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Tectonostratigraphic Status of the Proterozoic Babarmal Pink Marble from the Aravalli Supergroup

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Abstract: Present study reviews the tectono-stratigraphic status of Babarmal pink marble from the Aravalli Supergroup through mapping and petrographic study of marble as well as associated lithologies. The pink marble is predominantly calcitic and characteristically different from dolomitic carbonate rocks of the Jhamarkotra Formation, the Lower Aravalli Group. The marble is devoid of organic matter and phosphate content unlike the Jhamarkotra dolomite. The pink marble is underlain by quartz-pebble rich conglomerate. This assemblage represents a rare lithological association which has not been reported so far from the Aravalli Supergroup.

Besides the above differences between the Babarmal pink marble and the Jhamarkotra dolomite we also noted significant similarities between the two with respect to greenschist facies metamorphism and three phases of deformational history. Similarities in both these aspects imply that the pink marble like the Jhamarkotra dolomite can be corroborated with the Aravalli orogenic cycle. While on the basis of distinguishing lithological and petrographic features the pink marble-pebbly conglomerate, the lithoassemblage is suggested to be designated as "Babarmal Formation" as a modification to the Babarmal Formation of Gupta et al. (1997) which constituted of pink marble.

The outcrop patterns on the high resolution map shows that the Babarmal litho-assemblages are sandwiched between the Barytes bearing meta-volcanics (that represent the underlying Delwara Formation) and the dolomite-quartzite-phyllite (that represent the overlying Jhamarkotra Formation) of the Lower Aravalli Group (Roy and Jakhar, 2002). Hence we suggest to place the Babarmal Formation as the middle stratigraphic unit of the Lower Aravalli Group of the Aravalli Supergroup.

Keywords: Tectonics, Stratigraphy, Proterozoic, Pink Marble, Pebbly conglomerate, Babarmal, Aravalli Supergroup.

INTRODUCTION

The Proterozoic NE-SW striking Aravalli Mountain Belt is an important constituent of the Precambrian rocks in the northwestern Indian shield. The belt is mainly constituted of the Palaeoproterozoic rocks of the Aravalli Supergroup. The Aravalli Supergroup underlies the Mesoproterozoic Delhi Supergroup and is unconformably underlain by the Archaean Banded Gneissic Complex (BGC) (Gupta et al. 1980, 1997) alternatively called as Mewar Gneiss by Roy et al. (1993). Tectono-stratigraphic status of the Aravalli Supergroup was studied by various workers that are well exposed in the 'Type area' around Udaipur city (N 73°24': E 23°40') (cf. Roy and Jakhar, 2002). Though various workers carried out detailed studies on the Palaeo-proterozoic Aravalli Supergroup rocks but still there are some lithounits that remain debatable on account of their tectono-stratigraphic status and lithological uniqueness.

One such lithounit from the Aravalli Supergroup is Babarmal 'Pink Marble' (N 73°44': E 24°24') which lies proximal to the rocks of the type area of the Aravalli Supergroup around Udaipur city (Fig.1) and exhibits uniqueness due to its pink colour. Heron (1953) described the stratigraphic status of the Babarmal pink marble and considered it as part of "Raialo Series" that represented the Eparchean interval at 2500 Ma (Table 1). Later, Gupta et al. (1980; 1997) modified the stratigraphic status of the pink marble and considered it as part of the Babarmal Formation (D7) of the Matoon Sub-group in the Debari Group of the Palaeoproterozoic Aravalli Supergroup (Table 1). This change in the stratigraphic status of the Babarmal pink marble was very significant because it was raised to younger Palaeoproterozoic status from the previously described Eparchaean interval by Heron (1953). Roy and Jakhar (2002) considered the Babarmal marble to similar Palaeoproterozoic stratigraphic status but designated

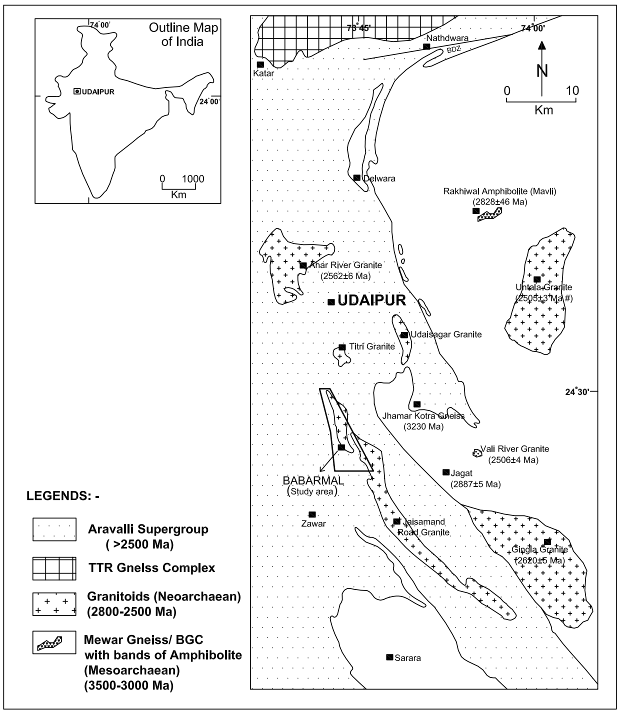

Fig.1. Regional geological map of the study area showing location of Babarmal marble on 1:50000.

the rocks as part of the Jhamarkotra Formation of the Lower Aravalli Group of the Aravalli Supergroup (Table 1). On the contrary Maheshwari et al. (2002) on the basis of heavy carbon and oxygen isotope study opined that the pink marble could be younger than the dolomites of the Jhamarkotra Formation but did not assign any separate status.

Previous studies on the pink marble resulted in contradictions on its stratigraphic status. One view stated an Eparchaean interval equivalent status (~2500 Ma) (Heron, 1953) while the other opined that the marble body belonged to the Aravalli Supergroup and is Palaeo-proterozoic in age (Gupta et al. 1980, 1997; Roy and Jakhar, 2002; Maheshwari et al. 2002). The Palaeo-proterozoic age span of the Aravalli Supergroup is 2200-1850 Ma (Chaudhary et al. 1984; Sarangi et al. 2006; Ahmed et al. 2008). The incongruence observed in the lithostratigraphic status of the Babarmal marble from the previous studies implied that the marble could have distinct tectonic history in comparison to its surrounding lithologies. Present study aims to understand the lithostratigraphic correlation of the Babarmal pink marble with the rocks of the Aravalli Supergroup and to establish its tectono-stratigraphic status.

GEOLOGY

The Babarmal pink marble is exposed near the 'Type area' of the Aravalli Supergroup around Udaipur city (Fig.1; Roy and Jakhar (2002); Table 1). The rocks that belong to the Aravalli Supergroup unconformably overlie the Mewar Gneiss Complex (2500-3300 Ma) which is constituted mainly of granitoids of diverse age and composition (Roy and Kröner, 1996; Wiedenbeck et al.

