Geochemistry of Metamorphism in the Malikhera-Mokanpura Area of Dariba-Rajpura-Bethunmi Polymetallic Sulphide Belt Rajasthan

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Abstract: ***The present paper deals with geochemistry of metamorphic aspect of the rocks of the Malikhera-Mokanpura area. The rocks are metamorphites in nature and are characterized by a varied key metamorphic minerals and mineral assemblages. An attempt has been made to work out the various mineral assemblages to ascertain the metamorphic facies and zones. Estimates of pressure and temperature conditions operating during the formation of metamorphic assemblages have been made. The lowest grade of metamorphism attained by these rocks rajpura-Dariba area is of quartz-albite-biotite sub facies of the green schist facies The highest is staurolite-almandine sub facies of amphibolite facies in the Barrovian type of metamorphism***

Keywords: Rajpura-Dariba polymetallic belt, Malikhera-Mokanpura Area,Regional metamorphism, green schist facies, amphibolite facies

1. Introduction

The Malikhera-Mokanpura area is adjacent area to the Rajpura mineralized block of Dariba-Rajpura-Bethunmi polymetallic sulphide mineralized belt. The belt is almost 17 kms. long with Dariba as its southern end and Bethunmi as its northern end. The proposed area of study is northern extention of well known Rajpura-Dariba polymetallic sulphide deposit. The Malikhera-Mokanpura area (Latitude 74°07 to 74°11’ and Longitude 24°57’ to 25°00’) is part of Survey of India Toposheet No. 45 K/4 and 45 L/1. The area is part of newly created Rajsamand district. Earlier, it was part of Udaipur district In fact it is a junction of three political districts, Rajsamad, Chittorgarh and Udaipur within the radius of 15 kms.The topographical map of the area has been prepared by the author (Fig. 1) which has served as base map to prepare a geological map of the area. The map of various zone of metamorphism of the area prepared by the author has been presented as Fig. 1.

2. Metamorphism Assemblage

The pelitic metasediments in the study area are characterized by the following mineral assemblages:

1) Biotite-muscovite-sericite-chlorite-quartz.
2) Biotite-muscovite-sericite-almandine-quartz.
3) Biotite-muscovite-graphite-almandine-quartz.
4) Biotite-muscovite-graphite-almandine-Kyanite-quartz.
5) Biotite-muscovite-graphite-almandine-Kyanite-Staurolite-quartz.

Impure carbonate metasediments are represented mineral assemblages

a) Calcite-dolomite-quartz.
b) Calcite-tremolite-quartz.
c) Dolomite-calcite-tremolite-quartz.

3. Distribution of Metamorphic Zones

The rocks of the Malikhera-Mokanpura area have undergone progressive regional metamorphism of the Barrovian type showing an upward increase in grade of metamorphism from chlorite to kyanite and staurolite. The metamorphic mineral assemblages of each zone has been studied petrographically.

The lowest grade of metamorphism attained by Rajpura-Dariba area is of quartz-albite-biotite sub facies schist facies. The highest is staurolite-almandine sub facies facies in the Barrovian type of metamorphism. Impact metamorphism along with dynamothermal metamorphism is certainly present in the area, but the progressive nature of metamorphism east ward indicate effect of intrusive body, beneath There is clear ‘metamorphic doming’ atleast at a side or half of the same is F exposed. Presence of such intrusive body has also evident in underground 400 level at 65° N where neo-magma has already been reported (Shrivastava, 1992). Winkler (1967) has assigned 400°C to 550°C temperature range to the green schist facies and 550°C-670°C to the amphibolite facies. 650°C is the temperature where anatexis starts. The begining of anatexis in the area is further supported by gravity survey (Reddi and Remakrishna, 1988). Five major metamorphic zones have been recognized on the basis of specific mineral reactions.

These zones are separated by four isograded which runs almost in N-S direction Out of these three isogrades sre making typical Barriovian type metamorphism of pelitic sediments and last one separating calcareous rocks dolomitic marble from pelites.), showing various zones of metamorphism. The assemblage of silliminite zone have not been encountered.

Zone I : Quartz-Chlorite zone.
Zone II : Garnet zone (Graphite-Almandine-Muscovite-Biotite).
Zone III : Kyanite zone (Kyanite-Graphite-Almandine-Muscovite-Biotite).
Zone IV : Staurolite zone (Staurolite-Kyanite-Graphite-Almandine-Muscovite-)
Zone V : Calcite-dolomite-Tremolite-Actinolite zone.

