International Field Workshop
on the

MARWAR SUPERGROUP, RAJASTHAN, INDIA

Mukund Sharma
S. K. Pandey
S. Kumar

The Society of Earth Scientists,
INDIA

Field Guide

International Field Workshop
on the

Marwar Supergroup, Rajasthan, western India

(20^{th}-28^{th} January 2014)

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S. Kumar

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SES Field Guide - 1

The Marwar Supergroup, Rajasthan, western India

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Cover Page: Panoramic view of Sonia Sandstone at Khatu Village.

First Inner cover: Route Map (top) and Columnar joints in Malani Rhyolites at Jodhpur.

Back cover: *Cruziana* isp from the Nagaur Sandstone, Dulmera quarry, Bikaner.

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CONTENTS

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Welcome to the International Field Workshop

The Organizing Committee of the *International Field Workshop on the Marwar Supergroup, Rajasthan, western India* is glad to welcome participants to Rajasthan-the geologically important and the culturally vibrant state of India. Geological past of this area encompasses successions from Precambrian to Recent time periods. Remanent of the Rodinia Supercontinent are found in the Nagaur – Ganganagar basin and the sedimentary sequences of the basin constitute the Marwar Supergroup (MSG). In recent past, various aspects of the geology of the MSG have been explored. Palaeobiology, biostratigraphy, palaeomagnetism, isotope geochemistry, geochronology, basin evolution, palaeobiogeography and hydrocarbon potentials of the basin are well established. These disciplines have attracted several research groups from India and abroad to study and examine the various interesting sections of the Marwar Supergroup. Studies were focused to understand the basin configuration, palaeolatitudinal situation in geological past and their relation with the global events during Cryogenian – Ediacaran – Cambrian.

Palaeobiological data have increased exponentially regarding the understanding of early megascopic as well as microscopic life during the enigmatic Ediacaran and Cambrian Period of the Marwar Supergroup. Some of these studies have challenged established notions about the development of lithosphere and biosphere during the Neoproterozoic. The main aim of the workshop is to assess the recent developments in various fields. This workshop offers several interesting sections for the study of palaeobiology, sedimentology and biostratigraphy. 34 participants from countries like Argentina, China, Germany, Oman, Spain, UK, USA and India have confirmed their presence in the workshop. During 9 days field workshop, we will examine 25 stops covering the representative lithostratigraphy of the Marwar Supergroup. We have made all efforts to incorporate all the major specialities in the field workshop related to palaeobiology, sedimentology, geochronology and palaeomagnetism to suit various participants with their expertise.

The programme consists of half day pre-field workshop formal inauguration in the afternoon of 20th January at Jodhpur in which a few lectures on the Malani Igneous Suite, Ediacaran-Cambrian palaeobiology, palaeo-position of the basin and stratigraphy of the Marwar Supergroup would be delivered by the invited speakers. During the field workshop we will be camping at Jodhpur, Nagaur, Bikaner and Jaisalmer (Sam) districts of the Rajasthan State. The valedictory session of the workshop will be held at Hotel Rajputana, Jodhpur on Tuesday 28th January 2014. In the intervening period, we will cover about 2500 km on wheels. Participants may fly back from Jodhpur on 28th January or stay back for enjoying the beauty and marvels of Rajasthan.

In January, the average temperature in western India remains between 1º to 25º C. Nights are pretty cool. It is the best time for undertaking fieldwork in this part of India. We advise you to put on clothes in layers so that can be easily peeled off, if needed, during day time. It is requested that you wear hat and apply Sun-screen lotion in order to avoid direct harsh Sun-rays. Carry ample water while trekking. Drinking water and fruits will be available on the vehicles. Road conditions are good for most of the spots except some sectors where we have to negotiate our speed. Some of the sections are close to small towns where we could have some bumpy drive. Normally it is a dry spell of the year, we hope conditions would be kind enough, but occasionally planned stops may need alteration according to local road and weather conditions.

The organizing committee is confident that you all will enjoy the trip and find the field workshop useful.

Mukund Sharma
Organizing Secretary

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INTRODUCTION

The time span across the Precambrian-Cambrian boundary is very important in the history of Earth as most significant changes have taken place in the lithosphere, biosphere and atmosphere. Evidence of such changes are preserved only at few places where they are affected in general by post-depositional deformation and metamorphism resulting in modification and even total obliteration of the original syn-sedimentary signatures in the rocks. These evidence are preserved in only very limited sites where rocks are least effected by deformation and metamorphism and where preservation of rocks is of good quality. Thus, such sites can be considered unique and significant and need to be studied in detail. One such site is the deposits of the Marwar Basin which are more or less un-deformed and unmetamorphosed and represents a time period from Neoproterozoic to Lower Cambrian.

The Marwar Basin, also referred to as Nagaur-Ganganagar Basin, constitutes the second largest Proterozoic basin in India, after the Vindhyan Basin (Fig. 1). It is developed in the west of the Aravalli mountain chain, in the desert setting of the western Rajasthan. It does not extend beyond south of Malani Igneous

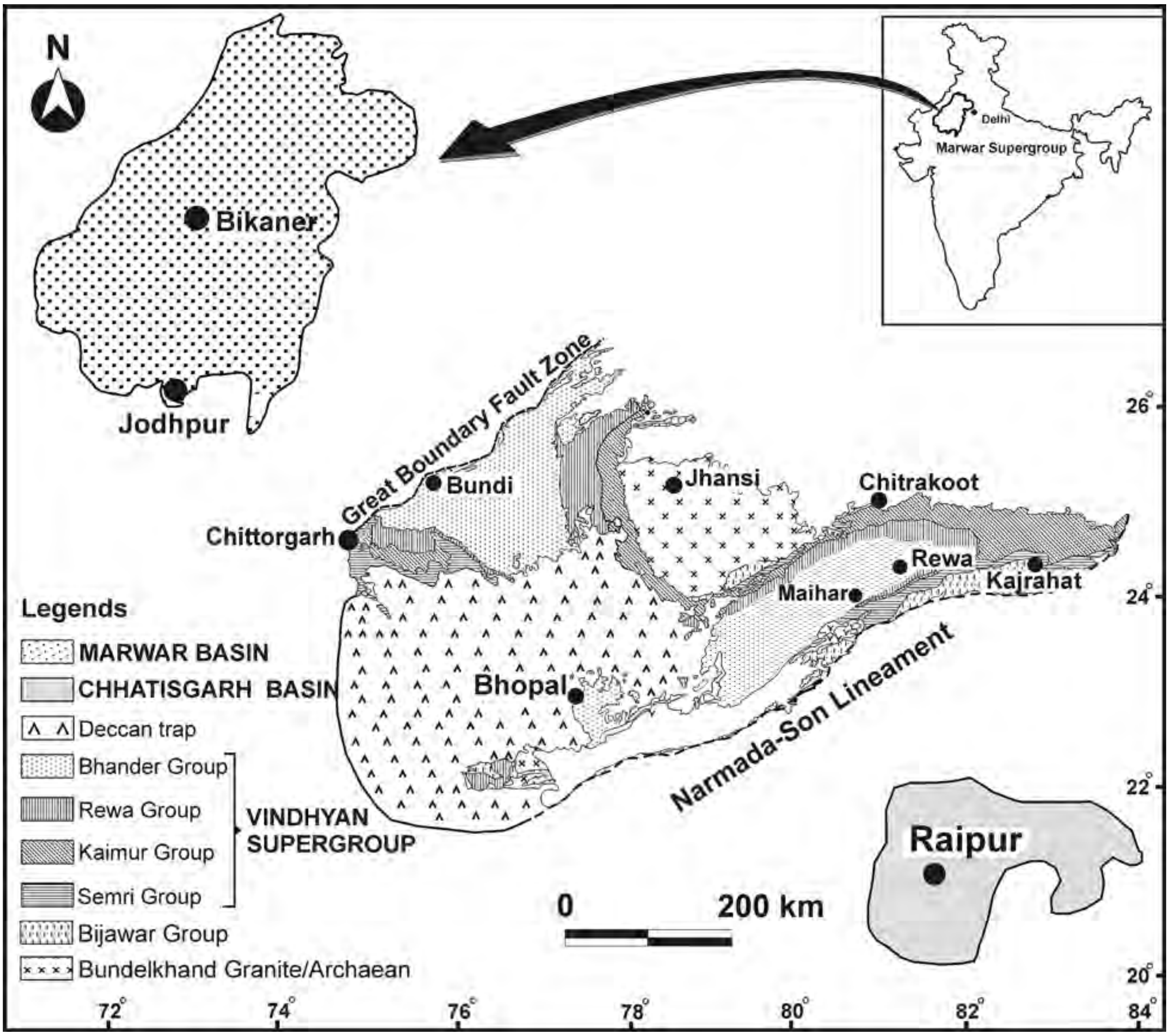

Fig. 1—The present disposition of the Marwar, Vindhayan and Chattisgarh Basins. (redrawn after Gopalan *et al.*, 2013).

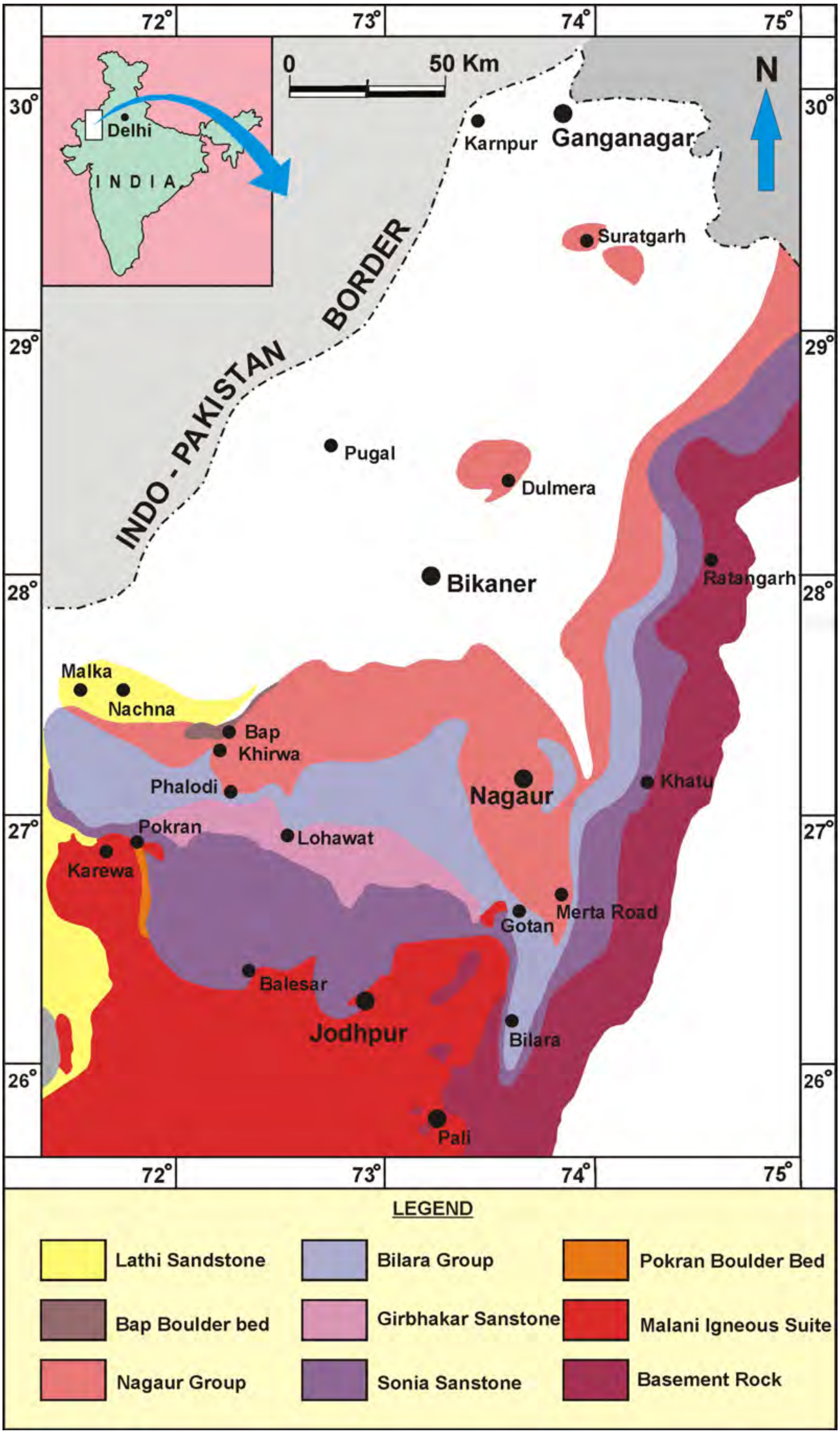

Fig. 2—Geological Map of the Marwar Supergroup. (redrawn after Pareek, 1984).

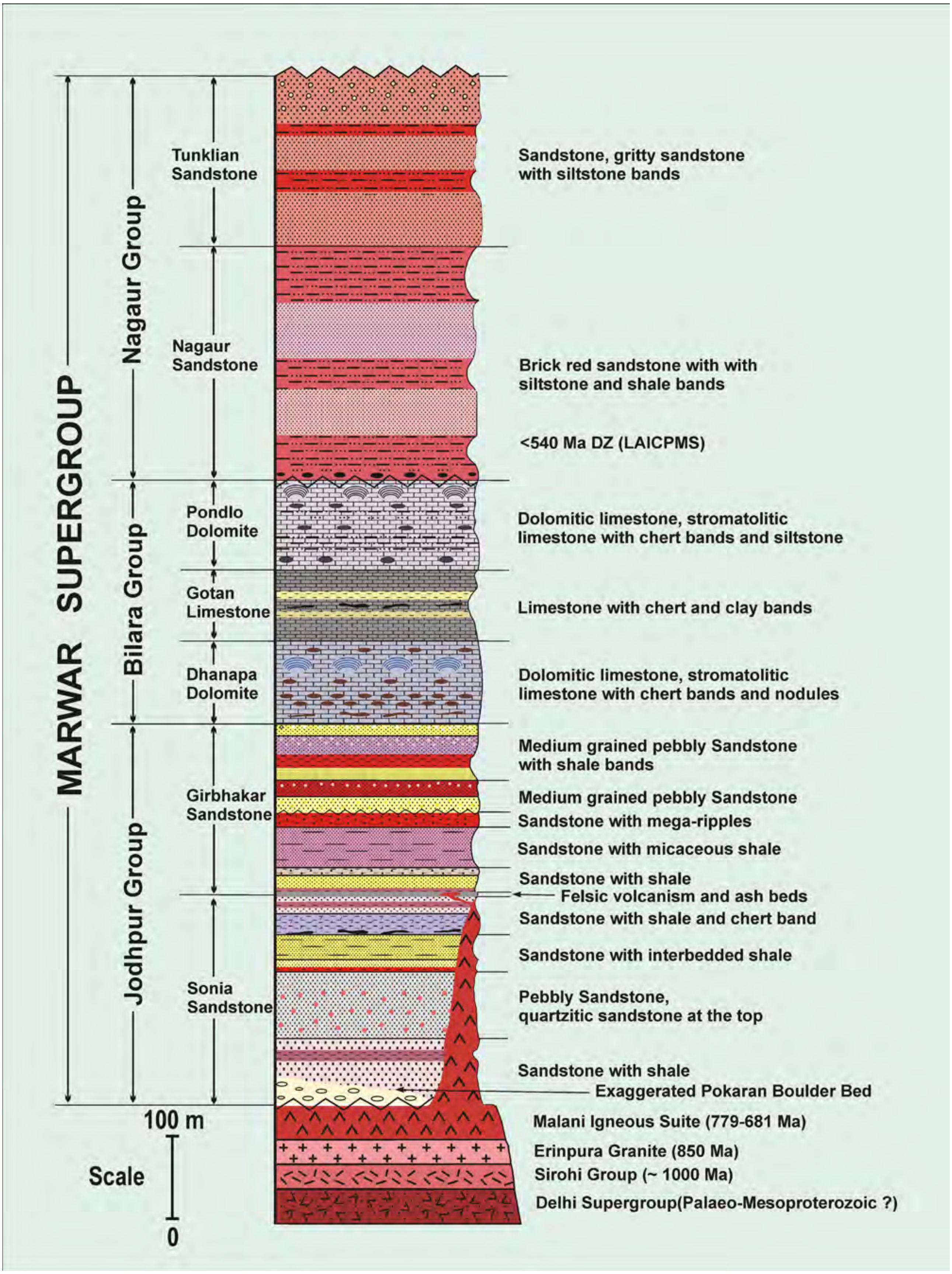

Fig. 3—Generalized lithostratigraphy of the Marwar Supergroup.

province and is considered to be bounded by Jodhpur - Pokaran - Balotra - Chhotan Ridge (Pareek, 1984). In the earlier times, the rocks of the Marwar Basin were considered as an extension of the Vindhyan Basin and named as the Trans-Aravalli Vindhyans. The rocks of both the basins were unmetamorphosed, undeformed and were considered unfossiliferous with comparable lithological attributes separated only by the Aravalli mountain chain. As such it was logical to presume their common association. But, now they are considered as two separate basins. The rocks of the Marwar Basin are designated as the Marwar Supergroup which attains a thickness of ca. 1000 m (Chauhan, 1999) and the rocks of the Vindhyan Basin are termed as Vindhyan Supergroup which have a thickness of ca. 4000m. Recent estimates of the cumulative thickness of the Marwar Sediments is 1500 m (Kumar & Chandra 2005). The Marwar Supergroup unconformably overlies the Malani Igneous Suite which has been dated as between 779–681 Ma (Rathore *et al.*, 1999) and is unconformably overlain by the Permian Bap Boulder Bed (Figs. 2 & 3). Earlier, the Marwar Supergroup was assigned Cambrian age in spite of the fact that no Cambrian fossil was reported from these rocks. But, now, these rocks are considered Neoproterozoice to Lower Cambrian on the basis of available radiometric dates of the underlying Malani basement rocks, Ediacaran body fossils in the lower horizon and trilobite trace fossils in the younger horizon of the Marwar Supergroup. These rocks give an excellent opportunity to unravel the mysteries of nature as the rocks are unmetamorphosed and undeformed with beautiful preservation of sedimentary structures. There is a possibility of locating Precambrian/ Cambrian boundary with in the Marwar succession which will help in global correlation of the succession.

PROLOGUE TO THE FIELD WORKSHOP

Studies by the Geological Survey of India established occurrence of several lignite mines in Rajasthan. Growing energy demands of the country attracted national and international oil exploration companies to Rajasthan. Oil India Limited, Oil and Natural Gas Corporation Limited, Cairn Energy India Limited; John Energy India Limited; Eni Italy; *Schlumberger*, France; Weatherford US; MI Swacko; Global Geo Resources, Canada and Smith Bitts sought licences, mounted several exploratory surveys and conducted studies on the sedimentary successions of Rajasthan including the Marwar Supergroup. Dr. Andrea Cozzi of Eni India organized two field workshops (Cozzi *et al.,* 2007, Cozzi 2008). Department of Geology, University of Jammu and MPRG, Department of Earth Sciences, University of London jointly co-sponsored the two days International conference during 20-21 February, 2008 in Jammu. On this occasion a Pre-Conference Field workshop entitled *Hunting for Old Oil and Gas* was also organized at Jodhpur to examine the Marwar Supergroup. Field Guide books were also circulated (Cozzi *et al.,* 2007, Cozzi 2008). Geological Survey of India contributed extensively on our understanding of the geology of the Marwar Supergroup. Recent Ediacaran-Cambrian fossil discoveries have created interest among the international geo-scientific community in the Marwar Supergroup. Several independent studies are being pursued on various geological aspects of the Marwar Supergroup. *The Society of Earth Scientists* considered it an opportune moment to organize an International Field Workshop for the geo-scientific community to examine the interesting sections of the Marwar Supergroup, chart out future course of studies and national and international collaborations.

IMPORTANCE OF FIELD WORKSHOP

The important geological sites are studied by individuals as well as groups and their findings are discussed in different conferences and seminars. But there are many field observations which are debatable and need critical evaluation that could not be resolved in seminar halls. Such observations can be discussed and resolved only in the field itself and hence lies the importance of field workshops where different workers come together to discuss field observations on the outcrop itself and try to reach consensus and resolve issues. The field workshop on the Marwar Basin is an attempt to share observations concerning the Marwar Supergroup and intends to resolve issues related to stratigraphy, palaeontology, structural geology and basin evolution and possibly identify a team of workers who could collect samples to work together on problems and could give results in a mutually agreed time frame.

MALANI IGNEOUS SUITE

Malani igneous rocks, represented dominantly by rhyolites, form the basement rocks for the Marwar Basin. 'Malani Beds' was the name given to a series of volcanic rocks developed in the erstwhile Marwar State by Blanford (1877). These rocks, now termed as Malani Igneous Suite (Pareek, 1984), are exposed in the Thar desert between Jodhpur in the east and Barmer in the west which further extends in Pakistan. It covers an area of ~51000 sq. km. in the western part of India. According to Pareek (1984) the Malani Igneous Suite commenced with a volcanic phase marked by a felsic lava giving rise to tuff, rhyolite and rhyolitic porphyries (Fig. 4). This was followed by co-magmatic plutonic intrusions giving rise to Jalor and Siwana granites (Fig. 5). The last volcanic event is marked by a dyke phase represented by felsic, intermediate and mafic rocks. The total computed thickness of the Malani Igneous Suite (MIS) is ca. 3500m (Pareek, 1981). However, in the Jodhpur area the total thickness of MIS is only 340m comprising three rhyolite flows each overlying a pyroclastic band. The distinction between the different flows is marked by colour differences and compositional and textural

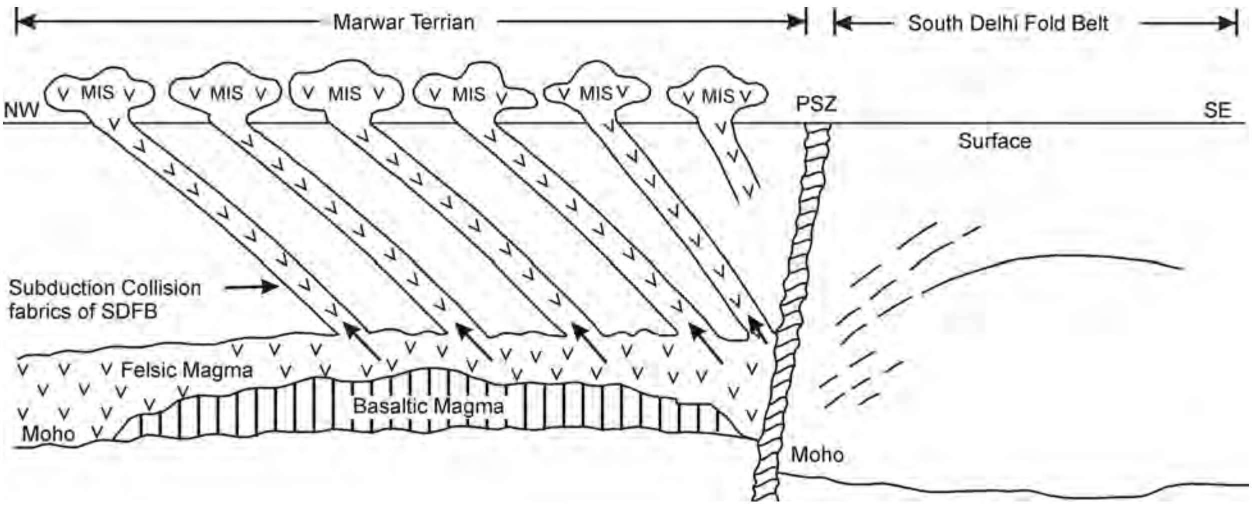

Fig. 4—A conceptual model for the evolution of the Malani Igneous Suite in the Marwar Terrain at 750 Ma. Post-Delhi collisional episode of asthenospheric upwelling–lithospheric thinning accretes the basaltic magma at the base of the crust. The required heat is provided by this process to melt the crustal rocks and generate the felsic magma, which in turn is transported to the surface by subduction–collision fabric of the SDFB. MIS — Malani Igneous Suite. (redrawn after Vijayarao, 2013).

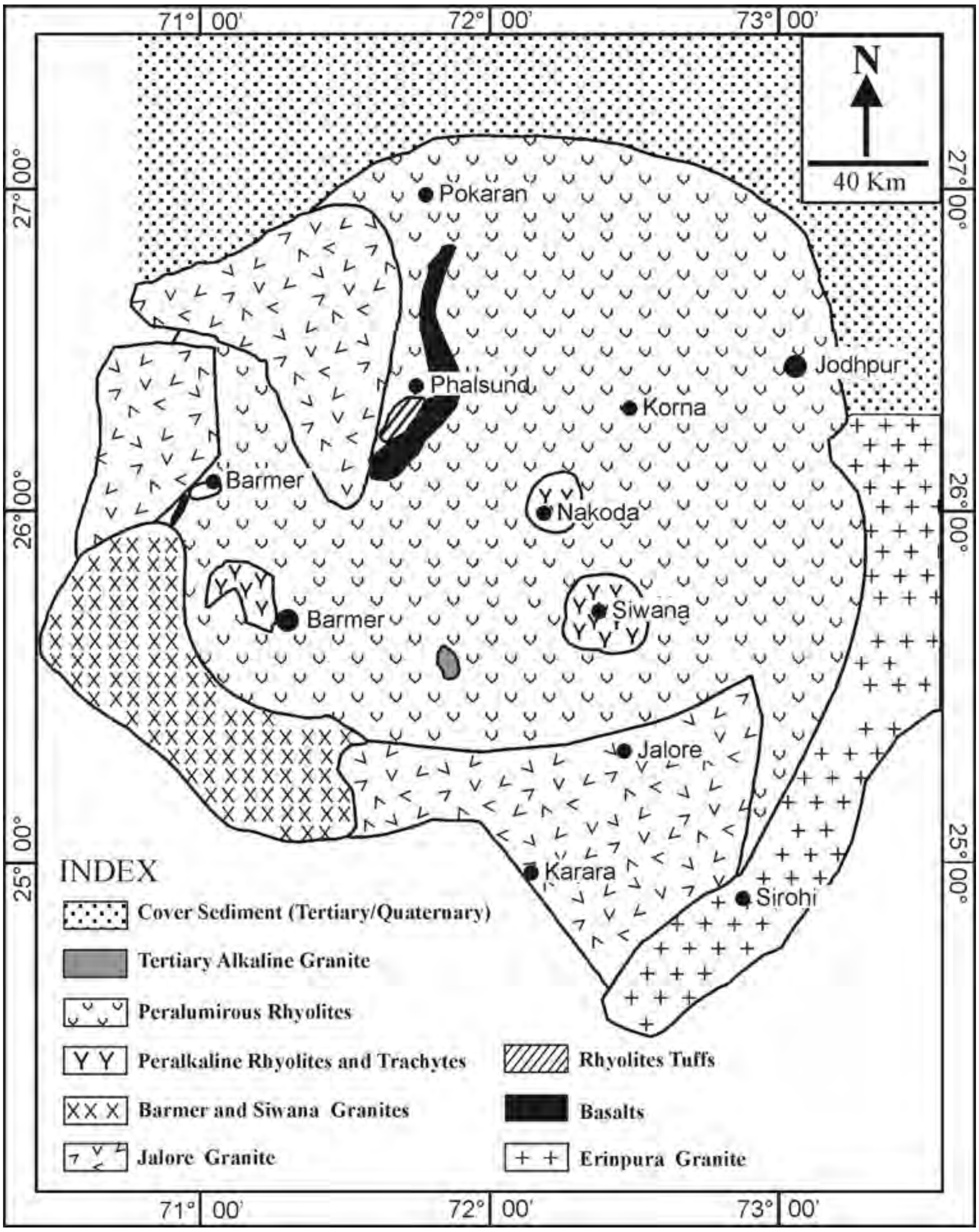

Fig. 5—Geological map of the area showing extent of the Malani volcanic rocks (redrawn after Bhushan, 1995; Sisodia, 2011).

variations. In the Jodhpur Hill area, the tuff is 70m thick and exhibits terrace weathering. The tuff is welded and shows rhyolitic composition. It is characterised by columnar jointing with dominant jointing trend NNE-SSW and WNW-ESE. The jointing is vertical and the column are rectangular to hexagonal attaining a length of 30m and more (Pareek, 1984). Recently, Sisodia (2011) challenged the mode of origin of Malani Igneous Suite and suggested and alternative mode of their formation. He concluded that the area represented by Malani Rhyolite is highly eroded, complex, impact crator.

