CHAPTER-6

RESUME

VI.1.A STRATIGRAPHY :

The Jharol belt rocks represents the upper parts of the Aravalli system of Heron (1953), occurring around Jharol and Phalasia to the west of the Rakhabdev - Dungarpur lineament in the southern region of Rajasthan. These rocks were first classified as Jharol group by Mathur et.al. (1973) which, according to him, consists of different types of phyllites like chlorite schist, intervened by thin quartzite bands and minor bands and lenses of calc-schists. The correlation of these rocks with the upper sequence of the Aravalli Supergroup has been attempted by Gupta et.al. (1980) and (1992), (Table- IV.1). Roy (1991) also believes that the Jharol group is equivalent to the upper Aravallis representing deep sea sequence of distal turbidite deposits (Table- VI.2).

The Jharol metasedimentary sequence of proterozoic age, has been re-investigated and re-classified by the present author, using IRS-FCC data supported by extensive field mapping, structural analysis, petrographic and metamorphic studies. It consists of several lithounits deposited unconformably over the mafic and ultramafic basement rocks, recognised by the present author as oceanic crust, comprising of highly folded talc-chlorite schists, Table - VI.1

stratigraphic Succession of the Aravalli Supergroup

	Shelf sequence		Deep-water sequence	
UPPER ARAVALLI GROUP	Ultramafic intrusives Lakhawali Phyllite Kabita Dolomite Debari Formation	Conglomerate arkose and quqatizite (=Dantalia quartzite)	Jharol Formation	Mica schist and thin beds of quartzite, Ultra-mafics
Unconformity				
MIDDLE ARAVALLI GROUP	Tide Formation	Slate/phyllite with thin beds of dolomite and quartzite		
	Bowa Formation	Quartzite and quartzo-phyllite (=Machhla magra quartzite)		
	Mochia Formation	Dolomite, carbonaceous phyllite, quartzite etc. with ore bodies of lead, zinc & silver (=Katar dolomite)		
	Udaipur Formation	Greywacke-slate-phyllite, lithic arenite, diamictic conglomerate (=Sishmagra conglomerate)		
Unconformity				
LOWER ARAVALLI GROUP	Jhamarkotra Formation	Dolomite, quartzite, carbonaceous phyllite, silcrete, ferricrete & thin local bed of stromatolitic phosphorite near the base; local pockets of copper & uranium deposits (='Rajolo marbles' of Iswal, Nathdwara and Kelwa)		
	Delwara Formation	Meta-volcanics with thin beds of meta-sediments (='Bari volcanics')		
Unconformity				
(ARCHAEAN)	Mewar Gneiss	pre-Aravalli gneisses, granites, amphibolites & meta-sediments.		

(After Roy, 1991).

Table - VI.2

Classification of Aravalli Supergroup

ARAVALLI SUPERGROUP 2500 - 2000 m.y

CHAMPANER GROUP	Rajgarh Formation Shivarajpur Formation Jaban Formation Narukot Formation Khandia Formation Lambia Formation			
LUNAWADA GROUP	Kadana Formation Bhukia Formation Chandanwara Formation Bhawanpur Formation Wagidora Formation Kalinjra Formation			
SYNOROGENIC RAKHABDEV	GRANITE ULTRAMAFIC	AND SUITE	GNEISS	
JHAROL GROUP	DOVDA GROUP	NATHDWARA GROUP		
Shamalaji Formation Goran Formation	Devthari Formation Dapti Formation			Rama Formation Haldighati Forma^n Kodmal Form^n
BARI LAKE GROUP	Khamnor Formation Varla Formation Sajjangarh Formation	KANKROLI GROUP		sangat Formation Puthol Formation
UDAIPUR GROUP	Udaipur Sector Banaswara Formation Nimachmata Formation Balicha Formation Eklinggarh Formation Sabina Formation	Sarada Sector Zawar Formation Baroimagra Formation Mandli Formation		Rajnagar Formation Morchana Form^n Madra Formation
DEBARI GROUP	Debari Sector Jhamarkotra Formation Berwas Formation Jaisamand Formation Delwara Formation Gurali Formation	Jaisamand Sector Rabarmal Formation Dakankotra Formation Jaisamand Formation Delwara Formation	Sarada Sector Kathalia Formation Sisamagra Formation Natharia-ki-pal Formation Basal Formation	Ghatol Sector Jagpura Form^n Mukandpura Form^n Jaisamand Form^n Delwara Form^n Gurali Formation

