CHAPTER-5

GEOLOGICAL EVOLUTION AND TECTONIC IMPLICATIONS

V.1 ESTABLISHED FACTS :

In the preceding pages, the author has given a variety of evidences based on her own data from the study area as well as its environs, as also on the work of numerous previous geologists working on the geology of Rajasthan, to build up a concept which provides an alternative model for the geological evolution of the Jharol group. The structural pattern of the Jharol group of rocks, depositional histories, metamorphic characters and geochronology, all these when taken together, require an altogether a new approach to their evolution.

The classical concept of geosyncline, isostasy and mountain building, when applied to the rocks of Jharol group fails to explain two very important factors :-

1. Involvement of basement in all the three AF_2, AF_3 and AF_4 foldings found in study area.

2. Cause and mechanism to explain strong push from SSW to give rise to AF_4 folding.

The Aravalli and B.G.C. rocks were fully involved in the AF_2, AF_3 and AF_4 foldings, while the rocks of the study area and its environs have not been affected by AF_1 folding indicating that these rocks might have been deposited more or less during this folding but consolidated and metamorphosed soon after that.

The chronology and trends of the various fold episodes have been summarized in Table-V.1.

Four episodes of folding (AF_1, AF_2, AF_3 and AF_4) have been established in the Aravalli rocks, while the Delhis reveal effects of three foldings (DF_1 = AF_2, DF_2 = AF_3 and DF_3 = AF_4). These remaining three foldings are common to both rock sequences and developed during the Delhi orogeny.

The details of these fold episodes from Delhi and Aravalli terrains are available in the work of Naha and Halyburton (1974), Naha et.al. (1984), Gangopadhyay and his associates (1967, 1968, 1970, 1973, 1975) and Roy (1974), Sychanthavong and Merh (1981), Sychanthanvong (1990).

Table- V.1 : SUMMARY OF FOLD EPISODES REPORTED IN THE DELHI AND ARAVALLI ROCKS :-

EVENTS	ARAVALLI	DELHI	TREND	OROGENY
First AF_1	Present	Absent	E-W	ARAVALLI
Second AF_2=DF_1	Present	Present	NNE-SSW	
Third AF_3=DF_2	Present	Present	NNE-SSW (Coxial with AF_2)	Delhi
Fourth AF_4=DF_3	Present	Present	WNW-ESE	

The last fold episode AF_4 is superimposed almost across the AF_2 and AF_3 in the Aravalli AF_4 has a more or less WNW - ESE trend, and its intensity is maximum in the south west. North-eastward the AF_4 folds progressively open out, and are represented by open gentle flexures on the AF_2 and AF_3 fold limbs only. On the other hand,in the south and southwest, these AF_4 folds are tight and overturned to the north east. This folding has given rise to numerous troughs and crests extending for several kilometres each. The various E-W or WNW-ESE transverse faults are so common in the southern parts of the Aravalli range, cutting across Kumbhalgarh, Gogunda and the basement, appear to be related to the same deformation which gave rise to AF_4. It is along such fractures that numerous younger dykes have been emplaced. The stresses responsible for AF_4 and E-W, WNW-ESE and ENE-WSW faulting were perhaps generated due to a north eastward push given by the East African (Pangean Continent at 600my.) Burk, Dewey and Kidd (1976), Mc Williams (1981), Sychanthavong (1990).

V.2 MODE OF DEPOSITION OF THE JHAROL GROUP :

Rifting and volcanicity occur simultaneously in the Aravallibasin, followed by sedimentation as evidenced by the basal conglomerate having volcaniclastic matrix (Roy et.al.,

1971;Roy and Paliwal, 1981; 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 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 Transform Fault (RDTF) where the underlying basement rocks are made up of gneisses and granites. To the west of this fault complex, and closer to the Delhi contact, the 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.

The striking absence of conglomeratic beds at the base of the Jharol group implies the marine environment off the continental shelf areas. Thus, the Jharol quartzites (sheared as well as massive) do not represent the littoral beach sand or shelf zone sand deposits of the Jharol sea as postulated by earlier workers. The original constituents of these quartzites comprise comparatively clean-washed quartz (with few feldspars) sand particles deposited in a basin free from suspended silty/muddy sediments. The conglomeratic rocks, which are formed from coarse gravelly clastics are normally accumulated along the river mouth and adjacent littoral zones are found only to the east of the RDTF.

According to the model, the RDTF marks the end of the shelf environment floored by the attenuated Archean crustal basement rocks. This fault played important role in controlling the pattern of sedimentation and the change of sedimentary facies of the Jharol metasedimentary sequence.

