CHAPTER - I

PURPOSE & SCOPE OF THE PRESENT WORK

&

REVIEW OF PREVIOUS WORK

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I.1 INTRODUCTION

The granulite terrains, the so called petrological windows to the deeper part of the earth's crust, drew the attention of the petrologists all over the world after it was realized that these rocks could provide vital clues to the chemical, petrological and tectonic evolution of Earth's middle and lower crust. This is based on the fact that these rocks contain mineral assemblages which owe their origin to extremely high pressure - temperature conditions which could prevail only in the deeper part of Earth's crust. As such high P-T conditions can never exist at shallow levels. Another important observation that such granulite terranes are ubiquitously associated with major tectonic features like shears, thrusts or in terms of plate tectonics - the plate margins, leads to the conclusion that these are the uplifted portions of middle and lower crustal segments.

Ever since the first description of charnockite by Thomas Holland in 1900 from Madras, a lot of work has been done by petrologists and the South Indian Granulite province became the focus of attraction of the metamorphic petrologists from all over the world. Systematic investigationsof this granulite province with special emphasis on mineralogical, petrological, chemical studies, estimation of P-T-fluid conditions of metamorphism, characterization of prograd and retrograde path of evolution etc. with limited geochronological studies are available. In the past decade lot of isotopic and fluid inclusion studies have been carried out with a view to finding their applicability in characterization of metamorphism. New theories have been proposed on the basis of these studies on the genesis of granulites based on south Indian granulites. Similar investigations were also carried out on the adjacent Eastern Ghat granulite province of India. The granulite provinces of other parts of India, however, remained largely neglected particularly the Western India and Central India. Occurrence of granulite facies rocks in Rajasthan (Western India) was reported by Heron (1917, 1935) and Gupta (1934). Much work has been done in recent years in the Sandmata Granulite Complex of South-Central Rajasthan by different workers.

Desai et al. (1978) reported for the first time existence of granulite facies rocks in the Balaram - Abu Road area of North Gujarat and Southern Rajasthan. These workers carried out detailed petrographic and structural studies (Patel et al, 1985, Desai & Patel, 1992) with limited major element chemistry. Srikarni et al (1996), with the help of geophysical data, suggested that the North Gujarat granulite terrain is possibly the southern extension of the granulite terrain of south -central Rajasthan (Sandmata-Bhinai- Bhim Karera area). To the southeast of this granulite terrain, a granulite - amphibolite facies terrain was studied in detail (Limaye, 1992). Geophysical data in conjunction with satellite imagery studies reveals that these areas are bounded by tectonic discontinuities to the east, west and north. A similar scenario is reported in the Bhilwara Supergroup (Gupta et al., 1992) of rocks in South-central Rajasthan where granulite facies Sandmata Complex is suggested to occur as tectonic slices or slivers In all the cases granulites facies terrain is juxtaposed with amphibolite facies rocks (Sinha-Roy et al, 1995; Mohanty & Guha, 1995). Do such geological settings represent progradeamphibolite - granulite transition ? If not, what could be the reason for the juxtaposition of these rocks of contrasting facies ? One more important observation is that all the known occurrences of granulite facies rocks in Rajasthan lie to the east of the Phulad dislocation zone (PDZ). The southern extension of PDZ has been suggested to be represented by the Kui - Chitrasani fault (KCF) of the study area (Srikarni et al, op cit) where too the granulite facies rocks occur to its east. On the basis of Bouguer gravity data of Rajasthan and North Gujarat PDZ - KCF lineament has been suggested to represent a destructive plate margin where westward subduction of Archaean (and Proterozoic) sequence of NW India took place (Srikarni et al, op cit). The occurrence of the granulite facies rocks as tectonic slices / slivers has been attributed by these workers to be due to obduction during the late stage of Delhi orogeny.

In order to find logically acceptable answers to these querries,the author undertook the present research in the polymetamorphic terrain at the southern end of the Rajasthan - Gujarat granulite belt in the Balaram - Abu Road area. The present study, apart from studying the field relationship between the different granulite rock types, their petrology, mineral chemistry and petrochemistry for characterization of the P-T-Fluid conditions; also incorporates the synthesis of the available geophysical data of Rajasthan - North Gujarat in conjunction with the remote sensing studies using photogeology and satellite imagery interpretation for deciphering the tectonic history of the study area vis-a-vis the granulite provinces of Rajasthan and their possible correlation. These studies have been essential for assigning the stratigraphic status to this granulite province.

A detailed account of the granulite provinces of Rajasthan is beyond the scope of the present work. However, a brief account of the granulites of Rajasthan could not be avoided in the review of previous work as these do have relevance in the correlation and tectonic evolution of the granulites of western India.

Heron and Ghosh (1938) in their classic work "Geology of Palanpur, Danta and part of Idar States" presented an elaborate account of geology of the area under study and adjoining areas of Precambrian rocks of North Gujarat. Their account of various occurrences of metasedimentaries, basic and granitic rocks and correlation with successive well defined events in the overall geological evolution Western India remained an important source of geological information of N.Gujarat till Desai et al (op cit) brought out a number of structural and metamorphic complexities in Balaram -Abu Road area which escaped the attention of Heron and Ghosh (op. cit)

According to Desai et al (op cit) and Patel et al (op cit), a part of the metasedimentaries (mainly Ajabgarh Group of Heron and Ghosh) in fact comprises a low pressure metamorphic province. They are the first to report various mineral assemblages forming pelitic and calc granulites and charnockitic rocks indicative of metamorphism under pyroxene granulite sub-facies. They identified several metamorphic events in the area and demonstrated it to be a polymetamorphic. They opined that the Balaram - Abu road area should be older than the Aravalli and Delhi Supergroup and should possibly belong to Bhilwara Supergroup of Archaean age of Rajasthan

OBJECTIVES OF THE PRESENT WORK

1 The occurrence of granulite facies terrain in Balaram - Abu Road area of North Gujarat and Southern Rajasthan in NW India.

