CHAPTER IV

FIELD OBSERVATIONS

Geology of the area

Pre-Cambrian Aravalli group of rocks are exposed over the vast areas of Panchmahals and Baroda districts. They constitute a thick pile of arenaceous, argillaceous and calcareous metasediments now represented by their low grade metamorphic equivalents such as slaty phyllite, phyllite, schist, crystalline limestone and dolomite.

The stratigraphy of the Aravalli system covering all the graphite occurrences is summarized in the table below. The geological succession of the area is based on the geological sequence presented by different workers.

Post Aravalli Intrusives	(	Granites, pegmatites, aplites, quartz veins.
Aravalli	(	Gneisses, schists and bands of crystalline limestones with bands or layers of graphitic rocks
	(	Mica schists and phyllites with graphitic horizons
	(	Quartzite with calc-silicate members

---------- Unconformity ----------

Pre-Aravalli	(	Granites, gneisses and schists

In the following pages, detailed field investigations of the graphite occurrences in the area, lithology including megascopic characters in brief, and structure in general are given. Detailed petrographic study is given in the subsequent chapter.

Pre-Aravalli rocks underlying the Aravalli formation of this area are rather difficult to identify at many places as their nature has been considerably modified on account of the mixing up of the Post-Aravalli intrusive granite with the Pre-Aravalli granite, gneiss and schist. The lowermost member of the Aravalli system is not exposed in the study area.

The rock formations exposed near Ankli, Sewania, Virpur and Muthai graphite mines are described in the following pages.

Ankli : The Ankli mine is situated 1½ km east of the State highway connecting Devghad Baria and Chhotaudepur. The depth of the mine is 10-12 m and the length is 30-35 m. The rocks exposed in the mining area are graphite schist, graphite gneiss and pink granite. The crystalline limestone and gray granite are exposed few meters away from the mine.

Graphite schist is gray to grayish black due to the presence of graphite and is well foliated. Quartz and mica are the abundant gangue minerals present in these rock formations. The general strike of the formation is ENE-WSW. The dip varies from 40°-45° due N. The schistose rock shows alternate layering or bands of grayish brown band consisting of earthy black graphite with mica and light yellowish band composed largely of quartz and little graphite (plate I). Graphite is disseminated in schist along with mica, the grains of which are difficult to separate in handspecimen. At some places graphite schist is weathered to an earthy mass.

Plate I. Graphite schist showing alternate grayish brown and light yellowish bands (Ankli).

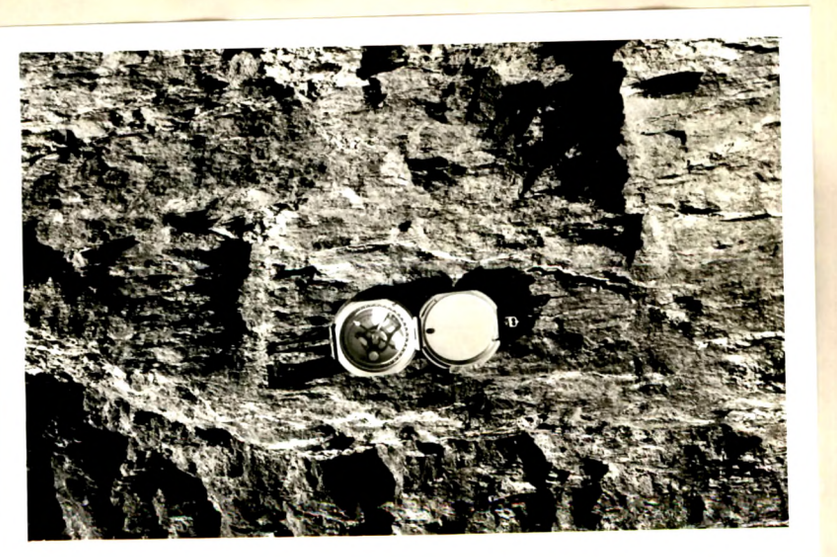

Plate II. Quartz veins in graphite schist (Ankli)

Graphite schist near the contact of granite shows tightly foliated gneissic structure. The veins of milky quartz of thickness varying from 1/2 to 1½ cm occur along and across the schistose formation and hence are distinctly later (plate II). Calcite mainly occurs as stringers cutting the foliations. Sometimes pyrite is irregularly scattered in schistose formation. The schistose formation consisting primarily of quartz, occasional feldspar and graphite, represents metamorphosed Pre-Cambrian argillaceous sediments.

