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A PRELIMINARY STUDY OF THE GRAPHITE-BEARING ROCKS, AT PATLEPANI-MOHRIWALI AREA, MUZAFFARABAD, A.K.

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ABSTRACT

Graphite at Patlepani-Mohriwali area, District Muzaffarabad (A.K.) occurs in a skarn formed due to an intrusion of pegmatite in recrystallised limestone of Salkhala Series of Pre-Cambrian age. Skarn formed at the upper contact of pegmatite, devoid of graphite, is barren skarn, whereas, at lower contact is fully mineralised with graphite. Mineralised skarn show a well defined zonation pattern from pegmatite to amphibole-pyroxene-graphite skarn to pyroxene-amphibole-graphite skarn to plagioclase-garnet-graphite skarn.

Graphite has an average concentration of 12% and occurs in skarn as concordent lenses, disseminated flakes, bands and is formed in two phases; organic carbon present in original impure limestone was converted into amorphous to semi crystalline graphite during regional metamorphism of area. During the subsequent process of skarnification, this amorphous to semi-crystalline graphite was fully crystallised and being mobile migrated into low pressure zones of skarn.

INTRODUCTION

Graphite is a form of carbon and occurs in nature in the form of crystalline flakes, plumbego, and as amorphous variety, black lead. The phanerozoic graphite deposits are found associated with coal bearing metasedimentary rocks. These deposits are usually stratiform, low grade and confirmable with the enclosing metasediments. Precambrian graphite deposits are found in medium to high grade regionally metamorphosed rocks, i. e. schist, gneisses, as disseminated flakes, concordent lenses and pods etc.

The occurrence of graphite, in area presently known as Azad Jammu and Kashmir, was reported by D.N. Wadia (1953) in slates and schists of Salkhala Formation in District Muzaffarabad. Detailed investigations on the mineral started in 1966 by the then West Pakistan Industrial Development Corporation (WPIDC) in District Muzaffarabad and Kotli. In Muzaffarabad exploration was carried out on graphite schist exposed near Nauseri and Reshian. Whereas, in Kotli it was reported to be associated with Eocene rocks. As a result of detailed exploration sufficient reserves of the mineral were proved. However, extensive laboratory studies by Pakistan Council of Scientific and Industrial Research (PCSIR) Laboratories at Lahore, established that the mineral cannot be beneficiated and upgraded. Hence the work on the deposits was abondoned.

In 1974, Azad Kashmir Mineral and Industrial Development Corporation (AKMIDC) located graphite deposit in Mohriwali, Neelum Valley. Initial Laboratory studies by the PCSIR Laboratories Lahore and some foreign Laboratories proved suitability of this graphite for industrial purpose. AKMIDC in association with Pakistan Mineral Development Corporation (PMDC) carried out detailed geological investigation to prove the reserves of the mineral. These investigations concluded low reserve potential of these deposits, only to the tune of 15,000 tonnes. The deposits, therefore, were classified as uneconomical.

In 1984, another geological party (headed by S. Qureshi) was deputed to explore the Mohriwali area for graphite. The efforts of the party proved successful and a skarn containing graphite mineralization was discovered in Patlepani Nar area.

The new discovery of graphite in Patlepani Nar is located at an aerial distance of about 120 k.m. NNE of Muzaffarabad in Neelum Valley. The area falls in Survey of Pakistan topographic Sheet No. 43–L/8.

REGIONAL GEOLOGY

The area of Azad Jammu and Kashmir State Constitutes a part of the Great Himalayas. Wadia (1953) divided the Great Himalayas on the basis of geology and structure into three broad stratigraphic zones. Based on this classification, the area of the State falls in two Himalayan zones. The northern and north eastern part of District Muzaffarabad and northeastern part of District Poonch fall in Central or Himalayan zone, whereas, the rest of District Poonch, District Kotli and District Mirpur constitute part of outer or sub-Himalayas. The two zones are separated by a major thrust fault, the so called "Main Boundary Thrust".

The mountains of Central Zone consist of metasedimentary rock sequences of Salkhala Series, Hazara Formation, the Panjal Volcanic Series, Gundwana group and granitic igneous batholiths. The Salkhala Series are exposed in Neelum Valley and Leepa Valley of District Muzaffarabad and consists of phyllites, thin quartzites, calc-schists, carbonaceous slates, sericite schist, marble and gneisses. They turn around the Western Syntaxis, being thrust centripetally over the Paleozoic and Mesozoics (Gannser, 1964).