(After Gupta et.al.1992).

amphibolites, hornblende gneisses and serpentinites. The basal formations represent thin bands and lenses of micaceous quartzite embedded in the coarse garnetiferous biotite gneisses and schists, followed upward by thick and rather continuous horizon of massive quartzites, and thick non-garnetiferous chlorite phyllites and schists with bands and lenses of crystalline limestones.

The stratigraphic classification of the study area has been proposed. The proposed stratigraphic classification (Table- VI.3) is a modification of the already known classification of Gupta et.al., (1980, 1992) mentioned above. The present author, based on her new findings, has introduced three more formations viz: the Barvalli, Kirat and Bagpura formations in addition to the two-fold classification of Gupta et.al (op.cit.) which consists of Goran and Shamlaji formations only. According to the present classification, the Goran formation strictly represents only the garnetiferous pelitic schists and the Shamlaji formation represents only the massive quartzites overlying the garnetiferous schist. The oceanic type basement rocks (Barvalli formation) and the overlying gneissic rock (Kirat formation) have not been described in Gupta et.al's classification. Also, the non-garnetiferous schists and phyllites, occurring above the Shamlaji formation, have not been classified by Gupta et.al., (1980, 1992) as a separate formation. The present author proposes to assign them as

Table - VI.3 : Stratigraphic succession of the Proterozoic rocks of the Jharol area, south-western Rajasthan.

Age	Group	Formation	Lithology
MIDDLE PROTEROZOIC		Intrusive	- Dolerites and basaltic dykes - Ultramafic rocks(serpentinites, talc chlorite schists, actinolite schist.
	Gogunda Group	Kumbhalgarh/ Richer	- Argillaceous/Calcareous
		Antalia	- Arenaceous (quartzite)
	JHAROL GROUP	Bagpura	- Phyllite schists - Quartz-biotite-muscovite schist.
		Shamlaji	- Massive quartzite
		Goran	- Garnet mica schist
		Kirat	- Kamalnath micaceous quartzites - Staurolite-garnet schists and gneisses. - Sillimanite gneisses alternated with sheared quartzites.
		Barvalli	- Amphibolite garnetiferous gneisses. - Amphibolites, asbestos-bearing serpentinites.

Bagpura formation, in the proposed classification. This proposal is made since the rocks belong to a separate sedimentary facies of pelagic - argillaceous nature representing deep sea facies (Sugden and Windley, 1984; Sugden et.al, 1990). Detailed studies carried out by the present author confirm that the Jharol rocks have been deposited in a deep sea environment as stated by earlier workers but resting over the oceanic crust. Roy and Nagori (1990), Roy (1991) have also recognised the Jharol rocks as distal deep sea turbidite but postulated that their basement rocks are made up of the Banded Gneissic Complex of rocks. No modern deep sea sequences have been deposited over the continental basement rocks, their underlying rocks are layer-2 and layer-3 oceanic crustal rocks representing oceanic crust ophiolites.

1.B STRUCTURES :

Structurally it is well-known that four episodes of folding are encountered in the Aravalli rocks (AF_1, AF_2, AF_3 and AF_4) Naha and Halyburton (1974), Naha et.al (1984), Roy (1991) and three episodes of folding are found in the Delhi rocks ($DF_1 = AF_2$, $DF_2 = AF_3$ and $DF_3 = AF_4$; Sychanthavong and Merh (1981); Sychanthavong (1990); Gangopadhyay and Laheri (1984). This structural contrast strongly suggests that these rocks really belong to two separate systems (Supergroups) Aravalli and Delhi as proposed earlier by Heron (1953) and accepted practically by almost all workers. It is known that the Aravalli rocks have been involved in the Delhi foldings and AF_1, E-W Aravalli folding is of Pre-Delhi in age (Naha et.al., 1984).