2. To study the possibility of this granulite facies terrain being the southwestern continuation of the granulite facies rocks of Bhilwara Supergroup of Archaean age of Central Rajasthan

3. To study the geochemistry of the granulites and to reveal the nature of their precursors which constituted the basement for the pelitic and calc granulites of the area.

4. To estimate the conditions of granulite facies metamorphic event using geothermo-barometry based on mineral phase equilibria.

5. To reconstruct the upliftment history of this granulite terrain and to consider the same as tectonic slivers due to obduction leading to decompression and partial retrogression.

6 To study the effect of thermal imprint on account of the emplacement of the younger Erinpura Granite

7. To utilize the geophysical data of the Precambrian shield of W India in order to correlate the granulite facies terrain under study with Archaean granulite provinces of Rajasthan.

8. Application of geophysical data in conjunction with remote sensing (photogeology and satellite imagery) study and regional geological maps in evolving a satisfactory Archaean - Proterozoic tectonic history and to decipher the relationship between granulites of the study area with Delhi Supergroup rocks of the adjoining area.

I.2 METHODOLOGY

Chapter-I presents the scope and limitations of the present study and reviews the previous work in the study area and adjoining areas as also the contribution of workers in the granulite terrains of Rajasthan.

Chapter-II presents the geological setting of the study area vis a vis regional geological setting of Precambrian rocks of Rajasthan and Gujarat.

Petrography and chemistry of the mineral phases of the different lithounits viz. Pelitic granulites, calc granulites, and charnockites are presented in chapter-III through Chapter-V. Major element, trace element and Rare Earth element geochemistry of the different lithounits is given in chapter-VI.

Characterization of the P-T-Fluid conditions as deduced from the coexisting mineral phases, mineral reactions geothermobarometry and metamorphic history of the area is given in Chapter-VII. Geophysical data (Bouguer gravity, magnetic and seismic reflection) of the Precambrian areas of North Gujarat and South-central Rajasthan relevant to tectonic history and stratigraphic correlation is given in Chapter-VIII. Tectonic history including the upliftment history (and the related evidences), as reconstructed on the basis of foregoing chapters and review of the other known granulites of Rajasthan, is presented in Chapter-IX. Chapter-X presents the summary & coclusions. Tectono-stratigraphic status of the granulites of the study areas vis-a-vis Bhilwara Supergroup, Aravalli Supergroup and Delhi Supergroup is interpreted which also includes a discussion on the nature of relationship between the granulite facies study terrain and the adjacent amphibolite facies Delhi Supergroup rocks of Ambaji area as deduced from photogeological and satellite imagery studies with limited ground checks Such indirect evidences regarding the age of the granulites of the study are of cardinal importance in view of the lack of any radiometric geochronology of these granulites

I.3 REVIEW OF PREVIOUS WORK

Before we deal with the geology of the study area it would be worthwhile to have a glimpse of the views of the previous workers, which have been published / presented before the scientific community as frequent reference will be made to these works in this thesis.

I.3a *Workers in the study area*

Heron and Ghosh (1938) gave a pioneering account of the geology of the erstwhile princely states of Palanpur and Danta and adjoining small estates of Sudasna, Balusana, Umbri and Satlasna and a small portion of the State of Idar. They considered that the area consists chiefly of representatives of Ajabgarh Series- the upper division of the Delhi System and the Erinpura Granite intrusive into it. In the extreme north-west, mica-schists and injection gneisses enter Palanpur State (now Banaskantha District) from Sirohi which were attributed by Coulson (1933) to the Aravalli System According to them, the quartzites- probably Alwar Series, of the Delhi System, mapped by Coulson in Sirohi State, do not extend southwards in Palanpur area. They described phyllites to occur in the form of a V shaped outcrop, the triangular space in the middle being occupied by basic rocks mostly gabbros and dolerites (Khapa). In the limbs of the V also, intrusive dolerite and gabbro are present in the phyllites with pegmatite and granite at the apex High dips of about vertical and isoclinal structure in phyllites is mentioned by these workers A fault transversely cuts this structure (which corresponds to Kui-Chitrasani fault of the present work)

Desai, Patel and Merh (1978) are the first to report the occurrence of granulite facies rocks from the Balaram - Abu Road area of Banaskantha District of North Gujarat and Sirohi District of Southern Rajasthan Assemblages such as quartz - perthite - garnet - biotite - sillimanite - cordierite - spinel, cordierite - garnet - hypersthene - biotite - K-feldspar - plagioclase (An_{25-30}) - quartz, and quartz - K-feldspar - garnet -biotite - sillimanite - graphite (khondalite ?) representing pelitic granulites and psammites (quartz - cordierite - garnet assemblage) and diopside - scapolite (meionite) - plagioclase - wollastonite - sphene - apatite - calcite and quartz was described by them as calc granulites. They also reported an interesting occurrence of hypersthene (aluminous variety) bearing calc granulite. They are the first to describe charnockitic rocks constituting the basement for these high grade metasedimentaries. Among the charnockitic suite,they identified ultrabasic, basic, intermediate and acid varieties in the Balaram - Virampur - Khapa area. On the basis of mineral assemblages, they suggested pyroxene granulite sub-facies of regional metamorphism and that Balaram - Abu Road area is petrologically a complex metamorphic terrain and that the lithounits of the area do not belong to Alwar or Ajabgarh Series of Delhi System but could be pre-Delhi. These workers suggested these to be possible extension of charnockitic rocks of Western Ghats of Kerala and south Mysore, now constituting the basement for the Aravallis and Delhis.

