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Petrographical, micro-structural and metamorphic characteristics of the Parsoi rocks, Mahakoshal Group, Sonbhadra district, Uttar Pradesh

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Abstract

The low grade metamorphic rocks of the Precambrian Parsoi Formation of the Mahakoshal Group exhibit a variety of microstructures even under the thin section due to multiple deformational episodes which the area has experienced. The original petrographical characters of the rocks have been modified significantly due to these deformational and metamorphic episodes. The petrographical characters observed in the field and under the microscope have been discussed along with the microstructural features. Evidences of ductile, brittle-ductile and brittle deformation can be observed easily in these rocks. The rocks also show the evidences of regional, contact and cataclastic metamorphisms.

Key Words- Petrography, Micro-structures, metamorphism, Mahakoshal Group, Sonbhadra

Introduction

Along the Son Narmada South Fault (SNSF) in Sonbhadra district of Uttar Pradesh, the Mahakoshal Group rocks are at tectonic contact with the Chhotanagpur Granite Gneiss Complex (CGGC) of central India. The SNSF is a major fault in Central India, which also represents the southern boundary of the Son Narmada Lineament Zone. The northern boundary of this zone is demarcated by Son Narmada North Fault (SNNF). The Mahakoshal rocks in the central India are exposed between SNSF and SNNF and exhibit multiple phases of deformation (Srivastava, 1996, Srivastava and Gairola, 1997).These deformations have resulted in various changes in the characteristics of the rocks of the Mahakoshal Group. The changes occurred in petrographical characters and microstructural features of the rocks are the manifestations of the conditions of the deforming forces that have acted on them since their formation. Each rock type possesses different mechanical and physical properties that vary with conditions under which it deforms. As a result, diverse varieties of structures are displayed by the rocks due to deformation and metamorphism. Therefore the systematic studies and analysis can reveal many aspects of the tectonic events that the rocks have undergone. The deformed early Proterozoic Mahakoshal rocks occurring in the vicinity of the SNSF are represented by Parsoi Formation which have been metamorphosed. The present study examines these petrographic

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characteristics and microstructures of the rocks which belong to the Parsoi Formation in the southern part of Sonbhadra district of Uttar Pradesh (Fig. 1) and deciphers their conditions of metamorphism.

Geological setting

The Mahakoshal Group of rocks occurring south of Vindhyan Supergroup were earlier considered as those belonging to Bijawar Group as a part of Bijawar Syneclise exposed north and south of the Vindhyan rocks in Central India. Narain and Thambi (1978) first used the term Mahakoshal Group for these rocks. The Mahakoshal rocks have been studied by many workers who have carried out works in isolated area in order to understand the geology and structures of these Precambrian rocks. The studies carried out by workers like Roy and Bandyopadhyay (1990); Ameta (1990), Jain *et. al.,* (1995); Srivastava (1996, 2012), Srivastava and Gairola (1997, 1999, 2004); Roy and Devrajan (2000); Acharyya (2003) Roy *et. al.,* (2006); Mohan *et. al.,* (2007), Ramakrishnan and Vaidyanadhan (2008), Meert *et. al.,* (2010) and Singh and Srivastava (2011) have contributed significantly in this regard, however, there exists a vast gap in the knowledge regarding the tectonic evolution of Mahakoshal and adjoining rock occurring in the Central Indian Tectonic Zone (CITZ). The early worker classified the Mahakoshal rocks differently into two fold (Agori and Parsoi Formations) or three fold divisions (Chitrangi, Agori and Parsoi Formations). Roy and Devrajan (2000) have reclassified the Mahakosal Group into Sleemanabad, Parsoi and Dudhmaniya Formations. The present study area (Fig.1) which lies in the southern part of Sonbhadra district of Uttar Pradesh, forms a part of Parsoi Formation comprising dominantly of slates and phyllite with basic intrusives at places. These rocks have shown a complex pattern of their distribution due to multiple deformations in the geological past.

Petrographical characteristics and micro-strucutres

In the present work, different rock types exposed in the study area have been dealt with in respect of their megascopic and microscopic characters. The megascopic characters of the rock types are primarily concerned with the physical appearance of the rocks, their colour, tone, mineral assemblages, texture and structures as visible by naked eyes in the field or in hand specimen samples. The study of rocks under the microscope reveals the mineral composition and textural relationships which helps in deciphering the grade and episodes of metamorphism. The thin section study not only helps in classifying the rock types, but also helps in establishing their metamorphic and tectonic histories. The petrographical characteristics and the microstructures of the rocks occurring in the study have been discussed here.

