CHAPTER II

GEOLOGICAL FRAMEWORK

GEOLOGICAL FRAMEWORK

INTRODUCTION

The predominantly rocky and arid state of Rajasthan is unique from the point of view of its geology. Geologically this state constitutes the northwestern part of the Peninsular India comprising one of the oldest mountain chains of the earth, **'The Aravalli Mountain Range'**. Apart from this, it is perhaps the only state in India possessing a stratigraphy representing all the eras of the Geological Time Scale. The NE-SW trending Aravalli Mountain Range possibly marks a line dividing the older groups of rocks in the east and the younger ones in the west.

GEOLOGY OF RAJASTHAN

The geology of the entire Rajasthan area does not fall within the scope of this study. However, the continuity of outcrops, distribution pattern and lithology as well as numerous aspects of tectonism in the author's study area owe their characteristics to the regional features, spanning up to Delhi in the northeast, north Gujarat in the southwest and Jaisalmer in the west.

Since the times of the Britishers, the geology of Rajasthan had received the attention of earth scientists, which has resulted in the generation of voluminous valuable literature on various aspects of Geology.

Geologically, the Rajasthan region is characterised by a wide range of lithostratigraphic units, belonging to Proterozoic, Palaeozoic, Mesozoic, Tertiary and Quaternary eras . The Proterozoic rocks are predominantly confined to the mountain range and the peneplains of eastern Rajasthan, categorised as Bhilwara, Aravalli, Delhi, Vindhyan Supergroup of rocks and associated intrusives. The Palaeozoics are represented by the Marwar Supergroup of rocks. The Mesozoic, Tertiary and Quaternary group of rocks are of course, well developed; however, due to lack of continuity of surficial outcrops because of the dunal sand cover, these litho-units have not been assigned the Supergroup status. A brief account of the various lithostratigraphic units is given as under:

PROTEROZOIC ROCKS

Being the oldest sediments, the Proterozoics of Rajasthan have been studied in great detail. But the structural style and stratigraphy of these sediments remained full of intricacies and debate. However, it is the work of A. M. Heron (Heron 1917, 1932, 1936, 1953) which has provided the basic framework for the Proterozoic rocks of Rajasthan. His four-fold classification envisaging an overall evolution of these rocks through three orogenic cycles, still forms the basis for the stratigraphic classification. Later on, the detailed works carried out by Raja Rao (1967), Raja Rao *et al.* (1971), Crawford (1970), Roy (1988), Gupta *et al.* (1980, 1992), etc., have thrown further light on the knowledge about these Proterozoic rocks, which have now been given the status of Supergroup and are classified as:

- The Bhilwara Supergroup (3200-2500 M.y.)
- The Aravalli Supergroup (2500-2000 M.y.)
- The Delhi Supergroup (2000-800 M.y.)
- The Vindhyan Supergroup (700 -600 M.y.)

Each Supergroup is well defined by regional unconformities and/or structural discordances. The details on the various folding events reported within the Proterozoic rocks of Rajasthan can be summarised as under:

Proterozoic folding events in Rajasthan

Events	Trend	BGC/Aravalli	Delhi	Post-Delhi (Malani & Vindhyans)
F_1	E-W	AF_1	-	-
F_2	NNE-SSW	AF_2	DF_1	-
F_3	NNE-SSW	AF_3	DF_2	Present
F_4	ESE-WNW	AF_4	DF_3	Present

Bhilwara Supergroup

The rocks of the Bhilwara Supergroup (formerly the B.G.C.) constitute the basement for the massive younger lithological sequences. The main rock types are various gneisses, schists, amphibolites, ultramafics and associated intrusives. The Bhilwara Supergroup of rocks are predominantly occurring in the eastern and southeastern parts of Rajasthan around Bhilwara, Ajmer, Nathdwara, Mangalwar, east of Rakhabdev etc. These rocks exhibit a complex history of structural style and polyphase metamorphism. The details on the subdivisions of the Bhilwara Supergroup, their lithologies and associated intrusive bodies are given in Table 2.1.

Aravalli Supergroup

The sediments of the Aravalli Supergroup, unconformably overlying the pre-Aravalli (Bhilwara Supergroup) rocks, mainly include the rocks of the Aravalli system and Raialo series put forward by Heron (1953). The Aravalli Supergroup of rocks in their type area around Udaipur and South Rajasthan are composed of pelitic and calcareous metasediments with basic flows. These rocks have undergone polyphase deformation and metamorphism. A number of lithostratigraphic units have been recognised in the Aravalli rocks of both shelf and deep sea facies (Paliwal, 1981 and Roy, 1990). The rocks of Aravalli Supergroup show a complex deformation history, and have

Table 2.1 Litho-stratigraphy of the Bhilwara Supergroup (3500 M.y. to 2500 M.y.)

Group	Lithology	Intrusives
Hindoli/Sawar	Slate, phyllite, metagreywacke and metavolcanics	Pegmatites, granites and basic rocks (Berach, Untala and Gingla granites)
Mangalwar Complex	Migmatite, composite gneisses, feldspathised mica-schists, schists, amphibolite, dolomite, dolomitic marble and quartzite	
Sandmata Complex	Migmatite, biotite schists, gneisses, amphibolite, pyroxene-granulite, dolomitic marble and ultramafic rocks	

undergone four phases of folding *viz.*, AF_1, AF_2, AF_3 and AF_4 (Naha and Halyburton, 1977; Naha *et al.* 1967, 1984). The Aravalli sediments are also characterised by a number of ductile shear zones and brittle faults. The rocks of Aravalli Supergroup are also intruded by the Udaipur and Darwal granites in Udaipur area and ultramafic intrusives in Rakhabdev, Gogunda areas.

The Aravalli Supergroup of rocks have been further subdivided into Groups and Formations. A detailed lithostratigraphic classification, as proposed by Gupta *et al.* (1992) is given in Table.2.2.

Delhi Supergroup

Lying unconformably over the older sediments of Bhilwara and Aravalli Supergroups, the Delhi Supergroup of rocks form a major constituent of the Aravalli Mountain Range. These marine clastics with subordinate chemogenic sediments are characterised by a number of concordant/ discordant intrusive as well as extrusive phases. The rocks of the Delhi Supergroup extend in a NE-SW trending rectilinear belt from Delhi in the north to Himmatnagar in the south for almost 850 km length. These rocks forming the Aravalli orographic axis separate the plains of Marwar in the west from the hilly tract of Mewar in the east. They punctuate in the desert sands in Northeast Rajasthan and from north of Sambhar lake, continue as isolated ridges into the main expanse of Delhi's in northeastern Rajasthan. In the southwest beyond Himmatnagar the solid geology is lost under the alluvial cover.

