Chapter 2. Regional Geology and Previous work

2.1 General

Precambrian rocks of the north-western India viz. parts of southern Rajasthan and north-eastern Gujarat categorized under Aravalli Mountain Belt (AMB), mainly comprises three important Proterozoic supracrustals, differentiated on the basis of depositional environment and tectono-magmatic events. These rocks encompass 1. The Bhilwara having an age more than 2500 Ma. 2. The Aravalli within time frame of 2500-2000 Ma. 3. The Delhi which ranges up to the time frame of 700 Ma. The meta-sediments and associated intrusive as well as extrusive igneous phases corresponding to these three Proterozoic sequences have been designated as the Bhilwara, the Aravalli and the Delhi Supergroups. These three Supergroups are further classified to several Groups and Formations (Gupta et al., 1980; 1992; 1995; 1997).

The Bhilwara Supergroup is flanked by the Aravalli and Delhi Supergroup of rocks at the south-west and north-east part of the Aravalli Mountain Belt (AMB) respectively (Fig. 2.1), and is found to be separated by an erosional unconformity. The crescent shaped outline of Bhilwara Supergroup extends for about 400 km from Deyi in the northeast till Pipalkhunt in the south. The generalized strike trend varies from north to south like NE-SW near Hindoli area, N-S near Chittorgarh and finally attends NW-SE at the southern extremity. The grade of metamorphism increases from greenschist facies near Hindoli area in the east to granulite facies at Sandmata region in the west.

The northern extremity of the Aravalli supracrustals lies near Kankroli area and is exposed over 350 km till Champaner in the south. The width of these supracrustals gradually increases from 40 km in the north to 150 km in the south. The eastern margin of the Aravalli rocks gets terminated with an erosional unconformity with underlying Bhilwara Supergroup of rocks, whereas the western margin is bounded by overlying Delhi Supergroup of rocks. However, its southern extremity is obscured by the cover of Deccan traps and recent sediments. The Aravalli Supergroup is characterized by greenschist facies metamorphism and shows evidences of multi-deformational events, associated with syn-tectonic acidic intrusives. The Delhi Supergroup of rocks forms the major orogenic belt at the NW of AMB, which separates the Marwar plains from the hilly swathe of Mewar in Rajasthan. These rocks have its continuity at north-east till Parbatsar to Himmatnagar in the south-west. The overall strike distance is about 450 km with width range of 25-150 km from north-east to south-west extremity. The Delhi Supergroup of rocks represents greenschist to granulite facies metamorphism associated with syn-orogenic granite activity.

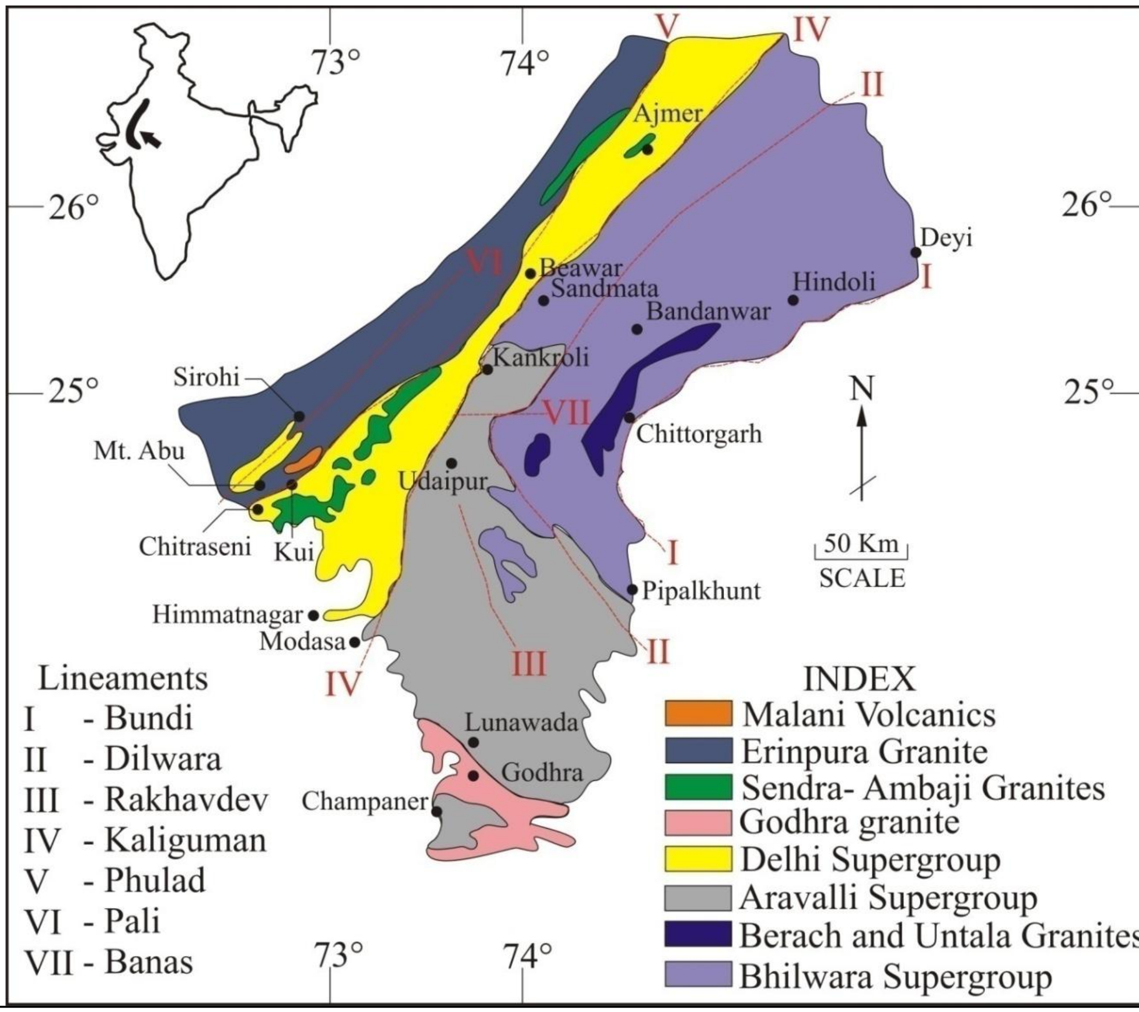

Figure 2.1: Generalised geological map of Aravalli Mountain belt; (modified after Gupta et al., 1992).

The area under investigation lies at the southern most part of Aravalli Mountain Belt (AMB), classified as Southern Aravalli Mountain Belt (SAMB). The study area belongs to the Champaner Group of the Aravalli Supergroup, which forms the southernmost extension of the Aravalli rocks in Gujarat (Fig. 2.2).

