CHAPTER 2

BACKGROUND INFORMATION

2.1. GENERAL

The *Aravalli Mountain Belt* (AMB) stretches for more than 700 km from Delhi in the north to almost upto Ahmedabad in the south. It is a major mountain belt of tectonic origin in northwestern India. The AMB of Rajasthan and northeastern Gujarat comprises a number of fold belts of early and middle Proterozoic age. These folds evolved through the development of a series of basins in which sediments and volcanics were laid down in several successive groups bounded by unconformities. Fig. 2.1 is the generalized geological map of AMB based on maps of the G.S.I work (G.S.I map of 1969, c.f. Roy, 1988; Gupta et al. 1980). The oldest constituent of the Aravalli region is the basement gneiss (> 3000 Ma; Roy, 1988). This is overlain by the Aravalli Supergroup and Delhi Supergroup of early and middle Proterozoic ages respectively. According to Roy (1988), the late Proterozoic rocks in the Aravalli mountain range are represented by the Champaner and Sirohi Groups of rocks.

The area investigated by the author around Lunavada, Santrampur and Kadana in Panchmahal district of Gujarat comprises a major part of the Lunavada Group of rocks, an important lithostratigraphic unit of *the Southern Aravalli Mountain Belt* (SAMB) extending from southernmost parts of Rajasthan into northeastern Gujarat. Fig. 2.2 shows a part of the lithostratigraphic map of SAMB around Lunavada (after Gupta et al. 1980).

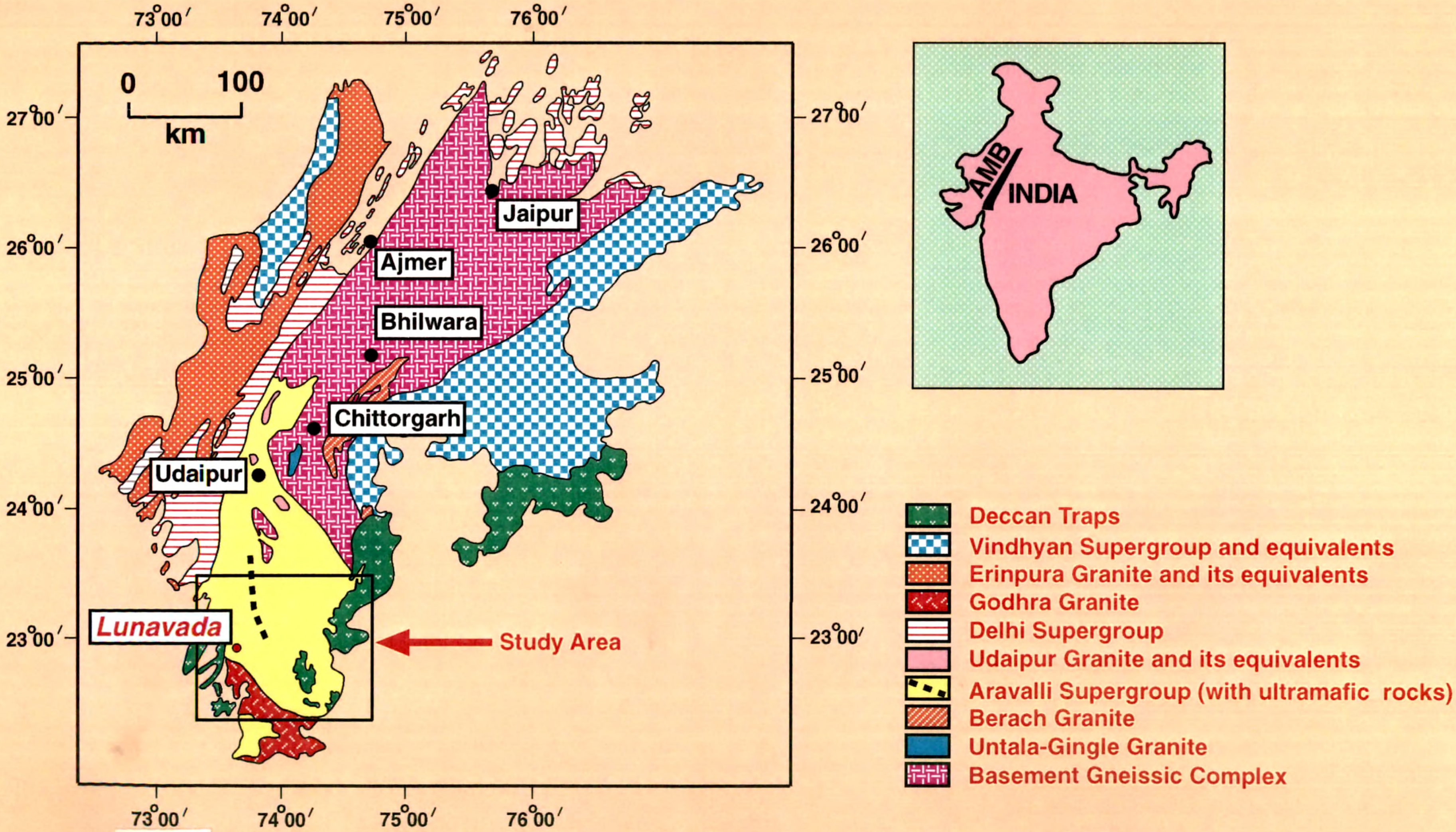

Fig. 2.1 **GENERALIZED GEOLOGICAL MAP OF THE ARAVALLI MOUNTAIN BELT, NORTHWESTERN INDIA (after Geological Survey of India);**