The vertical sedimentary facies change of the Jharol group was mainly due to vertical movement along the RDTF and other major faults within the shelf zone controlling the uplift and subsidence of the frontal horst, termed here as Khojuri-Sisarma continental basement block, which existed since the time of initial rifting of the Aravalli basin (Figure-V.1). The lower sequence comprising of gneisses alternated with thin bands of quartzites (Kirat formation) overlain by schists (Goran formation) were deposited in an off-shelf environment (deep sea abyssal plain) over the oceanic crust. The deposition was synchronous with the

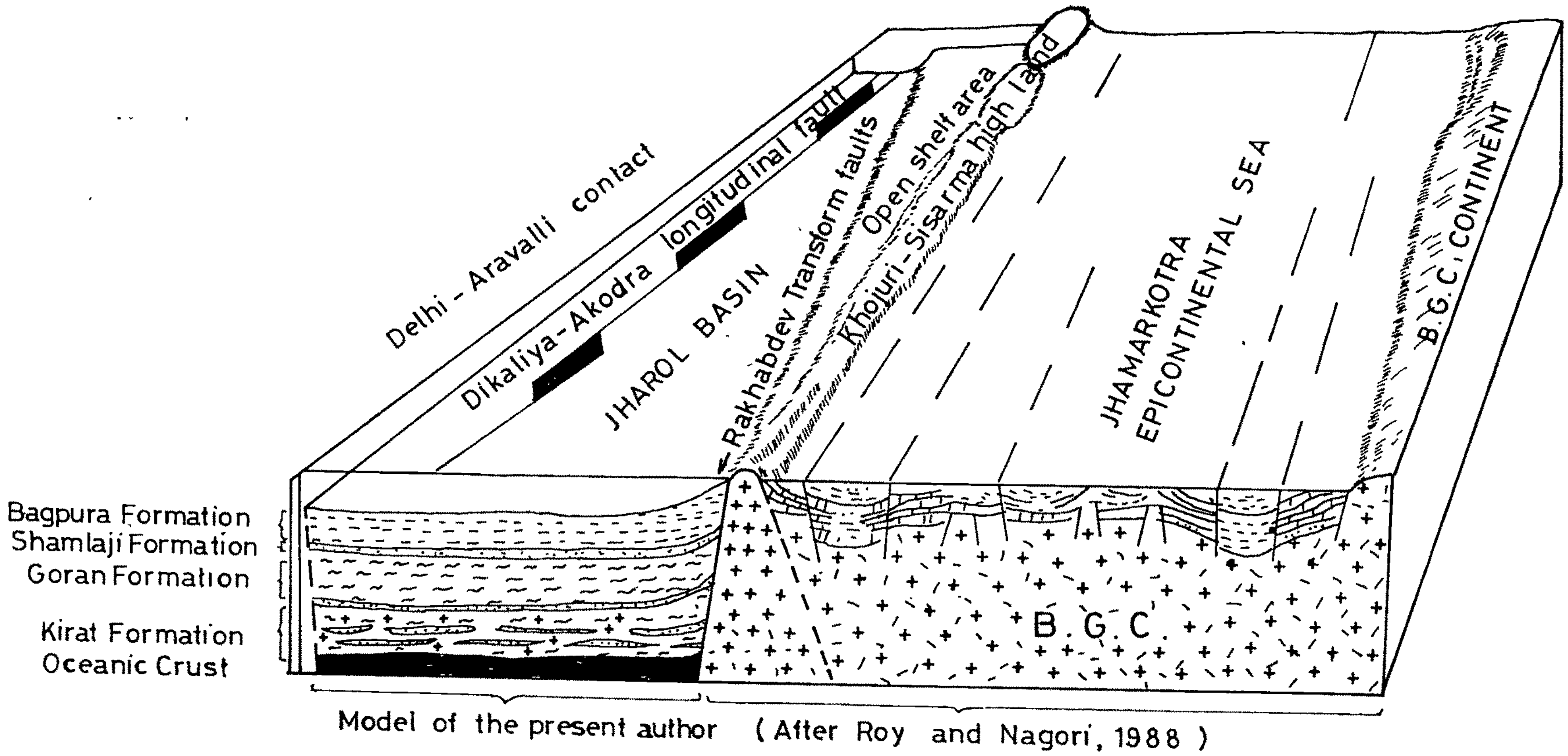

Figure V.1 Basin evolution of the Jharol group and the main Aravalli Sequence.

progressive sea-floor spreading of the Jharol sea. I opine that the whole sequence represents deep sea fan turbidite deposits. The sandy materials have been transported to the basin by deep sea turbidity currents and the pelitic materials have been transported by turbidity currents through sheet-flow mechanism and by tidal currents through suspension process. The upper thick massive quartzites (Shamlaji formation) have been deposited when the Khojuri-Sisarma block was uplifted forming an island chain, thus, considerably reducing the inflow of the clayey and muddy suspended sediments into the Jharol basin. After this episode of sand sheet deposition, the Khojuri-Sisarma islands were submerged allowing the suspended sediments to spread over the basin again. This episode went on for very long period of times permitting the uppermost thick pelitic horizon (Bagpura formation to have been deposited in the basin. The deformation has set in after the deposition of the Bagpura formation as evidenced by the uniformity of fold geometries througout the belt.