MARWAR SUPERGROUP

Geological Setting

The rocks of the Marwar Basin are exposed in the southern part of Rajasthan as dispersed hillocks in the Thar desert and in the central and northern areas the exposures are absent but information about the basin is now available based on bore hole data generated by different agencies. Thus, two different stratigraphic classifications are available for the Marwar Basin; one for the exposed rocks in the southern part and another for the subsurface region of the central and northern part. The Marwar Basin is developed over the eroded surface of the Malani Igneous Suite and older metamorphites (possibly rocks of the Delhi Supergroup and post Delhi igneous rocks) occupying an area of ca. 100000 sq km in the western Rajasthan and parts of Punjab and Haryana in the west of the Aravalli mountain chain (Kumar, 1999). It is part of a large, elongated, asymmetrical intracratonic sag basin trending NNE–SSW with a slight westerly tilt. The basin spans ca. 750 km from south to north and 300 km from east to west (Kumar, 1999). It is considered to be a southerly extension of the basin developed in the Salt Range of Pakistan. The successions of rocks of the Marwar Basin are named as the Marwar Supergroup. It is believed that the basin came into existence through rejuvenation of NNE–SSW Archaean and Proterozoic lineaments. The Malani Igneous Suite represents an event of anorogenic felsic magmatism post-dating the Erinpura granite (850 Ma). The Malani Igneous Suite has been dated as 779–681 Ma (Rathore *et al.*, 1999). Torsvik *et al.* (2001) provided the maximum age of the Marwar Supergroup by the youngest MIS age of 748 Ma. Because the Marwar sediments unconformably overlie the Malani igneous rocks, it restricts the older age limit of the Marwar Basin to be younger than ca. 681 Ma. The rocks of the Marwar Basin are unmetamorphosed and undeformed. The rocks are more or less horizontal in most of the area. Pareek (1981, 1984) has subdivided the Marwar Supergroup into three groups: the Jodhpur Group, the Bilara Group and the Nagaur Group (Table 1). Each group has been further subdivided into formations. The Jodhpur and Nagaur Groups are represented by arenaceous facies and the Bilara Group is represented by a calcareous facies. A somewhat different lithostratigraphic succession is developed in the central and northern part of the basin where the rocks are encountered in the subsurface region and the lithostratgraphy is based on the bore-hole data. Here, the Bilara Group is absent and, instead, an evaporitic facies is developed belonging to the Hanseran Evaporite Group. The Hanseran Evaporite Group is again overlain by the Nagaur Group. The Hanseran Evaporite Group has been considered a facies variant of the Bilara Group but some workers consider Hanseran Group as an additional lithostratigraphic unit between Bilara and Nagaur Groups.

The main lithostratigraphic units of the Marwar Supergroup are as follows:

Nagaur Group	Lower Cambrian
Bilara Group	Ediacaran?
Jodhpur Group	Ediacaran

Table 1—Lithostratigraphic succession of the Marwar Supergroup, western Rajasthan (after Pareek, 1984).

Supergroup		Group	Formation	Lithology
		Bap beds		
			Unconformity	
Ediacaran to Lower Cambrian	Marwar Supergroup	Nagaur Group (75-500m)	Tunklian Sandstone	Medium to coarse grained Sandstone, pebbly sandstone
			Nagaur Sandstone	Reddish to green colour Sandstone with intercalation of clay bands
		Bilara Group (100-300m)	Pondlo Dolomite	Dolomite, Limestone, cherty dolomite, stromatolitic limestone
			Gotan Limestone	Dark grey laminated limestone with bands of clay chert and dolomite
			Dhanapa Dolomite	Stromatolitic limestone, dolomite, siliceous dolomitic limestone with chert at base
		Jodhpur Group (125-240m)	Girbhakar Sandstone	Brick-red sandstone, Siltstone and shale. Sandstone pebbly to gritty near top
			Sonia Sandstone	Maroon Siltstone and shale, creamish sandstone with abundant sedimentary structures including Salt Pseudomorph
			Pokaran Boulder Bed	Boulders, cobbles and medium to coarse grain sandstone
			Unconformity	
		Basement		Malani Complex

Jodhpur Group

The Jodhpur Group represents the oldest group of the Marwar Supergroup which unconformably overlies the Malani Igneous Suite. The Jodhpur Group has been subdivided into three formations by Pareek (1984); in stratigraphic order these are the Pokaran Boulder Bed, the Sonia Sandstone and the Girbhakar Sandstone (Table 1). However, Chauhan *et al.* (2004) have subdivided it into two formations and included the Sonia Sandstone and the Girbhakar Sandstone of Pareek (1984) under the Jodhpur Sandstone (Table 2). Thus, the lowermost horizon is represented by the Pokaran Boulder Bed, which is developed in

Table 2—Stratigraphic succession of the Marwar Supergroup (modified after Pareek, 1984 and Chauhan *et al.*, 2004).

Age	Supergroup	Group	Formation	Lithology
Permo - Carboniferous			Bap Boulder Bed	
Unconformity				
Early Cambrian	Marwar Supergroup	Nagaur Group (75-500 m)	Tunklian Sandstone	Brick red sandstone, siltstone & red clay stone
			Nagaur Sandstone	Brick red sandstone, siltstone & red and green clay beds
To		Bilara Group (100-300 m)	Pondlo Dolomite	Cherty dolomitic limestone
			Gotan Limestone	Interbedded dolomite & limestone
			Dhanapa Dolomite	Dolomitic limestone with chert lenses
Late Neoproterozoic		Jodhpur Group (125-240 m)	Jodhpur Sandstone	Reddish gritty sandstone with maroon clay beds
			Pokaran Boulder Bed	Conglomerate
Unconformity				
Malani Igneous Complex / Aravalli Rocks				

the south western part of the basin and attains a thickness of only 4 m followed by the Jodhpur Sandstone.

Pokaran Boulder Bed

It unconformably overlies the Malani Igneous Suite and developed near Pokaran in the north to Hariyoli *nadi* in the south for a distance of 42 km and extends further southwest to Sankara and adjoining areas. The boulders, cobbles and pebbles of rhyolite, granites, syenite and basic rocks of the Malani Igneous Suite are seen in reddish to brownish sandy matrix (Pareek 1981). Kumar, V. (1999) has mentioned the occurrence of glaciated boulders within this horizon and linked it to the Late Proterozoic glaciation. Chauhan *et al.* (2001) have identified three distinct mode of occurrence for the boulder bed, *viz.*, massive boulder bed, stratified conglomerate and boulder spread (Table 3). These three forms of boulder bed independently rest over the basement Malani rhyolite and/or granite and mark an erosional unconformity. According to Chauhan *et al.* (2001) the massive conglomerate is the product of weathering and disintegration of the basement rocks operating under semi-arid to arid condition. The boulder spread is envisaged to be glaciogenic, and stratified conglomerate is a product of arid condition. According to them the three types of boulder bed are

Table 3—Lithostratigraphic succession of the Pokaran Boulder Bed, near Pokaran (after Chauhan *et al.*, 2001).

	SUBUNIT	LITHOLOGY	SPECIAL FEATURES
POKARAN BOULDER BED	Pokaran Sandstone	Fine to medium grained reddish brown to greyish brown sandstone, red to maroon shaly sandstone.	Poorly to moderately developed trough cross bedding. Well developed trough cross bedding; overall palaeocurrent trend southwards
		------hiatus------	
	Stratified Conglomerate	Subrounded to rounded pebbles and cobbles of reddish to greyish brown, dark reddish brown, layered tuffaceous rhyolite, ignimbrite and polyphyritic rhyolite. These are enclosed in coarse sandy rhyolite matrix.	Crude stratification marked by parallel arrangement of pebbles. A few cobbles show striation marks.
		------hiatus------	
	Boulder Spread	Boulder cobbles and pebbles of grey and reddish grey porphyritic and tuffaceous rhyolite and rarely greyish brown, vesicular basalt, pink coarse grained granite without any matrix.	Cluster of isolated boulders, cobbles and pebbles. Most of the boulders show striation marks; inferred palaeocurrent trend is northeastwards.
		------hiatus------	
	Massive Conglomerate	Subrounded to rounded boulders and cobbles of reddish brown to greyish brown, dark reddish brown layered tuffaceous rhyolite, ignimbrite and porphyritic rhyolite enclosed in matrix of very coarse grained sandy rhyolite.	Structureless.
		------unconformity------	
	Basement	Reddish brown to greyish brown tuffaceous rhyolite, ignimbrite and pinkish grey porphyritic rhyolite.	Light and dark layers of tuff, ignimbrite and porphyritic rhyolite are massive.

formed under different palaeoenvironmental and palaeoclimatic conditions suggesting that Pokaran Boulder Bed may be polygenetic in origin. Bhatt *et al.*, (2005) argued in favour of Pokaran Boulder Bed being glacial till in origin. However, our field observations did not reveal glacially striated boulders within outcrops at Pokaran and Sankra; Cozzi (2008) argues that at Pokaran, the boulder beds inter-fingers and wanes laterally into basal sandstone and shales of the Sonia Formation and therefore conglomerate was locally derived and not supporting the glacial origin and long hiatus. In our opinion the boulder bed appears to be a product of a fluvial regime and glaciogenic origin for the boulder bed is not acceptable. The red coloured sandstone overlies the boulder bed which is locally named as the Pokaran Sandstone showing well developed large scale-cross bedding. It is considered as representing the Jodhpur Sandstone of the Jodhpur Group in the Pokaran area.

Table 4—Lithostratigraphic subdivisions of Sonia Sandstone (after Khan & Sogani, 1973).

Sonia Sandstone	**Unit G**	Maroon shale, medium to fine grained sandstone with band of ochreceous shale	25m
	Unit F	Interbedded shale, chert, jasper and cherty dolomite	28m
	Unit E	Silicified sandstone with bands of chert	1.5m
	Unit D	Maroon, yellowish-green shales, with red and purple sandstones, containing salt pseudomorphs	30m
	Unit C	Interbedded red shale and quratzitic sandstone	15m
	Unit B	Maroon coloured, gritty pebbly sandstone occasionally quartzitic towards the top	82m
	Unit A	Buff, creamish, whitish, slabby sandstone, pebbly sandstone, arkosic sandstone and maroon shale, with ripple marks and other sedimentary structure	75m

Jodhpur Sandstone

'Jodhpur Sandstone' is the name given by Chauhan *et al.* (2004) which includes the Pokaran Boulder Bed, the Sonia Sandstone and the Girbhakar Sandstone of Pareek (1981, 1984). It is represented by fine to coarse grained sandstone, siltstone, shale and pebbly sandstone, According to Awasthi & Prakash (1981) sandstones of the various formations of the Jodhpur Group are mainly quartz-arenites and occasionally sub-feldspathic, feldspathic and subarkosic arenites. Tourmaline, zircon and rutile form the bulk of the non-opaque and non-micaceous heavy mineral assemblage of the sandstones. Garnet, kyanite, sphene, anatase, actinolite, hornblende, dumortierite and monazite are encountered less frequently. Sandstones of the Jodhpur Group are mineralogically mature, are mostly silica cemented and contain less than 5% matrix. The maximum thickness of the Jodhpur Group is 240 m (Pareek 1984). In classical lithostratigraphic subdivisions of Jodhpur Group, Pokaran Boulder Beds are followed by Sonia Sandstone and Girbhakar Sandstone.

Sonia Sandstone

Deposition of Sonia Sandstone over Malani Igneous Suite is marked by maroon coloured shales followed by greenish grey lenses which are overlain by creamish, buff and reddish to fine grained sandstone. Best exposures are noted in Garsuria (26° 26' 30"N, 73° 44' 00"E; 45F/11) and Sonia Hills (26° 24' 00"N; 73°, 36' 15"E; 45F/11). Mappable divisions of the Sonia Sandstone proposed by Khan & Sogani (1973) are given in Table 4. It is extensively quarried in Sursagar area for building purposes. The overlying Girbhakar Sandstone denotes a break in sedimentation that is marked by the pebbles and chert of Sonia Sandstone which occur in the lowest horizons of the Girbhakar Sandstone. The thickness of the Sonia Sandstone is 256 m.

Girbhakar Sandstone

The Girbhakar Sandstone is 100 meter thick sequence exposed in a hillock 383 near Lohawatwala Bhakar due NW of Lohawat and it is composed of reddish sandstone. It is mainly constituted of gritty micaceous sandstone alternating with gritty and pebbly

Table 5—Lithostratigraphic subdivisions of Girbhakar Sandstone (after Khan, 1971)

Girbhakar Sandstone	Whitish to pale yellow, coarse to fine grained, partly-pebbly sandstone	10m-20m
	Red to purple, medium grained, gritty pebbly sandstone, containing thin bands of sandy and micaceous shale	60m-70m
	Brick-red to partly whitish, massive, medium grained, pebbly sandstone, more prominently towards the top	15m-20m
	Purple to whitish and pale yellow, medium grained, gritty pebbly sandstone	15m-20m
	----------------------------Diastem--------------------------	
	Brick-red to purplish sandstone showing mega ripples	15m-20m
	Red to purple, sandy and micaceous shale with argillaceous sandstone	50m-55m
	Purple to greenish, brown, laminated shale with thin interbeds of claystone, siltstone, showing flute casts	5m-10m
	Yellow to purple, whitish, reddish and purple sandstone, vuggy at the top, with bands of shale at the base	15m-35m

layers. Alternating bands of green and red shales with mica particles are commonly noted in the sandstone. Varied types of sedimentary structures are noted in the Sursagar, Balesar and Lohawat areas of Jodhour district. Further divisions of the Girbhakar Sandstone proposed by Khan (1971) are given in Table 5. The thickness of the Girbhakar Sandstone ranges between 185 and 250m (Pareek, 1984).

Bilara Group

The Bilara Group represents the middle part of the Marwar Supergroup and is made up of calcareous facies with dominant lithology made up of dolomite, limestone and dolomitic limestone and shales. The outcrops of the Bilara Group are scanty and can be seen only in the southern part of the basin. A number of cement and lime factories draw their raw material from this horizon. It attains a maximum thickness of ca. 300 m and pinches out in both the eastern and western parts of the basin (Pareek 1984). In the north, it is replaced by an evaporitic facies of the Hanseran Evaporite Group, which is considered homotaxial with the Bilara Group. However, some workers consider Hanseran Evaporite Group as an additional group and placed it between Bilara Group and Nagaur Group. The stratigraphy of the Hanseran Group is based on borehole data, as exposures are absent. The Hanseran Evaporite Group is an evaporite sequence represented by cyclic deposits of halite, potash minerals which alternate with anhydrite, clays, dolomite and limestone attaining a thickness of more than 600m (Dey, 1991). It is considered as the extension of the southern part of the Saline Series of the Salt Range of Pakistan (Kumar, 1999).

The Bilara Group has been subdivided into three formations by Pareek (1984): in stratigraphic order these are the Dhanapa Formation, the Gotan Formation and the Pondlo Formation. The Dhanapa Formation attains a thickness of ca. 100 m and is represented by chert, cherty dolomite and stromatolitic dolomite. The Gotan Formation is ca. 30 m thick. It is represented by limestone, dolomitic limestone with chert and clay bands. The stromatolites are poorly developed. The Pondlo Formation is the uppermost formation of the Bilara Group, with a maximum thickness of ca. 80 m. It is represented by dolomite, dolomitic limestone, siliceous dolomite, claystone, siltstone and sandstone. Stromatolites are also recorded in certain parts. The contact between Girbhakar and Dhanapa is generally conformable and transitional as seen at Pichyak to Palri passing through Birawas and Garhsuriya.

Dhanapa Formation

The Dhanapa Formation is constituted of chert at the base followed by laminated to bedded cherty dolomite, siliceous dolomitic limestone and stromatolitic limestone. Varieties of stromatolites are noted in the Dhanapa Dolomite. The chert is thinly bedded to massive, varying in colour from yellowish, reddish, smoky and chocolate. The contact between Girbhakar and Dhanapa Dolomite (bedded in nature) has been noted close to Pichyak dam where bedded and laminated chert occurs as rubble forming low ridges. The other areas where chert occurs as rubble are Hingoli, Indio, Dhaonda, Nagri and Dhanapa. The type area of the Dhanapa Formation is Dhanapa village. It is also well developed at Haras, Khosapura, Borunda and Gorawat villages.

Gotan Formation

The Gotan Limestone is constituted of limestone and bands of clay. Industrial grade limestone found in this formation is mainly used by the cement factories and lime kilns. Carbonate mud mound features and fetid odour emitting from freshly chipped limestone are very characteristic of this part of the Bilara Group. It is well exposed near Gotan village.

Pondlo Dolomite

The Pondlo Dolomite is constituted of dolomite, cherty dolomite, claystone, siltstone and reddish sandstone/dolomite/limestone. The contact between Pondlo Dolomite and Nagaur Sandstone has been noted in Asawari (26° 47' 00"N; 73° 40' 54"E; 45A/9) and Shiv Sar near Phalodi (27° 08' 30"N; 72° 21' 30"E; 45A/8). The top section close to Phalodi is stromatolitic. A 15cm thick siliceous oolites containing band is noted near Lordiyan (27° 03' 15"N; 72° 29' 00"E; 45A/8). Occurrences of chert and stromatolites have been used as important features to demarcate the three divisions of the Bilara Group. Chert is significant in the lower part but increases gradually in the upper part. Stromatolites are profusely present in the lower part, almost absent in the middle part and moderately present in the upper division of the Bilara Group. The Gotan Limestone has large scale finely laminated carbonate mud mounds. Three distinct divisions are clearly demarcated in the type localities however, it is difficult to demarcate boundaries between Dhanapa & Pondlo and Pondlo & Gotan in the field. Therefore it requires further geological mapping to establish three divisions of the Bilara Group. Industrial or chemical grade limestone is exposed near Bilara, Gotan and Barna villages. Cavernous structures are also noted in the limestone near Barna village.

Hanseran Evaporite Group

In the northern part of the Marwar Basin the exposures are absent but the rocks are present in the subsurface region, as inferred on the basis of borehole data. A new group designated as the Hanseran Evaporite Group is given to the entire halite-bearing subsurface sequence found in the central and northern parts of the basin sandwiched between the underlying arenaceous Jodhpur Group and the overlying predominantly argillaceous Nagaur Group (Dey 1991; Rastogi *et al.*, 2005). It attains a maximum thickness of 652 m, as found in a borehole near Hanseran in

Bikaner District. It is considered to be a facies variation of the Bilara Group developed in the southern part. As such, the Hanseran Evaporite Group is homotaxial with the Bilara Group.

The Hanseran Evaporite Group shows gradational contacts with the underlying Jodhpur Group and the overlying Nagaur Sandstone (Dey 1991) (Fig. 6). However, Mazumdar & Strauss (2006) consider the contact as unconformable between Hanseran and Nagaur. It is represented by dolomite, stromatolitic dolomite, magnesite, anhydrite, reddish claystone, halite and halite with potash salts in a repetitive sequence. Some workers have placed it as an additional group between the Bilara Group and the Nagaur Group (Chauhan *et al.,* 2004).

Nagaur Group

Youngest succession of the Marwar Supergroup, the Nagaur Group attains a maximum thickness of ca. 500 m (Pareek 1984). It is subdivided into the Nagaur Sandstone and the Tunklian Sandstone. The Nagaur Sandstone unconformably overlies the Pondlo Dolomite. For long it was considered that the beginning of the Nagaur Sandstone is marked by ca. 5-m-thick conglomerate near Phalodi, which shows an assortment of cobbles and pebbles in a pink to brown sandy to calcareous matrix (Sinha, 1975). This conglomerate is locally developed at Khichan, Malar and Bari Bawari and has been designated as the Khichan Conglomerate. A few workers do not agree on the placement of Khichan Conglomerate between Pondlo Formation and Nagaur Formation and consider that it overlies the Nagaur Formation (Jain *et al.,* 2001). They established the unconformable contact between Nagaur Formation and overlying Khichan conglomerate. This conglomerate is exposed at Bhomiyaji Temple on Phalodi Malar Road and also in a pond near Jain Dadawadi near Khichan. It is overlain by a thick succession of red to brick-red sandstone, siltstone and claystone with blotches of clay and thick evaporite sequence comprising limestone at the base, dolomitized limestone, dolomite, gypsum, anhydrite, halite and meagre potash salts at the top (Pareek 1984). The youngest horizon of the Marwar Supergroup is the Tunklian Sandstone, which is made up of brick-red claystone, siltstone, calcareous clay and gritty to pebbly sandstone with fragments and pebbles of chert, dolomite, quartz, quartzite, Malani granite and rhyolite (Pareek 1984). Kumar & Pandey (2008b, 2010), Srivastava (2013) have discovered well-developed trace fossils from the Nagaur Sandstone exposed in the Dulmera area, Bikaner district, Rajasthan. Recently, two body fossils have been described from the Dulmera area; Singh *et al.* (2013) have reported redlichid arthropod which can also be compared with an articulated arthropod tergites and Srivastava (2012) has described a worm-like problematic megafossil which is comparable to priapulids. These fossils help in assigning Lower Cambrian age to the Nagaur Group.

Nagaur Formation

The Nagaur Sandstone is constituted of thick succession of highly friable brick red to red claystone, siltstone and sandstone. Bands and blotches of white and green clay are found associated with the sandstone. Sometimes pebbles of chert, dolomite, quartz, quartzite and Malani Rhyolite are seen in the sandstone. Exposures of Nagaur Formation are scanty. At Dulmera these exposures yield variety of Lower to Middle Cambrian trace-fossils. It is fine to medium grained, well sorted in nature under microscope.

Tunklian Formation

The Tunklian Formation is constituted of brown-purple to violet coloured gritty sandstone, fine grained sandstone and silty shale. The best exposure is seen near Tunklian Hill near Gotan.

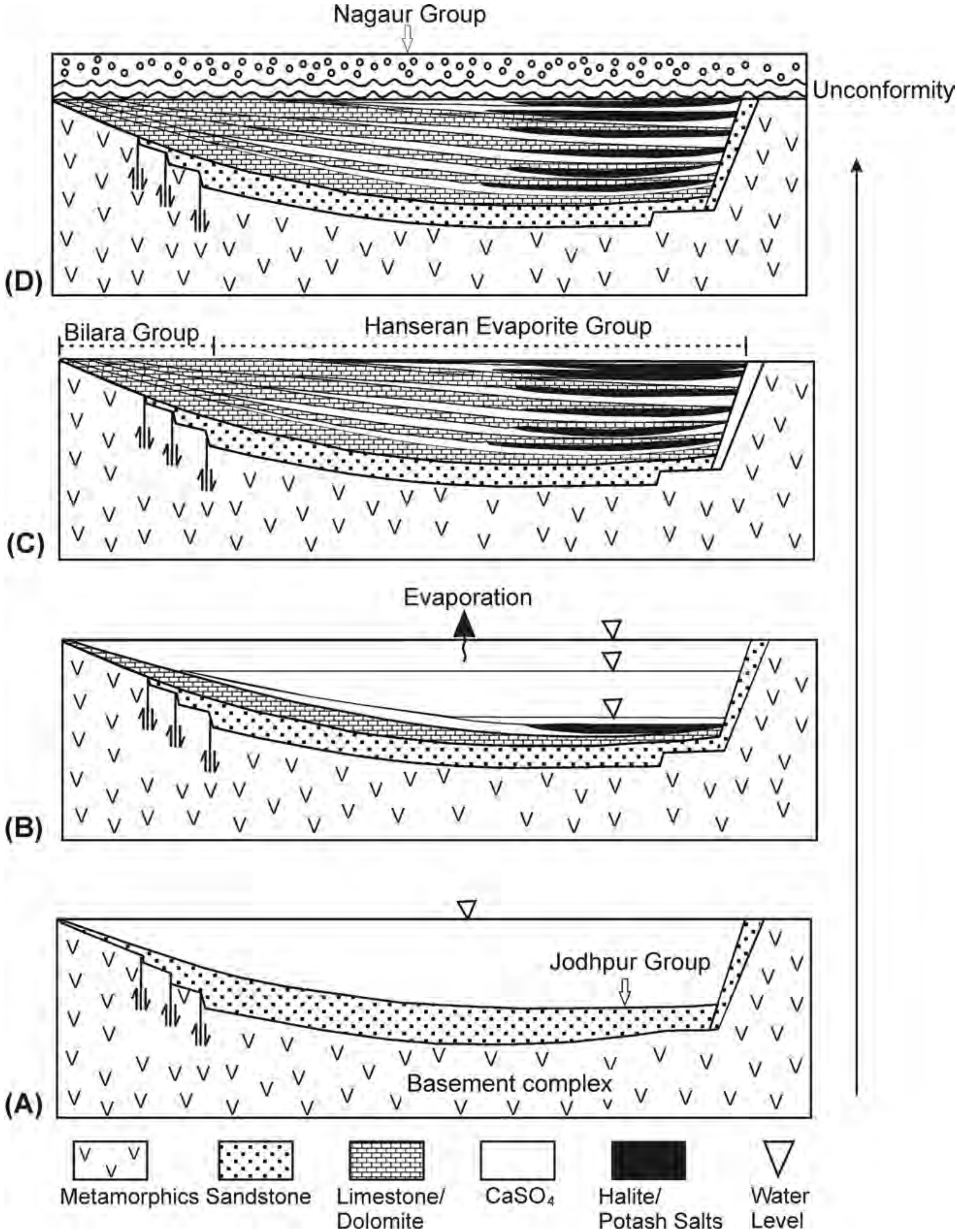

Fig. 6—Schematic basin evolution model for the Marwar Supergroup depicting temporal and spatial relationship between the Bilara and Hanseran Evaporite Groups (redrawn after Mazumdar & Strauss, 2006).

Birmania Basin

The Birmania Basin is an isolated basin, developed ca. 125 km SW of Pokaran and occupying an area of ca. 100 sq km (Pareek, 1984). It is situated in the southwestern extremity of the Marwar Basin. The basic difference between the Birmania Basin and the Marwar Basin is that the former is deformed while the rocks of the Marwar Basin are undeformed. Only two formations have been reported from this basin. The older is the Randha Sandstone, which unconformably overlies the Malani Igneous Suite, and the younger is the Birmania Formation, which has an angular unconformity with the Randha Sandstone (Table 6). The Randha Sandstone is an arenaceous sequence made up of maroon and grey shales and sandstones. The Birmania Formation is made up of shales, cherty limestone, dolomite, phosphorite, sandstone and calcareous sandstone. The total thickness in the Birmania Basin is estimated to be ca. 900 m. The rocks of the Birmania Basin are extensively deformed and are pre-Lathi in age (Pareek, 1984), in contrast to the rocks of the Marwar Supergroup, which are more or less undeformed. The Birmania Dolomite is unconformably overlain by the Lathi Sandstone of Jurassic age. The Randha Sandstone has been correlated with the Sonia Sandstone (middle part of the Jodhpur Sandstone) and the Birmania Dolomite has been correlated with the Bilara Group. Mazumdar & Strauss (2006), on the basis of sulphur isotope data, have suggested that the rocks of the Bilara and Hanseran Evaporite Groups are a coeval facies variant. Maheshwari *et al.* (2002, 2007) have noted that carbon-isotope values of the Birmania succession are similar to those observed in well-established Precambrian–Cambrian boundary sections globally. The absence of the Nagaur Group in the Birmania Basin is explained by suggesting that either it is not developed in the basin or has been eroded (Pareek, 1984). Banerjee (1986) has suggested that the phosphorite horizon of the Birmania Basin may belong to the global cycle of a Lower to Middle Cambrian phosphatization.