According to **Powar and Patwardhan (1984)** Ajabgarh Group comprises calcareous and pelitic metasediments. The rocks of the Delhi and Aravalli Supergroups have been subjected to complex history of folding and dislocation. The earliest phase of folding (F1) is marked by isoclinal and reclined folds with fold axis plunging W-WNW. On these, N-NNE trending F2 and F3 (coaxial with F2 of smaller dimensions) were superimposed. F2 and F3 folds are most persistent. A mild phase of cross folding on E-W to WNW-ESE trending axes (F4) resulted in the development of doubly plunging structures. Spatial and temporal variations in the type and grade of metamorphism, as per these authors, is depicted in **Fig.- 1.1**. Metamorphic conditions show that the rocks of the Delhi Supergroup reveal imprints of metamorphism in the west-central and central parts of the fold belt while only low pressure regional metamorphism is recognised in the northern and southern parts of this belt.

These workers also pointed out that despite the fact that Delhi metasediments have been profusely invaded by Erinpura and Bairath granites, contact metamorphic aureoles did not develop.

Further they opined that in Palanpur-Abu Road region, at the southern end of the Delhi-Aravalli belt, calcareous metasediments of Ajabgarh Group are profusely intruded by Erinpura granites. In this region the critical mineral assemblages are quartz - sillimanite - biotite - garnet - K-feldspar - spinel in the pelitic rocks, and calcite - forsterite - scapolite - phlogopite in carbonate rocks. Clino-pyroxene - pargasite - tremolite - hornblende - plagioclase is found in metagabbros. They suggested upper amphibolite facies of regional metamorphism.

Patel, Desai and Merh (1985) during regional structural mapping established that high-grade polymetamorphic terrain of Balaram-Abu Road area of Banaskantha District of N. Gujarat and S.Rajasthan forms a triangular (wedge) shaped outcrop bounded by three distinct lineaments viz. (i) Or-Surpagla tectonic junction separating these polymetamorphites from Delhi Supergroup rocks towards north, (ii) Kui-Chitrasani fault (trending NNE-SSW) along which these high-grade rocks are juxtaposed with Erinpura Granite and (iii) Or-Deldar fault which post-dated the Kui-Chitrasani fault in the north. In the southern part these high grade rocks are covered by alluvium / soil.

During structural mapping of the area southeast of Amirgad, **Biswal (1988)** brought out five phases of deformation and pointed out that two of these phases of deformation are absent in Delhi Supergroup elsewhere (He assumed the lithounits in the area to belong to Delhi Supergroup).

Desai and Patel (1992) gave a detailed account of petrography of the granulite facies rocks of Banaskantha district of N.Gujarat. Assemblages such as sillimanite -