V.3 BASIN EVOLUTION :

Roy (1991) has suggested that the Jharol basin was opened simultaneously with the Lunavada and they were the last to open during the three stages of intracratonic rifting and evolution of the Aravalli depositional basins. The primary factors involving the sedimentation in the

Aravalli basins were controlled by the periodic subsidence of faulted blocks within a system of complex grabens separated by horsts (Roy and Paliwal, 1981; Nagori,1988; Roy and Nagori,1990). This interpretation gains further support from geochemical data of metavolcanics which are associated with the basal formations of the Aravalli rocks occurring to the east of the RDTF. In discrimination diagrams, based on immobile minor and trace elements, these metavolcanics show a close affinity with mid-oceanic Ridge Basalts (MORB), while the immobile in compatible element patterns and element ratios resemble those of enriched continental tholeiites which erupt at the time of initial rifting (Raza and Shamim Khan, 1993).

In the Jharol basin, the mafic volcanics show MORB geochemical affinity (Abu-Hamatteh et.al.,1994). This is strongly supported by field evidences that these metavolcanics are associated with ultramafic rocks, mostly serpentinite and tremolites-talc-chlorite schists, which do not occur in continental rift tectonic set-up. These mafic volcanics might have been erupted in Mid-Oceanic Ridge tectonic setting (may be of the Red sea stage), together with caught up ultramafic materials, obviously free from contamination with continental crust as indicated by their trace element chemistry (Abu-Hamatteh et.al., 1994). The interpretation suggesting that these mafic and associated ultramafic rocks represent oceanic crust (Figure- V.1) is fully satisfied by these geochemical data. Submarine eruption of the volcanic rocks along the Modi-Dikaliya strike slip fault (Figure- V.2) is also evident by the presence of pillow and vesicular structures (Mohanty et.al., 1993). How far westward the Jharol basin is extended remains unclear because of thrusted contact between the so-called older Jharol sequence and the younger Delhi rocks. Their strikes are also parallel.

Sugden et.al. (1990) have suggested that the Delhi rocks have been deposited directly over the shelf-rise sedimentary sequence (Jharol) with conformable contact. My examination along this contact shows that it is a synthetic shear zone and therefore, can be mistaken as a conformable contact. The movement along this sheared contact must be sinistro-pivotal type, bringing about the Gogunda quartzites to juxtapose in the south with the Shamlaji quartzites and Bagpura phyllitic schists, and in the north with Kirat and gneisses and Goran garnet-mica schists. At most places, the Gogunda quartzites dip at high angle (70° - 80°) beneath the Jharol rocks, as for example around, Ogna, Ora and Som area. Further south around Vijaynagar and Bhiloda area of north Gujarat, this contact has been interpreted to represent an inverted unconformity (Patel, 1975). Around Gogunda area, this contact is more or less vertical (Sugden et.al.,1990). It appears likely that the Shamlaji and Bagpura formations have a narrow age difference with the Gogunda group of