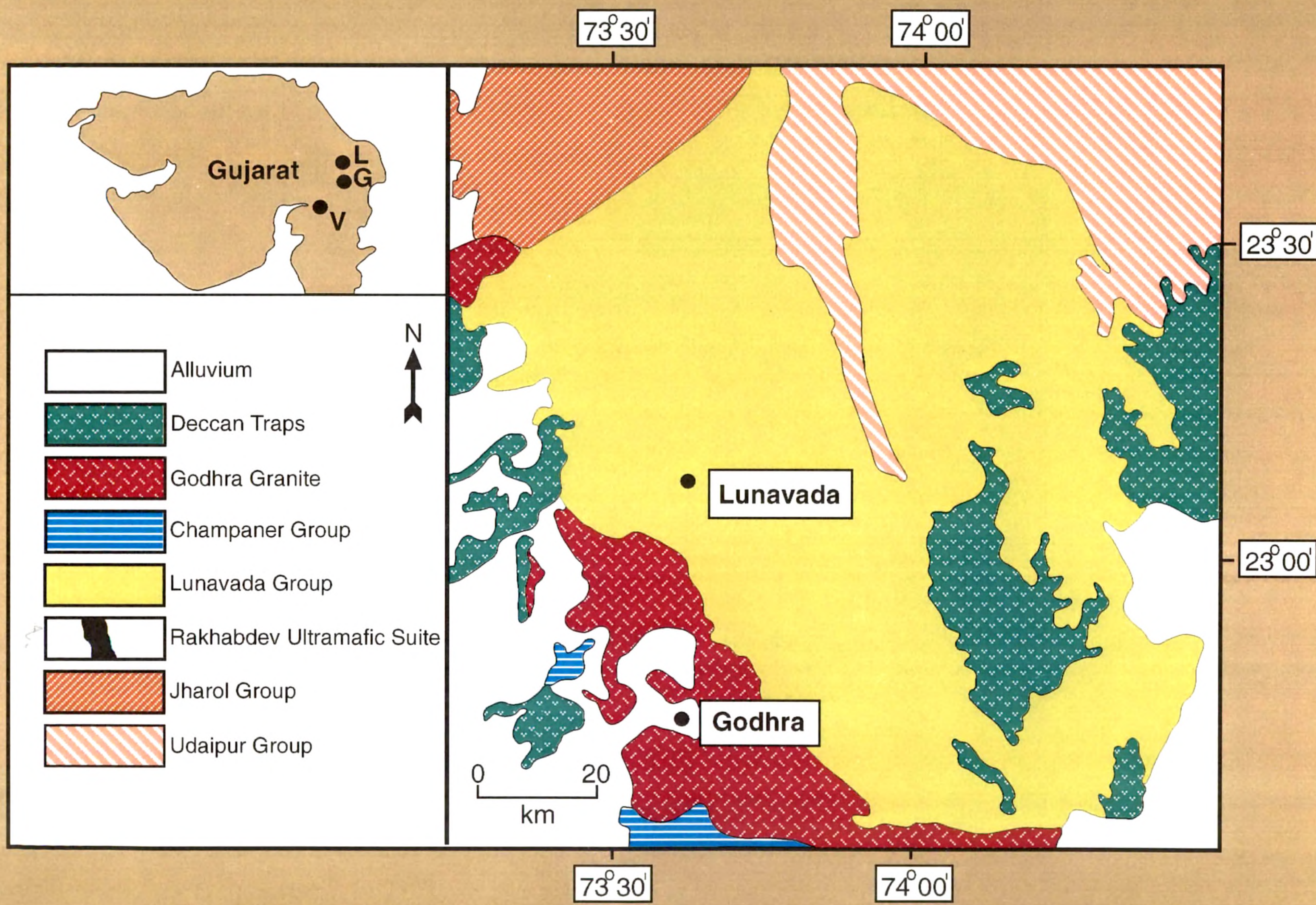

Fig. 2.2 . **Lithostratigraphic map of the area around Lunavada (after Gupta et. al. 1981). Inset: L=Lunavada; G=Godhra; V=Vadodara**

The present knowledge about the geology of the region is a result of a large amount of geological information that has accumulated since the nineteenth century. Therefore, before describing the stratigraphic framework of the Aravalli mountain range as is understood today, the author found it appropriate to give a brief historical perspective of some important studies carried out in the Aravalli region specially around southern Rajasthan and northeastern Gujarat.

Blanford (1869), one of the pioneers of Indian Geology, was the first to investigate the geology of western India. He classified the Azoic rocks in the southern part of the Aravalli mountain range into four series (Blanford, 1869, p.27) as under:

Vindhyan series
Bijawar series
Champaner beds
Metamorphic series

Hackett (1877) designated the metamorphites as the Aravalli series, aptly named after the AMB. Subsequently, several workers of the Geological Survey of India carried out geological investigations in the southern parts of the AMB. Some of the notable accounts are of Bruce Foote (1898), Fermor (1909), Middlemiss (1921), Hobson (1926) and Rama Rao (1931) who gave good descriptions of the geology of Baroda (Vadodara), Shivrajpur-Pavagadh, Idar, Chotta Udepur and Baria areas respectively. Detailed studies in central and northern parts of Rajasthan were done by Coulson (1933), Gupta (1934) and an excellent compilation of the geological studies done upto the middle half of this century on the Aravalli mountain range in Rajasthan has been given by Heron (1953). Table 2.1 gives the stratigraphic framework of the Aravalli mountain range described by Heron (1953).

TABLE 2.1

PRECAMBRIAN STRATIGRAPHIC FRAMEWORK OF THE ARAVALLI MOUNTAIN BELT (after Heron, 1953)

	Malani Series	Rhyolite tuff	Granite, ultrabasic rocks
			Erinpura Granite, pegmatite, aplite, epidiorites and hornblende-schists.
Delhi System	Ajabgarh Series	Upper Phyllites Limestones Biotic limestones and calc-gneisses Calc-schists and composite gneisses	
Delhi System	Alwar Series	Quartzites Arkose, grits and conglomerates	
	Raialo Series	Garnetiferous biotite-schists Limestone (marble) Local basal grit	
			Aplogranite, epidiorites and hornblende-schists ultrabasics.
	Aravalli System	Impure limestones, quartzites, phyllites, biotite schists, composite gneiss. Quartzites, grits and local soda syenites conglomerates Local amygdaloids and tuffs	
	Banded Gneissic Complex	Schists, gneisses and composite gneiss Quartzites	Pegmatites, granites, aplites and basic rocks

Over the past one and a half centuries the stratigraphic nomenclature of the "Aravallis" has undergone metamorphosis. Hacket (1877) designated the metamorphites as Aravalli series. Heron (1917) revised the status of the sequence as Aravalli System. Iqbaluddin and Mathur redesignated the Aravalli System as Aravalli Group following the lithostratigraphic rank classification in 1966 (c.f. Gupta et. al., 1992). Raja Rao (1967, c.f. Sastry, 1992) proposed the term Bhilwara Group for the pre-Aravalli sequence. Mathur et al. (1973) recognized several Groups within the Aravallis, which necessitated its elevation in the lithostratigraphic hierarchy to Aravalli Supergroup. Gupta et al. (1980) gave a lithostratigraphic map of the entire Aravalli region and reviewed the lithostratigraphy of Proterozoic rocks of Rajasthan and Gujarat in 1992. Tables 2.2 and 2.3 give the lithostratigraphy of the Proterozoic rocks of Rajasthan and Gujarat described by Gupta et al. (1992).

According to Gupta et al. (1980, 1992), the Bhilwara Supergroup comprising parts of Bundelkhand Gneiss, the entire BGC and some parts of the lower Aravalli System of Heron, represents the oldest rock group, and this basement is overlain by early Proterozoic Aravalli Supergroup and the middle Proterozoic Delhi Supergroup, including the middle and upper parts of the erstwhile Aravalli System and the entire Delhi sequence. The outcrops of Raialo Series which occur as outliers in the Aravalli terrain have been grouped with the Aravalli sequence, while those which occur in the Delhi terrain have been included with the Delhi sequence.

Since the present study area falls within Gujarat, the author finds it rational to give a brief description of the Proterozoic rocks (succession) of Gujarat as given by

Gupta et. al. (1980, 1992) and Merh (1995). Table 2.4 gives the succession of the Proterozoic rocks in Gujarat (after Merh, 1995).

2.2. ARAVALLI SUPERGROUP IN GUJARAT

Of the six groups belonging to the Aravalli Supergroup described by Gupta et al. (1980, 1992), only the three upper groups, viz. Jharol, Lunavada and Champaner are encountered in Gujarat.

2.2.1. Jharol Group

The oldest Proterozoic rocks in Gujarat belong to this Group and are exposed in the Sabarkantha district, north of Modasa, extending northward through Shamlaji into Rajasthan. The exposure is about 40 km wide and the constituent rocks are phyllite, chlorite schist, garnetiferous mica schist with intercalations of quartzite and minor lenses and bands of calc-schist and crystalline limestone. The rocks for the major part fall within the Shamlaji Formation, and originally consisted of sediments of shaly flysch type deposited in a distal trough during orogenic phase. The rocks have undergone polyphase deformation and show a low to medium grade metamorphism (greenschist to amphibolite facies).

2.2.2. Rakhabdev Ultramafic Suite

This ultramafic magmatic horizon shows better development at Rakhabdev and Dungarpur further north in Rajasthan but in Gujarat it is represented by metamorphosed ultramafic rocks as strings of discrete outcrops in Idar and Lunavada areas. According to Merh (1995), emplacement of these ultramafics

TABLE 2.2

CLASSIFICATION OF ARAVALLI SUPERGROUP (after Gupta et al. 1992)

CHAMPANER GROUP	Rajgadh Formation Shivrajpur Formation Jaban Formation Narukot Formation Khandia Formation Lambia Formation			
LUNAVADA GROUP	Kadana Formation Bhukia Formation Chandawara Formation Bhawanpura Formation Wagidora Formation Kalinjara Formation			
SYNOROGENIC GRANITE AND GNEISS				
RAKHABDEV ULTRAMAFIC SUITE				
JHAROL GROUP	DOVDA GROUP		NATHDWARA GROUP	
Samlaji Formation Goran Formation	Devthari Formation Dapti Formation			Rama Formation Haldghati Formation Kodmal Formation
BARI LAKE GROUP	Khamnor Formation Varla Formation Sajjangarh Formation		KANKROLI GROUP	Sangat Formation Puthol Formation
UDAIPUR GROUP	*Udaipur Sector* Banswara Formation Nimachmata Formation Balicha Formation Eklinggarh Formation Sabina Formation		*Sarda Sector* Zawar Formation Baroimagra Formation Mandh Formation	Rajnagar Formation Morchana Formation Madra Formation
DEBARI GROUP	*Debari Sector*	*Jaisamand Sector*	*Sarada Sector*	*Ghatol Sector*
	Jhamarkotra Formation Berwas Formation Jaisamand Formation Delwara Formation Gurali Formation	Babarmal Formation Dakankotra Formation Jaisamand Formation Delwara Formation	Kathalia Formation Sisamagra Formation Natharia-ki-Pal Form. Basal Formation	Jagpura Formation Mukandpura Formation Jaisamand Formation Delwara Formation Gurah Formation