Blanford and Hackett are considered as pioneer workers to reveal the geology of the Aravalli region. The early classification given by Blanford (1869) divided the rocks of the Aravalli region into four series, viz. 1. the metamorphites; 2. the Champaner; 3. the Bijawar and 4. the Vindhyan Series. Later on, Hackett (1877) revised the nomenclature of oldest "Metamorphites" of Blanford's classification as "Aravalli Series". Eventually, other workers gave a detail account on geology of southern Aravalli region, namely, geology of Baroda state by Bruce Foote (1898); in and around Shivrajpur region by Fermor (1909); a work on Idar granites by Middlemiss (1921); geology of Chotta Udepur region by Hobson (1926) and geology of Baria state by B. Rama Rao (1931).

Heron (1953) revised the status of the said sequence as "Aravalli System" (Table. 2.1). In the year 1966, the classification of the Aravalli System was restructured as "Aravalli Group" by Iqbaluddin and Mathur. Mathur et al., (1973), elevated the lithostratigraphic status of the "Aravalli System" to "Aravalli Supergroup" by recognizing various groups within the Aravalli Supergroup.

Based on the lithostratigraphy, structure, metamorphism, structural disposition and depositional environments, the Aravalli Supergroup of rocks were further subdivided into nine groups namely, the Debari, the Udaipur, the Bari-lake, the Kankroli, the Jharol, the Dovda, the Nathdwara, the Lunavada and the Champaner Group. Out of these, groups within two sets are equivalent to each other. Set 1- the Bari-lake Group equivalent to Kankroli Group and Set 2- the Jharol, the Dovda and the Nathdwara are all equivalent to each other. The same has been substantiated by Sastry, (1992) and Gupta et al., (1992; 1997) (Table 2.2).

Being author's key focus on the Champaner Group mainly located within Gujarat, the author found it appropriate to give a brief description of groups belonging to the Aravalli Supergroup exposed within Gujarat.

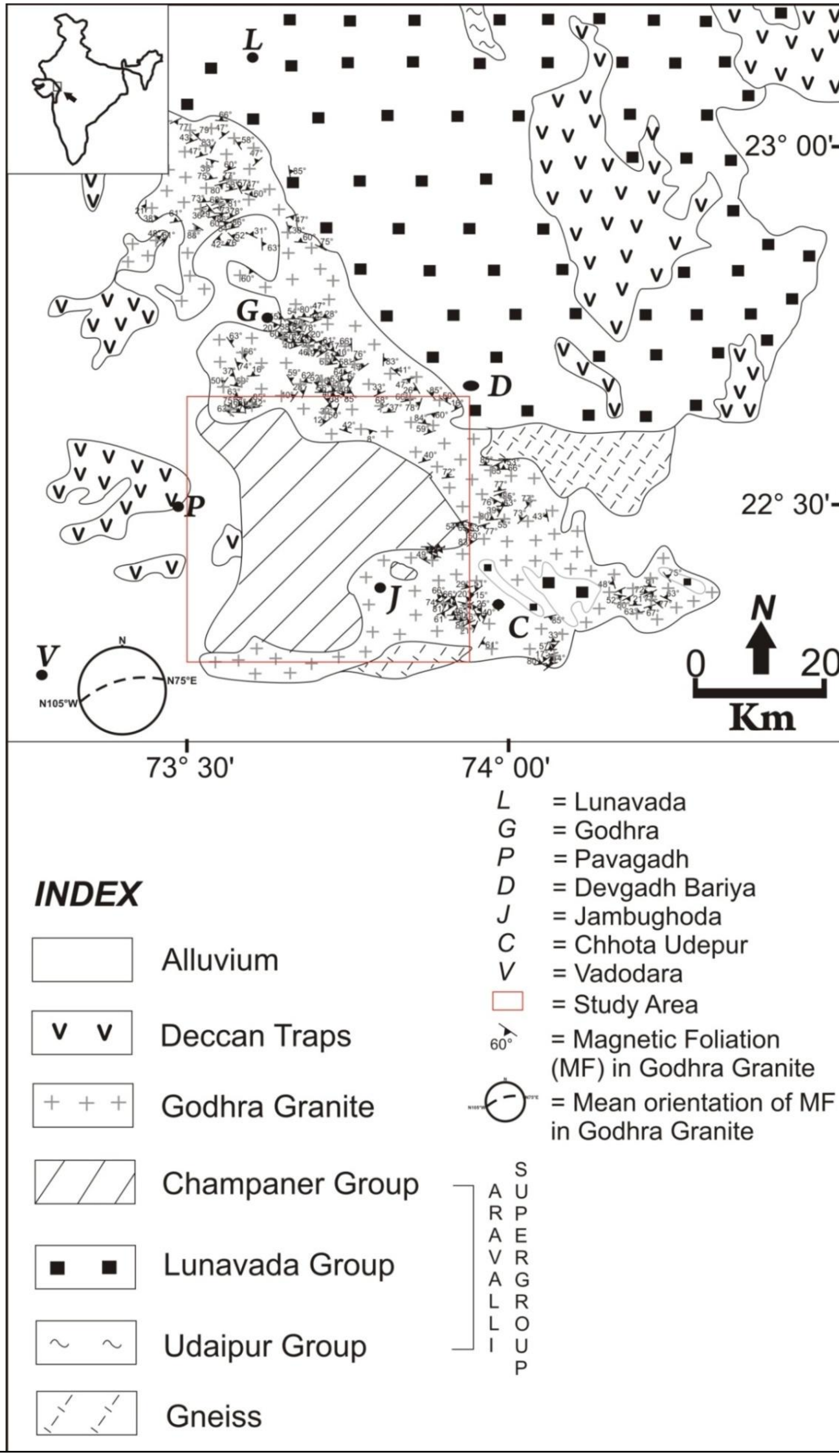

Figure 2.2: Lithostratigraphic map of Southern Aravalli Mountain belt; (modified after Gupta et al., 1992). Magnetic foliation data presented within Godhra granite is after Mamtani, (2014). Red square indicates the study area.