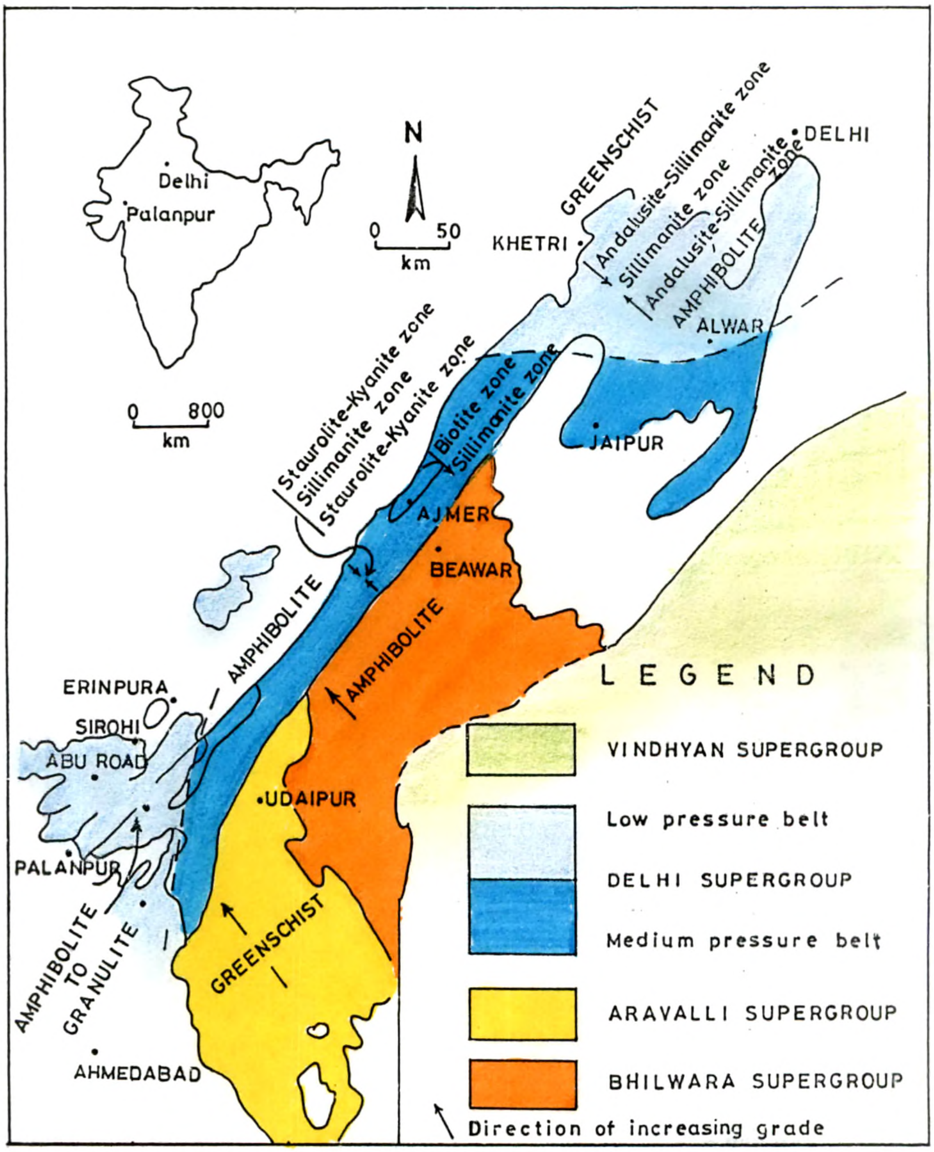

Fig. 1.1 Metamorphic facies map of Rajasthan and Gujarat (After Powar and Patwardhan, 1984)

garnet bearing khondalites, garnet - cordierite - sillimanite representing psammo-pelitic suite, cordierite - hypersthene bearing pelitic granulites together with cordierite - garnet - spinel - sapphirine granulites, quartz dominant psammites and diopside - scapolite calc-granulites resting over a suite of charnockitic rocks. On the basis of coexisting mineral assemblages of various rocks, peak metamorphic P-T conditions of 650-800°C and 6 to 8 kbars are suggested by them. They suggested that these granulitic rocks stratigraphically belong to Bhilwara Supergroup of Archaean age.

With the help of geophysical data (Bouguer gravity and magnetic data) in conjunction with the mineral assemblages of the granulite facies terrain of Balaram - Abu Road area of N. Gujarat and S.Rajasthan, **Srikarni, Desai and Patel (1996)** established a correlation between granulite facies terrains of N.Gujarat (Balaram - Abu Road area) and those of Rajasthan (Sandmata Complex of Ajmer - Pushkar Valley and Bhim - Karera area) with gravity high domains of the Precambrian shield of Rajasthan and N.Gujarat. On the basis of high gravity anomaly, these workers suggested the existence of granulite facies rocks concealed beneath alluvium in the area northeast of Palanpur (with limited field subsurface (bore hole core) samples confirming the interpretation). They also correlated the Phulad Dislocation Zone (PDZ) with a prominent gravity lineament extending from Jhunjhunu in Rajasthan to Palanpur in N.Gujarat. They also pointed out that all the known granulite provinces in this shield occur to the east of this lineament. According to these authors, the PDZ represents an ancient suture marking a collision of a northwesterly moving "Indian Plate" with another crustal block and its westward subduction. They pointed out that the most of the granulite facies rocks of N.Gujarat and Sandmata Complex of Rajasthan are bounded by tectonic planes or/and occur in the vicinity of PDZ. Based on the existing geological knowledge of the region and geophysical data, they suggested that these granulite terrains in fact represent tectonic slices or slivers uplifted due to obduction in the late stage of the Delhi orogeny and suggested a possible subsurface continuation of the granulite facies terrain of N.Gujarat with the Sandmata Complex of Rajasthan and hence assigned Archaean age to these rocks.

Biswal et al (1996) worked on the pelitic rocks of the area SE of Amirgarh and Mawal and suggested that granulite facies metamorphism is post F1-F2 stage of folding and was due to emplacement of gabbro-norite-basic charnockite intrusive in the area.

I.3b *Workers in the adjacent areas*

Coulson (1933) summarised the geology of Sirohi State and stated that majority of the area is occupied by igneous rocks (mostly granitic) and identified four basic phases, two acid phases and an angular unconformity between Aravallis and Delhis.

The first basic phase, according to him, occurred during the Aravalli time and represented by basic tuffs and lavas interbedded with Aravalli metasediments. The second basic phase according to him was Delhi or post-Delhi but pre-Erinpura granite. The third basic phase was post-Erinpura granite but pre-Malani. The last basic phase was a minor post-Malanis. The first major acid igneous phase is represented by Erinpura Granite of gigantic magnitude. The second acid igneous phase is represented by the Malani volcanics (rhyolites etc.)

Sharma and Nandi (1934) classified the basic rocks of Ambaji - Danta area according to their structural and mineralogical characteristics and suggested three phases of basic igneous activity in this area during the post Aravalli period (Table-I). The oldest intrusives, according to them, are more metamorphosed than the younger ones. They classified these into epidiorites, hornblende schists and pyroxene granulites

The second phase of igneous intrusion according to them, is marked by the meta-gabbro and meta-dolerite which respectively occur as intrusive masses and dykes in the granitoid gneisses. These are far less metamorphosed than the older pyroxene granulites described above.

The third phase of igneous intrusives in Danta area is devoid of any metamorphic imprints. These comprise olivine dolerites and olivine basalts which occur as dykes and sills traversing the calc gneisses and calc schists of Delhi Supergroup. These are probably Post-Erinpura granite in age.