The Hazara Formation is exposed around the Muzaffarabad Town, Kalamula, Bedori, Raji and Hillan, in Tehsil Haveli, District Poonch and in District Kotli and consist of grey, dark grey to black slates, phyllitic slates, phyllites and chloritic schists with graphitic intercalations.

The Panjal System was divided by Middlemiss (1896) into Lower Panjal Agglomeratic slates; composed of grey to black slates, and Upper Panjal Trap which comprises of volcanic rocks exposed along the Main Boundary Thrust in District Muzaffarabad and in District Poonch. These are mainly green colour, fine grained rocks of basaltic and andesitic composition (ECL, 1978).

The Gondwana group overlies the Hazara Formation and consists of moderately metamorphosed shales, arenaceous phyllitic slates and are exposed in Batar Valley of Tehsil Haveli, District Poonch (ECL, 1978).

Igneous rocks exposed in the area include granitic batholiths of Jura-Neelum of Tertiary age, whereas granite of Kel and Gurez area has been considered to be of Paleozoic age (Ghazanfer *et al.,* 1984).

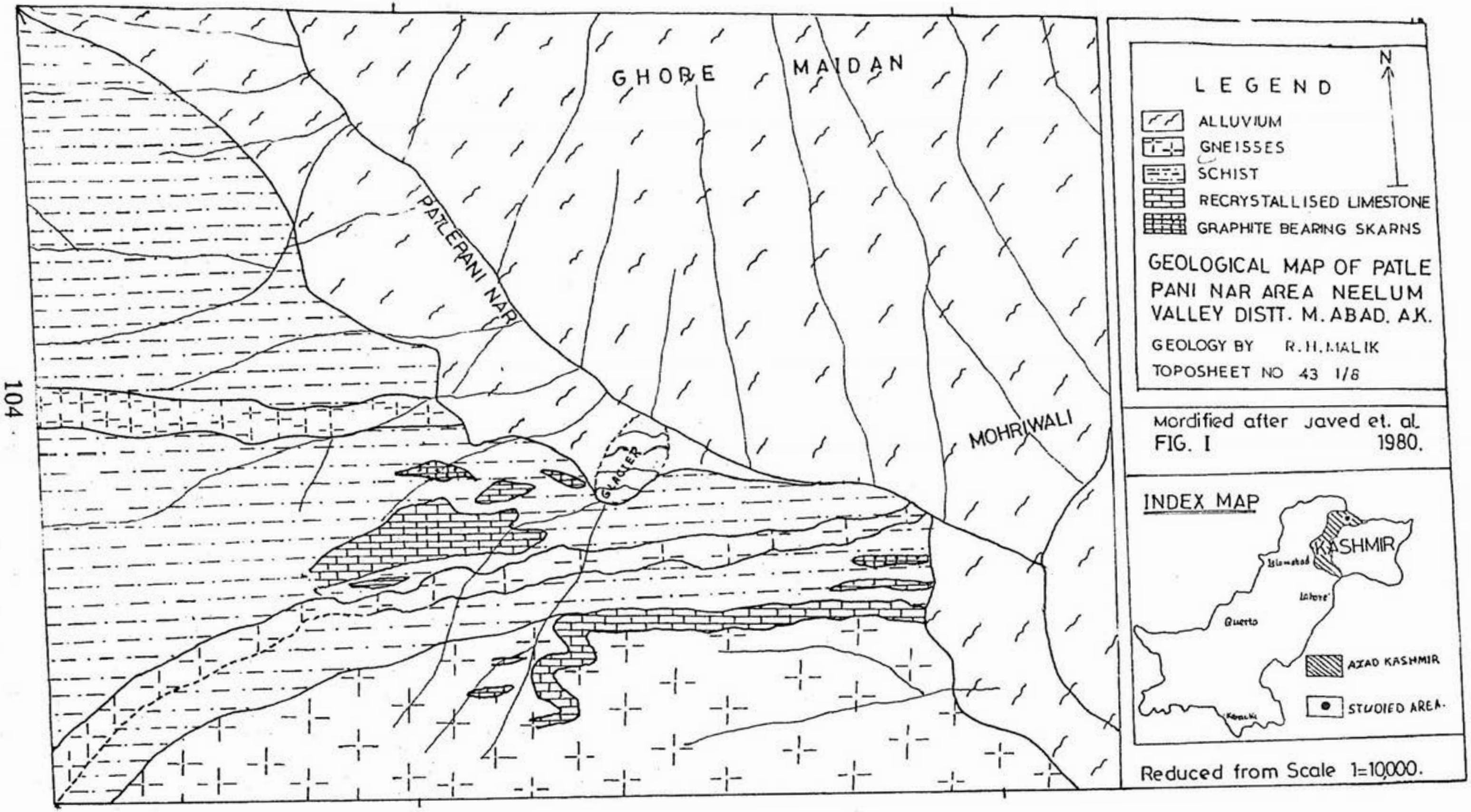
The outer or Sub-Himalayan zone lies south of Main Boundary Thrust and comprises of sedimentary rocks of deep marine to continental fluviotile sediments and metamorphic rocks. Various lithostratigraphic units exposed in the area include Abbottabad Formation of Cambrian age, AK-Fireclay-Bauxite horizons of Paleocene age, Patala Formation and Margala Hill limestone of Paleocene to Eocene age, Murrees Formation of Miocene age and the Siwaliks of late Miocene to Pliestocene age (ECL, 1978).