Slate

In field the slates are observed as grey, brown, green and sometimes olive green in colour. These anchimetamorphosed rocks have preserved the original bedding planes which can be recognized by different light and dark coloured bands. The thickness of the individual bands may vary from a few millimeters to a few centimeters. These bands have different mineralogical compositions. The more prominent dark coloured bands in the rock are marked by higher concentration of argillaceous minerals which are hard to recognize individually owing to their extreme fineness. The light coloured bands are marked by the concentration of arenaceous minerals mainly quartz. These bands in slates have shown high degree of folding from tight-isoclinal folds to close, open, chevron and sometimes even gentle fold styles. The folding patterns of argillaceous and arenaceous bands may or may not be the same. The slaty cleavages (S_2) which are the characteristic features of these slates have also been folded in different styles.

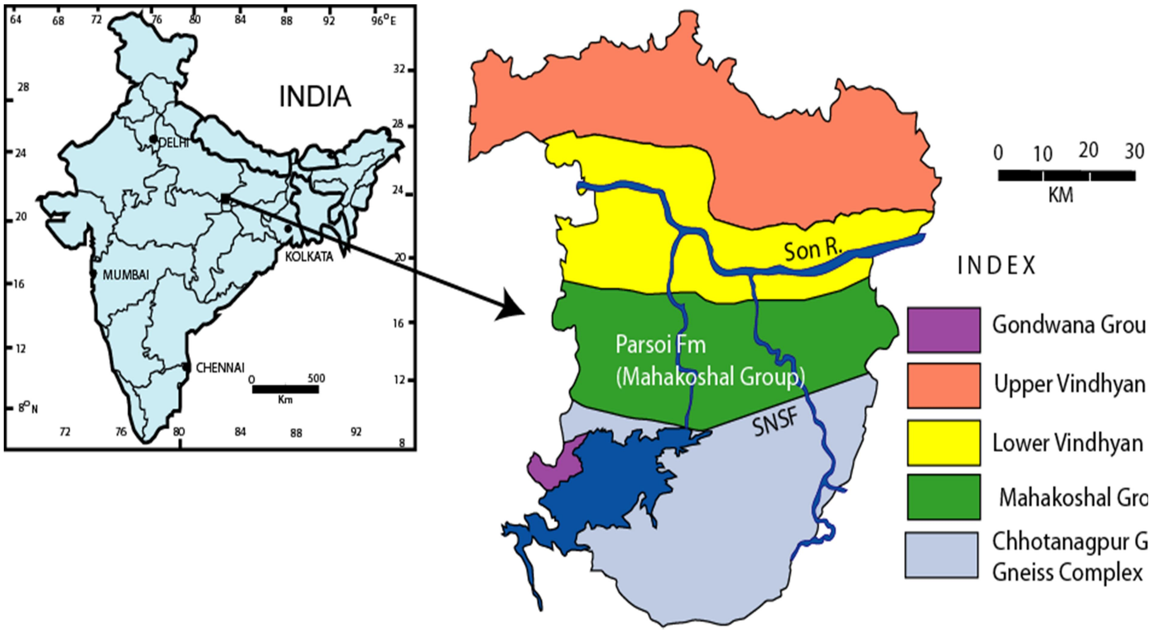


Fig.1: Location and geological map of the Sonbhadra district of Uttar Pradesh. (SNSF= Son Narmada South Fault)

In general, the slaty cleavages are parallel to the bedding plane, however, they may also give an oblique relations giving rise to intersection lineations, particularly near the fold hinge zone. The folding patterns of the S_2 in these rocks were of great help in recognizing different generation folds. The slates are intruded by numerous quartz veins which may occur both concordant and discordant to the bedding of the rock. Sometimes these veins have shown ptygmatic folds.

Under the microscope the bedding (S_1) is marked by the colour bands consisting of argillaceous and arenaceous layers (Fig.2A, B). In general the rock is fine grained in which the arenaceous bands have relatively coarser grains- mostly of quartz, than the argillaceous one. At times the rock is so fine-grained that the identification of individual minerals becomes very difficult. The bedding plane is overprinted by slaty cleavages (S_2) which are more or less parallel to the axial plane of the folds on bedding plane. The slaty cleavage (S_2) is defined by the preferred orientations of the platy minerals like chlorite and sericite which have given rise to lepidoblastic texture to the rock. At times S_2 in the rock is poorly developed but at other times it is well developed and crenulated. The rock has also shown crenulation cleavages which belong to both, the zonal and discrete of Gray (1977). In some cases rough cleavages have also been observed. In general the bedding plane (S_1) and slaty cleavage (S_2) are found parallel but they have also seen oblique relationship near the fold hinge zone (Fig.2). The rock has often been traversed by the quartz veins which at times, have shown buckle folds or pinch-and -swell structures. The chief mineral constituents of the slate are chlorite, quartz and sericite while plagioclase, iron oxides, zircon also occur in small amounts.