The rocks of the Delhi Supergroup were affected by multiple episodes of folding *viz.*, $DF_1(AF_2)$, $DF_2(AF_3)$, and $DF_3(AF_4)$ (Naha *et al.*, 1984, 1987; Sychanthavong and Merh 1984, 1985; etc.) and polyphase metamorphism. The sedimentary and volcanic rocks of the Delhi's are found to have recrystallised first under regional metamorphism (up to amphibolite facies), which was later superimposed by the thermal metamorphism (hornblende-hornfels facies).

The important granitic bodies within the Delhi Supergroup include: (i) the Erinpura granites, (ii) the Sendra granites, (iii) the Ambaji granites and (iv) the Kishangarh syenites.

Table 2.2 Litho-stratigraphy of the Aravalli Supergroup of rocks (2500 M.y. to 2000 M.y.) [after Gupta *et al.*, 1992]

<table>
<tr><th colspan="3">Group</th><th colspan="4">Formation</th><th>Lithology</th></tr>
<tr><td colspan="3">CHAMPANER GROUP</td><td colspan="4">Rajgarh Formation
Shivrajpur Formation
Jaban Formation
Narukot Formation
Khandia Formation
Lambia Formation</td><td>Metasubgraywacke, phyllite, mica schist, quartzite, gneiss and petromict metaconglomerate, minor dolomitic limestone and manganiferous phyllites</td></tr>
<tr><td colspan="3">LUNAWADA GROUP</td><td colspan="4">Kadana Formation
Bhukia Formation
Chandanwara Formation
Bhawanpur Formation
Wagidora Formation
Kalinjara Formation</td><td>Phyllite, mica schist, quartz-chlorite schist, metasubgraywacke, metasiltstone, metasemipelite, metaprotoquartzite and quartzite with minor dolomitic limestone, petromict metaconglomerate, manganiferous phyllite and phosphatic algal dolomite</td></tr>
<tr><td colspan="7">SYNOROGENIC GRANITE AND GNEISS
RAKHABDEV ULTRAMAFIC SUITE</td></tr>
<tr><td>A
JHAROL
GROUP</td><td>B
DOVDA
GROUP</td><td>C
NATHD-
WARA
GROUP</td><td>A
Samalaji Fm.
Goran Fm.</td><td>B
Devthari Fm.
Dapti Fm.</td><td>C
Rama Fm.
Haldighati Fm.
Kodamal Fm.</td><td></td><td>Phyllites, chlorite schist, garnetiferous mica schist, quartzite, minor calc-schist, marble, hornblende schist, biotite schist, amphibolite gneiss, migmatite, calc-silicates, minor dolomites, etc.</td></tr>
<tr><td colspan="2">A
BARI LAKE
GROUP</td><td>B
KANKROLI
GROUP</td><td colspan="2">A
Khamnor Fm.
Varla Fm.
Sajjangarh Fm.</td><td colspan="2">B
-
Sangat Fm.
Puthol Fm.
Rajnagar Fm.
Morchana Fm.
Madra Fm.</td><td>Basic metavolcanics, metamorphosed pyro-clastics and volcano-epiclastic rocks, quartz-pebble conglomerate, meta-arkose, quartzite, phyllite, metasiltstone, minor dolomite, chert, garnetiferous muscovite-biotite schist, hornblende schist gneiss, marble</td></tr>
<tr><td colspan="3">UDAIPUR GROUP</td><td colspan="2">Udaipur Sector
Banswara Fm.
Nimachmata Fm.
Balicha Fm.
Eklinggarh Fm.
Sabina Fm.</td><td colspan="2">Sarada Sector
Zawar Fm.
Baroimogra Fm.
Mandli Fm.
-
-</td><td>Phyllite, metagraywacke, mica schist, migmatite, quartzite, dolomite, marble, phosphatic stromatolite bearing dolomite, chert and amphibole schist</td></tr>
<tr><td colspan="3">DEBARI GROUP</td><td>Debari
Sec.
Jhamarkotra
Fm.
Berwar
Fm.
Jaisamand
Fm
Delwara
Fm
Gurali
Fm.</td><td>Jaisamand
Sec.
Babarmol
Fm.
Dokankotra
Fm.
Jaisamand
Fm
Delwara
Fm
-</td><td>Sarara Ki
Pal Sec.
Kathalia
Fm
Sisamogra
Fm
Nathania Ki
Pal Fm
-

Basal
Fm</td><td>Ghatol
Sec.
Jagpura
Fm.
Mukandpura
Fm.
Jaisamand
Fm.
Delwara
Fm
Gurali
Fm</td><td>Petromict conglomerate, meta-arkose, quartzite, phyllite, mica schist, basic metavolcanics with associated pyroclastics, calcareous quartzite, dolomites, limestone, calcitic marble, ferruginous chert, algal phosphatic dolomite and chert, carbonaceous and manganiferous phyllite</td></tr>
</table>

The Delhi Supergroup of rocks have been further classified into various groups, belonging to different sectors. An overall lithostratigraphic sequence as envisaged by Gupta *et al.*(1992), is given in Table 2.3.

Vindhyan Supergroup

Lying unconformably over the Aravalli Supergroup of rocks is a thick pile of siliceous, argillaceous and calcareous sedimentary sequence designated as **The Vindhyan Supergroup**. These sedimentaries, on account of their structural discordance with the Delhi sediments, have been considered to be the last member of the Proterozoic era; deposited in the eastern margins of the Aravalli orogenic complex around Chittaurgarh, Bundi, Kota and Sawai Madhopur in eastern Rajasthan. At Chittaurgarh and further northeastward, these horizontally to sub-horizontally disposed Vindhyans are seen in contact with the highly folded Aravalli rocks, which is attributed to a major fault *viz.*, 'The Great Boundary Fault' (GBF). A generalised stratigraphy of the Vindhyan Supergroup of rocks is given in Table 2.4.

IGNEOUS INTRUSIVES/EXTRUSIVES

The rocks of the Bhilwara, Aravalli and Delhi Supergroups have been influenced by the episodic intrusions of igneous activities, either synchronous to the folding event and/or in the waning phase of the deformation. Few important igneous intrusives having significant bearing on the geological evolutionary history of the Rajasthan Proterozoics are as under:

Bhilwara Supergroup: These basement rocks have been intruded by the acidic igneous activity around 2060 Ma. coinciding with the E-W Aravalli-B.G.C. folding (AF_1) and metamorphism (Sharma *et al.*, 1980). These potassic to granodioritic-tonalitic granites *viz.*, the Berach, Untala and Gingla granites are occurring within the type area.