GEOLOGY OF THE AREA

The area investigated is a part of the oldest sedimentary rocks of the Himalayan zone, named as Salkhala series by D.N. Wadia (1953) and Sharda Group (Ghazanfar *et al.,* 1981). These Paleozoic sediments were subjected to regional metamorphism and the argilaceous, calcareous and dolomitic members were converted to dark hornblendes, garnet gneisses, marble and schists (Wadia, 1953).

Major lithological units of the area consists of micaceous, garnetiferous and graphitic schist, crystalline limestone, gneisses and amphibolites (Fig. 1). The pegmatites and quartz veins; mostly product of metamorphic differentiation, are observed intruding the country rocks quite frequently.

Regional trend of the lithological units is northeast dipping in southeast direction. The area on whole represents regionally metamorphosed rock of low to medium grade. The various rock units exposed in the area are described below:-



GEOLOGICAL MAP OF PATLE PANI NAR AREA NEELUM VALLEY DISTT. M. ABAD. A.K.

FIG. I

Schists

The schists are the major lithological units of the area and exhibits various colours ranging from rusty brown to yellowish on weathered surface. On fresh surface, these are greenish to greenish grey and medium to coarse grained. Based on various minerals assembledges, schists can be sub-divided into quartz-mica schists, garnet-mica schist, kyanite schist and graphite schists. Quartz-muscovite schist is comparatively dominant over other units. It is more resistant to weathering, therefore, makes prominent ridges in the area. Quartz-muscovite schist is comparatively more compact than other varieties. Garnet-mica schist is finely bedded and garnet is poorly developed. Garnet is fine-to medium-grained and of dull red colour. Kyanite schist occurs mostly around Chattewala granitic body.

There are quiet a few graphitic schist beds in the area, especially, in Tarli Domel area. The rocks vary in texture, thickness and graphitic carbon contents from place to place.

Gneisses

The gneisses constitute another major lithological unit in the area and overlie schists. These are hard compact and medium-to coarse-grained rocks. The colour of the rocks on weathered surface, generally, varies from brown to brownish grey, while on fresh surface, it is generally greyish-white to dull white. The gneisses are well jonited and foliated. Megascopically, the rocks consist of quartz, feldspar, mica (mostly muscovite) and tourmaline.

Recrystallised limestone

Thin to thick bedded, medium-to coarse-grained, recrystallised limestone is an important lithological unit of the area. It is generally, lenticular and found intercalated with schists and gneisses. Coarse grained varieties are pure and white. It generally exhibits lenticular character which indicates severe tectonic activity in the area. The colour of the rocks on weathered surface ranges from dark grey to yellowish brown, whereas, on fresh surface it is light grey to grey. Another characteristic feature of the recrystallised limestone is the emission of sulphur dioxide, when hammered. Developmnt of skarn is common phenomena in the area, where hydrothermal quartz veins, pegmatite or amphibolites are in contact with the recrystallised limestone. Skarn thus formed are light green to green in colour and consists of calcite, dolomite, corderite, tremolite, diopside, pyroxene and graphite mineral assemblage.