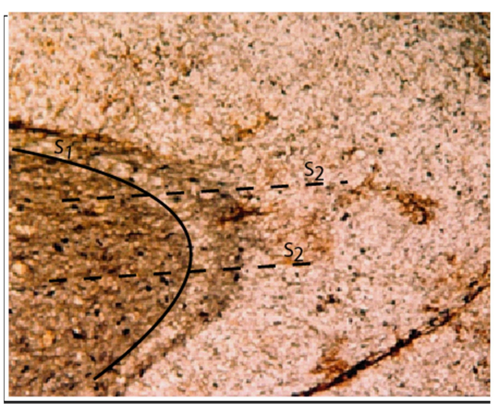
Quartz: Quartz is a dominant mineral in the slates of the present area. The arenaceous bands of quartz are largely constituted of quartz. Besides, quartz also occurs in substantial amounts in the argillaceous bands too. On the basis of grains size, their characteristic and relationship with other minerals 3 types of quartz have been recognized. Quartz I which is fine grained and shows undulose extinction, forms the essential constituents of the rock. Quartz II is coarser than quartz I. Quartz III occurs as veins in the rock and is much coarser than quartz I & II. On the basis of textural relations, it can be said that the quartz I are pre-tectonic with respect to D_1 deformation. The wavy extinction in quartz II & III suggests that deformation continued even after the emplacement of veins (Quartz III) in the slates. This is also supported by the existence of mesoscopic ptygmatic folds in the quartz veins in the slate rocks. The quartz II & III have inclusion of chlorite, sericite plagioclase and iron oxides.

***Chlorite*:** The chlorite flakes define the foliation in the rock. This mineral showing a faint pleochroism from yellowish green to green and exhibiting first order interference colour, occurs in a variety of forms. The mineral generally occurs along S_2 with its poorly developed cleavage parallel to the slaty cleavage, but at times well developed cleavages in lens-shaped flakes are perpendicular to the schistosity, particularly near the fold hinge zone. At times the chlorite grains are streaky and occur in tiny specks. These minerals are highly dusted with iron oxides. The leached iron oxides are also observed along the cleavages planes or grain boundaries. Based on the textural relations and properties of the grains two generations of chlorite have been recognised. Chlorite I occurs as larger lens shaped grains and show distinct cleavages but indistinct grain boundaries. The preferred orientation of these grains defines the slaty cleavage (S_2). However, their grain boundaries have been modified by the development of chlorite II, which is formed parallel to the axial surfaces of the folds, as crenulation/strain-slip cleavages. Chlorite II has poorly developed cleavage and contains inclusion of quartz I and chlorite I. At times the poorly developed cleavages of chlorite II and well developed cleavages of chlorite I are inclined or even perpendicular, particularly near the hinge zone of the folds.

***Sericite*:** Sericite occurs as diminutive flakes associated with chlorite I parallel to S_2 planes. It also occurs in the argillaceous bands defining the bedding planes and as inclusion in the chlorite II quartz II & III and felspar.

***Felspar*:** There are few minute grains of felspar present in the slate. Both K-felspar and plagioclases (albite or oligoclase) have been observed. These tiny grains show their characteristic twinning and occur generally in argillaceous bands where they have been sericitised. The felspar grains also occur as inclusion in chlorite or quartz grains.

***Iron Oxides*:** Iron oxides occur as accessory minerals in the rock but their amount is appreciably high. They are not only seen as tiny specks but also occur as leached out materials from chlorite I and II. The iron oxides have been recognized as hematite, magnetite or limonite.



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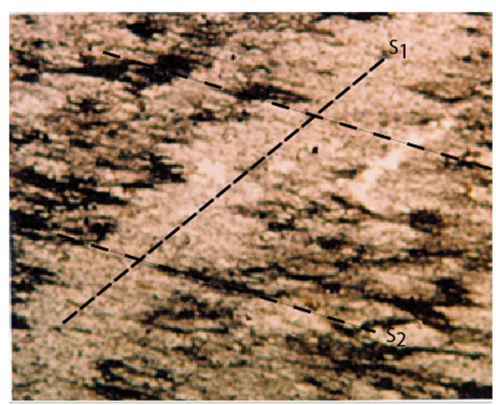


B

Fig. 2.A. The arenaceous band (light colouled) and argillaceous bands (dark) represent the original bedding plane (S_1)in the slate under the plane polarized light. The rock is showing the development of slaty cleavage (S_2) parallel to axial plane of the folds on bedding plane.
B. A closure view of the fold hinge zone where the bedding planes S_1 and Slaty cleavage S_2 are at high angles.