Aravalli Supergroup: The igneous activities associated with the Aravalli sediments are characterised by the magmatic materials of doleritic, epidioritic, basaltic sill and dyke type, ultramafic, amphibolitic and granitic composition. The Udaipur, Amet and Darwal granites are

Table 2.3 Litho-stratigraphic classification of Delhi Supergroup (after Gupta *et al.*, 1992)

<table>
<tr><th></th><th>South-western Rajasthan and North-eastern Gujarat</th><th>Ajmer Sector</th><th>North-eastern Rajasthan</th></tr>
<tr><td rowspan="3">INTRUSIVES (Post Delhi)</td><td colspan="2">MALANI IGNEOUS SUITE
Plutonic and volcanic</td><td rowspan="3"></td><td rowspan="3"></td></tr>
<tr><td colspan="2">ERINPURA GRANITE</td></tr>
<tr><td colspan="2">GODHRA GRANITE GNEISS</td></tr>
<tr><td rowspan="7">DELHI SUPERGROUP 2000 - 740 M.y.</td><td>PUNAGARH GROUP (Sojat, Bambolai, Khambal and Sowania Formations)</td><td>SINDRETH GROUP (Angor and Goyali Formations)</td><td rowspan="3"></td><td rowspan="4">DADIKAR, BAIRATH AND SIKAR GRANITES</td></tr>
<tr><td colspan="2">SIROHI GROUP (Jiyapura, Reodhar, Ambeshwar and Khiwandi Formations)</td></tr>
<tr><td colspan="2">SENDRA AMBAJI GRANITE AND GNEISS</td></tr>
<tr><td colspan="2">PHULAD OPHIOLITE SUITE</td><td>KISHANGARH SYENITE</td></tr>
<tr><td colspan="2">KUMBHALGARH GROUP (Todgarh, Beawar, Kotra, Ras, Barr, Sendra, Kalakot and Basantgarh Formations)</td><td>AJABGARH GROUP (Ajmer Formation)</td><td>AJABGARH GROUP (Kushalgarh, Sariska, Thanagazi, Bharkol and Arauli Formations)</td></tr>
<tr><td colspan="2" rowspan="2">GOGUNDA GROUP (Richer, Antalia and Kelwara Formations)</td><td rowspan="2">ALWAR GROUP (Srinagar and Naulakha Formations)</td><td>ALWAR GROUP (Rajgarh, Kankwarhi, Pratapgarh, Nithar, Badalgarh and Bayana Formations)</td></tr>
<tr><td>RAIALO GROUP (Dogeta and Tehla Formations)</td></tr>
</table>

the important granitic bodies emplaced around 1600 ± 50 Ma., coinciding with the $DF_1(AF_2)$ folding (Sharma *et al.*,1980).

Delhi Supergroup: Perhaps the igneous activities followed by the uplift of Delhi Supergroup rocks during the last stage of $DF_2(AF_3)$ was the major one, affecting large areas of Aravalli proto-continent. The leuco-granites of Bairath, Sikar, Sendra, Erinpura, Ambaji and Godhra, covering the entire mountain range, are testimony to this massive event, which took place around 900 ± 50 Ma and these are found throughout the Alwar and Ajabgarh groups (Sychanthavong and Merh, 1984). Apart from these granitic bodies, these metasediments have also witnessed intrusions of metabasics, metavolcanics, ultramafics and nepheline syenites.

Malani Igneous Suite

This extensive magmatic event has been emplaced during different phases of DF_3 (AF_4) folding (Sychanthavong and Merh, 1984) around 700 ± 50 Ma. (Sharma *et al.*,1980). These rocks mainly occupy vast tracts to the west of the Aravalli Mountain Range. The extrusive phase of these Malani's consists of tuffs, welded tuffs, rhyolites, rhyolite porphyry and mafics; whereas the intrusive phase comprising the Jalore and Siwana granites is relatively of younger age, i.e., 600 M.y. (Crawford, 1970). Recently, the work carried out by Rathore, 1994 (personal communication), on the Malani Igneous Suite, confirms the emplacement of these rocks in different phases. According to Rathore, the Malani intrusives and extrusives are the products of three major activities which took place in the time span between 780 M.y. and 640 M.y. However, the Mundwara Igneous Complex gives a very young age and perhaps can be taken as contemporaneous to the Deccan Trap activity.

PALAEOZOIC ROCKS

Forming the Aravalli and Delhi Supergroup of rocks as the easternmost boundary and the Malani Igneous Suite as the southern boundary, the arid terrain of Western Rajasthan formed an extensive basinal setup from Cambrian to Tertiary. These major depositional basins *viz.*, (i) Marwar Basin - Cambrian, (ii) Bap-Badhaura Remnant - Permian, (iii) Lathi Basin - Lower

Jurassic, (iv) Jaisalmer Basin - Mesozoic and Tertiary, (v) Palana-Ganganagar shelf - Tertiary, and (vi) Barmer Basin - Cretaceous-Tertiary were responsible for accumulating an enormous thickness of sedimentary sequence of marine and deltaic environment (Pareek, 1981).

Marwar Supergroup

The rocks of the Marwar basin, owing to their vast aerial coverage and over 1000 m thick sequence of horizontally disposed sedimentaries, have been given the status of Supergroup, *viz.*, the **Marwar Supergroup**. These sedimentaries overlying the Malani Igneous Suite comprise the arenaceous Jodhpur Group, the calcareous Bilara Group and the arenaceous Nagaur Group (Khan and Sogani, 1973).

In the western extremity of the Rajasthan shelf, i.e., Barmer area, a thick sedimentary sequence (Birmania Basin) lying unconformably over the Malani igneous rocks has been correlated with the Jodhpur and Bilara Groups of Marwar Supergroup. These rocks which have been designated as the Birmania Group comprise an older arenaceous (*Randha*) sequence and a younger calcareous (*Birmania*) sequence. The Birmania Group of rocks exhibit more or less similar lithologies to their counterparts of the Marwar Supergroup. These rocks also exhibit open folds having NNE-SSW strike with 35° - 80° dip towards west (Mukthinath, 1969).

The rocks of the Marwar Supergroup have been correlated with the Cambrian sequence of Upper Indus Basin, Salt Range and have been assigned an age of 600 - 500 M.y.(Wensink, 1975a & b and Pareek, 1981). The overall lithostratigraphy of the Marwar Supergroup with overlying late Palaeozoic rocks is given in Table 2.5.