Table 6—Lithostratigraphic subdivisions of Birmania Basin (after Muktinath, 1969)

Jurassic	Lathi Formation	Unconformity	
		7 Dark shale, calcareous sandstone and cherty limestone	10m
		6 Calcareous chert, dolomitic limestone and minor sandstone	6-60m
		5 Yellow limestone, siliceous limestone and variegated shale	30-105m
Palaeozoic (?)	Birmania Formation	4 Phosphoritic: Sandy calcareous shale and bedded phosphatic limestone	0-7m
		3 Massive calcareous and pure quartzitic sandstone	1-4m
		2 Buff coloured and fine grained calcareous ferrugious sandstone	50-270m
		1 Greyish-yellow or grey cherty limestone	80m
	Randha Sandstone	-------------------------Unconformity----------------------	
		Sandstone, subordinate calcareous rock and maroon shale	214m
		-------------------------Unconformity----------------------	
Pre-cambrian		Jalor-Siwana granite, rhyolite, rhyolite porphyry and porphyry; Metamorphics	

PALAEONTOLOGY

As mentioned earlier the Marwar Supergroup was considered unfossiliferous till early seventies except for the report of stromatolites as no fossil, including trace fossil, was known from these rocks. Khan (1973) for the first time reported the occurrence of a lone brachiopod *Orthis* from the Jodhpur Sandstone. However, the discovery of this fossil could not be replicated and hence has now been ignored. Awasthi & Prakash (1981) have mentioned the occurrence of trace fossils from the silty layers of the Jodhpur Sandstone from the Jodhpur area. Two types of trace fossils are mentioned. The first are thin, flat, circular objects of 0.5-3 cm diameter and with a thickness of about 4 mm. The flatter side is parallel to the bedding plane and is marked by a slightly raised rim 1 mm high. They resemble burrows attributed to *Laevicyclus* Quenstedt, 1879 (Awasthi *et al.,* 1979). The other type of trace fossils is also burrows, but about 3 mm in diameter cutting through the bedding and joined along the bedding planes by tracks. The first convincing report of any fossil was made by Raghav *et al.* (2005) from the lower part of the Jodhpur Sandstone. They reported a body fossil *Marsonia,* with medusoidal affinity and two trace fossils from the lower part of the Jodhpur Sandstone. After this report Ediacaran fossils *Aspidella* sp., cf. *Hiemalora* sp. and *Beltanelliformis minuta* were also reported from the middle part of the Jodhpur Sandstone (Sonia Sandstone) (Kumar & Pandey, 2007). These fossils support an Ediacaran age to the Jodhpur Sandstone. Recently, a five armed body fossil showing some resemblance with echinoids were also reported from the Jodhpur Sandstone (Kumar *et al.,* 2012.). Problematic body fossils of megascopic dimensions with Vaucheriacean affinity have also been recorded from the Jodhpur Sandstone (Kumar *et al.,* 2009). Recently, Srivastava (2013) has described large sized Ediacaran discs from the Jodhpur Sandstone. However, there is a possibility that these discs may also represent microbial mat structures and may be considered under MISS (Microbially Induced Sedimentary Structures). A unique feature of the Jodhpur Sandstone is the marked presence of microbial mat structures. Samanta *et al.* (2011) recorded a variety of microbial mat induced structures in bed across section within the coastal interval of the Sonia Sandstone. Well-preserved microbial mats including *Arumberia banksi* have been described from these sandstones (Sarkar *et al.* 2008; Kumar & Pandey 2009). On the basis of abundant ornamented sphaeromorphs, *Lophosphaeridium* spp., as well as various species of *Leiosphaeridia*, Prasad *et al.* (2010) have suggested a Late Ediacaran age for the Jodhpur Group. Recently *Thalassinoides*, a trace fossil has also been reported from the Jodhpur Sandstone (Parihar *et al.,* 2011; Parihar & Gaur, 2012; Kumar & Ahmad, 2012). The presence of *Thalassinoides* burrows in the Ediacaran Jodhpur Sandstone appears to be an oddity as it is difficult to comprehend such an advance burrow system which in the modern environment is produced by decapod crusctaceans. They are profusely developed in the Mesozoic and have never been reported from the Precambrian sediments. In our opinion they may be concretions and give a superfluous resemblance with the *Thalassinoides* burrows.

Stromatolites were reported as early as 1964 by Khilnani (1964) from the Bilara Limestone. Barman (1980, 1987) reported the occurrence of *Colleniella, Collenia pseudocolumnaris, Conocollenia, Cryptozoon occidentale, Stratifera, Conophyton* and oncolites from the Bilara Group, but no detailed morphology of these stromatolites has so far been described. But abundance of Conophytons and pseudocolumnar forms are noticed in these carbonates. Microfossils have also been described by Maithy (1984) from the Dhanapa Dolomite. He compared these fossils with *Nanoccocus vulgaris*, *Huroniospora psilata* and *Kakabekia umbellata*. Babu *et al.* (2007) have recorded a palynofossil assemblage of planktic and benthic forms from the Gotan Limestone. The assemblage is made up of 12 taxa of acritarchs and 5 taxa of cyanobacteria. The acritarch taxa are *Stictosphaeridium, Leiosphaeridia, Trachysphaeridium, Synsphaeridium, Polyedtysium, Octoedryxium, Cymatiosphaera, Cymatiogalea, Cristallinium, Buedingiisphaeridium, Pterosprmella* and *Aremoricanium*. The cyanobacterial assemblage is represented by both coccoids and filamentous forms: *Obruchevella, Polythrichoides, Siphonophycus, Myxococcoides* and *Gloecapsmorpha*. They have, therefore, suggested an Ediacaran age for this assemblage. Prasad *et al.* (2010) have reported an acritarch assemblage of *Asteridium* spp., *Dictyotidium birvetense, Pterospermella solida* and *Annulum squamaceum* from the lower part of the Bilara Group and assigned a latest Ediacaran to early Cambrian age. They have suggested a Precambrian/Cambrian boundary in the lower part of the Bilara Group. According to Prasad *et al.* (2010), the Hanseran Evaporite Group is marked by

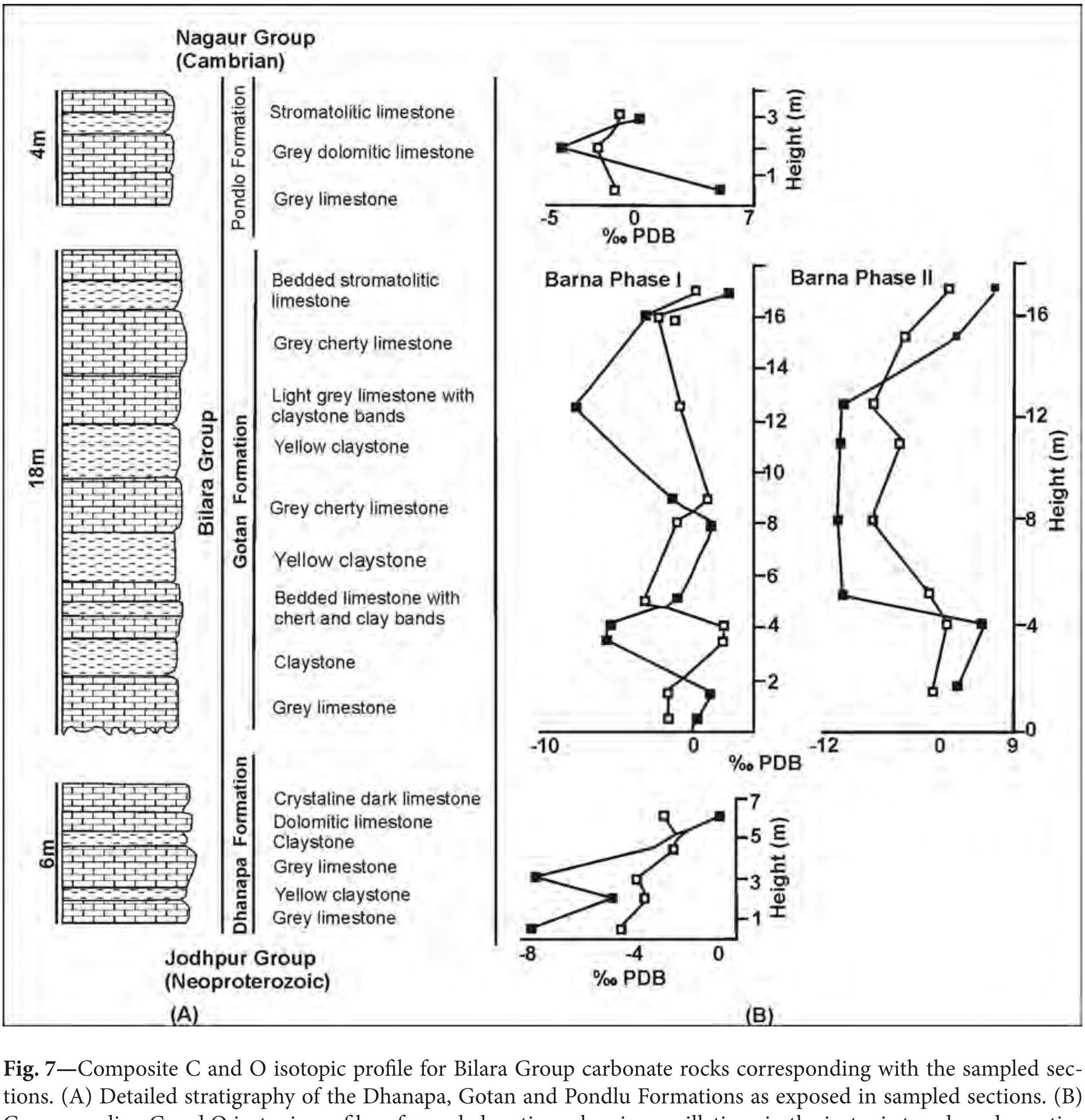

Fig. 7—Composite C and O isotopic profile for Bilara Group carbonate rocks corresponding with the sampled sections. (A) Detailed stratigraphy of the Dhanapa, Gotan and Pondlu Formations as exposed in sampled sections. (B) Corresponding C and O isotopic profiles of sampled sections showing oscillations in the isotopic trends and negative $\delta^{13}C$ anomalies. Height (in meters) indicates approximate height with reference to the base of the sampled section. (redrawn after Pandit *et al.*, 2001)

an abundance of acritarchs represented by *Retisphaeridium dichamerum*, *Dichtyotidium birvetense*, *Cristallinum cambriense*, *Comasphaeridium* sp. and *Archaeodiscina umbonulata*, suggesting a late Early Cambrian to Middle Cambrian age. According to Prasad *et al.* (2010), the succession overlying the Hanseran Evaporite Group is poorly fossiliferous but the succeeding unit of Upper Carbonate Sequence is marked by abundance of acritarchs *Cristallinium randomense*, *Cymatiosphaera crameri* and *Asteridium* spp. and late Cambrian marker forms such as *Striatotheca loculifera* and *Dorsenidium minutum*. These forms suggest Middle Cambrian to early Late Cambrian.

Kumar & Pandey (2008b, 2010) have discovered well-developed trace fossils from the Nagaur Sandstone exposed in the Dulmera area, Bikaner district. They have reported *Rusophycus disymus*, *Chondrites*, *Cruziana*, *Dimorphichnus obliquus*, *Monomorphichnus monolinearis*, *Diplichnites*, *Skolithos*, *Palaeophycus tubalaris* and *Planolites*, and a few trails and scratch marks. On the basis of these trace fossils they have suggested a Lower Cambrian age for the Nagaur Sandstone. Srivastava (2012) has described the occurrence of *Treptichnus pedum* from the Nagaur Sandstone which is a burrow whose presence marks the beginning of the Cambrian period. Recently two body fossils have been reported from the Dulmera area: Singh *et al.* (2013) have reported redlichid arthropod which can also be compared with an articulated arthropod tergites and Srivastava (2012) has described a worm-like problematic megafossil which is comparable to priapulids.

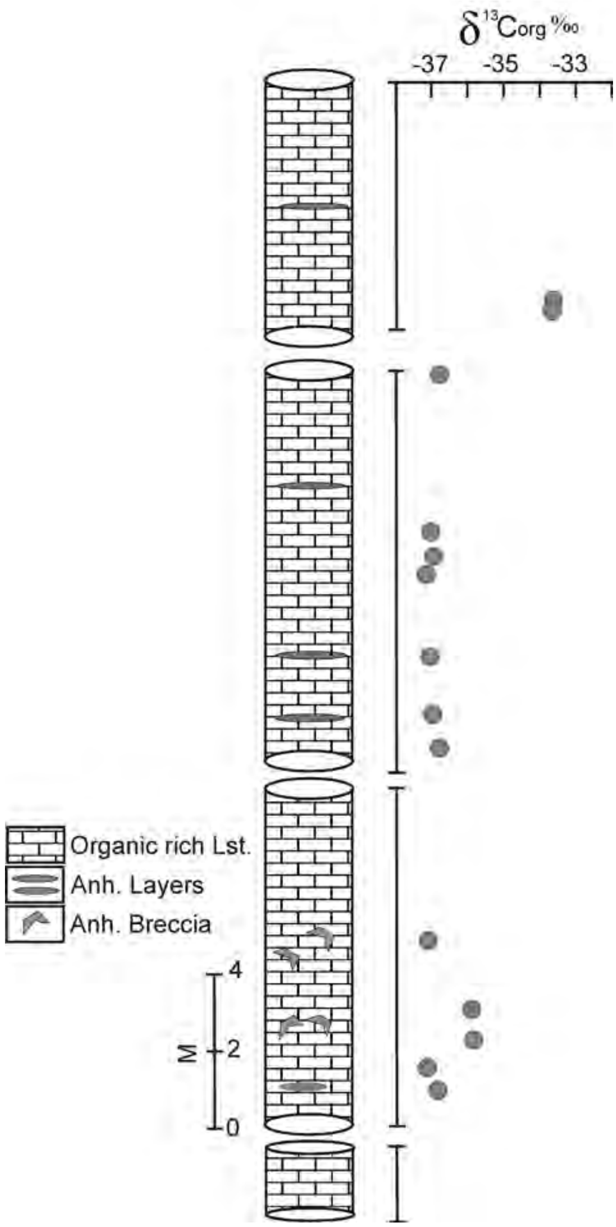

Fig. 8—Carbon isotopic composition of organic matter in Baghewala-II core. (redrawn after Mazumdar & Bhattacharya 2004)

ISOTOPE CHEMOSTRATIGRAPHY

Pandit *et al.* (2001) have studied the carbonates of the Bilara Group for carbon isotope values. They noted that the lower part showed marked oscillations in carbon isotope values with negative anomalies, but the upper part of the profile shows a gradual positive shift (Fig. 7). According to them, the carbon isotope signatures can be correlated with an end-Neoproterzoic–early Cambrian (Vendian – Tommotian) carbon-isotopic evolution curve. Mazumadar & Bhattacharya (2004) (Figs. 8, 9) studied the carbonate rocks in the Bilara type area and suggested that stable isotopic composition of these rocks show close

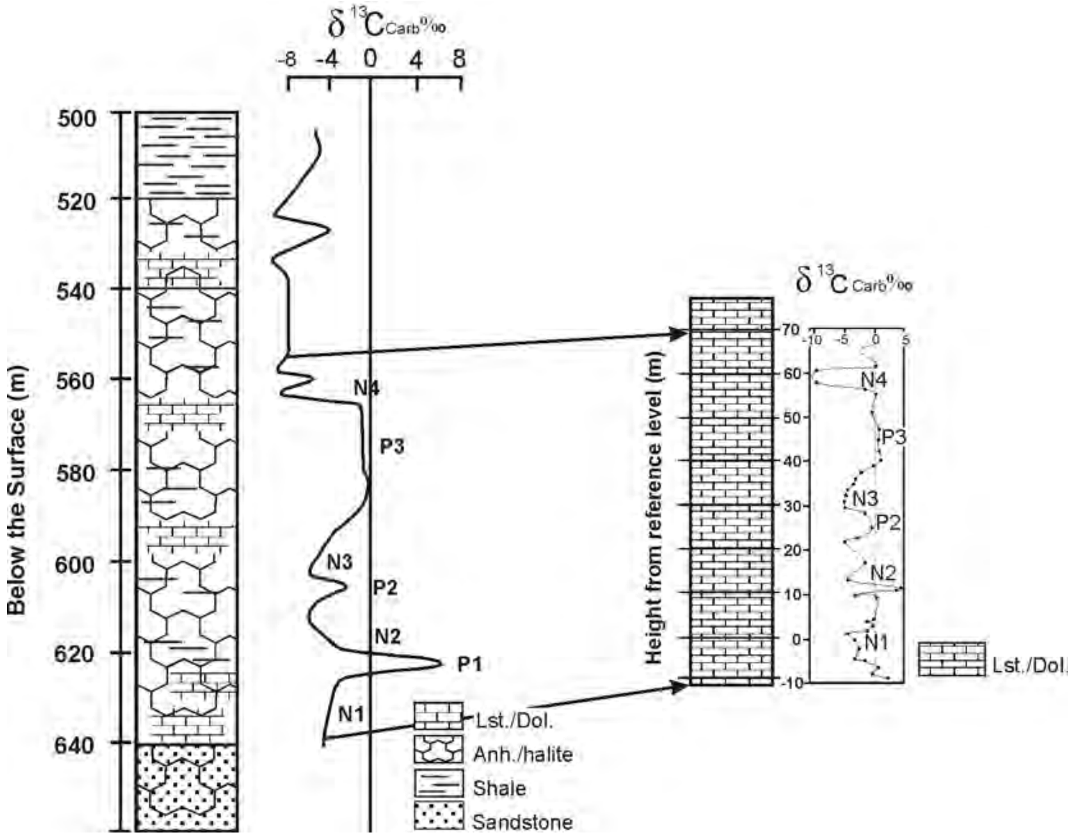

Fig. 9—Geological map of Nagaur-Ganganagar basin (modified after Strauss *et al.*, 2001) (redrawn after Mazumdar & Bhattacharya 2004).

similarity with Ara Formation (Huqf Group, south Oman salt basin) which transgresses the late Neoproterozoic-early Cambrian boundary. Extremely low $\delta^{13}C$ values in the Bilara Group indicate a glaciation-related cold climate at the end of the Neoproterozoic (Mazumdar & Strauss, 2006). On the basis of sulphur and strontium isotope analysis of both carbonate and evaporite groups Mazumdar & Strauss (2006) reached on the conclusion that both represent coeval facies variant (Fig. 10). Sulphur and strontium isotope ratios of the sedimentary rocks from both groups are quite similar and justify the interpretation that sediments from both the groups were deposited within the same age bracket. At the same time the sulphur isotopic composition for samples from the both the groups is in good agreement with globally observed trend of $\delta^{34}S$-enriched marine sulphate sulphur during Ediacaran and much of Cambrian time (Strauss *et al.*, 2001).

TECTONICS AND STRUCTURE

Basin Evolution

The Marwar Basin has an elongated configuration extending in NNW – SSW and is bounded by early to middle Proterozoic Aravalli-Delhi orogen in the east and the late Proterozoic Malani Igneous Suite (Fig. 11) in the south. In the north it abuts against subsurface Delhi – Sargoda ridge (see Chauhan, 1999). The basin extends further north and further northwestward and merges with Indus shelf (Fig. 12). It is bordered immediately northwest of Pokaran by the Jaisalmer basin and southwest of Jodhpur by the Barmer Basin, both are of the Mesozoic-Tertiary age.

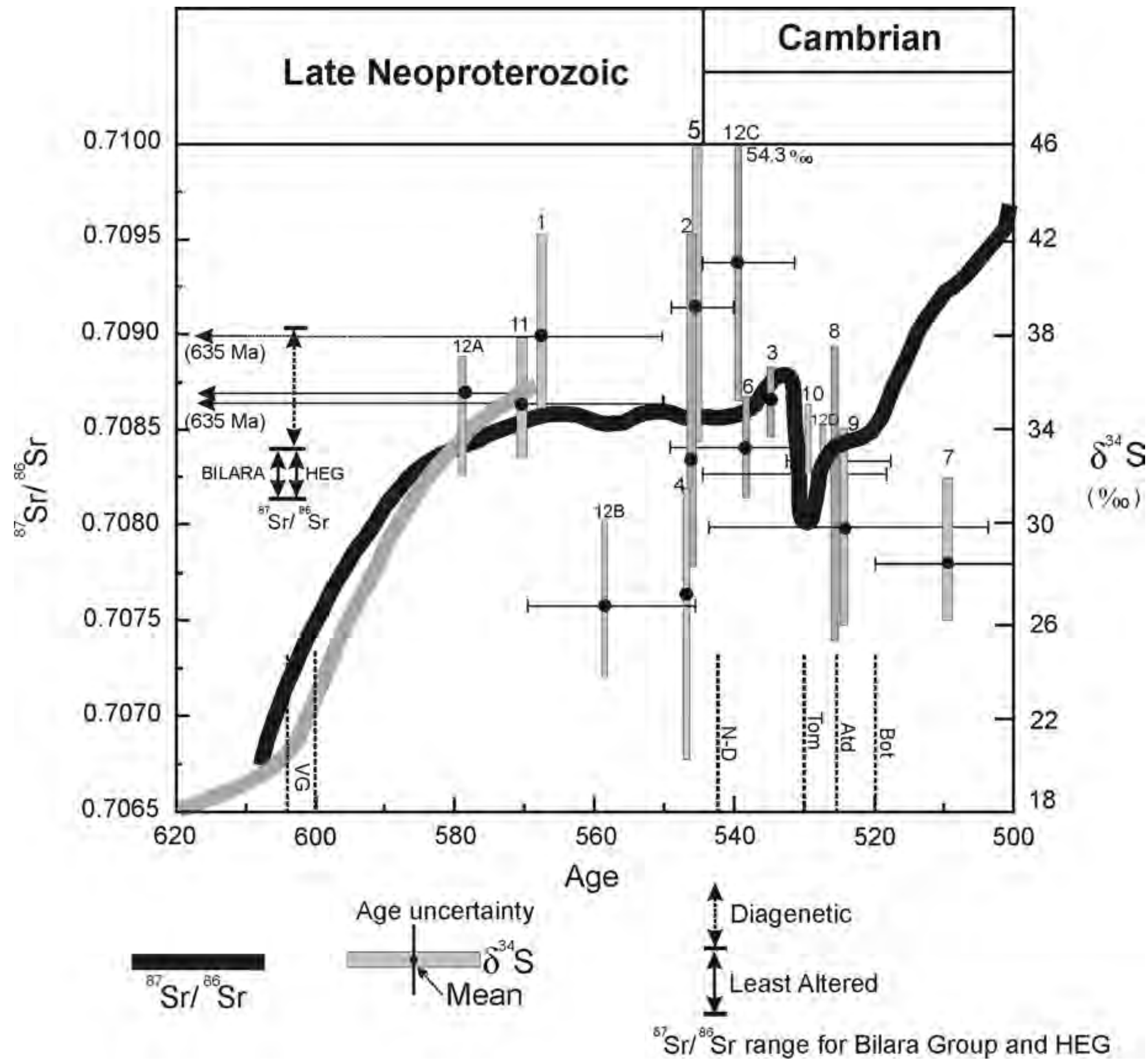

Fig. 10—Temporal variations of sulfur and strontium isotopic compositions of sea-waters through late Proterozoic and Cambrian. Sulfur isotopic compositions recorded for terminal Proterozoic and Cambrian from different basins are plotted for comparison. (redrawn after Mazumdar & Strauss, 2006, for further details see Mazumdar & Strauss, 2006).

Chauhan (1999) has discussed the evolution of Marwar Basin. According to him the lithofacies attributes affirm that the Marwar Basin behaved perfectly as an intracratonic sag basin maintaining shallow water milieu through out its life span. The basin slowly and steadily subsided without any syntectonic activity under the accumulating sediment load and maintained shallow water regime all through in order to further accommodate and design its various lithofacies. Various steps have been envisaged by Chauhan (1999) for the evolution of the Marwar Basin. It appears that the Marwar Basin is an outcome of thermal interaction of the lithosphere initiated by the Malani magmatism during the Proterozoic time. The hot spot activity or mantle plume which initiated Malani magmatism caused doming and thinning of Malani crust. However it could not impart enough thermal energy which could subject the crust doming and thinning to a such extent that it could fail by faulting and rifting, instead it gradually subsided due to slow cooling and developed into an intracratonic sag basin.

The basin remained as a perfectly stable shallow water basin through out its life span without any syntectonic activity.

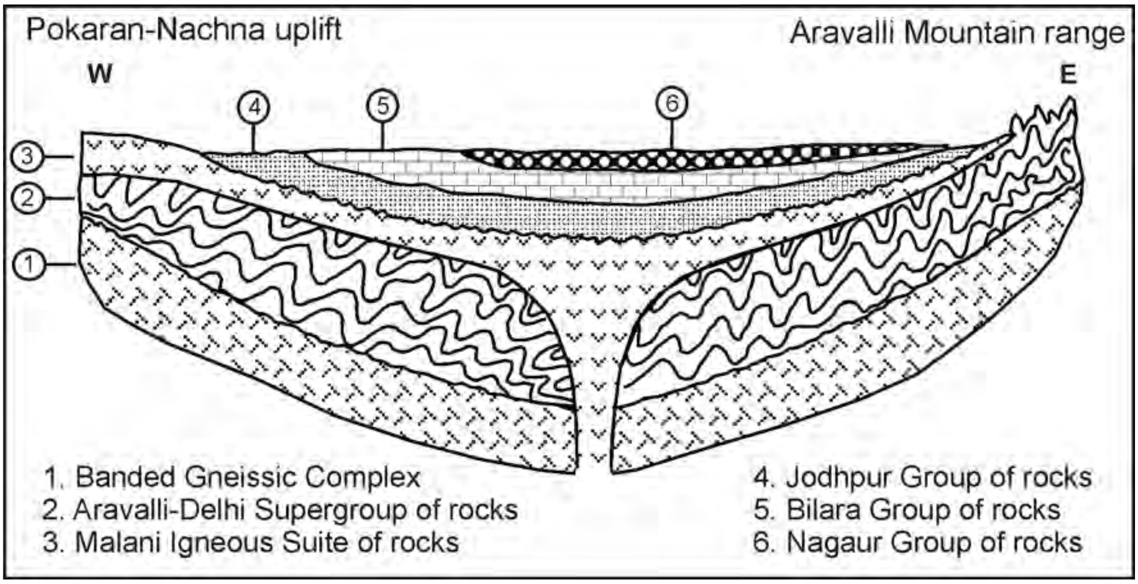

Fig. 11—Schematic model of the Marwar basin development (redrawn after Chauhan, 1999).

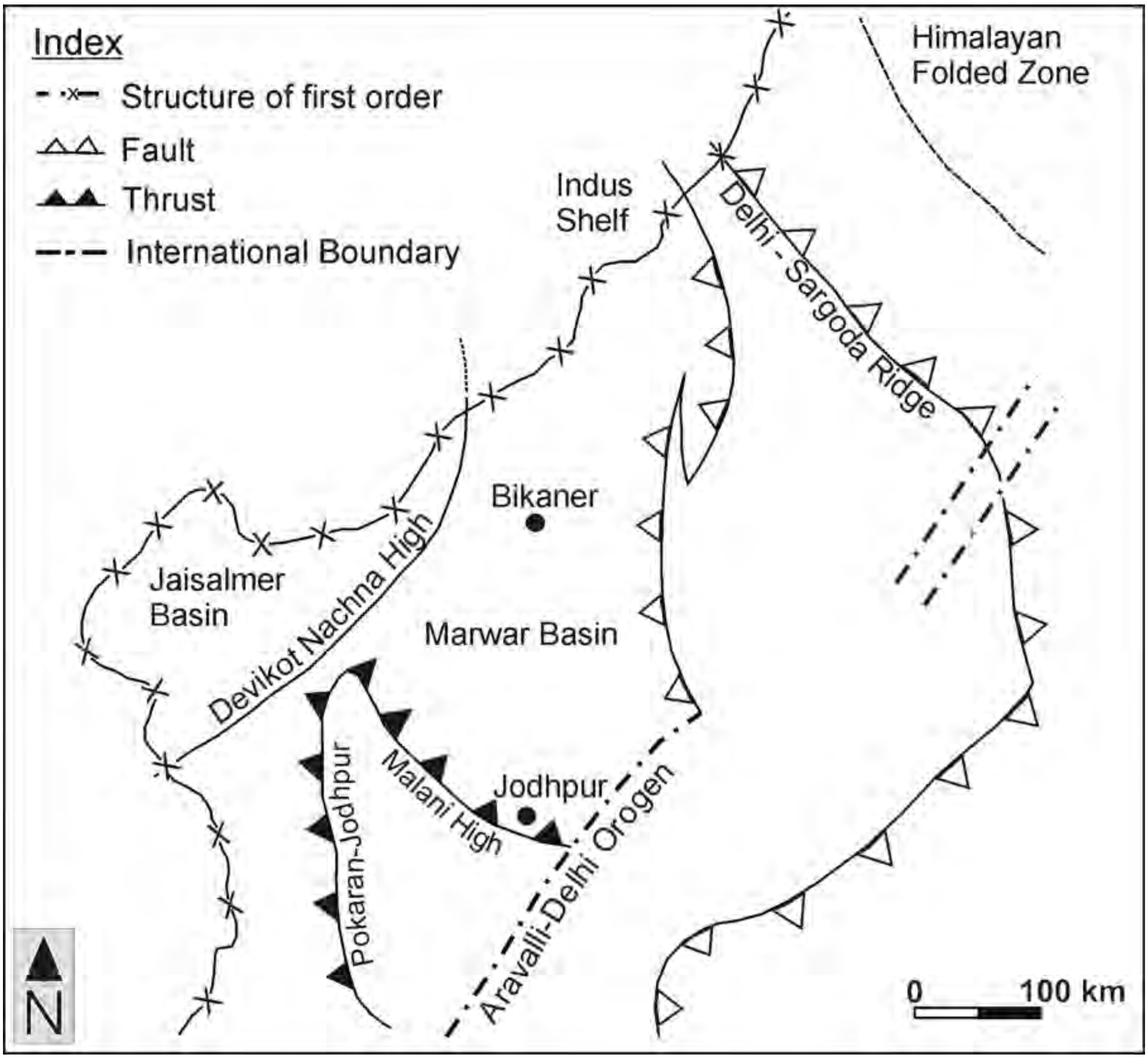

Fig. 12—Tectonic framework of Marwar and adjoining basins of western India (redrawn after Chauhan, 1999).

Palaeocurrent Analysis

Not much information is available on the palaeocurrent analysis for the Marwar Supergroup. Chauhan *et al.* (2001) mentioned the palaeoflow pattern inferred for the Pokaran Boulder Bed is northeasterly while it is southeasterly for the overlying Pokaran Sandstone (lower part of Jodhpur Sandstone) suggesting that these two units were formed by two independent depositional systems and there exists a discrete hiatus between them.