Pink granite occurs as patches and is exposed at the flanks of the mine with sharp contact. Graphite is not noticed in it. It is fractured, jointed and distinctly intrusive as it occurs across the schistosity and strike of the graphite formation.

Crystalline limestone: A number of crystalline limestone bands which are compact, massive and brittle, form thin lenticular runs, overlying the graphite schist. It is exposed NW of the mine. The general strike of the crystalline limestone bands is ENE-WSW. The dip varies from 45°-50° due N, and is conformable to the graphite schist. It is traceable for 34-50 m along the strike beyond which it is

hidden under soil cover. It contains silver white micaceous and pale brown tremolite (plate III).

Gray granite is intrusive into the Aravalli formation and occupies extensive areas. It is well exposed towards SE of the Ankli mine. The granite is generally coarse and massive but at places show porphyritic texture. The minerals present are quartz, feldspar and biotite. Both gray and pink varieties are present and this colour variation depends on the colour of the feldspar and the percentages of biotite present (plate IV). Granite cuts across the various Aravalli formations and shows sharp and irregular contact. The contact between granite and graphitic formation is not noticeable due to the soil cover.

Sewania: The Fulpari graphite mine is located on the right bank of the tributary of Panam river at a distance of 2 km north of Sewania (plate V). The mine area is a part of Fulpari village and is surrounded by plain cultivated ground. The length of the mine area is 30 to 35 m and the width is 12 to 15 m. The strike length of the graphite band is 40-95 meters. The main rock type is graphite bearing schist or calc-schist of Pre-Cambrian age intruded by younger pink granite. The regional strike of the schistose formation is East-West. The dip varies from 35°-50° due N.

Plate III. Crystalline limestone (Ankli).

Plate IV. Gray granite (Ankli).

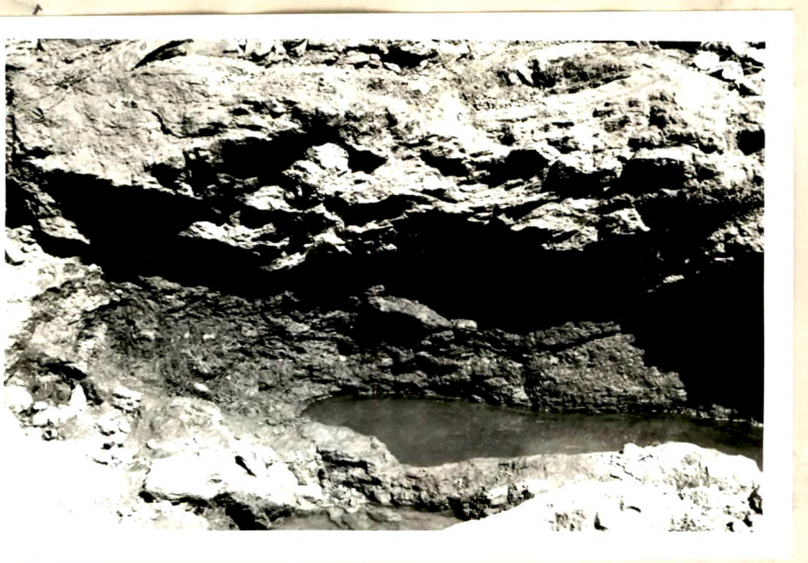

Plate V. Open-cast graphite mine (Sewania).