***Apatite*:** Few colourless grains of apatite have also been observed. These grains occur in rectangular laths or subhexagonal grains showing moderate relief and parallel extinction. Sometimes these minerals are altered to dahllite which shows colourless to pale brown colours.

***Zircon*:** Zircon occurs as accessory mineral in the rock. These colourless minerals occur as laths or grains with subrounded boundaries. They have shown characteristic zoning under cross nicols.

Phyllite

The phyllites of the Mahakoshal Group in the present area are brown, green, bluish green, fawn and at times light grey in colour. The rock has well developed schistosity, which is defined by the preferred parallel arrangements of micaceous minerals and platy quartz grains. The change from slate to phyllite is gradational and no distinct boundary as such, can be demarcated between them. Although some phyllites have still preserved the bedding plane (S_1), the gradual disappearance of S_1 due to superimposition of S_2, and increased percentage of micaceous minerals in the rock, help in identifying the rock as phyllite. The phyllites have shown porphyroblastic textures with the development of large porphyroblasts of andalusite (Fig.3) which are at times deformed (Fig.3B). The Phyllites have shown good development of crenulation cleavage and lineations. At times phyllites become streaky and mylonitised particularly near the fault zones.

A

B

Fig. 3A: Randomly oriented andalusite in phyllite suggesting their development by thermal metamorphism. B: Deformed andalusite crystals suggesting pos crystallization deformation.

Under the microscope the phyllites are differentiated from slates by higher percentage of flaky minerals such as chlorite, and better development of schistosity (S_2). The original bedding plane (S_1) are mostly obliterated but in some phyllites the S_1 can still be observed as colour bands under ordinary lights (Fig.4A). Defined by the preferred orientations of flaky minerals, the schistosity (S_2) is often crenulated (Fig.4B) with the development of new minerals along newly developed cleavages called as strain-slip cleavage/ crenulation cleavage (S_6) in the present work). In phyllites both, discrete and zonal types of crenulation cleavages of Gray (1977) are developed. The phyllites exhibit a lepidoblastic to grano-lepidoblastic textures (Fig.4C). With the development of andalusite, particularly near fault zones, the phyllites show a crystalloblastic texture. Locally, the phyllites are mylonitised where the psammitic and pelitic minerals become streaky. Chlorite, biotite, muscovite, sericite, quartz and felspar constitute the essential minerals of phyllites. The accessory minerals include hematite, ilmanite, magnetite and apatite. Andalusite occurs as large grains (upto >15 cm long) near the fault but its size and abundance decreases away from the fault.

***Chlorite*:** The light yellow to pale green and at times, slightly bluish flakes of chlorite define the foliation in the rock. On the basis of occurrence and nature, three types of chlorite have been recognised. Chlorite I occurs as light yellow to pale green relatively large flakes and imparts the phyllite foliation (S_2) (Fig. 4A). These flakes show a set of well developed cleavage. However, at times the cleavage is indistinct. At times chlorite-I occurs as hexagonal grains in a few schistosity parallel thin sections. Close to the crenulation cleavages chlorite I exhibit a tapering nature. The crenulation cleavage is defined by the preferred orientation of chlorite II exhibiting poorly developed cleavages and often spotty appearance of darker and lighter yellow or green colours. Sometimes the grain boundaries of chlorite I and II are parallel but in general these grains show oblique relations. At times the boundary of chlorite I remains parallel to Chlorite II flakes but the cleavages of chlorite I are oblique or perpendicular to the latter (Fig. 4A).This suggests that the grain boundaries of chlorite I has been modified during the deformation induced development of chlorite II. Chlorite I & II at times are characterised by high concentration of these lepidoblastic minerals in one zone and lesser abundance in other -particularly granulose bands Chlorite III occurs in small amounts as a retrogression product along some biotite. They do not have any definite grain boundary or distinct cleavage, but they show pleochroism-characteristics of chlorites. Often the flakes of chlorite defining the foliation exhibit diverse orientation due to microfolding (Fig. 4B).