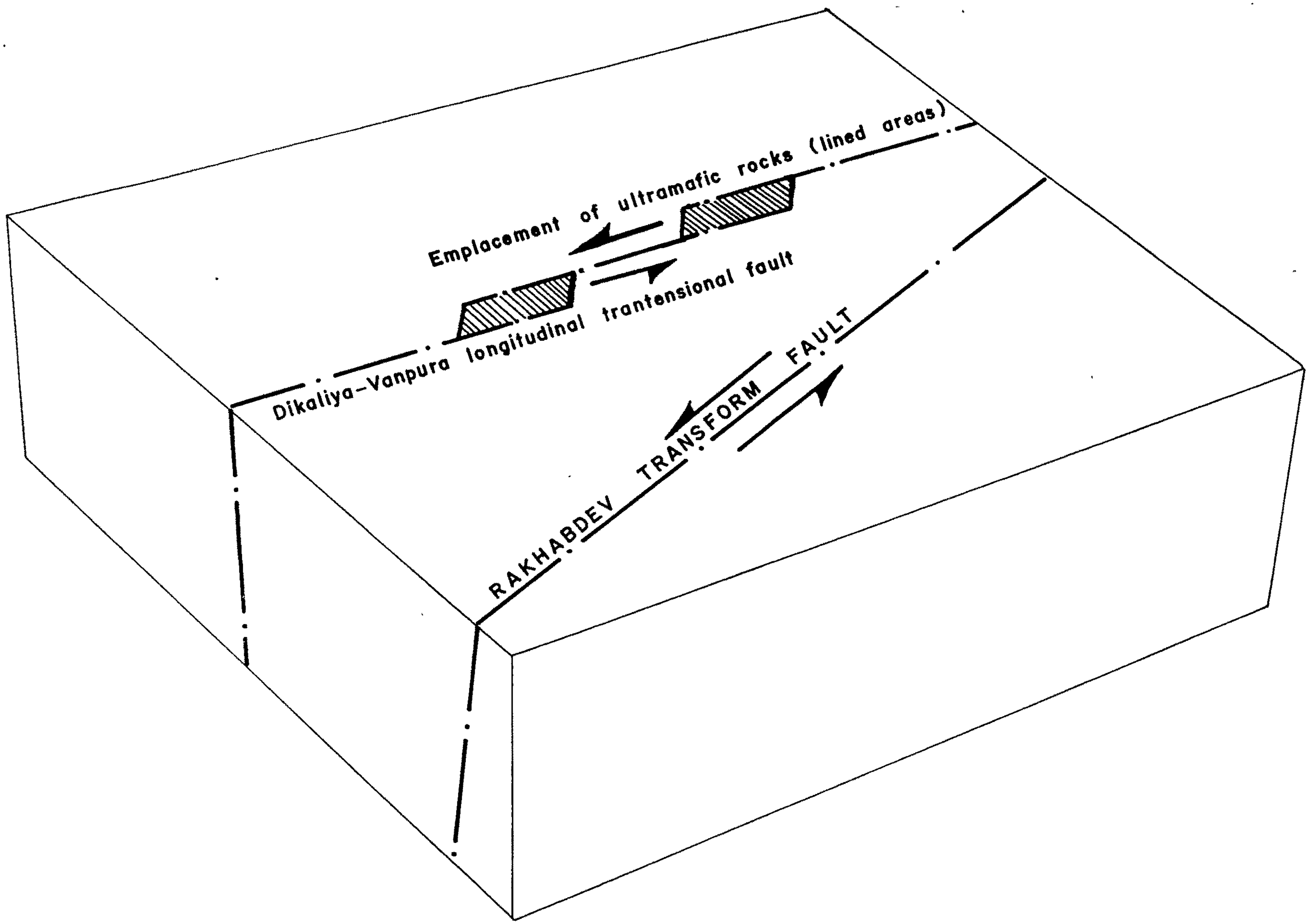

FIGURE- V 2. Sketch showing the sense of movement of the Rakhbdev-Dungarpur, transform fault and the Modi-Dikaliya strike-slip fault.

rocks. This means that the southern Delhi basin was opened after the deposition of the Kirat and Goran formation (Figure- V.1)

V.4 TECTONIC MODEL :

Several plate tectonic models have been proposed to explain the geological intricacies of the entire Rajasthan region viz: Sychanthavong (1975, 1990); Sychanthavong and Desai (1977), Sychanthavong and Merh (1981, 1985), Sen(1981), Powar and Patwardhan (1984), Sinha-Roy(1986), Deb and Sarkar(1990), Sugden et.al.(1990).

(1) **Sychanthavong and Co-workers (1977, 1981) :-**

The earlier proto-plate tectonic model given by Sychanthavong and Desai (1977), Sychanthavong and Merh(1981) for crustal evolution of Aravalli-Delhi fold belt. These author believe that during 2100 Ma the Aravalli-BGC proto-continent started drifting southward toward the Dharwar and Singhbhum protocontinent from larger northern protocontinent. This process of drifting was continued upto 1600 Ma. During this interval Delhi sea opened up in which Delhi rocks were deposited. For sedimentation of Delhi rocks they believe that Alwar Group of carbonate predominate sediments were deposited in the mio-geosynclinal basin over the B.G.C. -Aravalli proto continental shelf while the

Ajabgarh group of pelagic deep sea sediments were deposited in the leptogeosynclinal basin over the oceanic crust. The junction between the Alwar and the Ajabgarh (the Idar-Deogarh-Ajmer- Khetri-fault zone)represent the trench zone along which the Delhi oceanic plate subducted. Subsequently oceanic plate moved eastward and squeezed the Delhi sediments against the protocontinental foreland in the east. This culminated in the Delhi orogeny and generated the Aravalli-Delhi fold belt.

(2) **Sen (1981)** :-

According to him Udaipur tectonic belt represents the open sea side situated to the west and in front of the convex face of the island arc. The ultramafic ophiolite line serves as a dividing line between the two contrasting facies types of sediments roughly locates the upper surface of the subduction zone and the trench. The rocks lying in between this lineament and the arc volcanics, thus are the sediments and volcanogenic rocks that had filled in the arc trench gap.

The subduction accompanying the evolution of the Udaipur belt was joined at some stage by an incipient rifting of the microcontinent west of the Udaipur sea. The continued eastward plate movement stretched the eastern margin of this continent to give rise to a shallow coastal sea with a broad shelf area both of which became the sites of continued sedimentation.

The folding and deformation of the rocks in the arc trench and the arc completed the evolution of the Udaipur belt, deforming open ocean sediments and lavas of the trench and the arc completed the evolution of the Udaipur belt. By this time a major portion of the oceanic crust below the Udaipur sea was consumed by subduction. As a result the western micro-continent was brought close to BGC microcontinent.