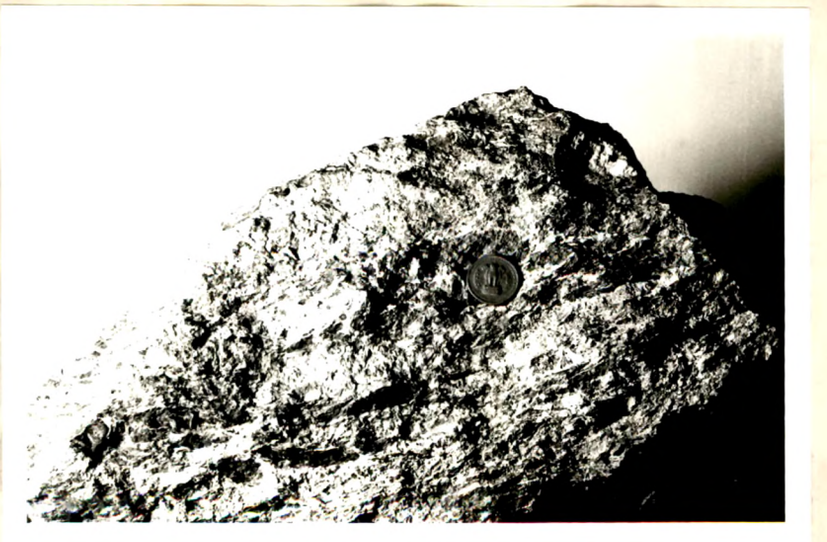

Plate VI. Graphite schist (Sewania).

The schistocity is

Graphite schist is gray to dark gray, friable and well foliated,
well developed. On the flank of the mine, the compact lowgrade graphite schist is overlain by the well-foliated graphite schist. Graphite is highly disseminated along the foliations of the schistose rock (plate VI). The concentration of graphite in the schistose rock is in the form of bands which vary in thickness from 1 to 7 cm. The schistose rock is more compact and foliations are disturbed near the contact of granite. The graphite schist contains quartz, calcite and graphite as common minerals. Pyrite grains are scattered irregularly in the earthy mass. The schistose formation consisting primarily of quartz, calcite and graphite, represents metamorphosed Pre-Cambrian argillaceous-calcareous sediments. Distinct veins of milky quartz and minute veins of calcite are oriented parallel and across the foliation of the schistose formation. The light yellowish bands of sandy material varying in thickness from 2 in. to 1 ft are parallel to the strike of the schistose formation (plate VII). The sharp contact is observed between pink granite and graphite schist locally showing small folds.

Pink granite: Medium to fine grained pink granite is highly fractured and is exposed on the northern flank

Plate VII. Sandy layers within the graphite schist (Sewania).

Plate VIIIA. Granitic exposure in mine section (Sewania).

Plate VIIIB. Pink granite (Sewania).

(plate VIIIA and B). Two sets of joints are apparent, both having East-West strike. Dip of one set is almost vertical and that of another set is 40°-50° due N. Graphite is absent in the fractures and joints. The granite is distinctly a later intrusive and is considered to be Post-Aravalli in age.

Graphite deposits near Sewania mine occurring as isolated patches 1 to 2 ft below the surface are not of economic importance.

Virpur graphite mine is situated 3 km from Jhoz, East of State highway connecting Devghad Baria and Chhotaudepur. In the mine area the main rock types are quartz-mica-graphite schist and crystalline limestone. Few meters to the east of the mine, granite and biotite schist are exposed. The length of the mine is 12-15 m. The general strike of the schistose formation is N-S. Dip varies from 35°-40° due NW. The strike of the crystalline limestone bed is same as that of quartz-mica-graphite schist. Local folding is observed in the mined section (plate IX). On the flank, the limbs of the fold show presence of alternate bands or layers of quartzose material and graphite-schist. Foliations are well observed.

Plate IX. Local folding in graphite schist (Virpur).