Table 2.1: Pre-Cambrian 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

Table 2.2: Classification of the Aravalli Supergroup (After Gupta et al., 1980; 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	Devthari Formation			Rama Formation
Goran Formation	Dapti Formation			Haldghati Formation
				Kodmal Formation
BARI LAKE GROUP	Khamnor Formation		KANKROLI GROUP	
	Varla Formation			Sangat Formation
	Sajjangarh Formation			Puthol Formation
UDAIPUR GROUP	Udaipur Sector		Sarda Sector	Rajnagar Formation
	Banswara Formation		Zawar Formation	Morchana Formation
	Nimachmata Formation		Baroimagra Formation	Madra Formation
	Balicha Formation		Mandh Formation	
	Eklinggarh Formation			
	Sabina Formation			
DEBARI GROUP	Debari Sector	Jaisamand Sector	Sarada Sector	Ghatol Sector
	Jhamarkotra Formation	Babarmal Formation	Kathalia Formation	Jagpura Formation
	Berwas Formation	Dakankotra Formation	Sisamagra Formation	Mukandpura Formation
	Jaisamand Formation	Jaisamand Formation	Natharia-ki-Por Form.	Jaisamand Formation
	Delwara Formation	Delwara Formation		Delwara Formation
	Gurali Formation		Basal Formation	Gurah Formation

2.2 Aravalli Supergroup exposed within Gujarat

Out of nine groups of the Aravalli Supergroup (Gupta et al., 1992), only three groups namely, the Jharol Group, the Lunavada Group and the Champaner Group are exposed within Gujarat (Merh, 1995) (Table 2.3). The brief description of each group in terms of its extent, lithology, structure and metamorphism is as under:

2.2.1 Jharol Group

The Jharol Group forming the oldest group exposed as a linear belt having trend N-S with its southern extent till Modasa in Gujarat. The strike length of the said group is about 190 Km with a width of 40 km. The Jharol Group gets tapered towards the northern direction, where the width of its extent gradually reduces to 2-5 km. The eastern extent of the Jharol Group marks the unconformable layer with the Bari-lake Group, whereas the older groups of the Delhi Supergroup are found to be resting over it along the western direction.

Table 2.3: Proterozoic Succession of Gujarat (after Merh, 1995)

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

The chief rock-types of the group are exposed as an intercalated sequence of phyllites, garnet mica schists and quartzites towards the northern extremity. The metamorphic grade along with the deformational complexity inflates towards west, characterized by NNE-SSW striking trends with a facies ranging from lower-greenschist to lower-amphibolite facies conditions respectively.

2.2.2 Rakhabdev Ultramafic Suite

The Aravalli Supergroup is distinctly marked by three magmatic events; of which two are basic and the last event represent acidic magmatism. The oldest basic magmatic activity at the base of the Aravalli Supergroup is well known as the Delwara-Siri volcanics. The rest middle aged magmatism recorded between two groups of the Aravalli's; i.e. between Jharol Group and Lunavada Group, have been coined as 1. the Rakhabdev Ultramafic Suite and 2. Syn-orogenic Granite and Gneiss (Gupta et al., 1992). From the three major magmatic events only the Rakhabdev Ultramafic Suite is exposed as discontinuous trail of outcrops within Gujarat near Idar and Lunavada regions. As per the view of the earlier workers the present ultramafic suite has a concordant relationship, which intruded during early deformation of the Aravalli supracrustals (Gupta et al., 1997). In other words it represents cessation of the Aravalli sedimentation and an on-set of deformation to appear these meta-volcanics as bands and lenses parallel with the fabric of the Aravalli meta-sediments (Merh, 1995). The Rakhabdev Ultamafics predominantly consists of serpentinite, talc-carbonate rocks with variable proportions of asbestos, and chlorite schists of highly altered and metamorphosed variety (Ghosh, 1934). These rocks can be traced along two major lineaments 1. the Rakhabdev, which extends in Gujarat and 2. the Kaliguman in Rajasthan. Deformational signatures appear in the form of broad open northerly plunging folds of regional scale, whose limb extends within Gujarat (Patel and Merh, 1967). The western limb can be traced along Idar and Shamlaji area, whereas the eastern limb is exposed north of Kadana near Lunavada area.

2.2.3 Lunavada Group

The rocks of the Lunavada Group have a polygonal extent geographically marked by the villages like Kushalgarh, Dharsua, Mahur and Sejwada at eastern, western, northern and southeastern direction, respectively. The Lunavada Group of rocks overlies Udaipur Group at the north-eastern direction in Rajasthan and along northwest there exists Jharol Group in Gujarat. There are total six formations identified in the Lunavada Group namely, Kalinjara, Wagidora, Bhawanpur, Chandanwara, Bhukia and Kadana. The part of the Kadana Formation is exposed within Gujarat rest other lies in the parts of Rajasthan (Iqbaluddin, 1989). The Lunavada Group comprises of phyllites, chlorite biotite schists, amphibolites of both ortho and para varieties, metasubgraywacke, metaconglomerate, quartzite with minor bands of dolomitic limestone. Quartzites stand as high ridges and intervening low lying areas are characterized by softer rocks such as chlorite schists (Gupta and Mukherjee, 1938; Narayana, 1974). The entire sequence is invaded by Godhra granite pluton (Narayana, 1969, 1970, 1971, 1974). Two phases of deformation recorded till mid 1990 are marked by two set of fold trends 1. N-S and 2. ESE-WNW (Gupta et al., 1997). However, latest work carried out by (Mamtani, 1998; Mamtani et al, 2000; Mamtani et al., 2001) suggest three phases of deformation within Lunavada region. D_1 and D_2 deformations are coaxial having NE-SW trending folds. The D_3 phase of deformation has developed broad open warps and kinks on kilometer long limbs of D_1 and D_2 folds. The superposition of these three deformational events has generated various interference fold patterns. Combination of D_1 and D_2 folds has generated “Type III” or “Hook shaped” geometry on a regional scale; whereas the last phase of deformation has overprinted “Type I” i.e. “Dome and Basin” geometry of (Ramsay and Huber, 1987). The D_3 deformation is also distinguished by syn-post thermal event i.e. Godhra granite. The grade of metamorphism in the Lunavada region increases from chlorite-schists in the north to garnet-mica schists in the south, respectively. The overall regional metamorphism has reached up to upper greenschist to lower amphibolite facies condition.

2.2.4 Champaner Group

The Champaner Group has a horse shoe shaped outline, which extends from Jambughoda in the east to Champaner in the west and Malao in the north-west to Rustampura in the south. The entire group forms an "inlier", which is surrounded by younger plutonic intrusive i.e. Godhra granite in the east, north and south, whereas thick patch of Deccan trap along with few infratrappean are exposed along its western direction. A few isolated, detached outcrops characterized by low mounds are located at eastern end of the group, within the granite country near Jothwad, Uchapan, Nani Khatva and Moti Khatva. Main rock type of the group includes cyclic sequence of phyllites, quartzites and meta-conglomerates intercalated with minor-to-major bands of dolomitic limestones. The regional metamorphic grade has reached up to greenschist facies. The entire sequence forms an anticlinorium with westerly plunging antiforms and synforms. Overall the Champaner Group characterise simple deformation with single trend of folds i.e. E-W to ENE-WSW and represents no interference fold patterns on regional or mesoscopic scale (Roy, 1985; 1988; Merh, 1995).