Awasthi *et al.* (1977) have measured the palaeocurrent of the Jodhpur Formation (Jodhpur Sandstone) and noted that it is northerly in the eastern part and changed gradually to westerly direction in the western part. According to them the low variance, presence of mud cracks, profusely cross bedded, coarse bedded nature of the sandstones, virtual absence of shale indicate that these were deposited by braided fluvial streams. Awasthi & Prakash (1981) have given much more detailed account of the palaeocurrent analysis for the Jodhpur Sandstone and reached on the conclusion that the Jodhpur Group of rocks was deposited during a number of transgressions and regressions. The most common palaeogeographic scenario was that of braided streams flowing to west, northwest and north from the Piper Road Block side. Further downstream towards the sea, low-energy beaches developed which passed into a wide shelf zone. However, during deposition of formation E (the youngest unit) of the Jodhpur Group, the first low-energy beaches developed along the margins of the Pipar Road Block, but as the shoreline prograded over the wide shelf, storm-influenced beaches replaced the low-energy beaches. The problem of this analysis is that no distinction is made between current generated structures and wave generated structures which favoured bias in favour of fluvial system.

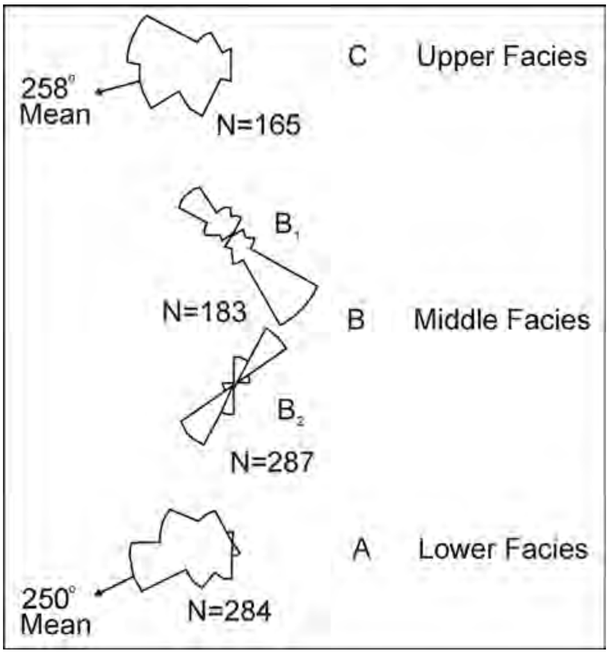

Fig. 13—Palaeocurrent azimuth distribution pattern shown by cross-bedding in Jodhpur Group at Jodhpur(A and C) and asymmetrical ripples (B1). B2 shows trend of ripple crests. (redrawn after Chauhan *et al.*, 1991)

Chauhan *et al.* (1991) have described the palaeocurrent pattern for the sandstones exposed around Jodhpur where they have identified three facies; the lower facies shows unimodal pattern towards west-southwest possibly of alleviating river system. The middle part is definitely marked by a bimodal palaeocurrent pattern in the southeast and northwest suggesting a tidal action. The upper part again shows a unimodal pattern in the west northwest direction (Fig. 13). No palaeocurrent data is available for the Bilara and Nagaur Groups.

Depositional Environment

Awasthi & Prakash (1981) have identified six lithofacies in the Jodhpur Group and interpreted them in terms of environmental facies as braided fluvial facies, low-energy beach facies with tidal effects during depositional regression, storm-influenced beach facies during depositional regression, low-energy beach facies during depositional transgression, lagoonal facies and shelf facies. The most common palaeogeographic scenario was of braided streams flowing to the sea. Streams flowed west, northwest and north of the Pipar Road situated in the southern part of the area of study.

Chauhan *et al.* (1991) have identified three facies associations within the Jodhpur Sandstone. The lower is made up of an inter-bedded succession of sandy shale, shaly sandstone and medium-to coarse-grained sandstone. The festoon cross bedding is the most dominant sedimentary structure. The dominant current direction is unipolar in the WSW direction. It represents a coarsening-upward sequence and has been assigned a deltaic environment of deposition. The middle part is made up of medium-to fine-grained red to maroon sandstone and the upper part is made up of medium-to coarse grained sandstone with intercalations of pebbly to conglomeratic sandstone. Well-preserved wave and current ripples, interference ripples and both small and large cross-beddings are profusely preserved. It shows a bipolar current direction with the dominant current direction trending SE–NW (Chauhan *et al.,* 2004). Ram & Chauhan, (2001) studied the lithofacies of the Jodhpur Sandstone of the Bhopalgarh area and conluded that these were deposited by braided river system.

Chauhan *et al.* (1991, 2004) have assigned a beach environment of deposition for the middle part. The thickly bedded pink sandstone of the middle facies is overlain by coarse to pebbly sandstone. At a few places even salt pseudomorph is also seen in shaly horizons. Conglomerates are also seen that are polymictic. Cross-bedding is occasionally seen. The upper facies shows unipolar current direction trending WSW, dominantly shows a fining-upward sequence, and has been assigned a braided channel deposit of a fluvial system (Chauhan *et al.*, 1991).

Sarkar *et al.* (2012) studied the lower part of the Sonia Sandstone and proposed three divisions for the 85 meters thick succession as a product of non-marine interval of deposition and demonstrated in a detailed study that the geometry of bounding surfaces as well as constituent facies and architectural elements make the three divisions distinct from each other. This study provided the inputs for understanding of the Precambrian fluvial system.

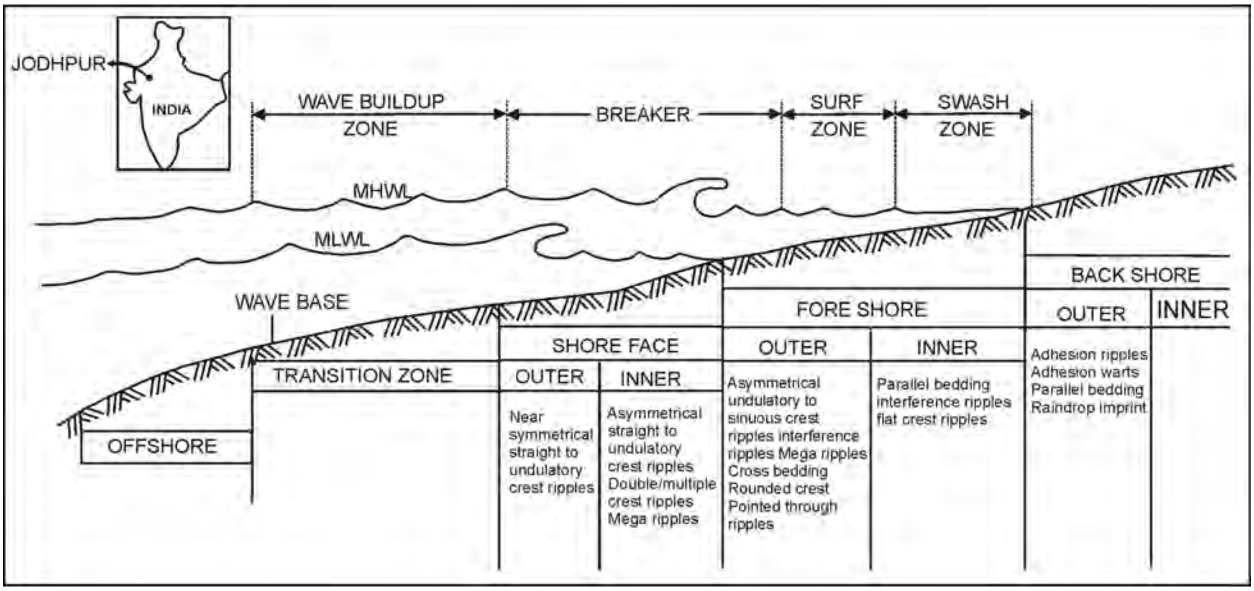

Fig. 14—Schematic representation of dynamic and geomorphic units in proposed nearshore-beach environment of Jodhpur Sandstone and associated inferred sedimentary structures of the area (redrawn after Chauhan *et al.*, 2004).

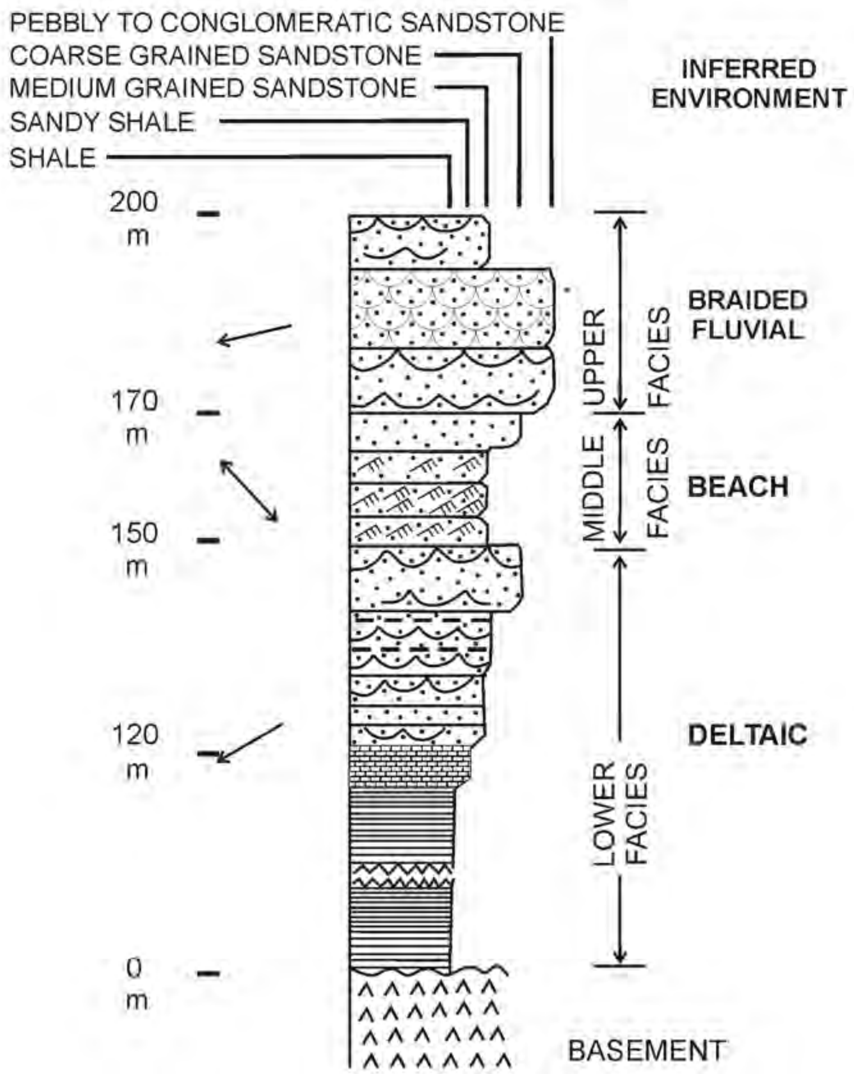

Fig. 15—Stratigraphic section of Jodhpur Group of rocks in Jodhpur town showing lithofacies association, dominant palaeoflow direction and inferred depositional environments (redrawn after Chauhan *et al.*, 1991).

FIELD STOPS

(Abbreviations: DRM-District Resource Map, prepared by Geological Survey of India; DS-Degree Sheet, TS-Topo Sheet, prepared by Survey of India. Distances provided under Approach heading are calculated from City Headquarters).

Stop 1

(Fig. 16)

Antennae Hill Section

Location—N 26º18'73.5"; E 73º01'09.3"; DRM-Jodhpur, DS-45F, TS-45F/3.

Approach—Approximately 10 Km NNW from the Jodhpur City.

Key Observations—On the Antennae Hill, close to Tekari Mata temple is exposed the unconformable contact between Malani Rhyolite and Sonia Sandstone of the Marwar Supergroup. Weathered and broken brecciated large pieces are engulfed in the earliest deposited sediments of the Marwar Supergroup. In the Jodhpur area, the Jodhpur Group shows distinct lateral variations at the base, at few places reddish shales of the Sonia Sadnstone directly overly the Malani fractured rocks. The lowermost unit of the Jodhpur Group is exposed ~100 km NW of Jodhpur near Pokaran where Pokaran Boulder Beds are in contact with the Malani Rhyolites and overlain by the Sonia

Fig. 16—Contact between the Sonia Sandstone and the Malani Group of rocks marked by dotted yellow line.

Sandstone. This variation is attributed to the undulatary palaeotopography of Malani flows and spread which developed through very long duration of erosion (~150 Ma). The Jodhpur Group deposited over these palaeotopographic highs and lows on lapping the basement highs at different stratigraphic levels. After deep excavations the site is good for collection of fresh rock specimens for geochronological dating.

Time allotted—45 Minutes.

Stop 2

(Fig. 17)

Mehrangarh Fort Section

Location—N 26°17'51.5"; E 73°01'11.4". DRM-Jodhpur, DS-45F, TS-45F/3.

Approach—Approximately 10 Km NNW from the Jodhpur City.

Key Observations—Famous and majestic Mehrangarh Fort is standing on the Malani Rhyolites. It is constructed of the Sonia Sandstone brought from the vicinity. Close to the entrance

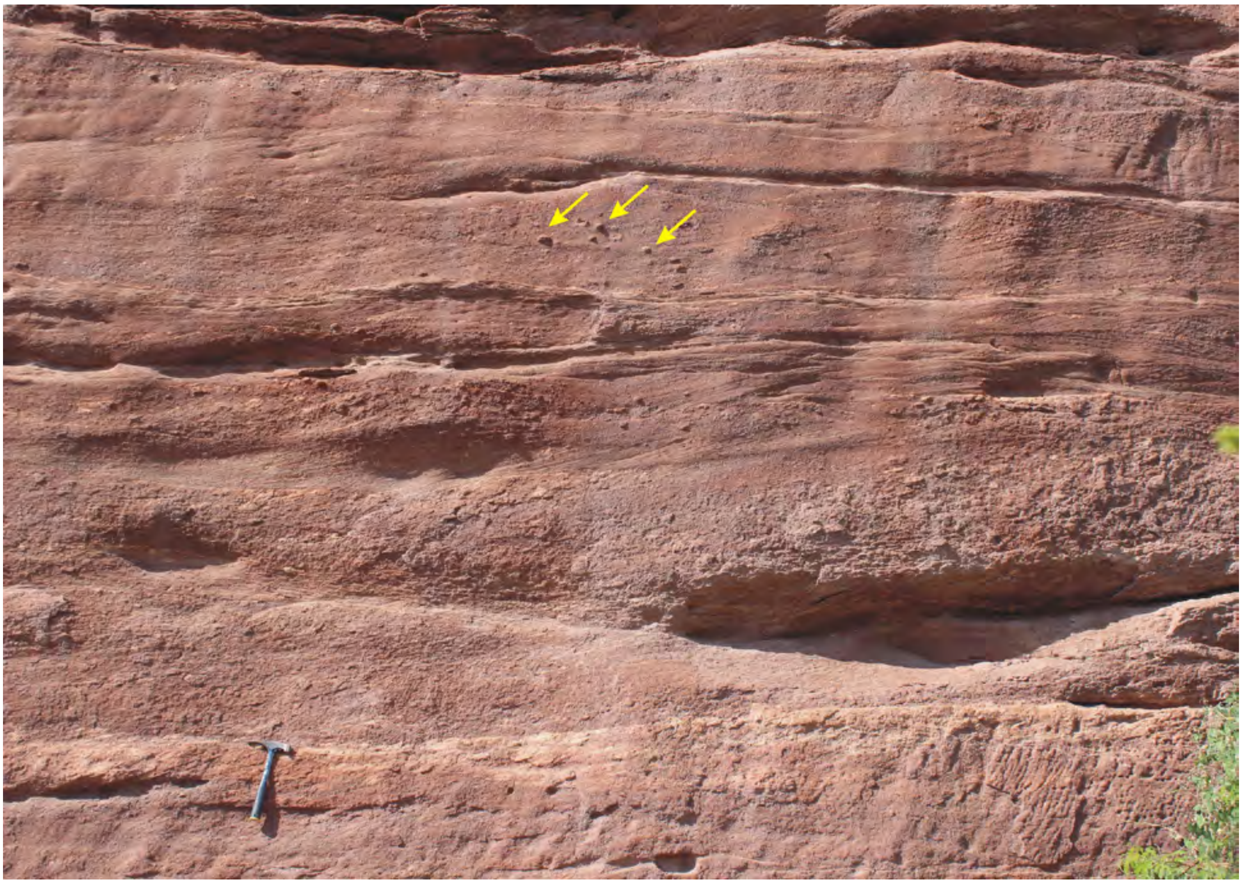

Fig. 17—Large scale cross bedded Sonia Sandstone exposed behind the Mehrangarh Fort containing different sizes of nodules.

of the fort marks the contact between the Malani Rhyolite and Sonia Sandstone. This Contact is well exposed on pedestrian route behind the Fort. Large scale cross bedding and small nodules are prominent features to be observed at this site. Sarkar *et al.*, (2012) considered this part of Sonia Sandtone as Division II which is devoid of mudstone.

Time allotted—30 Minutes.

Stop 3

(Fig. 18)

Beri-Ganga Section

Location—N 26°22'57.16"; E 73°03'34.51". DRM-Jodhpur, DS-45F, TS-45F/3.

Approach—Approximately 20 Km N from the Jodhpur City on Jodhpur-Mandore Road NH-65.

Key Observations—Contact between the Malani fractured rocks and red coloured shale Unit of the Sonia Sandstone is noted at this site, shales are overlain by Sonia Sandstone. It also denotes the distinct lateral variations at the base. This variation is attributed to the palaeotopography which developed through very long duration of erosion (~150 Ma). It shows that various units of the Jodhpur Group were deposited over these palaeotopographic highs and lows at different stratigraphic levels.

Fig. 18—Contact between underlying shaly siltstone facies and overlying large scale cross bedded sandstone facies of the Sonia Sandstone marked by yellow dotted line.

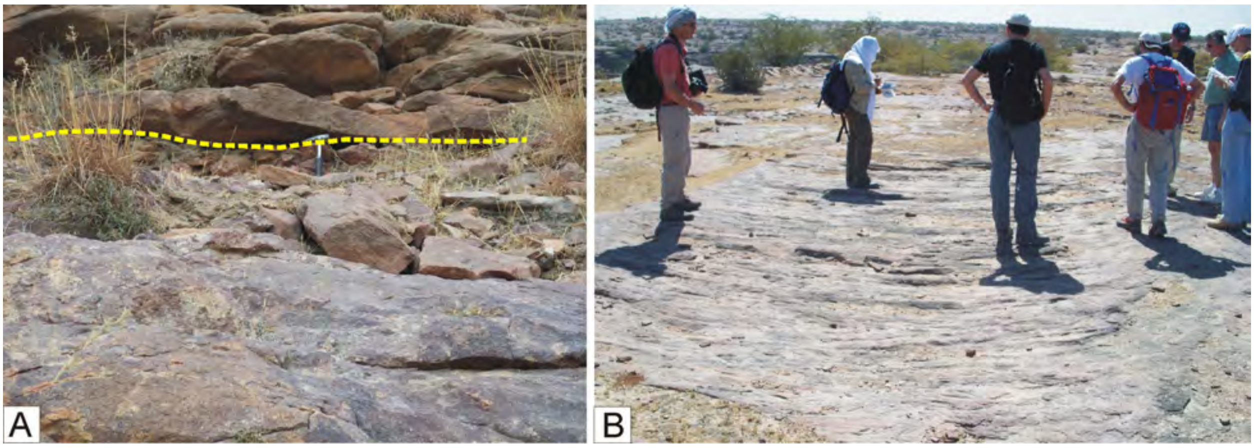

Fig. 19—(A) Yellow dotted line shows contact between underlying MIS and overlying sandstone facies of the Sonia Sandstone. (B) Large scale trough cross bedding on the top of the Girbhakar Sandstone

Time allotted—30 Minutes.

Stop 4

(Fig. 19)

Daijar Mata Temple Section

Location—N 26º23'52.2"; E 73º03'09.6". DRM-Jodhpur, DS-45F, TS-45F/3.

Approach—Approximately 23 Km N from the Jodhpur City on Jodhpur-Mandore Road, NH-65.

Key Observations—Daijar Mata Temple Section is another spot showing good unconformable (non-conformity) contact between the Malani Igneous Suite and the upper part of the Jodhpur Group. It is constituted of coarse grained, trough cross bedded quartose sandstone and conglomeratic sandstone of Girbhakar Formation. In the temple complex towards the top of the sequence is exposed the Girbhakar Sandstone which is about 30 m in thickness, tightly cemented and constituted of coarse lithology showing planar bedding and trough cross bedding. The contact between Malani and Girbahkar Sandstone is again attributed to the palaeotopography. Various units of the Jodhpur Group were deposited over these palaeotopographic highs and lows. Girbhakar Sandstone is the third unit of Jodhpur Group which directly overlies the Malani Rhyolite in this area. Palaeocurrent directions are WSW direction. The uppermost part of the Jodhpur Group is constituted of pebbly gravely sandstones and has been considered to have deposited as a braided fluvial deposit (Chauhan *et al.*, 2001).

Time allotted—30 Minutes.

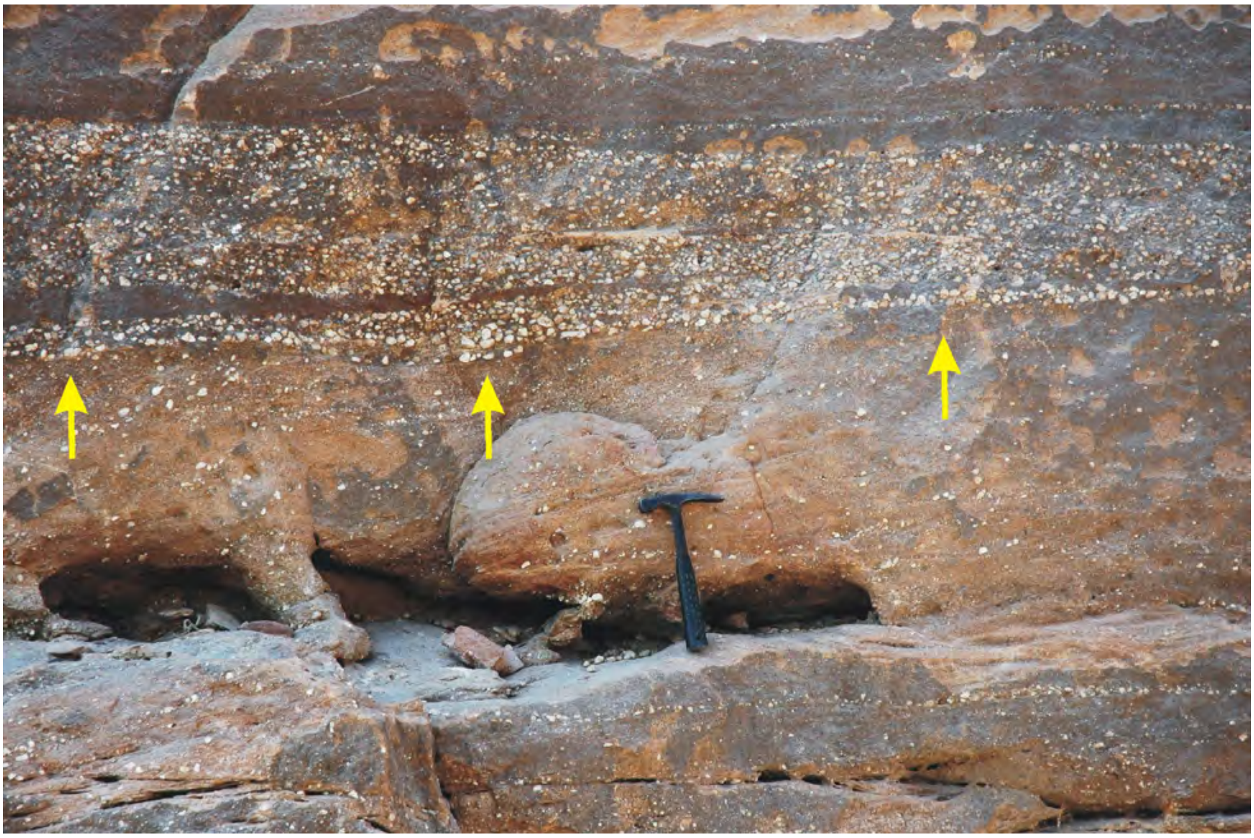

Fig. 20—Upper part of the Girbhakar Sandstone dominated by gravels, cobbles and gritty sandstone.

Stop 5

(Fig. 20)

Radar Hill Section

Location—N 26°19'45.8"; E 73°00'13.2". DRM-Jodhpur, DS-45F, TS-45F/3.

Approach—Approximately 16 Km N from the Jodhpur City on Fidusar-Balsamand Road, NH-114.

Key Observations—On either side of the Fidusar-Balsamand Road in the Jodhpur City are exposed the upper part of the Jodhpur Group known as Girbhakar Formation. It is constituted of pebbly gravely sandstones. Several cycles of gravely sandstone are recorded in these sections. Chauhan *et al.* (2001) and have described it as deposited in a braided fluvial regime. It is constituted of coarse grained, trough cross bedded quartose sandstone and conglomeratic sandstone.

Time allotted—30 Minutes.

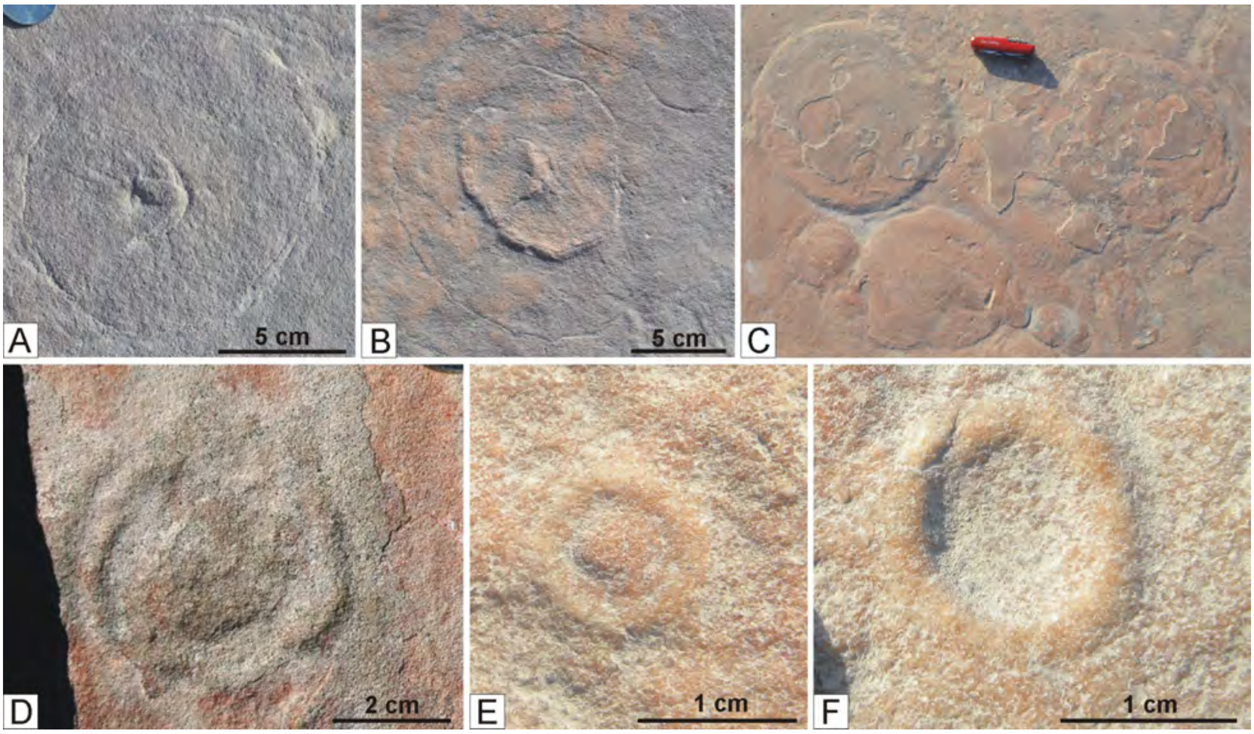

Fig. 21—Variety of Ediacaran fossils are well preserved on the top surface of the Sonia Sandstone (A-B) Lichen like features; (C) Discoidal bodies; (D-F) *Aspidella* and small medusoids.

Stop 6

(Fig. 21)

Sursagar Quarry Section – 1 (Sun-Moon Factory)

Location—N 26°19'41.6"; E 72°59'52.09". DRM-Jodhpur, DS-45B, TS-45B/15.

Approach—Approximately 15 Km N from the Jodhpur City on Sardarpura Road.

Key Observation—This section shows the middle part of the Sonia Sandstone. In certain beds Microbially Induced Sedimentary Structures (MISS) are recorded. Kumar & Pandey (2009) reported Ediacaran megaplant fossil with Vauchericean affinity. Fossil *Heimalora* and *Aspidella* are reported from this quarry (Kumar & Pandey 2009). Kumar *et al.*, (2012) have reported five armed body fossil from this section.

