OVERHAND CUT-AND-FILL MINING METHOD AS APPLIED TO GRAPHITE MINING IN SRI LANKA WITH SPECIAL REFERENCE TO BOGALA MINES

by
P.V.A. Hemalal

Abstract

Overhand Cut-and-Fill Mining Method has proved itself to be the most suitable method for mining of vein-type graphite deposits in Sri Lanka. At present the entire Sri Lankan production of graphite comes from vein-type deposits. Though it demands fairly a large amount of timber for supports and is highly labour-intensive nature, it has the merits of very low dilution and high level of recovery. Regaining Sri Lanka's lost share in world graphite market, hinges on the expansion of our productive capacity and efficient mining of existing and new deposits. Cut-and-Fill method and its variants will essentially be the predominant mining method applicable in the particular geological terrain where vein-type deposits are presently found.

1.0 Introduction

Sri Lanka has some of the best quality graphite deposits in the world with a carbon content ranging from 95 to 99% and has maintained a leading role in high grade graphite production reaching 30000 tons per annum recorded during the periods covering the last two World Wars. There were between 3000-4000 graphite pits scattered throughout the island (Fig. 1). The existence of graphite deposits was known prior to the 19th century following the increasing demand for graphite with the industrial revolution and the advances in military technology in the West. At present, there are only two large underground mines namely Kahatagaha/Kolongaha and Bogala mines producing almost the entire Sri Lankan graphite production. Amongst them Bogala maintains the biggest share.

The aim of this paper is to present information on the practice of the above method at Bogala Underground for mining of high-grade vein type deposits. The paper discusses the geology of the vein graphite deposits followed by the history of evolution of mining methods and the details of stopping operations with economics. The author has analysed production and cost data for the last 7 years and presents a summary of main statistics at the end of the paper.

2.0 Properties and Uses of Graphite

Graphite is a soft, black mineral, a crystalline form of carbon which crystallizes in a hexagonal system. Graphite like some other forms of carbon, burns only at high temperatures. Natural graphite is normally unaffected by acids, molten alkalis at low red heat. Graphite has a hardness of 1 to 2 (Mohr's scale) and a specific gravity of 2.09-2.25. It has a metallic lustre, sometimes dull or earthy. Graphite melts at about 3650°C and vaporizes at about 4500°C. At 600-700°C graphite slowly decomposes in the presence of oxygen to form carbon dioxide.

Most of the world production is consumed in the metallurgical industries, in crucibles, foundary facings, moulds, retorts, pouring nozzles, ladles, refractory bricks and other similar articles. Other important uses of natural graphite are in the manufacture of lubricants, brushes for electrical machinery, dry-cell batteries, pencils, polishes and electrodes.

3.0 Graphite Occurrences in Sri Lanka

There are three main modes of graphite occurrences in Sri Lanka, namely: (a) disseminated graphite flakes in country rocks; (b) vugs, lenses and pods; and (c) large vein-graphite deposits. The vein type, which is the most important commercially, is found within the Highland Series but mostly in the South Western Group (Fig. 1). Although there are a large number of scattered abandoned

Mr. P.V.A. Hemalal, *MSc(Hons)Moscow-Min.Eng., MIMM(UK), CEng, Senior Lecturer, Department of Mining and Minerals Engineering, University of Moratuwa.*

Formerly, Mining Engineer - Bogala Mines of State Mining and Mineral Development Corporation.

graphite workings in the Highland and Southwestern Group, only a few mines are currently in production. At present mining is being carried out at Bogala, Rangala, Dodangaslanda, Ragedara and Kolonne (Fig. 1).

4.0 Geology of Bogala Mine

4.1 Location and Access

The Bogala Graphite Mine, owned by the Bogala Graphite (Lanka) Ltd is situated 104 Km Northeast of Colombo along paved roads (Fig. 1). The topography is quiet rugged in the vicinity of the mine with mean elevation of 150 m above sea level.

4.2 General Geology and Mineralisation

Precambrian high-grade metamorphic rocks of the Highland Series are the host rock of graphite mineralisation. They are mainly quartzo-feldspathic gneisses, quartzites, charnockites and garnatiferrous gneisses. Occasional small pockets of coarse-grained pegmatites are present. The mineralisation of Bogala is of vein type. The graphite occurs in narrow and long, rather irregular veins which sometimes change strike sharply over a short distance. Widths of veins may vary from a few centimeters to several meters under exceptional circumstances. Any vein irrespective of width, may terminate unexpectedly.