Bap-Badhaura Remnant

A NE-SW trending narrow stretch extending between Nokhra and Bap is represented by the glacially striated bouldery-cobbly formation - the Bap Boulder Beds and the solitary outcrop of marine sedimentaries - the Badhaura Sandstone (Misra *et al.*,1962). The Bap remnants comprise

Table 2.4 Generalized litho-stratigraphy of Vindhyan Supergroup (after G.S.I., 1980)

Group	Lithology	Thickness (m)
Bhander	Shales, limestones, dolomites and sandstones	1000
Rewa	Shales, sandstones and conglomerate	2000
Kaimur	Quartzite-gritty to conglomeratic, shales, breccia, sandstones, mudstones and siltstones	400
Semri	Shales, limestones, sandstones with basal quartzite and conglomerate	300-900
Unconformity		
Aravalli Supergroup		

Table 2.5 Litho-stratigraphy of Palaeozoic rocks in Western Rajasthan

Period and Age (M.y.)	Marwar Basin		Birmania Basin	
	Group*	Lithology	Group	Lithology
Permian (180)	Badhaura	Sandstone	-	-
	Bap (Remnants)	Striated boulders and cobbles	-	-
Cambrian (600-500)	Nagaur*	Sandstone, siltstone, claystone	-	-
	Bilara*	Limestone and dolomite	Birmania	Limestone
	Jodhpur*	Sandstone, shale	Randha	Sandstone
Malani Igneous Rocks				

gravels and cobbles of phyllite, slate, quartzite, granite, tuffs, rhyolites and amphibolites of Precambrian domains; and limestone and dolomite of Marwar Supergroup.

The Badhaura remnants comprising an intercalated sequence of variegated sandstones, shales, clays and siltstones, include a variety of faunal remains of Permian age. These sedimentaries have been subjected to extensive pre-Jurassic erosion and exist only as remnants.

MESOZOIC ROCKS

The Mesozoics in Rajasthan are represented by the sedimentary sequences belonging to the **Lathi, Jaisalmer, Barmer basins and the Palana-Ganganagar shelf** (Narayanan, 1964; Dasgupta, 1975). These Mesozoic sediments are seen overlying the rocks of the Malani Igneous Suite, the Marwar Supergroup and the Bap-Badhaura remnants of Permian age. They cover a vast stretch extending from Barmer in the south to Mohangarh in the north and Jaisalmer in the west to Lathi in the east.

Jurassic Rocks

The NNE-SSW striking gently dipping freshwater sedimentary sequence in Western Rajasthan has been designated as the *Lathi Formation*. These sedimentaries, with an aggregate thickness of more than 400 m, comprise coarse grained and current bedded sandstones, conglomerates, arose, lithic arenites, siltstones and shales with ferrugenised bands and haematitic nodules. They are also characterised by an abundance of dicot fossil woods (La Touche, 1902; Pandey, 1993).

Cretaceous Rocks

The rocks belonging to the Cretaceous period represent a marine sedimentary sequence of Jaisalmer and Barmer Basins. In the **Jaisalmer Basin**, these Cretaceous sediments comprise *Jaisalmer limestone, Baisakhi shale, Bedesar sandstone, Parihar sandstone* and *Abur limestone* (Dasgupta, 1975). The aggregate thickness of these sedimentaries exceeds 700 m and are characterised by numerous faunal fossil assemblages.

In the **Barmer Basin**, the Cretaceous rocks are represented by a solitary outcrop, the '*Fatehgarh Sandstone*' overlying the Lathi sandstone. These rocks comprise ferruginous sandstone, conglomerate, phosphatic sandstone and mudstone, with an aggregate thickness of 50m. The stratigraphic succession of these Mesozoic sediments is given in Table 2.6.

CENOZOIC ROCKS

The sedimentary sequences representing the Palaeocene and Eocene periods of Cenozoic Era in Western Rajasthan depict deltaic conditions followed by marine transgression.

In the Jaisalmer Basin, the Tertiaries comprise the sedimentary sequence of:

(i) *Sanu Sandstone* with intercalated clayey horizons and ferruginous shales deposited under freshwater conditions.
(ii) *Khuiala Limestone* comprising fossiliferous sandstone, siliceous limestones, Fuller's earth and varieties of limestones deposited under marine conditions.
(iii) *Bandah Limestone* comprising fragmented limestone, bentonitic clays, ochreous marl and carbonaceous shales deposited under marine conditions.

In the Barmer Basin these Tertiary sediments having an aggregate thickness of 400 m are represented by:

(i) *Akli Bentonite*,
(ii) *Mandai Sandstone*, and
(iii) *Kapurdi Fuller's earth*.

The Palana-Ganganagar shelf comprises the *Marh Sandstone* and *Jogira Fuller's earth*, with an average thickness of 350 m.

The lithostratigraphic succession of the Tertiary sequences for all the three depositional basins in Western Rajasthan is given in Table 2.6.

Table 2.6 Lithostratigraphic succession of the Mesozoic-Tertiary sequence in the Rajasthan shelf area (after Pareek, 1981)

Age (M.y.)	System	RAJASTHAN SHELF		
		Jaisalmer Basin	Barmer Basin	Palana-Ganganagar Shelf
50	Lower-Middle Eocene	Bandah Formation (75 m)	Kapurdi Formation (30 m)	Jogira Formation (121 m)
	Palaeocene-Lower Eocene	Khuiala Formation (100 m)	Mandai Formation (100 m)	Marh Formation (210 m)
70	Palaeocene	Sanu Formation (75 m)	Akli Formation (265 m)	Palana Formation (> 120 m)
	Upper Cretaceous	-	Fatehgarh Formation (50 m)	
	Lower-Middle Cretaceous	Abur Formation (66 m)		
	Lower Cretaceous	Parihar Formation (305 m)		
130	Upper Jurassic	Bedesar Formation (65 m)		
	Middle Jurassic	Baisakhi Formation (150 m)		
		Jaisalmer Formation (150 m)		
	Lower Jurassic	Lathi Formation (450 m)	Lathi Formation (330 m)	

These Tertiary sedimentary sequences as well as the older lithostratigraphic units are overlain by the Quaternary sediments of fluvial, aeolian, lacustrine and residual origin. A detailed account on their nature, mode of occurrence, distribution and their sequence stratigraphy is dealt separately in the proceeding chapter on 'Quaternary Geology'.