Table-I

Younger Intrusives	Olivine dolerites and olivine basalts	Post-Erinpura Granite
Older Intrusives	Meta-gabbro and meta-dolerites	Post-granitoid gneisses
Oldest Intrusives	Pyroxene granulites, epidiorites and hornblende schists	Post-Aravalli but Pre-granitoid gneisses.

According to **Deshpande et al. (1970)**, the mineral assemblages of Danta area are indicative of metamorphic conditions transitional between hornfels and granulite facies, within the Japan type of metamorphism of Hietanen's metamorphic series. The pressure range between 2 and 3 kbars and temperature of about 700°C is indicated The existence of conditions transitional between the granulite facies and the hornfels may probably be due to the emplacement of Erinpura granite that outlasted the regional metamorphism.

Deb et al. (1989) estimated the model Pb isotope ages of 1010 Ma for the syngenetic ores of the sediments comprising Ambaji-Deri deposits (northeast of the study area) and hence the direct age of the South Delhi Fold Belt (SDFB).

Based on the juxtaposition of mineral assemblages characteristic of two different metamorphic facies (mineral assemblage of almandine amphibolite facies interlayered with those of granulite facies) together with superimposition of thermal metamorphism (due to Erinpura granite), **Limaye and Desai (1995)**, suggested Danta area to be a polymetamorphic terrain with two metamorphic events that predated and synchronised with Delhi deformation.

While describing the bimodal volcanism in Jharivav area of Amba Mata region of Delhi fold belt of N.Gujarat, **Deb et al. (1995)** identified a suite of differentiated felsic lava. On the basis of such features as general lack of schistosity and physical attributes like highly scoriaceous nature, development of pillow breccia etc. and other volcanic structures in the felsic rocks, they suggested sub-aqueous emplacement under low hydrostatic pressure during the waning phases of regional metamorphism in the region.

I.4 PREVIOUS INVESTIGATIONS IN METAMORPHIC TERRAINS OF N.W.INDIA

Fermor (1936) Presented a possible correlation of the ancient schistose Formation of Peninsular India.

Gupta (1934) identified granulite facies rocks in Mewar (Sandmata) area of Rajasthan.

Heron (1953) classified the Precambrian rocks of Rajasthan and Gujarat into Banded Gneissic Complex (BGC), represented by migmatites, schists, gneisses, and granite of Archaean age, overlain successively by Aravalli and Delhi Series of rocks and intruded by Erinpura granite and Malani Volcanics and granite (Proterozoic).

Crawford (1970) proposed that, metamorphism is most intense along the Aravalli lineament, where it is of amphibolite facies near Ajmer (Rajasthan) increasing to granulite facies southwards into Gujarat. Powar and Patwardhan (1984) also reiterated this view.

Rode, Pandya and Deshmukh (1969) reported charnockites and other granulite facies rocks from Bhim - Karera region of Rajasthan.

Gyani (1970, 1971) & Gyani and Omar, 1996) identified granulite facies rocks in Bhinai - Bandanwara - Gyangarh area of Rajasthan. They carried out detailed studies of these rocks particularly regarding geo-thermobarometry and geochemistry.

Raja Rao et al (1971) named the Archaean basement complex rocks of Rajasthan as Bhilwara Supergroup.

MacDougall et al (1983) dated the older mafic enclaves within BGC as 3 5 Ga

Sychanthavong and Merh (1984) propounded a proto-plate tectonic model to explain the very complex geological evolution of the Delhi rocks and their underlying basement. They contested the interpretations of Heron and later workers.

According to them

1. Delhi rocks were not deposited in an intracratonic autogeosyncline (over a landmass of BGC, Bundelkhand and Aravallis)

2. Aravallis with some part of BGC and Delhis represent a continuous metasedimentary sequence of deposition on the platform along the margin of Bhilwara craton. Instead of vertical tectonics, they proposed oceanic plate subduction outsetting F1 (first folding), M1 (first metamorphic event) and I1 (first igneous activity) developments. According to them, the upliftment of Delhi rocks forced the subduction zone to shift forming a new zone of marginal plate deformation of F2, M2 and I2. F3, M3 and I3 developed on account of continental plate collision between cratonic India and Africa, during the unification of Pangean Continent (Gondwanaland). Due to superimposition of three events of wide range, age of mineral assemblage and intrusion is seen.

They divided the mafic rocks of Delhi Supergroup in Banaskantha and Sabarkantha districts of N.Gujarat on the basis of their modes of occurrence and petrology as under :

1. Ortho-amphibolites and granulites occupy the fold cores of the macroscopic anticlinal folds.

2. Ortho-amphibolites and pyroxene / hornblende granulites occupy the NNE-SSW trending zones of longitudinal dislocations and occur in close association with serpentinites and peridotites

3 Olivine gabbros, olivine dolerites and andesites occupy the zones of NNE-SSW as well as WNW-ESE trending fractures.

Metamorphic Evolution

On the basis of petrological studies they established three metamorphic events namely M1, M2 and M3 as described earlier. Delhi rocks of Sabarkantha and Banaskantha districts of N.Gujarat i.e. Posina-Kherod-Ambaji-Balaram-Abu Road-Bhatana-Kapasia show amphibolite and granulite facies metamorphism. The mineral assemblages show polymetamorphism too. They further mention that the low pressure-high temperature belts show a very wide distribution in the Precambrian terrains of all the continents, while the intermediate or low pressure - medium pressure belts adjacent to them are only sporadic and are related to and depend upon the plate tectonics which controlled the continental growth during that eon. The high P - low T belt in this part of Precambrian terrain has been obscured by later metamorphic episode of low - pressure - high temperature mineral assemblages. There are some assemblages which have survived as relict minerals of high pressure - low temperature character. These minerals are stable under the new conditions of such metamorphic event. This metamorphic superimposition has considerably obscured the original picture and brought about confusion in the recognition of paired metamorphic belts. The sporadic remnants of high pressure minerals no doubt betray the original presence of high pressure - low temperature belt in this Precambrian terrain of Gujarat and Rajasthan.