***Quartz*:** Three generations of quartz have been recognised in the phyllites. Fine grained quartz I occurs as the constituents of the original bedding plane (Fig.4A) and as inclusions in chlorite and biotite. Quartz II are medium-grained and form the granulose bands giving rise to grano-lepidoblastic textures (Fig. 4C) to the phyllites. These grains have their longer dimensions parallel to the schistosity. At times these grains are closely interwoven with the mica minerals. The quartz grains show undulose extinction as the effect of post-crystallisation deformation. Quartz III occurs as still larger grains in the form of veins. These grains have also been observed as porphyroblast or poikilioblast like appearance having numerous grains of pre-existing minerals (Fig.4C). Presence of undulose extinction in these grains and development of ptygmatic folds in these veins suggest post-crystallisation deformation. The veins have been overprinted by flaky minerals like chlorites in a direction parallel to direction of crenulation cleavage. The relationship of crenulation cleavage and veins suggest that the former is either syn- or post-tectonic with respect to buckling of the latter.

***Biotite*:** The yellowish brown to dark brown pleochroic biotite occurs in two varieties. On the basis of their characteristics and mutual relationship with the deformational fabric in the rock, these varieties have been called as biotite I and biotite II. Biotite I occurs along the schistosity in close association with chlorite I, suggesting its syntectonic origin with chlorite I during D_1 phase of deformation, but its abundance is much lower in comparison to the chlorites. The medium to fine grained biotite II occurs along the crenulation cleavage. It often superposes the schistosity and even shows penetration effect in the schistosity, suggesting that they have come later than the schistosity under the effect of stresses responsible for post D_1 deformation in the rock. Both the varieties of biotite exhibit leaching of iron oxide along the cleavages. Sometimes the biotite has been retrograded to chlorite.

***Muscovite*:** Muscovite occurs in minor amounts in the rocks along chlorite and biotite in the schistosity (S_2) and crenulation cleavage. Depending upon their association and orientation they have been recognised as muscovite I (occurring parallel to S_2) and muscovite II occurring parallel to crenulation cleavages.

Andalusite**:** The andalusite crystals occur as almost square colourless large crystals having high relief. The andalusite crystals contain a high concentration of impurities particularly in the centre. This impurity might have been concentrated at the centre of each crystal, representing the initial growth stage when the structure was unable to free itself from inclusion (Deer *et al*., 1983). As the crystal grows, the foreign materials are brushed aside to the edges, which is most effective in the direction perpendicular to the prism face (Deer *et al*., 1983). The andalusite crystal boundaries are affected by crenulation cleavages suggestive of post-crystallisation deformation. Sometimes the andalusite crystals show complete retrogression leaving only the square shaped crystal outline.

Plagioclase**:** Plagioclase minerals with low anorthite content (albite or oligoclase) occur in the granulose bands of phyllites. They occur in minor amounts and are at times altered to sericite.

Sericite**:** Sericite occurs in tiny flakes in bands showing original bedding plane (S_1) and also in minor amounts as alteration product in felspar grains. They also occur as inclusion in the mica minerals and quartz.

Other Minor Constituents**:** Among other minor constituents iron oxides are abundant. They occur in the rock as inclusion in pre-existing minerals and also as leaching product along the periphery or cleavages of chlorites and biotite. The iron oxides recognized in the rock are hematite, ilmanite or magnetite. The other minor constituent minerals recognized are apatite and zircon which occurs as tiny laths chiefly in the granulose bands.

Dolerite

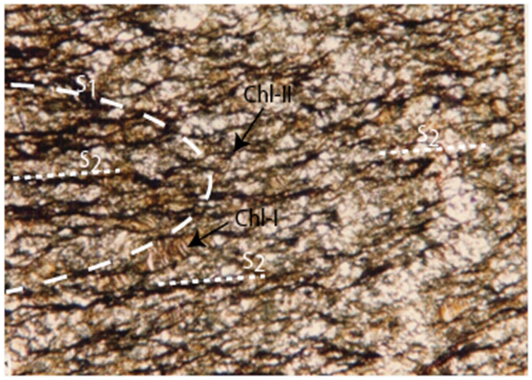
The dolerite occurs in the form of dikes in the present area. These melanocratic basic rocks are generally dark green or grey in colour. The rock is fine to medium grained, hard and compact. Under the microscope the dolerites show the characteristic ophitic (Fig.4D) and at times sub-ophitic textures. The chief mineral constituents are clinopyroxene and plagioclase, however orthoclase, zircon and apatite are also present.

Clinopyroxene**:** The colourless to pale green larger grains of clinopyroxene occur as poikiliocrysts having small laths of plagioclase. They have typical 2 sets pyroxene cleavage cutting each other approximately at 90^o. The high relief and inclined extinction angle suggests that these are mostly augite (Fig.4D). Sometimes the clinopyroxenes are fractured.