GEOLOGY OF THE STUDY AREA

It has already been stated that the study area predominantly constitutes a part of the Trans-Aravalli terrain of Western Rajasthan, comprising the lithostratigraphic sequences of Proterozoic, Palaeozoic, Cenozoic and Quaternary eras. Hence, the geological setting of the study area owes its characteristics to the regional geological framework. Based on the work carried out by various geologists, the author has compiled the pre-Quaternary lithostratigraphy of his study area (Table 2.7), and prepared the geological map of the study area (Fig. 2.1).

PROTEROZOIC ROCKS

The Proterozoic rocks in the study area comprise the lithologies belonging to the Delhi Supergroup and Post-Delhi intrusives. These rocks have been studied in great detail by numerous workers, *viz.*, Hacket (1881), Heron (1917,1932,1953), Dasgupta (1964), Raja Rao *et al.* (1971), Sen (1971), Gangopadhyay (1972), Ray (1976), Sychanthavong and Desai (1977), Naha *et al.*(1984), Sinha Roy (1984,1988), Powar and Patwardhan (1984), Roy and Das (1985), Roy (1988), Singh (1988), Deb and Sarkar (1990), Sychanthavong (1990), Gupta *et al.* (1992) etc.

Delhi Supergroup

The Delhi basin of northeastern Rajasthan is characterised by a number of fossil horsts, grabens and arches, broadly constituting three major sedimentation domains (Singh, 1984). These are, from west to east, the **Khetri**, **Alwar** and **Bayana-Lalsot sub-basins**. The Delhi Supergroup in this part rests on a high grade heterolithic pre-Delhi sequence with a well marked unconformity defined by angular relationship between the two and a thick conglomerate sequence at the base of the former (Datta and Ravindra, 1980).

Table 2.7 Pre-Quaternary geological succession of the study area

Era	Supergroup	Group/Series	Lithology
Quaternary	-	-	Pleistocene-Recent Alluvium and aeolian sands
Unconformity			
Tertiary	-	Palana Series	Variegated clays, evaporites, Fuller's Earth, bentonite, lignite
Palaeozoic	Marwar	Nagaur Group	Sandstones, shales, siltstones, conglomerate, gravel
		Bilara Group	Limestone
		Jodhpur Group	Sandstones, shales, conglomerates
Unconformity			
POST-DELHI INTRUSIVES			Malani Rhyolites, Erinpura granite, migmatites, aplites, pegmatites
Precambrian	Delhi	Ajabgarh Group	Quartzites, biotite schist, calc-schists, calc-gneisses, phyllites, marble and conglomerate
		Alwar Group	Quartzites, phyllites, schists, calc-gneisses, marbles
		Rayanhalla Group	Banded siliceous marble, quartzites, phyllites, schists, conglomerates
Archaean	Pre-Aravallis (Bhilwara)	-	Baded Gneissic Complex (BGC), unclassified gneisses and granites, schists, amphibolites, dolomitic marble, subordinate metasediments, migmatites, pegmatites, etc.
BASE NOT SEEN			

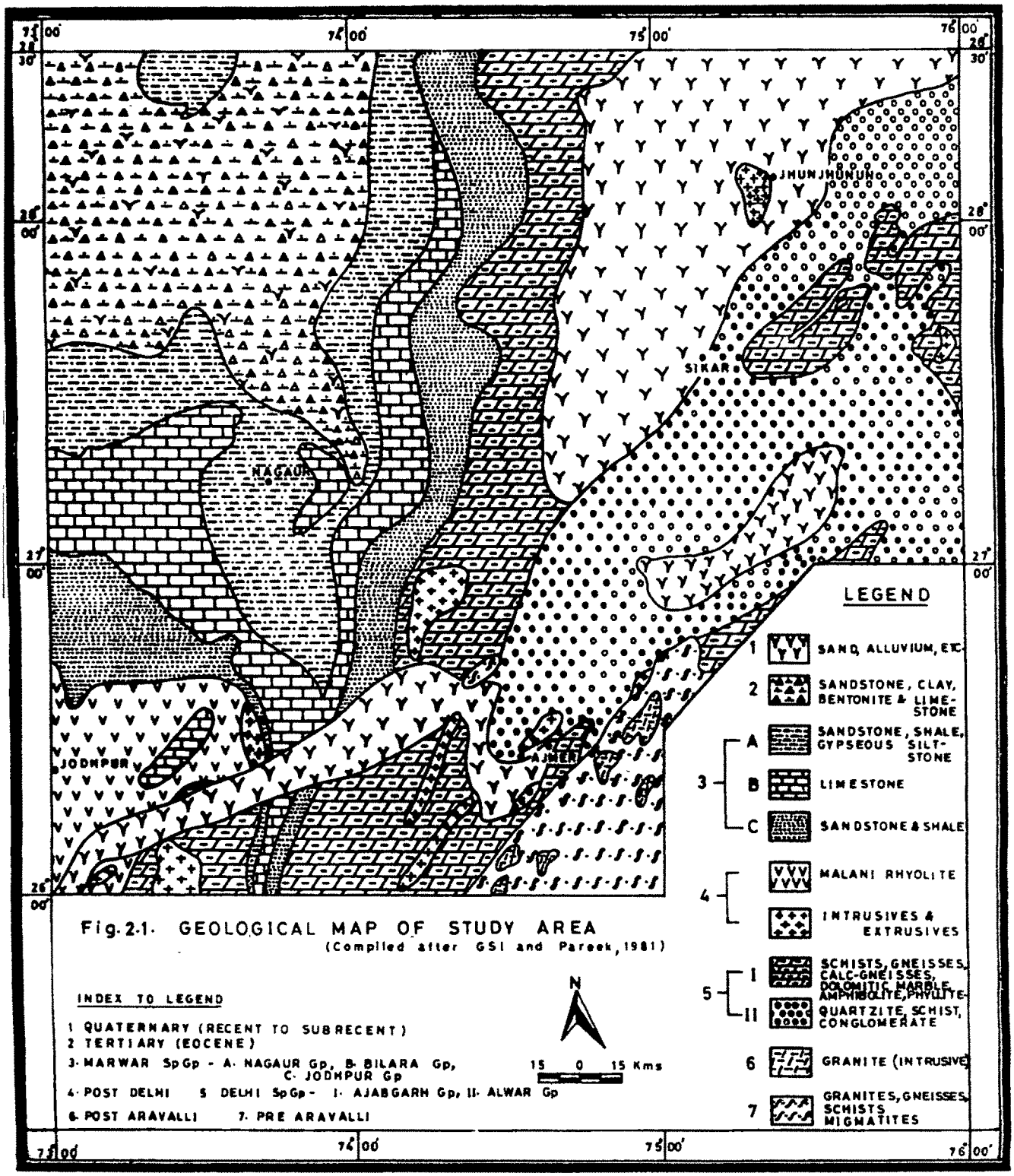

Fig. 2.1. GEOLOGICAL MAP OF STUDY AREA
(Compiled after GSI and Pareek, 1981)

Stratigraphically the Delhi Supergroup of rocks have been divided into three distinct Groups, separated from each other by unconformities. These are:

1. an uppermost Ajabgarh Group (commonly pelitic with metavolcanics).
2. a middle Alwar Group (predominantly arenitic with metavolcanics).
3. a basal Rayanhalla Group (a new name proposed for the Raialo series of Heron, 1917, present in the Alwar basin; a dominantly carbonate-metavolcanic-arenite association.)

