite prices depend on several criteria, such as flake size and carbon content, which may vary widely within a deposit, the published prices tend to be rather vague, sometimes giving a wide range of prices for a given product.

Due to lack of proper information, we will have to base our prices on demand and supply which is a widely accepted method.

The present prices of our graphite are given below.

Carbon Percentage	Particle Size	FOB price per M/T in US $
97-99	-325	1760/-
97-99	+ 10 mm	1520/-
97-99	-200 mesh	1520/-
90-92	-5 mm	750/-
80-83	-5 mm	475/-

As you could see from the above, price varies according to two factors; carbon and the particle size.

PLACE - Channel of distribution

1. End-users

2. Indenting agents

3. Traders

4. Wholesale distribution

OUR MARKETS

Country	**1988**	**1989**	**1990**
Japan	2799	1653	2673
U.K.	1700	980	888
U.S.A.	2560	607	552
West Germany	97	100	160
Australia	544	412	36
Pakistan	32	30	60
Thailand	208	38	135
India	206	182	188
Other	229	90	40
Total	8542	4156	4765

PROMOTION

As graphite is used only for certain industries, advertising in mass media will not give the best results. Therefore, we advertise in selected journals such as Industrial Minerals published in U.K. However, the most suitable way of sales promotion for this type of product is personal selling by visiting individual customers.

APPLICATION

1. Refractories
2. Magnesia-carbon refractories
3. Crucibles
4. Steel making
5. Bearings & Carbon brushes
6. Foundries
7. Pencils

8. Break lining

9. Dry batteries

10. Lubricants

11. Expanded graphite

12. Powder metallurgy

13. other uses

COMPETITION

Our main competitors are China, Madagascar, Norway and Canada. During 1988 the Chinese production came down by 50% to 100,000 M/Tons. Therefore, graphite prices went up and we also benefited. However, they managed to bring the production upto normal level of 200,000 M/Tons during 1990. The success of small graphite producers like us depends on how fast we could adjust our prices to changing situations in the outside market.

Estimated World Production

	1989	**1990**
Australia	15,000	12,000
Brazil	40,000	40,000
Canada	6,000	9,000
China	180,000	200,000
Checkozlovakia	15,000	15,000
West Germany	10,000	10,000
India	50,000	50,000
Korea DEM P.A.	20,000	20,000
Korea Republic of	100,000	100,000
Madagascar	16,000	16,000
Mexico	45,000	45,000
Norway	2,000	7,000
Sri Lanka	6,000	6,000
Turkey	10,000	10,000

U.S.S.R.	90,000	95,000
Zimbabwe	15,000	12,000
Others	20,000	20,000
	640,000	**669,000**

Source : Mining Journal 90

Although the estimated world production is 669,000 the estimated world trade of graphite is around 200,000 M/Tons against Sri Lanka present export figure of 5,000 M/T. This shows that our present market share is 2.5% and that Sri Lanka cannot play a major role in determination of world graphite prices. We will have to determine the price based on the demand and supply on our graphite.

FUTURE OF GRAPHITE INDUSTRY

Our graphite reserves are limited, compared to estimated world deposits of 1000 million tons. Therefore, the only way we could develop this industry is by developing new products which are required for graphite based industries. At present, we export standard products which are further processed overseas. We need to engage in market research to identify,

1. New specifications

2. the present demand

3. the customers

4. prices

and to find out ways and means to acquire the required technology to produce such new products.