

VINDHYAN BASIN, SON VALLEY AREA, CENTRAL INDIA

S. Kumar • Mukund Sharma



The Palaeontological Society of India

Department of Geology, University of Lucknow
Lucknow - 226 007, (U. P.)
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Frontispiece-A view of the Mangesar Hill showing the Dhandraul Quartzite overlying Scarp Sandstone demarcated by the white line, Sonbhadra District, Uttar Pradesh.

PSI - Field Guide

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Front Cover-A view of the Sangrampur Hill in the Chitrakut area, Chitrakut District, Uttar Pradesh. The Bundelkhand Granite is seen below whereas the Semri Group is noted above it.

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Foreword

The Vindhyan sediments attracted the attention of geologists for palaeobiological evidence since the beginning of the last century when some carbonaceous markings in shales in the Neemuch district, Madhya Pradesh were reported. Since then the Vindhyan were the centre of attention for multiple reasons. It not only yielded economic minerals like diamonds, pyrite, limestone, dolomite and not to mention such prosaic item like building stone etc. but also searched for evidences of life, basin evolution and sedimentary tectonics. Attempts are being made to search for hydrocarbons. It occupies large area covering Bihar, Uttar Pradesh, Madhya Pradesh and Rajasthan making it the largest Proterozoic Basin in Indian subcontinent. The Vindhyan attain a huge thickness which can be measured in kilometers. With the present understanding of the Vindhyan Supergroup, these rocks represent a time period beginning from 1800 to 600 Ma covering a time gap of 1200 Ma. This is a time when most important changes took place on earth in atmosphere, biosphere and lithosphere. Thus, the Vindhyan sediments are the repository of such changes and significant inferences can be achieved if these sediments are given due attention. A very important thing about these sediments is that these rocks are virtually unmetamorphosed and least deformed with excellent preservation of sedimentary structures. Thus, these rocks are well suited for field training of both under and post-graduate students. These can also be an ideal material for unraveling the mysteries of nature by research scholars. The present guide book can be a good starting point for both students and research workers. It has all the details about the updated information on the Vindhyan Basin in general and for the Son Valley in particular. For each traverse it also summarizes geology for the beginners. An added advantage in the Guide Book is an extended bibliography on the Vindhyan Basin. I am very hopeful that this publication will be useful for all those who are interested in the Vindhyan Basin.

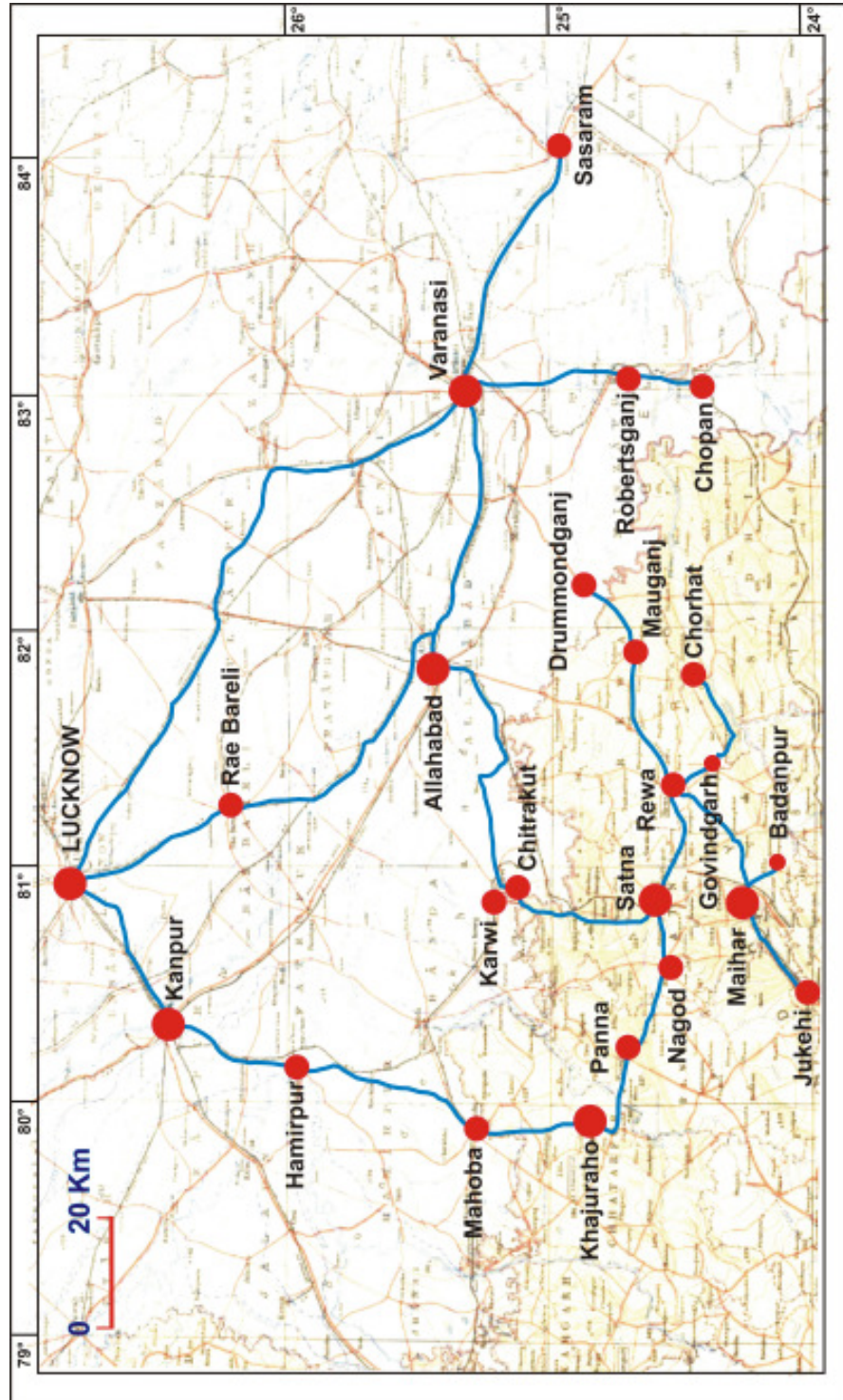
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The present Field-Guide book is an enlarged version of the earlier limited circulation field-guide books prepared for the participants of the International Field-Workshops organised by the Palaeontological Society of India in 2002 (S. Kumar and S. K. Gupta) and 2010 (S. Kumar and Mukund Sharma). We received several constructive suggestions on them by a number of participants. We incorporated many of their suggestions in the present field guide book for which we are especially grateful to Late Prof. H. J. Hofmann, Mc-Gill University, Canada; Prof. Bruce Runnegar, UCLA, USA; Dr. N.C. Mehrotra, Director, BSIP, India; Mr. Ravi Shanker and Mr. Sumant Gupta, formerly of GSI, India. Prof. A. K. Jauhari, Department of Geology, University of Lucknow and Prof. D. M. Banerjee, Department of Geology, University of Delhi. Mr. V. K. Sharma, Sonbhadra and Dr. Ravi Chaurey, MGCGV, Chitrakut helped during the field work. We thank the officers of the U. P. Directorate of Geology and Mining, officers of the National Mineral Development Corporation, Majhgawan Mine, Panna district for administrative support to access various leased areas and also sharing geological information. It was suggested that the guide book can be very useful to future research workers and students if published in the form of a book with which the Executive Council of PSI also agreed. We thank the Palaeontological Society of India for publishing the updated version of the guide book. Dr. Graham Shields-Zhou was also kind enough to provide partial financial assistance under IGCP-512 for publication of this guidebook. The constant persuasion and encouragement of Prof. M. P. Singh, the Secretary of the Palaeontological Society of India was also a major factor for making this publication possible. We are thankful to Drs. Erfan Mondal, AMU, S. K. Pandey and Yogmaya Shukla, BSIP for the help during the preparations of the field-work as well as during the preparation of the final manuscript. Permission from various publishers for permitting us to use their copy-write material is duly acknowledged. The guidebook was completed during the tenure of a DST project (SR/S4/ES-348/2008) sanctioned to SK and DST-RFBR Project (INT/RFBR/P-102) sanctioned to MS.

Route Map



Introduction

The Indian peninsular shield and the Himalayan region have many thick sedimentary successions of the Proterozoic age (Fig. 1). Out of these, the peninsular successions are unmetamorphosed and least affected by tectonic disturbances. This makes them suitable for the study of exogenic processes, early life and its interaction with the sediments, synsedimentary tectonics and basin evolution. As such, these sediments are excellent repository of important events occurred during the Proterozoic Eon. In general, most of these successions represent deposits of intracratonic basins. Out of these, the Vindhyan sediments constitute deposit of the largest sedimentary basin occupying an area of ca. 1,20,000 sq km in central India (Figs. 2 & 3). In addition, estimated ca. 80,000 sq km is covered by the Deccan Traps and ca. 10,000 sq km is lying under the cover of Gangetic alluvium in the north (Mathur, 1987). The northern extension of the Vindhyan Basin under the Ganga alluvium is based on geophysical and drilling data (Narain and Kaila, 1982; Srivas-

tava *et al.*, 1983). The eastern limit of the Vindhyan Basin is near Sasaram in Bihar and the western limit is close to Chittorgarh in Rajasthan. The southern and southwestern limits are partly covered by the Deccan Traps and the northern limit is either marked by the Bundelkhand granites or partly extends under the Gangetic alluvium. The Bundelkhand Granite Complex (BGC) occupies an important position with respect to the Vindhyan Basin as it has divided the basin into two parts: eastern part developed in the Son Valley and western part in the Chambal Valley. Both show different lithostratigraphic successions. The total thickness of the Vindhyan sediments is ~ 4500-5000 m. The Vindhyan Basin is bounded in the northwest by the Delhi-Aravalli orogenic belt (the Great Boundary Fault) and in the southeast by the Narmada-Son lineament (Fig. 4).

Over a decade, a number of reports were published on palaeobiology and geochronology that attracted the attention of scientific community for the following reasons:



Fig. 1- Distribution of Proterozoic basins in India.

1. The presence of Precambrian/Cambrian boundary was reported within the Bhandar Group by Friedmann *et al.* (1996) and Friedmann and Chakraborty (1997) on the basis of the stable carbon isotope values, and within the Rohtasgarh Limestone (the Semri Group) by Azmi (1998) on the basis of the presence of small shelly fossils and brachiopod.
2. Discovery of trace fossils produced by triploblastic animals in the Rampur Formation (Chorhat Sandstone, the Semri Group) by Seilacher *et al.* (1998).