Table 1. Stratigraphic succession of the Precambrian rocks in Rajasthan

Heron (1953)	Gupta et. al. (1997)				Roy and Jakhar (2002)			
Delhi system (2000-700m.y.)	Delhi Supergroup				Delhi Supergroup			
							Lakhwali Formation	Jharol Formation
"Raialo series" Aravalli system (Archaean)	ARAVALLI SUPERGROUP	Jharol Group	Dovda Group	Nathdwara Group	ARAVALLI SUPERGROUP	Upper	Kabita dolomite	
							Debari Formation	
		Barilake Group	Kankroli Group					
							Tidi Formation	
		Udaipur Group				Middle	Bowa Formation = Machla mangra Formation	
							Mochia Formation = Zawar formation	
		Debari Group (Babarmal Formation)					Udaipur Formation	
							Jhamarkotra Formation	
						Lower	Delwara Formation	
Banded Gneiss Complex (>2500 m. y.)	Bhilwara Supergroup						Mewar Gneiss	

1996). The Aravalli orogeny commenced after the cratonization of the Mewar Gneiss Complex around 2500 Ma (Wiedenbeck et al. 1996). The onset of the orogeny is evident in form of submarine and sub-aerial volcanic activity, palaeosol erosional features and local basal conglomerates (Roy et al. 1993). The Palaeoproterozoic age for the onset of the Aravalli orogeny was inferred from the Sm–Nd systematics that indicated 2326±321 Ma age of komatiite lava in the Delwara Formation (Ahmad et al. 2008). The maximum age for the Aravalli Supergroup was constrained by 2075-2150 Ma Pb-Pb model ages (Deb and Thorpe, 2004) and the minimum age as ~1900 Ma (Chaudhary et al. 1984; Sarangi et al. 2006). The ages for the synkinematic greenschist facies regional metamorphism of the Aravalli Supergroup is dated between 1.7–1.8 Ga (Biju-Sekhar et al. 2003).

The rocks of the Aravalli Supergroup in the 'Type area' outcrops along two belts: An eastern belt that comprises shale-sandstone-carbonate shelf facies and a western belt of carbonate-free shale sequences with thin bands of arenite interpreted as deep-water facies association (Roy and Paliwal, 1981). The shelf facies rocks consist of three unconformity bounded litho-assemblages viz. the Lower, the Middle and the Upper Aravalli Groups (Table 1) (Roy and Jakhar, 2002). The dolomitic carbonate rocks of the Jhamarkotra Formation together with the volcanics and the arenites interbands of the Delwara Formation constituted the Lower Aravalli Group. The dolomites were deposited in different shallow sub-basins under subtidal to supratidal environments (Banerjee, 1971 a, b; Chauhan, 1979; Choudhuri and Roy, 1986; Roy, 2000) and as well as in the shelf-bank depositional environment (Roy and Paliwal, 1981).

METHODOLOGIES ADOPTED

Regional scale outcrops of the pink marble were studied with the help of satellite imagery (Fig. 2). A regional outcrop pattern of the marble body was developed on 1:50000 (Fig. 3). The marble outcrops were mapped high resolution at 1:10000 through conventional contact mapping method to understand the deformational patterns and tectonic history (Figs. 4, 5 and 6). Lithologies were identified with the help of petrographic studies and major mineral compositions. The study area was divided into sectors and synoptic diagram was prepared by the plots of planar and linear structures for structural analyses. Data were plotted on the lower hemisphere on Lambert's equal area net. Plots were made using the 'Rockware' software for presentation. Basin scale litho-stratigraphic column of the Babarmal basin was prepared

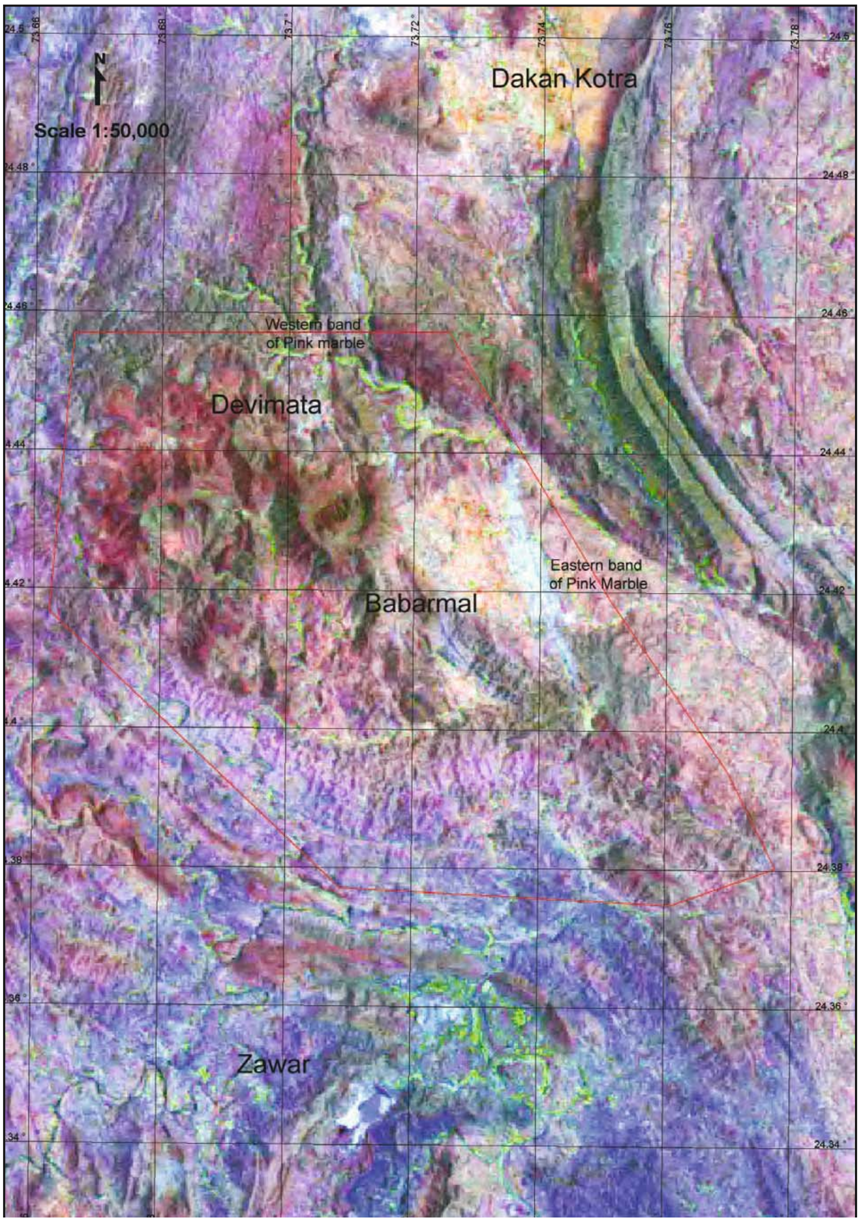

Fig.2. Satellite imagery picture of the pink marble at Babarmal on 1:50000. The marble bands are represented by white tone in the imagery.

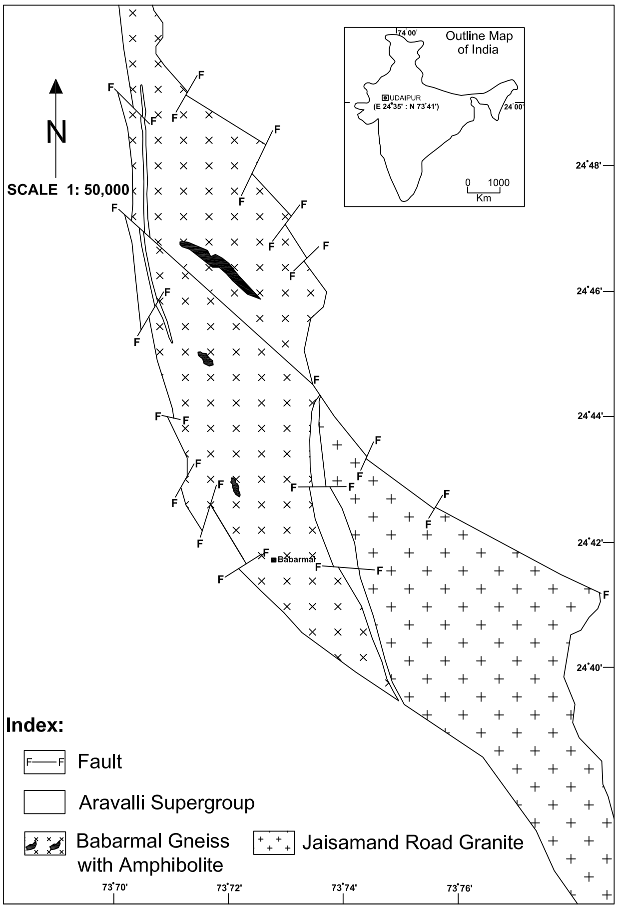

Fig.3. Geological map of the study area prepared with the help of imagery showing position of the pink marble on 1:50000

and correlated with the other sub-basins of the Jhamarkotra Formation.