The detail description of work pertaining to the Champaner Group carried out by several workers has been outlined in the next section. The author finds it suitable to explain each work separately from erstwhile to latest in a chronological order.

2.3 Previous work carried out on the Champaner Group

The present section describes note-worthy contributions of previous workers on the Champaner Group and surrounding areas. The aim of writing this section separately is to build an overall understanding on the Champaner Group and neighboring areas in terms of its geology and structure, which will act as a platform to demonstrate new ideas proposed by the author in his present work.

2.3.1 W. T. Blanford (1869)

William Thomas Blanford one of the pioneer worker of Indian geology was first to explore the geology of western India. He classified the rocks of the western India into four series, under the category of “azoic rocks” (meaning: having no trace of life). Metamorphic Series; Champaner Series; Bijawar Series and Vindhyan Series, in the order of superposition.

He termed the oldest “Metamorphic Series” to the rocks occurring at the base. These rocks were gneisses, older schists, quartzites and other crystalline like granites and syenites. Blanford found that another sequence of rocks is resting over the basement, which he coined as “Champaner Series”. He enumerated in his monograph that the chief rock type of the Champaner Series are quartzites, due to its omnipresent nature from base to top of the sequence at specific interval. These quartzites were more or less similar to the quartzites found in the Metamorphic Series. Apart from quartzite he also mentioned few rocks showing highly crystalline and cleaved nature namely, slates, meta-conglomerates and dolomitic limestones. One important observation Blanford made in his work that all the rocks are stacked one over the other in an inclined fashion with devoid of any exposed basement. However, he considered granite exposures along the eastern extremity of the Champaner region as a base for these meta-sediments. Champaner being the nearest and famous town located in the present terrain, he grouped these rocks under the heading of “Champaner Series”. Under his purview he also investigated younger series of rocks like Bijawars at the east and Vindhyans at the north and jotted his distinctive remarks over them. He suggested that rocks of the Bijawar Series were less metamorphosed than the Metamorphic Series but much more crystalline than rocks observed in Vindhyan Series.

2.3.2 L. L. Fermor (1909)

Lewis Leigh Fermor, a British chemist and geologist investigated Champaner Series in 1905, due to his keen interest in manganese deposits. In his work, “The manganese ore deposits of India”, he quoted that the rocks of the Champaner Series are correlatable with the rocks of the Dharwars of South India. On the basis of mode of occurrence and origin, Fermor classified manganese ores of Champaner into two categories, 1. Primary ores; 2. Secondary ores. The manganese ores found in Champaner are composed of pyrolusite and psilomelane with less amount of braunite. The ores found near Shivrajpur area were termed as "primary Ores" of less metamorphosed variety, where as Mn bearing hornblende (winchite) found near Jothwad he grouped as "Secondary Ores" developed on account of granitic fluid.

2.3.3 G. V. Hobson (1926)

Hobson gave a concise account on the metamorphites and granites of the Chotta Udepur region. These rocks are considered as Pre-Champaner rocks located at the east and south-east of the Champaner Series. In his work he also investigated rocks in and around Pani Mines area (falls within Champaner Series) and projected a generalized stratigraphy from Kadwal to Raypur:

Phyllites intercalated with quartzite

Siliceous Calc-granulite

Mn rich phyllites and mica schists

Quartzite

Meta-conglomerate

Phyllites

Calc-granulite with tremolite ± actinolite

Phyllite and schists

Gneiss with tourmaline

He further observed that these rocks possess east-west strike with vertical dips. The granites present in vicinity to these rocks are of grayish variety and show intrusive contact with the country rocks. Furthermore, these granites can be only distinguished based on the textural criteria. Due to its intrusive nature with the Champaner rocks, Hobson suggested that the Champaner Series is younger to the Dharwarian rocks.

2.3.4 Rama Rao (1931)

Rama Rao had different views than the earlier workers. He suggested that the rocks of the Champaner Series are equivalent to sub-divisions of the Delhi System. According to his observations the rocks of the Champaner Series are identical to the sub-divisions of the Delhi System based on the lithological parameters and similar association of rocks in their order of superposition. Being his prime focus on the rocks of the Bariya State (NE of the Champaner region), he classified Champaner Series located near Bariya region into three different rock assemblages, separated based on the unconformable conglomeratic horizon:

Rajgad Shales

Dharia Limestone

Bariya quartzite

Poyelli felspathic quartzite

--------------Conglomerate------------- (?)

Poyelli limestone, argillite

Micaceous gneiss

--- (?)

Archaean schists and gneisses

2.3.5 Gupta and Mukherjee (1938)

Gupta and Mukherjee (1938) considered Champaners as older to the Delhis but younger to Aravallis. They arrived at present conclusion by differentiating the intrusives exposed in and around Champaner Series. According to them, two varieties present within the Champaner region, viz. 1. Granites and gneisses (intermixed variety) and 2. Granites (located at the north towards Godhra). The former are post-Aravallis but pre-Delhis, while the latter are equivalent to Erinpura granite (post-Delhis). Such discrimination was made based on the resemblance of the pegmatitie dykes of latter variety within Erinpura granites.

2.3.6 Rasul (1963; 1964; 1965)

Rasul made a sincere attempt in establishing the stratigraphic sequence of the Champaner Series around Shivrajpur area. While mapping the complete sequence he encountered various meta-conglomeratic units around Jaban, Richhbar and Malabar. These meta-conglomerates bear concordant relationship with the overlying and underlying rocks. Due to this present fact he proposed that it is difficult to sub-divide the rocks of the Champaner Series into diverse assemblages, in spite of having distinct meta-conglomeratic horizons. Further, he agreed with the Blanford's view that no basement is seen in vicinity to the Shivrajpur region.