Rayanhalla Group

The rocks of the Rayanhalla group unconformably overlie a metamorphic-granitic assemblage of pre-Delhi age. ("Aravallis" of Heron, 1917; "pre-Aravallis" of Sant and Sharma, 1973) and is overlain unconformably by the conglomerate-quartzite sequence of basal Alwar Group. Seen developed in a localised area in the northeastern extremity of Rajasthan, this lithological sequence which had been earlier correlated with the pre-Delhi calcareous sequence of main Aravalli synclinorium has now been given a status of separate Group (Gupta *et al.*, 1992).

The rocks of the Rayanhalla Group have been further divided into three formations (Singh, 1988), *viz.*

(i) *Dogeta Formation*: The Dogeta Formation is characterised by the rocks of banded siliceous marble, quartzite, phyllite, schists and conglomerates. A depositional sequence typically seen under carbon shale with barrier island environment is typical of this formation (Singh, 1988). The Dogeta Formation which constitutes an aggregate thickness of more than 900 m, is seen occurring in the study area near Ras and Makrana.

(ii) *Nithar Formation*: Lithologically this formation comprises quartzites, with intermittent lenses of oligomictic conglomerates, reflecting typical beach-tidal flat environment and has been defined as a separate formation by Singh (1984). The occurrence of these sequences are restricted to the eastern fringe of the Delhi Supergroup around Raialo village.

(iii) *Tehla Formation*: The Tehla Formation consists mainly of quartzite, phyllite, schists, marble etc with associated conglomerate. This formation maintains a gradational relation with the underlying Dogeta Formation. The rocks of the Tehla Formation are unconformably overlain by the rocks of the Alwar Group. The exposures of these formations are restricted to the area south of Alwar only.

Alwar Group

The rocks of the Alwar Group comprise metamorphosed ferruginous and arenaceous clastics with subordinate argillaceous and calcareous rocks and interlayered basic volcanics deposited in a mio-geosynclinal basin and resting unconformably over the Rayanhalla Group.

The Alwar Group of rocks in the study area are mainly confined to the NE-SW trending Aravalli Mountain Range. In the southwestern parts of the study area, these rocks are seen occurring as narrow discontinuous bands and is predominantly conglomeratic in composition. It attains significant aerial extent from Ajmer in the south and covers vast stretches upto Delhi in the northeast, having more than 100 km width up to Sikar, and with intermittent outcrops of post-Delhi intrusives. The continuity of these rocks in the western margins is concealed under a thick cover of aeolian material.

The lithological assemblage of Alwar Group has been further classified into three major formations, *viz.*, (i) lower *Rajgarh Formation*, (ii) middle *Kankwarhi Formation* and (iii) upper *Pratapgarh Formation*. (Sant and Sharma, 1973; Singh, 1988 and Gupta *et al.* 1992).

(i) *Rajgarh Formation*: This formation predominantly comprises conglomerates, arkosic quartzites, feldspathic quartzites and quartzites and has an aggregate thickness of more than 3000 m. At places these arenaceous sequences have phyllitic and schistose rocks at their base (Dasgupta, 1968). The quartzites are dominantly amphibolitic in nature. The rocks of this formation are mainly occurring in the central parts of the study area around Ajmer, Pushkar, Kishangarh, Sambhar etc.

The so called Barr conglomerate of Heron (1917), which has been considered as the base of the Alwars in south-central parts of the study area, has raised doubts due to the lack of typical conglomeratic features. According to Sychanthavong *et al.* (1989), it represents a flattened, sheared and boudinaged zone of closely packed grey quartzite layers within the more ductile schists belonging to the younger Ajabgarh Group. There are no Alwars and Aravalli-BGC basements present in the region west of Barr.

(ii) *Kankwarhi Formation*: This formation is represented by the sequence of argillaceous and pelitic composition with associated impure calcareous and amphibolitic rocks. Being least resistant to erosion, they occupy low grounds and pediment portions. These rocks are predominantly occurring in the central and northeastern parts of the study area.

(iii) *Pratapgarh Formation*: The lithological sequence comprising massive orthoquartzites, calc-gneisses, schists and marbles, has been designated as Pratapgarh Formation. Patchy outcrops of these rocks are seen distributed in the central and northeastern parts of the study area.

Ajabgarh Group

The Ajabgarh Group comprises a sequence of argillites with intercalated arenites and subordinate carbonate deposits. This group of rocks lies conformably over the rocks of Alwar Group (Gupta *et al.*, 1992).

Owing to large scale variation in the rock types, lack of continuity in outcrops and in the available geologic data, the lithostratigraphy of the Ajabgarh Group of rocks is full of intricacies. Dasgupta (1968) has carried out a detailed mapping of the Khetri copper belt and has divided these rocks into five units. Sant and Sharma (1973) and Singh (1988) have mapped the area around Ajabgarh proper and divided these rocks again into five units. However, their stratigraphy and assigned lithological assemblages show vast imparity. The central parts of Rajasthan around Ajmer and further south has remained a bone of contention, from the point of view that they are the part of Alwar's or Ajabgarh's (Raja Rao, 1967; Gangopadhyay and Lahiri, 1984; Sychanthavong *et al.*, 1989, etc.). The complexities produced due to the above reasons have made it difficult for the author to derive upon an acceptable lithostratigraphy of the Ajabgarh's in the study area. Hence, the author has adopted the lithostratigraphy (i) for the rock assemblages exposed south of Ajmer and (ii) those of the north, i.e., Khetri and Ajabgarh proper separately.

(i) The lithological assemblage of the Ajabgarh's and younger sediments, deposited in a lepto-geosynclinal basin over the basic oceanic crust has been worked out in detail by Sychanthavong and Merh (1986) and Sychanthavong *et al.* (1989), and provides the succession as given in Table 2.8.

(ii) The stratigraphy of the Ajabgarh rocks exposed in the northeastern parts of the study area have been worked out by Dasgupta (1968), Sant and Sharma (1973), Singh (1988) and Gupta *et al.* (1992). The overall lithostratigraphy as worked out by these workers is given in Table 2.9.