Felspar**:** The felspars are mostly represented by the plagioclase however, orthoclase in minor amount is also present. Plagioclase occurs as small crystals enclosed in the larger grains of augite (Fig.4D). Characterised by the typical lamellar twinning of the plagioclase variety present in the rock is labradorite. Orthoclase showing simple twinning and occur as smaller crystals in the rock.

Zircon**:** Few grains of zircon showing characteristic zoning are distributed in random orientation.

Apatite**:** Apatite occurs as colourless, small laths or prismatic or six sided crystals in the rock



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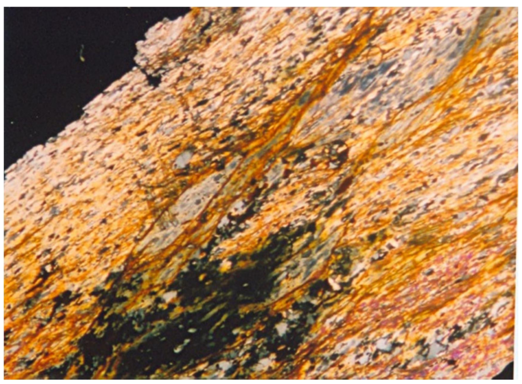

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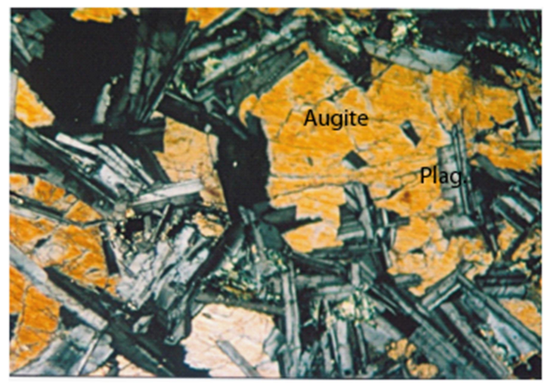


D

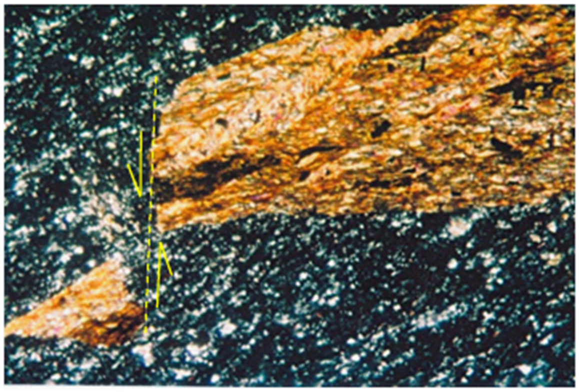
Fig.4A: Development of foliation (S_2) in phyllite across the bedding planes (S_1) in the hinge zone of a fold. Chlorite I is showing mineral cleavage across the S_2 direction while Chlorite II is developed parallel to the axial plane of the fold. The original S_1 is stilled preserved by large quartz grains forming a layer. B: photomicrograph showing microfolding in phyllite. The dark coloured bands are rich in chlorites while the lighter band is dominated by quartz. (Plane polarized light). The dark colour futher darkens by presence of biotite along the chlorite. C: Grano- lepidoblastic texture in the phyllite. D: photomicrograph of dolerite showing ophitic texture.

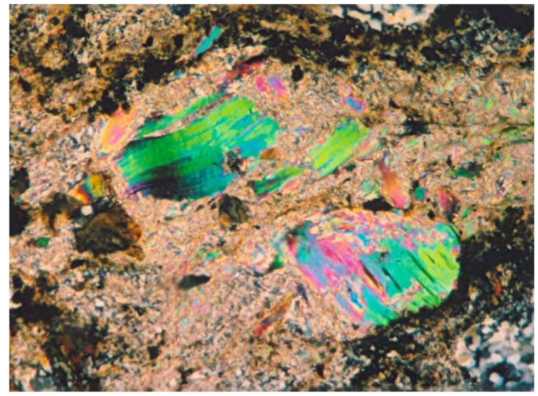
Mylonite

The mylonitic rocks form as a result of ductile deformations which occurs in the crustal rocks at temperature generally in excess of 250 to 350^{o} C and are found near the fault zones (Twiss and Moores, 1992). The mylonites of the area have shown matrix of very fine grains that are derived by strong reduction in grain size from the original rocks. In these rocks, the matrix has been found generally as siliceous or argillaceous. The relict coarser size fragments of the rocks are the porphyroclasts which are generally the fragments of phyllite (Fig. 5A,B). At times micro-faulting in the mylonitic rocks have been observed suggesting post mylonitization faulting of the rocks (Fig. 5A). The mica minerals of the phyllite are sometime showing the deformation of the mineral cleavages due to shearing (Fig. 5B). The rock shows a weak foliation developed in the matrix in addition to those already present in the phyllite pophyroclasts. This is due to recrystallisation of mineral grains during the ductile deformation.