Ramakrishna (1986) and Reddy & Ramakrishna (1988) interpreted the gravity data of Rajasthan and Gujarat shield and estimated the depth of Moho as 37 km under the horst and shallower Moho depths of 34 km on either side of horst and suggested rise of Moho on shoulders of horsted central block. High gravity domains, trending in NNE-SSW direction were suggested to represent the basement horsts which are bounded to their NW by a nearly vertical fault (trending NNE-SSW) and to their southeast by a gentle southeasterly dipping fault. According to them, the low gravity areas to the NW of these horsts represent the complementary trench or graben or trough. A gravity lineament trending NNE-SSW separates the horsts from the trenches. The highest gravity values of +35 to +40 mgal in their Bouguer gravity map occur in the area northeast of Palanpur in N.Gujarat (just south of the area of present research). They estimated the depth of these basement highs (horsts) to be 11.1 km while in the gravity non-anomalous areas the depth to the basement as 23.5 km. For these estimations a density contrast of 0.23 gm/cc was suggested assuming the density of supra-crustals as 2.67 gm/cc and that of older uplifted crust (basement) to be 2.9 gm/cc, to explain the gravity anomaly. The significance of geophysical data is discussed elaborately in chapter-VIII.

Fareeduddin, Sharma and Bose (1991) reported the occurrence of tectonic slices of high grade rocks in Pilwa-Chinwali-Arath area NNW of Ajmer. According to them these high grade metamorphites occur in discontinuous strips over a distance of 25 km within the Alwar metasediments of middle amphibolite facies. As these granulite facies rocks are involved in all the deformational phases of the surrounding Delhi rocks, they suggest that the metamorphism and and emplacement event took place during the Delhi orogeny. Sharma (1988) is of the opinion that deep crustal rocks of Sandmata complex emplaced within the Archaean continental block of the BGC occur far away from Delhi fold belt and the granulite facies metamorphism is also an outcome of Delhi orogeny.

Gupta, Mathur and Arora (1992) reclassified BGC of Precambrian shield of Rajasthan into (i) Sandmata Complex, (ii) Mangalwar Complex and (iii) Hindoli Group in ascending order. These three together constitute the Bhilwara Supergroup of Archaean age (2 5 Ga - 3 0 Ga) The Sandmata Complex comprises granulite facies rocks (pelitic-, psammopelitic-, and calc-granulites, leptynites and charnockitic rocks represented by enderbite plutons). The Mangalwar Complex comprises migmatites and the associated greenstones (Mohanty and Guha, 1995). The Hindoli group comprises a younger greenstone sequence. The Bhilwara Supergroup is successively overlain by Aravalli Supergroup and Delhi Supergroup with distinct first order unconformities. Their map map of regional synthesis with the proposed stratigraphic lexicon is depicted in a generalized form in **Fig. 1.2.**

Sinha-Roy, Guha and Bhattacharyya (1992) examined the polymetamorphic granulite-facies pelitic gneisses of Sandmata Complex and concluded that these rocks are the basement for the Early to Middle Proterozoic Aravalli and Middle to Late Proterozoic Delhi sequences. According to them these granulite facies rocks are tectonically emplaced along ductile shear zones within reworked amphibolite facies greenstone-tonalite ensemble of the Mangalwar Complex (2.9 Ga). The mineral assemblages in the important rock types of the area are :

Enderbite-charnockite	Kf-Pl-Opx+Cpx-Gt+Hb+Bi
Migmatite gneiss	Qz-Bi-Hb-Pl+Mc
Porphyriticgranite	Qz-Bi-Pl-Pr+Gt (Anjana granite)
Two-pyroxene granulite	Opx-Cpx-Pl-Qz-Gt-Kf+Hb+Bi
Leptynite	Pl-Qz-Gt-Kf
Calc-granulite	Di-Gr-Fors-Wo-Br, Di-Cc-Sc-Qz, Tr/Act-Hb-Di-Kf-Qz
Pelitic granulites	Bi-Gt-Sil-Or-Pl-Qz, Hyp-Cd-Sp-Pl-Sil-Gt, Cd-Gt-Bi-Sil, Ged-Sil-Qz-Bi-St-Cd-+Ky-Gt

Mineral Abbreviations : Bi-biotite, Gt-garnet, St-staurolite, Sil-sillimanite. Ky-kyanite, Hb-hornblende, Opx-ortho-pyroxene, Cpx-clinopyroxene, Hyp-hypersthene, Pl-plagioclase, Kf-K-feldspar, Or-orthoclase, Mc-microcline, Cc-calcite, Sc-scapolite, Di-diopside, Wo-wollastonite, Tr-tremolite, Act-actinolite, Gr-grossularite, Fors-forsterite, Br-brucite, Cd-cordierite, Ged-gedrite, Sp-spinel, Qz-quartz.