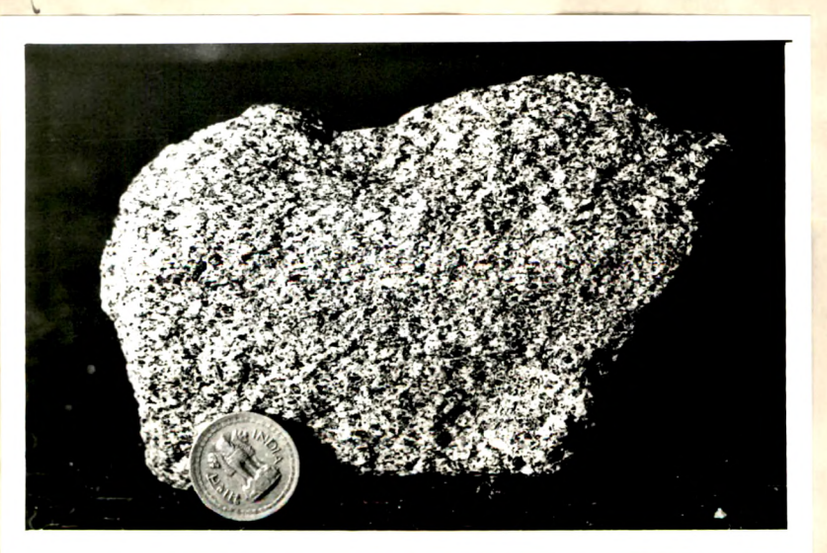

Plate X. Quartz-mica-graphite schist (Virpur).

Quartz-mica-graphite-schist is silvery gray and shows schistose structure due to sub-parallel orientation of elongate quartz with feldspar and mica (plate X). Graphite disseminated along the foliations of the rock, is closely associated with quartz, feldspar and mica. This graphite bearing schist differs from other graphitic schist in its silvery gray colour and greater percentages of quartz, feldspar and mica. The schist is soft and friable. On the southern flank of the mine the quartz-mica schist and quartz-mica-graphite-schist occur as alternate layers (plate XI).

Crystalline limestone, a medium grained, gray to grayish blue rock is exposed in the mine area. It is conformable with graphite schist. The presence of tremolite indicates effects of contact metamorphism on limestone due to intrusion of granite.

Biotite schist is black due to the abundance of biotite. The rock is schistose in nature and the asscoated rock is granite (plate XII).

Gray granite is exposed few meters away from the mine. Quartz, feldspar and mica are the main minerals present in

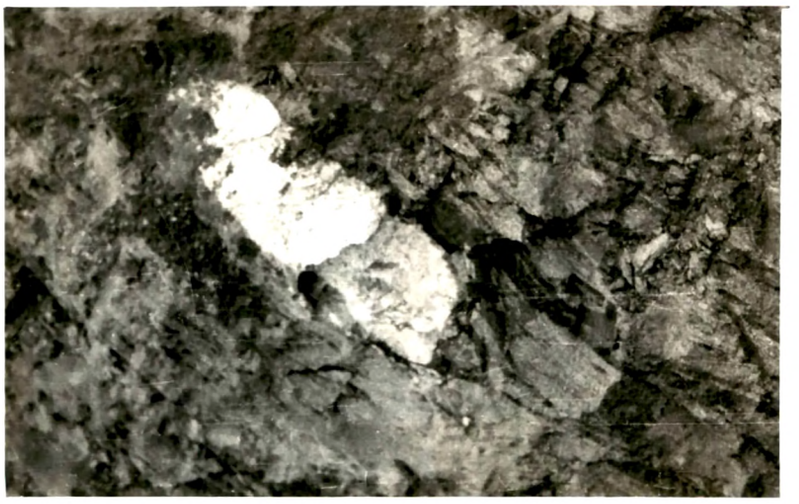

Plate XI. Alternate layers of graphite schist and quartz-mica schist (Virpur).

Plate XII. Biotite schist (Virpur).

the rock. It is intrusive in nature.