Metamorphic conditions

The rocks of the Mahakoshal Group have shown many characteristic features of the greenstone belt of the world (Anhaeussar *et al*., 1968; Anhaeussar, 1970; Ingram, 1977; Tripathi and Mishra, 1994; Jain *et al*, 1995), therefore, metamorphism above greenschist facies is less expected. The Parsoi Formation of the Mahakoshal Group has exhibited low metamorphic grades with evidences of contact and cataclastic metamorphism too. On the basis of study of petrographic characters, microstructures and textures three broad metamorphic types have been recognized as prograde regional (M_1), low pressure/thermal (M_2) and cataclastic/ retrogressive (M_3) for the rocks. The metamorphic conditions and their possible relation with the tectonic phases have also been discussed together.





A **B**

Fig.5A Photomicrograph of mylonite having large porphyroclast of phyllite. The porphyroclast has also been subjected to microfaulting. B: Photomicrograph of phyllonite. The large porphyroclast of mica mineral grain is showing deformation of mineral cleavage.

M_1 Prograde Regional Metamorphism

The textural relations and mineral assemblages of the slates and phyllites of the present area suggest that these rocks were derived from originally sedimentary rocks that is evident by the presence of bedding plane (S_1) in some slates and phyllites in the Parsoi Formation of Mahakoshal Group. It has been indicated earlier that the same minerals of different generations have been developed from the same bulk composition due to polyphase metamorphism. Thus, on the basis of textural relationships, two episodes of prograde metamorphism (named as M_{1a} & M_{1b}) have been recognized.

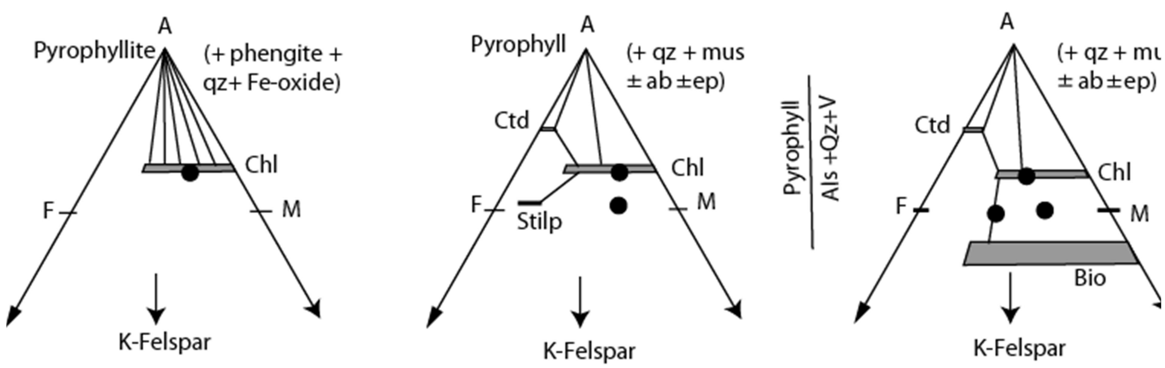


Fig.6 AFM diagram for the observed mineral assemblages in the pelitic rocks during prograde regional metamorphism of Parsoi rocks of the Mahakoshal Group in Sonbhdra district Uttar Predesh.

M_{1a} Metamorphism: M_{1a} episode of metamorphism is very intense and most pronounced in the rocks of the present area. During this phase the original characters of the rocks were almost annihilated and new minerals developed in tectonically controlled conditions which resulted in new fabrics in the rock. One of the most monumentous ascriptions of the M_{1a} metamorphism is the development of slaty cleavage or phyllitic foliation (S_2), which is characterised by the formation of new minerals like chlorite I, biotite I, muscovite I etc. in a well marked parallelism. The relationship of S_1 and S_2 observed in F_1 folds suggests that the M_{1a} episode of regional metamorphism was syntectonic to the first phase of deformation (D_1). Besides the foliaceous minerals, the other minerals generated were the newly formed inequant quartz and felspar grains along the S_2. The pelitic assemblages observed in these rocks have been shown on AFM diagram in Fig.6 which reveals that the rocks of this region have undergone metamorphism upto greenschist facies. Although largely the rocks have shown metamorphism up to chlorite zone in this area, but the metamorphic condition in the Mahakoshal Group sometimes approaches to the biotite zone of the greenschist facies.