TABLE 2.3

CLASSIFICATION OF DELHI SUPERGROUP (after Gupta et al., 1992)

	Southwestern Rajasthan and Northeastern Gujarat		*Ajmer Sector*	*Northeastern Rajasthan*
INTRUSIVES (Post-Delhi)	MALANI IGNEOUS SUITE Plutonic and volcanic			
	ERINPURA GRANITE			
	GODHRA GRANITE HNEISS			
DELHI SUPERGROUP 2000-740 m.y.	PUNAGARH GROUP (Sojat, Bambolai, Khambal and Sowania Formations)	SINDRETH GROUP (Angor and Goyali Formations)		
	SIROHI GROUP (Jiyapura, Reodhar, Ambeshwar and Khiwandi Formations)			
	SENDRA AMBAJI GRANITE AND GNEISS			DADIKAR, BAIRATH AND SIKAR GRANITES
	PHULAD OPHIOLITE SUITE		KISHANGARH SYENITE	
	KUMBHALGARH GROUP (Todgarh, Beawar, Kotra, Ras, Barr, Sendra, Kalakot and Basantgarh Formations)		AJABGARH GROUP (Ajmer Formation)	AJABGARH GROUP (Kushalgarh, Sariska, Thanagazi, Bharkol and Arauli Formations)
	GOGUNDA GROUP (Richer, Antalia and Ketwara Formations)		ALWAR GROUP (Srinagar and Naulakha Formations)	ALWAR GROUP (Rajgarh, Kankwarhi, Pratapgarh, Nithar, Badalgarh and Bayana Formations)
				RAIALO GROUP (Dogeta and Tehla Formations)

TABLE 2.4

PROTEROZOIC SUCCESSION OF GUJARAT (after Merh, 1995)

	Post-Erinpura Granite Mafic rocks, Erinpura Granite (=Malani) Godhra Granite
Delhi Supergroup	Pre-Erinpura Granite Mafic rocks Sirohi Group Ambaji Granite Kumbhalgarh Group Gogunda Group
Aravalli Supergroup	Champaner Group Lunavada Group Rakhabdeve Ultramafic Suite Jharol Group

appears to have taken place during the closing period of the Aravalli sedimentation when the deformation had just set in, and the original intrusive bodies formed bands and lenses concordant with the early Aravalli schistosity. The ultramafic belt of North Gujarat and South Rajasthan forms a large regional antiform plunging due north whose limbs fall within Gujarat (Patel and Merh, 1967). The western limb comprises the Idar outcrops around Shamlaji, Modasa and Bhiloda while the eastern limb extends from Dungarpur in Rajasthan to Ditwas (10-15 km north of Kadana) in Panchmahal district of Gujarat. These eastern limb outcrops form a NNW-SSE trending narrow zone of discrete outcrops. In their present metamorphosed state, the ultramafics are seen to contain mostly talc and serpentine with variable proportions of actinolite-tremolite (asbestos), chlorite and calcite or dolomite (Ghosh, 1934).

2.2.3. Lunavada Group

The Lunavada Group occupies parts of Sabarkantha and Panchmahal districts in Gujarat and represents a thick accumulation of clastogenic metasediments with minor bands of chemogenic and biogenic rocks. Gupta and Mukherjee (1938) of the G.S.I considered them as belonging to the Aravalli System and stated that the principal constituent rocks were phyllite, schist, quartzite and dolomite. Rama Rao (1931) who investigated the rocks falling within the limit of the former Baria State (southern parts of the Group) thought them to be the northern extension of the Champaner Series. Recent investigations by the G.S.I (Gupta et. al. 1980, 1992) have provided some details of the lithology, depositional events and environments and structure of the area.

Rocks of the Lunavada Group occupy a roughly polygonal area of 10,000 sq. km in Sabarkantha and Panchmahal districts in Gujarat and Dungarpur and Banswara districts of southern Rajasthan (Merh, 1995). In Sabarkantha, the rocks of this Group occur broadly to the east of line joining the towns of Modasa and Shamlaji and marking the junction with the Jharol Group to the west. This boundary however is not well defined and to some extent conjectural. The Group occupies most parts of Lunavada, Baria and Santrampur talukas of Panchmahal district. In the south the sequence is terminated by the Godhra Granite. The southeastern boundary is obscured by a cover of Deccan Trap and Cretaceous Infratrappeans. The constituent rocks represent a sequence of phyllite, mica schists, quartz chlorite schists, meta-subgreywacke, meta-siltstone, meta-semipelite, meta-protoquartzite with minor layers and thin sheets of dolomitic limestone, petromict meta-conglomerate, manganiferous phyllite and phosphatic algal dolomite (Gupta et al. 1980, 1992). According to these workers, lithological characteristics of this Group suggest that the rocks represent a shallow marine environment, perhaps in the intertidal beach and shelf zones. At a few places, the rocks are reported to have preserved sedimentary structures like laminated bedding, cross-bedding and ripple marks. The quartzite ridges show a complex zigzag pattern of the quartzite outcrops and dome and basin structures due to multiple foldings and a complicated structural history.

The Lunavada Group has been divided into six formations viz. Kalinjara, Wagidora, Bhawanpura, Chandanwara, Bhukia and Kadana formations on the basis of strike persistence and local relationship of superposition (Gupta et al. 1980, 1992). However, according to these workers, the lithostratigraphic units do not reflect the chronostratigraphy. According to Iqbaluddin (1989), only the Kadana formation falls within Gujarat while all the other formations occupy areas of southern Rajasthan.

2.2.4. Champaner Group

The Champaner Group, earlier referred to as Champaner Series, forms an important and well developed Pre-Cambrian sequence of Gujarat. It is exposed ideally in the hilly areas northeast of Baroda and occupies parts of Chota Udepur (Vadodara district) and Shivrajpur and Jambugoda (Panchmahal district). The Group has attracted considerable attention of previous workers mainly for its manganese mineralization. The name Champaner Series was given by Blanford (1869). Fermor (1909) correlated them with the Dharwars of South India. Rama Rao (1931) thought them to be equivalent to the Delhi System. Heron considered them to be a part of Aravalli System. Gupta and Mukherjee (1938) also considered the Champaners to be equivalent to the Aravallis. Gopinath et al. (1977) studied the rocks of the Champaner belt and suggested that they can be divided into Champaner, pre-Champaner and lower Aravallis on the basis of the presence of an earlier deformation and development of conglomerate marking unconformity.

The Champaner rocks form roughly a rectangular outcrop 40 km northeast of Vadodara, stretching from Malao in the northwest to Masabar in the southeast and from Champaner in the west to Jambughoda in the east. Lithologically the Champaner Group consists of a sequence of meta-subgreywacke, sandy phyllite, mica-schists, protoquartzite, petromict meta-conglomerate, dolomitic limestone and manganiferous phyllite. The entire sequence is folded to form an anticlinorium with westerly plunging antiforms and synforms (Merh, 1995). The rocks of the Group have undergone one single major phase of deformation which has resulted in the development of open to tight isoclinal folds with axial traces trending in a WNW-ESE to E-W direction and steeper axial plane schistosity, oblique to the original bedding planes. Gopinath et al. (1977) reported three episodes of deformation in the rocks of the Champaner region. The F_1 folds are isoclinal to overturned with ENE-WSW to WNW-ESE trending axial traces. The F_2 folds are open, steeply inclined and moderately plunging to WNW with axial traces trending in the WNW-ESE to E-W direction. The F_3 folds were found to be open with steep northerly plunge and N-S trending axial traces. Gopinath et al. (1977) assigned the F_1 phase to pre-Champaner and F_3 phase to post-Champaner foldings. According to Gupta et. al. (1992), there is no field evidence pertaining to an earlier deformation and development of axial plane schistosity and the Champaners suffered only a single phase of deformation. According to them, the variation in orientation and attitudes of the folds and foliations at a few places is due to the post-tectonic emplacement of the Godhra Granite. The grade of metamorphism is upto greenschist facies. The contact metamorphism has given rise to the development of calc-silicate skarns, a good example is seen at Jotwad near Jambughoda (Merh, 1995). According to Gupta et. al., the Champaner sequence represents an original accumulation of clastic sediments with carbonate rocks, representing molassic association deposited in a basin separated from the Lunavada Group. Merh (1995) has suggested that the Lunavada and the Champaner basins were perhaps separated by a basement high.