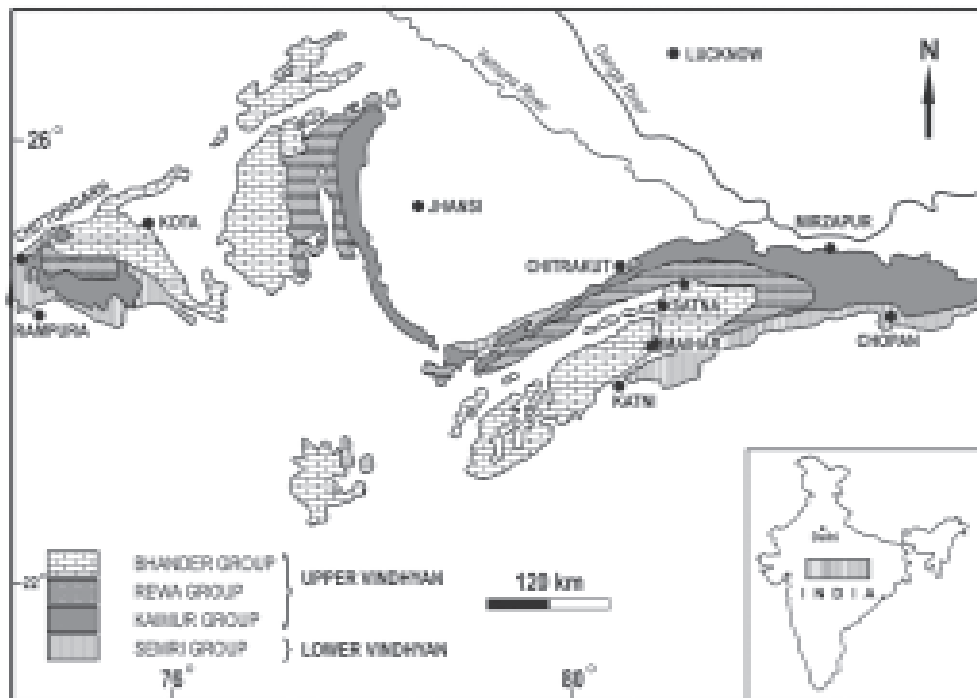


Fig. 2-Location and geological map of the Vindhyan Basin (After Krishnan and Swaminath, 1959).

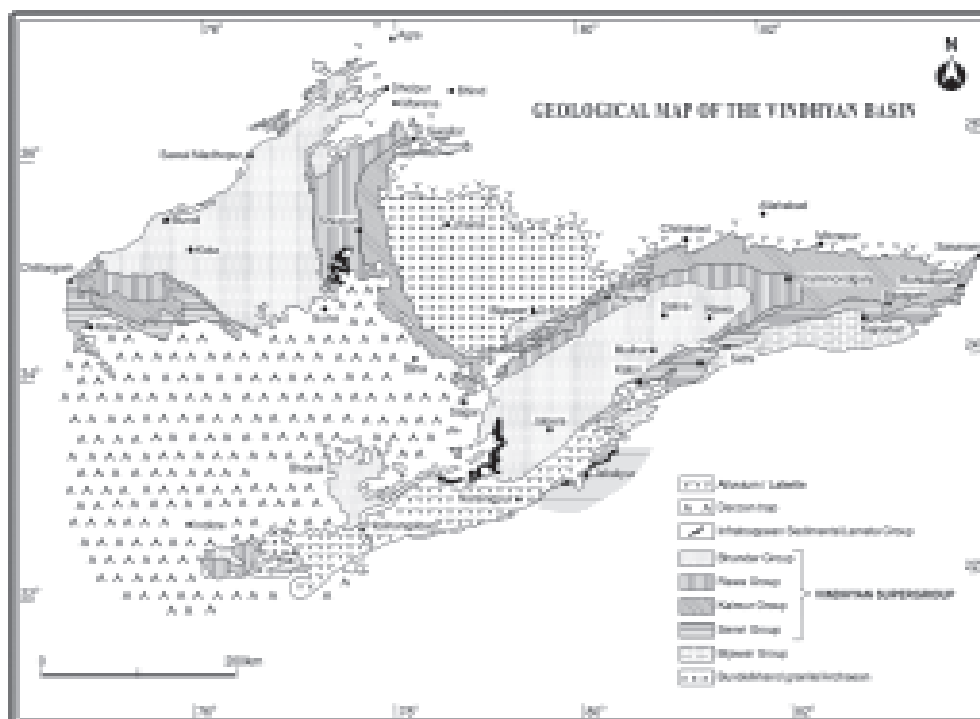


Fig. 3-Regional geological map of the Vindhyan Basin (After Soni *et al.*, 1987).



Fig. 4-Map showing the Vindhyan Basin bounded by the Great Boundary Fault and the Son – Narmada Lineament (After Raza and Casshyap, 1996).

3. Report of Ediacaran fossil *Spriggina* from the Semri Group by Kathal *et al.* (2000) and the Ediacaran fossils of metazoan affinity by De (2003, 2006a) from the Bhandar Limestone and Sirbu Shale of the Bhandar Group.
4. New radiometric dates of the Vindhyan sedimentation by Ray *et al.* (2002, 2003), Rasmussen *et al.* (2002), Sarangi *et al.* (2004), Gregory *et al.* (2006) and Bengtson *et al.* (2009) have modified the concept of the beginning of sedimentation in the Vindhyan Basin.
5. The youngest formation of the Vindhyan Supergroup, the Shikaoda Sandstone (Maihar Sandstone), in the Son Valley Section has been suggested an Ediacaran age on the basis of the presence of microbial mat *Arum-*

- beria* and the body fossil *Beltanelliformis* (Kumar and Pandey, 2007a).
6. Bengtson *et al.* (2009) have confirmed the presence of small shelly fauna in the Tirohan Limestone (=Rohtasgarh Limestone) but asserted that it has no element which could suggest the Cambrian age.
 7. Recent studies have suggested 500 Ma gap between the established age and new palaeomagnetic studies for the Upper Vindhyan (Malone *et al.*, 2008). The palaeomagnetic data has been interpreted to suggest that the Vindhyan sedimentation ended around ~ 1075 Ma (Gregory *et al.*, 2006; Malone *et al.*, 2008; Basu, 2009).

All these reports present a scenario that is inconsistent with our present understanding of biosphere and basin evolution at the global level. These have serious implications for the regional geological set-up, correlation and evolution of the Vindhyan Basin as well as for the evolutionary palaeobiology.

Prologue to the Field Guide

In March 1999, a workshop on the *Stratigraphy and Palaeobiology of the Vindhyan Basin* was organised in the Department of Geology, University of Lucknow in collaboration with the Palaeontological Society of India (PSI) to discuss some of the discoveries reported in 1998. A number of participants of the workshop along with the scientists drawn from the different national organisations visited the localities from where the small shelly fos-

sils and brachiopods were reported by Azmi (1998). The team also visited the locality from where the trace fossils from the Rampur Formation (Chorhat Sandstone, the Semri Group) were reported (Seilacher *et al.*, 1998). Those trace fossils were considered to be produced by the triploblastic animals. Both these reports did not find much favour with the majority of the scientific community in India and abroad. The PSI, realizing the significance of the discoveries, decided to organise an *International Field Workshop on the Vindhyan Basin*. It had a much larger participation from the active workers to discuss the findings of the subsequent reports on the work of Azmi (1998) (Bhatt *et al.*, 1999; Bhargava *et al.*, 2000; Chakrabarti, 2001). In this backdrop, an International Field Workshop was organised in 2002. Besides R. J. Azmi and other Indian scientists, H. J. Hofmann, B. Runneger, Linda Sohl, S. M. Porter and J. R. Lyons also participated. Dr. Azmi demonstrated his material to the participants of the field workshop for study. The resultant discussions established that no Cambrian age can be assigned to the Rohtasgarh Limestone and the Semri Group was considered to be Palaeoproterozoic to Mesoproterozoic. However, Azmi and his group continued to assign the Cambrian age to the Rohtasgarh Limestone (Azmi and Paul, 2004; Azmi *et al.*, 2007, 2008; Joshi *et al.*, 2006).

Independent investigations by Bengtson *et al.* (2009), of the Tirohan Limestone which can be correlated with the Rohtasgarh Limestone from which Azmi (1998) had originally reported small shel-

ly fauna and brachiopod, indicated that the fossil bearing phosphatic unit in the Tirohan Limestone is Late Palaeoproterozoic in age. Bengtson *et al.* (2009), in fact, accepted the shelly nature of fossils but refrained from considering the material as small shelly fauna that represents the Cambrian age. Instead, they assigned the traditional Palaeoproterozoic to Mesoproterozoic age to the Semri Group based on fresh datings of the sediments. These two claims have further compounded the palaeobiological scenario of the Vindhyan sediments. It has serious implications for the concepts of early evolution of life as shelly fauna globally occurs near the Precambrian-Cambrian boundary and its presence in early Mesoproterozoic sediments is unexplained at present. In view of these serious challenges, the PSI played a catalyst's role. It decided to organise another International Field Workshop to address these questions and provide an opportunity to the experts to examine the crucial sections to help resolve the controversy of the age of the Vindhyan, and to understand how material akin to small shelly fauna could occur somewhere near the transition of the Palaeoproterozoic–Mesoproterozoic. Or, our understanding of the evolution of life needs rethinking?

The field guide-books were prepared for the participants of the International Field Workshops held in December 2002 and January 2010. The present guide-book is an enlarged, updated and modified version of the earlier guide-books prepared by Kumar and Gupta (2002) and Kumar and Sharma (2010). In the present guide-book, a description originally includ-

ed in the earlier guide-book concerning the section of Varanasi-Robertsganj-Dalarnukoot (also Renukut) has been retained for the benefit of the researchers, though this section was not covered during the field work in January, 2010.

Previous studies

The Vindhyan Basin occupies a large area in Central India and attains a huge thickness of more than 5 km. The rocks are unmetamorphosed and undisturbed to moderately disturbed with low angle dips. Oldham (1856) was the first to use the term 'Vindhyan' for the entire group of rocks forming a prominent feature along the northern bank of Narmada River known as *Vindhya Parbat* or *Vindhyan-chal*. Subsequently, significant contributions were made on the geology of the Vindhyan by Meddlicott (1859), Mallet (1869), Hackett (1881), Vredenburg (1906a, b), Coulson (1927), Heron (1922, 1932, 1936), Auden (1933), Ahmad (1962, 1971), Mathur (1962, 1981d, 1987), Banerjee (1964, 1974, 1982), Misra (1969), Akhtar and Srivastava (1976), Prakash (1967), Prakash and Dalela (1982), Bhardwaj (1973, 1980), Bhardwaj and Mathur (1989), S. Kumar (1976a, 1978a), Singh (1973, 1980a, 1985), Bhattacharyya *et al.* (1980), Prasad (1984), Sastry and Moitra (1984), Mishra *et al.* (1990), Shukla and Sharma (1990), B. Kumar *et al.* (2002), Sarkar and Bose (1992), Soni *et al.* (1987), Chakrabarti (1990, 2001), Akhtar (1978, 1996), Valdiya (1969), Sarkar *et al.* (1996), Venkatachala *et al.* (1996), Bhat-

Table 1-Broad subdivisions of the Vindhyan Supergroup as proposed by Auden (1933).