Zone I : Quartz, chlorite zone

Chlorite in coexistence with biotite, muscovite and quartz are grouped in this zone. The rocks of this zone, are comprised of quartzite and chlorite schist (with little biotite).

The quartz chlorite-biotite zone falls under the greenschist facies. the main mineral assemblages of this zone established on the basis of petrography These mineral assemblages show progressive metamorphic reactions and also retrogressive metamorphic event. The generation of chlorite and biotite are recognised under thin section. The first generations of chlorite and biotite are represented by large flakes of green and brown colour respectively, which are oriented parallel to the main foliation plane (S1). The chlorite and biotite of second generation are aligned at an angle to the foliation plane. The biotite of second generation occurs as porphyroblast across the foliation which also defines the crenulation cleavage (S2).

The appearance of biotite marks an increase in rise of P-T conditions. It is formed largely at the expanse of the chlorite and muscovite as is evidenced by patchy distribution of chlorite and porphyroblastic development of biotite (Plate 1 Figure:1).

The possible reactions suggested are :

1. 3 muscovite + 5 chlorite → 3 Biotite + 4 Al rich chlorite + 7 quartz + H20 (Winkler, 1967)
2. Chlorite + muscovite + hematite → Biotite + H20 + 02 (Heitanen, 1967).

According to Winkler (1967), the beginning of the green schist facies is marked by the reaction involving break down of kaolinite. The equilibrium temperature of the reaction is 390°c ± 10°C at 2 kb PH2O and 405°c ± 10°C at 7 kb PH2O (Althaus, 1966). Furthermore, Winkler (1965) experimentally demonstrated that pyrophyllite, paragonite and chlorite can crystallize by heating mixtures of clay minerals and quartz to temperatures of about 400°C at PH2O = 2kb. Thus, according to him greenschist facies begins at temperature of 400°C.

Zone II : Garnet zone

This zone succeeds the chlorite-biotite-quartz zone. The first appearance of almandine in the area defines the assemblage Graphite-AlmandineBiotite-Muscovite and quartz.

Almandine is typical garnet of the garnetiferous schists resulting from regional metamorphism of argillaceous sediments, and as such it is used as a zonal mineral in regions of progressive metamorphism of these rocks (Plate 2 Fig. 2). The almandine may be developed from the chlorite grades although, not all chlorites have an appropriate FeO/ MgQ ratio for the production of almandine. In higher grades of regional metamorphism almandine may also be produced from the breakdown of mica to give garnet and potassium feldspar and from the reaction of staurolite with quartz to give garnet and potassium feldspar and from reaction of staurolite with quartz to give garnet and Kyanite or Sillimanite (Chapman, 1952). The rise in the Mg/Fe ratio in the Adirondack garnets with increasing grade of metamorphism is believed to be the result of partitioning of Mg and Fe between the garnets and the coexisting biotites at high temperatures and pressure (Compare, however, Miyashiro, 1956) Although typically a mineral of regional metamorphism, almandine may also occur as a product of thermal or contact metamorphism. It occurs only in certain aureoles, which typically contain white mica and which lack potassium feldspar, suggesting that it is restricted to relatively wet aureoles. Yodder (1955), in the light of experimental data on the almandine stability field, suggested for these occurrences of almandine that either (a) the contact is wet and the temperature is higher than the upper stability limit of the hydrous minerals, yet lower than the breakdown temperature of garnet, or (b) the contact is dry and therefore, the garnet would be preserved at any temperature below its breakdown curve or (c) the water content of the rock is so low that the bulk composition lies in the water deficient region, and hence garnet is stable with hydrous minerals in the absence of free water at temperature below the breakdown temperatures of the hydrous minerals.

Zone III : Kyanite zone

The transition from zone II to III is observed by the appearance of kyanite (Plate 3 fig 3). The rocks of this zone are composed of Kyanite-Graphite-Almandine-Biotite-Muscovite-Quartz schist.

Kyanite occurs typically as a mineral of regional metamorphism of pelitic and more rarely psammitic rocks. It has been used as a zonal mineral developing before sillimanite with increasing grade of metamorphism. Francis (1956) has shown that Staurolite (± Kyanite) pelites occur in the epidote-amphibolite facies, while staurolite free kyanite pelites are found in the amphibolite facies. Kyanite may arise also from the dehydration of paragonite with the addition of quartz and from the inversion of andalusite in areas where a regional metamorphism is superimposed on a normal thermal metamorphism (Harker, 1954). Stress of rising pressure during a fall in temperature may bring about the inversion of sillimanite to Kyanite (Hietanon, 1956). Its occurrence together with staurolite and sillimanite in a thermal aureole has been noted by Mc Call (1954) who described porphyroblastic Kyanite in a narrow zone along a granite margin where pelitic schist have been invaded by numerous granite sheets.