The mineralization is usually pure graphite with relatively little included gangue. The gangue is mainly lenses of the wall rock and minor pyrite, chalcopyrite, calcite, quartz and feldspar. Two major veins appear in the central part of the mine (Fig. 2) and have following parameters. (Table 1).

In addition, several split-offs occur in the mine. They have generally lower strike extension and thickness. The vein systems namely Ketawala and Pankohena are located at the Southern and Northern boundaries of the mine field and they are only partially explored. (Figure 3)

5.0 Evolution of Mining Methods

There is reasonable evidence to assume that some of the graphite mining methods were borrowed from traditional gemming methods and practices during the early period. Shallow pits were sunk in the vein and digging continued till dewatering became a problem. The pit was then abandoned and several subsequent pits were sunk along the strike of the vein till the vein width became uneconomical. In later years with the use of steam pumps, greater depths could be reached and, a system of open stopping was adopted as a means of control of rock pressure. At Bogala Underground, the Cut-and-Fill stopping method was adopted at levels below -129m(Fig. 2) and presently, nearly 70% of the ore is extracted by this method. At present, to cater for an annual production of 4000mt of graphite, nearly 15 stopes adopting this method are in operation.

6.0 Cut-and-Fill Mining Method

6.1 General

The main distinguishing feature of Cut-and Fill systems is filling of the worked-out space with a filling material as the stope advances. Filling is intended to prevent the displacement of country rock after extraction of the ore.

The Overhand Cut-and-Fill method is very flexible and is readily adaptable to almost any ore body. This method is best employed in steeply-dipping, thin ore bodies with considerable vertical extent, ore areas that require selective mining, ore areas where weak wall conditions exist.

Among it's advantages are the possibility of continuous sampling of the ore block as it is mined, possibility of selective mining which reduces dilution and the possibility of keeping large scale ground movement to a minimum.

Among the disadvantages are the cycliclic nature of ore production, labour intensiveness and high skill of miners, low productivity, high degree of ground control, difficulty in ventilating the stope environment.

6.2 Application at Bogala Underground

6.2.1 Stope access

'5th pit' shaft which starts at -120m(-72Fm*) level nd extends down to -367m(-2050Fm) below surface provides, access to the present mining area below - 285m(-188Fm) level. Access from shaft to stopes are through main level cross-cuts (-255m(-142Fm), -307m(-170Fm), -367m(-205Fm)) and through a system of winzes driven at 40-45m apart from each other along the strike of the vein(Fig. 2, 4). Main level drift and intermediate level drift which is not linked to the shaft, form down-the-dip boundaries of the ore block (Figure 5).

* Depth measurements during the early days were done in fathoms and measurements were taken along the dip of the vein. Depth levels shown in metres have been taken vertically. Thus, the figures in fathoms do not tally with the

corresponding metre figure. Even in present practice, levels are designated in fathoms.

6.2.2 Development

Stope development commences with sinking of two winzes, dividing them into ladder and hoisting compartments and equipping (Figure 5). This is followed by removal of a complete horizontal slice with a height of 2.2 - 2.4m, just above the roof of the existing lower drift of the block. Block bottom initial support is achieved by the placement of a line of reinforced concrete ribs with a spacing of 1.5m within the newly-created space (Figure 5). One month after placing these RC supports, the block is ready for extraction.

6.2.3 Stoping

General

Slices of ore 2.0 - 2.2 m of height are taken successively from bottom to top of the block, and the void created is filled with waste rock, generated in the stope itself or transported from elsewhere underground. Removal of a slice starts from one of the boundary winzes and progresses towards the other. (Figure 5). If the graphite vein is thin (width less than 20 cm), light blasting has to be performed to break the whole mass and later separate graphite lumps by hand-picking from among the rock debris. In the case of a thicker vein (width more than ~20cm), every attempt is made to separate graphite from the in-situ mass with pick or bar, without resorting to blasting (Figure 6). Extreme care is taken to minimise dilution and loss. In performing this work, the skill of the minor plays an important role.