Time allotted—45 Minutes.

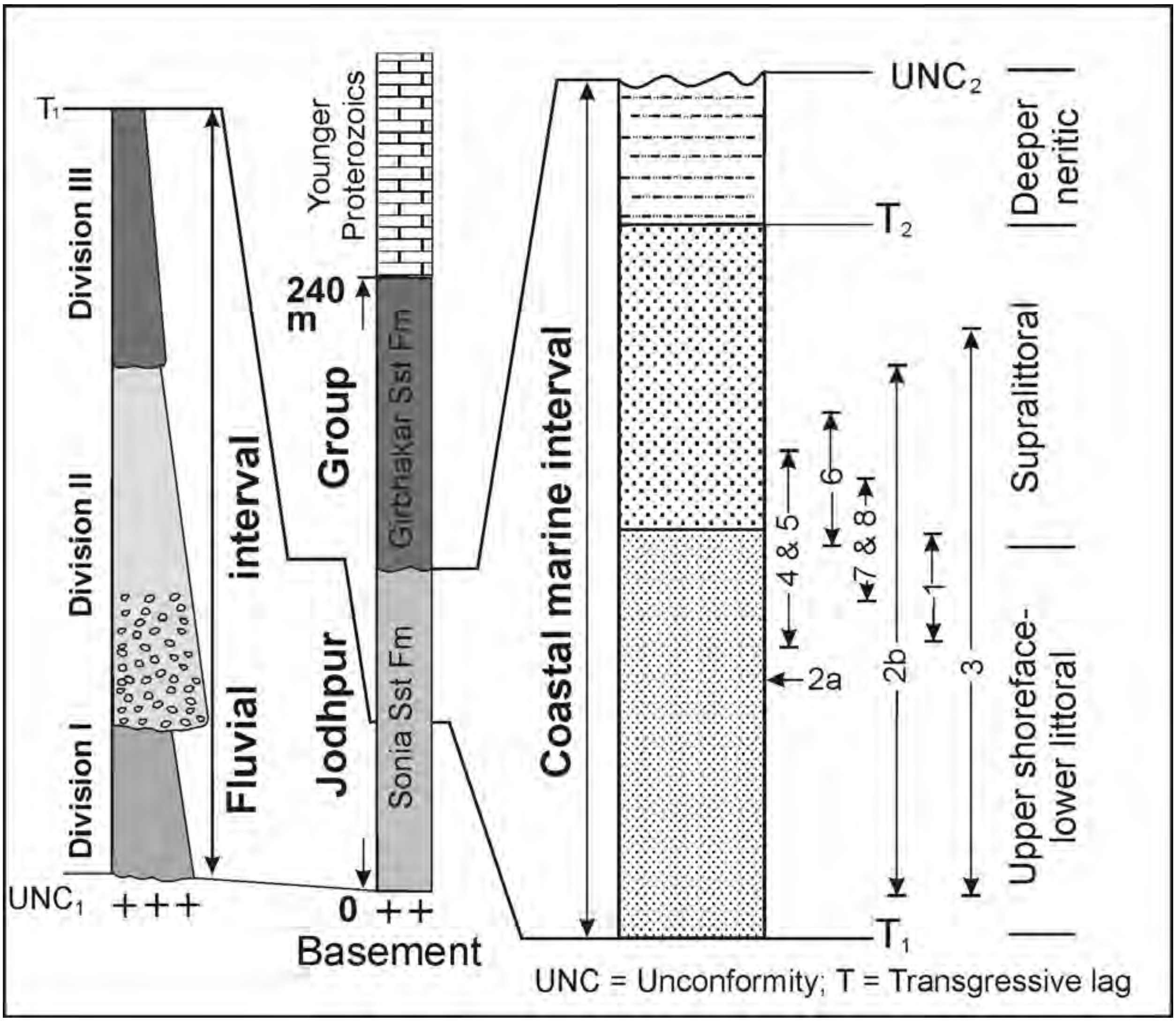

Fig. 22—Temporal shift in palaeogeography-palaeoenvironment inferred for the Sonia Sandstone at the base of the Jodhpur Group, Rajasthan, India (redrawn after Bose *et al.*, 2012, see Bose *et al.*, 2012 for further details.)

Stop 7

(Figs. 22, 23)

Sursagar Quarry Section – 2 (Gehlot Mine)

Location—N 26°19'48.5"; E 72°59'49.5". DRM-Jodhpur, DS-45B, TS-45B/15.

Approach—Approximately 15 Km N from the Jodhpur City on Sardarpura Road.

Key Observations—Large size Ediacaran discs are reported from this quarry (Srivastava 2013). These discs are found in the beds overlying the MISS containing beds. Extensive occurrences of *Aspidella* of varying sizes are noted on the top surface of the Sonia Sandstone. Giant sea weeds like features are also found on the top and sole surfaces of Sonia Sandstone. These features are found towards the top of Sonia Sandstone. The sandstone unit containing these features were

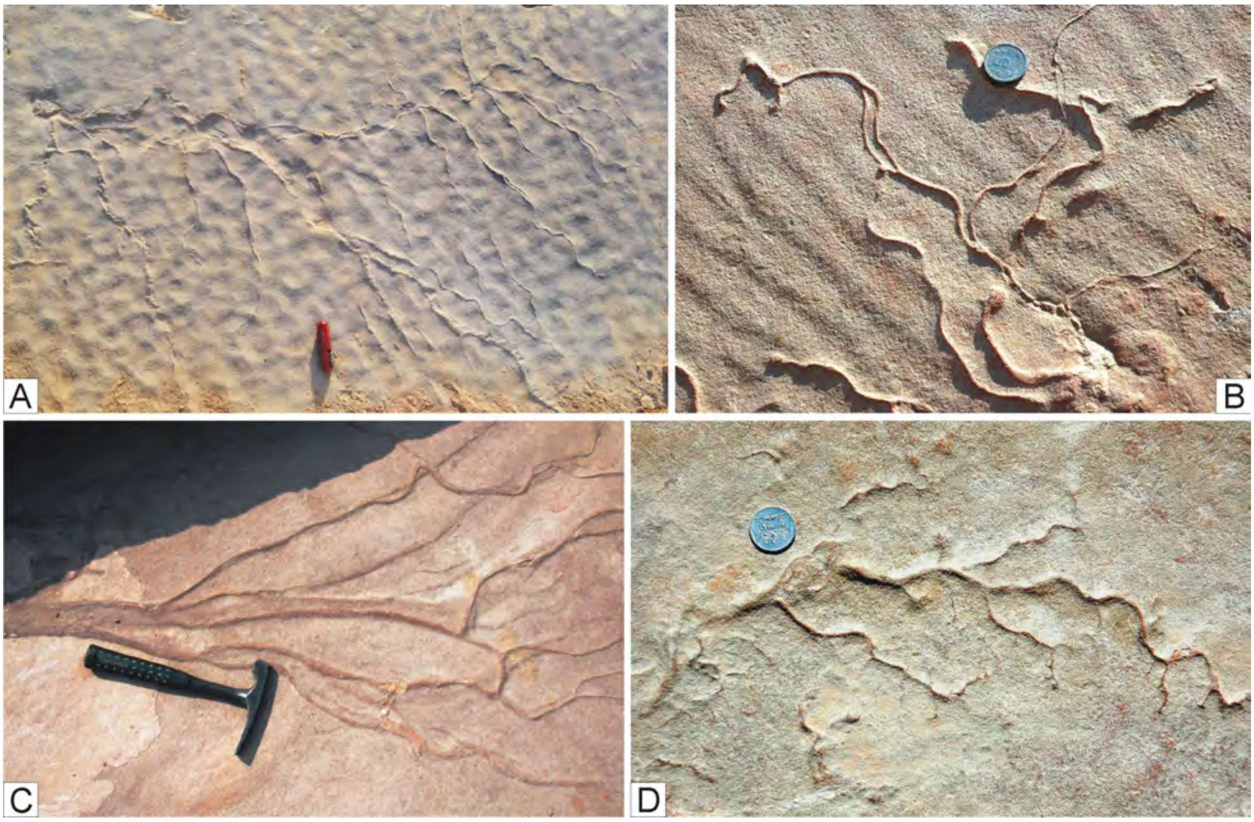

Fig. 23—Giant sea weeds like features are well preserved on the horizontal bedded as well as on the rippled surface of the Sonia Sandstone.

deposited in coastal marine interval (Bose *et al.*, 2012). Mat protected patchy ripples and various other sedimentary structures are noticed in these mines.

Time allotted—45 Minutes.

Stop 8

(Fig. 24)

Sursagar Quarry Section – 3 (Giant Nodule)

Location—N 26º19'42.7"; E 73º00'07.9". DRM-Jodhpur, DS-45F, TS-45F/3.

Approach—Approximately 15.5 Km N from the Jodhpur City on Sardarpura Road.

Key Observations—In this quarry, 10-20 m thick succession of the Jodhpur Sandstone is exposed also referred to as the Sonia Sandstone. Within these sandstone are found several giant nodules. Though nodules are very common in both sandstones and calcareous rocks but generally they are very small and commonly less than 1 meter in diameter. The Jodhpur Sandstone, however, shows the presence of giant nodules which range in diameter between 2 to 6 m. The shape of these nodules is more or less spherical. Some of the nodules are distorted. The record of the giant nodules is unique to this stratigraphic unit. These are made up of the same material as that of the host rock.

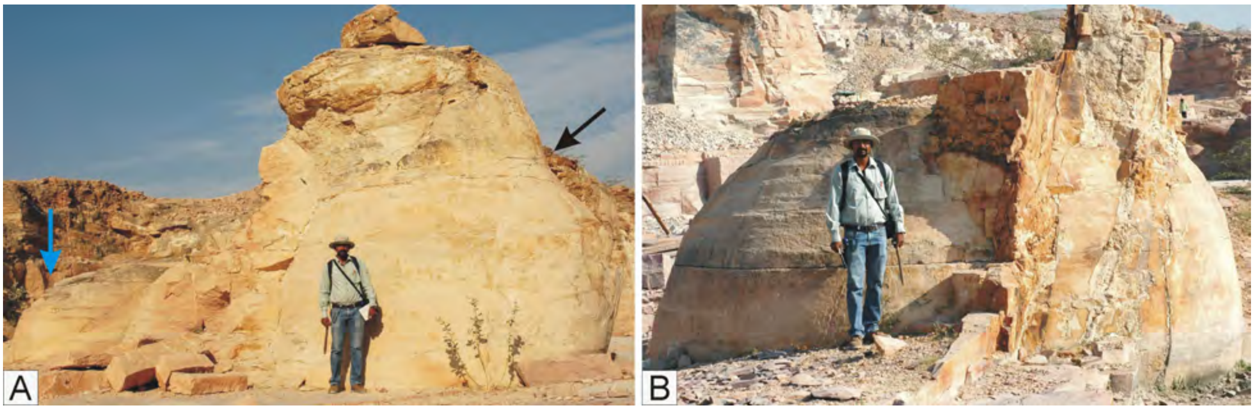

Fig. 24—(A-B) Giant nodules in the Sonia Sandstone (SKP as scale).

Fig. 25— *Hiemalora* preserved on the fine to medium grained Sonia Sandstone.

The host rock is made up of quartz arenite. These nodules are secondary structures and formed by concentration of silica (Kumar *et al.*, 2011). It appears that silica diagenesis which played important role in the formation of quartz arenite is responsible for the formation of these giant nodules. Relative hardness played an important role in the formation of these nodules. No internal structure has been observed. There is no colour differentiation between the nodules and host rocks. This mine also shows the presence of problematic structures which may have algal affinity. *Hiemalora, Aspidella* and microbial discs have also been recovered from this mine. Singh *et al.* (2013) have studied these nodules in detail.

Time allotted—30 Minutes.

Stop 9

(Figs. 25, 26)

Golasni Quarry Section

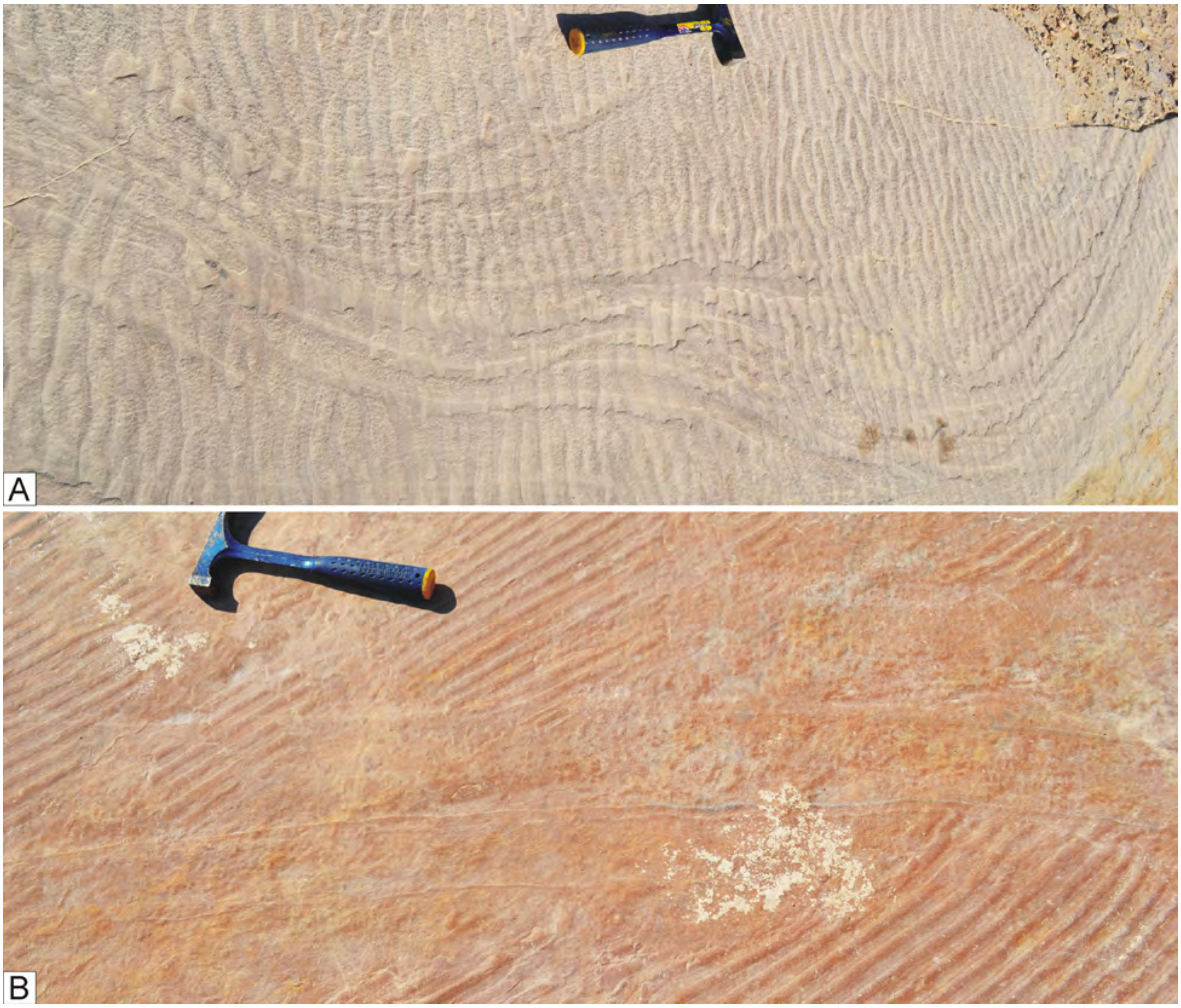

Fig. 26—(A-B) Drag marks reported on the rippled surface of the Sonia Sandstone possibly produced by the sea weeds/ Kelp in coastal marine environment.

Location—N 26°19'12.04"; E 72°56'46.1". DRM-Jodhpur, DS-45B, TS-45B/15.

Approach—Approximately 20 Km NNW on NH-114 from the Jodhpur City.

Key Observation—Middle part of the Sonia Sandstone is exposed in this quarry. Fossil *Hiemalora* has been recorded from the bedding top surface of the Sandstone. Large size Ediacaran discs are absent in this quarry. Poorly preserved small sized *Aspidella* are also noted on the top surface of the Sonia Sandstone. Dragging structures of giant sea weeds like features are noted on the top of the Sonia Sandstone which is considered the deposit of coastal marine interval (Bose *et al.,* 2012). Various types of mat protected features are recorded by Kumar & Ahmad (2014).

Time allotted—30 Minutes.

Stop 10

Devatara village Section

Location—N 26°31'13.6"; E 73°23'14.4". DRM-Jodhpur, DS-45F, TS-45F/6.

Approach—Approximately 60 Km NE from the Jodhpur City on Jodhpur-Bhopalgarh Road, NH-112 & SH-63.

Key Observation—In dug well section grey mafic granite belonging to Erinpura Granite and Gnessic complex is encountered. It is a good site for collection of granite samples for geochronology. Erinpura Granite is considered to be older than Malani Igneous Suite.

Time allotted—30 Minutes.

Stop 11

(Figs. 27-29)

Artiyan Kalan Section – 1

Location—N 26°33'10.6"; E 73°24'53.5". DRM-Jodhpur, DS-45F, TS-45F/6.

Approach—Approximately 66 Km NE from the Jodhpur City on Jodhpur-Bhopalgarh Road, NH-112 & SH-63.

Key Observation—The lower most part of the Sonia Sandstone exposed in Artiya Kalan area has shown presence of certain flattened circular disc like structures. These sections exposed in the Artiyan Kalan and in the nearby Dhoru locality have been divided into five units (see Raghav *et al.*, 2005). They have described these structures as *Marsonia artiyansis* belonging to phylum Cnidaria and class Scyphozoa. These features are present in the maroon to brownish shales that is the second litho-unit from the bottom. Kumar & Ahmad (2012) have restudied these features. De & Prasad (2011) have recorded Vendian-Ediacaran fossil assemblage showing *Nemiana* & *Beltinelliformis*

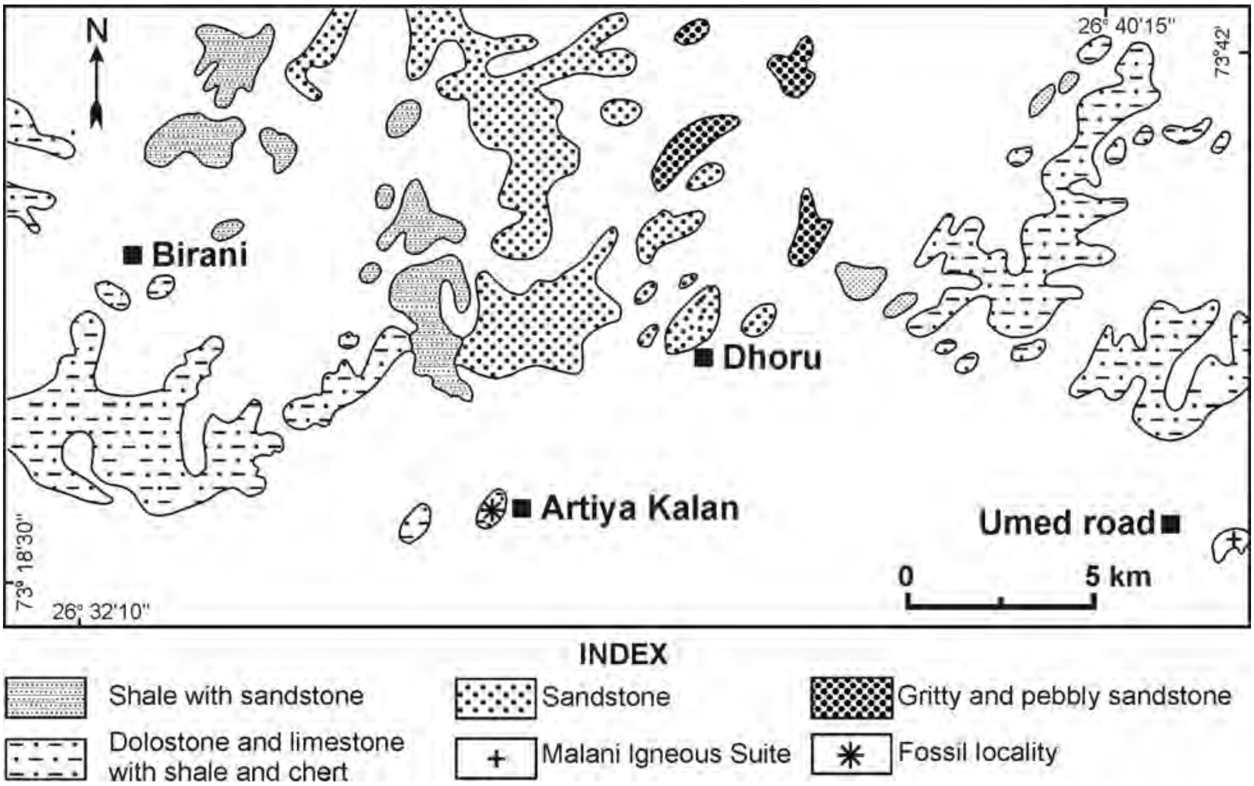

Fig. 27—Detailed geological map of the Artiya Kalan area, Jodhpur District, Rajasthan showing fossil locality. (Redrawn after Raghav *et al.*, 2005).

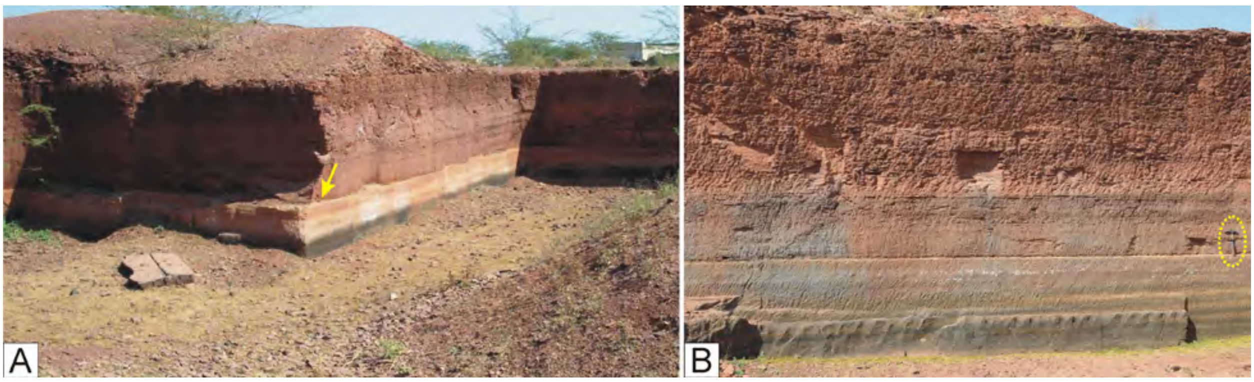

Fig. 28—*Marsonia artiyansis* (a Medusoid) reported from the shaly silty sandstone facies of the Sonia Sandstone (yellow arrow indicate fossil horizon); (A) Field photograph of Artiyan Kalan section; (B) Close-up view of the section

type of preservation from Artiyan Kalan. Mat Structures, Kinneyia Structures and variety of sedimentary structures are also noted in these sections.

Time allotted—90 Minutes.

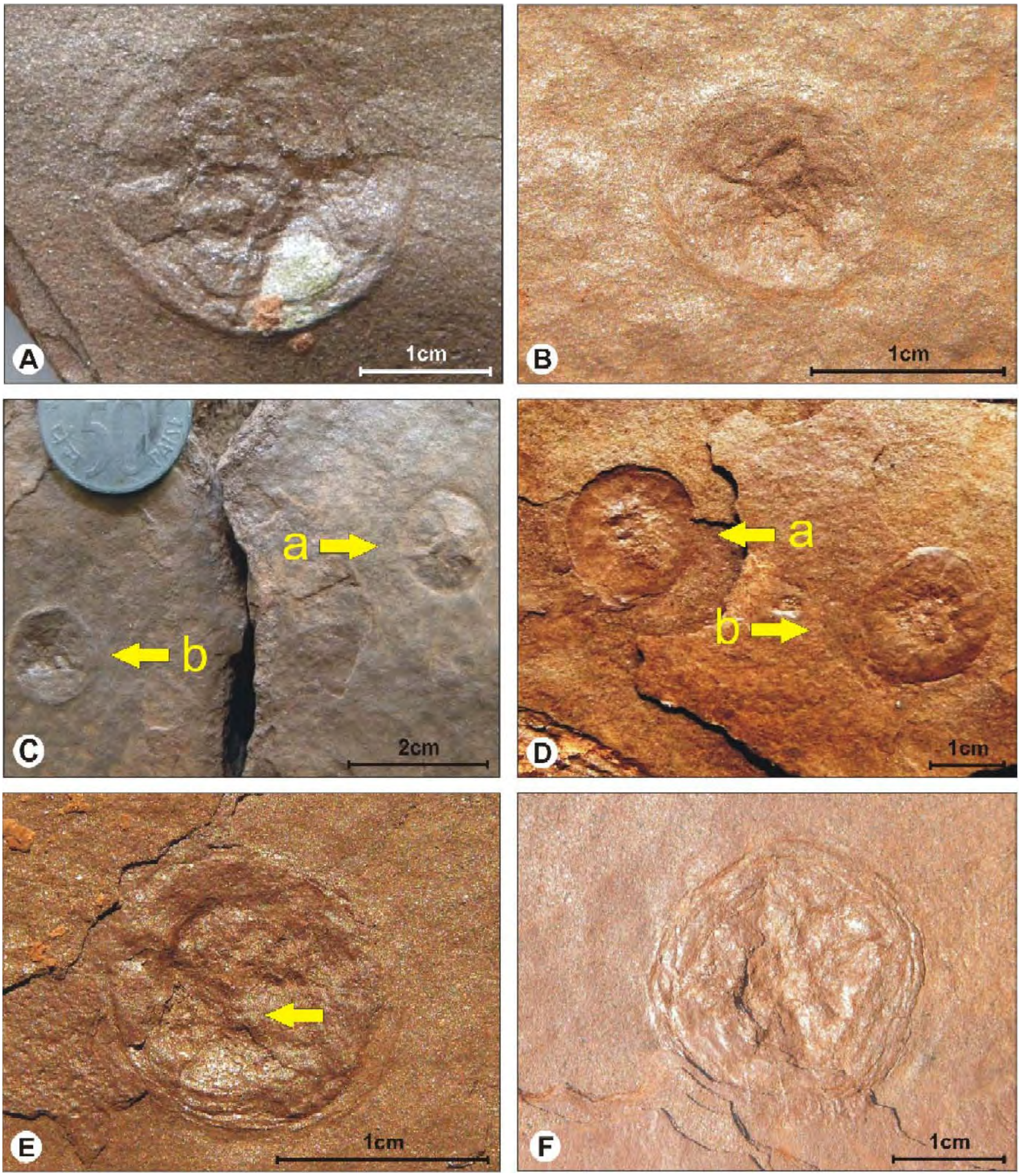

Fig. 29—A-F - Ediacaran Medusoid *Marsonia artiyansis* Raghav 2005, from the Jodhpur Sandstone, Jodhpur District (Kumar & Ahmad, 2012).

Stop 12

(Fig. 30)

Artiyan Kalan Section – 2 (Raut Ram ki Dhani)

Location—N 26°35'31.0"; E 73°25'22.6". DRM-Jodhpur, DS-45F, TS-45F/6.

Approach—Approximately 75 Km NE from the Jodhpur City on Jodhpur-Bhopalgarh Road, NH-112 & SH-63.

Key Observation—Unit F of Sonia Sandstone is exposed in the vicinity of Stop 11 (Table-4). Lots of chert, jasper and cherty dolomite are being excavated sorted and traded for making grinding mills. Deposition of this unit demarcates a transgression of the sea in the area.

Time allotted—30 Minutes.

Fig. 30—Carbonate unit of the Sonia Sandstone overlain by the shaly silty sandstone facies of the Sonia Sandstone. Parallel bedded lamination can easily observed.

Fig. 31—Pink coloured Limestone unit in Pondlo Dolomite.

Stop 13

(Fig. 31)

Garasni Section

Location—N 26º46'39.9"; E 73º38'58.4". DRM-Jodhpur, DS-45F, TS-45F/9.

Approach—Approximately 105 Km NE from Jodhpur on Jodhpur-Bhopalgarh-Asop Road.

Key Observations—Pondlo Dolomite is exposed in the surrounding fields. Close to the temple, pink coloured limestone and dolomite are exposed. This band of pink coloured limestone can be traced over long distance indicating it as an event bed. Pareek (1982) had recorded siliceous oolites from Pondlo Dolomite.

Time allotted—30 Minutes.

Stop 14

(Fig. 32)

Asawari Temple Section

Location—N 26º47'07.00"; E 73º41'02.09". DRM-Nagaur, DS-45F, TS-45F/9.