Zone IV: Staurolite Zone

The next higher grade of metamorphism is represented by staurolite zone. The rocks of this zone consisting of staurolite schist. The first appearance of porphyroblast of staurolite marks the beginning of staurolite zone **.** The isograde of this zone is parallel to subparallel to the regional trend of the country rock.

Staurolite occur as porphyroblasts and are wrapped by the micaceous minerals defining the schistosity (S1). The staurolite may contains the inclusions of quartz. Staurolites are commonly twinned in cross fashion.

Staurolite is a common product of regional metamorphism and is particularly characteristic of medium grade schists derived from argillaceous sediments. In such mica schists, staurolite is associated particularly with almandine garnet, muscovite, Kyanite and quartz. Staurolite as formed also at a lower grade of regional metamorphism when converted from chloritoid. Although, staurolite bearing rocks are commonly rich in alumina, high alumina in the host rock is not essential to its formation and staurolite has been reported from metamorphosed grits and impure carbonate rocks. Staurolite and Kyanite often occur together in the progressive regional metamorphism of pelitic sediments. With increasing metamorphic grade, however, Kyanite persists beyond staurolite, and staurolite is replaced by Kyanite and almandine :

$$6(OH)_2\,Fe_2\,Al_9\,Si_4\,O_{22} + 11\,SiO_2 + 1\tfrac{1}{2}\,O_2 \rightarrow 4\,Fe_3\,Al_2\,Si_3\,O_{12} + 23\,Al_2\,SiO_5 + 6\,H_2O$$

(Staurolite) (Almandine) (Kyanite)

This break down of staurolite and the formation from chioritoid, 19 rock containing excess silica also involve quartz, the stability field !df staurolite plus quartz defines the lower and upper limits of staurolite stability in magnetite free rocks The pressure range being considered from 4 to 8 K bar by many workers but 10 K bar in pure Mg member of staurolite with Fe solid solution Kyanite will form in such circumstances at 450°C and 4 K B pressure Andalusite would have formed if the pressure would have been further low. Staurolite indicate a pressure of 6 KB. and temperature 550°C to form as normal staurolite from pelitic sediments.

Garlick and Epstein (1967) suggested that regionally metamorphosed schist containing kyanite and staurolite appear to have crystallized at 520°C-600°C, on the basis of oxygen isotope data. This data is consistent with the staurolite + quartz stability data of Richardson (1968). According to Hoschek (1969) amphibolite facies of kyanite zone sets in at about 575°C 15°C at 2 kb H20 pressure. Staurolite and muscovite react in presence of quartz to produce kyanite or vioca-versa. The reactions suggested are:

1) Staurolite + chlorite + muscovite + quartz ↔ Kyanite + biotite + H_2O (Carmicheal, 1970)
2) Staurolite + muscovite + quartz → Kyanite + biotite + almandine + H_2O (Thompson and Norton, 1968)
3) Staurolite + muscovite + quartz → Biotite + kyanite + H_2O (Hoschek, 1969)
4) Chlorite + biotite + quartz →Almandine rich garnet + Biotite ± H_2O (Chakravarty and Sen 1967)
5) Chlorite + muscovite + quartz → Almondine garnet + biotite + H20 (Thampson and Norton, 1968)

With the increase in P-T condition staurolite is the earliest mineral to appear in the amphibolite facies. It is form at the expanse of muscovite and chlorite in presence of quartz. Close association of biotite and staurolite and textural appearance of biotite being replaced by staurolite is observed. Staurolite can be formed by any of the following reactions

1) Chlorite + 3 muscovite → Staurolite + 3 biotite + 7 quartz + 14 H_2O (Hoschek, 1969)
2) Chlorite + muscovite + quartz → Almandine garnet + biotite + staurolite + H_2O (Winkler, 1967)
3) Fe-rich chlorite + muscovite → Staurolite + biotite + almandine + H_2O (Hoschek, 1967)
4) Garnet + chlorite + muscovite → Staurolite + biotite + quartz + H_2O (Carmichael, 1970)

For the 1st reaction Hoschek (1969) ascertained following P-T conditions.
540°C ± 15°C at 4 kb H_2O pressure
565°C ± 15°C at 7 kb H_2O pressure

Winkler (1974) arrived at somewhat similar P-T condition for the formation of staurolite. It can be inferred that the staurolite zone in the area is formed in the temperature range between 540°C to 565°C ± 15°C at pressure varying from 4 to 7 kb.