RESULTS

Regional Relationship of Babarmal Marble Observed on Imagery

Outcrops of the pink marble show pale blue to whitish tone on the digitally enhanced Landsat band 5 on 1:50000 (Fig. 2). The light blue tone belts appear as two parallel linear structures which were partially connected at southern margins. The two carbonate belts lie within the pinkish tone granitic rocks. The granitic rocks on the eastern and western edges are flanked by curvilinear sharp rising ridges of quartzite (Fig. 4). Few high rising sharp crest ridges that represent quartzite are also observed within the low-lying granitic rocks. Landsat data reveal that the pink-marble is not the part of the high rising ridges but outcrop almost along the foothills of these ridges. The Landsat data also reveal several faults with E-W trend that traverse all the lithounits in the Babarmal basin.

Litho-assemblages at Babarmal Associated with the Marble

Litho-assemblages at Babarmal were mapped on high resolution at 1:10000 to understand the field relationships in detail. Pink-marble outcrops as two distinct prominent bands marked as the eastern and the western band (Fig. 4). The bands are present within the basement granite-gneisses, locally called as Jaisamand Road granitic-gneiss (Roy and Jakhar, 2002). The eastern pink-marble band is approximately 6 km in length with maximum width of 500 m while the western pink-marble band is almost 9 km in length with width between 100 to 150 m. Both the bands strike almost N-S criss-crossed by several E-W faults (Fig. 4). The eastern band pinched towards north and south that gave an appearance of elongated lensoidal body.

Pink-marble face shows develop-ment of fine laminated green colour chlorite rich bands that alternate with calcitic bands (Plate 1a). Compositional variations in the pink marble are noted where the chlorite rich bands and calcitic bands showed differential weathering patterns. Elephant skin weathering was observed on the marble outcrop. Quartz veins invariably penetrate the marble outcrops. Iron rich specks also occur as small irregular bands that alternate with the marble and chlorite bands. Few thin lenses of pink-marble were also present as enclaves within the granite gneiss (Plate 1b).

The Babarmal marble is closely associated with a pebbly conglomerate horizon which is sandwiched between the marble and gneisses. The pebbly-conglomerate occurs on either sides of the eastern band of pink-marble as linear thin and discontinuous band. The outcrops of the pebbly conglomerate were mostly covered by mine dump. The pebbly conglomerate shows minor variations in clasts size, shape and composition on local scale. The shapes of the pebbles are oval, lensoidal, oblate, and in few cases angular also (Plate 1c). The matrix of the pebbly conglomerate is composed mainly of quartz. Pebbles of quartz are lensoidal and stretched along X-direction (Ramsay, 1967) parallel to foliation (Plate 1d) that depict shearing. Gradations in pebble size were also noticed in stratigraphic sense. The size of pebbles in general decreased from gneisses towards the pink-marble.

In the northern parts of the map area (Fig. 3) another outcrop of pebbly conglomerate is present as linear discontinuous band on the flanks of the gneisses which underlie the western band of pink-marble (Fig. 4). This conglomerate outcrop comprises quartz and mafic pebbles. The emplacement of the mafic body had induced ductile shearing in the gneisses that represent ductile flowage (Plate 1e). It also altered matrix composition of the

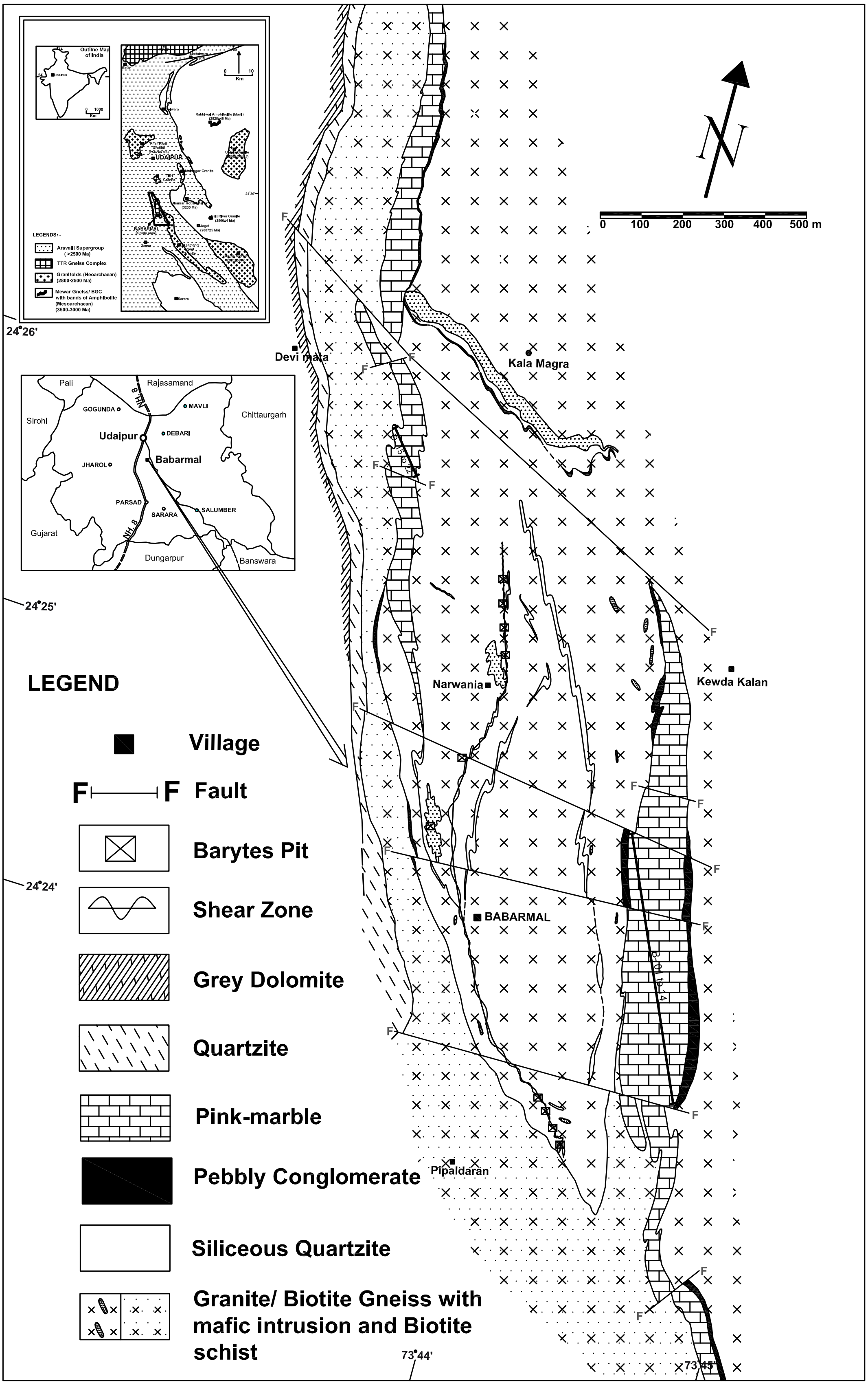

Fig.4. High resolution geological map of the study area prepared on 1:10000 showing outcrop patterns of different lithounits at Babarmal.