Approach—Approximately 109 Km NE from Jodhpur on Jodhpur-Bhopalgarh Road, NH-112 & SH-63.

Fig. 32—Field photograph of the Asawari Temple Section.

Key Observations—Contact between Pondlo Dolomite and Nagaur Sandstone is seen in a pond cutting. The upper part of the Pondlo Formation, in close contact of the Nagaur Sandstone, is also stromatolitic at certain areas. Overlying sandstone is gritty and arkosic in nature. Note the facies change inferred through depositional environment.

Time allotted—30 Minutes.

Stop 15

(Fig. 33)

Jaswant Sagar Dam Section (Pichyak)

Location—N 26°13'21.5"; E 73°41'15.5". DRM-Jodhpur, DS-45F, TS-45F/12.

Approach—Approximately 74 Km East from Jodhpur City on NH-112.

Key Observations—Jaswant Sagar Dam near Pichyak exposes the Girbhakar Sandstone and overlying Dhanapa Dolomite and rubble of bedded chert in the foreground. Sandstone is brick red to partly whitish medium grained and pebbly, followed by red to purple, medium grained gritty pebbly sandstone. Pebbles of varied sizes are also noted in the sandstone. Thin section studies of the bedded cherts have yielded variety of cyanobacterial remains and larvae? (Mehrotra *et al.,* 2008).

Time allotted—30 Minutes.

Fig. 33—(A) Jaswant Sagar Dam Section (Pichyak); (B) Different sizes of nodules embedded within the parallel bedded Sonia Sandstone; (C) Chert embedded within the chunk of carbonate.

Stop 16

(Fig. 34)

Pundlu Section

Location—N 26°29'34.6"; E 73°48'00.1". DRM-Nagaur, DS-45F, TS-45F/15.

Approach—Approximately 96 Km ENE on Jodhpur-Merta Road via Pipar city on SH-21.

Key Observations—Pundlu section offers vertical exposures of Gotan Limestone. It is a good sampling site for carbonate isotope studies. Collection site shows large scale excavation of Gotan Limestone. It is industrial grade which is being used by the local cement factories, and lime kilns. Certain sub mm scale planner lamination with irregular fenestrae with dark grey bands emit fetid smell on freshly broken surfaces. In some of the mines carbonate mud mounds can also be seen.

Time allotted—45 minutes.

Fig. 34—Large scale carbonate mound in the Gotan Limestone near Pundlu.

Stop 17

(Fig. 35)

Dhanapa PHC Section

Location—N 26°33'41.5"; E 73°44'41.1". DRM-Jodhpur, DS-45F, TS-45F/10.

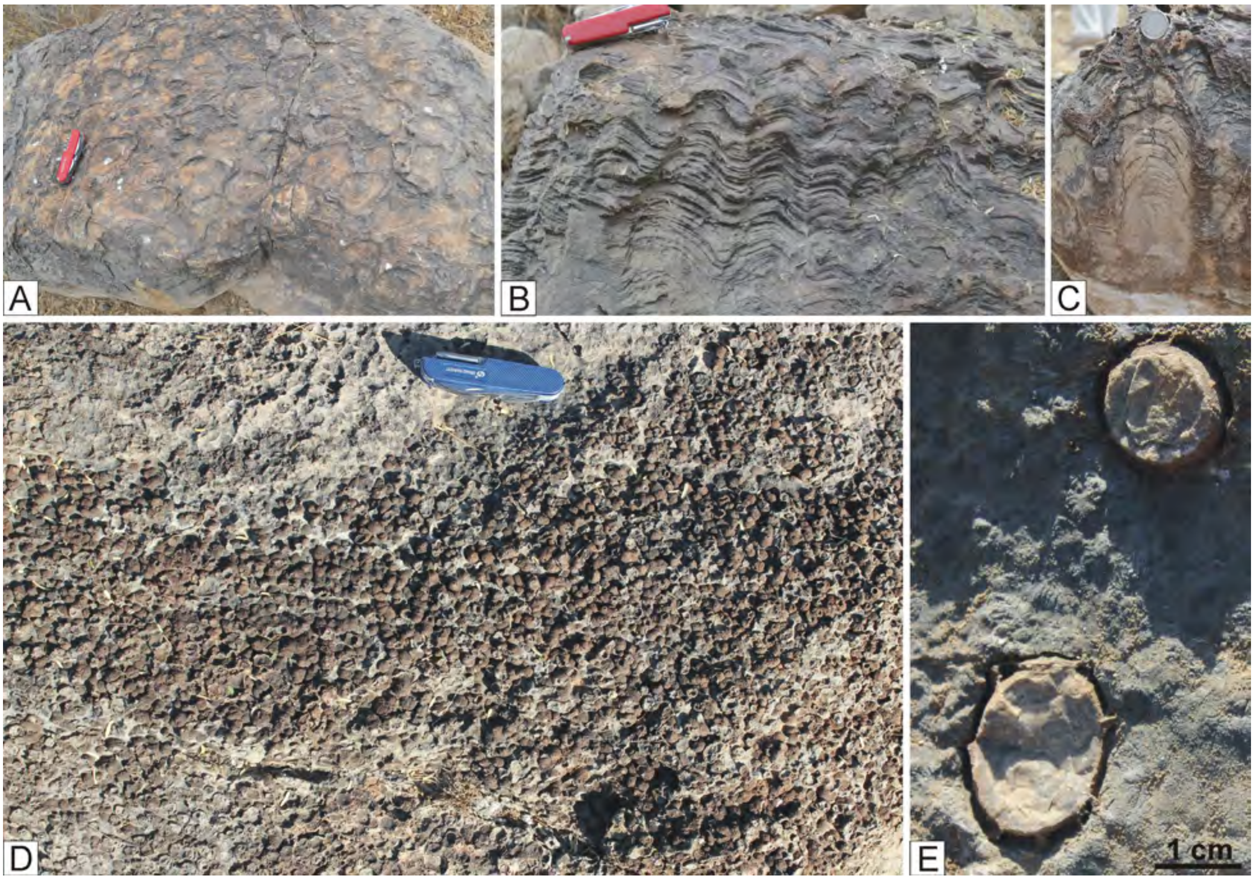

Fig. 35—(A) Bedding plane and Longitudinal sectional view of columnar stromatolite within the Dhanapa Formation; (B) Well developed laminites; (C) Well developed columnar stromatolite. (D) Oolites exposed on the outcrop section of Dhanapa Dolomite; (E) Chert nodule embedded in the Dhanapa Dolomite.

Approach—Approximately 97 km ENE from Jodhpur City Via Pipar city on Dhanapa-Talanpur Road.

Key Observation—Dhanapa Dolomite is well developed near Dhanapa Primary Health Centre. Varity of stromatolites are recorded at different levels of the dolomite at this locality and at Phalodi and Moria in Jodhpur. A few bands of cherty dolomite are also recorded. Stromatolites are less developed in these bands. However chert bands occurring in the Bilara locality have yielded variety of cyanobacterial fossils. Verma & Barman (1980), Barman (1987) have described many stromatolites from this section. Well preserved meter scale stromatolites are observed at Dhanapa and Bilara localities. At certain places synsedimentary deformation and slumping in the laminae have been observed. Few bands of oolites are also recorded close to Dhanapa.

Time allotted—30 Minutes.

Stop 18

Tukliyan Hill Section

Location—N 26°38'13.7"; E 73°46'13.6". DRM-Nagaur, DS-45F, TS-45F/14.

Approach—Approximately 103 Km ENE from Jodhpur City on Jodhpur-Pipad City-Borunda-Pondlo Road, MDR-75.

Key Observation—Best exposures of Tunklian Sandstone are noted in the type area known as Tukliyan Hill. Tunklian Sandstone is constituted of medium grained quartoze sandstone and pebbly conglomerate. Trough cross bedding is noted throughout the formation. Chauhan (1999) considered that the braided fluvial depositional environment resulted in the deposition of the sandstone. There is disagreement among the workers regarding the formation status of Tunklian Sandstone. Cozzi (2008) considers that Tunklian Sandstone favours continental fluvial environment characterized by meandering streams rather than braided rivers. Poorly preserved Cambrian trace fossils are recorded from the shale-sandstone intercalations.

Time allotted—30 Minutes.

Stop 19

Kerali Mine Section (RSM)

Location—N 26°40'02.6"; E 73°43'59.56". DRM-Nagaur, DS-45F, TS-45F/10

Approach—101 Km NE form Jodhpur City via Pipad City on Borunda-Pondlo Road, MDR-75.

Key Observation—Kerali Mine Section offers good exposures of Gotan Limestone. It is mainly constituted of limestone, inter-bands of clay and chert. Industrial grade limestone is being mined in the area for supply to local cement factories and lime kilns. Sub mm scale dark grey bands or planner lamination with irregular fenestrae emit fetid smell on freshly broken surfaces. In some of the quarries carbonate mud mounds can also be seen.

Time allotted—45 Minutes.

Stop 20

(Fig 36)

Khimsar-Bhowanda-Manakpur Road Section

Location—N 26°52'49.4"; E 73°31'05.5". DRM-Jodhpur, DS-45F, TS-45F/9.

Approach—110 km NEN from Jodhpur City on NH-65 then take the right turn from Khimsar via Bhawanda.

Key Observations—This section shows transition of Gotan Limestone-Pondlo Dolomite. Characteristic pink coloured limestone and dolomite are exposed in few mines. Similar pink coloured band has been noted near Garasini village. This band of pink coloured limestone can be traced over long distance indicating it as an event bed. Significance of the pink coloured limestone is yet not determined on global scale. Pink limestone is considered as Cap Carobonate of Edicaran age.

Time allotted—30 Minutes.

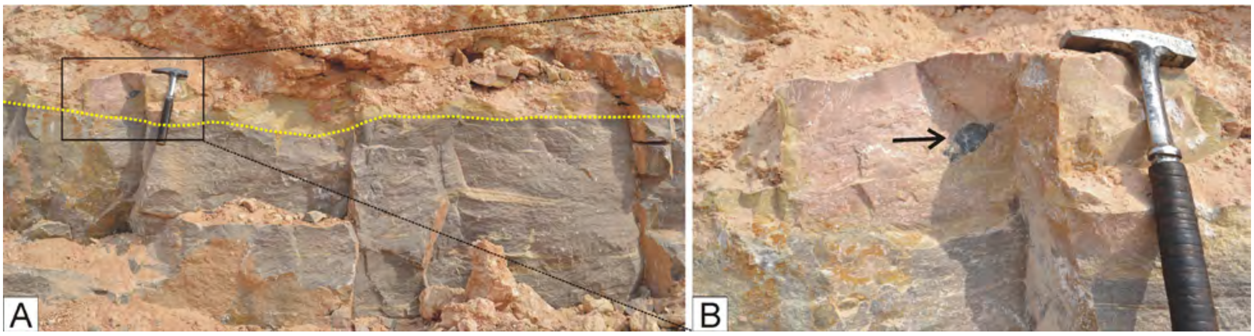

Fig. 36—A) Prominent pink coloured limestone band is well developed throughout the strike (B) Close-up view of inset view of (A), Arrow shows the chert lens.

Stop 21

(Figs. 37-41)

Chhoti Khatu Section

Location—N 27°09'46.8"; E 74°21'11.1". DRM-Nagaur, DS-45I, TS-45I/8.

Approach—65 Km E from Nagaur City via Tarnau, RJ-SH-19.

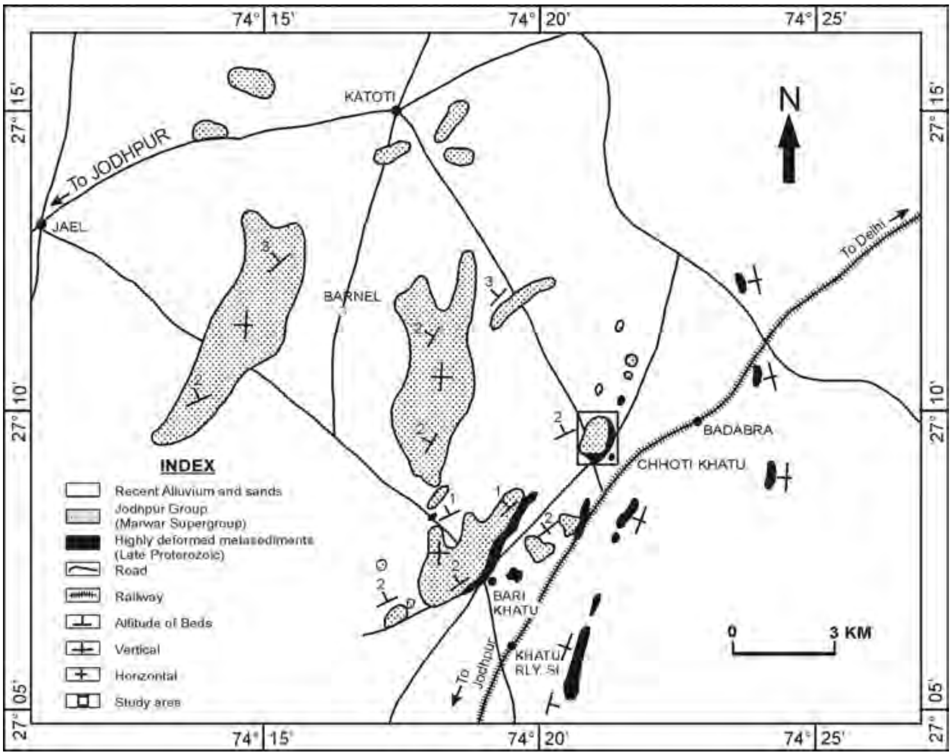

Fig. 37—Geological Map of the Khatu area, Nagaur district, Rajasthan. (Paliwal, 1998)

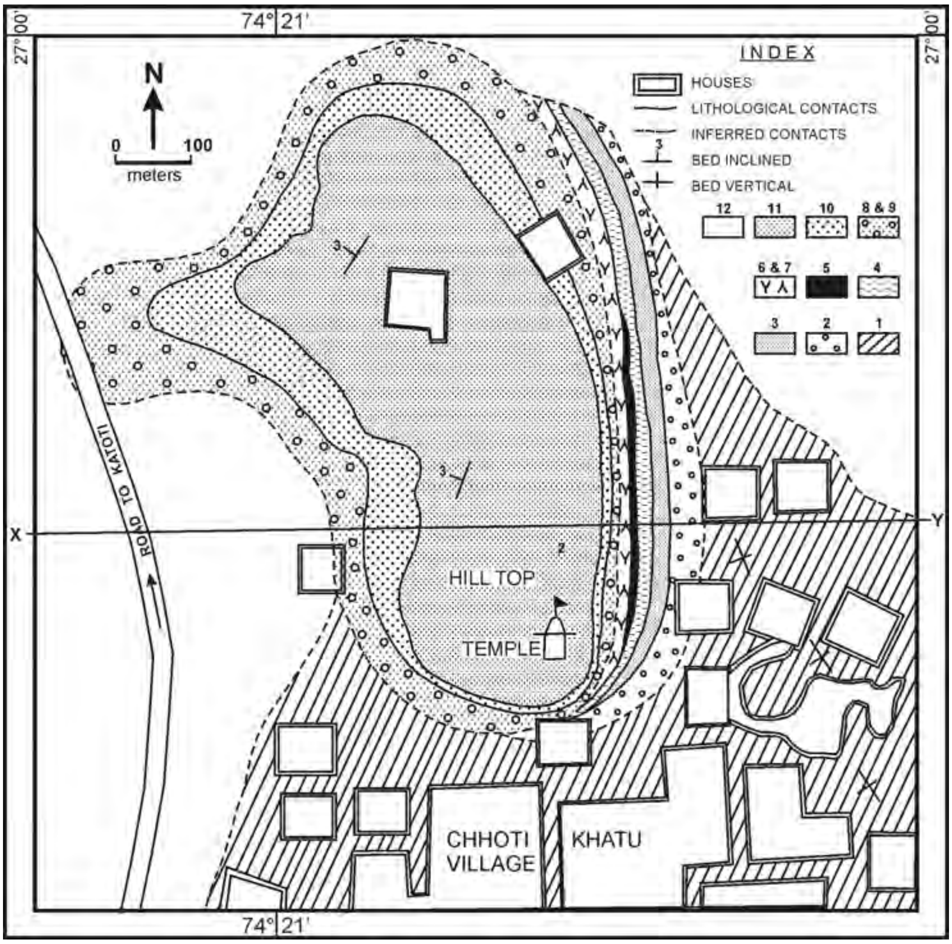

Fig. 38—Geological cross-section of the Chhoti Khatu hill along X-Y line shown in the detailed Geological Map of the area (Paliwal, 1998)

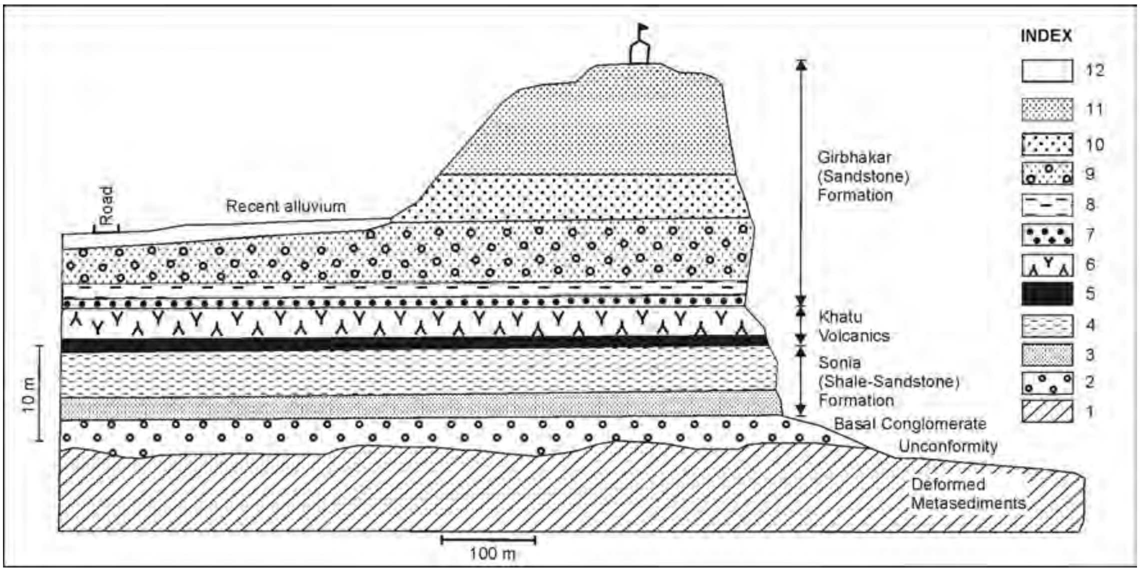

Fig. 39—Detailed Geological Map of the Chhoti Khatu hill. 1- Deformed Precambrian slates and phyllites, 2- Polymicritic basal conglomerate, 3- Maroon coloured fine grained ferrugenous sandstone, 4- Soft and friable ferruginous and micaceous shaly sandstone, 8- Quartzose conglomerate, 9- Maroon coloured, cross-bedded, pebbly sandstone, 10- Light coloured, cross bedded, pebbly sandstone, 11- Buff coloured, medium grained sandstone with cross bedding, ripple marks, and rain imprint and siliceous concretion at the base, 12- recent alluvium and desert sands. (Paliwal, 1998)

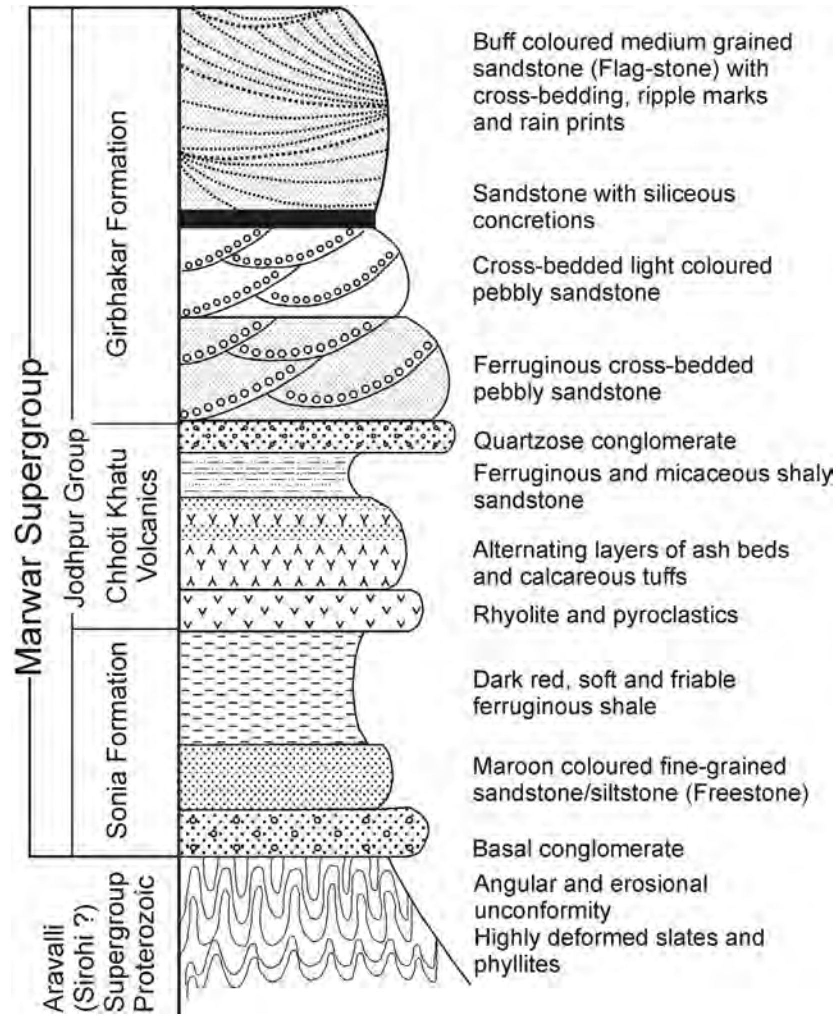

Fig. 40—Geological Succession of rocks exposed at Chhoti Khatu village. (Paliwal, 1998)

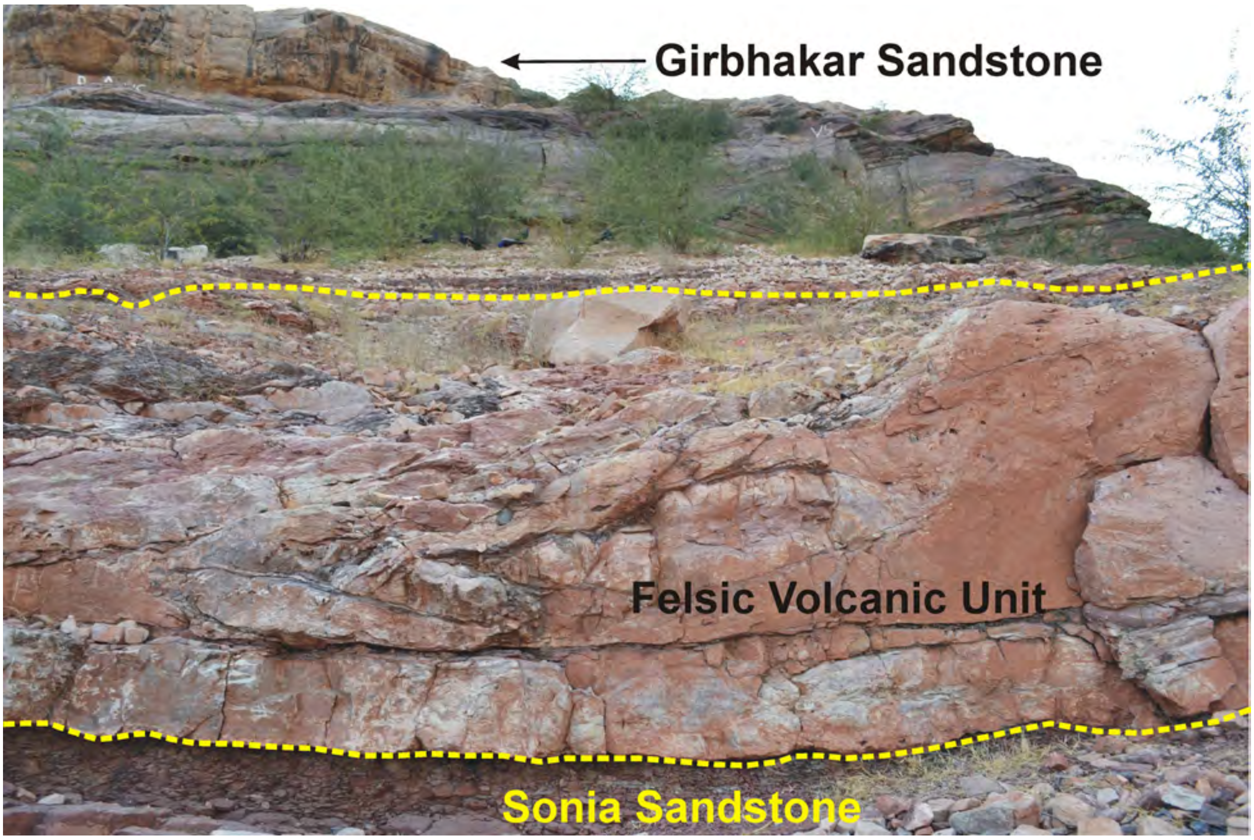

Fig. 41—Field outcrop of the Chhoti Khatu section showing Felsic Volcanic unit underlain by silty shaly sandstone facies of the Sonia Sandstone, whereas top part represents gritty pebbly sandstone facies of the Sonia Sandstone.

Key Observations—Paliwal (1998) reported felsic volcanic unit inter-layered with the sediments of the Marwar Supergroup. The volcanic unit is sandwiched between the underlying Sonia Sandstone and overlying Girbhakar Formation exposed in the Chhoti Khatu village as flat topped hillock in Nagaur district. Freshly broken exposures of the pyroclastic material show massive and compact nature. Large fragments of pyroclastic rocks are founded within the fine grained pyroclastic material. Rhyolite shows distinct flow structures. Paliwal (1998) marked a hiatus on the top surface of the volcanic tuffs as the tuff sequence is irregular and rugged showing intense weathering and subareial exposure for quite long time before the deposition of overlying sediments. The sequence of Sonia Sandstone, Volcanic tuffs and Girbahkar Sandstone unconformably overlies the highly deformed basement rocks constituted of metasediments made up of slate, phyllites and quartzite. The deformed sequences are considered to belong to Sirohi Group of Neoproterozoic age (Paliwal *et al.*, 1995) and Roy and Sharma (1996). Semi circular to circular mound like structures are common in the nearby Bari Khatu locality. Kumar & Pandey (2009) reported Ediacaran fossils belonging to *Arumberia banksi, Beltanelliformis* and *Rameshia rampurensis* from the fine to medium grained sandstone exposed in the Bari Khatu section.

Time allotted—60 Minutes.

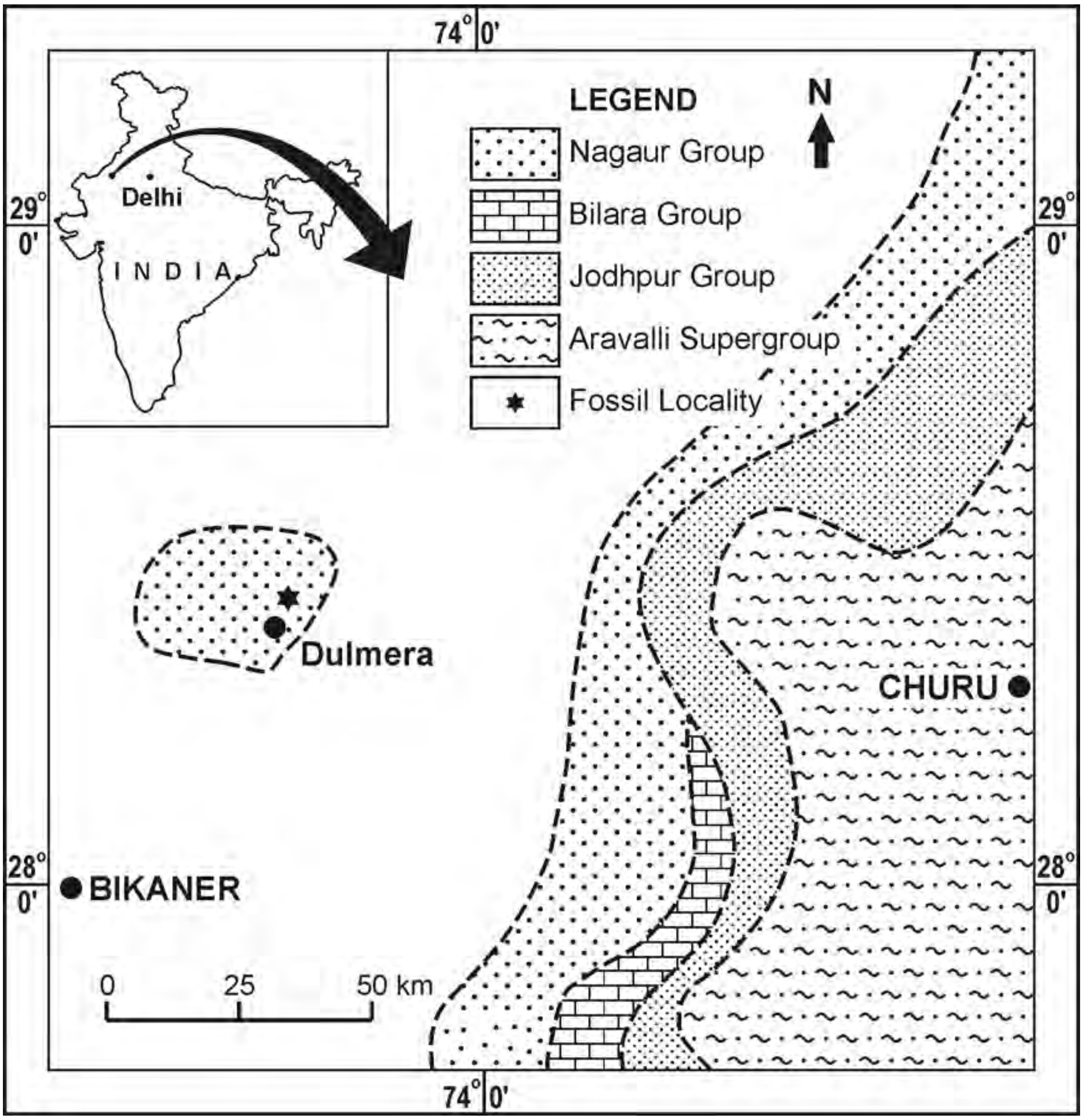

Fig. 42—Geological and location map of the Dulmera area, District Bikaner, Rajasthan (after Pareek, 1984).