(3) **Powar and Patwardhan (1984)** :-

They believe that in the beginning of the proterozoic the Aravalli-Delhi belt was on a stable, ensialic crust at present the Bhilwara Supergroup. Then there was outpouring of the mantle material which resulted in faulting and crustal separation in between the continental rift valleys and oceanic openings. As a result of this an intracontinental basin was formed in which the sediments of the Aravalli Supergroup were deposited.

According to them there was two depositional environment in the Aravallis epicontinental and deep sea which was the result of the longitudinal faulting within the basin. There was immense extrusion and intrusion of basic magma as the sedimentation was progressing. The transfer of heat vertically led to the closure of the rift.

Rifting and subsidence, marginal to the Aravalli belt, in the second phase formed a new basin. Thick pile of arenaceous, pelitic and calcareous sediments together with basic magmatism of Delhi Supergroup were deposited in this new basin. Large scale crustal anatexis was probably responsible for the acid magmatism manifested in the form of late synkinematic to post-Kinematic granitoids.

(4) **Sinha Roy (1988) :-**

He has shown a two stage rifting history in Aravallis, whose floor was oceanic or transitional. The rifts which evidently failed were the main Aravalli aulocogen where the rifting and sedimentation took place. By the eastward underthrusting of Rakhabdev-Gaon-Guda suture the Aravalli aulocogen was crushed.

The evolution of the Delhi belt was dichronous with Alwar Khetri rift formation in North Delhi belt and ocean opening type in South Delhi belt. The rifting of the North Delhi belt was abortive but they developed into an oceanic trough by Ca 1300 Ma. This South Delhi trough was closed by following the subduction with formation of a trench with accretionary carbonate - dominated turbidite, a magmatic arc and a marginal basin.

(5) **Sugden, Deb and Windley (1990) :-**

Early rifts, the Bhilwara aulocogen and the Aravalli continental margin arc difficult to prove agewise and also from other points of view.

Depending on the speculation "Polarity of subduction" the development of Delhi island arc and the possible environment of the Jharol belt is observed. The problems of proterozoic orogenic belts are if the Jharol belt is taken as telescoped sequence of deep pelagic continental rise sediments then eastward subduction took place below the western side of the arc, and the Alwar and Ajabgarh sediments formed in the back arc basin possibly underlain by attentuated remnants of continental crust.

Around 1500 Ma the Aravalli-Jharol sediments were thrust eastward over the BGC craton with restacking accomodated by reactivation of old listric normal faults. During arc-continent collision, continental lithosphere is thrust under the arc complex. A thrust stack of back or forearc and shelf rise sediments are transported eastwards over the continental margin. The Rakhabdev lineament evolved into a major shallow west dipping thrust, with continued convergence, the early thrusts steepen and wrenching parallel to the belt was initiated. Ultimately, the early thrusts are rotated to a vertical attitude and material is extruded laterally and vertically. At this stage dextral, strike-slip, motion parallel to the belt is great and 'flakes' of continental crust arc back-thrust over the Aravalli thrusts.

The final configuration of the constituent belts was controlled by possible indentation of the eastern basement block into the acreted orogen.

(6) **Deb and Sarkar (1990)** :-

According to these people the sediments of the Aravalli-Jharol belt were deposited approximately in the time range 2.0-1.7 Ga. Around 1.8 Ga along the Rakhbdev-Dungarpur lineament the protocontinent separation took place, which led to asthenospheric upwelling and on the western side of the Aravalli belt the oceanic crust was formed and the abortion of Bhilwara rift took place. Around 1.7 Ga the subduction of oceanic crust westwardly took place under the attenuated block of the separated continent to the west. Which resulted in the formation of the Jharol accretionary prism on the continental rise and an incipient arc. Around 1.5 Ga this ocean was closed which led to the collision of the Aravalli continental margin with the arc-microcontinent and obduction eastwardly of the oceanic crust along the Rakhabdev lineament, marked also by the shelf rise boundary. This event according to them can be observed throughout the orogen.

The plate tectonic model adopted here is an extension of ideas putforth by Sychanthavong (1990), with special reference to the deformational mechanism controlling the folding and metamorphism of the Jharol group and its equivalent in the region (Figure- V.3). In this model, the Delhi oceanic plate subduction has played an important role in the folding of the Jharol rocks.

The main mechanical force controlling the deformation was induced by the Delhi oceanic plate subduction of oblique deep-slip process along the Idar-Kotra-Barwara (north of Gogunda) shear zone, the junction between the Kumbhalgarh and the Gogunda groups. This oblique subduction push was the controlling factor for the development of AF_2 folds imprinted throughout the region. The Aravalli and B.G.C. rocks have also been affected by this folding.