Rasul also studied the genesis of manganese ores near Shivrajpur and Pani mines areas and suggested that the ores are mostly pyrolusite, cryptomelane and manganite, formed on account of secondary processes of concentration and replacement, and are subjected to stretch on account of metamorphism. Furthermore, he put forward that Champaner Series rocks have not suffered bulk change in chemical composition (except loss of water) even after metamorphism. The stratigraphic sequence proposed by Rasul is as follows:

<table>
<tr><td colspan="3">Recent and Sub-Recent Alluvium</td></tr>
<tr><td rowspan="8">Archaean Age</td><td>Post-Aravalli Intrusives</td><td>Kalsar granite and granitoid gneiss</td></tr>
<tr><td rowspan="7">Champaner Series</td><td>Bamankua impure limestone with pyrite</td></tr>
<tr><td>Mn bearing Phyllite of Shivrajpur</td></tr>
<tr><td>Bhat Quartzite</td></tr>
<tr><td>Richhbar Grit and Conglomerates</td></tr>
<tr><td>Jaban Slate</td></tr>
<tr><td>Narukot Quartzite</td></tr>
<tr><td>Basement Not Exposed</td></tr>
</table>

2.3.7 Sadashivaiah (1963); Sadashivaiah and Naganna (1964); Sadashivaiah and Tenginakai (1966)

Sadashivaiah and his co-workers gave an in depth description on the isolated band of calc-silicate skarns at Jothwad region. Sadashivaiah reported minerals such as wollastonite, diopside, epidote, phlogopite and scapolite, indicative of contact metamorphism. He differentiated rocks of the Jothwad region into two groups based on the petrographic criteria, viz. 1. Wollastonite-bearing rocks and 2. Diopside-garnet-epidote-phlogopite skarns. Sadashivaiah and others reported mn-bearing hornblende (winchite) occurring as segregations and patches at the contact of pegmatites and manganese ore within granite country. They also suggested that formations of these minerals indicate intense effect of metasomatic fluid on impure limestones coeval with granites and gneisses of the Champaner region.

2.3.8 B. B. Jambusaria and Merh (1967)

Jambusaria and Merh (1967) explained the effect of deformation on the graywacke conglomerates of the Jaban region. They explained origin and source direction of the clasts present within conglomerate from east and south-east direction. The clasts such as granites, gneisses must have been derived from the older plutonic basement, whereas the clasts like phyllites, quartzites and marbles, probably from the rocks belonging to the Pre-Champaner Series. The meta-greywacke and conglomeratic band experienced deformation by the generating oblique foliation to the bedding. Moreover, the effect of deformation over the clasts is obvious and can be appreciated based on the flattening to the respective clasts. The clasts belonging to the competent group such as quartzites, granites and gneisses where originally flat but acquired spherical to sub-spherical shape on account of the stress acted over it. The clasts of the incompetent group such as phyllite and marble have been flattened along the foliation, due to the compression at right angles to it.

2.3.9 B. Bhaskar Rao and D. Emile (1968)

The work carried out by B. B. Rao and D. Emile on the folded calc-silicate rocks and manganese ore bands in the Jothwad hill. They classified the skarn rocks into three types, viz. 1. Piemontite bearing rock 2. Winchite bearing rock and 3. Wollastonite bearing rock. Based on the chemical analyses they suggested that the wollastonite bearing rocks are confined near granites of the study area, whereas piemontite bearing rock occur at an intermediate distance from the acidic melt. These regular zoning of the rocks are often interrupted by the presence of granite tongues and veins. Winchite rich rock appears at the junction of calc-silicate rocks and manganese ore bordering the pluton. Based on the petrographic criteria following mineral assemblages were identified by the authors as follows:

1. Wollastonite-diopside-garnet-scapolite-quartz-calcite.
2. Diopside-garnet-scapolite-quartz-calcite
3. Diopside-winchite-quartz-scapolite-calcite
4. Winchite-quartz-manganophyllite-calcite
5. Piemontite-epidote-diopside-quartz-scapolite-calcite
6. Piemontite-epidote-quatz-scpolite-calcite

2.3.10 D. D. Yellur (1969)

Yellur (1969) reported Lead-Zinc mineralization from the rocks of the Khandia region (southern most extention of Champaner Series). He suggested that the Champaner Series rocks are folded to form sigma shaped outline and later modified by bedding slippages along ESE-WNW trend. According to his work the Lead-Zinc mineralization is confined to calcareous phyllite-dolomite limestone member of the upper Champaner Series. On the basis of detail structural evidences, he suggested that (a) the mineralization is structurally controlled and prevails along the shears parallel to WNW direction; (b) mineralization is also restricted to the WNW plunging axes of drag folds. Modeled age determination through Pb isotopes suggest an age of 2000 Ma., which are correlatable with Dharwars and Iron ore province of Bihar.

2.3.11 B. B. Jambusaria (1970)

B. B. Jambusaria (1970) gave a succinct account of the geology around Shivrajpur, with special reference to the stratigraphy, structure and metamorphism. The salient features of the results from his investigation are as under:

Stratigraphy: Jambusaria proposed threefold classification of the Champaner Series, which he summarized as lower, middle and upper Champaner. According to him, the complete sequence of the Champaner Series is resting on Banded Gneissic Complex (BGC) of Pre-Aravalli System, separated based on the unconformity. The lower-middle and middle-upper Champaner also consists in between a variety of unconformity as disconformity and paraconformity, respectively. Younger to the Champaner Series he marked an acidic intrusive activity (Godhra granite) of post-Aravallis but pre-Delhis and is solely related to Champaner orogeny. The detail stratigraphic succession of the Champaner Series worked out by him is as follows:

<table>
<tr><td colspan="3">Intrusive Granites</td><td>Post-Champaner (=Post-Aravalli but Pre-Delhi)</td></tr>
<tr><td rowspan="5">Champaner Series</td><td>Upper</td><td>Rajgad Slates</td><td rowspan="5">Aravalli</td></tr>
<tr><td colspan="2">--------------------------Paraconformity----------------</td></tr>
<tr><td>Middle</td><td>Bamankua Limestones
Shivrajpur Quartzites and phyllites
Bhat Slates
Jaban Conglomeratic Graywackes
Jaban Slates
Narukot Quartzites</td></tr>
<tr><td colspan="2">--------------------------Disconformity----------------</td></tr>
<tr><td>Lower</td><td>Gandhra Pelitic Group
Chhota Udepur Dolomites
Basal Conglomeratic Quartzites</td></tr>
<tr><td colspan="3">--------------------------------------Unconformity----------------</td><td rowspan="2">Pre-Aravalli</td></tr>
<tr><td colspan="3">Basement Gneissic Complex</td></tr>
</table>

Structure: The Champaner Series experienced folding to form ‘S’ shaped pattern, comprising two major anticlines and synclines. Two phases of deformation has been detected having orthogonal axial traces (D_1 ~ E-W to ESE-WNW and D_2 ~ N-S). The rocks of the Champaner region are also characterized by slippages parallel to strike of the axial plane of F_1 and F_2 folds, projected in the form of radial pattern. Moreover, the post intrusive granite has greatly modified the pre-existing structure of the Champaner Series by doming up of sequences, imparting westerly plunge to the fold axis and tightening of earlier minor folds.