Muthai mine, located 1.5 km north of the Muthai village is surrounded by hillocks of quartzite and granite (plate XIII). The length and width of the mine are 40-45 m and 10-15 m respectively. The depth is 10-15 m. The graphitic band exposed is of the thickness of 5 to 8 meters. The strike length is of about 250 meters. The main rock types exposed in the mine area are quartz-mica-graphite schist and granite. The general strike of the graphite is NWN-SES. Dip varies from 60°-80° due west. Granite occurs as wall like intrusive (plate XIV A). At places pegmatite and quartz veins varying in thickness from 1 to 4 inch run along as well as across the schistosity of the rock. On the western side of the mine, there are many local occurrences of graphite which are not of economic importance. The granite hills are composed of medium to coarse grained gray granite. Pegmatites in quartzitic hills consist of quartz, feldspar, tourmaline and mica. A beneficiation plant for graphite is also located near the mine.

Quartz-mica-graphite schist is medium grained, grayish black to black and well foliated. The microflakes of graphite are disseminated in the schistose rock in close association with quartz and mica. Some graphite bearing rocks on weathering show stains of iron (plate XV).

Plate XIII. Open-cast graphite mine (Muthai).

Plate XIVA. Wall-like granite exposure in mine section (Muthai)

Plate XIVB. Granite (Muthafi).

Plate XV. Quartz-mica-graphite schist (Muthai).

Plate XVI. Vein of pegmatite in graphite schist (Muthai).

Granite is leucoratic and coarse grained. It consists of quartz, feldspar and mica as chief minerals (plate XIV B).

It shows sharp contact with graphite schist. There is a marked absence of graphite except at the contact where the graphitic material occurs associated with quartz and feldspar due to later tectonic activity. The medium to coarse grained granite exposed in the hilly terrain away from the mine consists of quartz, feldspar and mica.

Pegmatite is pinkish due to the presence of microcline. Graphite is not traceable in the rock. It has a distinctly intrusive relationship (plate XVI). Veins of milky white quartz occur along and across the foliations of the rock. Calcite veins occur as thin stringers.

The field characters reveal that the graphitic schist associated with granite is a regionally metamorphosed Pre-Cambrian argillaceous sediment. The intrusive granite is also affected by later tectonic activities. Pegmatite and quartz-vein are the later intrusives and are of Post-Aravalli age.

Graphite deposits exposed near Chaena and Kundal villages are not of economic importance. At Chaena, fine-grained grayish quartz-mica-graphite schist resembles

slaty phyllite having mica, quartz and graphite as its chief constituents (plate XVII). Graphite is disseminated in quartzose matrix and is closely associated with mica and quartz. The rock is so fine-grained that megascopically the identification of minerals is difficult. The foliations are not well developed. In physical appearance it resembles a low-grade regionally metamorphosed rock. Near Kundal, graphite occurrences are within the schistose rock. The grayish-black, quartz-mica-graphite schist of limited extent contains abundant graphite. In stream section inferior graphite of amorphous type occur in graphytic phyllite. The associated rock is argillaceous limestone and quartzite at places.

Jaloda: Graphite deposits are located near Jaloda village, 3 km from Nani Dumali, on state highway joining Chhotaudepur and Baroda. Quartz-mica-graphite schist is well exposed in the low lying area between two hillocks. The medium to fine grained, hard and compact quartzite is located at the foot-hills. The general strike of the graphite schist is NE-SW and the dip varies from 45°-60° due south. The low undulating area is well oultivated, fertile land. Milky quartz veins are also exposed in the area.

Plate XVII. Graphite schist (Chaena).