Based on the above stated structural contrast, the present author has been able to work out the structural history of the study area and assign the overall stratigraphic position for the Jharol rocks as post Aravalli but Pre-Delhi in age.

Detailed field observations revealed that the Jharol group of rocks is devoid of AF_1 folds. All the refolded folds are of AF_2 and AF_3 interferences which became southernly plunging due to AF_4 cross-folding. These structures have been cut by transverse faulting making the early two folded structures to become more complicated folds. This type of complicated refolded structure is well preserved practically everywhere but more concentration is found near Bichhwara village. The absence of AF_1 folds suggests that the Jharol Group of rocks as a whole may be younger than their assigned stratigraphic position as upper Aravalli sequence. It, otherwise, requires an explanation with an absolute deformational tectonic model.

Besides the study of the folding history of the area, the author has also attempted to analyse the shear structures recorded in the field as well as on the microscale. Several shear sense indicators have been examined, most of them represented by meso-scale duplex structure developed due to interfolial movement during synthetic shear movement. Majority of shear sense indicators recorded in the study area are of sinistral shear movement controlled by dip-slip movement in the initial stages of shear deformation but culminated by strike-slip movement in the initial stages of shear deformation but culminated by strike-slip movement. These shear sense indicators when critically examined and correlated with regional tectonics they show interesting deformational history of non-coaxial shear deformation of the entire orogen governed by large scale horizontal movement. Such movement also reflects the development of microscale structures as well. On microscale the development of shear indicators like microfaults along the crenulation planes, mica-fishes, sigmoidal displacement of quartz grains, pull-apart structures, flattening of quartz grains, grain boundary displacement and the exhibition of typical S-C mylonite structures are observed. Most of the mica-fishes indicate sinistral sense of shearing along the C-surfaces. Few dextral shear indicators are seen suggesting that there was, some internal rotation within the rock mass during the bulk shear deformation. Based on this microscale structural study in addition to the observations of mega as well meso-scale structures, a regional tectonics of southern Rajasthan region. The study of microshear indicators is useful in the interpretation of metamorphism and folding relationship as evidenced by the development of mineral assemblages during various events of mineral paragenesis, mineral deformation and recrystallization.

1.C METAMORPHISM :

Metamorphically, the Rajasthan pre-cambrians have been studied only sporadically by some workers (Lal and Shukla, 1975; Sharma and Narayana, 1975; Sharma, 1977, 1983a, 1983b, 1983c; Sharma and Mac Rac, 1981; Sharma et.al., 1987; Desai et.al, 1978; Sychanthavong and Merh, 1981; Gangopadhyay and Sen, 1972; Gangopadhyay and Lahiri, 1983; Sinha-Roy and Mohanty, 1984). The Banded Gneissic Complex of rocks have imprints of polymetamorphism ranging in facies from high-rank amphibolite to granulite, while the Aravalli sequence shows polymetamorphic effects from low-grade green-schist to amphibolite facies, and the Delhi rocks exhibit high-rank greenschist to granulite facies, showing the regional metamorphic events and one diapthoresis. Thermal metamorphic effects are recorded only around the granitic intrusions and mafic plutons mostly found in the Banded gneissic complex and in the Delhi rocks.

Systematic metamorphic studies in the Jharol belt rocks have not been carried out and no literature on metamorphic petrology is available. The present study reveals interesting metamorphic imprints in the Jharol belt rocks. In all, two regional metamorphic episodes each of which taking place synchronous with folding have been detected, and one retrograded (diapthoresis) metamorphic event accompanied by extensive shearing (dislocation metamorphism of Turner and Verhoogen, 1962; Turner, 1968) has also been recognized. The first two events were taking place during AF_2 and AF_3 foldings (termed here as M_1 and M_2) as evidenced by the internal deformation, (folding and rotation), recrystallization of low-grade minerals into high-grade mineral assemblages. The latter event (M_3) is found only along the major shear zones where maximum chloritization is observed.