Metamorphism: The Champaner Series has undergone regional metamorphism over printed by contact metamorphism due to the granite pluton. Regional metamorphic textures coincide with the Champaner orogeny and reached upto chlorite grade (greenschist facies condition). Contact metamorphism over argillaceous composition has lead to the development of hornfelses within the contact aureole, whereas in case of impure calcareous it has developed skarns. On account of granitic intrusion, migmatisation has caused gradual transformation of phyllites to coarse grained feldspathic gneisses.

2.3.12 Gopinath et al., (1977)

Gopinath and others studied the rocks belonging to the Champaner Series and surrounding regions. Based on the available structural records and occurrence of meta-conglomeratic band they differentiated the rocks of the Champaner region into three categories, viz. 1. The Champaners 2. The Pre-Champaners and 3. The lower Aravallis. They considered the granitised gneisses occurring at the south-western margin of the Champaner meta-sediments, as the rocks of the lower Aravalli sequence, which compose mainly rounded grains of quartz embedded in a matrix of quartz, feldspar, biotite and less proportion of muscovite. These rocks show sharp contact with respect to the Pre-Champaner and Champaner Series rocks. The rocks exposed at the north-western margin of the Champaner Series near Devgad Baria and at the extreme east near Chhota Udepur are termed as upper Aravallis or Pre-Champaner rocks. These rocks reveal intercalated sequence of quartzites and garnet mica schists. Lastly, the rocks belonging to the Champaner Series represent a low grade sequence of phyllite, quartzite and meta-conglomerate and are distinctly different than the rocks of the lower Aravallis and Pre-Champaner region.

They collectively explained three folding phases within the Champaner belt. The first fold event F_1 is characterized by isoclinal to overturned nature folds with axial trace ranging in ENE to WNW direction. F_2 event comprises folds of open, steeply inclined and moderately plunging nature with WNW to E striking trends. The last event F_3 is suggested by the development of two small, rather open, northerly plunging, synclinal structures in the northern part of the Champaner belt as well as in the upper Champaner inlier of Jothwad, located north-west of Jambughoda.

2.3.13 Shah et al., (1984)

Shah and his co-workers stated the origin of lead mineralization within the Khandia region of the Champaner Series. During the course of their investigation they inferred that the Champaner Series rocks differ from Aravallis in terms of sedimentation, structure and metamorphism. They proposed that the mineralization is on account of collision of Aravalli and Dharwar protocontinents. Moreover, the collision of these two protocontinents folded the Champaner metasediments and the fractured hinges served as an inlet for the mineralizing fluids.

2.3.14 Gupta et al., (1992; 1997)

The generalized stratigraphic framework pertaining to the Aravalli supracrustals has been given by Gupta et al., 1992. They differentiated several groups under the heading of the Aravalli Supergroup. Their observations suggested that the Champaners belong to the part of upper Aravallis and designated the Champaner Group as a youngest Group in the Aravalli Supergroup. However, the Champaner metasediments do not bear evidences of older deformation and represent merely folding of primary bedding without the generation of preferred schistose fabric. Though suffered only single deformational event, the swaying of fold trends within Champaner metasediments are on account of post-intrusive Godhra granite. These views were slightly modified by Gupta et al., 1997. Out of four deformational episodes observed within the Aravalli domain (i.e. AD_{1-4}), the fold trends seen within the Lunavada and the Champaner Group were termed as AF_4 (~ E-W to WNW-ESE) and AF_5 (~ N-S) folds of AD_4 episode. Due to the last deformational episode the grade of regional metamorphism has reached upto greenschist facies condition having chief rock-types such as phyllites, mica-schists, quartzites and calc-silicate rock.

2.3.15 Merh, (1995)

Merh (1995) gave an insight on the basement of the Champaner Group. According to him the Champaner Group of rocks deposited on the older gneissic basement can be separated based on the basal conglomeratic horizon. Furthermore, the basement over which the Champaner Group of rocks resides is difficult to distinguish due to its intermixing character with the post-intrusive granites. At places the Champaner metasediments attaining migmatitic appearance at the junction of these granites. The Champaner Group also possesses contact metamorphic effect by the development of calc-silicate skarns at Jothwad, NW of Jambughoda. These granite and gneisses separate the neighboring rocks of the Bariya region belonging to the Lunavada Group, which holds similarity in terms of lithology with the Champaner metasediments. Overall 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 perhaps by a basement high.

Further SE of the Champaner region, there lies rocks of Chhota Udepur region. These rocks were considered as a part lower Champaner Group due to its structural disposition and nearness to the Champaner metasediments.

2.3.16 Srikarni and Das, (1996)

Srikarni and Das (1996) gave a detail litho-stratigraphic sequence and sedimentation history of the Champaner Group. They divided Champaner Group based on the five conspicuous marker horizons of which two are conglomerate horizons, which separates Champaner Group into lower, middle and upper Subgroups. The lower Champaner Subgroup represents Lambia Formation comprise four main rock-types from 1a-d. 1a forms the base of the Champaner Group having quartzite and basal oligomictic conglomeratic horizon. 1b, 1c and 1d are represented by phyllite and spotted slate, dolomitic limestone rich in stromatolites and phyllites respectively. The middle Champaner Subgroup clubs rocks belonging to the Khandia and Narukot Formation and are divided into four sub-categories (i.e. 2a-d). These rocks marks distinct gradation in terms of grain size from oligomictic conglomerate at the base of Khandia Formation, followed by quartzite to meta-arkose variety and finally grades into phyllite. The upper most subgroup of the Champaner represents the thickest sequence covering the rest of the formations of the Champaner Group. The Jaban, the Shivrajpur and the Rajgad Formation are placed within upper Champaner Subgroup and are divided into five chief litho units (i.e. 3a-e). Polymict boulder-cobble conglomerate appears at the base of the upper Champaner Subgroup deputed at 3a, followed by quartzite and meta-arkose as 3b, manganiferous phyllite and quartzite as 3c, siliceous dolomitic limestone as 3d and thick band of phyllite containing minor bands of siltstone/ quartzite with occasional thin limestone bands constitute as 3e. Detail stratigraphic framework pertaining to the Champaner Group proposed by these workers is given in the (Table 2.4).