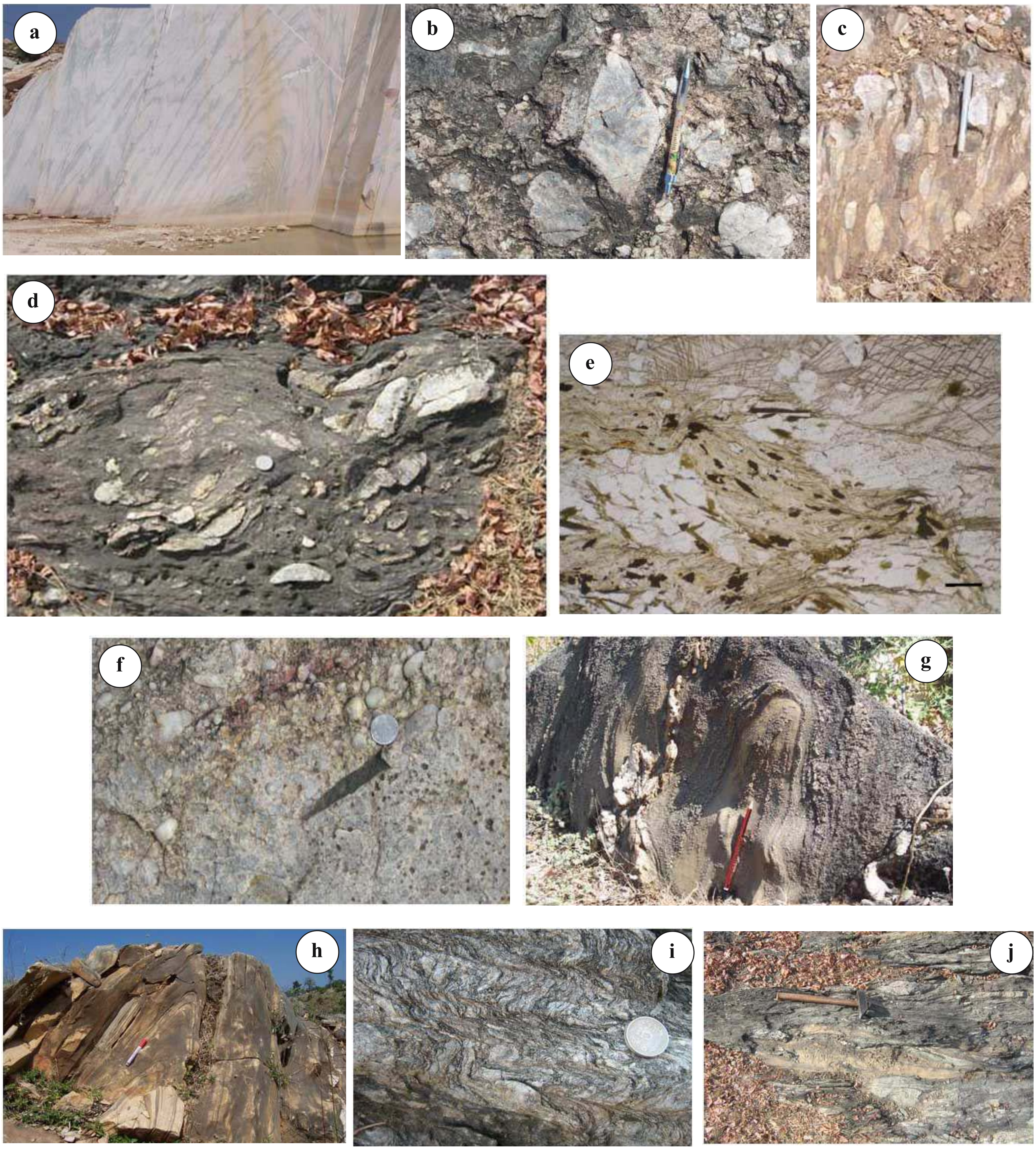

Plate 1. (a) Greenish black colour chlorite rich bands co-folded within pink-marble forming anticline. **(b)** Pink-marble present as an enclave within the granite gneiss. **(c)** Angular pebbles within the gneissic matrix. **(d)** XZ plane of conglomerate showing the stretched and elliptical pebbles of quartz within the gneissic matrix. **(e)** Oriented pebbles of quartz along ductile flowage direction. **(f)** Photomicrograph showing the sheared bands of fibrous variety of chlorite and biotite alternating with calcite in pink-marble. The dark specks of pyrite and magnetite are present in the fibrous minerals. (Bar = 0.28 mm, -nicol). **(g)** Rip-up clast of gneisses embedded within the quartz rich matrix pebbly conglomerate. **(h)** Inclined isoclinal fold in pink marble. **(i)** Reclined tight fold in pink marble. **(j)** Closed spaced crenulations cleavage developed in the granite gneiss.

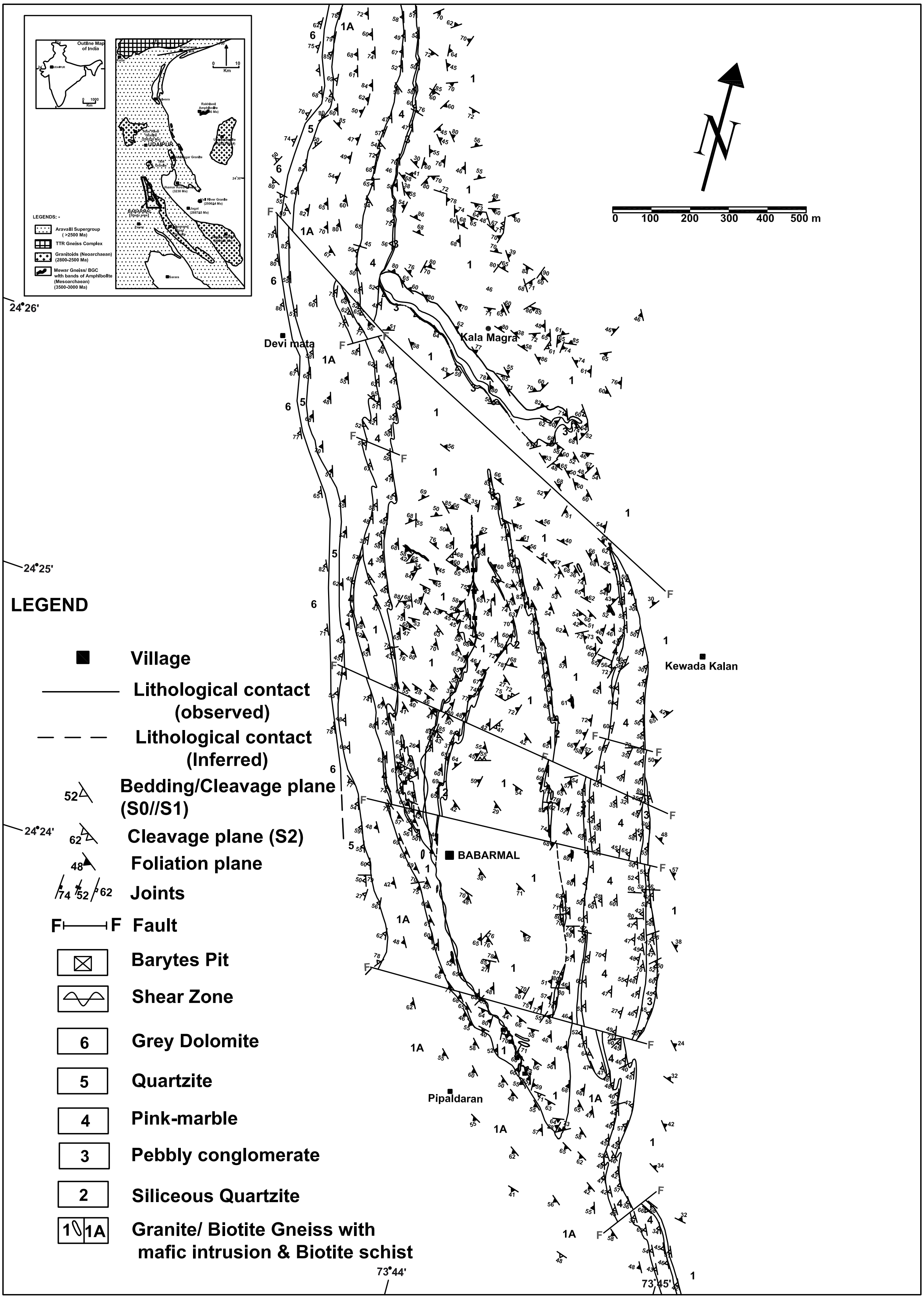

Fig.5. Structural data map showing orientations of various structural elements associated with various lithounits at Babarmal.