Stop 22

(Figs. 42-45)

Dulmera Section

Location—N 28º24'08.09"; E 73º39'28.05". DRM-Bikaner, DS-44H, TS-44H/11.

Approach—67 Km NNE from Bikaner City on Sri-Ganganagar Highway (NH-15).

Key Observations—Approximately 18 m thick section is exposed in different pits of Dulmera quarry. Beds are more or less horizontal in the area. The lithology is dominated by sandstone with minor siltstone and shales. Prominent sedimentary structures are large scale and small scale cross bedding, massive bedding and parallel bedding. Wave ripple marks and mud cracks are also noted.

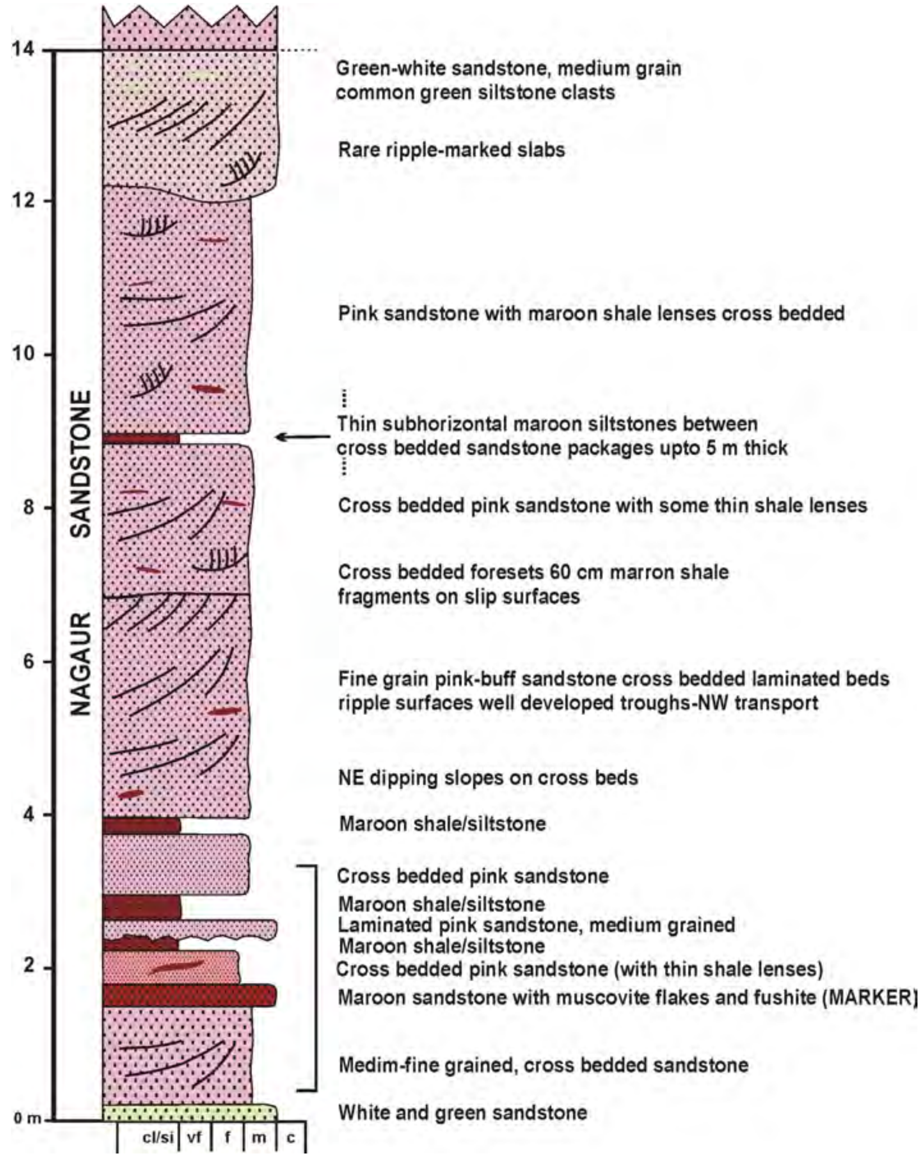

Fig. 43—Generalized litholog of the Nagaur Sandstone exposed in Dulmera quarry.

Fig. 44—Field photograph of the Dulmera quarry showing Nagaur Sandstone.

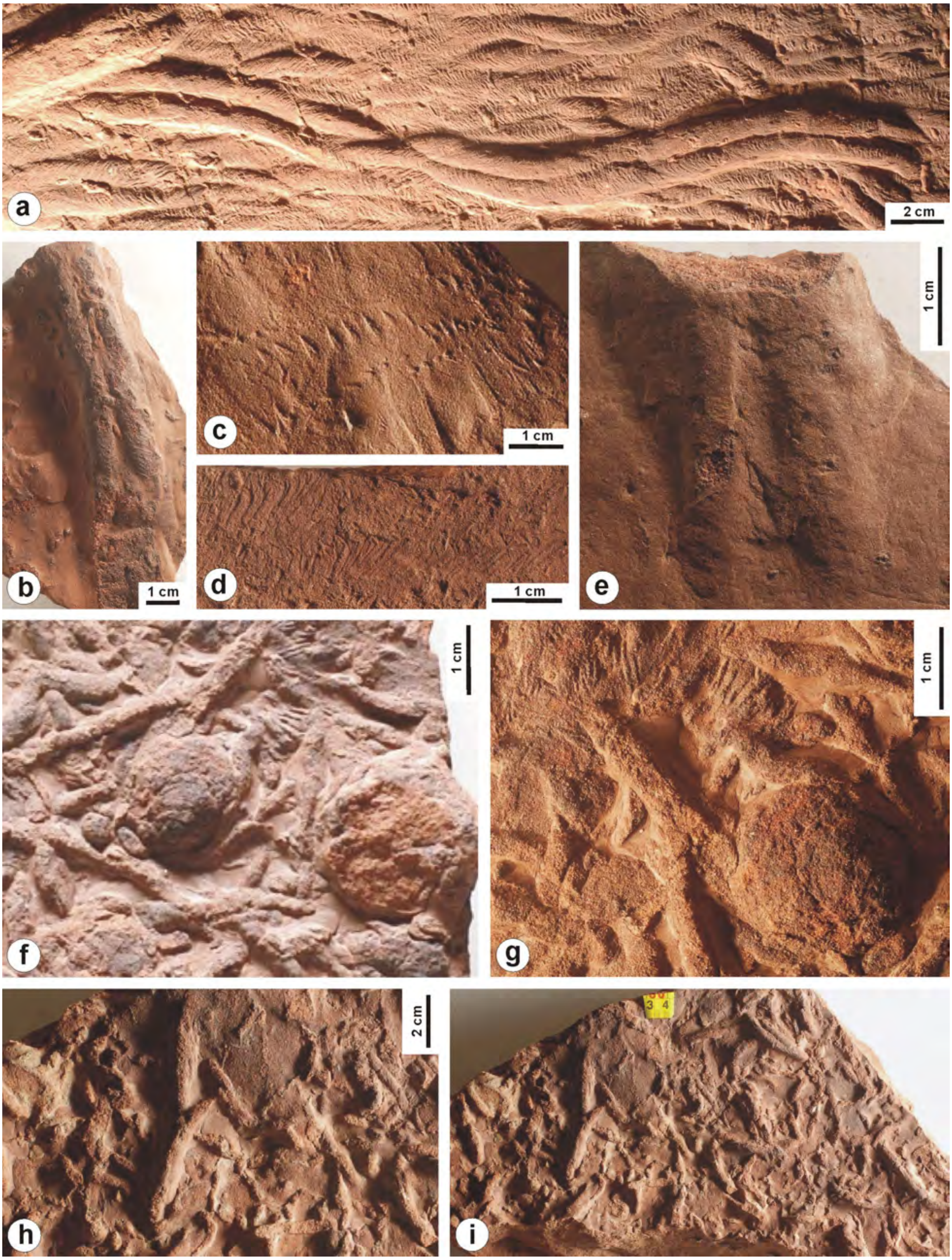

Fig. 45—Different types of trace fossils produced by arthropod preserved on the red colour siltstone facies of the Nagaur Sandstone.

Kumar & Pandey (2008) for the first time reported trace fossils produced by trilobites from these quarries. Reported forms included *Cruziana* isp., *Dimorphicnus* isp., *Rusophycus* isp., and *Aulichnites* isp. These trace fossils were reported from the contact zone of maroon coloured silty shales and red coloured sandstone. In subsequent detailed study, Kumar & Pandey (2010) reported thirteen trace fossils from the Nagaur Sandstone which included *Chondrites* isp., *Isopodichnus* isp., *Diplichnites* ips., *Skolitos* isp., *Palaeophycus tubularis*, *Planolites* isp., Ichnogenus A, trails and scratch marks and referred this assemblage to *Cruziana* assemblage and suggested Lower Cambrian age. Srivastava (2012a, b) reported *Treptichnus pedum* & problematic fossil Priapulid –like fossils from the upper part of the Nagaur Sandstone and suggested that Precambrian –Cambrian boundary lies in the Nagaur Sandstone. Recently Pandey *et al.,* (2014) reported 15 ichnospecies and 8 ichnogenera from this site belonging to ethological categories Pascichnia, Repichnia, Cubichnia and Fodinichnia and representing arthropod and worm like burrowing biota. The assemblage has been assigned to *Cruziana tenella* ichnozone and to Stage two (Upper Part of Terreneuvian Age). Prasad & De (2011) reported an extensive assemblage from Dulmera locality. Singh *et al.,* (2013) claimed to have found single poorly and partially preserved specimen of an arthropod from micaceous silty sandstone horizon of the Nagaur Sandstone exposed at Dulmera quarry. They suggested its affinity with articulated arthropod tergites.

Time allotted—120 Minutes.

Stop 23

(Fig. 46)

Fig. 46—Field outcrop section of the Khichan Conglomerate exposed near Jain Dadawadi, Phalodi.

Khichan Section (Jain Dadawadi)/ Bhumiaji Temple Section

Location—N 27º07'39.8"; E 72º24'34.4". DRM-Jodhpur, DS-45A, TS-45A/8.

Approach—166 Km SW form Bikaner City NH-15.

Key Observations—There is a debate among various researchers regarding the position of the Khichan Conglomerate (Jain *et al.*, 2001). Previously it was considered denoting a break between Pondlo Dolomite and Nagaur Sandstone. Of late it has been placed over the eroded surface of Nagaur Formation. It is hard compact light pink coloured conglomerate comprising of pebbles, gravels and gritty sandstone. There is limited acess to the two outcrops present in the area. Khichan is a famous bird sanctuary where migratory birds from far off places come to a pond. The walls of the pond have been tiled with the boulders excavated from the Khichan hence a poor exposure is avalibale in Jain Dadawadi complex. Another exposure is available in Bhumiaji Temple compound which is a private property surrounded by barbed wire and access is conditional.

Time allotted—45 Minutes.

Stop 24

(Figs. 47-49)

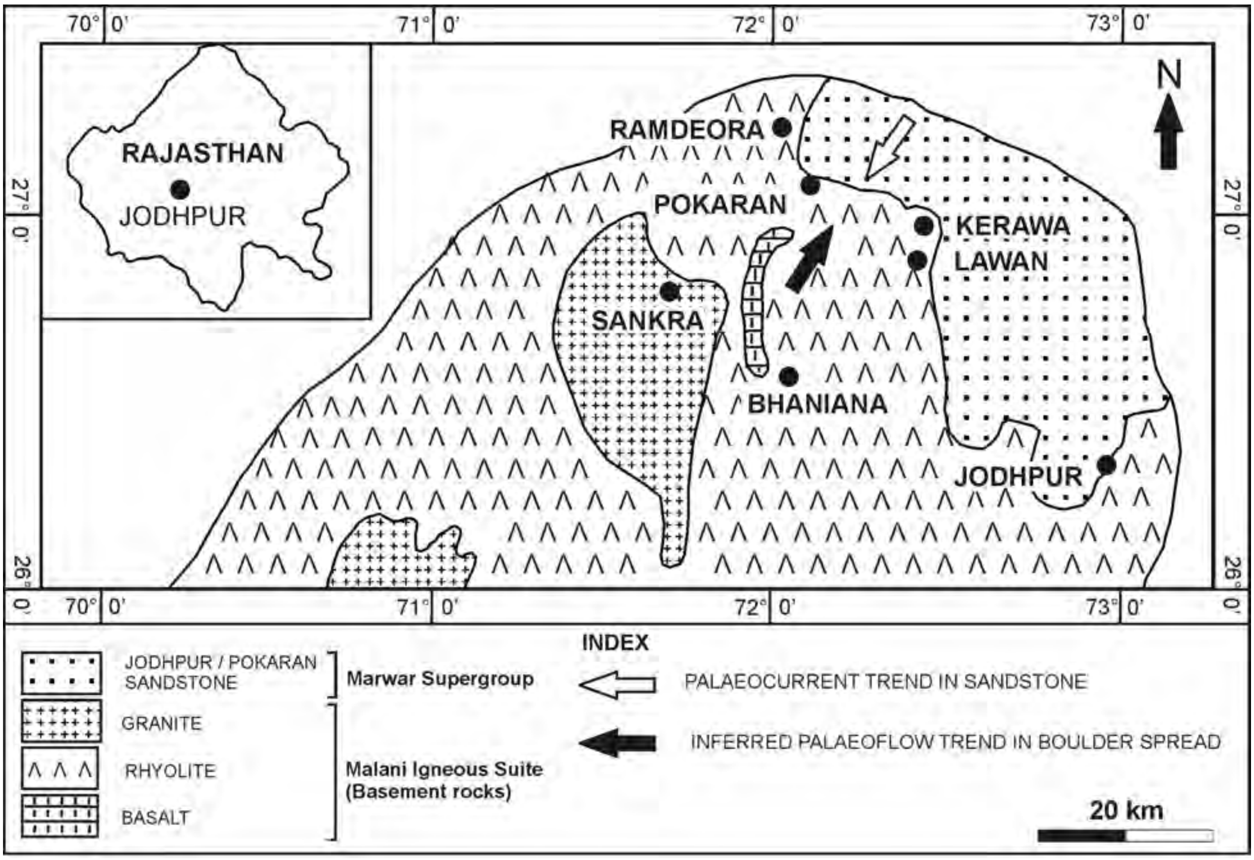

Fig. 47—Geological map of Pokaran and adjoining area (modified after Bhushan, 1985)

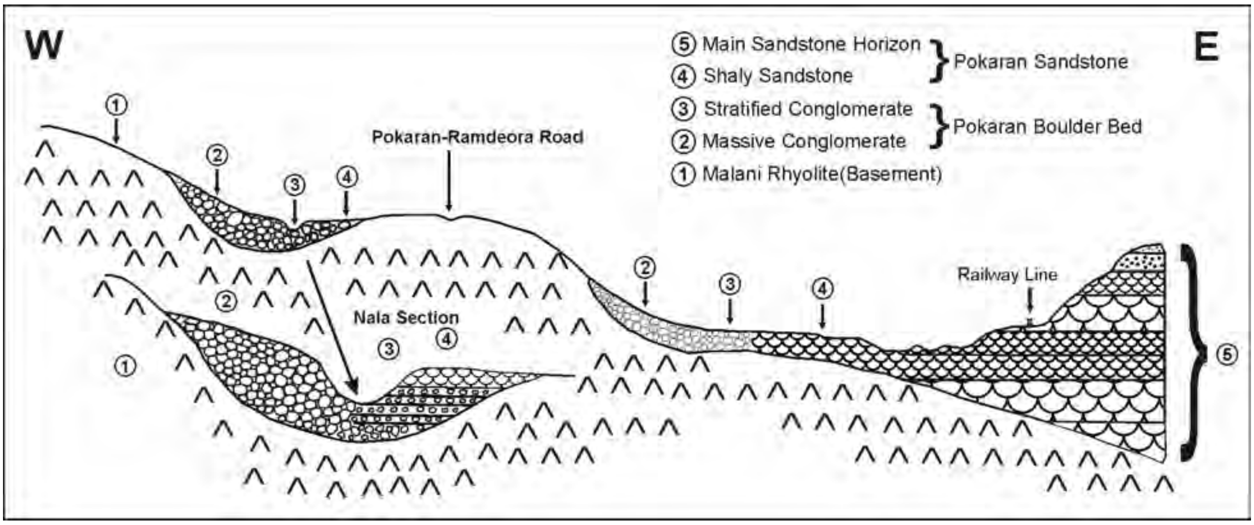

Fig. 48—Schematic geological section of the Pokaran area showing relationship between massive conglomerate, stratified conglomerate and basement of Malani Rhyolite (after Chauhan *et al.*, 2001)

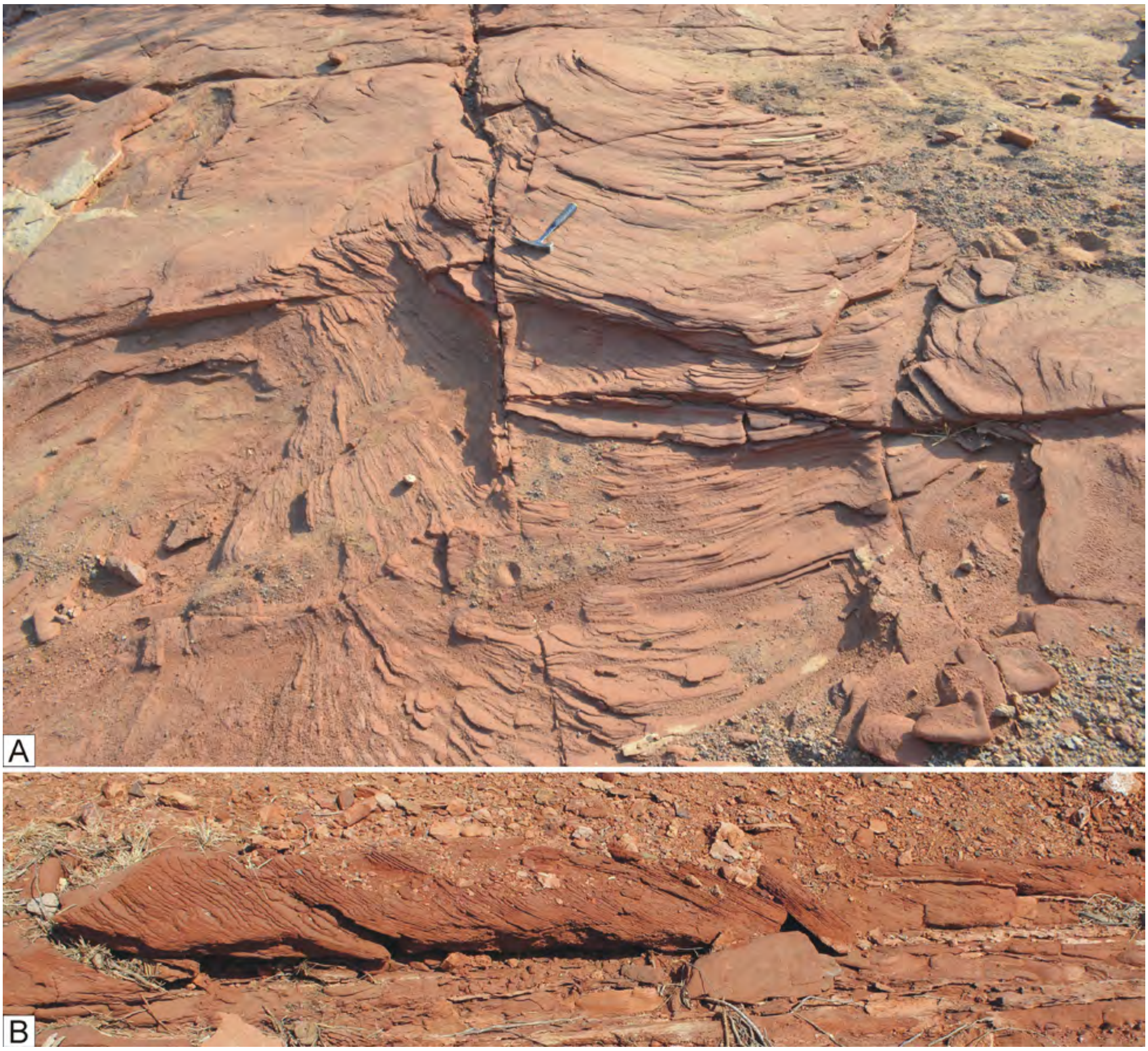

Fig. 49—(A) Planner view and (B) Cross section of large Trough Cross Bedding in the Basal part of the Sonia Sandstone near Pokaran.

Pokaran Boulder Bed Section (Gafur Khan ki Dhani)

Location—N 26º56'12.4"; E 71º54'07.1". DRM-Jaisalmer, DS-40N, TS-40N/13.

Approach—Approximately 110 Km East of Jaisalmer on NH-15 near Pokaran Motel of Rajasthan Tourist Development Corporation.

Key Observations—Pokaran Boulder Beds (PBB) marks the initiation of Marwar Supergroup. A narrow stretch of PBB exposed near the trijunction at Pokaran is matter of great debate. Several workers have interpreted it in many ways. Some of the workers considered it to be of glacial origin. Chauhan *et al.,* (2001), on the basis of occurence of boulders of basement with glacially produced striations, considred it of glacial origin. Bahtt *et al.*, (2005) even proposed time gap between PBB and Sonia Sandstone. PBB is exposed in *Nala* sections at Gaphur Khan Ki Dhani. Large scale trough cross bedding is seen in the Sonia Sandstone exposed in the Nala cutting. Our inspection of PBB did not reveal glacially striated boulders. PBB have been noted interfinguring shale and sandstone of the Sonia Formation. Chauhan *et al.,* (2001) have divided the PBB into two parts at the type section: Pokaran Boulder Bed and Pokaran Sandstone, both of which are further divided into massive conglomerate, stratified conglomerate, shaly sandstone and main sandstone horizon are noted.

Time allotted—60 Minutes.

Stop 25

(Fig. 50)

Baukan Section (MIS)

Fig. 50—Outcrop section of MIS near Baukan on Pokaran-Jodhpur Road.

Location—N 26°35'40.5"; E 72°19'34.8". DRM-Jodhpur, DS-45B, TS-45B/6.

Approach—Approximately 70 km SE from Pokaran via Dechhu on Pokaran-Jodhpur Road (NH-114).

Key Observations—Rocks of Malani Igneous Suite are exposed on either side of the road. After deep excavations the site is good for collection of fresh rock specimens for geochronological dating.

Time allotted—30 Minutes.

Compiled by: V. K. Singh, Shamim Ahmad and S.C. Mathur

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The bibliography, compiled below, cites all the references mentioned in the Field-Guide Book. Besides, many additional references on the Marwar Supergroup are also incorporated, making it most comprehensive collection on references on the Marwar geology published up to 2013. We are aware that in spite of our best efforts it is by no means exhaustive. Some gaps exist, in publications such as those where there is passing reference about the Marwar geology or mentioned in some conference abstracts which are not circulated widely, could not be include. Even with these limitations we are confident that this bibliography will be useful for students and researchers alike.

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ABSTRACTS

BASEMENT COVER RELATIONSHIP OF MARWAR SUPERGROUP WESTERN RAJASTHAN

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ABSTRACT

Nagaur basin is the largest basin of Thar desert in western Rajasthan extending from Jodhpur in south to Haryana in north, covering an area of about 1,00,000 Sq.Kms. The erstwhile Trans-Aravalli Vindhyans have been redesignated as Marwar Supergroup, comprising lower arenaceous Jodhpur group, middle calcareous Bilara Group and upper arenaceous Nagaur Ggroup of rocks deposited in this basin.

The basement for Marwar Supergoup (MSG) is essentially the volcano-plutonic rocks of Malani Igneous suite (MIS). The Neoproterozic anorogenic MIS has been divided into three stages of magmatism. The first stage represents bimodal volcanism, distributed predominantly as rhyolite lava flows and subordinately as basalts. The second stage is manifested by the peraluminous and peralkaline plutonic activity. Dyke swarms reflect the third and the final magmatic activity. Malani magmatism triggered in an extensional tectonic setting from anhydrous 'A' type melts, where repeated basaltic intrusion provided sufficient heat for the melting of continental crust and generate felsic magma. The unconformity between underlying MIS and overlying MSG is marked by the presence of Pokaran Boulder Bed (PBB), perhaps representing the late Precambrain glaciation. Some of the rhyolites of Malani complex are dated as 745± 10 Ma (Crawford and Compston, 1970). The alkaline granites intruding these rhyolites have been dated as 735 Ma. MSG is overlain by the Bap glacial boulder bed and Badhaura Formation of Permain age. The earlier workers correlated MSG to Kaimur and Bhander Group of main Vindhyan basin. However, Prasad (1984) considered Vindhyans of Riphean age, leaving no room for correlation between these two distant basins having a different environment of depositional and geological setting.

MSG is dominated by the continental to shallow marine arenaceous and calcareous facies. A thick evaporite sequence, where halite beds exceed 100m in thickness, are sandwiched between the intertidal arenaceous sequences of Jodhpur/Nagaur group. The voluminous halite and potash sequences have been precipitated during the regressive phase in the *sabkhas* and *lagoons*. A near similar environment of deposition giving rise to phosphorite deposit near Birmania, 130 Km north of Barmer has been correlated to the global phosphogenic episode of the Lower to Middle Cambrains (Banerjee, 1985). An upper Proterozonic-Lower Palaeozoic-littoral sea perhaps continued from western Rajasthan to Kashmir, Hazara and Garhwal Himalayas. The Cambrain Tal basin of Garhwal Himalayas is held equivalent to the Nagaur basin. The Vendian-Lower Cambrain salt basins of Iran-Oman and Pakistan extended a bay into the Nagaur basin.

The presence of thick halite horizons marks MSG lithologically correlatable with the Saline Series of Salt Range. Khan (1973), discovered stromatolites and fossil (Orthis) of Cambrain affinity.

Some of diversified burrow structures reported from Osian 30 Km north of Jodhpur are also of near Cambrain age. It is, therefore, concluded that Marwar Supergroup along with Birmania phosphorite are of late Precambrain to early Cambrain age, being homotaxial with Salt Range of Pakistan.

GEOBIOLOGY OF THE EDIACARAN PERIOD

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ABSTRACT

The Ediacaran-Cambrian boundary represents a critical transition in the history of Earth and life. In the past decade, significant progress has been made in Ediacaran geobiology to allow a better understanding of the interactions between environmental and biological evolution across this critical transition. With integrative paleobiological, stratigraphic, sedimentological and geochemical data, we can now establish a more robust chronostratigraphic framework for geobiological investigation of the Ediacaran Period. The discovery of new fossils allows us to have a more complete understanding of Ediacaran biodiversity, paleoecology, and evolutionary dynamics. The calibration and application of novel geochemical proxies gives us new tools to reconstruct paleoenvironmental conditions in the Ediacaran Period. In this talk, I will discuss some of the recent findings made by my research group and our collaborators, focusing on (1) the importance of acritarchs and stable carbon isotopes in the stratigraphic correlation of Ediacaran successions, and (2) the fossil record of animals in the Ediacaran Period. Much of the data that I will discuss came from the Ediacaran successions in South China, which are similar to those in northern India. Thus, the geobiological interpretations based on Chinese data can and should be further tested in India in order to refine our understanding of the geobiological evolution across the Ediacaran-Cambrian transition.