Sedimentation history of the Champaner Group suggested by Srikarni and Das marks the overall thickness of the Champaner metasediments more than 2100 mts. The thick pile of sequence got deposited in three major cycles of which the lower most cycle is incomplete and rest two starts with the conglomeratic horizon having scoured contact with underlying phyllite. These conglomerates show evidences of submarine fan complex and deposited due to activation of major marginal/ intrabasinal faults, which promoted coarser clastic supply to the basin. Paleocurrent data suggests that the provenance was towards the south with an extension towards north due to several episodes of block faulting. Basement exposed along the southern part of the Champaner Group display complex deformation with higher grade of

metamorphism than the Champaner metasediments. Based on the homogeneity in terms of rocktypes the Champaner Group show similarity with the Debari Group of middle Aravalli and Lunavada Group of upper Aravalli Supergroup.

Table 2.4: Stratigraphy of the Aravalli rocks in and around Champaner region
(After Srikarni and Das, 1996).

Age	Group/Sub-group	Formation	Member	Lithology
Cretaceous to Eocene	Deccan Traps			Basic flows, basic and alkali dykes
Cretaceous	Infratrappean (Bagh Beds)			Sandstones and Limestones
Neo-Proterozoic	Godhra Granite			Post-tectonic and syntectonic granite and granodiorite
Palaeo-Proterozoic	Champaner Group	Rajgarh	3E	Slates and slaty phyllites with thin calc-silicate bands
			3D	Dolomitic limestone
		Shivrajpur	3C	Manganiferous phyllites and quartzites
			3B	Quartzite and meta-arkose
		Jaban	3A	Polymictic conglomerate with greywacke
		Narukot	2D	Grey phyllite and carbon phyllite
			2C	Meta-arkose and greywacke with intraformational conglomerate
		Khandia	2B	Quartzite and meta-arkose
			2A	Boulder/Cobble conglomerate- clasts mainly of quartzite with minor magnetite, quartzite and phyllite
		Lambia	1D	Phyllite/biotite schist (in the eastern part)
			1C	Dolomitic marble and calc-silicate rock
			1B	Phyllite/biotite schist and spotted slate
			1A	Quartzite and impersistant conglomerate
Palaeo-Proterozoic	Pre-Champaner Gneissic Complex			Granite gneiss, quartzite and pelitic gneiss

2.3.17 Karanth and Das, (2000); Das (2003)

Karanth and Das (2000) and Das (2003) explained the deformational history of the Pre-Champaner Gneissic Complex (PCGC) in Chotta Udepur region. The broad conclusions in their own words are listed below:

1. There are four episodes of folding in the PCGC of which early two (D_1 and D_2) have produced folds of reclined nature (F_1~ N or S plunging fold axes and F_2~ W plunging fold axes) and the

later two (D_3 and D_4) have resulted in open upright folds (F_3~ E or W plunging fold axes and F_4~ N-S trending upright warps with kink bands).

2. The mesoscopic F_1 and F_2 folds in layers of different competency are of variable wavelength and are disharmonic in nature, suggesting that they are produced on account of buckling mechanism.
3. Amplitude versus wavelength ratio for F_1 and F_2 folds is fairly high.
4. F_1 and F_2 folds intersected at high angles which tends maximum at Luni dam (~upto 90^o) and minimum near Goidia (~around 45^o).
5. F_2 and F_3 are co-axial depicting evidences of hook shaped pattern.
6. Mutually perpendicular nature of F_1 and F_2-F_3 indicate that the tectonic forces changed from E-W compression in early period to N-S in the later period during the Pre-Cambrian times and finally ended up with the E-W compression.
7. Difference in orientation of folding patterns indicates that the rocks of the PCGC apparently appear to belong to a separate tectonic regime and not related to the Aravalli tectonism.
8. Three metamorphic events (M_{1-3}) have been recorded of which two are progressive and the last event is retrogressive. M_1 and M_2 have reached upto amphibolite facies condition where as M_3 is characterised by retrogressive hydration reactions.

2.3.18 Das et al., (2009)

The authors carried out a preliminary study on the thermal metamorphism in the Champaner Group. Their views suggested that the low-grade regionally metamorphosed rocks of the Champaner Group show over printing of contact metamorphism due to the intrusive Godhra granites of Neo-Proterozoic age (935 ± 20 Ma). Their work covered majority of the locations depicting contact metamorphic signatures, viz. Chalwad, Wav, Goldungri, Nanikhatwa, Raypur, Kundal, Wadek and Jharav. At these various locations thermal metamorphism has resulted into the development of andalusite and cordierite hornfelses in argillaceous protolith. Winchite bearing calc-silicate rocks are developed in response to manganese silicates and oxides in manganiferous arenaceous rocks and talctremolite-actinolite dominant calc-silicate rock generated due to impure carbonate composition. They deduced based on the major components in the metamorphic system such as CaO, Al_2O_3, FeO, MgO, SiO_2, H_2O and CO_2. Except in case of Goldungri, additional two components were used (i.e.) MnO and K_2O yielding towards formation of minerals in a complicated system. Based on the mineral assemblages and textures the metapelites of the Champaner Group have undergone albite-epidote hornfels facies and hornblende-hornfels facies of contact metamorphism. At Kundal, there prevails highest temperature (~ more than 650^o C), indicate sanidinite facies condition.

2.3.19 B. K. Sahu (2012)

The author made an attempt to differentiate various litho-tectonic units of the Southern Aravalli Fold Belt (SAFB) using aeromagnetic data. The map generated though the aeromagnetic data signifies well defined boundaries using broad wave-length and long strike-length anomalies, viz. the Rajgad Formation metasediments belonging to the Champaner Group are separated by the older Lunavada Group. The data also clarifies the thick patch of granite gneisses over which both the metasedimentary sequences are resting. With the help of magnetic relief, the aeromagnetic map has been prepared having seven distinct lithounits from A-G. Rajgad Formation corresponds to zone A having flat relief and less variation in the magnetic anomaly. The zone B in the north-eastern part of the SAFB represents the Lunavada Group. Zone C corresponds to the meta-argillite and minor quartzite patch with sporadic occurrences of amphibolites and has been treated as a separate tectonic block having shallow basement. Zone D, E and G are restricted to sporadic porphyritic granites and granite gneisses between the Champaner and Lunavada Group. Lastly, the zone F is characterized by the high magnetic relief and located at the SW part of the SAFB. This zone has been assigned the name of the lower Champaner metasediments and associated gneisses derived due to the process of granitisation.