Zone V: Calcite-Dolomite-Tremolite-Actinolite zone

The metamorphism of quartz-bearing carbonate rocks provides interesting examples of metamorphic reactions. Eskola (1922) and later Bowen (1940) made a systematic study of the sequence of reactions occurring in carbonate rocks at some given CO_2 pressure in response to rising temperature. The following minerals, well known from progressive metamorphism, are formed tremolite, forsterite, diopside, wollastonite, periclase (brucite), monticellite, akermanite, spurrite, mervinite, larnite, and others. Later, Tilley (1948) added talc as the mieral forming at even lower temperature than tremolite.

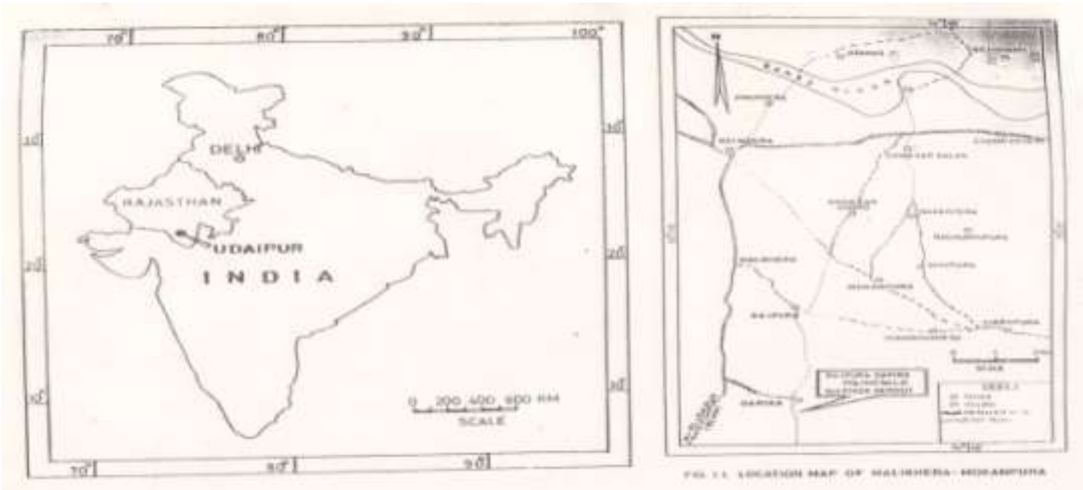
Metamorphic reactions of siliceous carbonates liberate CO_2, but since water is present in the rock before metamorphism, one cannot regard CO_2 pressure and temperature as the only factors in metamorphism petrology and mineral assemblages are shown in photomicrographs presented in Plates from 20 to 23. Besides temperature, the total fluid pressure (being the sum of the partial pressures of CO_2 and H20) and the ratio of the two partial pressures (or the mole fraction of either CO_2 or H_2O) have to be taken into account. Therefore in most reactions involving carbonates the equilibrium is (at least) bivariant. This is true even if H_2O is absent in the reaction equation, because H_2O always is a constituent of the fluid phase present in metasediments. In the supercritical state the two components H_2O and CO_2 costitute one single fluid phase; they are miscible in all proportions. The application of bivariant equilibria to natural parageneses is more complicated.

In the present case, formation of tremolite can be explained simply following reaction.
5 Dolomite + 8 Quartz + I H_2O = I tremolite + 3 calcite + 7 CO_2