2.3. DELHI SUPERGROUP IN GUJARAT

In Gujarat, the Delhi Supergroup is represented by the three older Groups viz. Gogunda, Kumbhalgarh and Sirohi Groups (Merh, 1995). These three Groups when traced from east to west successively occupy NNE-SSW trending linear bands. It is to be noted that whereas the Gogunda and Kumbhalgarh Groups include the Delhi System rocks of Heron and Ghosh (1938), the Sirohi Group which occurs in the extreme northwest corner across the Banas river was originally considered as belonging to the Aravalli System (Coulson, 1934; Heron and Ghosh, 1938). A brief description of each Group of the Delhi Supergroup rocks occurring in Gujarat is given below.

2.3.1. Gogunda Group

Rocks of this Group were included in the Alwar Series by Heron (1953). However, subsequent mapping of southwestern Rajasthan and north Gujarat outrcrops by the Geological Survey of India established lack of continuity of outcrops in Gujarat with the type area for Alwar in NE Rajasthan. As a result, the term Alwar Series has been abandoned (Merh, 1995). The same has now been subdivided into two distinct geographic entities, the southern portion having being redesignated as Gogunda Group, its northern counterpart being the Alwar Group. Quartzites, slates, chlorite schists and biotite schists occupying the area to the east of Sabarmati river, northeast of Khedbrahma form the Gogunda Group in Gujarat. The eastern and northwestern limits of this Group in Gujarat are marked by Jharol and Kumbhalgarh Groups respectively. The metamorphosed terrigenous clastics comprising quartzite and interbanded schist with subordinate impure calcareous metasediments, deposited mainly in the shelf zone of the Delhi trough have been included in the Gogunda Group.

Merh (1995) has given a good description of the field relationships of the rocks of the Gogunda Group in Gujarat. According to him, the quartzite which is conglomeratic at the base rests unconformably over the older Group and the junction extends in NNE-SSW direction from east of Himmatnagar to Bhiloda and across the border of the state almost following the Hathmati river. Though the rocks of Delhi Supergroup should rest over the older Aravalli Supergroup, the actual field relationship between them is not normal. In the southern portions of North Gujarat, the Jharol rocks are seen overlying the Gogunda Group because of an overturned field relationship (Merh 1995). Pelitic rocks in the vicinity of Bhiloda show a relatively low metamorphic grade and are slate and biotitic schist. But in their western part, they are dominantly biotite gneiss which is best seen in the area to the north of Idar town between calc-gneiss exposures at Vadali and Chorivad quartzite ridge. The gneiss is a granitized biotite schist. Structurally, the rocks show a number of narrow NNE-SSW trending synclines and anticlines with overall dips due east.

2.3.2. Kumbhalgarh Group

The metamorphosed calcareous sediments with subordinate argillaceous and arenaceous sediments deposited in the shelf interior of the Delhi trough have been included into the Kumbhalgarh Group. Lithologically this Group is represented by a sequence of calc-gneiss and calc-schist, pure and impure calcitic marble, muscovite-biotite gneiss, calc-biotite schist, migmatite and gneiss, quartzite, cataclastic conglomerate and amphibolites (Gupta et al., 1980: 1992). The Kumbhalgarh Group is extensively developed in North Gujarat and was originally mapped as Ajabgarh Series by Heron and Ghosh (1938). It occupies large areas in the eastern parts of Banaskantha district comprising almost entire Danta-Amabji and Palanpur talukas. As far as Gujarat is concerned, this Group is the most important stratigraphic unit of the Delhi Supergroup showing striking lithological variations, structural complexities and magmatism.

The Kumbhalgarh Group has a sharp contact with the rocks of the underlying and overlying Groups. However, at places, interfingering and gradational relationship, both along and across the strike has been observed (Gupta et. al. 1992). On the basis of lithological and structural homogeneity, strike persistence and mappability of the individual units, the rocks of the Kumbhalgarh sequence have been divided into Todgarh, Sendra, Beawar, Kotra, Barr, Barotia, Ras and Basantgarh Formations which according to these authors do not indicate the order of superposition.

The rocks of this Group have been regionally metamorphosed upto the amphibolite facies and effects of contact metamorphism are well marked towards the western side where they are intruded by acidic and basic rocks. Migmatisation of the schistose rocks and amphibolites is ideally seen to the south of Ambaji in Gujarat. Around Danta, the rocks of the Kumbhalgarh Group occur in intimate association with granitic rocks and show a granulite facies metamorphism characterized by cordierite and sillimanite.

2.3.3. Sirohi Group

This Group comprises a thick sequence of flysch like finer argillaceous sediments along with intercalations of arenaceous and calcareous sediments and outcrops in the Sirohi area of Rajasthan and the northern extremities of Banaskantha district in Gujarat. Lithologically the Sirohi Group is constituted of a thick pile of metasediments consisting predominantly of phyllite, mica schist and biotite schist with intercalated bands of calcitic marble and quartzite. The rocks of this Group were considered as the Aravalli System by Coulson (1933) and Heron (1953). Subsequent work on these rocks by the G.S.I led to its classification in the Delhi Supergroup occupying areas to the west of the main Delhi Synclinorium. The rocks are deformed and have been regionally metamorphosed to greenschist facies followed by migmatisation (Gupta et. al. 1992).

In Gujarat, the rocks of the Sirohi Group do not come in contact with the underlying Kumbhalgarh Group as they are surrounded and intervened by the Erinpura Granite to the east, south and west. Structurally, the rocks reveal large antiforms and synforms gently plunging due NNE. Patel (1971) studied these rocks (then considered as Aravallis) in Bhatana-Kapasia area and found that the rocks showed a higher metamorphic grade and consisted of biotite and calc-gneiss. The calc-gneiss provides abundant evidence of fold superposition and cross folding, the interference patterns being identical to those of the calc-schist and calc-gneiss of Kumbhalgarh Group (Merh, 1995). The metapelites are sillimanite and cordierite bearing garnetiferous gneiss and minerals present are sillimanite, kyanite, garnet, quartz, biotite, muscovite and feldspars with or without cordierite. Rocks with sillimanite porphyroblasts are recorded at villages Padar, Kapasia, Bhatana and

Deri. Kyanite crystals are abundant in the exposures between Kapasia, Dattani and Deri. The bands and lenses of calc-gneiss and marble that occur within the pelitic gneiss are made up of calcite, diopside, quartz, calcic feldspar and biotite. Sometimes hornblende is also present, and at a few places dominance of this mineral has rendered the rock to be categorized as a para-amphibolite. An interesting feature of this area is the thermal effect of an intrusive granite superimposed over the regionally metamorphosed rocks. It is observed that the thermal aureole has given rise to corderite-andalusite-sillimanite bearing calc silicate hornfels. In the immediate vicinity of the granite, metasomatism has changed the pelitic gneiss into a migmatitic rock characterized by augens and porphyroblasts of potash feldspar.