Table 2. S- pole interpretations of the Babarmal Region

Sector No.	Nature of planar data	Nature of S pole Diagram	Axial Plane	Fold Axis	Fold Geometry	Comments
A	C	Several maxima spreaded along the π girdle direction	N 48° → E 68°	55° → S 17° W	Tight fold with plunging inclined fold geometry	L_1 and L_2 lineation scattered around axial plane
B	F	Several maxima, strong maxima present towards NE corner of the stereogram which are partial spreaded along the girdle while few low population maxima spreaded around periphery of stereogram with broad warp	N 25° → E 83°	82° → N52° E	Open fold with Reclined fold geometry	—
A+B	F+C	A maxima is observed on the stereogram with spread parallel to the girdle	N 75° W → 83°N	69° → N 87° W	Inclined Upright fold geometry	
C	F+C	Two Strong maxima spreaded both side of the π girdle A sub maxima in the southern side of the stereogram	S 72° → W 83°N	55° → S 81° W	Tight, Upright fold geometry	Lineation L_1 are spreaded around the beta axis while L_2 is on the southern side as scattered data
C	F	Two maxima, One single maxima is strong, spreaded along the partial of girdle while second low population maxima is very week spreaded southern corner of the stereogram	S 81° E → 84°	58° → N 87° W	Open fold with nearly upright fold geometry	Lineation around axial plane but in scattered form
C	C	Two Strong maxima spreaded both side of the π girdle. Few low population maxima also present western margin of the stereogram	N 30° → E 42° E	18° → S 5° E	Plunging inclined fold geometry	
D	F+C	Two maxima are observed scattered data on the southern side of stereogram	S 82° → W 74° N	52° → N 76° W	Isoclinal, Plunging Inclined fold geometry	Lineation L_1 and L_2 is present in scattered form
D	C	Single strong circular maxima spreaded along the girdle direction.	S 10° E → 82° W	22° → S 6° E	Isoclinal to plunging inclined fold geometry	—
E	F+C	Two maxima along the ð girdle towards NE side of the stereogram	S 49° W → 88°NW	58° → S 51° W	Tight, Upright fold geometry	L_1 are clustered around the beta axis while L_2 are present in the southern side of the stereogram
E	C	Single maxima elongated along the girdle direction	S 74° W → 75° N	67° → N 66° W	Plunging inclined fold	—
F	F+C	Strong single maxima on the eastern side of the stereogram.	N 15° E → 52° E	23° → S 5° E	Isoclinal, Plunging Inclined fold geometry	L_1 are spreaded along the ð girdle direction while L_2 is present around $â_2$
Total area	Cleavage S_2	Strong maxima present in the central part of the stereogram, spreaded in scattered form along the girdle direction	–	76° → N 8° W	Upright fold geometry	—

F= Foliation planes in granite gneiss, biotite schist, biotite gneiss and siliceous quartzite. C = Cleavage plane parallel to bedding ($S_0//S_1$) in pink-marble, quartzite and Grey dolomite conglomerate by the addition of mafics like biotite, opaque and pyrite in the matrix. The elongated pebbles in some outcrops are fractured oblique due to the ductile shearing.

Besides the conglomerate horizons associated with the marble, the western band of the marble features a sheared contact with the granitic gneiss on its western side (Fig. 4). Shearing transformed the gneiss into phyllonite. In southern parts the marble band pinched due to extreme stretching. This is evident by sheared contact nature of the marble with the mylonitized granitic-gneiss. The phyllonite pinched northwardly also where the marble directly overlie the siliceous quartzite. On the western flank the quartzite is overlain by the grey dolomite. Towards north the grey dolomite is in continuation with the stromatolitic dolomite band of the Jhamarkotra Formation.

Petrography of the Marble and Pebbly-conglomerate at Babarmal

The pink marble constitute medium to fine grained calcite that shows polygonal shape and granular to granoblastic textures (Plate 1f). Presence of two sets of cleavage with polysynthetic twining help to identify calcite which was distinguished from dolomite by Alizarin test that stained pink. Some calcite grains are elongated along the preferred orientation direction parallel to foliation plane. The marble is devoid of detrital component and the most of the grains are recrystallized. Some micaceous minerals like pinninite-chlorite (with Berlin Blue birefringence) and biotite (with one set of cleavages and parallel extinction) were present in the marble (Plate 1f). Fibrous varieties of chlorite occur tightly interlaced within the inter-granular spaces of calcite. Quartz occurs as secondary mineral and appears as recrystallized masses. Sphene is present as accessory mineral scattered within the chlorite bands. Pyrite and magnetite occurs as opaque mineral with characteristic cubic shape (Plate 1f).

The clasts in pebbly conglomerate are dominantly of quartz followed by minor amount of feldspar, mafic and rock fragments. Rounded to sub rounded and circular shaped quartz formed the coarser grains surrounded by the finer ones. The quartz grains formed a mosaic of sub-grains form due to recrystallization. The grain contacts in the recrystallized aggregates are straight. Quartz grains also occur as inclusion within oligoclase feldspar and shadow zone of strained fractured feldspars. The later suggests that the shear movement was along the foliation plane. Feldspar (oligoclase and microcline) are rounded to sub-rounded, and elliptical in shape and are recognized as colourless in plane polarized light. The feldspar grains were cloudy and spongy in nature that reflected impact of alteration. Both Carlsbad and albite twining are observed in oligoclase that had high relief and the extinction varied from 18° to 25°. Microcline exhibits cross hatched twining with perthitic texture, low relief and extinction angle of 24°. Mafics are randomly distributed in the matrix. The clasts embedded in the arkosic matrix comprise more than 90% of vein quartz, chert and quartzite. The rip-up clasts of gneisses forms important clast composition (Plate 1g). Pebbly conglomerate is composed of altered feldspar and sericite within the matrix turning the matrix to arkosic. Fine pyrite grains are present scattered. The pebbly conglomerate horizon is devoid of carbonate, phosphate and organic carbon minerals like the pink marble but commonly observed in other proximal carbonates and associated lithologies.

Structural Patterns in the Babarmal Marble

Three fold geometries are identified in the marble and associated conglomerate lithounits. First fold is tight isoclinal that gives parallelism of primary sedimentary features-bedding plane (S_0) and the first generation cleavage (S_1) (Plate 1h) and hence could be corroborated with the first deformation (F_1). These folds are reclined and have dominant westerly plunge. The second fold has upright to steeply incline axial plane (Plate 1i) and can be ascertained to the second phase of deformation (F_2). In profile these folds are open. The inter-limb angles are between 10° and 20°. Third fold is in the form of open warps and has sub-vertical axial planes and is preserved as crenulations and can be linked to the third phase of deformation (F_3) (Plate 1j).