In Utli Domel area, where marble is in contact with an amphibole bed, occurrences of ruby have been located. These precious stones are developed along the bedding planes. Other minerals found associated with ruby mineralization include phlogopite, muscovite, fucsite, pyrite, chrome diopside and garnets. Association of graphite and ruby with this unit, makes it the most productive lithological unit of the area.

Amphibolites

The amphibolites are another unit in the area. These are found intercalated with marble and schists. These are medium-to coarse-grained and occur in the form of bands and layers. The thickness of the unit vary from few cms to meters. Megascopically, these consists of hornblends and garnets, which is mostly almandine. The contact of these rocks with associated unit, is generally sharp, showing intrusive character. Based on field observation, it is concluded that both ortho-and para-amphibolites exist in the area.

Quartzites

This unit is found intercalated with other units of the area. These are massive, hard and fine-to medium-grained. On fresh surface the colour of the rocks vary from greyish-white to white, whereas, on weathered surface is yellowish-white.

Igneous rocks of the area

The igneous rocks in the area are granitic intrusions and pegmatites. Few granitic intrusions in Mohriwali area, especially in and around Ghore-Medan graphite occurrences were reported by Javid *et al.* (1980). On fresh surface these are white, medium-to coarse-grained, and are well jointed. Mineralogically, the rocks consist of potash as well as plagioclase feldspars, biotite and muscovite.

Pegmatites and quartz veins are found intruding schists and gneisses frequently. Generally, these are small or irregularly shaped, but follow the regional trend. Pegmatites are generally simple consisting of quartz, feldspar, tourmaline, muscovite, biotite and phlogopite. Quartz veins are mostly the product of metamorphic differentiations.

STRUCTURE

The rocks exposed in the Shontar Nala, probably from part of southern flank of the Nanga Parbat anticlinorium. Except minor displacements along the shear zones, no major structural disturbance has been noted in the area. Folding is very common, especially in recrystallised limestone. The recrystallised limestone in Patlepani area exhibits pinching and swelling character which is attributed as boundinage structures, resulting from extension. Since, this bed was more competent than the overlying schists, therefore, due to extension, broke into series of elongated bodies and overlying schists being very incompetent flow in between broken bodies. At places, where rate of strain did not exceed the rate at which the recrystallised limestone was to behave in ductile manner, the boundinage failed by necking. It is due to this phenomena that in the area recrystallised limestone occurs as lenticular or tabular bodies.

THE GRAPHITE DEPOSITS

In Mohriwali area six isolated occurrences of graphite have been reported by Javid *et al.*, (1980) in their report titled "Find report on Graphite Deposits of

Mohriwali". Four out of six were reported from Sarwali Nar, whereas, two were reported from west and southwest of Patlepani Nar. Mineralization in Patlepani Nar was reported to occur in a small area with no significant extent.