In amphibolites, exposed around Barvalli village, diopside co-exists with hornblende and plagioclase indicating of higher metamorphic grade is observed with occassional appearance of sphene. This is the indication of M_2 metamorphic assemblage having higher temperature condition. The survival of M_1 metamorphic assemblages are observed in the amphibolites of Mohmad Phalasia area where epidote - albite-quartz amphibolites are exposed and the garnet amphibolite gneisses at Kirat village. They are extremely compressed and strongly foliated with flattened and stretched garnet crystals. Wherever the amphibolites are sheared during later movement they are seen to have been altered into hornblende chlorite schist, with unbroken down sphene. Such rocks are exposed at Jhanjhar village, closely associated with massive amphibolites. The associated ultramafic-rocks (serpentinites) have also been metamorphosed and recrystallised into asbestos bearing chlorite schists with chromite.

The above lying pelitic gneisses and schists with thin bands and lenses of quartzites (Kirat formation) also show similar responses of metamorphic history. In Kirat, Ora and Amliya gneisses, staurolite is seen co-existing with biotite and rotated garnet. They are seen to have overgrown on the tiny pre-existing garnet crystal nucleii which in turn co-exist with biotite and muscovite. Staurolite is seen rotated and folded along with garnet in almost all the thin sections studied. In some thin sections, they are seen co-existing with sillimanite the transformation products of muscovite. Staurolite is seen altered into ottrelite in the later metamorphic episode indicating diapthoresis of the rocks. The embedded quartzite horizon also show similar metamorphic responses. The biotite quartzites consist of sillimanite - biotite-muscovite-quartz assemblage developed oblique to the pre-existing foliation made up of quartz and biotite. Since, the rock is extremely rich in quartz only two metamorphic imprints can be recognized.

In garnet mica-schist (Goran formation) around Bichhwara and Jharol villages, similar responses of metamorphic effects are observed. The second generation of garnet crystals are seen to overgrow on the pre-existing schistosity indicating synkinematic M_2 mineral assemblage. At Bicchwara fold nose, such garnet crystals are seen overgrown on the crenulation cleavages of AF_3 generation of folds. They are seen co-existing with the recrystallized biotite and quartz grains preferredly oriented along the AF_3 crenulation cleavage planes. At other places, sillimanite co-exists with these minerals. Along the shear-zone, chloritization is observed having chlorite crystals altered from biotite. The Bagpura formation also shows identical metamorphic imprints. The first metamorphic foliation, developed during AF_2 folding, consists of folded tiny flakes of biotite and muscovite with some aggregates of quartz crystals. The later mineral assemblages are coarse biotite flakes co-exist with quartz, both of which have overgrown on the tiny closely spaced early foliation and mostly crystallised parallel to AF_3 axial plane cleavages. Chlorite crystals are quite fresh and found as alteration products of both the earlier biotite crystals. They are more prominent along the shear zone.

1.D TECTONICS :

Rifting and volcanicity occur simultaneously in the Aravalli basin, followed by sedimentation as evidenced by the basal conglomerate having volcaniclastic matrix (Roy et.al., 1971; Roy and Paliwal, 1983; Roy, 1990). Nagori (1988), supporting this idea, has interpreted that the rocks of the Aravalli Supergroup are distributed along two sub-parallel belts showing different facies sequence. These two depositional environments in the Udaipur area, according to him, represent- (1) epicontinental facies observed as interbedded quartzites, pelitic schists and carbonate rocks, and (2) deep sea facies observed as a thick pile of phyllites. These workers claimed that the occurrence of meta-volcanics, including chlorite schists, hornblende schists and ortho-amphibolites, associated with basal sequence, are indicative of the existence of syn-depositional volcanism. This interpretation holds true for areas situated to the east of the Rakhabdev - Dungarpur mafic-ultramafic complex where the underlying basement rocks are made up of gneisses and granites (B.G.C rocks). To the west of this complex, and closer to the Delhi contact, the present author has found that the ortho-amphibolites associated with ferro-magnesian rocks occupy anticlinal fold cores overlain by garnetiferous gneisses and schists alternated with bands and lenses of quartzites of varying thicknesses indicate simultaneous sea-floor spreading and sedimentation representing deep-sea environment.