THE MARWARSUPERGROUP, PURANA-III BASINAL SEDIMENTATION IN NW INDIA: PALAEOMAGNETIC AND GEOCHRONOLOGIC CONSTRAINTS

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ABSTRACT

The Precambrian geologic history of peninsular India covers nearly 3.0 billion years of time. The Peninsula is an assembly of five different cratonic nuclei known as the Aravall-Bundelkhand, Eastern Dharwar, Western Dharwar, Bastar and Singhbhum cratons along with the Southern Granulite Province. Final amalgamation of these elements occurred either by the end of the Archaean (2.5 Ga) or the end of the Paleoproterozoic (~1.6 Ga). Each of these nuclei contains one or more sedimentary basins (or metasedimentary basins) of Proterozoic age. In our view, it appears that basin formation and subsequent closure can be grossly constrained to three separate intervals that are related to the assembly and disaggregation of the supercontinents Columbia, Rodinia and Gondwana. The oldest Purana-I basins developed during the 2.5-1.6 Ga interval, Purana-II basins formed during the 1.6-1.0 Ga interval and the Purana-III basins formed during the Neoproterozoic-Cambrian interval.

The Marwar Supergroup refers to a 1000-2000 m thick marine and coastal sequences that covers a vast area of Rajasthan in NW-India. The Marwar Basin uncomformably overlies the ~750-770 Ma rocks of the Malani Igneous Suite and is therefore considered Late Neoproterozoic to Early Cambrian in age (Purana-III basin). Upper Vindhyan basinal sediments (Bhander and Rewa Groups), exposed in the east and separated by the Aravalli-Delhi Fold Belt, have long been assumed to be of the same age as the Marwar basin. Recent studies based on detrital zircon populations of the Marwar and Upper Vindhyan sequences show some similarity in the older populations, but the Vindhyan sequence shows no zircons younger than 1000 Ma whereas samples taken from the Marwar Basin show distinctly younger zircons. This observation led some to conclude that the Upper Vindhyan and Marwar sequences did not develop coevally.

While there are alternative explanations for why the two basins may differ in their detrital zircon populations, paleomagnetic studies may provide independent evidence for differences/similarities between the assumed coeval basins. We have collected samples in the Marwar Basin and present the paleomagnetic results. Previous palaeomagnetic studies of Marwar basinal sediments are problematic and have been misinterpreted to correspond with the Upper Vindhyan sequence. The vast majority of our samples are consistent with previously published studies that show only a recent field overprint in the region; however, a small subset of hematite-bearing rocks from the Jodhpur Formation (basal Marwar) exhibit directional data (Dec= 89ºInc= -1º ⟨95=9º) that are

distinct from the Upper Vindhyan sediments and may offer additional support for temporally distinct episodes of sedimentation in these proximal regions. A VGP based upon our directional data is reported at 1ºS 344˚E (dp=5, dm=9º). We conclude that the Marwar Supergroup developed near the close of the Ediacaran Period and is part of a larger group of sedimentary basins that include the Huqf Supergroup (Oman), the Salt-Range (Pakistan), the Krol-Tal belt (Himalayas) and perhaps the Molo Supergroup (Madagascar). These basins formed during the final amalgamation of the Gondwana Supercontinent.

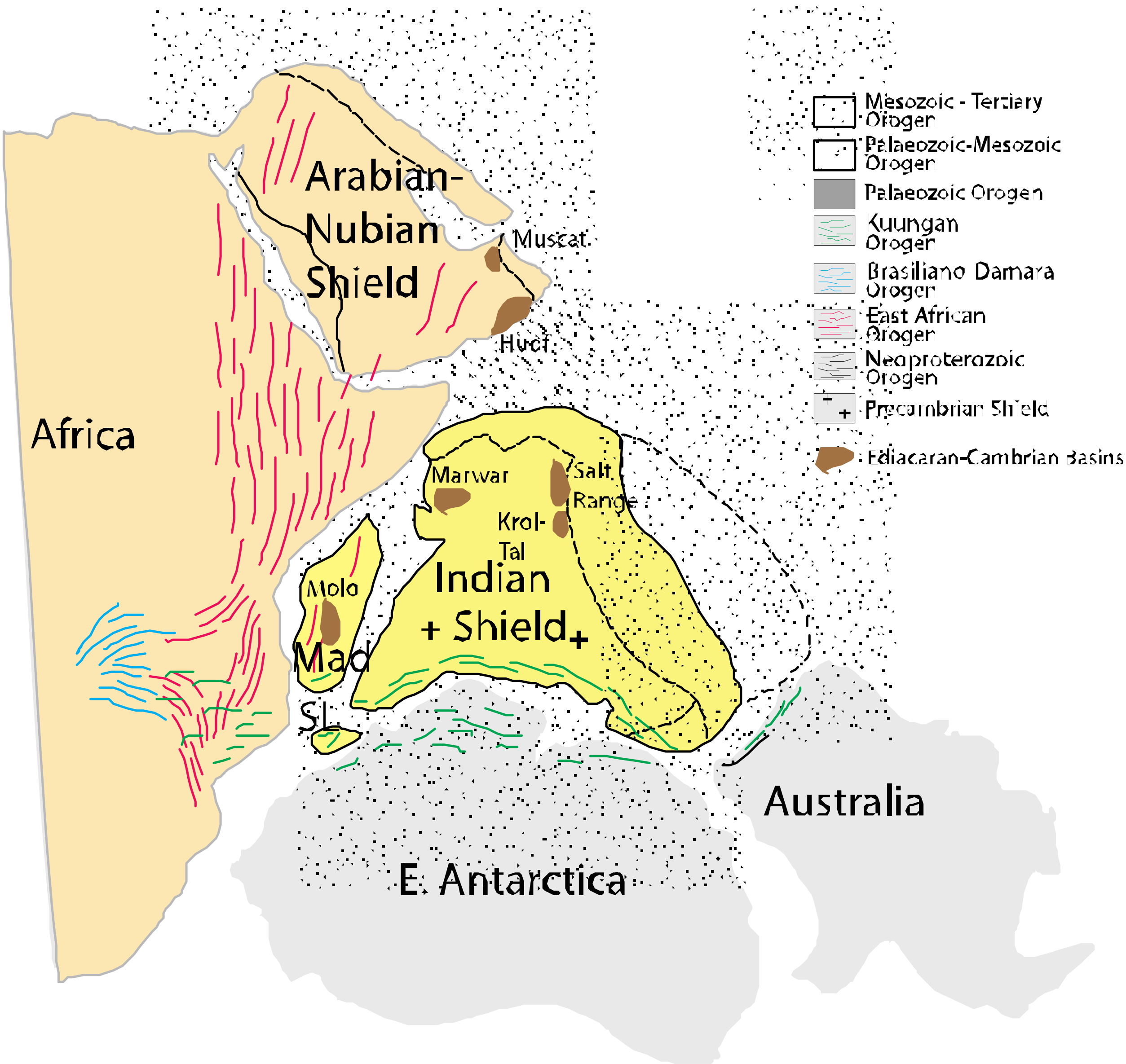

Figure 1. The Marwar Basin in Gondwana context.

STRATIGRAPHY AND EVIDENCES OF LIFE, MARWAR SUPERGROUP, WESTERN RAJASTHAN: AN OVERVIEW

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ABSTRACT

The rocks of the Marwar Supergroup are developed in the desertic setting of the western part of Rajasthan lying in the west of the Aravalli mountain chain. The Marwar Supergroup was earlier known as the Trans-Aravalli Vindhyans as it was considered as the western extension of the Vindhyan Basin developed in the central India. The Marwar Supergroup unconformably overlies the Malani Igneous Suite which has been dated as 779 – 681 Ma. The rocks are represented by conglomerate, sandstone, siltstone, shale, limestone and dolomite. They are undeformed and unmetamorphosed and show an excellent preservation of sedimentary structures. In most of the areas the rocks are horizontal. The Marwar Supergroup has two facies; one in the southern part of the Basin where the rocks are exposed and the other is developed in the central and northern parts in the subsurface region where the geology is based on bore-hole data. The exposed rocks are subdivided into three groups; in stratigraphic order these are the Jodhpur Group, the Bilara Group and the Nagaur Group. Each group has been further subdivided into different formations. In the north in subsurface region a new facies is developed which is named as Hanseran Evaporite Group characterised by the development of potash deposit. It is considered as an equivalent of the Bilara Group but a few workers have considered it as an additional Group younger to the Bilara Group and placed it between the Bilara Group and the Nagaur Group. The Jodhpur Group shows the presence of a 4 m thick conglomerate horizon only in the western part of the Basin near Pokaran. It shows unconformable contact with the underlying Malani Igneous Suite. The boulder bed has been a matter of debate about its glacial, fluvioglacial or fluvial origin.

Earlier the Marwar Supergroup was considered as unfossiliferous but stromatolites were known since 1964. A medusoid was first reported from the Jodhpur Sandstone in 2005 after that *Hiemalora* and *Aspidella* were discovered from these sandstones. Problematic fossils with algal affinity were also reported from these rocks. The Jodhpur Sandstone is characterised by a variety of microbially mediated sedimentary structures (MISS) including the presence of *Arumberia banksi*. It appears that the presence of MISS is unique to the Jodhpur Sandstone due to its Ediacaran age. A variety of stromatolite morphologies are present in the Bilara Group including *Conophyton*. These stromatolites differ in comparison with the stromatolites of the Bhander Group of the Vindhyan Supergroup.

The Jodhpur Sandstone has yielded poorly preserved burrows and trails. The Nagaur Group shows a variety of trace fossils many of which have a trilobite affinity and helpful in suggesting a Lower Cambrian age to the Nagaur Group. The important forms are *Cruziana*, *Rusophycus, Diplichnites, Bergaueria, Monomorphicnus*, *Treptichnus pedum, Dimorphicnus*, *Chondrites*, scratch marks and burrow forms. The Nagaur Group has also yielded poorly preserved articulated arthropod tergites or trilobite and Priapulid-like fossils.

U-PB LA-ICP-MS ZIRCON AGES FORM THE MARWAR SUPERGROUP AND ITS UNDERLYING BASEMENT

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ABSTRACT

We present recent U-Pb ages of detrital zircon grains from sedimentary rocks of the Marwar Supergroup and magmatic zircon ages of granitoids and rhyolites from the underlying basement.

Zircon concentrates were separated from ~1 kg sample material at the *Senckenberg Naturhistorische Sammlungen Dresden (Museum für Mineralogie und Geologie)* using standard methods. Final selection of the zircon grains for U-Pb dating was achieved by hand-picking under a binocular microscope. Zircon grains of all grain sizes and morphological types were selected, mounted in resin blocks and polished to half their thickness. Zircons were analyzed for U, Th, and Pb isotopes by LA-SF ICP-MS techniques at the Museum für Mineralogie und Geologie (GeoPlasma Lab, Senckenberg Naturhistorische Sammlungen Dresden), using a Thermo-Scientific Element 2 XR sector field ICP-MS coupled to a New Wave UP-193 Excimer Laser System. A teardrop-shaped, low volume laser cell was used to enable sequential sampling of heterogeneous grains (e.g., growth zones) during time resolved data acquisition. Each analysis consisted of approximately 15 s background acquisition followed by 30 s data acquisition, using a laser spot-size of 25 and 35 μm, respectively. A common-Pb correction based on the interference- and background-corrected ^{204}Pb signal and a model Pb composition was carried out if necessary. Raw data were corrected for background signal, common Pb, laser induced elemental fractionation, instrumental mass discrimination, and time-dependant elemental fractionation of Pb/Th and Pb/U using an Excel® spreadsheet program developed by Axel Gerdes (Frankfurt am Main, Germany). For analytical details see Gerdes and Zeh (2006). Concordia diagrams (2σ error ellipses) and concordia ages (95% confidence level) were produced using Isoplot/Ex 2.49 (Ludwig, 2001) and frequency and relative probability plots using AgeDisplay (Sircombe, 2004). The ^{207}Pb/^{206}Pb age was taken for interpretation for all zircons >1.0 Ga, and the ^{206}Pb/^{238}U ages for younger grains.

U-Pb ages of granitoids from the basement of the Marwar Supergroup are in the range of 828 ±8 Ma and 831 ± 6 Ma. Detrital zircons from clastic sediments point to local sources. We will give a comparison to zircon populations from neighbouring geological units and plates (Arabian platform, Lesser Himalayas).

A NEW INSIGHT IN THE GEOLOGY OF THE JODHPUR GROUP OF THE MARWAR SUPERGROUP OF JODHPUR CITY, WESTERN RAJASTHAN, INDIA: IMPLICATION FOR GEOTOURISM, HYDROGEOTOURISM AND HANDICRAFT IMPORTANCE.

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ABSTRACT

The Marwar Supergroup has been subdivided into three groups, the Jodhpur Group, the Bilara Group and the Nagaur Group. The Jodhpur Group overlies the Malani Igneous Suit of rocks (779 ± 10 Ma to 681 Ma). The Jodhpur Group is subdivided into the Pokaran Boulder Bed, the Sonia Sandstone and the Girbhakar Sandstone. All these formations could not define and elaborate the constituent facies of their sequences. The stratigraphic status of various facies of Jodhpur Group especially the Sonia Sandstone and the Girbhakar Sandstone are more clear and distinguishable by the work of Mathur *et al.*, (2013). As such, the various facies of the Jodhpur Group can be redistributed as per lithology, field, basement cover relationship, sedimentary structures and their depositional environment. Accordingly, Jodhpur Group is divided in to Facies 'A' i.e. Lower Umed Bhawan Formation (UBF), Facies 'B" i.e. Middle Sursagar Formation (SSF) and Facies 'C' i.e. Upper Motisar Hill Formation (MHF). These three formations constitute three distinct sandstone plateaus in the Jodhpur city. All these formations are overlain by Quartrnery Jodhpur City Formation comprises clayey, silty to sandy alluvium and underlies rocks of Malani Igneous Suite of rocks. The distribution, disposition and deposition of sediments of Jodhpur Group are governed by the configuration of basement rocks of MIS. The field relationship and disposition of various rocks of the Jodhpur clearly suggests that below 260 RL, UBF was deposited, between 260 to 353 RL the SSF was deposited on eroded surface of lower facies of UBF. The MHF was deposited above 353 RL.

The Jodhpur city is a famous tourist place of India. The famous tourist places like historical Mehrangarh Fort, Ship house, Umed palace (constructed of Jodhpur Sandstone) and Jaswant Palace (constructed of Makarana Marble), are some of the unique structures situated on rocks of MIS and MSG. They are unique geo-tourism places along with huge outcrops of columnar joints in rocks of MIS. Jodhpur city is also endowed with more than one thousand unique natural and traditional water impounding structures (surface and ground water bodies) which have wide spectrum of geological aspects especially as Hydrogeotourism sites of the Jodhpur city. Jodhpur is also famous for its handicraft industry of which handcraft items of Jodhpur Sandstone and Makarana Marble are unique and famous. The paper embodies all aforesaid geological, geotourism, hydrogeotourism and handicraft aspects.

THE MALANI IGNEOUS SUITE OF ROCKS NORTHWESTERN PENINSULAR INDIA

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ABSTRACT

Trans-Aravalli Block

The TAB is unique in the geological evolution of the Indian Shield as it marks the major period of anorogenic (A-Type), within plate, high heat producing (HHP) magmatisim represented by the Malani Igneous Suite (55000 sq km:732 Ma) comprising peralkaline (Siwana), metaluminous to mildly peralkaline (Jalor), and peraluminous (Tusham and Jhunjhunu) granites with cogenetic carapace of acid volcanics (welded tuff, trachyte, explosion breccias and perlite) characterized by volcano-plutonic ring structures and radical dykes. The suite is bimodal in nature with minor amount of basalt, gabbro and dolerite dykes . The Siwana ring structure (30km in E-W, 25km in N-S direction) is the most spectular feature of the Thar desert. The represtatives of the Malani suite also occur at Kirana Hills, and at Nagar Parkar, Sindh, Pakistan (Fig. 1). (for a review, Kochhar, 2000) . The vocano-plutonic ring structures, high heat flow, elevated basement rocks (gravity anamoly), 120 km across low velocity anamoly beneath TAB are symptomatic of plume activity in the region. The location of low velocity anamoly which coincides with Siwana ring structure, beneath Sarnu-Dandali area marks the site of Malani plume.

Nomenculature

The term 'Malani beds' was introduced by W. T. Blandford in 1877 for a volcanic series of porphyritic lavas and ash beds exposed in western Rajasthan especially in the then Malani district of erstwhile Marwar Jodhpur State (McMohan, 1884) correlated the Tusham (Haryana) felsites with the Malani bed and suggested that 'Tusham granites represent roots of deepseated portions of ancient volcanoes'. La Touche (1902) included Siwana and Jalor Granites which are contemporaneous with rhyolites and these were described as in the Malani igneous suite.

Regional geology and the age of MIS

The Malani acid volcanic and the contemporaneous granites are younger than the Aravalli/ Delhi geosynclinals deposits with which, they are associated at places. The time gap between the Delhi Orogeny and the emplacement of the MIS is 700Ma, which is much more than the average span of an orogency. No direct relationship of the MIS with the Aravalli Delhi cycles are observed in the field. Thus MIS is anorogenic and cannot be related to any subduction process (Sinha-Roy *et al.*, 1998) or volcanic cryogenic arc (Dharma Rao, 2011) .

Crawford and Compston (1970), determined an age of 745±10Ma (Rb-Sr method) for the Malani granites and rhyolites. Dhar *et al.* (1996) determined an age of 723±6 Ma for the

Malani granites and rhyolites. On the basis of argon-argon dating of two Jalor granite samples, Rathore *et al.* (1999) made a far-fetched conclusion of a 500-550Ma thermal event. According to them, sample JR-15 is an altered sample and JR-17 also appears to be more radiogenic than related samples. This was questioned by Kochhar. Kochhar and Dhar, 2000, Torsvic *et al.* (2001b) who opined that 500-550Ma age spectra were of poor quality with no statistically valid plateau. The dating of the Diri, Gurpratap Singh rocks of doubtful Malani affinity (Kochhar 1998), at 779±10 Ma by Rathore *et al.* (1996) led Roy (2003) to erroneously suggest that the span of Malani rocks is about 100 Ma 779 to 680 Ma. New U/Pb ages for Malani rhyolites ranged between 771± 2 and 751±3 Ma (Unpublished data of Tucker *et al.* 2001 cited by Torsvic *et al.* 2001b). The location of Tucker *et al.*'s samples are not known. Gregory *et al.* 2009 also suggest a shorter duration of the Malani magmatic activity (771-750 Ma). Zircon from the siliceous tuff and unfoliated rhyolite tuff from pamta hill (Angor Formation) have been dated at 765 Ma and 768 Ma respectively. These rocks have resemblance to the Malani volcanic (Dharma Rao *et al.*, 2011).Gregory *et al.*, (2009) have described the MIS as the July 2007 LIP of the month. In view of the smaller aerial extent < 0. 1 M sq. km. , igneous volume > 0. 1M km and < 50 my life span, the intraplate Malani magmatism cannot be described as the Large Igneous Province (c Bryan and Ernst, 2008)

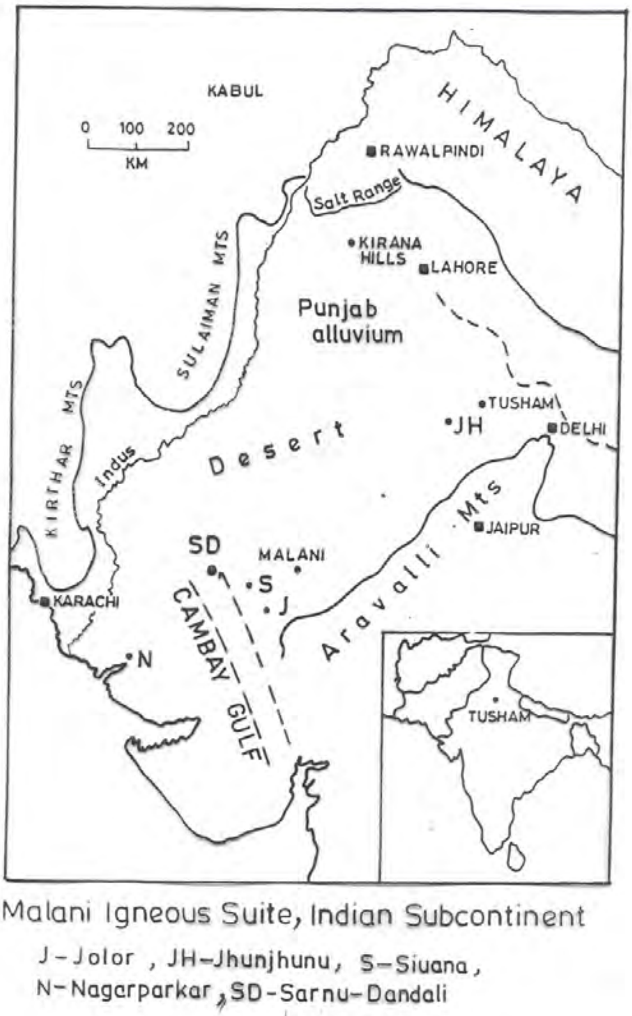

Fig 1. Location Map of the Malani ignous suite

Geochemical Characteristic of the MIS

The Malani magmatism is shows high abundances of HFS, Zironium, niobium, ga, Zn, Y, REEs (except Eu) Pb and Nd isotopic compositions Siwana Granites show that these are mantle derived, and Jallore Granites, the combined Sr and Nd data indicate primary mantle derivation with a valuable degree of contamination of crust of archean age. the role of halogens influxing the trace elements from mantle is indicated. The granites show potential for U, Th, Sn-W and related rare metal mineralization.

Geodynamic significance

The importance of Malani Magmatism in geological evolution of the trans aravali block of the Indian shield lies in its role in the configuration of a Late Proterozoic Supercontinent-the Malani supercontinent comprising TAB of the NW Indian shield, Seychelles, Medagascar, South China, Siberia, Mongolia, Kazikiastan and Tarim. (Kochhar 2007, 2013, a, b).

TECTONO-SEDIMENTARY EVOLUTION OF THE GANDAK MEGAFAN, MIDDLE GANGETIC PLAIN, INDIA: A STUDY OF FORELAND BASIN SEDIMENTATION

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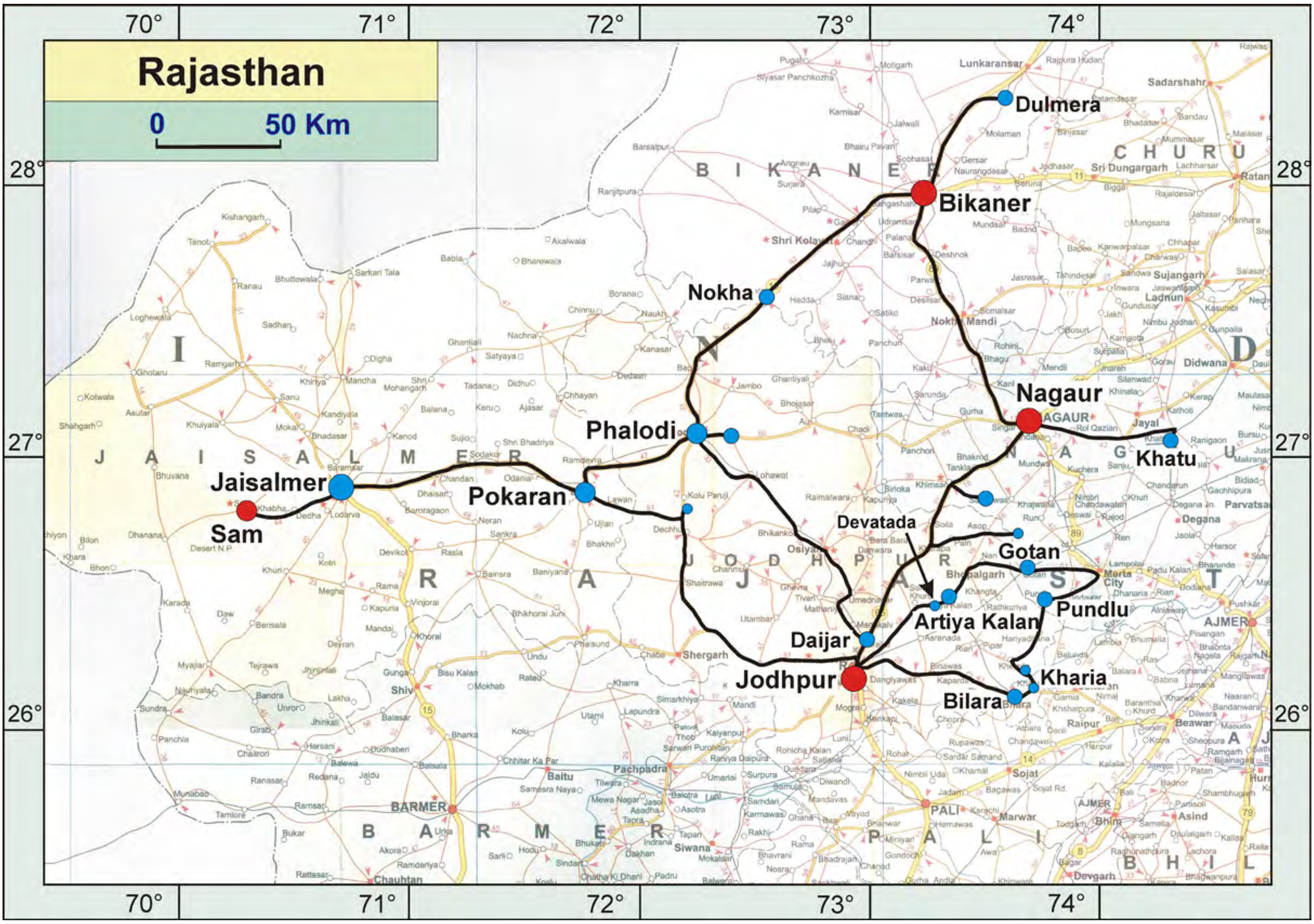
ABSTRACT

The Gandak megafan in the middle Gangetic plain of the Indo-Gangetic foreland basin rests on the Rapti-Gandak tectonic block, bounded by the Rapti fault-II in the west and the Gandak fault in the east. Being a part of the Indo-Gangetic foreland basin, which is a tectonically active basin in recent times, its sedimentation process is greatly controlled by the Neotectonic activities. This mega alluvial architecture was formed by lateral eastward migration (80 km) of the Gandak River in two distinct phases (11.76-10.73 Ka and 9.23-8.45 Ka) due to northeastward tilting of the Rapti-Gandak tectonic block. Eastward migration of the river has left behind two progressively older planes to the west. Slow eastward tilting favored extensive siltation on the top surface. The post tilting episodes of neotectonism developed two longitudinal faults (Nichlul fault at the proximal part and the South Motihari Thrust splay in the middle) and four transverse normal faults (Rohini fault, Gorakhpur-Padrauna fault, Bahraj-Bettiah fault and Maharajganj-Dhaka fault) on the megafan surface in different times. Out of these four normal faults, the Gorakhpur-Padrauna and the Bahraj-Bettiah faults segmented the Rapti-Gandak block into three tectonic sub-blocks (from north to south: Maharajganj, Captainganj and Siwan sub-blocks). The topographic breaks along the faults provided potential sites for generation of frequent splays from the Gandak River and few new inland streams on the megafan surface. The newly generated splays together with the inland streams deposited four terminal fans (Gandak terminal fans I-III and Jharni terminal fan) on the megafan surface on the downthrown blocks of the concerned faults. These terminal fans having few meters thick sediment are spread on the megafan covering 49 % surface area and are marked by localized high rate of sedimentation. The Gandak terminal fan-I (5.41 Ka) and II (5.84 Ka) were formed on the downthrown blocks of the Nichlul fault and the South Motihari thrust splay, respectively. Development of the Bahraj-Bettiah fault at 1.41 Ka led to the subsidence of the Siwan sub-block along with the Gandak terminal fan-II and formed a wide swampy area in its south. This fault also gave rise the Jharni terminal fan on the NW part of the Siwan sub-block. The reactivation of the South Motihari thrust splay at 1.29 Ka formed the Gandak terminal fan-III on the Siwan sub-block at the same location as the Gandak terminal fan-II. Growth of the newly formed Gandak terminal fan-III gradually fills up the swamps and at places the swamps have been filled up completely. Spatial and temporal distribution of the terminal fans and their sedimentary architectures too reflect the neotectonic activities of the underlying sub-blocks along with the bounding faults. In the Siwan sub-block, high sedimentation rate, low stream power and lower slope of the terminal fans facilitate channel aggradations and frequent avulsions. Tilting of the sub-blocks promote frequent lateral eastward channel migration and abandonment. Hence, the aggraded abandoned channels on the Gandak terminal fan-III remain as sandy mounds within the flood plains. As the basin is segmented into smaller blocks and sub-blocks, the sedimentation gets more localized as terminal fans.



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