The rocks of the Delhi Supergroup have undergone three phases of deformation *viz.*, DF_1 and DF_2 (co-axial, NNE-SSW) and DF_3 (WNW-ESE). However, Naha *et al.* (1988) have identified four episodes of deformation (DF_1 - DF_4) in the metasedimentaries of the middle Proterozoic Delhi Supergroup around Khetri.

Table 2.8 Lithological assemblage of the Ajabgarh's and younger sediments [after Sychanthavong and Merh (1986) and Sychanthavong *et al.* (1989)]

Group	Lithology
Marwar Supergroup	
Erosional Unconformity	
Intrusives	8. Kalakot quartz pegmatites and aplites, Jetpura granites and Babra quartz porphyries
	7. Epidiorites, meta-dolerites and foliated granites
Flysch Deposits	6. Slates, phyllites, quartzites and cherts (Punagarh Group)
Intraformational Unconformity	
Ajabgarh Group	5. Impure crystalline limestones
	4. Biotite-garnet schists
	3. Calc-gneisses with calc-silicate bands and cherty quartzites
	2. Calc-schists, para-amphibolites, garnet mica schists with boudinaged zone
	1. Migmatite gneisses and gneissic granites
Non-depositional Unconformity	
Oceanic Crust	2. Fault zone ortho-amphibolite (Jetpura)
	1. Fold core ortho-amphibolite (Kanoj-Nagelao)

Table 2.9 Litho-stratigraphy of the Ajabgarh Group of rocks in the study area (after Singh, 1988 and Gupta *et al.*, 1992)

Group	Formation	Lithology
Ajabgarh	Arauli-Mandhan	Quartzite, staurolite-garnet schist, carbon phyllite, etc
	Bharkol	Carbonaceous phyllite and gritty quartzite
	Thanagbazi	Mainly carbonaceous phyllite, mica-schist, impure dolomitic marble and minor quartzite
	Sariska	Brecciated and granular quartzite with intercalations of carbonaceous phyllite
	Kushalgarh	Mainly banded marble with minor bands of massive dolomitic marble and sericite schist

Punagarh Group

A thick clastic sequence accompanied by basaltic volcanic activity and deposited in an inland continental basin in Punagarh-Sojat area of Pali district has been assigned to the Punagarh Group (Gupta *et al.*, 1992). The rocks of this group are less deformed and represent typical flysch deposits lying unconformably over the Ajabgarh Group of rocks (Sychanthavong and Merh, 1984, 1985 and Sychanthavong *et al.*, 1989).

The rocks of the Punagarh Group extend from Sheopura in the northeast to Bhumadra in the southwest and from Jadan in the east to Nimla in the west. A few patchy outcrops also occur within the granitic terrain south of Bilara. The type sections at Pali and Marwar Junction are located in the neighbourhood of the study area.

Lithologically, the group consists of a sequence of shale, slate, phyllite, schists and quartzites, synsedimentary metabasic volcanics with pillow lava, meta-tuffs and bedded cherts (Dasgupta, 1968). The entire sequence exhibits single episode of deformation, giving rise to a doubly plunging syncline (Dasgupta, 1974). By taking into account the degree of lithological homogeneity and occurrence of synsedimentary basic flows marking the minor interludes in the depositional history, the rocks of the Punagarh Group have been classified into Sojat, Bombolai, Khambal and Sowania Formations.

POST-DELHI INTRUSIVES

The geology of the Aravalli Mountain Belt presents almost a continuous record of basic and acid magmatism dating from about 3500 M.y. to 750 M.y. The record is almost upto the Palaeocene in the Trans-Aravalli region. In the Delhi Supergroup, the magmatic history of the region can be divided into two distinct periods, *viz.*, (i) the Middle Proterozoic events comprising various acid and basic igneous rocks; about 1450 M.y., and (ii) the late Proterozoic magmatic events manifested by the Erinpura granite and Malani Rhyolites; 750 - 600 M.y. (Srivastava, 1988).

The Alwar Group of rocks have at their base a variety of mafic volcanics comprising numerous flows of vesicular and amygdaloidal basalts, tuffs and andesites (Singh, 1985). The Ajabgarh Group volcanics are seen exposed in a linear belt from Khetri in the north to Ambaji in the south and have been metamorphosed to hornblende schists and amphibolites (Bhattacharya and Mukherjee, 1984). This linear belt of metavolcanics at the base of the Ajabgarh Group has been described as the *Phulad Ophiolite Suite* by the Geological Survey of India. Apart from the metavolcanics, isolated occurrences of ultramafics (mostly serpentinised peridotite), gabbro, diorite and pyroxene granulites have been reported in the Trans-Aravalli region of the Delhi Mountain Belt. These basic rocks are tholeiitic in nature (Gangopadhyay and Lahiri, 1984). The Middle Proterozoic alkaline magmatic event is represented in the form of nepheline syenites of Kishangarh.

The Delhi Supergroup of rocks exhibit imprints of two acid magmatic events widely separated in time and space. The earliest granitic activity at 1600 M.y. is recorded in the Alwar basin in the northeastern part, wherein some of the granites have been emplaced along the cores of anticlines (Roy and Das, 1985). The Khetri granites are coeval with the second deformation in the Khetri copper belt.

A younger granitic activity between 850 to 750 M.y. is widespread and found throughout both the Alwar and Ajabgarh groups but more abundant in the western margin of the Delhi Mountain Belt. These granites which are popularly designated as the **Erinpura Granites** are extremely variable in their colour and texture. They are of both foliated and non-foliated massive types. The granite bodies occurring around Barr-Sendra regions post-date the F2 phase of the Delhi folding and their composition ranges from granodiorite to adamallite (Gangopadhyay and Lahiri, 1984). However, Sychanthavong *et al.*(1989) are of the opinion that these granitic bodies around Sendra are in fact post-Delhi granitized granites exhibiting gradual transformation of the schistose rocks into porphyroblastic gneisses to migmatites, that finally graded into foliated granites. They further stated that all these granites are tectonically controlled and restricted to zones of fracturing, as applicable to the case of granitic bodies of Barr and Sendra showing a faulted contact with the boudinaged zone. Outcrops of the granites have also been reported from

the Ana Sagar valley near Ajmer, Pisangan and Govindgarh near Beawar and near Jhunjhunun in the Kantli river basin.