Roy (1988, 1991) has suggested a different stratigraphic classification for the rocks of AMB. He renamed the pre-Aravalli basement comprising the pre-Aravalli gneisses (BGC), granites, amphibolites and metasediments as the Mewar Gneiss. Structural studies carried out to understand the basement-cover relationships revealed the presence of identical structures in the basement and overlying metasedimentary cover rocks (Aravallis) on the basis of which it has now been well established that the basement must have been remobilized in order to participate in the ductile deformation of the cover rocks, migmatizing a large part of the metasedimentary cover in the process (Naha and Roy, 1983). Based on the studies carried out in the type area of the Aravalli Supergroup around Udaipur, Roy (1991) has classified the Aravalli Supergroup into three Groups viz, lower, middle and upper Aravalli Groups, each of which consists of several formations. This classification of the Aravalli Supergroup is given in Table 2.5. According to Roy (1991), the Aravalli

Table 2.5

STRATIGRAPHIC SUCCESSION OF THE ARAVALLI SUPERGROUP IN THE TYPE AREA (after Roy, 1991)

	Shelf sequence		Deep-water sequence	
UPPER ARAVALLI GROUP	Ultramafic intrusives Lakhawali Phyllite Kabita Dolomite Debari Formation	Congolomerate arkose and quartzite (=Dantalia quartzite)	Jharol Formation	Mica schist and thin beds of quartzite, ultramafics
	---- Unconformity----			
	Tide Formation	Slate/phyllite with thin beds of dolomite and quartzite		
	Bowa Formation	Quartzite and quartzo-phyllite (=Machhla magra quartzite)		
MIDDLE ARAVALLI GROUP	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 (='Raialo marbles'of Iswal, Nathdwara and Kelwa)		
	Delwara Formation	Meta-volcanics with thin beds of meta-sediments (='Bari volcanics')		
	---- Unconformity----			
(ARCHEAN)	Mewar Gneiss	pre-Aravalli gneisses, granites, amphibolites & meta-sediments		

Supergroup in the type area around Udaipur shows two contrasting lithofacies associations, a sand-shale-carbonate assemblage representing a near-shore shelf facies, and a totally carbonate-free shale sequence with thin interbeds of arenites. The latter has been interpreted as a distal (deep sea) facies. The Aravalli rocks of the shelf region are divided into three Groups separated by two unconformities. These are lower Aravalli Group (retaining the original suggestion of Roy et. al. 1984, 1988), Middle Aravalli Group and Upper Aravalli Group; the last two Groups together constituted the earlier described Upper Aravalli Group of Roy et al. (1984, 1988). The deep sea sequence is represented only by the Jharol Group in the type area and by the Lunavada Group in the southern Aravalli region and is equivalent to the Upper Aravalli Group of the shelf sequence.

Roy (1991) has invoked a scenario of intracratonic rifting to explain the distribution pattern of the Aravalli rocks in different belts and their stratigraphic correlation. A three stage evolution of the Aravalli depositional basins has been proposed which has some relevance to the stratigraphic position of the Lunavada Group also. At the outset, a series of rift basins were formed which were linked at triple junctions with one or more failed arms. The earliest basins to open were the Hindoli-Khaimala pair fringing the basement block now represented by Berach Granite. Simultaneously, the Udaipur basin and its northeastern counterpart (much of which is now covered under the Delhi Fold Belt) opened further west of the eastern basins. The triple junctions of these two pairs of "FRR rifts" were located west of the eastern basins. The triple junctions of these two pairs of "FRR rifts" were located west of Chittorgarh and west northwest of Nathdwara respectively. The Bhilwara basin which had an incipient opening at Bhindar during the first stage, opened at a later stage when the Udaipur shelf basins deepened further for receiving the turbidite sequence of greywacke and shale. The deep sea basins of Jharol and Lunavada were the last to open. This event, in all probability coincided with the emplacement of the ultramafic bodies within and along the margin of the basins.

It is important to mention here that the status of the Champaner Group and the Sirohi Group in the classification given by Roy (1988) and Roy et al (1993) is different from that given by Gupta et al. (1980, 1992). According to Roy, the Sirohi and the Champaner Groups must be considered younger to the Delhi Supergroup while Gupta et al. consider the Champaner and Sirohi Groups as parts of Aravalli and Delhi Supergroups respectively.

2.4. BACKGROUND INFORMATION ON THE STUDY AREA

Although no detailed structural studies have been carried out on the Pre-Cambrian rocks of the Lunavada region in Gujarat by previous workers, there have been a few notable contributions which have enhanced the understanding of the geology of the study area and its surrounding rocks. In this section the author has given a brief account of some of the studies on the rocks of southern Rajasthan and Gujarat which have some relevance to the present investigation.

2.4.1. Gupta and Mukherjee (1938)

The first ever geological account of the southern most parts of Rajasthan and northern parts of Gujarat was given by Gupta and Mukherjee in 1938. This included the Dungarpur, Banswara and Kushalgarh areas of southern Rajasthan and parts of Sabarkantha and Panchmahal (erstwhile Rewakantha states) around Lunavada, Santrampur, Sanjeli, Kadana and Balasinor. According to them the first investigation of the regions of Dungarpur, Banswara, Sant and Kadana was carried out between 1907-1914 by N.D.Daru under the superintendence of C.S.Middlemiss while parts of Pratabgarh, Jhabua and Kushalgarh were studied by Walker and Heron in 1907-1908. The areas to the south of the above regions were investigated by Gupta and Mukherjee between 1931-1935 and subsequently all the work was compiled and published by Gupta and Mukherjee (1938). They have stated that the area consisted of a undulatory topography with quartzites occurring as high ridges of quartzites while the low lying areas were occupied by softer rocks like chlorite schists and schists. The topographical variations were directly referred to the lithological differences in the constituent rocks. Table 2.6 gives the details of the geological formations given by Gupta and Mukherjee.

According to these workers, a highly intricate and varied gneissic complex represents the oldest formation of the area which is the pre-Aravalli gneissic complex (BGC) and is continuous with the BGC of central Mewar. Exposures of these rocks are reported from Pratabgarh, Dungarpur and Banswara. The rocks are characterized by a heterogenous assemblage of various rock types mostly of igneous origin. Some of the gneisses are described as streaky composite gneisses with widely varying texture and composition, associated with granite, aplite, pegmatite and amphibolite. These gneisses are overlain by the Aravallis, the junction being marked by an erosional unconformity represented by bands of conglomeratic or gritty quartzite formations. According to them, the Aravallis formed

Table 2.6

FORMATIONS PRESENT IN GUJARAT
(after Gupta and Mukherjee, 1938)

	Recent and sub-recent soil		
Recent and PostTertiary	Kankar, calcareous conglomerate, laterite etc.		
			Erosion unconformity
Eocene	Deccan Trap		
			Eruptive unconformity
Cretaceous			
	Infratrappeans	Bagh beds, Lameta beds, Nimar sandstone	
		Ahmednagar sandstone	
			Eruptive unconformity
Algokian	Delhi system	Alwar quartzites	
			Erosion unconformity
Archean	Aravalli system	Composite gneisses, phyllites, slates and schists with quartzite intercalations Limestone Basal quartzite and conglomerate	Intrusive quartz veins, pegmatites, granite Epidiorites (amphibolites)
			Erosion unconformity
	Pre-Aravallis	Banded Gneissic Complex	

by far the most widespread geological unit in southern Rajputana and north and central Gujarat. They were represented by (1) a basal quartzitic formation, often conglomeratic, (2) an impure calcareous facies, generally dolomitic in composition, and (3) an argillaceous series consisting of slaty, phyllitic and micaceous types along with arenaceous intercalatory bands. Gupta and Mukherjee (1938, p.179) have stated ***"It is not possible to map the various types of the argillaceous metamorphics separately. The intermittently soil covered condition of the country and the infinite gradation obtaining between the different types have rendered any attempt at separate mapping of these on the one inch to the mile scale maps impracticable"***

They observed that in the south, the Aravalli schists were bounded by an extensive exposure of a streaky and highly foliated biotitic gneiss. South of the gneissic belt the Aravallis were seen again, extending over the southern tracts of Panchmahal and Vadodara districts. These were the Champaner Series earlier described by Blanford (1869) and considered as the southern extension of the Aravallis.

The Aravallis are intruded by granite and associated aplite and pegmatite dykes, and extensive occurrence of which has been mapped around Godhra. To the north, the granite extends across the southern boundary of the erstwhile Lunavada state deep into its interior. In the east it covers a large area in the southwestern tracts of Baria. In the west the intrusive granites cross the Mahi into the Balasinor area. Southwards the outcrops of granite extend across the Kalol taluka of Panchmahal into the Baria taluka. The granites are reported to be free from any dynamic effects and its mode of occurrence and association with the Aravallis are clearly indicative of the fact that it has at no stage been involved in the tectonic movements responsible for the folding of the ancient sedimentaries. Based on the resemblance of the pegmatite dykes of this granite with those of the Erinpura Granite of northeastern Rajputana, it was concluded that the granite intrusion around Godhra is same as the post-Delhi Erinpura Granite.