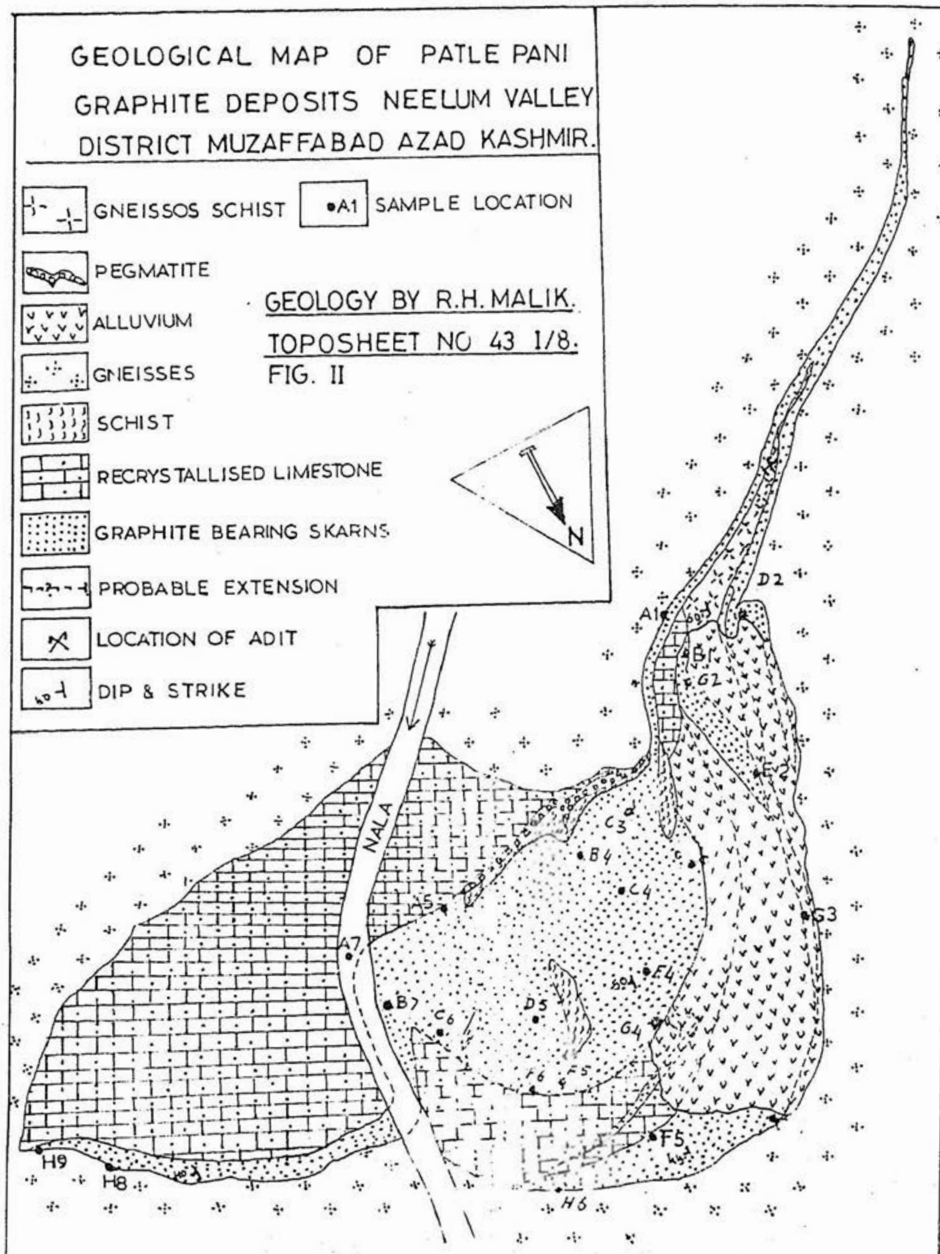
New discovery of graphite in Patlepani (Fig. II) occurs in a lensiod skarn body. In NW, where it is 2 m thick, is separated by 0.3 m thick band of gneissose schist. Thickness of this band increases towards NE due to which the skarn is separated into two prominent bodies. The upper body termed as body "A" in this report, is most significant for having maximum thickness, extent and higher concentration of graphite. The lower body containing graphite has small extent and less concentration of graphite. This body is termed as body "B" in this report. The skarn follows the regional trend and strikes N62°E with dip of 56°SE.

The skarn is exposed along the dip length for 150 m. Exposed strike length is 20 m with average thickness of 15 meters. The skarn contains several schist bands, which at places also contain graphite as dissemination. Schists are brown in colour on weathered surface and greyish on fresh surface. In hand specimen these consist of quartz, mica and feldspars. A pegmatite exposed at the upper contact of skarn is a sill and pinches in both the directions. It is whitish in colour and essentially consists of pegmatitic minerals. It appears that this body has played major role in the formation of mineralized skarn. The pegmatite is massive, compact and coarse grained. In the NW-like skarn, pegmatite has a maximum thickness of more than 20 meters, it pinches. Towards the NE it is one meter and divides upper skarn body "A" into two bodies i.e. I A and II A.

The upper body, i.e. IA, is devoid of graphite and termed in this report as "barren skarn". It pinches in both the directions. It is greenish in colour and has a thickness of few centimeters in NW, whereas, towards the NE after attaining maximum thickness of more than 20 meters, it pinches. Towards the NE it is twisted anticlockwise followed by a swing towards Northeast, where it overlaps the the lower graphite body II A. Pegmatite is not exposed at this place.

Skarn below pegmatite is termed as body II A, and contains almost all essential skarn minerals alongwith graphite. This body, like main skarn, shows lensiod character. It is exposed along the dip length for 60 m with an average thickness of 10 meters. It has an interesting thickness relation with overlying barren skarn body I A. Towards NW, where pegmatite is exposed, thickness of graphite body II A, is maximum while barren skarn is minimum. In NE, barren skarn body I A, has maximum thickness, whereas mineralised skarn II A, has minimum.