Bench width is maintained above 0.9m to facilitate transport within the stope and handling of timber used for roof support. The average monthly rate of advance is 3-4m, but in certain circumstances it may reach 10m. Removal of horizontal slices is continued in a sig-zag manner up to the upper drift (Figure 5). Duration of the stoping operation of an average block varies from 3 to 5 years.

The processes of the ore extraction cycle are as follows.

Drilling

Breast-drilling is adopted using Compair/Holman Silver Spear Integral Leg Drills. Normally, rounds of 0.9m in length ore drilled, using integral drill steels with tungsten carbide chisel bit of gauge 32-33mm (Figure 7, 8).

Blasting

Normally the maximum number of holes per round does not exceed 7-8 whether it is in graphite or in adjoining rock (Figure 7). In stope face blasting a kind of cautious blasting is practiced with light charges not exceeding 100g and 200g of Special Gelatine-80% (manufactured by Dynamit Nobel, Germany) respectively for graphite and rock. It is customary to use Safety Fuse Initiation for these small rounds.

Ventilation

Ascending ventilation is the general practice for the mine as shown in Figure 4. Use of compressed-air is resorted to as a means of face ventilation as the central mine ventilation system is incapable of ventilating the face adequately in the absence of auxilliary fans.

Ground Support

Before the removal of broken ore and rock from the face, roof support work is completed with the erection of timber caps with the ends placed in hitches cut in hanging wall and foot wall rock. Anchors made of 22mm diameter mild steel bars are used additionally to secure these caps. Rectangular section "Kempus" (Koompassia Malaccensis) beams of dimensions 200x100mm or circular section local timber such as Kumbuk (Terminalia arjuna), N (Mesua nagasarium), Mee (Madhuca longifolia), Palu Manilkara hexandra), Hora (Dipterocarpus zeylanicus), Wevarana (Alseodaphne semecarpifolia) are used as roof caps. Spacing varies from 0.6m to 1.0m (Figure 8). 50mm thick timber boards are used as spiling (Figure 9).

Roof caps serve the dual purpose of taking the hanging wall compressive load and supporting the weight of rock and graphite within the overlying arch (Figure 10).

The role of this particular support element is all the more important as the newly-filled rock debris fill is still unable to take the compressive loads resulting from hanging and foot wall convergence as it is subjected to the consolidation process. For securing weak stretches of wall rock, wedge-type mechanical bolts are used (Figure 10). If the walls are friable, metal strips tie the bolts together for added support.

Ore Haulage

Transportation within the stope usually consists of bringing the ore to the chute box by wheelbarrow (Figure 8). Ore is discharged from the chute box to the mine car, stationed in the lower drift. After loading, it is trammed manually to the nearest winze. Hoisting compartment of the winze is equipped with two parallel rails 0.5m apart and bolted to the hanging wall. The loaded bin is attached to the chassis which runs along the rails and hauled to the upper level by compressed-air operated Holman RWL-7 or JOY-JHA-20 hoist. Loaded bin is lowered on to trolley chassis placed in the upper level and trammed manually to the shaft (Figure 5).

6.3 Major Machinery and Equipment Used

1. Rock Drill-Compair/Holman
Model-Silver Spear
Power source-compressed-air
Drill bore/stroke - 70/50.8mm
Leg bore/feed - 60.3/11016mm
Weight-34kg.
Typical performance -32mm hole in garnet-biotite gneiss at 6.0 bar
Rate of penetration - 300mm/min
Air consumed - 68.4 litre/sec.

2. Hoist-Holman
Model-RWL7R
Power source-Compressed-air
Typical performance - 909Kg at 36m/min at 6.4bar
Air consumption - 11.5 m^3/min

3. Hoist-JOY
Model-JHA or JHAL
Power source-Compressed-air
Typical performance - 909 Kg at 36m/min at 6.4bar.
Air consumption - 7.4 m^3/min.

4. Sludge pump-Holman
Model-MK11-portable ejector type.
Power source-Compressed-air
Typical performance - 30.48m head -91 lit/hr.
Air consumption - 1.61 m^3/min at 5.6bar

6.4 Work Organisation

The mine works on a six-day per week schedule. Each working day is divided into two day-production shifts and a night maintenance shift. A shift is of 7.5 hour duration.