Alwar quartzites which form the basal series of Delhi System occupy the northwestern corner of the area mapped by Gupta and Mukherjee; they are reported to be in strike continuity with the Alwar quartzites of Mewar and northeastern Rajputana.

The Palaeozoic era, that followed the Pre-Cambrian is entirely unrepresented in the area. Patchily preserved formations belonging to the Mesozoic era (the infratrappeans) overlie the Pre-Cambrian rocks with a marked unconformity. The infratrappeans are represented by Ahmednagar Sandstone of Lower Cretaceous age and Bagh beds (and their fresh water equivalent rocks viz. the Lameta) of upper Cretaceous age. Gupta and Mukherjee have described outcrops of the infratrappeans (esp. the Lameta beds) from Kushalgarh-Banswara frontier, Jhalod and Dohad talukas and parts of Baria, Balasinor, Lunavada and Gabat. Bagh beds are reported to occur as thin lenticular, disconnected outcrops and narrow fringes along the margin of the Deccan Traps in Jhabua, Alirajpur States of central India agency (Madhya Pradesh) and Vajir, Agar, Naswadi, Boriad and Chota Udepur states of the erstwhile Rewakantha agency (Gujarat).

The infratrappeans are overlain by Deccan Traps which occur as outliers. The eastern margin of the area, Dohad and Jhabua area and the western frontiers of Lunavada and Balasinor states (erstwhile princely states) have preserved some patches of the Deccan Traps. The Deccan Traps are capped at places by laterites of Palaeocene age.

2.4.2. Narayana (1969, 1970/71, 1974)

The Pre-Cambrian rocks around Godhra and Devgadh Baria have been investigated in some detail by Narayana (1969, 1970/71, 1974). The Godhra Granite was classified into three types based on field and petrographic characteristics viz. fine grained granite, coarse grained granite and porphyritic granite (Narayana, 1969). He concluded that the Godhra Granite is of magmatic origin and shows clear intrusive relationship with the Aravalli rocks. Narayana also reported quartzite outcrops near Vejalpur in granite country showing sillimanite in the form of radial clusters in thin section. This he interpreted as an effect of contact metasomatism brought about by the granites.

Mylonitic rocks from Devgadh Baria area along the contact of the Aravalli rocks with the post-Aravalli granite and in the fault zones of the Banded Gneissic Complex (BGC) have been reported by Narayana (1970/71). On the basis of field and laboratory studies he concluded that mylonitization indicated dislocation metamorphism caused subsequent to the emplacement of the post-Aravalli granites. He suggested that the nature of the original rock controlled the formation of various types of mylonites. Where the original rocks were quartzites, they were subjected to extreme granulation and recrystallization, thus resulting in flinty crushed rocks and hartschiefer. Where the original rock was granite, it was not affected to such a high degree of crushing and recrystallization as the quartzites and in such conditions kakirites developed from granites. Narayana (1970/71) concluded that the conditions that favoured the formation of mylonites might be attributed to the dislocation metamorphism and the occurrence of the mylonites showing strong lateral movements along the margin indicate a thrust fault along which the Aravalli formations might have been glided over the granite body.

Narayana (1974) reported amphibolites to the south and southeast of Devgadh Baria in the form of disconnected bands showing concordant relationship with the rocks of the BGC and passing into striped varieties, and also as caught-up patches in granitic intrusive bodies. On the basis of field characteristics, petrography and geochemistry, he classified the amphibolites into two types - orthoamphibolites (i.e. of primary igneous nature) and para-amphibolites.

2.4.3. Patel and Merh (1967)

The talc-serpentinite ultramafic rocks occurring in the southern parts of Rajasthan and north Gujarat were investigated by Patel and Merh (1967). According to these workers exposures of metamorphosed ultramafic intrusions lie along a NNW-SSE belt extending from Kherwara, Rakhabdev and Dungarpur areas of Rajasthan right upto the border regions of Panchmahal in Gujarat; similar rocks also occur around Idar, Shamlaji, Modasa and Bhiloda areas of north Gujarat. Based on the mode of occurrence, structural characteristics and the regional tectonic setting, the various ultramafic exposures were classified into three groups:

1. Western exposures confined to Idar area of Sabarkantha where they almost invariably occur in the fold cores.
2. Northern exposures occurring in the neighbourhood of Kherwara-Rakhabdev forming striking outcrops on the crests of the hills or as bands in Aravalli chlorite schists.
3. Eastern exposures extending from Dungarpur SSE and consisting of almost connected narrow exposures for more than 50 km and running parallel to the foliation of the country rocks.

These workers suggested that the ultramafics were emplaced during the closing period of the Aravalli sedimentation when the deformation had just set in. They opined that the distribution of the various ultramafic bodies in Gujarat and south Rajasthan is most probably on account of the superimposition of the Delhi folding on the Aravalli rocks on account of which the entire ultramafic belt folded into a large antiformal structure gently plunging to the north. Thus, Patel and Merh (1967) concluded that all the widely scattered ultramafic exposures in southern Rajasthan and north Gujarat belong to a single ultramafic belt in the Aravallis subsequently folded into a large antiform wherein the western exposures around Idar occupy fold cores and show prominent axial plane cleavage thus indicating effect of Delhi folding. On the other hand the eastern exposures along the Dungarpur belt are devoid of minor folds indicating insignificant effect of Delhi folding while the northern Kherwara exposures from the crest of the northerly plunging antiform.

2.4.4. Jambusaria and Merh (1967) and Jambusaria (1970)

These workers carried out detailed geological investigation of the Champaner beds (now referred to as a Group) which consist of a thick sequence of argillaceous, arenaceous, calcareous and manganese-bearing beds. Based on the lithology and structure of the various formations and the conspicuous absence of ultramafic rocks in the Champaners, it was concluded that the Champaner basin was a miogeosyncline. It was opined that at least a part of the Champaners which separates them from the Aravalli rocks of Baria, could be the original basement acting as a barrier between the Champaners and the Aravalli eugeosyncline. Large number of angular anticlines and synclines plunging gently to the west have been reported. This folding of the Champaner Series is considered to be the earliest Aravalli fold trend recorded by several researchers in north Gujarat and Rajasthan. These workers concluded that the Champaner Series escaped the Delhi orogeny and has thus preserved the original E-W Aravalli trend.

2.4.5. Iqbaluddin (1989)

A Detailed account of stratigraphic, sedimentational, deformational and metamorphic history of the Proterozoic sequence exposed in the Kadana reservoir and adjacent areas (which forms the western part of the Indian shield and is included in Survey of India toposheet No. 46 E/15 and 46 I/3) has been given by Iqbaluddin (1989). An area of about 500 sq. km was mapped in parts of Banswara and Dungarpur districts of Rajasthan and Panchmahal district of Gujarat, falling within latitudes N23° 45' to N23° 30' and longitudes E73° 45' to E74° 15'. Since the western portion of the area mapped by Iqbaluddin forms the northeasternmost portion of the study area of the present author, it is essential to briefly discuss some of the important conclusions and interpretations made by him.

Iqbaluddin has reported that the oldest formation in the Kadana Reservoir area is the Vareth formation which belongs to the Udaipur Group and comprises quart-chlorite-sericite schist and chlorite phyllite. This is associated with the talc-chlorite schist and serpentinites of the Rakhabdev ultramafic suite. The chlorite schists, metasiltstones, meta-protogreywacke, garnetiferous-mica schist, quartzite and metaconglomerate make up the Lunavada Group which is younger to the Udaipur Group. There is a structural discordance between the Udaipur and the Lunavada Groups which is clearly seen at Jardo, Mor, Antari in Banswara district, Rajasthan. Based on lithological homogeneity, strike persistence and local relationship of superposition the rocks of the Lunavada Group have been classified into Wardia, Nahali, Bhawanpura, Chandanwara, Bhukia and Kadana formations in descending order of antiquity. Of these only the Kadana formation falls within Gujarat whilst the rest occur in Rajasthan. Table 2.7 gives the lithostratigraphic sequence of the Kadana reservoir and adjacent areas in Gujarat and Rajasthan.