	After Auden (1933)	Modified
Upper Vindhyan	Bhander Series	Bhander Group
	Rewa Series	Rewa Group
	Kaimur Series	Kaimur Group
	-----Unconformity-----	
Lower Vindhyan	Semri Series	Semri Group

tacharyya (1993, 1996), Bose *et al.* (2001), Casshyap *et al.* (2001), Raza *et al.* (2002), Sarkar *et al.* (2002a, 2002b), Prasad and Asher (2001), Chakraborty (2006), Kumar *et al.* (2005), Misra and Kumar (2005), De (2006a, b), Prasad *et al.* (2005, 2007), Prasad (2007), Sharma (1996, 2006a, b, c), Sharma and Shukla (2009a, b), Sharma *et al.* (2009), Srivastava (2009) and many others.

Auden (1933) gave a comprehensive stratigraphic framework of the Vindhyan succession exposed in the Son Valley. He subdivided the succession into four equal series namely the Semri Series, the Kaimur Series, the Rewa Series and the Bhander Series (Table-1). Following the recommendations of the Code of Stratigraphic Nomenclature, majority of the workers replaced the term 'Series' with 'Group' and gave the Vindhyan System the rank of a Supergroup. Traditionally, the Semri Group is referred to as the Lower Vindhyan and the Kaimur, Rewa and Bhander Groups as the Upper Vindhyan (Fig. 5). However, Mathur (1987) questioned the validity of two-fold subdivision of the Vindhyan Supergroup but the use still persists and is well entrenched in the literature. Of late, geochronological dates have also corroborated the two-fold divisions of the Vindhyan Supergroup.

A number of publications are available which deal with various aspects of the geology of the Vindhyan Supergroup. The Geological Survey of India published

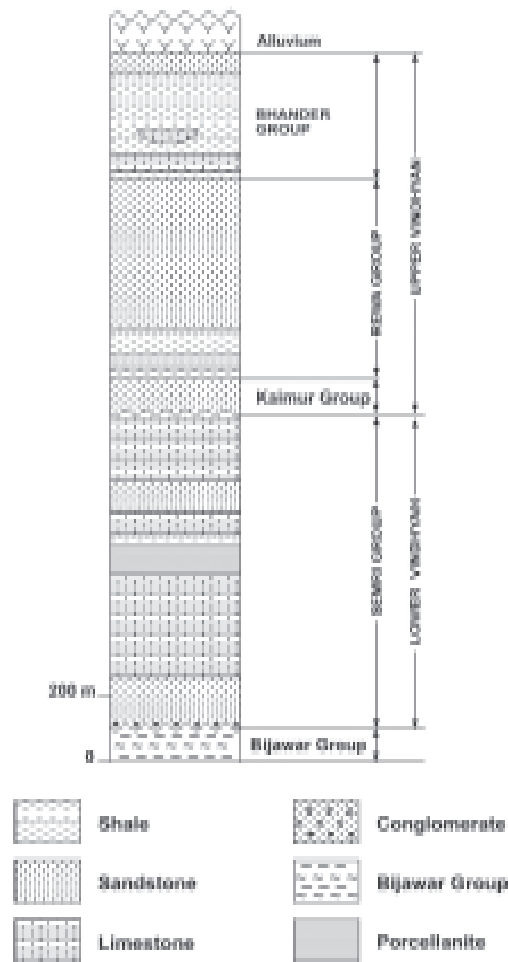


Fig. 5-Lithological succession of the Maihar area, Son valley, Satna District, M. P. (Kumar *et al.*, 2005).

the proceedings of the symposium on the *Vindhyan of Central India* in 1981. Valdiya *et al.* (1982) edited a volume entitled '*Geology of Vindhyanchal*', which incorporated papers on different aspects of the geology of the Vindhyan Basin. A well-prepared field guide-book on the geology of the Maihar area, M.P. was published by Bhattacharyya (1993). A Memoir entitled *Recent advances in Vindhyan Geology* edited by Bhattacharyya (1996) was published by the Geological Society of India that provided developments on the geology of the Vindhyan Basin. In 2003, a collection of papers on different aspects of the geology of Vindhyan Supergroup was published by the *Journal of the Palaeontological Society of India*. The most recent account on the Vindhyan geology was provided by Ray and Chakraborty (2006) in a special issue of the *Journal of Earth System Science* entitled *Vindhyan Geology: Status and Perspective*.

The Vindhyan Supergroup attracted many active research groups from India and abroad. In the last 50 years, a number of national/international field workshops were organized by different organizations of the country (Jadavpur University, 1983; Banaras Hindu University, 1996; University of Lucknow and the Palaeontological Society of India, 1999, 2002, 2010; Indian Institute of Technology-Bombay, 2007). Area specific field guides circulated on these occasions are not easily available for consultations except a field guide-book, published by the Geological Society of India, on the Upper

Vindhyan of Maihar area (Bhattacharyya, 1993).

Stratigraphy

The Vindhyan Supergroup has been lithostratigraphically subdivided into four groups; in stratigraphic order these are: the Semri Group, the Kaimur Group, the Rewa Group and the Bhandar Group (Table 1). The Vindhyan sediments show much facies variation and both horizontal and vertical gradation in lithology is well recorded. Thus, different areas show different lithostratigraphic successions. This aspect is well demonstrated when a comparison of lithostratigraphic succession is made between the eastern and western parts of the Vindhyan Basin. The stratigraphic succession of the eastern part does not compare well with the stratigraphic succession of the western part of the basin. Thus, in absence of the radiometric dates and definite index fossils, the correlation of the lithostratigraphic units of the eastern part with the lithounits of the western part of the basin has become very subjective. Such an attempt has led to very erroneous conclusions about correlations, as very little information is available on the facies variation of the different sequences of the Vindhyan Basin. Absence of any regional unconformity or regionally correlatable lithounit has also compounded the problem. Attempts were made to give a generalised lithostratigraphy for the entire Vindhyan Basin (see Sastry and Moitra, 1984; Bhattacharyya, 1996). Recently, Kumar (2011) suggested that the lithostratigraphic successions for the eastern

part of the Vindhyan Basin, i.e. the Son Valley Section and the western part of the Basin, i.e. the Chambal Valley Section should be dealt with separately. As only the Kaimur Group can be traced in both the areas with a fair degree of confidence, this horizon should be considered as a marker horizon. Therefore, all the lithounits underlying the Kaimur should be referred to as the Semri Group and the overlying successions to the Rewa and Bhander Groups. We agree with Kumar (2011) that name used for describing a lithostratigraphic horizon in the Son Valley should not be used for describing a lithostratigraphic unit in the Chambal Valley Section, as its continuity cannot be traced in both the sections.

Different formation names have been used for describing the lithostratigraphy of the Semri Group in the eastern and western parts of the Vindhyan Basin, but it is not the case with the Rewa and Bhander Groups where many common names have been used for both the areas such as the Panna Shale, the Jhiri Shale and the Ganurgarh Shale, etc. These horizons are well exposed in the Son Valley area and the same name describes similarly looking lithologic horizons in the Chambal Valley area. But their continuity cannot be traced in both the areas and there is a likelihood that they may represent different stratigraphic horizons in both the eastern and the western parts of the Vindhyan Basin. In the present field guide-book, the lithostratigraphic successions of the Son Valley are given in detail as these were covered during the field-work in 2010. The lithostratigraphic successions of the Chambal

Valley are given for comparison and overview. No attempt, however, has been made to modify the existing lithostratigraphic names as suggested by Kumar (2011) but the difference is emphasized by adding the name of the valley as a suffix in the bracket with the name of the formation; for example the Ganurgarh Shale in the Son Valley Section is referred to as the Ganurgarh Shale (Son) and in the Chambal Valley it is referred to as the Ganurgarh Shale (Chambal). It is emphasized that the formations and members with common names in the Bhander Group for both the sections are not necessarily correlatable.

Sequence stratigraphy for the Vindhyan succession has also been attempted by Chakraborty (2006).

Son Valley Section

The Son Valley Section constitutes the eastern part of the Vindhyan Basin. It includes Vindhyan rocks of the Sasaram-Rohtas area (Bihar), Dala-Chopan area (Uttar Pradesh) and Chitrakut-Rewa-Chorhat-Maihar-Panna area (Madhya Pradesh). In these areas, all the four lithostratigraphic groups, viz. the Semri Group, the Kaimur Group, the Rewa Group and the Bhander Group are exposed. A simplified geological map of the Vindhyan Supergroup is given in Fig. 3 and generalised lithostratigraphy is given in Table-2A.

Semri Group

The Semri Group is the oldest group of the Vindhyan Supergroup. Auden

Table 2A- Lithostratigraphy of the Vindhyan Supergroup (Modified after Sastry and Moitra, 1984).

Group	Subgroup	Formation
BHANDER		Maihar Sandstone (Shikaoda Sandstone)
		Sirbu Shale
		Bhander Limestone
		Ganurgarh Shale
REWA		Upper Rewa Sandstone (Govindgarh Sandstone)
		Jhiri Shale
		Lower Rewa Sandstone (Asan Sandstone)
		Panna Shale
KAIMUR		Dhandraul Quartzite
		Mangesar Formation
		Bijaigarh Shale
		Ghaghar Sandstone
		Susnai Breccia
		Sasaram Formation
----- Unconformity -----		
SEMRI	Rohtas Subgroup	Bhagwar Shale
		Rohtasgarh Limestone
	Kheinjua Subgroup	Rampur Formation
		Salkhan Limestone
		Koldaha Shale
	Mirzapur Subgroup	Deonar Formation
		Kajrahat Limestone
----- Unconformity -----		
Bijawar, Aravalli & Pre-Aravalli Group/Bundelkhand Granite		

(1933) originally referred to the Semri Group as the Semri Series. He divided the Semri Series into four stages as the Basal Stage, the Porcellanite Stage, the Kheinjua Stage and the Rohtas Stage. In gener-

al, most workers followed this subdivision by replacing the term 'Stage' by 'Formation' (see Table-2B). Attempts have also been made by a number of workers to strictly adhere to the suggestions given under the Code of Stratigraphic Nomenclature and modify the names originally given by Auden (1933). However, it resulted in the introduction of different names for the same lithostratigraphic horizon. This has created problem for communication and often one has to take help of the term used by Auden (1933). Although the terms assigned by the Auden (1933) are well entrenched in the literature but we have used the terms proposed by Sastry and Moitra (1984) and Bhattacharyya (1996) or wherever possible the terms given by Auden (1933) with least modifications. The modification is done only where it was necessary. The new names given by other authors can be taken as local names. Sastry and Moitra (1984) have subdivided the Semri Group into three subgroups and have clubbed the Basal Stage and the Porcellanite Stage under the Mirzapur Subgroup. The lithostratigraphic subdivisions as suggested by Sastry and Moitra (1984) for the Semri Group in both the Son Valley and Chambal Valley sections are given in Table-3.