A team of 10 miners headed by the team leader (Baas) is divided into two groups each comprising 5 miners. Each of these smaller groups handles the work in a production shift. Regular-shift miners are paid overtime for working in the night maintenance shift.

Miners are graded according to the skill and number of years of underground experience. i.e. from grade 1 to grade 6. The team leader (Baas) and his assistant (Kanghani) should be of grade 1 and grade 2 respectively. In the other end of the scale, new recruits are placed on grade 6. With experience, they are promoted to higher grades.

6.5 Stope Statistics

6.5.1 Production

Table 2 below shows production data for the years 1985 to 1990 with the exception of the year 1989 during which, activities of the mine was affected due to the civil disturbances in the country.

6.5.2 Costs

<u>Wages and Production Incentive</u>

Production miners are divided into 6 grades and are monthly paid. Basic wage scales range from Rs.1730/- per month for grade 6 to Rs.2490/- per for grade 1 employees (Figures as at December 1991).
The present incentive scheme is a group incentive schemes based on labour efficiency as revealed by output and attendance. Labour skills as represented by the grade of the miner is given due recognition by paying higher rates for mroe skilled grades. (Grades 6, 5, 4-1 point, grade 3-1.25 points and grades 2, 1-1.5 points).

<u>Materials</u>

Timber, steel and explosives are the major cost items. Direct costs of a typical Bogala stope are as follows : (Figures as at December 1991) (Table 3).

7.0 Conclusion

Overhand Cut-and-Fill method has proved itself to be the most flexible, productive and best method for the mining of steeply-dipping vein-type graphite deposits. The entire graphite production of Sri Lanka comes from vein type graphite deposits. The Author feels that the Bogala mine which is the highest producing unit operation has to hinge its future on this method notwithstanding the high consumption of timber. Only for wide veins (width more than 6m) which are exceptionally rare, the use of less productive Underhand Methods are necessary.

Acute unemployment problem in rural South Western Sri Lanka could be solved to a great extent if the abundant graphite resources of the South Western Sector could be developed and mined.

8.0 References

Agoshkov, M. Borisov, S., Boyansky, V. (1988 : Cut-and-Fill systems, Mining of Ores and non-metallic minerals, Moscow, Mir.

Cooray, P.G. (1983) : Small-Scale mining of graphite of Sri Lanka, AGID news No. 34, 4-8.

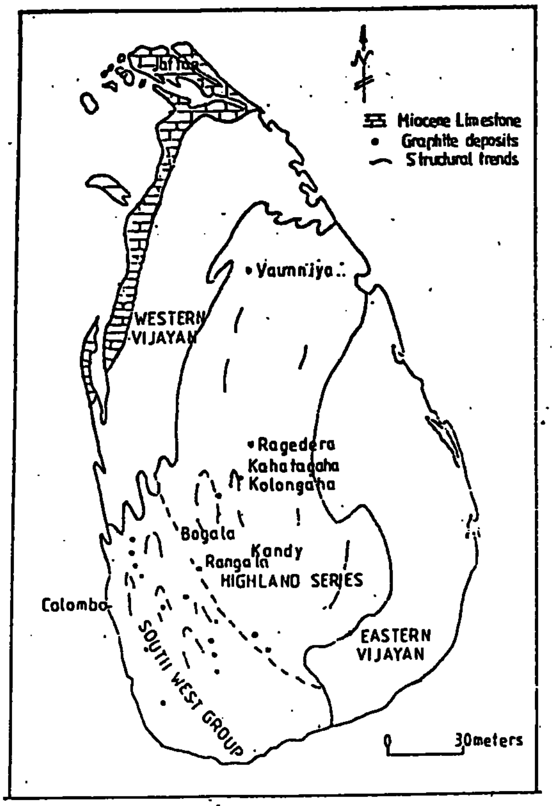
Casinader, R.A. (1980) : Graphite Mining and Occupational Culture, Economic Review, Vol. 16, 4, 8-9.

Dinalankara, D.M.S.K., Dissanayake, C.B. (1988) : the Geological Setting of Some Major Graphite Deposits of Sri Lanka. Journal Geological Society of Sri Lanka, Vol. 1, 18-25.

Erdosh, G. : Geology of the Bogala Mines, Ceylon and the origin of vein type graphite. Minnerallium Deposita 5, 375-382.