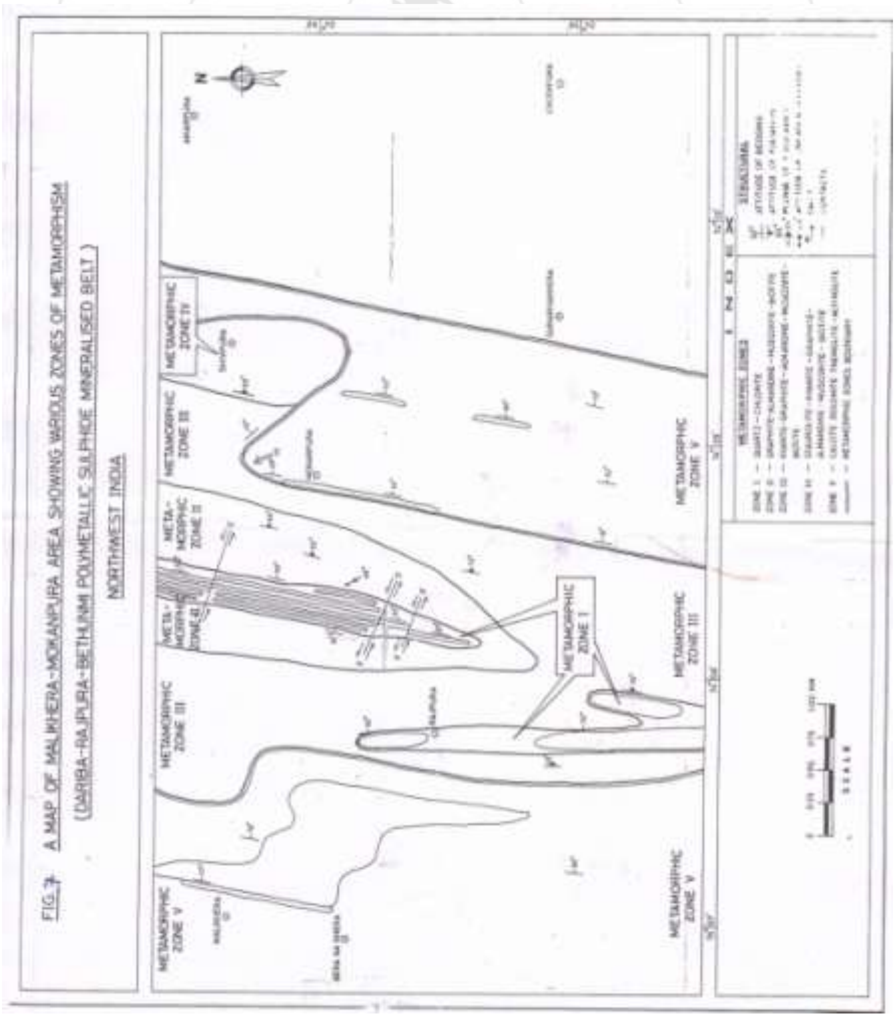
In the reactions shown in various circumstances by Winkler (1967), the reaction 4 is applicable to the area., reaction 4 is explaining the formation of tremolite in dolomitic marble. Otherwise the dolomitic marble is showing simply recrystallizations.

In the genesis of massive marble, the thermal metamorphism of sedimentary carbonate rocks (limestone or dolomite) produces recrystallization involving single phase, in which solid crystalline grains grow in a matrix of identical composition Shrivastava and Shrivastava (1989) have proposed that in ideal conditions, grains attempt to minimize interfacial tension by producing a stable configuration of 1200 triple point junction The theory (Shrivastava and Shrivastava, op cit) further state that the histograms occur nearer to 1200 tripple point, while plotting triple point angles as abscissa with distribution frequency as ordinate, will prove the superiority as regards the subgrade. All the photomicrographs from Malikhera marble shows a great deviation from 120° triple point junction, thus are of poor quality as for as degree of crystallinity is concerned.

Further, heterogenity of grain size ranges from fine grained to coarse grained texture even in a single photomicrograph. It shows a poor degree of recrystallisation during thermal metamorphism of the parent sedimentary rock. Apart from absence of homogenity in the degree of crystallinity, effect of deformation is also evident at Malikhera alongwith metamorphism resulted in producing linear alignment and elongation of the grains.



Location Map of Malikhera-Mokanpura



Map of Malikhera-Mokanpura Area Showing Various Zone of Metamorphism

4. Conclusion

According to geochemical study of metamorphism of the rocks of the Malikhera-Mokanpura area have undergone prograsive regional metamorphism of the Barrovian type showing an upward increase in grade of metamorphism from chlorite to kyanite and staurolite there are five various metamorphic zones marked in the metamorphic.The metamorphic mineral assemblages of each zone has been studied graphicalIy The lowest grade of metamorphism attained by these rocks rajpura-Dariba area is of quartz-albite-biotite sub facies of the green schist facies The highest is staurolite-almandine sub facies of amphibolite facies in the Barrovian type of metamorphism

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