Mirzapur Subgroup

In the the eastern part of the Vindhyan Basin, the Mirzapur Subgroup is constituted of the Deoland Formation, the Arangi Formation, the Kajrahat Limestone and the Deonar Formation.

Table 2B- Stratigraphic subdivision of the Semri Group.

	By Auden (1933)	Used in the present work	
Rohtas Stage	Limestone and shales	Rohtas Subgroup	Bhagwar Shale
	Nodular limestone and shales		
	Banded shales		
	Limestone		
	Nodular limestone and shale		Rohtasgarh Limestone
Kheinjua Stage	Glauconite beds	Kheinjua Subgroup	Rampur Formation
	Fawn Limestone		Salkhan Limestone
	Olive Shales		Koldaha Shale
Porcellanite Stage	Porcellanites etc.		Deonar Formation
Basal Stage	Kajrahat Limestone	Mirzapur Subgroup	Kajrahat Limestone
	Basal Conglomerate		Arangi Formation Deoland Formation

Deoland Formation

It is the lowermost lithounit of the Semri Group. Thickness varies from 200 m to 500 m. Auden (1933) named it as the Basal Conglomerate but Sastry and Moitra (1984) have named it as the Deoland Formation. It shows an angular unconformity with the underlying Bijawar phyllites. It is represented by sandstones, conglomerate, breccia and lenticular bands of calcareous grit, dolostone with occasional stromatolites. The pebbles are well rounded to subangular and reach up to the size of 20 cms. It is made up of red jasper, quartzite, vein quartz, chalcedony, black slate, shale, etc. The conglomerates grade horizontally as well as vertically into sandstones. The sandy horizons show cross-bedding and parallel bedding. Grading is also recorded. The upper part is represented by bleached shales which at times are siliceous containing ferruginous nodules and bands of earthy dolostone and

micaceous sandstone. The shales are extremely fine grained, thinly bedded and show both colour and textural banding. Coarse grained horizons show large scale cross bedding. Parallel bedding and wave ripple bedding are commonly present.

Arangi Formation

It overlies the Deoland Formation comprising mainly shales and exposed in the Son Valley. It attains a maximum thickness of 460 m. It is considered at par with the Basal Shale described by Rao and Neelakantam (1978).

Kajrahat Limestone

It attains a thickness of ca. 600 m and is represented by dark grey, bluish grey, dirty yellow limestone and dolostone. The limestone is light to dark grey, bluish grey, dirty yellow microcrystalline to coarsely crystalline. At places, the pink, dark grey

Table 3- Stratigraphic subdivisions of the Semri Group as suggested by Sastry and Moitra (1984).

Son Valley (After Sastry and Moitra, 1984)		Chambal Valley (After Prasad, 1984)		
Subgroup	Formation	Group	Formation	
Rohtas Subgroup	Bhagwar Shale	Khorip Group	Suket Shale	
	Rohtasgarh Limestone		Nimbahera Limestone	
Kheinjua Subgroup	Rampur Formation		Lasarwan Group	Bari Shale
				Jiran Sandstone
	Salkhan Limestone	Binota Shale		
	Koldaha Shale	Kalmia Sandstone		
Mirzapur Subgroup (Basal Subgroup)	Deonar Formation	Sand Group	Palri Shale	
	Kajrahat Limestone	Satola Group	Sawa Sandstone	
			Bhagwanpura Limestone	
			Khardeola Sandstone	
Arangi Formation	Khairmalia Andesite			
Deoland Formation				
-----Unconformity-----		-----Unconformity-----		
Bijawar Phyllites/ Bundelkhand Granite		Pre-Aravalli rocks/ Berach Granite		

to black shales are intercalated. There are horizons which show profuse development of stromatolites. Lower horizon is sandy and intercalated with the sandstone and shale. Small-scale ripple bedding, flaser and lenticular bedding, parallel bedding with low angle discordances, and mud cracks are commonly recorded. The upper part is dominantly stromatolitic with extensive fan-fabrics (Fig. 6). Prakash and Dalela (1982) have identified 12 lithounits within the Kajrahat Limestone.

Deonar Formation

Auden (1933) has named this horizon as Porcellanite Stage. It attains a thickness of ~ 300 m. It has been accorded the rank of a formation and is included in the Mirzapur Subgroup by Sastry and Moitra (1984). It is made up of alternat-

ing succession of silicified tuff and sandstone. The siltstone, shale and conglomerate have also been recorded. The porcellanites are banded, hard, fine-grained, varying in colour from black to pale green and show conchoidal fracture. Joints are very prominent. It has rhyolitic and andesitic appearance. It shows dominantly parallel lamination with both colour and textural banding. Even a very thin individual band can be traced laterally over a distance of tens of meters or even decameters. Grading is also seen in sandy horizon. Wave ripples and penecontemporaneous deformational structures have been recorded. Presence of abundant pumice, euhedral quartz grains, euhedral zoned zircon crystals and volcanic bombs indicate volcanic origin of these deposits (Roy and Banerjee, 2001). Srivastava *et al.* (2003) suggested that porcellanites of the Semri

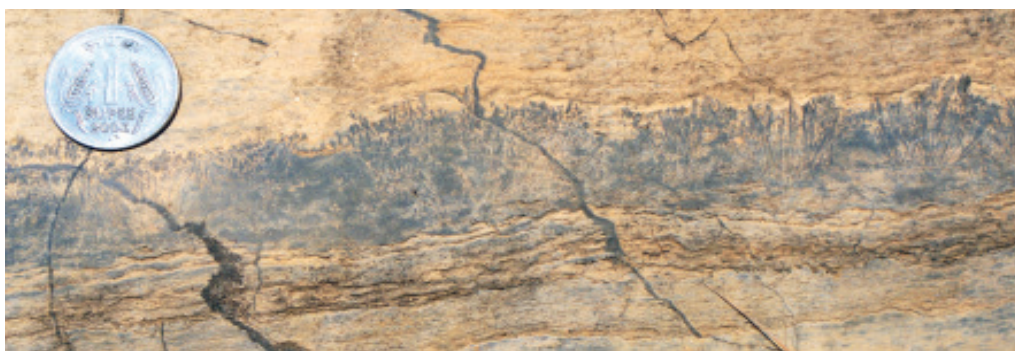


Fig. 6-Carbonate radial fan fabric in the Kajrahat Limestone of the Semri Group exposed in the Chhoti Mahanadi section in the Maihar area, Satna District, Madhya Pradesh.

Group represent submarine and terrestrial volcaniclastic and volcanogenic epiclastic sediments that were deposited in the tidal flat regions.

Kheinjua Subgroup

The Kheinjua Stage of Auden (1933) was later termed as the Kheinjua Formation and subsequently, Sastry and Moitra (1984) named it as the Kheinjua Subgroup. It has been subdivided into three formations, in stratigraphic order, these are the Koldaha Shale (Olive Shale), the Salkhan Limestone (Fawn Limestone) and the Rampur Formation (Glaucconitic Sandstone).

Koldaha Shale

The porcellanites are overlain by a thick unit of olive shales and siltstone with minor sandstone. The thickness varies from 70 to 120 m. This horizon has been given the name Koldaha Shale by Sastry and Moitra (1984). The shales show papery thin lamination with textural and co-

lour banding (Fig. 7). Parallel bedding with low angle discordances and lenticular bedding are common. Graded bedding is also recorded. The sandstones are grey with ripple bedding and parallel bedding. Wave ripple and current ripples with mud galls are also recorded. The shales are very friable and show pencil fractures. These shales have yielded millimetric carbonaceous films which have been attributed to macro-algae (Sharma, 2006a).

Salkhan Limestone

The Fawn Limestone is redesignated as the Salkhan Limestone by Sastry and Moitra (1984). It has also been referred to as the Bargwan Limestone (Prakash and Dalela, 1982). Its maximum thickness is 90 m. It is made up of fawn weathering, siliceous and cherty limestone and dolostone with minor shales. It shows excellent development of stromatolites. Associated black bedded cherts (Fig. 8) have yielded well-preserved microbiota. The limestone shows parallel bedding with low angle discordances and small scale ripple

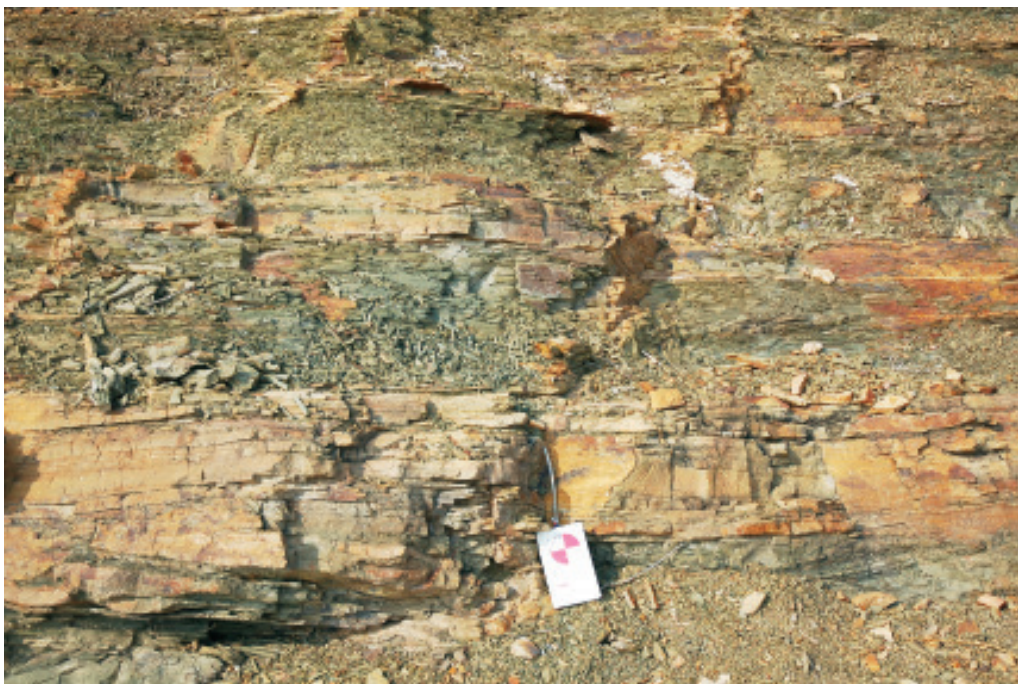


Fig. 7-The Koldaha Shale showing papery thin lamination and colour and textural banding in the Bansagar Section, Maihar, Satna District, Madhya Pradesh.

bedding, intraformational conglomerate and breccia with imbrication structure. Algal mat horizons are also seen.