The rock is compact, hard and fine-to medium-grained and has greyish-to greyish-green colour on weathered surface, whereas, on fresh surface it is greyish. In general, the colour depends upon the concentration of graphite in the rock. Where the concentration of graphite is more the colour of rock is greyish. Whereas, where the concentration of graphite is less it is greyish-green.


GEOLOGICAL MAP OF PATLE PANI
GRAPHITE DEPOSITS NEELUM VALLEY
DISTRICT MUZAFFABAD AZAD KASHMIR.
GNEISSOS SCHIST
SAMPLE LOCATION
PEGMATITE
ALLUVIUM
GNEISSES
SCHIST
RECRYSTALLISED LIMESTONE
GRAPHITE BEARING SKARNS
PROBABLE EXTENSION
LOCATION OF ADIT
DIP & STRIKE
GEOLOGY BY R.H. MALIK.
TOPOSHEET NO 43 I/8.
FIG. II
N
NALA
SCALE - 1: 400

Four samples were taken from the skarn body II A for petrographic studies. Samples locations are marked on map at Fig II and mineralogical composition is shown **in Table 1.**

Sample No. A_1 and D_3 represent mineralized skarn close to pegmatite, whereas, samples G_4 and H_9 have been taken at a distance from pegmatite. Petro graphic studies of samples show that composition of skarn at these localities varies from amphibole-pyroxene-graphite skarn to pyroxene-amphibole graphite. As the distance of skarn from pegmatite increases, concentration of amphibole decreases and

TABLE I. MODEL COMPOSITION OF THE GRAPHITE-BEARING ROCKS.

	A_1	D_3	G_4	H_9	C_2	D_1	H_6
Amphibole.	74	76	65	—	62	—	70
Pyroxene.	4	5	20	—	22	76	52
Graphite.	20	19	14	7	7	18	8
Quartz.	—	—	—	15	—	3	—
Biotite.	2	—	1	28	—	3	4.5
Axinite (?)	—	—	—	—	—	—	8
Philogopite.	—	—	—	—	—	2	—
Calcite.	—	—	—	5.5	—	-	0.5
Plagioclase.	—	—	—	30	-	-	—
Garnet.	—	—	—	12	—		—
Apatite.	—	—	—	—	—	1	5
Ore.	—	—	—	2.5	—	—	—

pyroxene increases. The texture of skarn close to pegmatite (sample No. A_1 and D_3) is hypidiomorphic to granoblastic, porphyroblastic and poikiloblastic. Both the samples have almost identical mineralogy, except the presence of biotite in addition to other mineral in sample A_1. Graphite is completely crystalline in both the samples with higher concentration and is intimately intergrown and included in amphibole. Flake size ranges from 0.03 to 1.5 mm in A_1 to 0.1 to 1 m.m in D_3.

Samples No. G_4 and H_9 constitute the central part of skarn and lie at distance from pegmatite. Pyroxene predominates amphibole in sample No. G_4, whereas, both pyroxene and amphibole are absent in sample No. H_9, which has been taken at the pinching end of skarn. Composition of skarn at this locality i.e. at H_9, is altogether different. The rock is granoblastic (hornfelsic) sub-phyroblastic and strongly poikiloblastic. Garnet, a characteristic skarn mineral is microscopic and belongs to grossularite-andradite series. Plagioclose which is absent from all other samples, constitutes bulk of rock. It also contains inclusions of garnet, mica and graphite, indicating that it has been formed during the process of skarnification. Biotite is the second major constituent and occurs as inclusions as well as discrete flakes and their aggregates. Other associated minerals include quartz and calcite. Graphite constitutes 7% of the rock and occurs as inclusions and intergrowths and ranges in size from 0.08 to 0.5 m.m.

Three samples were collected from skarn body B. Only one sample from the upper contact and two samples from lower contact were studied petrographically. The results are produced on **Table 1.**

Sample No. C_2 represents upper mineralised body. Skarn at this locality has some what similar composition to that of upper skarn body II A, and is amphibole-pyroxene graphite skarn .Concentration of pyroxene is comparatively more in this sample, whereas, graphite is low. Quartz is present and forms 8% of rock.