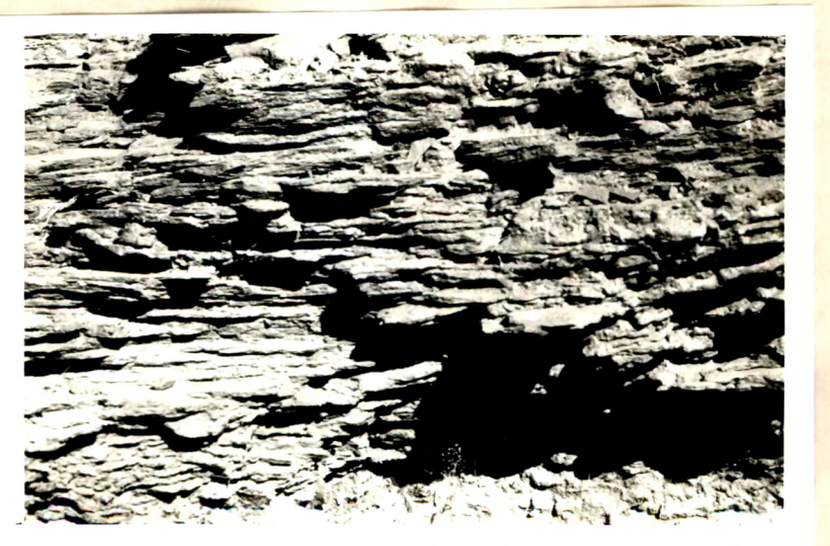

Plate XVIII. Quartz-mica-graphite schist (Jaloda).

Quartz-mica-graphite schist is grayish, fine grained and friable. Schistosity is well developed. The quartz and mica are the main gangue minerals identifiable in hand-specimen. Gray colour of the rock is due to the presence of graphite. The very tiny flakes of graphite are disseminated in the schists and are difficult to identify megascopically (plate XVIII).

Quartzite is medium to fine grained, hard and compact. The strike of the quartzite is same as that of the graphite schist. At places bedding is distinct. The graphite is not traceable in the rock (plate XIX).

The detailed investigation of the Narukot area by Directorate of Geology and Mining, has revealed the occurrence of graphite in graphitic phyllite over a strike length of about 180 meters. The average thickness is 30 meters. The general strike of the band is almost E-W and the dip is due north. Quartzites form the ridges in the area. They are grayish white, compact, thickly bedded, hard and well jointed. The sedimentary features such as current bedding and ripple marks are observed (Jambusaria, 1970).

Plate XIX. Quartzite (Jaloda).

Plate XX. Biotite schist (Jhab-Redhana).

The exposed bands of graphitic phyllite show alternate bands of shining graphite and siliceous material. The graphite content in the rock is generally poor except for few richer bands. This formation is cut across by quartz-veins. The rock shows number of minor disseminations and stringers of pyrite in addition to calcite veins. This would increase the impurities such as sulphur and lime.

Jhab-Redhana: The detailed mapping and drilling of graphite deposits were carried out by the Directorate of Geology and Mining. From the drilling data, it is evident that, graphite occurs as fine flakes along the foliation planes of graphite schists lying between two marker horizons of crystalline limestone, 10 to 40 meters thick. The fine flakes of graphite occur along the grain boundaries of quartz or are finely disseminated in altered feldspar.

Ferruginous clayey matter is mixed with fine particles of amorphous graphite. Some bands of phyllite are completely devoid of graphite. The other rock types present are biotite schist, graphite schist, amphibole-quartz-schist and crystalline limestone. They are intruded by granite, pegmatite and amphibolite. The thickness of graphite bands containing various percentages of graphite, varies along

the strike as well as dip direction. The general strike of the band is East-West, dipping due north. Pyrite, lime and pegmatitic material are the chief impurities.

Graphite schist is black, foliated and soft. The main minerals which can be megascopically identified are graphite and mica. Graphite schist is intruded by pegmatite and quartz-veins along its foliation planes. Pyrite also occurs sporadically in it. On the surface limonitic stains are visible. Pegmatite is responsible for spliting of graphite schist along the strike as well as dip directions. The strike length of graphite band is 900 meters and the maximum width is 20 meters.

Crystalline limestone which is hard, compact and siliceous at places occurs as coarsely crystalline, dull white to gray rock. It shows some greenish bands possibly of amphibole. The strike is conformable to the adjacent graphite schist bands. All its characters are obliterated and has become hard and compact due to the contact effect of pegmatitic intrusion.