Rampur Formation

A characteristic horizon of the Kheinjua Subgroup is a glauconite-bearing sandstone horizon (Fig. 9) which is redesignated as the Rampur Formation by Rao and Neelakantam (1978). Its thickness varies from about 100 to 800 m (Sastry and Moitra, 1984). It is represented by glauconitic sandstone and minor shales, pebbly grit, siltstone, conglomerate and breccia and thin limestone bands. Ripple marks, small scale cross bedding and mud cracks are abundantly recorded.

Rohtas Subgroup

The Rohtas Stage of Auden (1933) was later referred to as the Rohtas Formation and subsequently subdivided into two formations by Rao and Neelakantam (1978). The older is the Rohtasgarh Limestone and the younger is the Bhagwar Shale. Later, it was accorded the rank of a subgroup by Sastry and Moitra (1984).

Rohtasgarh Limestone

It is the basal unit of the Rohtas Subgroup comprising greyish to greyish black limestone and shales. It attains a thickness of ~ 200 m in east to 500 m in the west in Rewa district. At places, it shows development of nodules within the shales

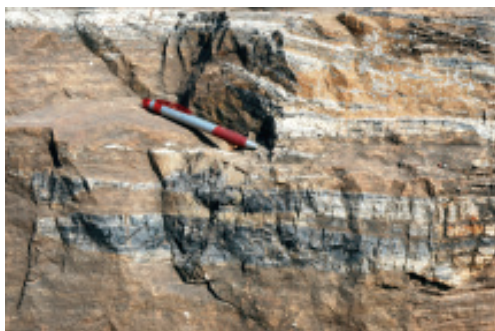


Fig. 8-Bedded chert in the Salkhan Limestone, Son Valley, Chopan area in Sonbhadra District, Uttar Pradesh.

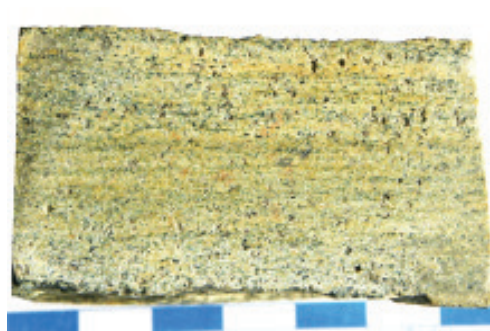


Fig. 9-A polished section of the glauconitic sandstone of the Rampur Formation, Son Valley, Chopan area, Uttar Pradesh showing parallel bedding. (one section of scale bar = 1 cm)

(Fig. 10) Dominantly it shows parallel lamination.

Bhagwar Shale

It is the uppermost lithounit of the Rohtas Subgroup and also the youngest lithounit of the Semri Group in the Son Valley area. Its thickness varies from 20 to 125 m. It is represented by silicified shale, sandstone and carbonaceous shale. Azmi (1998) recorded the small shelly fossils of the presumed Cambrian age from this horizon of the Maihar area, M. P., but the record has been challenged/rejected by majority of the workers for its age connotation.

Kaimur Group

It is the most extensively developed argillo-arenaceous succession and is the only horizon which can be traced from the eastern to the western parts of the Vindhyan Basin. Thus, it can be considered as a marker horizon. Thickness varies from a

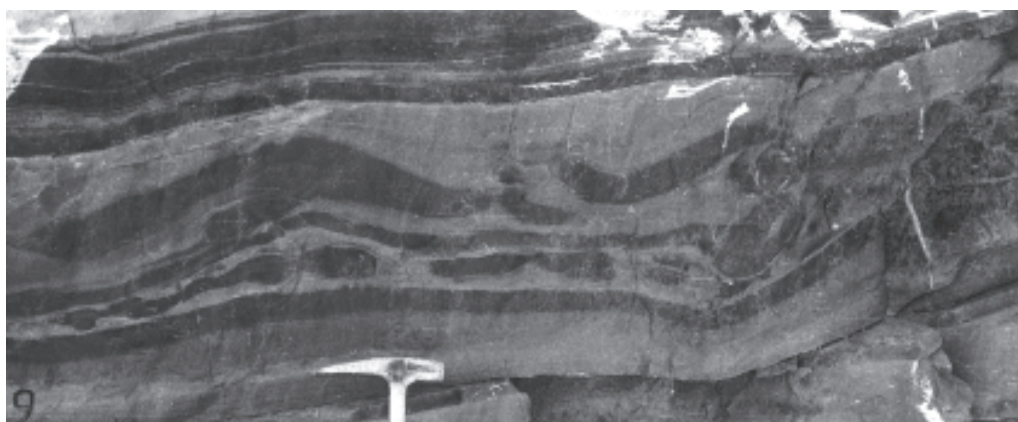
few meters to 400 m. It is best developed in the Son Valley area. Auden (1933) subdivided it into different lithounits which were subsequently given formal names by Sastry and Moitra (1984) (Table-4). Table-5 gives a comparative lithostratigraphic succession of the Son and Chambal valleys.

Sasaram Formation (Lower Quartzite)

It is the basal unit of the Kaimur Group and at places has an unconformable contact with the underlying Rohtasgarh Limestone/Bhagwar Shale. It is designated as the Sasaram Formation by Sastry and Moitra (1984). It is represented by white to grey, massive, current bedded sandstone. It also contains lenticular pebbly horizons. In the upper part, thinly bedded lenticular flagstone and mudstone are present which show excellent development of mud cracks and ripple marks. It attains a thickness of 35 m.

Table 4-Lithostratigraphic succession of the Kaimur Group.

	By Auden (1933)	By Sastry and Moitra (1984)
Upper Kaimur Stage	Dhandraul Quartzite Scarp Sandstone	Dhandraul Sandstone Mangesar Formation
Lower Kaimur Stage	Bijaigarh Shales Upper Quartzite Susnai conglomeratic breccia Silicified Shale Lower Quartzite	Bijaigarh Shale Ghaghar Sandstone Susnai Breccia Sasaram Formation

**Fig. 10-Nodular Limestone facies of the Rohtasgarh Limestone, the Semri Group, Murli Pahar, Rohtas District Bihar.***Silicified Shale*

It is represented by black micaceous shales with thin bands of sideritic ironstone. Intercalated with these shales are porcellanites. The carbonaceous shales readily bleach. The shales show parallel lamination. It attains a total thickness of 8 m.

Susnai Breccia

It is represented by breccia which is made up of rounded or angular fragments of porcellanite and red jasper seen in gritty or quartzitic matrix. It constitutes the upper member of the Sasaram Formation

of Sastry and Moitra (1984). Its thickness varies between 25 cm to 3 m. The angular habit of porcellanite gives the rock a brecciated look. This horizon has a lenticular disposition.

Ghaghar Sandstone (Upper Quartzite)

The Ghaghar Sandstone (Upper Quartzite) of Auden (1933) has been renamed as the Ghaghar Sandstone by Sastry and Moitra (1984). Its thickness is 15 m. It is mainly made up of sandstone intercalated with shale. According to Singh (1980), it shows megaripple bedding, herringbone cross bedding, flaser and lentic-

Table 5-Lithostratigraphic successions in Son Valley and Chambal Valley sections.

	Son Valley (After Auden, 1933)		Chambal Valley (After Prasad, 1984)
Kaimur Series	Dhandraul Quartzite	Kaimur Group	Akoda-Mahadev Formation
	Scarp Sandstone		Badanpur Conglomerate
	Bijaigarh Shale		Chittaur Fort Sandstone
	Upper Quartzite		
	Susnai Conglomeratic Breccia		
	Silicified Shale		
	Lower Quartzite		
-----Unconformity-----			
Semri Series	Rohtas Stage		Suket Shale

ular cross bedding, minor channels and current and wave ripples. In the lower part of the unit, the current-produced structures dominate and in the upper part, wave-produced structures are more common. It shows good development of mud cracks.

Bijaigarh Shale

The Ghaghar Sandstone (Upper Quartzite) grades into the Bijaigarh Shale. It is made up of greyish black shale, siltstone and sandstone and attains a thickness of 50 m. Singh (1980b) has identified three units. The lower and upper parts are sandy and the middle part is made up of black shales which is occasionally pyritiferous. Parallel lamination with low-angle discordances, lenticular bedding, wave ripple bedding, large scale bedding, rill marks, wrinkle marks, spring pits, incomplete mud cracks, modified ripples, load structures, channel fill structures have been recorded (Singh, 1980b). It shows conformable contact with the underlying Ghaghar Sandstone (Upper Quartzite).

Mangesar Formation (Scarp Sandstone)

The Scarp Sandstone of Auden (1933) has been redesignated as the Mangesar Formation by Sastry and Moitra (1984). It is represented by sandstone, green sandy siltstone, micaceous green and brown sandy shale with thin green shale. Cross bedding, parallel bedding, wave ripple bedding and wave ripple, claygals are commonly present. The sandstones are soft and colour varies from brown to red. It shows large-scale cross bedding and wave ripples. Clay gals are commonly present. It has a thickness of 200 m.

Dhandraul Sandstone (Dhandraul Quartzite).

This is the uppermost unit of the Kaimur Group. It is named as the Dhandraul Sandstone by Sastry and Moitra (1984). It is dominantly made up of white sandstone. It also shows purple staining. It shows large scale cross bedding and

parallel bedding. Ripple marks are common. It has a total thickness of ~100 m.

Rewa Group

This group is composed chiefly of sandstones and shales. It conformably overlies the Kaimur Group. It has been subdivided by Krishnan (1968) into four different lithostratigraphic units (Table-6). Sastry and Moitra (1984) have redesignated the Lower Rewa Sandstone and the Upper Rewa Sandstone as the Asan Sandstone and the Govindgarh Sandstone respectively. Table-6 gives the comparative lithostratigraphic successions of the Rewa Group in Son Valley and Chambal Valley.

Panna Shale

It is characterized by very well developed, thinly laminated greenish grey, khaki, brown and chocolate coloured shales. Bedding can be compared with rhythmic type laminations (Chakraborty and Chaudhari, 1990). Individual laminae are extremely persistent and can be traced for over tens of meters. Occasionally, it shows thin limestone bands. Evidence of wave and current activity are rarely recorded. Thickness varies from 100 m to 130 m.

Srivastava (2004) has recorded the presence of *Chuarina-Tawuia* assemblage.

Asan Sandstone (Lower Rewa Sandstone)

The Panna Shale is overlain by glauconite bearing medium to coarse-grained greenish grey brown weathering massive sandstone horizon designated as the Lower Rewa Sandstone by Krishnan (1968) and Asan Sandstone by Sastry and Moitra (1984). It forms a significant divide between the Jhiri Shale and the Panna Shale horizons. The sandstone shows profuse development of cross bedding, flaser and lenticular bedding and parallel lamination. Thin bands of diamond-bearing conglomerate are recorded in the upper part with pebbles and cobbles of vein quartz, jasper, etc. set in a sandy matrix.

Jhiri Shale

It is made up of red, reddish brown to greenish yellow shales and minor fine and medium grained sandstone. The shale-dominated facies shows lenticular bedding. The sand-dominated horizons are characterised by flaser bedding. Rai *et al.* (1997) have recorded *Chuarina – Tawuia* association from this horizon.