S-pole diagrams of the study area are used to analyze the effects of various deformations. Interpretations of these diagrams are described block-wise in detail in Table 2. A ductile shear zone occurs along the western flank of the Babarmal that has N-S strike. The shear zone hosts barytes mineralization in the ultramafic host rocks (Fig.4). The effect of the E-W faults is evident by displacement of the pink-marble bands (Fig.3) and by formation of drainage along the fault strikes. The effect of N-S faults has resulted in upliftment of the granitic gneiss in the central areas of the Babarmal which is evident by the formation of escarpment of cavernous carbonate caves.

DISCUSSION

Lithology and Petrography

The pink-marble is discriminated from the other carbonate litho-units of the Lower Aravalli Group on the basis of petrographical characters. The pink-marble is predominantly calcitic in comparison to the carbonates of the Jhamarkotra Formation in the Lower Aravalli Group that are mostly buff-grey dolomite. Dominance of calcite over dolomite in the marble was further established by the major element compositions of the marble that showed 47 wt% CaO and 1.2 wt% MgO (Mehta, 2009). Unlike the chemical composition of the pink marble Purohit and Rengarajan (2007) had shown that the grey dolomites of the Jhamarkotra Formation had high MgO and poor CaO concentrations. The grade of metamorphism in pink-marble is greenschist facies matching with the Jhamarkotra dolomites. Similarity in metamorphic grades of the marble and dolomite suggest that both the assemblages had suffered similar metamorphic transformations associated with the culmination of Aravalli orogeny at 1700-1800 Ma as suggested by Biju-Sekhar et al. (2003). This similarity in metamorphic grade supports the conclusion that the pink-marble was part of the Aravalli Supergroup (Gupta et al. 1980, 1995; Roy and Jakhar, 2002).

Large variations noticed in the clasts sizes in the pebbly conglomerate indicate poor sorting of the conglomerate. Presence of angularity in quartz and feldspar pebbles supported it. Shearing was evidenced by the development of stretched pebbles. Such secondary activities on pebbly conglomerate lead to porosity loss in diagenetic mass transfer or interstitial solution. This denotes reworking in pebbly conglomerates (c. Mosher, 1981). Pressure solution activity was very common in pebbly conglomerate and is evident on microscopic and macroscopic levels. The mixing of the rip-up clasts also shows that the conglomerate unit was considerably reworked. Grain size variation from coarser to finer in the pebbly conglomerate indicates that the direction of younging is towards the pink marbles. This suggests that the conglomerates are the older sequence underlying the marble. The contact between the two is partly sheared. The composition of the pebbly conglomerate, along with proximally associated calcitic pink marble indicate of a unique lithoassemblage hitherto not reported from any other basin from the Lower Aravalli Group of the Aravalli Supergroup of Roy and Jakhar (2002).

Structural Analyses

Presence of large scale faults had been confirmed by studying the satellite imageries of the region (Figs. 2 and 3). For the structural interpretation three separate maps were prepared (Figs. 4, 5 and 6). For the purpose of structural interpretation on macroscopic scale, the area was divided into six sectors considering the nature of outcrop pattern, orientation of foliation/cleavage planes, and small scale folds (Fig. 6). Sector-wise variations in fold axis are explained in tabular pattern and figure (Table 2 and Fig. 6). Three fold deformation is interpreted from this mapping which is represented by F_1 tight isoclinal, reclined and inclined fold geometry with dominantly westerly plunge (Plate 1h), F_2 fold with upright to steeply inclined axial plane (Plate 1i) and F_3 folds as open warps with sub vertical axial planes (Plate 1j) preserved as crenulations. The structural analyses suggest that due to superimposition of deformations and ductile movement in the rocks, no significant variations in the fold geometries is observed in different sectors. Further, the fold geometry of the area is also determined for the three tectonic belts, *viz.* the basement gneisses, the pink marble and pebbly conglomerate litho-assemblage and the Jhamarkotra quartzite and dolomite. The Babarmal calcitic-marble and the Jhamarkotra dolomite show similar deformational patterns. These deformation patterns significantly adhere to the fact that the pink marble and the pebbly conglomerate assemblages are part of the Aravalli Supergroup (Roy and Jakhar, 2002).

Tectonostratigraphy in Babarmal Basin

Relationship of Marble-conglomerate Assemblage with the Basement Gneisses

The contact between the pink marble and the basement gneisses is sheared (Fig. 4). The basement gneisses show transposition of foliations in the shear zones, which are represented along the western flanks. The transposition has resulted into formation of phyllonitic assemblages and complex outcrop patterns. It also led to gradual variation in metamorphic grades in the litho-assemblages which is evident from proximal occurrences of gneisses, schist and phyllonite. In few outcrops severe shearing developed mylonite. Mylonitization led to accrue of biotite and mafics in proximity along the strike of shear zone. This resulted into delineation of detached massive quartzite veins from the skewed biotite-mafic-rich zones. The mafic intrusions in the shear zones are rich in barytes (Avadich et al. 2006). Shearing is also evident in the associated pebbly conglomerates (Plate 1e). The stretched quartz pebbles are observed aligned along N-S strike direction parallel to biotite and chlorite with in the matrix. This phenomenon is interpreted as result of rifting under the crustal extension processes. The direction of extension was N-S along the shear zone which suggests that the rifts developed along E-W i.e. across the direction of extension. The rift-related basins resulted into volcanic activities at the onset of the Aravalli orogeny. These basins later became preferable sites for incipient sedimentation and pebbly-conglomerates with frequent inputs from the basement gneisses (Plate 1j) which were the first sediments to be deposited.