Two samples have been taken from the lower part of skarn body B in contact with underlying gneisses. Mineralogical composition is on Table 1. Skarn at this locality is banded and form a recumbant fold. Skarn in sample D_1 is comparatively fine grained. Pyroxene constitutes bulk of the rock and occurs as hydpidioblastic crystals. Amphibole is totally absent. Biotite is absent at this locality and instead phlogopite is present, indicating that original rock at this locality was dolomite. Based on mineralogy skarn at this locality is classified as pyroxene-graphite skarn. In sample No. H_6 rock is graphite-pyroxene-graphite skarn. Concentration of graphite is comparatively low (8%) and occurs as needles and grains. The skarn at this locality contains axinite (?) as well as calcite. Except this sample, axinite has not been found in any other sample.

No detailed mineralogical studies have been carried out to establish zonation pattern in the skarn. However, results of samples (discussed above) indicate that their is a definite zonation pattern. Three distinct zones are present in graphite-bearing skarn body II A. Part of skarn close to pegmatite has amphibole-pyroxene-graphite mineral assemblege, whereas the distance of skarn from pegmatite increase, pyroxene increase and at the extreme end, skarn has plagioclase-garnet assemblege. Characteristic skarn mineral assemblege suggest that original rock was mostly impure limestone having few dolomite zones. The skarn formation took place over a considerable temperature range.

ORIGIN OF GRAPHITE

Origin of graphite in Pre-Cambrian rocks is a matter of speculation since long. Various theories have been put forward in this respect and noteable amongst these are **discussed below :**

Clark *et al.* (1921) described the origin of graphite in Precambrian rocks as the interaction of magmatic gasses with carbon dioxide of the sediments. However, derivation of graphite from CO_2 was strongly opposed by Spence (1921) Craig (1954) who proved by thermodynamic evidences that this reaction is not possible in nature, except under very extraordinary conditions in which reduction by H_2 or mettalic Fe can take place.

Hollister (1980) explained the mechanism for the origin of graphite in Precambrian rocks as a result of thermal metamorphism of carbonaceous sediments. During the process of metamorphism carbonaceous sediments produce destructive changes in the heavier hydrocarbon molecules with graphite forming as one of the end minerals, i.e. Kerogen and heat = C (graphite) and heavy hydrocarbons.

It is possible, therefore, that much of the graphite found in Precambrian rocks is formed by the unbonding of kerogen or similar organic compounds, however, graphite could also form from the heavy hydro-carbon that were volatillised and migrated into fissures or fracture zones where they reacted with wall rocks to produce veins of high grade graphite. There is thus good geological and chemical evidence that the graphite found in all grades of Precambrian metamorphic rocks have the same source and that source is organic carbon. Mancuso *et al.* (1981) believe that sufficient organic carbon of high concentration and purity is available in Precambrian rocks as coal or anthroxolite to account for the graphite deposits which occur in Precambrian rocks.

Graphite in Patlepani-Mohriwali area occurs in two forms, as concordant lenses in skarns and as small veins in gneisses. Graphite in skarn is most significant from quality and quantity point of view. Graphite occurring in the forms of veins in gseisses has no economic significance, therefore, no detailed work had been carried out on it. This graphite is probably formed by the process of lateral secretion. Carbonaceous material was originally present in the sediments and during metamorphism and deformation by the process of lateral secretion migrated into the fracture system.

Patlepani graphite deposit is the largest of the economically important skarn deposits of the area. Petrographic and other studies of skarn indicate that originally it was impure limestone having organic carbon in sufficient quantity and purity. During regional metamorphism, this organic carbon was converted to amorphous to semi-crystalline graphite. The presence of amorphous to semi-crystalline graphite in schistose rocks of the area is a common feature. After regional metamorphism, this recrystallised impure limestone was intruded by pegmatite which converted it into skarn. During the process of skarnification, amorphous to semi-crystalline graphite was converted into fully crystalline graphite. The graphite occurring as disseminated specks present in white marble beds and in upper barren as well as lower mineralised skarn may have been formed either by unbonding of kerogen or similar organic compounds, which were present in original rocks or by release and precipitation of carbon from pre-existing carbonate minerals by direct methanation through a reaction with elemental hydrogen. With present studies, it is not possible to explain that with what process this graphite has been formed. Nevertheless, this type of graphite is present in the barren skarn and has increased the concentration of graphite in mineralised skarn.

During the subsequent Himalayan orogenies, due to the stresses, pinching, swelling and neckling of skarns, resulted. Graphite being mobile, migrated into low pressure zones, such as fractures etc. of the skarn and form concordant bodies. As such graphite in the skarn is present as different bodies with different concentrations.

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