M_{1b} Metamorphism: The M_{1a} episode was followed by a second phase of prograde metamorphism M_{1b}. During M_{1b} episode of metamorphism, new generation of flaky minerals were developed parallel to the axial plane of F_2 and F_3 folds. The effect of M_{1b} metamorphism has been observed only in low grade (upto green schist facies) rocks of the area. This suggests that the M_{1b} metamorphism was less intense than M_{1a}. The relationship of flaky minerals developed during M_{1b} with the folding of schistosity (S_2) suggests that the M_{1b} metamorphism which initiated with second phase of deformation D_2, was persistent upto the early part of D_3 deformation with a possible break in between. This break in the M_{1b} metamorphism must have been in the later part of D_2 deformation when temporary brittle conditions caused the development of faults and joints in the CGGC rocks.

M_2 Thermal Metamorphism

The M_1 episode of prograde regional metamorphism was followed by a low pressure (thermal) metamorphism which has caused the development of andalusite in the present area. The occurrence of andalusite in the Parsoi Formation has also been reported by Tewari (1961), Shrivastava and Dayal (1970) and Srivastava (1996). Shrivastava and Dayal (1970) have geochemically analysed the andalusites and also given the possible reserves of the andalusites present in Wyndhamganj area. In fact, the andalusites are found more or less in a continuous occurrence all along the ENE-WSW striking Son-Narmada-South Fault (SNSF). It has been observed in the present work that the size and content of the andalusite crystals is larger in the vicinity of the SNSF which decreases on going away from it. The same phenomenon reappears along faults which are minor fault and parallel to the SNSF. This behaviour of andalusite occurrence, in light of the present observations, can only be explained by the occurrence of some plutonic igneous bodies which have supplied the heat along the channel ways provided by SNSF and other faults to cause the development of andalusite by the low pressure metamorphism. The microscopic study of the andalusite grains suggests that these are affected by deformational phase D_4 and not by any earlier deformations. This is also supported by the deformations observed in the andalusite crystals (Fig.3B). Hence, it can be said that the low pressure metamorphism occurred before D_4 deformation but during or after D_3 phase of deformation of the rocks of the Mahakoshal Group.

M_3 Cataclastic and retrograde metamorphism

The M_2 episode was followed by M_3 episode in which the rocks have been sheared, brecciated and mylonitised. The mylonitisation and retrogression which are indicated by the cataclastic textures (Fig.5) and reversal of many prograde reactions due to hydration of minerals. The cataclastic and mylonitic textures suggest that metamorphism was dominantly associated with the brittle and brittle-ductile conditions of the deformation. The field and textural evidences suggest that this phase of metamorphism was actuated during the D_4 deformation. The M_3 metamorphism has also affected the andalusite crystals (Fig.3B) which were developed during M_2 metamorphism.

Discussion and Conclusion

The petrographic characteristics and micro-structural features are the manifestations of the deforming forces that have acted on the rock bodies since their formation. Each rock type possesses different mechanical and physical properties which vary with conditions under which it deforms. Therefore, diverse varieties of structures are displayed by the rocks which constitute the earth's crust. These structures may range from simple bedding plane to intense folding, faulting, jointing and many other related structures. The systematic study of the textures and micro-structures reveals the deformational and metamorphic histories of the rock bodies in different parts of the crust. Recent work on SNSF, the southern boundary of the Mahakoshal Fold Belt (MFB), shows deformation associated with N-S compression was superposed by a strong sinistral shearing movement that may have facilitated exhumation of lower crustal rocks south of SNSF (Roy et al 2002, Sharma 2009). The strong shearing between SNSF and SNNF have rotated the earlier formed folds axes into a broad gentle to open fold having fold axes in N-S directions during later part of deformation of these rocks. At least four phases of deformation named D_1, D_2, D_3 and D_4 have been recognized in rocks of the Parsoi Formation of the Mahakoshal Group. The microscopic level examinations of the rocks reveal that the rocks have been subjected to regional metamorphic grade up to of biotite zone of green schist facies. However, the microstructures suggest the original bedding planes of the sedimentary rock protolith are still preserved in some the rocks like slate and phyllite. In general the mineral assemblages are suggestive of the regional metamorphic condition that is highest near the Son Narmada South Fault (SNSF) while going away from the SNSF the metamorphic grade also decreases. Near the SNSF, the rocks have been subjected to a phase of thermal metamorphism which is a post-regional metamorphic event. Microstructures indicative of strong shear are also observed in the rocks near SNSF. The presence of mylonite along the SNSF strongly support, that the SNSF has reactivated and as a result the rocks have been subjected to cataclastic metamorphism and mylonitization and associated retrograde metamorphism.

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