Biotite schist is exposed over the major portion of the graphite bearing area. It is highly weathered and is intruded by granite, pegmatite and quartz veins. Pegmatite

is intimately associated with it and there is almost lit-par-lit injection along the foliation planes (plate XX).

Amphibole quartz-schist is well exposed and occurs in the form of narrow bands. It is also intruded by pegmatite and quartz veins.

In accordance with the classification suggested by B. Rama Rao (1931), the graphite bearing area lies within the Archean complex. From the detailed study of the geological set up and the general reconnaissance of the area, it appears that graphite bearing rocks belong to Aravallis (Champaner series).

Occurrence of graphite deposits

Graphite is widely distributed in the Pre-Cambrian rocks of Gujarat, composed of regionally metamorphosed sedimentary and igneous rocks. The economic deposits of graphite occur in the Pre-Cambrian metasediments and are confined to low, undulating grounds with considerable soil cover.

Spence (1919), has suggested three main types of graphite deposits on the basis of physical character of

graphite

1. Disseminated flake,
2. Crystalline (plumbago),
3. Amorphous.

Economic deposits of graphite in Gujarat can be broadly classified into two categories based on the physical properties of graphite.

1. Amorphous graphite deposits - amorphous graphite disseminated in argillaceous metasediments.
2. Flaky graphite deposits - flaky graphite disseminated in aranaceous metasediments.

Amorphous graphite is commonly in the form of minute particles more or less uniformly distributed in low grade metamorphic rocks such as phyllitic schist, schist and gneiss which occur in the vicinity of Narukot, Muthai, Ankli, and Sewania and contains 12 to 22 per cent graphitic carbon. Flaky graphite is disseminated in schists intruded by granite and pegmatite near Virpur and Jaloda and contains 5 to 12 per cent graphitic carbon. The graphite flakes are oriented parallel to the plane of foliation and occur in layers and lenses which are not similar in mineral composition. The graphite content of amorphous deposits depends on the

amount of carbon originally present in the deposits as there is no evidence of any enrichment by the intrusive rocks.

The chief constituents of graphite bearing rocks are quartz, feldspar, micas and graphite with varying amounts of calcium and iron minerals. The associated rocks are crystalline limestone, quartzite, granite and pegmatite. Most of the graphite occurrences of commercial importance are located in the foliated rocks such as phyllite and schist which have been intruded by massive igneous rocks of both acid and basic varieties. At some places graphite occurs intimately intergrown with quartz, feldspar and mica making a sort of graphitic gneiss. The prominent among the acid varieties are pink granite and pegmatite.

Graphite schist consists of bands or layers or seams of graphite in which the variation in the nature of foliation, directly reflects the percentage of graphite present in the rock. A light to dark gray graphitic schist is extremely foliated and friable. Pyrite is almost always present and is disseminated between the individual microflakes of graphite as at Sewania and Muthai. The grains of graphite are more or less evenly distributed in well developed foliated schist and are not concentrated along the border of the granitic

masses or along certain planes within them (which is against the magmatic flowage theory). Milky quartz and feldspar are present in veins and stringers, while calcite is mostly present in stringers. In some of the graphitic layers, slight movements subsequent to their formation, have bent the graphite flakes or crushed them to an earthy mass. The graphitic schist shows a contorted irregular pattern of quartz veins (milky quartz) embedded in the rock. They may be concordant with the structure of the host-rock or may be at times discordant. Minor foldings are observed in this rock.

The crystalline limestone exposed at Ankli and Virpur vary in width from a few inches to a foot or more. It is interbanded with the commoner types of schist and gneiss representing metamorphosed calcareous sediments. The quartz-graphite schist appears gray to dark silvery gray when fresh. On weathering it is stained yellow to brown. The outcrops of Post-Aravalli intrusive granite occur near Ankli, Sewania and Muthai.