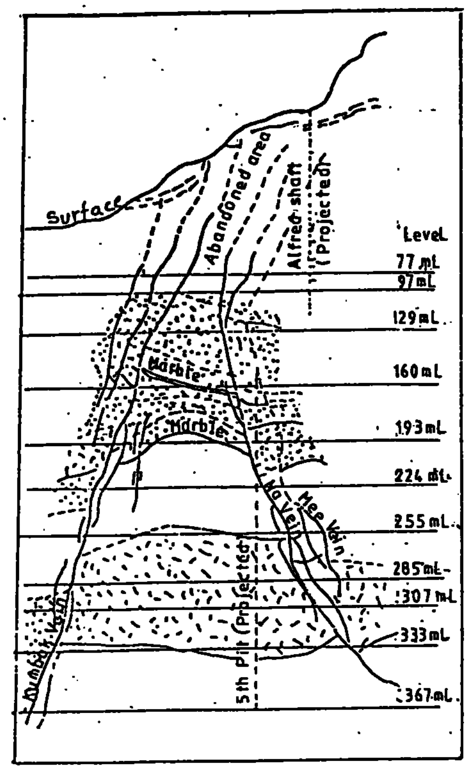
Waterland, Joel. K. Introduction to open cut-and-fill stopping. Underground Mining Methods Handbook, New York, Society of Mining Engineers, 523, 525, 528-530, 532-537, 549-550.

FIGURE 1



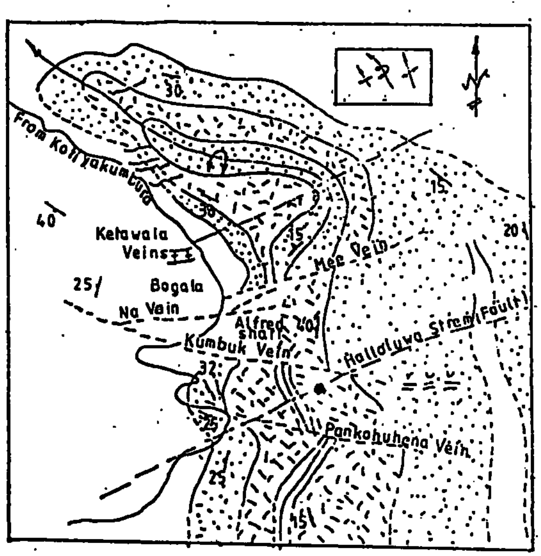
Major graphite deposits and geological divisions of Sri Lanka