Table 6-Lithostratigraphic succession of the Rewa Group.

	Son Valley		Chambal Valley
	After Krishnan, 1968	Sastry and Moitra, 1984	After Prasad, 1984
Rewa Group	Upper Rewa Sandstone	Govindgarh Sandstone	Govindgarh Sandstone
	Jhiri Shale	Jhiri Sahle	Jhiri Shale
	Lower Rewa Sandstone	Asan Sandstone	Indergarh Sandstone
	Panna Shale	Panna Shale	Panna Shale

Govindgarh Sandstone (Upper Rewa Sandstone)

It conformably overlies the Jhiri Shale and forms an escarpment facing south, close to Govindgarh in Rewa district, Madhya Pradesh. The Upper Rewa Sandstone has been redesignated as the Govindgarh Sandstone by Sastry and Moitra (1984). Based on the study in the the Drummondganj area, Chakraborty and Choudhuri (1990) have further divided this unit into Drummondganj Sandstone and Govindgarh Sandstone. The thickness of the Govindgarh Sandstone varies from ~ 100–250 m. It comprises pink, light pink with light yellowish brown and yellowish white fine to medium-grained massive sandstone. It shows profuse development of trough and planar mega cross-bedding. Other sedimentary structures commonly associated with this unit include parting lamination, ripple marks and clay-galls. At places due to increase in iron content, a purple brown colour is imparted to the sandstone with effect of lateretization. In the Panna township, this horizon has yielded

diamonds in the upper part in a pebbly to cobbly orthoconglomerate horizon.

Bhander Group

The Bhander Group constitutes the youngest group of the Vindhyan Basin. The original classification proposed by Krishnan (1968) was modified by Sastry and Moitra (1984) (Table-7). However, in the classification followed in the present work, the term Lakheri Limestone is discarded for the Son Valley section and earlier nomenclature the Bhander Limestone for the horizon overlying the Ganurgarh Shale is retained. In our opinion, the lithostratigraphic succession of the Bhander Group in the Chambal Valley is entirely different in comparison to the succession exposed in the Son Valley. The Lakheri Limestone is recognized in Chambal Valley and should not be compared lithologically with the Bhander Limestone of the Son Valley. The Bhander Limestone is characterised by the abundance of columnar stromatolites, while the Lakheri Limestone is devoid of them. The isotope signatures of both the limestones are very different. The mean

Table 7-Comparative lithostratigraphy of the Bhander Group in the Son Valley and Chambal Valley sections

		Son Valley	Chambal Valley
		After G.V. Rao in Awasthi, 1964	After Prasad, 1984
Bhander Group	Upper Bhander Sandstone	Shikaoda Sandstone	Dholpura Shale
	Sirbu Shale	Sirbu Shale	Balwan Limestone
	Lower Bhander Sandstone	Bundi Hill Sandstone	Maihar Sandstone
			Sirbu Shale
			Bundi Hill Sandstone
	Bhander Limestone	Lakheri Limestone	Samria Shale
	Ganurgarh Shale(?)	Ganurgarh Shale	Lakheri Limestone
			Ganurgarh Shale



Fig. 11-Columnar stromatolite *Baicalia baicalica* in the Bhandar Limestone, Aber, Satna District, Madhya Pradesh.

value of $\delta^{13}\text{C}$ for the Bhandar Limestone is 4.3‰ (PDB) and for the Lakheri Limestone it is -5.4‰ (PDB) (Kumar, 2005). For these reasons, Kumar *et al.* (2005) have suggested that these two units are distinctly separate horizons.

Ganurgarh Shale

It is the oldest formation of the Bhandar Group and overlies the Govindgarh Sandstone (Upper Rewa Sandstone) and underlies the Bhandar Limestone with conformable relationship. Its thickness varies between 100-270 m. It is made up of chocolate coloured shale, calcareous siltstone and fine-grained sandstone.

Bhandar Limestone

It constitutes the only significant calcareous horizon of the Upper Vindhyan in the Son Valley area. Its thickness varies between 80-100 m. It is dominantly made up of grey to dark grey limestone and greyish green shales. Columnar stromatolites are profusely developed (Fig. 11). It is extensively mined for cement and metallurgical industry and for making lime. The lower part of the Bhandar Limestone is made up of light brown coloured sandy limestone intercalated with thin mud layers. It shows mega ripple bedding, small scale cross bedding, parallel bedding, flaser and lenticular bedding, mud cracks and various types of ripple marks.

The middle part of this unit is made up of pure limestone, shaly limestone, algal limestone and thinly laminated dolostones with subordinate intraformational conglomerate and breccia. Oolitic limestone has also been recorded. It shows megacross bedding, herringbone cross bedding, small-scale cross-bedding, climbing ripple lamination, wave ripple bedding and molar tooth structures & penecontemporaneous deformational structures. Stromatolite-bearing horizons are quite common.

The upper part of the Bhandar Limestone is made up of greyish to yellowish brown, micritic limestone, oolitic limestone, stromatolitic limestone with gypseous lenses, siltstone and silty shale. This horizon shows parallel lamination, small and mega scale cross bedding, flaser and lenticular cross bedding, wavy bedding, current ripples, interference ripples, mud cracks and

penecontemporaneous deformational structures. The upper most part is siliceous. Macrofossils, microstromatolites and siliceous sponge-like forms have been recorded.

Sirbu Shale

It is made up of light yellow, grey to greyish green shales and siltstones interbedded with grey to brownish grey sandstones. It attains a thickness of 100-250 m. The shales alternate with sandstones. The thickness of sandstone layers varies considerably. The sandstone shows parallel bedding and cross bedding and various types of tool marks, scour marks, ripple lamination and ripple marks dominated by wave ripples. A few horizons also show presence of salt pseudomorph shales. Carbonaceous megafossils have been recorded from this horizon (Kumar and Srivastava, 1997). An arenaceous facies overlying the Bhandar Limestone identified by Krishnan (1968), Sastry and Moitra (1984) and Bhattacharyya (1993) as the Lower Bhandar Sandstone has been included within the Sirbu Shale.

Maihar Sandstone (Shikaoda Sandstone)

The Maihar Sandstone has also been referred to as the Upper Bhandar Sandstone. Sastry and Moitra (1984) named it as the Shikaoda Sandstone. It is the youngest horizon of the Bhandar Group in the Son Valley area. The Sirbu Shale grades into the Shikaoda Sandstone. It is made up of brown to red-coloured sand-

stone and deep red-coloured shales. Parallel bedding, large scale cross bedding, ripple bedding, flaser and lenticular bedding, with a very wide variety of wave and current ripples, rill marks, wrinkle marks, current crescent, deformational structures, channel structures, mud cracks and microbial mat structures are present in this unit. Tidal bedding are noted in mud-dominated horizons. Singh (1976) has observed two opposite current directions, one dominating over the other. According to Basumallick (1962a), the Maihar Sandstone is fine grained, moderately to poorly sorted and subgraywacke in composition. Kumar and Pandey (2008) have recorded microbial mat structures *Arumberia banksi*, *A. vindhyanensis* and *Rameshia rampurensis* and a body fossil *Beltaneliformis minuta*. On this basis, they have suggested an Ediacaran age to the Maihar Sandstone.

Radiometric Dates

Not many radiometric dates are available for the Vindhyan sediments. Vinogradov *et al.* (1964) were the first to date the glauconites of the Kheinjua Formation (Son Valley section) and the Kaimur Sandstone of the Chittorgarh area (Chambal Valley section) by K/Ar method which are now of vintage value. They suggested 940 ± 30 Ma for the Lower Kaimur Sandstone and 910 ± 30 Ma for the Upper Kaimur Sandstone. For the Rampur Formation (the Glauconitic Sandstone of Auden, 1933) they gave 1110 ± 60 Ma. Kreuzer *et al.* (1977) recalculated the earlier glauconite dates given by Russian workers by

using subsequently recommended radiometric constant and gave 1080 ± 40 Ma for the Semri Group and 890 Ma for the Kaimur Group. The Fission Track Dating method has been applied for the first time by Srivastava and Rajagopalan (1986, 1988) for the glauconites of both the Lower and Upper Vindhyan, but their methodology could not find favour with most of the geochronologists because of some inherent problems associated with their method and hence their data have been ignored. Rathore *et al.* (1999) dated the glauconites of the Sirbu Shale by K-Ar method and gave 741 ± 9 Ma as mean depositional age of the Sirbu Shale.

In the Panna area, a kimberlite pipe intruding the Kaimur Sandstone was dated as 1140 ± 12 Ma by Crawford and Compston (1970). Kumar *et al.* (1993) have dated it by Rb-Sr method as 1067 ± 31 Ma. It has been now dated as 1073 ± 13 Ma on the basis of $^{40}\text{Ar}/^{39}\text{Ar}$ dating (Gregory *et al.*, 2006). Kumar *et al.* (2001) have dated the glauconites of the Semri Group of the Chitrakut area by Rb-Sr method and suggested that the onset of the Vindhyan sedimentation is close to 1600 ± 50 Ma. Rasmussen *et al.* (2002) have dated the silicified tuffs bounding the Rampur Formation (=Chorhat Sandstone) by SHRIMP U – Pb Zircon method and suggested that the Chorhat Sandstone must have been deposited between 1628 ± 8 Ma and 1599 ± 8 Ma. Ray *et al.* (2002) have dated the silicified volcanic rock of the Porcellanite Formation (Deonar Formation) of the Semri Group. Two samples were analysed for U – Pb Zircon dates which gave age as 1632 Ma. Ac-

cording to them, the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of 0.70599 for the Bhandar Group is consistent with the Neoproterozoic age. Sarangi *et al.* (2004) have dated the *Grypania*-bearing Rohtas Formation and have given its age as 1599 ± 48 Ma. In the Chambal Valley, the Vindhyan sedimentation starts with andesitic flows, which have been dated by Crawford (cited in Prasad, 1984) as ca. 1250 Ma old. Bansal *et al.* (1999) dated two bore cores of lower Vindhyan of Son Valley, Madhya Pradesh and obtained Rb-Sr ages for the Kajrahat Limestone and Rohtasgarh Limestone as 1014 ± 18 Ma and 939 ± 22 Ma respectively. Now, these ages seem to be inconsistent with the more reliable described ages and hence can be ignored. Recently, Bengtson *et al.* (2009) carried out Pb isotope analyses of the phosphorite intraclasts that yielded an age of 1650 ± 89 . It suggests that fossils yielding stromatolitic unit of Chitrakut (Chitrakoot) is between 1700-1600 Ma old. It appears that the sedimentation in the eastern and western parts of the Vindhyan Basin started at different periods. The published geochronological data have been summarized in Fig. 12 (modified after Azmi *et al.*, 2007).