This is the first subduction zone process of Sychanthavong (1990). The mighty push of this first subduction process could transmit certain energy across the fault to control the development of tight AF_2 folds (mostly shear control) in the eastern region of the fault. The subduction push direction is about 45° oblique to the

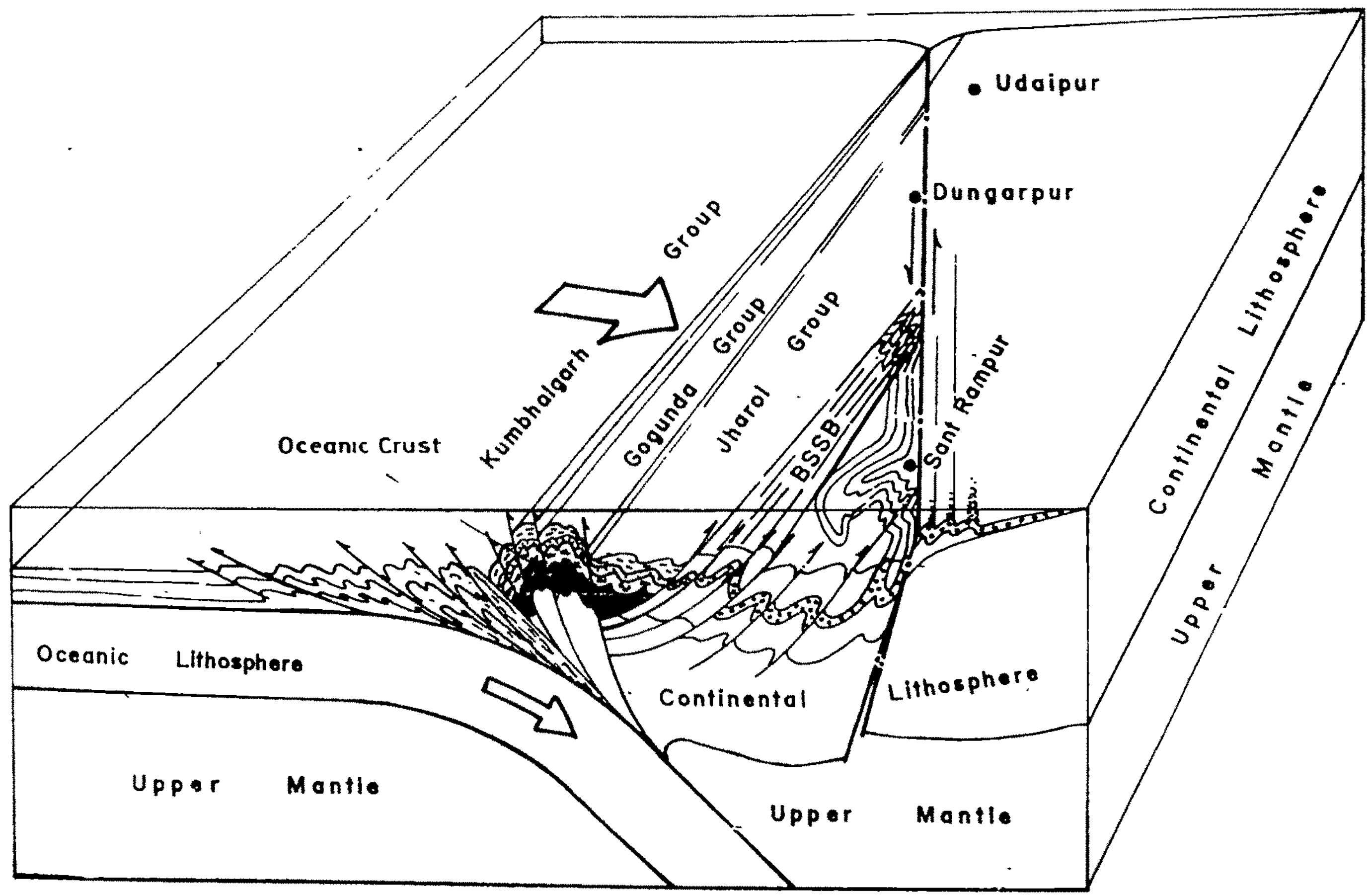

Figure V.3 Tectonic model illustrating shear deformation in the southern Rajasthan - North Gujarat region.

Rakhabdev Dungarpur transform fault deviating compressional forces into shear stresses along the fault zone, creating transpressional sinistral shear movement. This has given rise to maximum crustal shortening by upthrusting of several tectonic flakes bounded by shear zones.

AF_3 folding was controlled by similar stress field but different tectonic regime that occurred farther to the west of the Malani Igneous suite, after the uplift of the Kumbhalgarh, Gogunda and Jharol groups (Sychanthavong and Merh, 1981; Sychanthavong, 1990). AF_3 folding in the study area is comparatively weak since it is located very far from the second subduction zone. The stress transmitted by this subduction push could only weakly fold the Jharol group of rocks away from the shear zones. Those folds developed within the shear zones are quite tight especially the minor folds. As stated earlier that AF_4 folding was controlled by a strong push from southwest and was controlled by continental collision between Indian and East African cratons during the unification of Gondwanaland (Mc Williams, 1981; Sychanthavong and Merh, 1981).