FIGURE 2

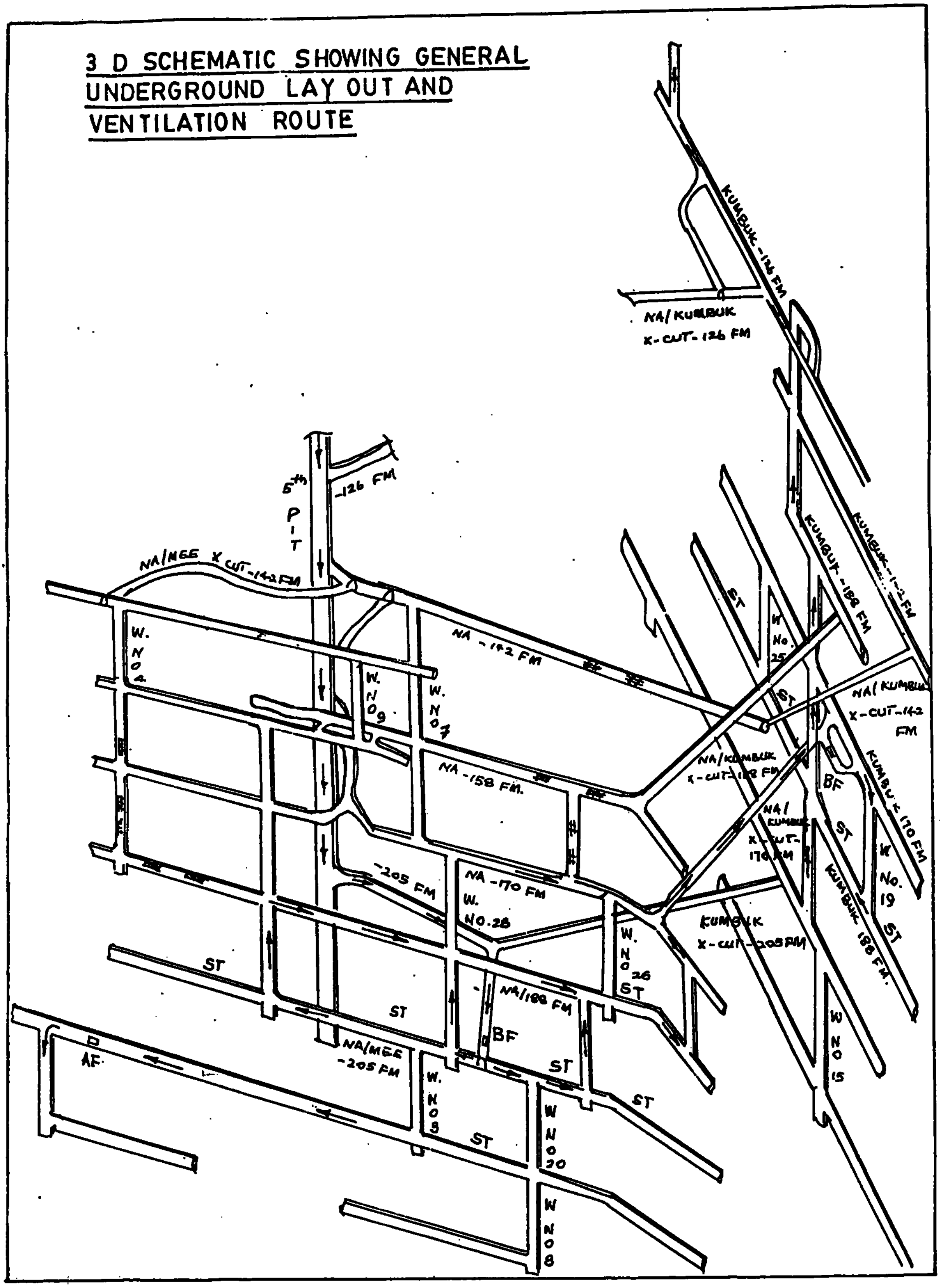


N-S section across the Bogala ore body. (after Dinalankara).

FIGURE 3



Lithology and structure of the graphite mines area (after Dinalankara)



Schematic showing General Underground Lay-out and ventilation route.

Legend :