2.3.20 Sharma and Golani (2013)

These authors reported magnesite bearing veins within calc-silicates of the Khandia Formation. These calc-silicate bands form the important organogenic unit which contains dominantly the stromatolitic structures. The area of investigation is restricted between Chalwad and Ranjitpura area located at the NE of Champaner Group and forms the major part of an antiformal structure having moderate plunge towards WNW direction. These magnesite veins occur within discontinuous bands and patches of calc-silicate rock. The origin of these magnesite may be due to magnesia rich fluids settled with the host rock on account of evaporation.

2.4 Late-Proterozoic Igneous Activity in and around Champaner Group: with special reference to its Geo-chemistry, Geochronology and Magnetic Foliation

Post-Aravalli igneous activity has been reported from the surrounding regions of the Champaner Group as well as from the southern extent of the Lunavada Group. This igneous activity is named as "Godhra Granite" on the basis of the type section occurring at Godhra, located north of the Champaner region. The Godhra granite has an Rb/Sr age of 955 ± 20 Ma. (Gopalan et al., 1979) and falls under the time bracket of Delhi orogenic cycle (i.e. 2000-700 Ma.: Gupta et al., 1997). The magmatic events associated with Delhi orogenic cycle are classified into three categories as (a) early orogenic phase; (b) syn-to-late orogenic phase and (c) post-orogenic phase. The early orogenic phase magmatic event is evident by shoreline volcanism at NE Rajasthan, referred to as "Phulad Ophiolite Suite". The magmatism associated with syn-to-late orogenic phase are Sendra-Ambaji granites. The end of the orogenic phase leading to the development of basic volcanism is manifested as pillow lavas (basalt) and tuffs. Moreover, the end of the Delhi orogeny marks two major thermal events of post-intrusive nature, viz. 1. Erinpura granite (830 ± 30 Ma.: Choudhary et al., 1981) and 2. Malani Rhyolite (745 ± 10 Ma.: Crawford, 1970). Newania Carbonatite (959 ± 24 Ma.: Dean and Powell, 1968) and the Godhra granite (955 ± 20 Ma.: Gopalan et al., 1979) considered to be equivalents of the Erinpura granite. The stratigraphic status of the Erinpura granite and the Godhra granite is quite debatable, as a consequence of which Merh (1995) suggested that the granites of Godhra and its surroundings are slightly older than the Erinpura granite. As far as the geographical extent is concerned, the Godhra granite occupies an area of c. 5000 sq km and located in the southern part of the AMB (Mamtani, 2014). The exposed granitic rocks forms the mirror image ‘C’ shaped outline in the SAMB, which delineates the Lunavada and the Champaner Group of the Aravalli Supergroup. The work carried out by Gopinath (1972) suggest that the Godhra granite has an intrusive relationship with rocks of the Lunavada and the Champaner Groups. Yellur and Gopinath, (1966) coined Champaner metasediments as “roof pendants” resting over the granite massif and same has been responsible to amend the surface structures during different stages of tectonic activity.

As the present focus of work is on the Champaner Group and associated igneous activity (i.e. Godhra granite), the author finds it rational to give a brief description of granites in terms of its geo-chemistry, geo-chronology and deduced magnetic foliation.

Geo-Chemistry: Gopalan et al., (1979) geo-chemically analyzed the granites of the Jambughoda region. The initial high $^{87}Sr/^{86}Sr$ ratio of 0.7130, suggest that granites were derived by the partial melting of the continental crust. Goyal et al., (1997) studied the granites of the same region with special reference to the uranium mineralization within the Champaner Group. The geochemical data of twelve representative samples suggested that the granites are rich in Rb, Ba, Y, Zr, Nb, La, Pb and Th, whereas the Sr, Co and Ni values are sparse for these granites. The higher values of Zr content for these granites indicate high degree of differentiation (Saxena et al., 1992). Tectonic discrimination diagram for these granites indicate that they fall in Volcanic Arc Granite field (VAG), however few samples do show an affinity for Within Plate Tectonic regime. The granite samples falling under VAG category give indirect evidence to the collisional processes. The granites of the region also show uranium values ranges from traces to 52 ppm, which is much higher than normal granites having 5 ppm values. The outcome of their work indicates that the uranium was concentrated in the residual magmatic and subsequent hydrothermal fluids, which got emplaced in the higher crustal levels. The uranium rich granite melt show signature of partial consolidation by leaving the remnant liquid phase enrich in U, alkalies and volatiles. Similar work carried out by Maithani et al., (1998) on Zoz granites, located east of Sukhi Dam classified granites of sub-aluminous nature. Moreover, these granites are also rich in uranium content and intergrowth of the orthoclase-albite as well as quartz-alkali feldspar supports its “A-type” variety. In order to provide an overall understanding in terms of geo-chemistry Goyal et al., (2001) analyzed 31 samples by covering the entire span of the exposed outcrops of Godhra granite. Majority of the samples are classified as high Ca-granites and show affinity towards per-aluminous to meta-aluminous nature. These granites are derived from the partial melting of the continental crust and emplaced in post-orogenic environment.

Geo-chronology: Over the last five decades significant geo-chronological studies have been carried out especially on the Godhra granite pluton. Most of these ages are calculated through Rb/Sr method except one by Sm-Nd method. These dates suggest that the emplacement of the Godhra granite started around 1168 Ma. and was prolonged till 938 Ma. These dates include: 1168 ± 30 Ma: Rb/Sr method (Srimal and Das, 1998); 1050 ± 50 Ma: Sm-Nd method (Shivkumar et al., 1993); 965 ± 40 Ma: Rb-Sr method (Goyal et al., 2001); 955 ± 1120 Ma: Rb-Sr method (Gopalan et al., 1979); 950 Ma: Rb-Sr method (Crawford, 1975) and 938.8 ± 20 Ma: Rb-Sr method (Srimal and Das, 1998).

Magnetic Foliation: Magnetic foliation within Godhra granites has been deduced through Anisotropy of Magnetic Susceptibility (AMS) analyses by Mamtani (2014). The results suggest that the Godhra granite show evidences of deformation having preferred magnetic foliation of ENE-WSW trend (Fig. 2.2). Feldspar laths within this syn-tectonic granite too trend WNW to W striking trends. Similar orientations have been acquired through AMS analyses for the neighbouring banded gneisses and which matches with the trend of the Central Indian Tectonic Zone (CITZ) (Sen and Mamtani, 2006). Broad conclusions using the above data recommends that the fabric development within the Godhra granite was coeval with the D_3 deformation of the banded gneisses, D_3 deformation of the Lunavada Group and D_1 deformation of the Champaner Group. Furthermore, all these events are related to Rodinia Supercontinent assembly during Grenvillian times (Mamtani and Greiling, 2005).

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