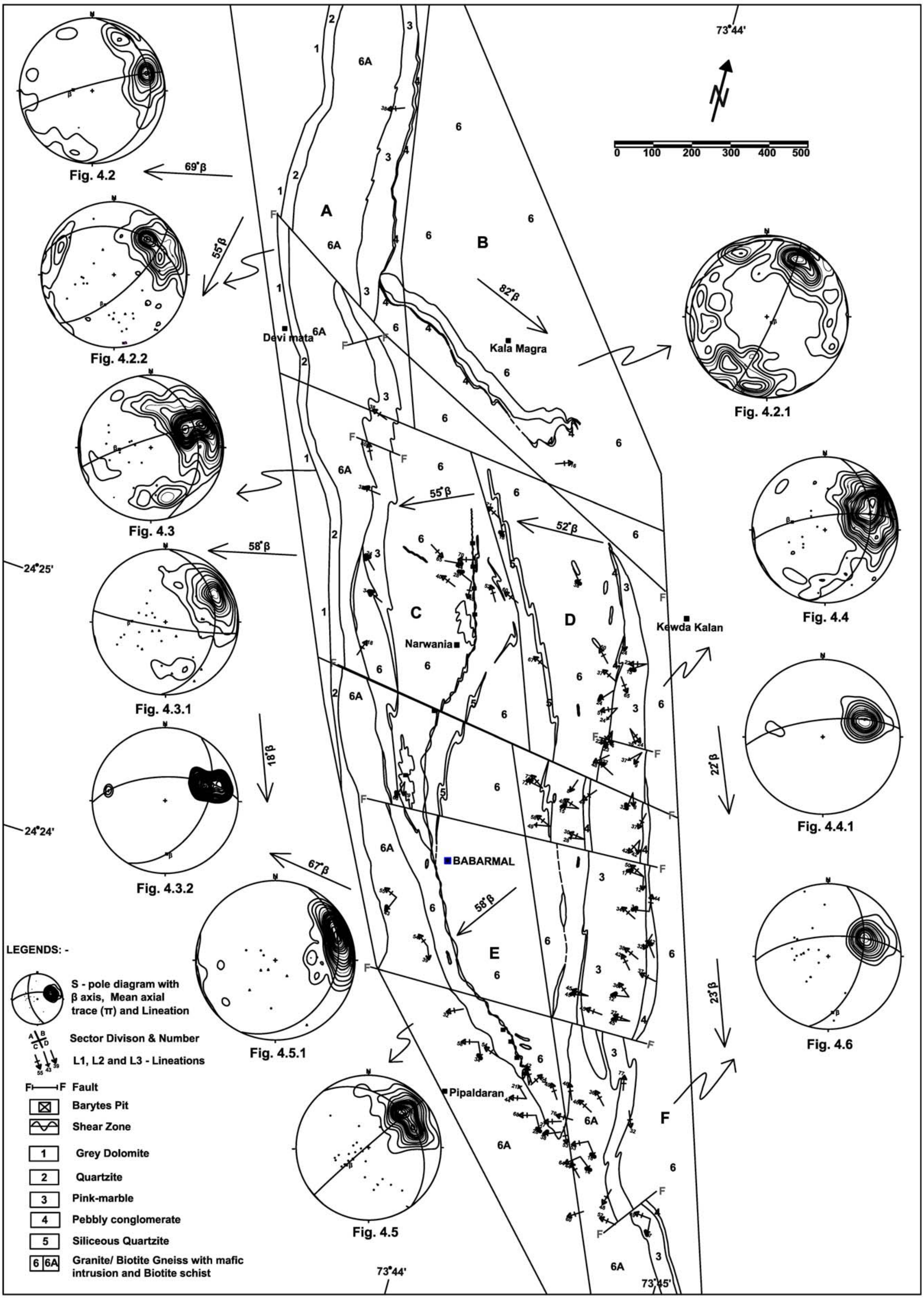

Fig.6. Sector division map of the region along with s-pole diagrams depicting the sector-wise variations in the deformation.

Relationship of marble-conglomerate assemblage with the baryte-bearing mafics

The western conglomerate band showed the enrichment of secondary mafic minerals in the matrix that were derived from the sheared mafic intrusive bodies. There is no mafic intrusion observed in the conglomerates. Similarly the pink marbles are also devoid of mafic intrusion and barytes. The observation suggests that the pink marble was not the product of the metamorphism induced by mafic intrusion. The observation further implies that the conglomerate-marble litho-assemblage was younger than the barite-bearing mafic bodies that were intrusive into the basement gneisses. Avadich et al. (2006) on the basis of sulphur isotope character of barytes interpreted that the barytes at Babarmal were stratigraphically equivalent to the barytes of the Delwara Formation. This interpretation further implies that the marble-conglomerate assemblage at Babarmal is younger to the Delwara Formation. The field relationships at Babarmal also show that the barytes bearing mafic rocks in the shear zone underlie the sheared western pink marble band.

Relationship of marble-conglomerate assemblage with the Jhamarkotra Formation

The calcitic pink marble of Babarmal showed metamorphism of green-schist facies that is similar to the Jhamarkotra Formation. The Babarmal pink marble unlike the Jhamarkotra dolomite did not transform diagenetically. This fact is verified from extremely low Mn/Sr ratios observed in the Babarmal marbles whereas the dolomite of Jhamarkotra Formation had medium Mn/Sr ratios (Purohit and Rengarajan, 2007; Mehta, 2009). The field relationship, at Babarmal on the basis of westerly dip direction and fold geometry patterns (Table 2), indicated that the pink marble underlie the Jhamarkotra dolomite and was distinctly separated by the quartzites along the western flanks in the study area (Fig. 4). The conglomerate-marble assemblages at Babarmal underlie the quartzo-dolomitic-phyllite sequence of the Jhamarkotra Formation. The conglomerate-marble assemblage exhibits deformation phases similar to the Lower Aravalli Group.

Revision proposed in the tectono-stratigraphic status of marble-conglomerate assemblage

The lithological and petrographic characteristics of the Babarmal litho-assemblages are different then the Delwara and Jhamarkotra Formation, so these rocks are not placed in either of the formation. It is proposed to name the pink marble-pebbly conglomerate lithoassemblage as "Babarmal Formation" that categorically differs from the Babarmal Formation (D7) from Debari Group of Gupta et al. (1995). The D7 Babarmal Formation constituted of single lithounit of pink marble and was considered equivalent to the dolomitic carbonates by the authors. The mess-up of nomenclatures by Gupta et al. (1995) had created ambiguity on correlation of rocks in the Aravalli supergroup. Roy and Jakhar (2002) had removed this ambiguity to certain extent but there correlation of Babarmal pink marble with the Jhamarkotra Formation was debatable because the marble is calcitic. The pink marble unlike the Jhamarkotra dolomite is not associated with the phosphate bearing stromatolites and black shale litho-facies. We propose to put the Babarmal Formation that constitutes of unique calcitic pink marble and pebbly-conglomerate litho-assemblage as part of the Lower Aravalli Group but lower in stratigraphic sequence to the Jhamarkotra Formation. A litho-log for the litho-assemblages present in the Babarmal basin is drawn that show relationship between different litho-units (Fig. 7). This litho-log is correlated with the litho-logs from different sub-basins that were part of the Jhamarkotra Formation in the Lower Aravalli Group with the help of tie lines (Fig. 8). The unique litho-assemblages as mapped in the Babarmal basin in present study are not observed in any other basin of the Lower Aravalli Group.

Extension of the pink marble belt is observed on the regional scale further towards SE. Patchy occurrences of the pink marble outcrops are seen in the entire Udaipur-Banswara-Belt (Fig. 9). The outcrops occurred in a narrow curvilinear pattern with slight variation in strikes due to faulting. The sedimentation in this curvilinear basin was protracted which is evidenced by the absence of dolomitization (Purohit et al. 2007). This type of sedimentation could probably be due to the narrow and intimate association of the rocks with the Archaean basement. The deposition of carbonate in different basins of the Udaipur-Banswara-Belt possibly took place under extremely restricted conditions. The restricted and protracted palaeoenvironmental conditions for the deposition of the Babarmal pink marble are interpreted from its diagenetically unaltered nature which is further confirmed from low Mn/Sr values of the carbonate.

CONCLUDING REMARKS

Following new inferences are drawn on the basis of review of the tectono-stratigraphic status of the Babarmal pink marble:

1. The 'Babarmal Formation' comprises two lithounits.

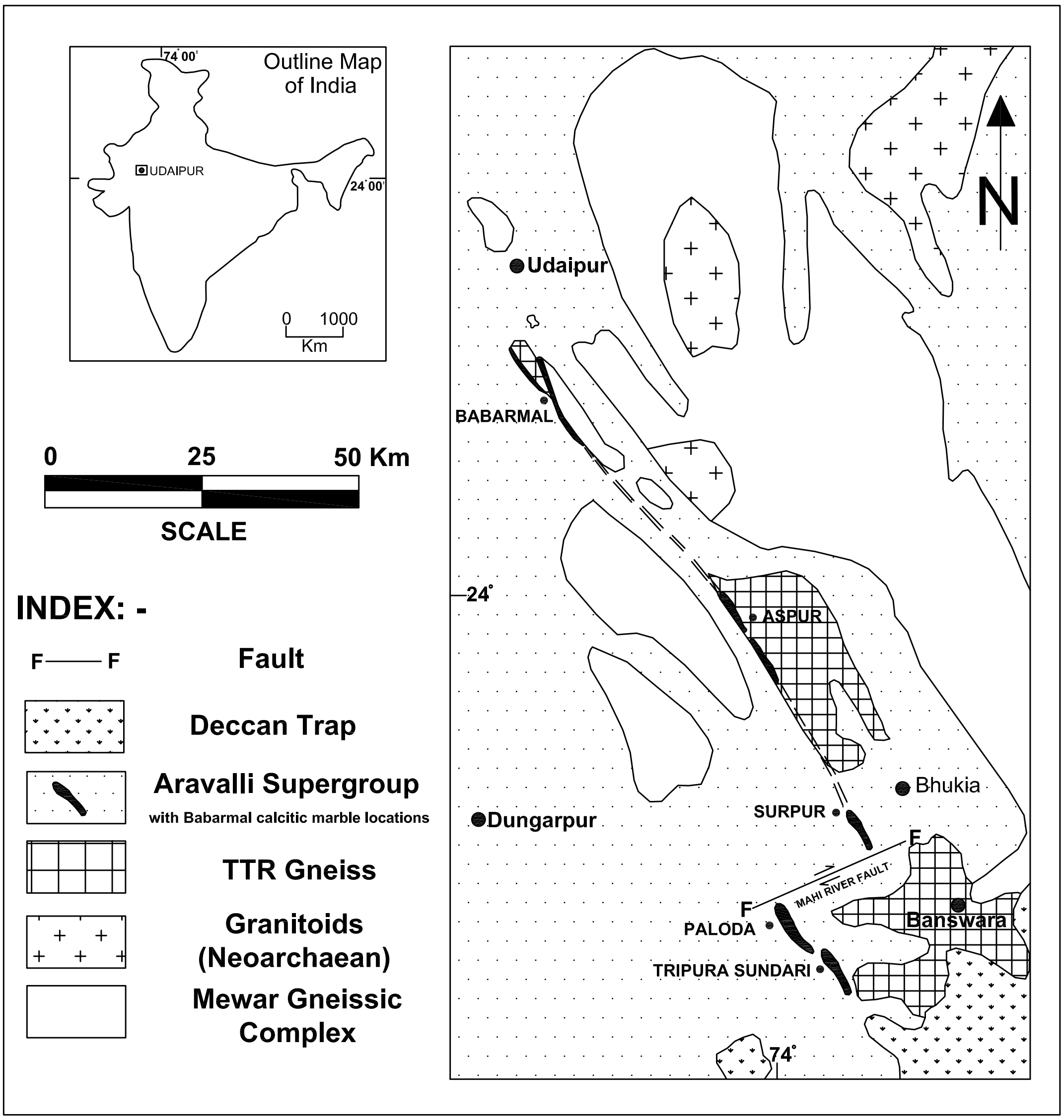

Fig.7. Geological map prepared to show the calcitic pink marble outcrops traced on regional scale of 1:250000.

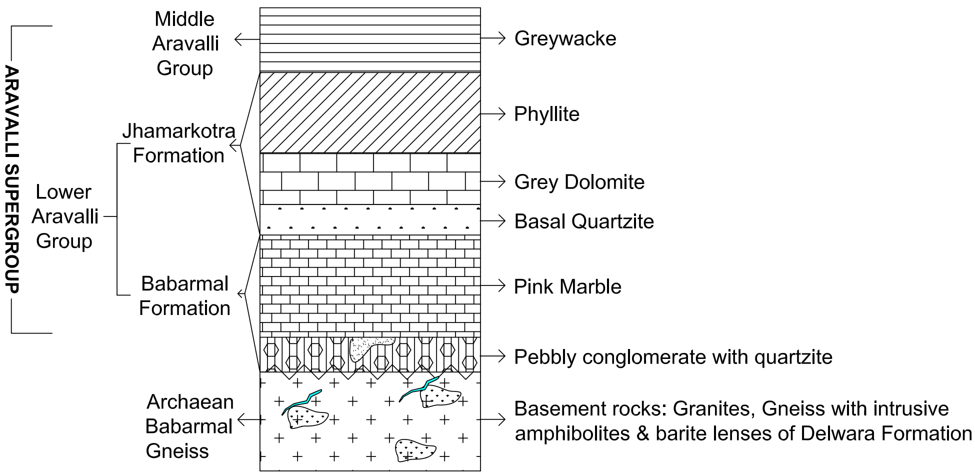

Fig.8. Litholog showing superposition sequence and relationship between the litho-assemblages at Babarmal

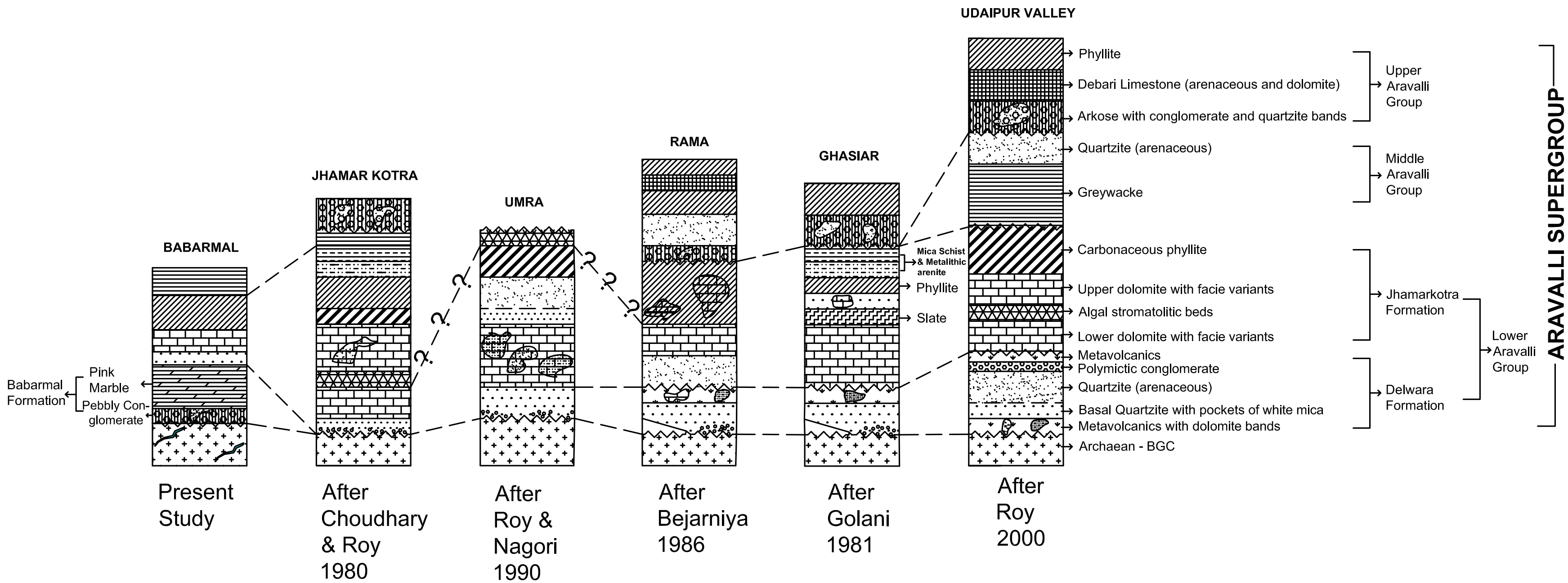

Fig.9. Litholog correlation diagram showing relationship between the different lithounits in various basins of the Lower Aravalli Group with the help of tie lines. The litho-assemblage of pebbly-conglomerate & pink marble is present only at Babarmal.

The lower lithounit is pebbly conglomerate with dominance of quartz-pebbles but is significantly reworked. The upper lithounit is calcitic pink marble which is poor in organic matter and devoid of phosphate content and stromatolites.

2. The Babarmal Formation is significantly different from the Jhamarkotra Formation with respect to the litho-associations and hence both the litho-assemblages cannot be established as time-equivalent.
3. The Babarmal Formation shows similarity with the Jhamarkotra Formation with respect to greenschist facies metamorphism and deformational style that is associated with the Aravalli orogeny. On the basis of these similarities the Babarmal Formation is placed between the Delwara Formation and the Jhamarkotra Formation, as part of the Lower Aravalli Group of the Aravalli Supergroup.

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