Malani Igneous Suite

The Malani Igneous Suite of rocks occupies vast tracts to the west of the Aravalli Mountain Range. They overlie the Proterozoic metamorphics of the Delhi Supergroup and underlie the Jodhpur formations of Marwar Supergroup. The rhyolitic outcrops are scattered in nature, covering vast stretches of the Thar Desert in the west. The exposures have also been reported from Tosham in Haryana and places in Jhunjhunun and Churu districts located in the northeastern parts of the study area.

The Malani Igneous Suite of rocks including Jalore-Siwana granites have been emplaced during different phases of F3 folding, i.e., between 600 M.y. and 750 M.y. The associated mafic and alkaline rocks of the Malani volcanic province have been considered to be of two younger magmatic events *viz.*, (i) a Mesozoic event (125 M.y.) related to opening of several sedimentary basins in Western Rajasthan, and (ii) a Palaeocene event related to collision of Indian plate with the Asian plate (Srivastava, 1988). The Malani Igneous Suite of rocks occurs mostly to the extreme southwestern parts of the study area, i.e., Jodhpur and its surrounding areas.

PALAEOZOIC ROCKS

The Trans-Aravalli sector in the west, which is popularly known as the Rajasthan Shelf Zone (RSZ), marks an important site in the sedimentation history during the Palaeozoic-Tertiary period. These sedimentary basins, responsible for the accumulation of a thick pile of sedimentary sequences, are characterised by their distinguished lithological assemblages. The study area which forms an integral part of the RSZ, abutting the Proterozoics on its eastern margins, comprises **Palaeozoic-Marwar Supergroup** and **Tertiary-Palana, Marh and Jogira Formations of Palana-Ganganagar Shelf rocks.**

Marwar Supergroup

The sedimentation history of the Marwar Supergroup of rocks can be ascribed to two major basins, *viz.*, Nagaur and Birmania. However, the study area exhibits exclusive development of arenaceous and calcareous sedimentary sequence belonging to the Nagaur basin.

The Nagaur basin sprawling from Jodhpur and Pokhran to Ganganagar, records over 1000 m thick sedimentary sequence, overlying the Malani Igneous Suite of rocks, and progressively covered by the Tertiary sediments in the north (Pareek, 1981). Based on the sedimentation characteristics and the lithological assemblages, the Marwar Supergroup has been classified into three groups, *viz.*, the Jodhpur, Bilara and Nagaur (Khan and Sogani, 1973).

Jodhpur Group

Predominantly arenaceous sedimentary sequence of the Jodhpur Group has been divided into an older *Sonia Sandstone Formation* and an younger *Girbhakar Sandstone Formation*. The Sonia Sandstone Formation unconformably overlies the Malani Igneous (Volcanic) rocks. The basal part of the Sonia Sandstone Formation comprises bouldery-cobbly sequence of Pokhran boulder beds; marking the western periphery of the Nagaur basin. This is followed by a thick horizon of maroon shales overlain by buff to reddish, fine to medium grained sandstones.

The Girbhakar Sandstone Formation is having at its base a pebbly horizon marked by pebbles of sandstones and cherts of Sonia Formation. The sedimentary sequence of Girbhakar sandstone Formation comprises varied lithology, *viz.*, yellowish and purple sandstones, laminated shales with interbedded claystones and siltstones, micaceous shales, argillaceous sandstones, ferruginous sandstones and gritty-pebbly sandstones with bands of sandy and micaceous shales.

The aggregate thickness of the Jodhpur Group is in the range of 100 m-240 m. In the study area, the Jodhpur Group of rocks occur in a linear stretch adjacent to the Delhi Group of rocks, the important locations are Ladnun, Nimbi Jodhan, Khatu and the areas around Jodhpur, Belwa, Tivri, etc (Plate II.1). The Sonia sandstone is extensively quarried and used as building stones.

Plate II.1 A view of sandstone quarry belonging to Jodhpur Group of rocks, thick pedogenised aeolian silt is also seen overlying the sandstones. Location: Nimbi Jodhan

Bilara Group

Lithologically, the Bilara Group of rocks are predominantly calcareous in composition. These sedimentary sequences have been further classified into three formations, *viz.*, *Dhanapa Dolomite Formation*, *Gotan Limestone Formation* and *Pondlo Dolomite Formation* in the order of superposition.

Dhanapa Dolomite Formation: This formation, having a cherty horizon at the base, comprises cherty dolomite and siliceous dolomitic limestone with stromatolitic structures at the top.

Gotan Limestone Formation: This formation is characterised by laminated and dark greyish limestones, dolomitic limestones and dolomites.

Pondlo Dolomite Formation: This formation comprises dolomite, cherty limestone with bands of claystone, siltstone and sandstone.

The Bilara Group tends to thicken from 100 m to 300 m towards north. The important localities of occurrence of Bilara Group of rocks in the study area are Bilara, Gotan, Khimsar, Rol, Chhajoli, etc.

Nagaur Group

The Nagaur Group of rocks comprise the *Nagaur Sandstone Formation* and *Tunklian Sandstone Formation*. The base of the Nagaur Sandstone Formation is marked by a conglomerate horizon, i.e., the Khichan conglomerate (Plates II.2a & b). Overlying these conglomerates are a thick sequence of red to brick red sandstone, siltstone and claystone with a thick evaporite sequence comprising limestone, dolomitised limestone, gypsum, anhydrite, halite and meagre potash salts. The Tunklian Sandstone Formation overlying the Nagaur Sandstone Formation, is made up of brick red claystone, siltstone, clays, pebbly sandstone, etc., with an aggregate thickness of over 400 m. The Nagaur Group of rocks occupy the central parts of the study area, the important localities being Merta Road, Mandwa, Nagaur, etc.

Plate II.2.a A view of residual peneplain having Khichan conglomerate (Nagaur Group) as a base, mined for construction work. Location: Roja

Plate II.2.b A close view of basal Khichan conglomerates showing released pebbles, gravels and cobbles burried under the aeolian sands. Location: Roja

TERTIARY ROCKS

The horizontally to sub-horizontally disposed sequence of the **Palana Ganganagar Shelf**, *viz.*, the *Palana series* overlie the Nagaur Group of rocks in the study area. This series comprises semiconsolidated coarse to very coarse grained sandstone with intercalated clay beds. The upper horizon of these sandstones is white to pink and the lower horizon is reddish brown in colour. Apart from these, the Palana Formation comprises greenish grey variegated clays associated with carbonaceous shales, shaly lignites and fuller's earth/bentonite. The Palana series of rocks are confined to the northwestern parts of the study area falling within the Nagaur and Bikaner districts.

The details on Quaternary sediments overlying the older lithostratigraphic sequences of the study area is given in the proceeding chapter.