The rocks of the Kadana reservoir area show AD_2, AD_3 and AD_4 deformations of the Aravalli tectonic system. The AD_2 deformation is manifested in the AF_2 folds which have AS_2 foliation. The AS_2 foliation occurs as a pervasive and penetrative fissility exclusively in the rocks of the Vareth Formation of the Udaipur Group and is totally absent in the rocks of the overlying Lunavada Group.

Table 2.7

LITHOSTRATIGRAPHIC SEQUENCE OF THE KADANA RESERVOIR AND ADJACENT AREA, RAJASTHAN AND GUJARAT STATES, INDIA (after Iqbaluddin, 1989)

Era/Period	Supergroup	Group	Metamorphites of Rajasthan: Rank	Metamorphites of Rajasthan: Lithology	Metamorphites of Gujarat: Rank	Metamorphites of Gujarat: Lithology
Palaeocene to Upper Cretaceous			Deccan Traps	Basaltic Lava flow		
			Unconformity			
PROTEROZOIC			Post-Aravalli Intrusives	Quartz veins Pegmatite veins		Quartz veins
PROTEROZOIC	Aravalli Supergroup			(top not seen)		
PROTEROZOIC	Aravalli Supergroup	Lunavada Group	Bhukia Formation	Meta-protoquartzite with intercalations of meta-subgreywacke, quartzite (quartz-arenite), meta-siltstone and quartz-sericite schist	Kadana Formation	Quartz arenite, meta-subgreywacke, meta-semipelite and meta-siltstone
PROTEROZOIC	Aravalli Supergroup	Lunavada Group	Chandanwara Formation	Meta-subgreywacke with intercalations of quartz-chlorite-sericite schist, meta-protoquartzite and quartzite (quartz arenite)		
PROTEROZOIC	Aravalli Supergroup	Lunavada Group	Bhawanpura Formation	Quartz-chlorite-sericite schist with intercalations of meta-protoquartzite and meta-subgreywacke		
PROTEROZOIC	Aravalli Supergroup	Lunavada Group	Nahali Formation	Quartzite and quartz-sericite schist with intercalations of conglomerate and pebbly quartzite		
PROTEROZOIC	Aravalli Supergroup	Lunavada Group	Wardia Formation	Quartz-biotite-sericite schist, garnetiferous quartz-biotite-sericite schist with intercalations of para-amphibolite, amphibole quartzite		
PROTEROZOIC	Aravalli Supergroup			(base not seen)		
			Unconformity			
PROTEROZOIC	Aravalli Supergroup	Rakhabdev Ultramafic Suite		Talc-chlorite schist, serpentinite and carbonate rock		
PROTEROZOIC	Aravalli Supergroup	Udaipur Group	Vareth Formation	Quartz-chlorite-sericite schist and chlorite phyllite		
				(base not seen)		

The deformation in the Lunavada Group of the rocks in the Kadana reservoir area corresponds to the AD_3 and AD_4 deformation episodes of the Aravalli Tectonic Systems, The structural fabric comprises AF_3", AF_3, AF_3', AF_4 folds; AS", AS_3, AS_3', AS_4 foliations and $A\beta_3$", $A\beta_3$, $A\beta_3$' and $A\beta_4$ lineations. The fabric evolved in four separate deformational phases; first, second and third phases correspond to AD_3 and fourth phase to AD_4 deformative episodes.

The first phase led to the development of AF_3" folds, AS_3" foliation and $A\beta_3$" lineation. The second phase of deformation led to the development of AF_3 folds and AS_3 foliation and $A\beta_3$ lineation. The AS_3 foliation is the most pervasive and penetrative set of foliation. It occurs as a schistosity in the Kadana formation and strikes generally from N-S to NNE-SSW and dips steeply towards W or WNW. The third deformation phase resulted in the development of AF_3' folds, AS_3' foliation and $A\beta_3$' lineation. With the progression of deformation, the shear mechanism dominated which led to the development of AS_3' crenulation cleavage. The AF_3' folds are developed on mesoscopic scale as puckers. The fourth deformative phase led to the development of AF_4 folds, AS_4 foliation. The AS_4 foliation strikes WNW-ESE and dips steeply towards NNE. The AF_4 folds are temporally post-tectonic to AF_3 and are kinematically related to the WNW-ESE trending Champaner folds.

According to Iqbaluddin (1989) the deformation of the Lunavada Group of rocks in Kadana reservoir area was accompanied with metamorphism which is dominantly upto greenschist facies. The metamorphic history of the Kadana reservoir area has been assigned to five phases viz., M_1, M_2, M_3, M_4 and M_5

phases in descending order of antiquity. The M_1, M_2, M_3 and M_4 phases are related to AF_1, AF_2, AF_3 and AF_4 fold episodes respectively whilst the M_5 phase is a static event. M_1 phase is manifested by elongation of quartz and rotation of sericite flakes parallel to the AS_3" foliation which is itself parallel to the being. M_2 phase resulted in recrystallization of quartz and sericitization syntectonically with AS_3 foliation. Chlorite-1, muscovite and actinolite crystallized at the expense of existing mineral population. Biotite-1 coexisted with chlorite-1. During the AF_3' folding, crenulation cleavage developed in the Wardia and Nahali formations (lying in Rajasthan) of the Lunavada Group and this was accompanied with M_3 phase of metamorphism during which garnet developed in the rocks. Garnet formed at the expense of chlorite-1 and quartz. Retrogression of biotite to chlorite-2 along cleavages and peripheral contact of porphyroblasts perhaps was achieved during waning of M_3 phase of metamorphism. M_4 phase is manifested by flattening, elongation and microfracturing of quartz and rotation of sericite along AS_4 foliation. The last phase of metamorphism was a M_5 phase which is a static event related to the rise of geoisotherm in the area post-tectonic to Aravalli deformation and around 955 Ma on account of intrusion of the Godhra Granite. This event led to static recrystallization of garnet and chlorite-3.

2.5. GEOCHRONOLOGY

Over the past few decades, considerable geochronological studies have been carried out on rocks of the AMB especially the granites and gneisses. The isotopic determination on Rajasthan was initiated with the pioneering work of Holmes et al. (1949), Holmes (1955) and Aswathanarayana (1956, 1959) who reported U-Pb ages on radioactive minerals from pegmatites. Later Vinogradov et al. (1964) contributed U-Pb ages on zircons from the pegmatites and metamorphic rocks, as well as K-Ar ages of the other rock forming silicate minerals. Sarkar et al. (1964) have also documented K-Ar ages of Pre-Cambrian formations of the region. On the basis of geochronological studies, Sarkar (1980) proposed a reinterpretation of the stratigraphy of the Aravalli region. Crawford (1969, 1970) carried out Rb-Sr isotope studies and proposed a broad framework of time classification of the Pre-Cambrian rock sequences of Rajasthan and Gujarat. Fission track ages were reported by Sharma et al. (1975) and Nagpaul et al (1976) for minerals from pegmatites of Bhilwara district of Rajasthan.

Crawford's work (1970) revealed that the BGC contains rocks of several ages and that the Aravalli rocks might be younger than 2500 Ma and older than 2000 Ma and that the Delhi rocks were first intruded by granites dated between 1700 and 1650 Ma. The work of Sarkar et al (1964) and Vinogradov et al (1964) on K-Ar mineral/rocks ages revealed 1200-1590 Ma for the BGC, 953-1020 Ma for the Aravalli rocks and 600 Ma for the Delhi rocks, which are interpreted as metamorphic events in the respective orogenic cycles.

The work of Vinogradov et al. (1964) on ages of detrital zircons from Aravalli schists, east of Udaipur gave an age of 3500 ± 200 Ma. This study was significant because it indicated for the first time the possible age for the provenance for the oldest Pre-Cambrian of the Aravalli region. It also implied the presence of a sialic protolith at least as old as the age of the zircons.

More recently, the Geological Survey of India in collaboration with the Physical Research Laboratory, Ahmedabad carried out Rb-Sr geochronological studies of granites from the Pre-Cambrian rocks of Aravalli region and their results (Choudhary et al, 1984; Sastry, 1992) provide the details and significance of the above collaborative research. The geochronological data of some of the rocks described by Sastry (1992) are given in Table 2.8.