ST - stope

BF - booster fan

F - auxilliary fan

↑ - vent. path

- areas not accessible for men and vent. air

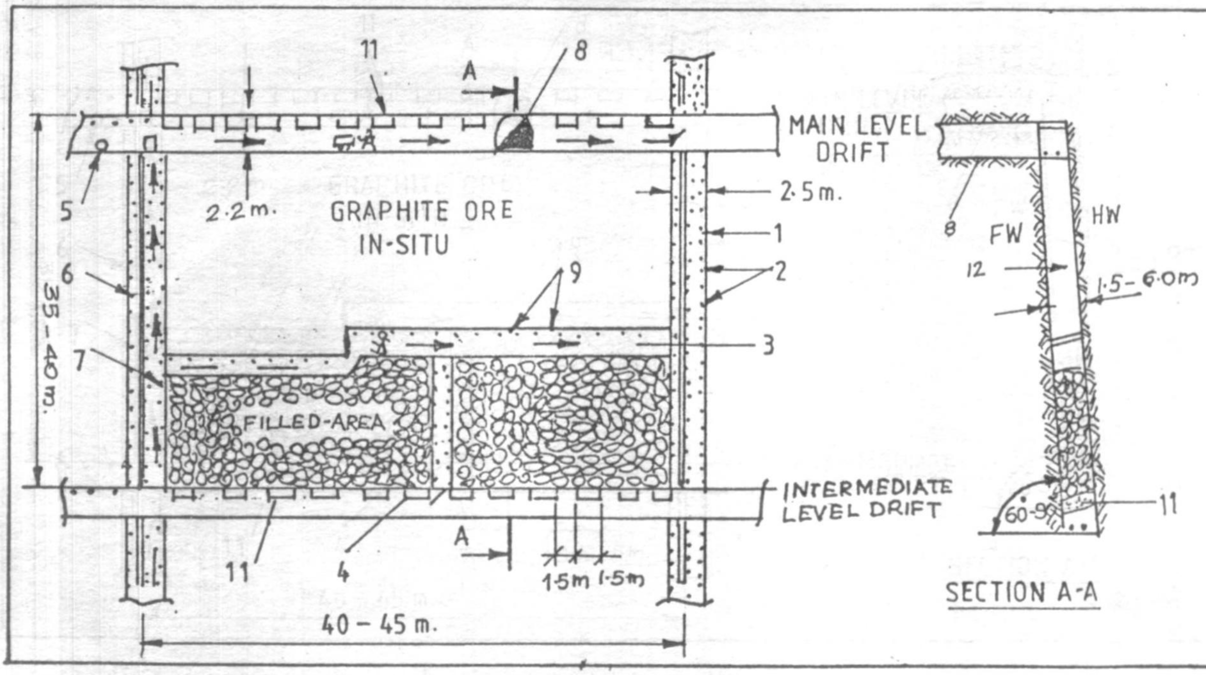


FIGURE 5

Longitudinal section of a typical stope illustrating the Overhand Cut-and-Fill mining method

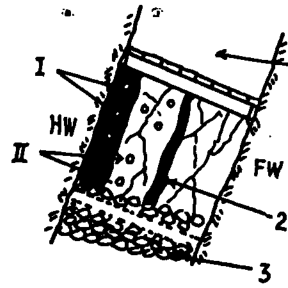
Legend:

1 - Winze
2 - Winze wall supports
3, 6 - Ladder way
4 - ore chute
5 - air hoist at upper level
7 - hoisting compartment
8 - cross cut
9 - bench roof supports
10 - chute box
11 - RC rib support
12 - graphite in-situ

FIGURE 6

Exposed graphite vein at stope face. Rich vein at right is separated from a thinner vein by rock

FIGURE 7



Schematic showing face drilling pattern

Legend:
I - Holes drilled in the vein
II - Holes drilled in rock
1 - graphite in situ
2 - graphite vein
3 - Filled area

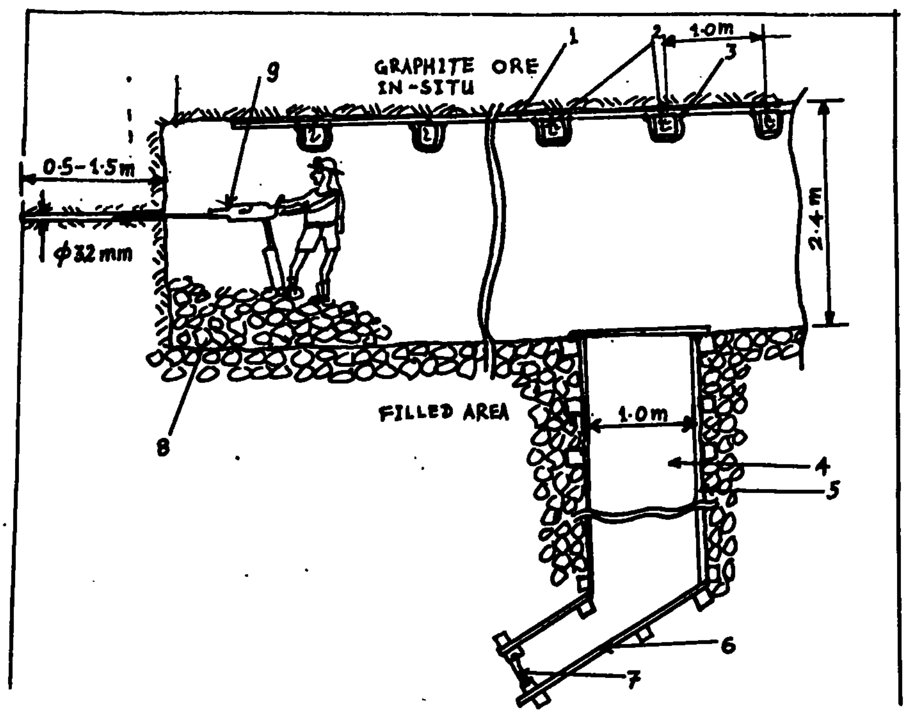


FIGURE 8

Schematic showing stope-drilling, roof support and method of ore discharge.