Based on the study of shear sense indicators on meso and micro-scale, the present author has tried to explain the folding mechanism related to shear movement, resulted from the subduction push, governing the deformation of the rocks of the study area. The amphibolites and associated ultramafics (Barvalli formation) represent a thin-skinned flake scraped off the main oceanic crustal rock to have been folded in the initial stage by pure shear but later by simple shear mechanism of sinistral shear sense (Figure- V.4A). The overlying pelitic gneisses, schists, quartzites have also suffered. They have been folded on AF_2 recumbent folds superposed by AF_3 upright folds (Figure- V.4B). There was thrusting between the amphibolites and the gneisses and due to decollement these type of structures have been formed. AF_2 folds show two generations. The earlier formed was totally recumbent and the latter one was overturned towards the same direction. This is a classic example of progressive simple shear mechanism. AF_2 folding was accompanied by metamorphic differentiation process resulted into the development of numerous quartzo-feldspathic veinlets along the shear gashes showing perfect sinistral sense of shear indicators discussed in Chapter-III. The various tails of these shear indicators (porphyroclasts) have been detached during AF_2 folding (Figure- V.4B). The single tailed porphyroclasts of quartzo-feldspathic shear indicators in amphibolites justify this interpretation (Plate- III.17). These structures again have been superimposed by AF_4 cross-folding making the fold pattern more complicated. The quartzo-feldspathic shear indicators have also been deformed by this folding making them more difficult to identify on a casual look. But critical examination of these shear sense indicators revealed