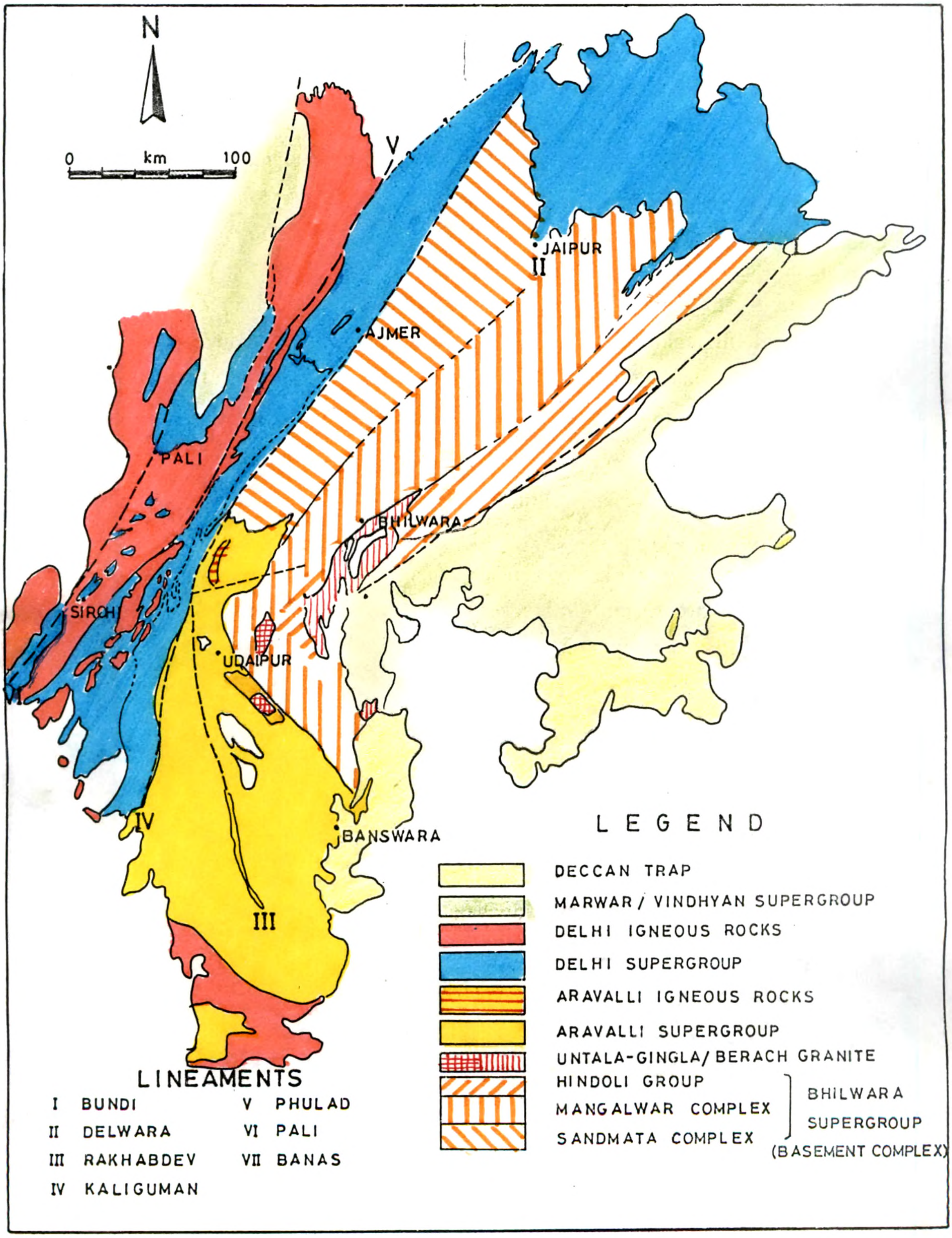

Fig. 1.2 Generalised Geological map of Precambrian rocks of Rajasthan and Gujarat (Modified from Gupta et al, 1992)

Fareeduddin (1995) reported tectonic strips of deep crustal metamorphites within the Anasagar migmatites to the northwest part of Aravalli-Delhi mobile belt. The high grade sequence comprises charnockite, pelitic granulite, 2-pyroxene granulite, leptynite, garnetiferous augen gneiss and garnetiferous amphibolite. These rock types are intruded by quartzo-feldspathic veins. P-T estimates of the co-existing mineral phases suggest (i) retrogressive presssures of 5.77 kb and 4.04 kb and temperatures of 650°C and 525°C for charnockite core and rim compositions respectively,. (ii) pressure of 9.5, 7.5 and 5.5 kb and temperature of ~630°C for pelites. He also suggested that granulite facies metamorphism predates Mid-Proterozoic thermal activity and that granulites formed either by dehydration melting reactions concomitant with migmatite formation or represent upthrust slices within amphibolite facies Anasagar migmatites

While discussing the polymetamorphic evolution of the Sandmata complex granulites, **Guha and Bhattacharyya (1995)** diagnosed two contrasting metamorphic events. The first high-grade (M1) metamorphic event (Archaean ?, before 1900 Ma) occurred before the onset of tectonic events and during widespread development of penetrative gneissosity (S1). The M1 metamorphism is coeval with widespread partial melt-forming event whereby stromatic migmatites and plutonic granodiorite bodies evolved. The second granulite facies metamorphism (M2), possibly at 1900-1723 Ma, accompanied the major ductile deformation and folding (D2-F2) and reworked the M1 granulites.