Ray (2006) has reviewed the geochronological data of the Vindhyan Supergroup and has opined that the age of the Lower Vindhyan in the Son Valley is now resolved whereas the age of the Upper Vindhyan as well as the stratigraphic correlation remain unresolved. He has suggested that the sedimentation in the Son Valley started sometime prior to 1721 Ma. Recently, Malone *et al.* (2008) interpreted the palaeomagnetic data of the Rewa

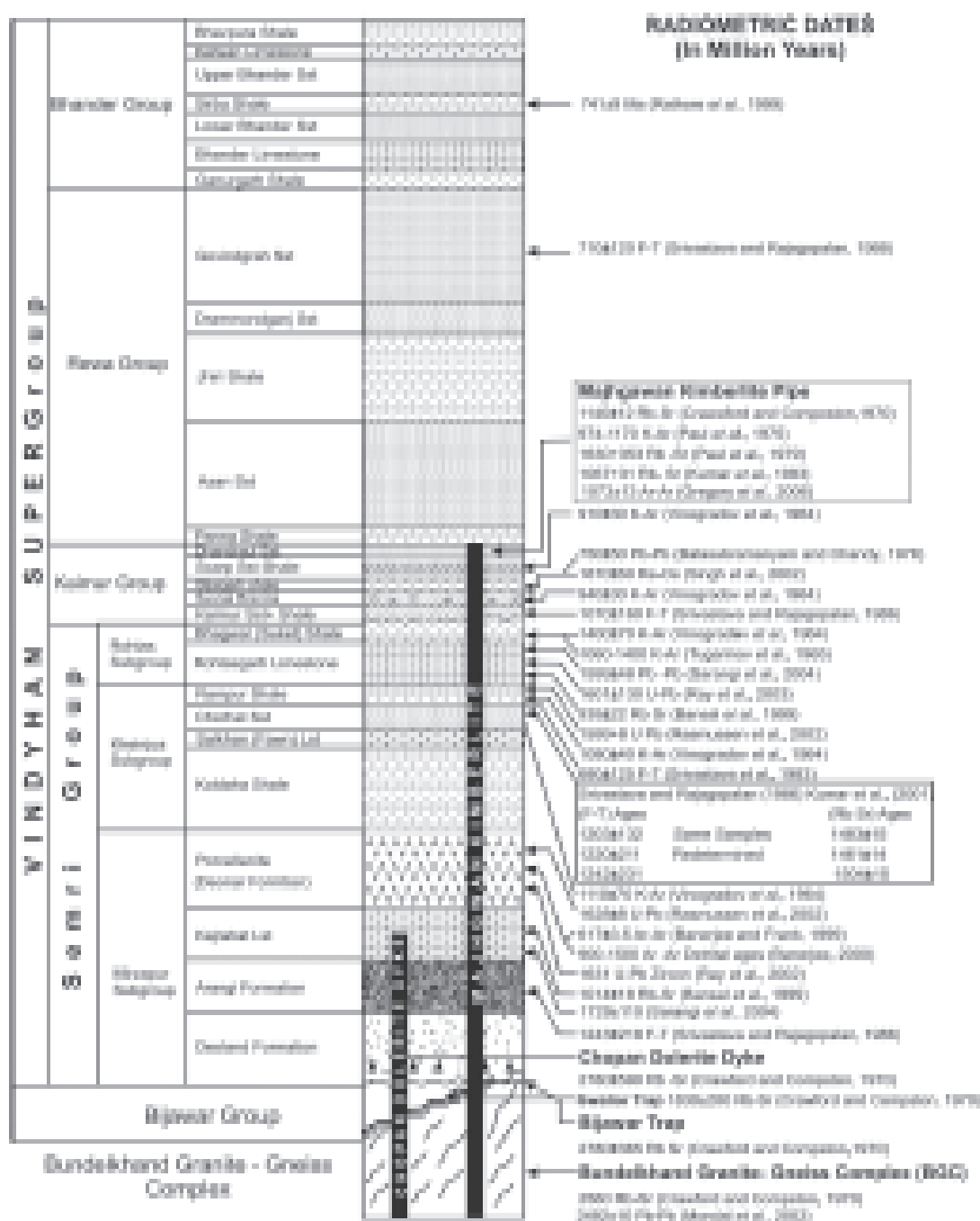


Fig. 12-Published geochronological data on the Vindhyan Supergroup (modified after Azmi *et al.*, 2007).

and Bhandar Groups and suggested that the Upper Vindhyan sequence might be up to 500 Ma older than the commonly considered age, meaning thereby, that the sedimentation in the Vindhyan Basin possibly ended around 1000 Ma ago. Mishra (2011) proposed a plate tectonic model in which he suggested hiatus of 500-600 Ma between the Lower Vindhyan and Upper Vindhyan sequences. This interpretation does not take into account the available outcrop geological information. In our opinion, geophysical data should be interpreted in the available geological framework and for this reason their interpretation can be ignored. All the available radiometric dates are summarised in Table-8. Thus, the beginning of sedimentation in the Vindhyan Basin must have started ~ 1800 Ma. The upper age limit of the Semri Group is ~ 1600 Ma. The deposition in the Kaimur Group started at ~ 1140 Ma but the end of deposition in the Vindhyan Basin has not been firmly established.

Palaeobiological remains

Stromatolites

There are several reviews and status reports on the Vindhyan stromatolites (Valdiya, 1969; Kumar, 1980, 1982; Raha and Sastry, 1982). The Vindhyan stromatolites have also been used by many workers for interbasinal and intrabasinal correlations and, on this basis, the age has been assigned to stromatolite-bearing units. While reviewing the Indian occurrences of stromatolites, Kumar (1980) has remarked that with incomplete data on

stromatolite morphology and use of different systems for naming the stromatolites, comparison of Indian forms with the stromatolites described from the other parts of the world is almost impossible. This statement still holds good because the taxonomical assignments attempted by several workers could not be verified and evaluated with a fair degree of confidence. Though attempts have been made in recent years to improve the quality of description of stromatolite forms (see Sharma, 1996; Raaben *et al.*, 2001; Misra and Kumar, 2005; Kumar *et al.*, 2009a), much refinement in the taxonomy is still required. Because of these problems, some very good and useful information on stromatolites has become less meaningful for discussion. Critical review of individual identification of stromatolite forms is not possible in the present work but some broad inferences could be drawn on the basis of the available information considering the above-mentioned difficulties.

Notwithstanding the identification of individual forms, a few general remarks can be made about the Vindhyan stromatolites:

1. The stromatolites are abundantly reported from different carbonate horizons of the Vindhyan Supergroup except the Nimbahera Limestone and the Lakheri Limestone of the Chambal Valley section. These are the only horizons which attain considerable thickness but are devoid of stromatolites. The Rohtasgarh Limestone of the Son Valley also shows a very poor development of algal laminites and is practically devoid of stromatolites.

2. The Semri Group is characterised by the presence of coniform stromatolites

(*Siren*, *Cyathotes*, *Thyssagetes*, *Ephyaltes* and *Calypso*) which are totally absent in the carbonates of the Upper Vindhyan, i.e. from the Rewa and Bhandar Groups (Kumar, 1999a; Misra and Kumar, 2005). These stromatolites support an age assignment of 1800 to 1600 Ma for the Semri Group. Kumar and Misra (2007) have also recorded a Palaeoproterozoic form *Mistassinia* from the Salkhan Limestone.

3. Misra and Kumar (2005) have described five forms from the Bhandar Group. These are *Baicalia baicalica*, *B. burra*, *Tungussia* sp., *Patomia ossica* and *Maiharina maiharensis*. Presence of *Cryptozoon* sp. has also been recorded in the Bhandar Limestone exposed at Aber.

4. In general, the Semri stromatolites show passive branching, while those of the Bhandar Group are characteristically actively branched.

5. Stromatolites in most of the cases represent shallowing upward sequences.

6. Phosphatic stromatolites have been reported only from the Tirohan Limestone (=Rohtasgarh Limestone) of the Son Valley section (Kumar, 1993).

7. The stromatolite assemblages for the Semri Group and the Bhandar Group are totally different and thus can be used for identifying the rocks of the Semri and the Bhandar Groups with a fair degree of confidence. Apparently, they appear to be quite useful for intrabasinal and interbasinal correlation. Kumar (1982, 1999a) has suggested a Lower to Middle Riphean age for the Semri Group and Upper Riphean

age for the stromatolite-bearing horizons of the Bhandar Group.

Microfossils

Microfossils are abundantly recorded from the Vindhyan sediments. Earlier reports are based on the recovery of fossils by traditional methods of maceration but from late seventies microfossils have also been described from the petrographic thin sections of black bedded cherts. Venkatachala *et al.* (1996) presented a detailed review of all microfossils reported till then. In the present summary, only those reports have been considered which have described microfossils from the petrographic thin sections of black chert. The macerated material is generally viewed with skepticism as there is always a possibility of contamination in the maceration technique, especially for Precambrian sequences and there is no way to establish syngenecity and indigenosity of the recovered fossils (see McMenamin *et al.*, 1983). However, a good attempt has been made by Prasad (2007) and his group (Prasad *et al.*, 2005, 2007) to recover the fossils from the Vindhyan sediments from the different stratigraphic horizons by using the traditional maceration method and have used the microfossil assemblages to suggest ages. Kumar and Pandey (2008) have reported the occurrence of six forms from the petrographic thin sections of the Balwan Limestone of the Chambal Valley Section. Table-9 gives the reported fossils from the different stratigraphic horizons from the petrographic thin sections of the bedded cherts. Azmi *et al.* (2007) have

Table 8-Radiometric dates of different horizons of the Vindhyan Supergroup and associated rocks.