1 - timber boards of 50mm thickness as roof supports
2 - timber roof caps of size 100 x 200 mm
3 - mild steel anchor - 22 mm ϕ
4 - Ore-chute box
5 - chute box timber lining
6 - discharge end
7 - chute box door
8 - broken ore and rock
9 - Compair/Holman integral leg drill

FIGURE 9

Stope roof support

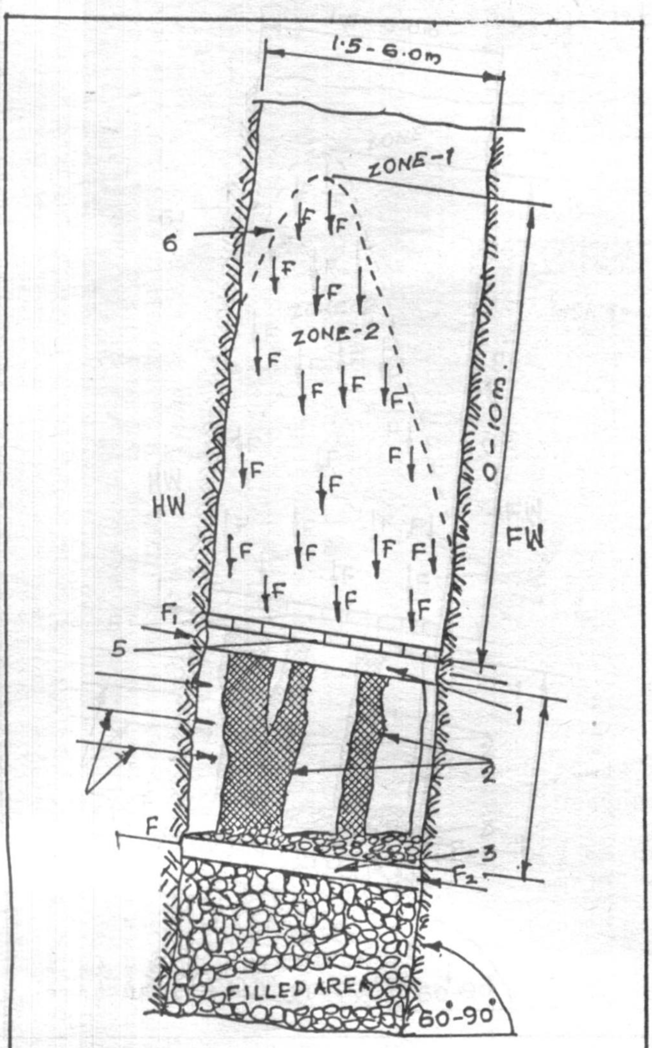


FIGURE 10

Legend :

1 - roof cap of the working bench
2 - graphite veins
3 - roof cap of the previous bench
4 - rock bolting
5 - board spiling
6 - arch boundary
F1, F2 - compressive forces acting on timber roof support
HW - hanging wall
FW - foot wall.

Tab.1.

ore body	strike dir.	dip	length (met.)	thick-ness	attit-ude	graph-qual.
Kumbuk	N65°W	80°-90° S	130-250	0.25m	stra-ight	medium
Na	N60°E	75°-90° N	150-300	0.50m	strai--ght to wavy	good

Tab.2

Year	Production(tonnes)					number of OHCF stopes	average producti--on per stope (mt)	man power for OHCF method (man-shifts)	labour producti--vity (Kg per man shift
	Total R.O.M*	from OHCF method	from mine development.	from UH* method	%OHCF from ROM				
1985	4046	2304	643	1100	57	9	256	18605	123.8
1986	4578	2598	1006	972	57	10	260	20272	128.2
1987	5005	3120	1240	643	62	12	260	26090	119.6
1988	3971	2794	51	773	70	12	233	24918	112.1
1990	3850	2894	770	181	74	13	227	29075	99.5

* ROM--Run-of-mine.
OHCF-Overhand Cut-and-Fill method.
UH---Underhand method.

Tab.3.

Cost component		Monthly cost.(Rs.)
Labour	Wages	21000
	Incentive	7000
Timber		18000
Explosive		10000
Energy (comp- air)		9000
Ventilation		2000
Other supplies		20000