Geochemical studies of the Jharol mafic volcanics indicate the mid-oceanic Ridge Basalts (MORB) chemical affinity (Abu-Hamatteh et.al., 1994) confirming the field evidences, found by the present author that these metavolcanics are highly folded occupying the core of anticlines below meta-graywacke rocks and are seen associated with ultramafic rocks, mostly metamorphosed serpentinites. Such rock association indicating deep sea facies cannot be expected to occur in the continental rift tectonic set-up, similar to the Red sea of today. These mafic volcanics might have been erupted in the mid-oceanic ridge tectonic setting together with the caught up ultramafic materials, obviously free from contamination with continental crust as indicated by their major and trace element chemistry (Abu-Hamatteh et.al., 1994) confirming that these mafic and associated ultramafic rocks represents oceanic crust. Submarine eruption of the volcanic rocks is also evident by the presence of pillow and vesicular structures (Mohanty et.al., 1993). How far west the Jharol basin is extended remains unclear because of thrusted contact between the so-called older Jharol sequence and the younger Delhi rocks. Both, the sequences have been deformed and folded concordantly showing similar fold geometry.

VI.2. CONCLUDING REMARKS :

From the interpretation of basin evolution, mode of deposition and deformation of Jharol rocks, following conclusions can be summarized.

1. The Jharol basin opened after the deposition of the

Aravalli basal formations and the overlying thick rythmic sequence (lower and middle, Aravalli group of Roy, 1991). The deformation of the basal formations and the thick rhythmic sequence consisting of graywackes, phyllites, arenites, etc, in the Aravalli belt might be coeval with the deposition of the lower Jharol rocks comprising of Kirat and Goran formations.

2. The Jharol group comprising Kirat, Goran, Shamlaji and Bagpura formations represents distal deep sea fan trubidite deposits accumulated over the oceanic crust made up, at present, of highly folded amphibolites and highly sheared serpentinites and tremolite - talc - chlorite - schists.

3. There are synsedimentary volcanics occurred at the base of the Goran formation. These volcanics at places, are exposed quite close to serpentinite ultramafic rocks and may be coeval. This phase of volcanic eruption might have been taken place during the tectonic instability in the region in connection with the opening of the south western Delhi basin. The upper Jharol rocks (Shamlaji and Bagpura formations) have a little age difference with the Gogunda group of the Delhi rocks.

4. The Jharol Group of rocks have been folded by three phases of folding $AF_2 = DF_1$, $AF_3 = DF_2$ and $AF_4 = DF_3$. No E-W trending AF_1 folds have been detected in the study area and its environs. Sinistral deep-slip accompanied by sinistral lateral shear movement were the main

mechanism controlling the folding of Jharol rocks.

5. The Jharol Group of rocks have been metamorphosed by two regional metamorphism and one diapthoresis. The earliest metamorphic event was of greenschist facies and the second event was of high rank amphibolite facies. Diapthoresis was mainly taking place due to dislocation metamorphism and was observed mostly along the shear zones.
6. The intrusive rocks are the least deformed massive serpentinites emplaced during AF_2 folding along the longitudinal transtensional openings. They have been metamorphosed and sheared only during AF_3 and kinked or fractured during AF_4 foldings. Dolerite and basaltic dykes represent the latest intrusive rocks emplaced during AF_4 folding. No granites are recorded anywhere in the Jharol belt.