Recently Gopalan et al (1990) and Roy and Kröner (1996) have dated the gneisses, granitoids and amphibolites of the pre-Aravalli basement rocks (Mewar gneiss of Roy, 1988). Tonalitic to granodioritic gneisses from the basement gneisses define a Sm-Nd isochron corresponding to an age of 3.31 ± 0.07 Ga. and mafic amphibolites within the gneisses define a isochron age of 2.83 ± 0.05 Ga. (Gopalan et al 1990). Roy and Kröner (1996) have given single Pb/Pb zircon ages for granitoids and gneisses constituting the Archean basement. Two gneisses occurring east of Udaipur have given an age of 3230 Ma (Jamarkotra gneiss) and 2887 Ma (Jagat gneiss). The granitoids that display an intrusive relationship with the gneisses have yielded an age of 2666 Ma (Untala trondjhemite), 2620 Ma (Gingla leucogranite) and 2658 Ma (Jagat luecogranite). The above work thus provides a good evidence for the multistage evolution of the Archean crust (Roy and Kröner,1996). Based on the geochronological studies Roy and Kröner (1996) have proposed a geochronological framework for the evolution of the Aravalli Archean Crust (Table 2.9).

Table 2.8
Rb - Sr ISOCHRON AGES OF THE GRANITES FROM THE PRECAMBRIANS OF RAJASTHAN AND NORTHEASTERN GUJARAT AND THEIR SIGNIFICANCE (after Sastry, 1992)

Supergroup	Particulars of the Granites dated by Rb-Sr Method	PRINCIPAL EVENTS: Whole-rock isochron age (in m y)	PRINCIPAL EVENTS: Wholerock-mineral isochron age (in m.y)	REMARKS
	Erinpura granite and Pali granite	830 ± 30	550 ± 20	The distinction drawn on the basis of observation (Gupta et al 1980) between the syn-to-post-orogenic Erinpura granite and the syn-orogenic granites that occur along the Aravalli Mountain Range is not reflected in the Rb-Sr isochron ages of these representative granite bodies
Delhi Supergroup	Aravalli Mountain granites Sendra, Sadri-Ranakpur and Sai granites;	850 ± 550	514 - 560	Two distinct whole-rock isochron ages and whole rock-mineral isochron ages for granites within the Delhi Supergroup are suggestive of two tectono-thermal episodes. It is significant to note that the period of magmatism of the younger granites seems to have caused strontium isotopic re-equilibration among the mineral phases of the older group of granites.
Delhi Supergroup	Ambaji microgranite	760 ± 50		
Delhi Supergroup	N E Rajasthan granites Khetri granites, Bairat, Dadikar and Harsora granites	1500 - 1700	700 - 850	
Aravalli Supergroup	Ahar River granite	Disturbed Rb-Sr systematics precluding an isochron age		Darwal granite is considered as syn-tectonic intrusive into the Aravallis The isochron age represents at least the minimum age for Aravalli sequence Mineral isochron age is suggestive of secondary thermal event overprinted due to younger Delhi deformation.
Aravalli Supergroup	Darwal granite	1900 ± 80	770 ± 30	
Bhilwara Supergroup	Amet granite	1870 ± 200		The stratigraphic position of the metasediments around Amet granite is not yet clearly fixed-whether it is part of the Aravalli or Bhilwara sequence
Bhilwara Supergroup	Berach granite	2445 ± 100	1440 ± 70	Berach granite is considered as a late tectonic intrusive granite into the Bhilwara sequence around 2600 m y. The mineral isochron age is indicative of secondary thermal event around 1450 m.y
Bhilwara Supergroup	Untala & Gingla granite	2900 ± 100	900 ± 35	Untala and Gingla granites are considered as syn-orogenic granites within the Mangalwar complex Irrespective of the origin of these granites, plutonic or anatectic, the isochron age around 3000 m y. is suggestive of at least the minimum age for the Bhilwara Supergroup. The mineral isochron age at 900 m.y is indicative of secondary thermal event
Bhilwara Supergroup	Sarada migmatite	Disturbed Rb-Sr systematics precluding an isochron age		

Table 2.9

GEOCHRONOLOGICAL FRAMEWORK FOR THE EVOLUTION OF THE ARAVALLI CRATON (after Roy and Kröner, 1996)

Age (Ma)	Emplacement events
?	Metadolerite dykes (Jagat Type II amphibolites
2505±3#	Pink granite of Untala.
Shearing and low temperature metamorphism	
2620±5	Gingla granite
2658±5	Jagat granitoid
2666±6	Untala trondhjemite (gneiss)(enclave in the pink Untala granite)
Ductile deformation, repeated folding and metamorphism	
2828±46*	Intrusion of mafic dykes of Mavli (=Jagat Type I amphibolites
2887±5	Banded tonalite-trondhjemite-granodiorite gneiss of Jagat
~3230	Intrusion of tronhjemite veins, folding and formation of a new foliation
3281±3 to 3307±65*	Earliest ingneous protoliths of the banded gneisses of Jhamarkotra

Single zircon ion-microprobe U-Pb age (M.Wiedenbeck, J.N. Goswami & A.B.Roy, unpbl. data)
* Sm-Nd whole-rock isochron ages (Gopalan et al. 1990)

Significant geochronological studies have also been carried out on granites of Gujarat by Crawford (1975), Gopalan et al (1979), Merh (1978) and Trivedi et al (1987). Since the study area of the present author falls within Gujarat and also because the Godhra Granite occurs quite close to the study area, the author has thought it proper to discuss the geochronological studies of the rocks of Gujarat in some details.

Crawford (1975) dated the Mount Abu and Idar granite and got a Rb-Sr total rock age of 735 $\pm$ 15 and 740 $\pm$ 15 Ma respectively. Based on the above study Crawford postulated that all the granites in Gujarat (including those around Godhra) had the same age as those of the Malani- Mt.Abu suites., the latter of which were dated at 745 Ma by Crawford (1970). Gopalan et al (1979) were the first to report Rb-Sr isochron ages of the granites occurring around Godhra and those intruding the Champaner Group rocks and the gneissic rocks around the Champaner. The two granite suites have the same age of 955 $\pm$ 20 Ma. These studies thus disproved the postulation of Crawford (1975), that all the granites of Gujarat have a common age of around 745 Ma. The granites in central Gujarat around Godhra belong to the older group. On the other hand, the intrusive masses of Idar and Gabbar (Ambaji) in north Gujarat belong to the younger group which are almost of the same age as the Mt.Abu and Jalor-Siwana granites of Rajasthan (Merh, 1978).

It is important to mention here that Crawford (1975) carried out a single analysis of a schist pebble from the Champaner Series conglomerate and got an age 950 Ma. Crawford suggested that this did point at the possibility of the Champaners being younger to the Aravallis. However, he postulated that the entire conglomerate from which the pebble was taken might have been metamorphosed after its deposition and hence the age of 950 Ma might be the age of metamorphism. Hence he concluded that Heron's (1953) correlation of the Champaner with the Aravalli system was correct. However, the geochronological studies done by Gopalan et al (1978) established that the age of Godhra Granite and those intruding the Champaner rocks were identical and tallied with the age of the pebble from the Champaner dated by Crawford (1975). This led Merh (1978) to suggest that the likely age of metamorphism of the Champaner sediments which was almost same as that of the associated rocks younger to the Aravallis, was perhaps equivalent to the Delhi's.

Trivedi et al (1987) got a Rb-Sr whole rock isochron of 720 Ma for Idar granite, almost same as the age given by Crawford (1975). The Rb-Sr mineral isochron of the samples also gave the same age. These workers concluded that the Idar granite was not subjected to any significant thermal episode subsequent to its emplacement at about 720 Ma (Trivedi et al, 1987). On the other hand Choudhary et al (1984) gave an age of 800 ± 50 Ma for the Erinpura (proper), Sai, Sadri-Ranakpur and Sendra granites of Rajasthan. These constituent minerals at about 550 Ma which is at least 200 Ma later than their emplacement, This indicates a elevated thermal field impressed at this time on these granitic bodies in Rajasthan. It is therefore established that whilst the Erinpura type granites in Rajasthan were affected by a thermal event post-dating their emplacement, the granites of the same age in north Gujarat and older age (Godhra Granite) in central Gujarat were not affected by any younger thermal event.