On the basis of mineral parageneses and phase equilibria studies, they suggested that M1 high-grade event occurred at 800-1000°C at 7-10 kb pressure in an "anticlockwise" P-T path, followed by isobaric cooling from 700-750°C at 8-10 kb whereby the infracrustal Sandmata Complex rocks were brought to a stable geotherm at intermediate crustal depth. In contrast, the second granulite metamorphism (M2) "reworked" the M1 high-grade granulites in a clockwise P-T-t path at 700-800°C and 4.5-5.5 kb during decompression of the M1 assemblages. They also suggested overthrusting of high-grade rocks (Sandmata complex) and underthrusting of the low- to medium-grade rocks (Mangalwar Complex) during Proterozoic fold belt evolution.

Mahadevan (1995) suggested that BGC has mid- lower-crustal features and may represent deep exhumed crustal segment.

According to **Sharma (1995)** the granulite facies metamorphism associated with the Aravalli Mountain Orogeny is Proterozoic and appears to predate the intrusion of 1723 Ma old granodiorite - charnockite co-magmatic series. He proposed an ensialic orogenesis model as against the plate tectonic model. Magmatic underplating is proposed by him to be responsible for granulite facies metamorphism. According tohim, 2.8 Ga old Untala granite and 2.6 Ga old Berach granite have crustal origin but the 3.3 Ga old tonalitic gneiss seems to be a product of upper mantle with possible crustal mixing.

While discussing geology, tectonics and crustal evolution of south-central Rajasthan, based on a transect across Rajasthan Precambrian terrain, **Sinha-Roy, Malhotra and Guha (1995)** suggested that major ductile shear zones (DSZ) and the thrust zones in the basement rocks are the responses to the crustal deformation linked with the closing of the Aravalli ocean basin. some of these thrust zones, particularly the Banas Dislocation zone (BDZ) and DSZ bounding the lower crustal Sandmata granulites are therefore, likely to be of deep crustal nature. They also suggested a west directed subduction generating the Phulad ophiolite etc. They gave tectonic profiles along the transects depicting deep crustal features as deduced from the geotectonic development of the craton. They synthesized a map of tectonic domains of South-central Rajasthan showing important dislocation zones **(Fig. 1.3)**. According to them, the rock types of the Sandmata complex are composed largely of granulite facies gneisses of diverse compositions e.g. meta-pelitic, meta-psammitic gneisses, basic intrusives and enclaves, clastic and chemogenic sediments which occur as xenoliths, streaks and patches and thrust bounded large bodies in the gneissic terrain. The Mangalwar Complex (M.C.) of the BGC terrain contains varied lithological assemblages and tectonic units of a "greenstone like" sequence now represented by ortho-amphibolites, highly diverse meta-sediments such as meta-pelitic and aluminous paragneisses, fuchsite bearing quartzite and low Mg-marbles and calc silicate gneiss, coarse clastics such as greywacke and tuffaceous sediments.

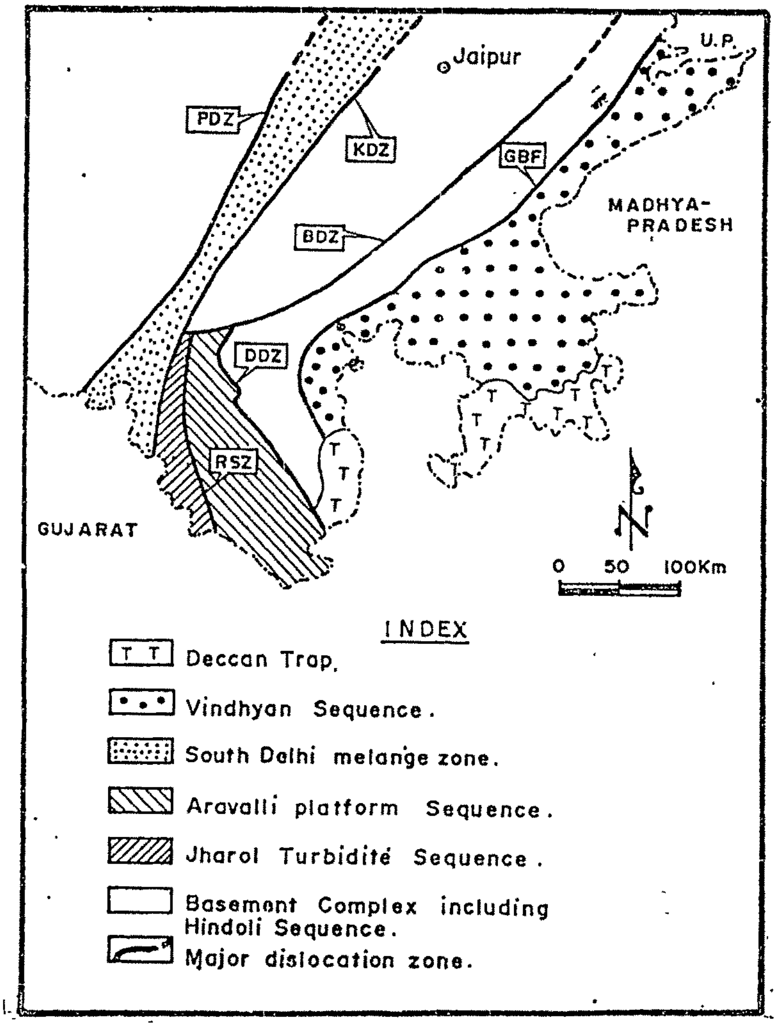

Fig.13. Tectonic domains of South-Central Rajasthan showing important dislocation zones. Geology of Northwest part after Kumar *et al.* (1992). South Delhi after Gupta *et al.* (1994) and Vindhyan Basin after Prasad (1984).