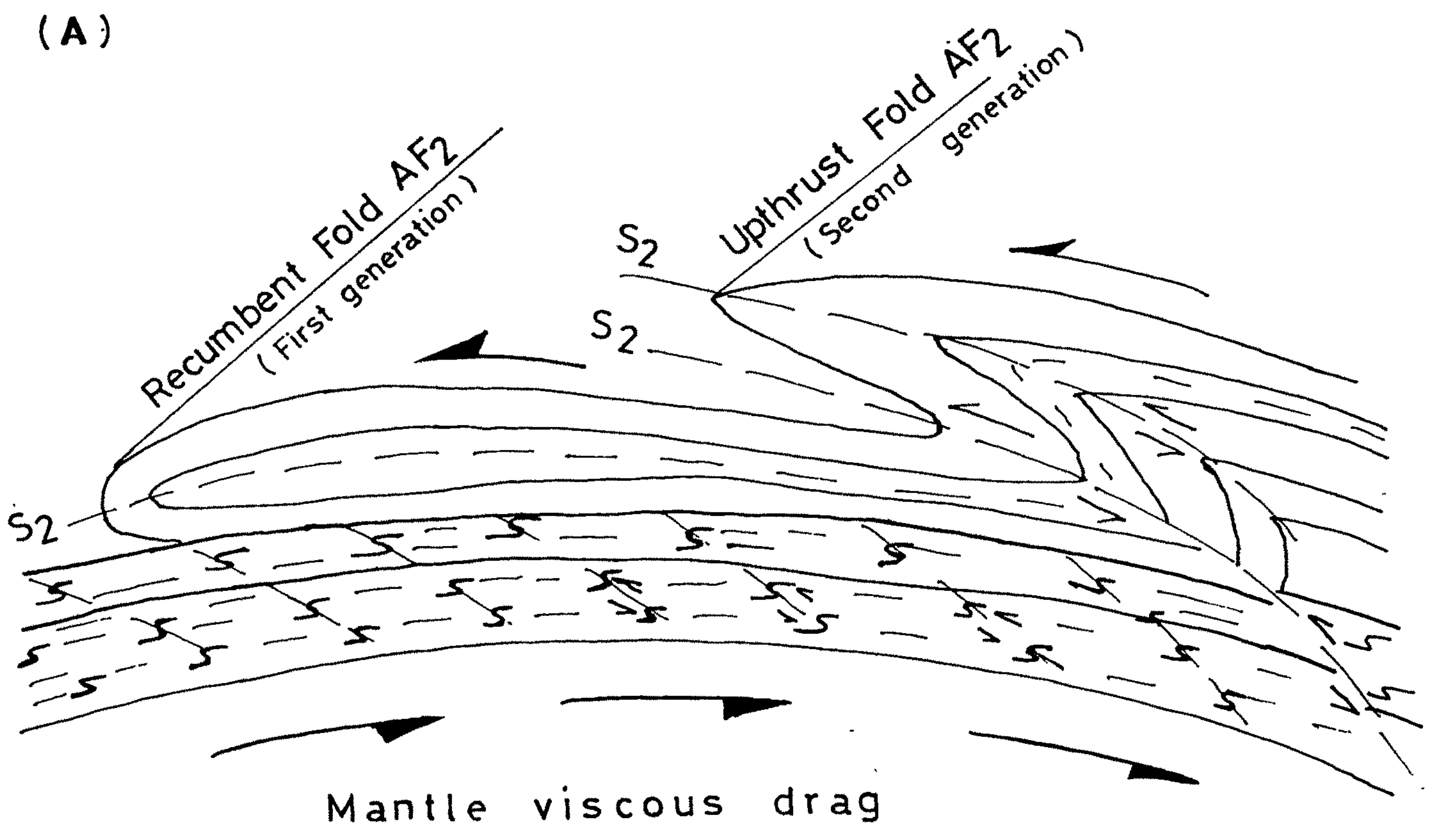

Figure V4A Sinistral shear movement due to subduction tectonics involving mantle viscous drag resulted in the development of decollement fold stack (AF_2 folding). S-Shaped solid lensoids indicate the development of shear indicators.

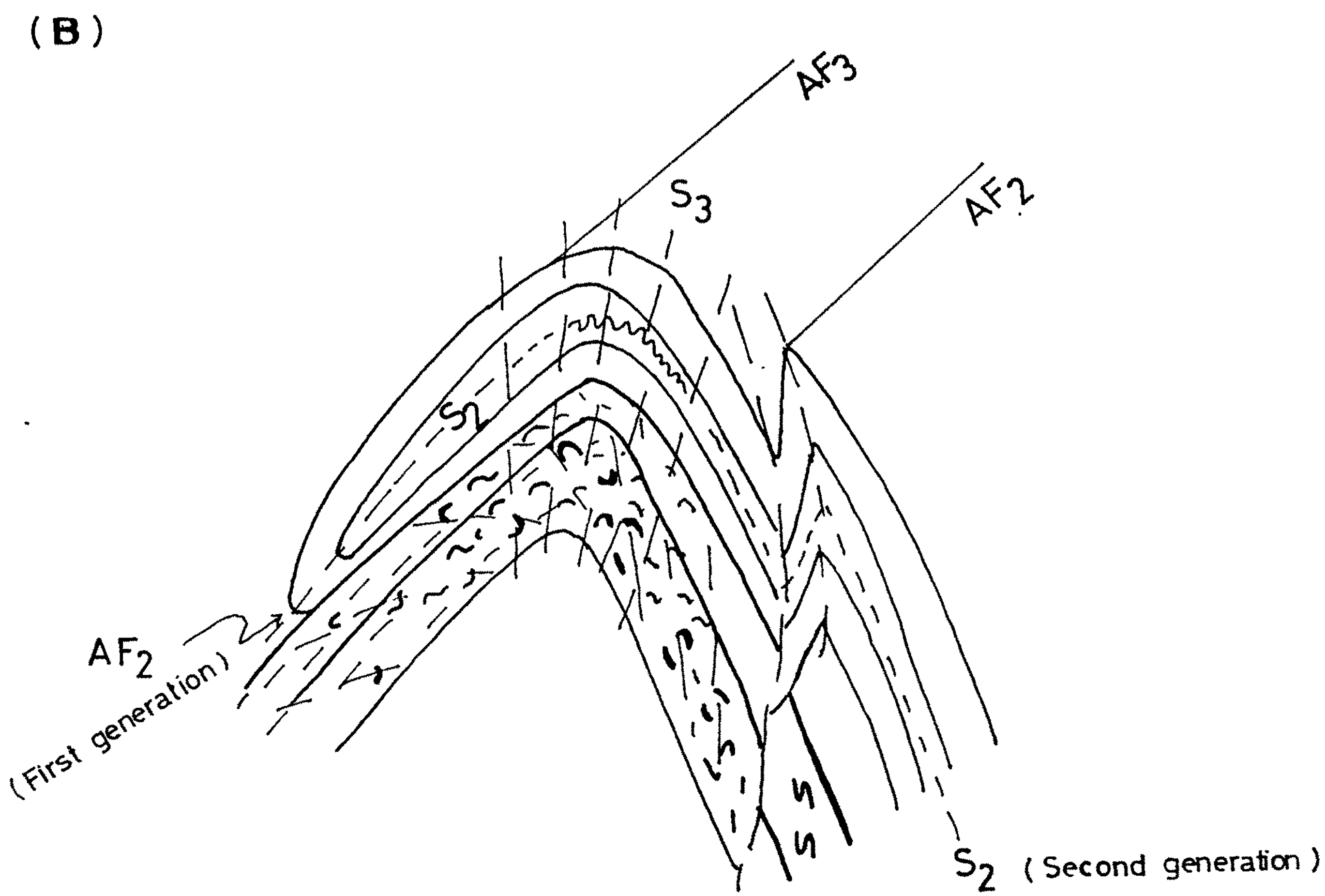

Figure V.4B AF_3 folding superimposed on AF_2 folds, controlled mainly by simple shear mechanism accompanied by flattening.

complete history of deformation of the area. The overlying gneisses and schists also show similar structures and similar geometries of folds and shear indicators. It is claimed that this tectonic model can only explain the described structures in Chapter-III.