The graphite bearing gneiss is mainly composed of diopside, mica, amphibole, sphene, and calcite with occasional feldspar. The presence of this mineral

assemblage suggests contact metamorphism due to later intrusion. This rock shows light bands consisting of gangue minerals and dark bands consisting of graphite and iron oxides.

The following observations were made during the course of the field investigations of the various graphite deposits in the Pre-Cambrian rocks of Gujarat.

1. The bands or layers of graphitic rocks are more or less parallel to the bedding of crystalline limestone, quartzite and quartz-schist as at Ankli, Jhab-Redhana, Virpur and Nadatod.

2. The strike of the graphitic bands is parallel to the strike of the bedding foliations of the graphite schist.

3. The contacts of quartz veins, pegmatite and granite with graphite bearing rocks are sharp. Graphite is absent in the fractures and joints. The foliations are more or less perpendicular to the intrusive contact (plate XXI).

4. The grains, flakes and foliations of graphitic rocks are uniformly distributed for considerable distances away from the contact, except at the

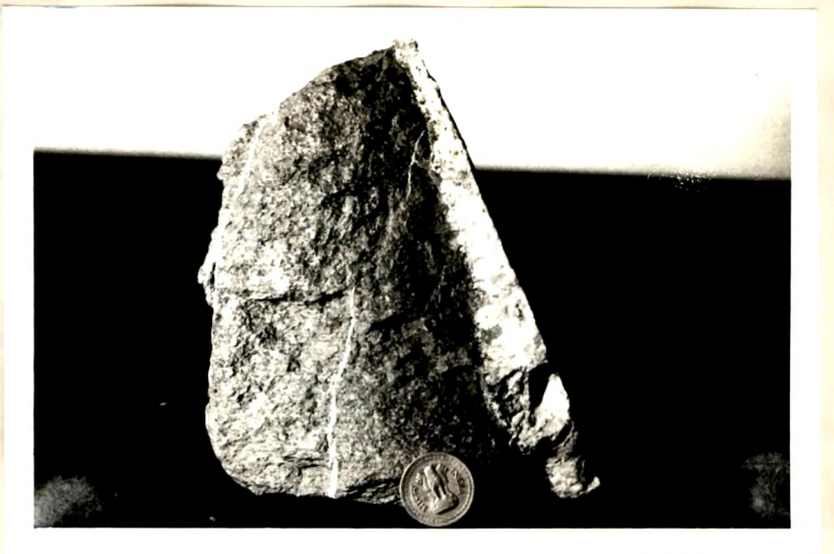

Plate XXI. Sharp contact between graphite schist and pegmatitic vein (Muthai).

extreme contact. Absence of larger concentration of graphite near the contact zone.

5. Complete absence of vein type crystalline graphite bearing horizons cutting across the graphitic schist.

6. Change in size of the graphite flakes with the distance increasing away from the contact zone, as e.g. at Muthai.

There are many isolated patches of local concentration of disseminated graphite as at Kundal, Chaena, Fulpari etc. At places the general outline, margin or main trend of the disconnected thin layers or lenses of graphitic rocks confirms with the stratification of the country rock e.g. near Ankli.

Mining

Open-cast mining methods are used to excavate graphite ore upto a depth of 15-20 meters in gentle to steeply dipping graphite bearing formations at Ankli, Sewania, Virpur and Muthai. Selective mining methods are employed to work out the deposits on the flanks or those having least overburden consisting of hard and massive rocks. The soft and friable graphite bearing rock is dug out by pick and shovel and removed by manual labour. The main rock types in mined

sections, are pink granite, crystalline limestone, dolomite, quartzite, pegmatite and graphite bearing phyllite, schist and gneiss. Starting from the surface, the excavation proceeds along the strike of the graphite bands. The mined material is broken into smaller pieces, consisting 50 to 70 per cent rocky impurities which are removed by hand picking. In this area water-table lies at 20 to 24 meters below the surface, hence any mining below this depth has to face water problem. The run of mine ore containing 2 to 18 per cent of fixed carbon is exploited for graphite and transported to the beneficiation plant.