Formation	Geographical Position	Method	Age	Reference
Sirbu Shale, Bhandar Group	Narsinghgarh, Damoh, M. P.	K-Ar	741 ± 9 Ma	Rathore <i>et al.</i> 1999
Bijaigarh Shale, Kaimur Group	Amjhore, Rohtas	Re-Os	1670 ± 60 Ma	Singh <i>et al.</i> 2002
Kimberlite pipe, intruding Kaimur Sandstone, Kaimur Group	Majhgawan Village, Panna, M. P.	Rb-Sr	1140 ± 12 Ma	Crawford and Compston, 1970
Rohtas Limestone, Semri Group	Different localities in Son Valley, M.P. & Rajasthan	K-Ar	1150 Ma	Paul <i>et al.</i> 1975
Rohtasgarh Limestone, Semri Group	Tikaria, Katni, M.P.	Pb-Pb, isochron	1601 ± 130 Ma	Ray <i>et al.</i> 2003
Tirohan Limestone (=Rohtasgarh Limestone) Semri Group	Janakikund, Chitrakut (M.P.)	Pb-Pb, isochron	1599 ± 48 Ma	Saranghi <i>et al.</i> 2004
Rampur Shale, Semri Group	Sidhi district, M.P.	Pb-Pb Isochron	1650 ± 89 Ma	Bengtson <i>et al.</i> 2009
Rampur Shale	Sidhi district, M.P.	SHRIMP, U-Pb, Zircon	1599 ± 8 Ma	Rasmussen <i>et al.</i> 2002
(Tuff Bands), Semri Group	Sidhi district, M.P.	SHRIMP, U-Pb, Zircon	1602 ± 10 Ma	Rasmussen <i>et al.</i> , 2002
Deonar Formation	Sidhi district, M.P.	U-Pb, Zircon, ⁸⁶ Sr/ ⁸⁶ Sr Isotope	1628 ± 12 Ma	Ray <i>et al.</i> 2002
(Two rhyolitic volcanic horizons), Semri Group	Sidhi district, M.P.	SHRIMP, U-Pb, Zircon	1631 ± 1 Ma	
Deonar Formation	Sidhi district, M.P.	SHRIMP, U-Pb, Zircon	1631 ± 5 Ma	Rasmussen <i>et al.</i> 2002
(Porcellanite Formation), Semri Group	Chitrakut area, U.P.	Rb-Sr Model ages	1628 ± 8 Ma	Kumar <i>et al.</i> , 2001
Base of Semri Group	Kajrahat village, Sonbhadra district, U.P. Bijawar, M.P.	Rb-Sr	1409 ± 14 Ma to 1531 ± 15 Ma	Crawford and Compston, 1970
Chopan Dolerite Dyke probably in pre-Vindhyan/Lower Vindhyan rocks	Bijawar, M.P.	Rb-Sr	2370 ± 590 Ma	Crawford and Compston, 1970
Bijawar lava overlying Bundelkhand Granite and underlying Vindhyan rocks	Khajuraho, Chhattarpur (M. P.) and Jhansi (U. P.)	Rb-Sr	2780 ± 365 Ma	
Bundelkhand Granite		Pb-Pb Zircon	2555 ± 55 Ma	Crawford, 1969, 1970
Gneissic Complex		(SIMS)	2492 ± 10 Ma	Mondal <i>et al.</i> 2002

summarized palaeobiological remains of the Vindhyan Supergroup with biased age assignment.

The cyanobacterial forms dominate the microfossil assemblage. None of the reported microfossils have any age significance except the occurrence of *Obruchevella* reported from the Bhandar Group by Kumar and Srivastava (1997) which can be considered as a possible indicator of the beginning of the Vendian age for the upper part of the Vindhyan succession. Acritarchs have been reported from non-stromatolitic cherts of the Semri Group of the Chitrakut area (Kumar and Srivastava, 1997; Anbarasu, 2001a). Srivastava (2009b) reported *Trachyhystriosphera*, an acanthomorphic acritarch from the Sirbu Shale of Rajasthan (Chambal Valley Section) and suggested that the age of the Sirbu Shale should lie near Cryogenian (850 – 630 Ma). Kumar (1999b) has reported (?) sponge spicule-like forms from the petrographic thin sections of the black bedded chert of the Bhandar Limestone and has suggested early Vendian age as the presence of sponge spicules is firmly established in the Cambrian but their occurrence from the Vendian has only recently been noted.

Megafossils

Megafossils were reported as early as 1909 when Jones recorded carbonaceous discs from the Suket Shale, the youngest horizon of the Semri Group in Chambal Valley. These were identified and established as *Chuarina circularis*. Since then, a large number of reports have been pub-

lished on the occurrences of megafossils. Carbonaceous megafossils have been reported both from the Lower as well as Upper Vindhyan. Up to mid nineties, all the available records of macrofossils, which were 50 at that time, were reviewed by Venkatachala *et al.* (1996) and out of these they accepted 13 reports as true fossil reports and rest were considered as either nonfossils or dubiofossils (see Table-9). Out of the 13 fossils accepted by Venkatachala *et al.* (1996), Kumar and Gupta (2002) accepted only four reports of carbonaceous fossils as true fossils and rest were placed in the category of dubiofossils as many morphologies reported earlier as trace fossils and burrows can also be produced by inorganic processes. Since the publication of Venkatachala *et al.*'s (1996) review, Seilacher *et al.* (1998), Azmi (1998), Rai *et al.* (1997), Kumar (2001), De (2003, 2006a), Srivastava (2005), Sharma (2006a, b, c) and Sharma and Shukla (2009 a, b) have recorded additional megafossils. Report of triploblastic animal traces by Seilacher *et al.* (1998) has been rejected by Kumar (2001), Chakrabarti (2001) and Hofmann (2005). Seilacher (see Kerr, 2002) has expressed that these trace fossils might not have been produced by animal. Sharma (2004) has reviewed and updated the status of megafossils described from the Vindhyan Supergroup.

The oldest megafossil record from the Vindhyan Supergroup is from the Koldaha Shale (Olive Shale) of the Semri Group in the Son Valley Section (Sharma, 2006a). He described a variety of carbonaceous films, which were attributed to mul-

Table 9-List of microfossils reported from the different stratigraphic horizons from the black bedded chert

Stratigraphic Horizon	Son Valley	Microbiota	Chambal Valley	Reference
Balwan Limestone (Bhandar Group)			<i>Siphonophycus septatum</i> , <i>S. robustum</i> , <i>Myxococcoides chloreloidea</i> , <i>Eoentophycus</i> sp. <i>Gloeodiniopsis lamellosa</i> <i>G. sp.</i>	Kumar and Pandey, 2008
Sirbu Shale			<i>Gloeodiniopsis</i> sp. <i>Glenobotrydion aenigmatis</i> <i>Myxococcoides</i> sp. <i>Eoentophycus</i> sp. <i>Sphaerophycus</i> sp. <i>Eomicrocystis</i> sp. <i>Trachyhystrichosphaera</i> sp. <i>Leiosphaeridium</i> sp. <i>Cymatiophaera</i> sp. <i>Siphonophycus</i> sp. <i>Archaeotrichion</i> sp. <i>Obruchevella</i> sp. <i>Oscillatoriopsis</i> sp. cf. <i>Gunflintia</i> sp. <i>Trachyhystrichosphaera</i> sp.	Kumar and Srivastava, 1997b Srivastava, 2009
Bhandar Limestone	Sponge spicule like forms Filamentous forms			Kumar, 1999b
Salkhan Limestone	<i>Myxococcoides minor</i> <i>Myxococcoides grandis</i> <i>Sphaerophycus parvum</i> <i>Sphaerophycus medium</i>			McMenamin <i>et al.</i> , 1983 Kumar and Srivastava, 1995 Sharma, 2006

Huroniospora sp.
Huroniospora psilata
Palaeoanacystis vulgaris
Palaeoanacystis minor
Eosynechococcus moorei
 cf. *Palaeopleurocapsa* sp.
Eosynechococcus isolatus
Eosynechococcus grandis
Diplococcus sp.
Tetraphycus major
Tetraphycus congregatus
Tetraphycus hebeiensis
Conhemisphaera pendulua
Clonophycus elegans
Clonophycus ostiolum
Kheinjauasphaera vulgaris
Glenobotrydion aenigmatis
Melasmatosphaera media
Eoentophysalis belcherensis
Eoentophysalis magna
Gunflintia minuta
Eomycetopsis ?siberiensis
Coniunctiophycus gaoyuzhuangense
Coniunctiophycus majorinum
Archaeoellipsoides sp.
Bactrophycus oblongum
 cf. *Trachysphaeridium* sp.
Leiosphaeridia jacutica
Palaeolynbya sp.
Oscillatoriopsis brevicovexa
Oscillatoriopsis sp.
Oscillatoriopsis media
Oscillatoriopsis longa
Oscillatoriopsis grandis
Oscillatoriopsis constrictum
Siphonophycus kestron
Siphonophycus robustum
Siphonophycus septatum
 cf. *Eomicrocoleus crassus*

ticellular/thalloid macroalgae. The Rampur Formation (= Chorhat Sandstone = Glauconitic Sandstone) which has been dated as more than 1600 Ma old has yielded *Chuar* – *Tawuia* assemblage along with other carbonaceous remains of uncertain biological affinity (Srivastava and Bali, 2006). The Rohtasgarh Limestone (Formation) of the Semri Group which has also been dated as 1599 ± 48 Ma has yielded *Chuar* – *Tawuia* – *Grypania* assemblage. Discovery of Ediacaran fossil *Spriggina* by Kathal *et al.* (2000) from the Rohtasgarh Limestone has been evaluated by Kumar (2001) as nonfossil. Kumar (2001) has described nine carbonaceous fossils from the Suket Shale (Uppermost horizon of the Semri Group of Chambal Valley section, Rajasthan) viz., *Tawuia dalensis*, *T. indica*, *Chuar circularis*, *C. vindhyanensis*, *Suketia rampuraensis*, *Tilsoia khoripensis*, *Chambalia minor*, *Beltina danai* and Form A. He suggested that the *Chuar circularis*, *Tawuia* and *Tilsoia* are parts of a multicellular plant *Radhakrishnania* which perhaps belonged to Chlorophycean or Xanthophycean plant. Recently, Sharma *et al.* (2009) have proposed that various carbonaceous circular forms reported from the Vindhyan Supergroup are taxonomic variants of *Chuar*. In another publication, Sharma and Shukla (2009a) have demonstrated that the megascopic *Grypania* fossils are prokaryotic in nature.

Rai *et al.* (1997) have reported *Chuar* and *Tawuia* from the Jhiri Shale exposed in the Sohagi Ghat area, Madhya Pradesh exposed on Allahabad – Rewa

Road. Kumar and Srivastava (1997, 2003) have discovered carbonaceous megafossils *C. dulniensis*, *Chuar circularis*, *Tawuia dalensis*, *Chambalia minor*, *Bhanderia maiharensis*, cf. *Lanceoforma* sp. and cf. *Phascolites symmetricus* from the Bhander Group. They have also suggested a genetic relationship between *C. dulniensis*, *Chuar circularis*, and *Bhanderia maiharensis*. These fossils are reported from the shales belonging to the Bhander Limestone and Sirbu Shale exposed around Maihar Township, Satna district, Madhya Pradesh. *Chuar* is the most abundant form recorded both in the Bhander Limestone and Sirbu Shale but *Tawuia* is very rare, recorded only in the Bhander Limestone. They erected one new genus *Bhanderia* and three forms have been described informally as Form A, Form B and Form C. Srivastava (2002) has reported *Chuar* and *Tawuia* from the Dholpura Shale which represents the youngest horizon of the Bhander Group in the Chambal Valley, Rajasthan. Srivastava (2004) has reported the occurrence of *Chuar*, *Tawuia* and *Tilsoia* from the Panna Shale, the oldest horizon of the Rewa Group. De (2003) has reported fossil medusoid genera resembling *Ediacaria* (Sprigg, 1947) from the shale horizon occurring at the base of the Bhander Group but in our opinion, it has a very doubtful biogenic origin and can simply be referred to as a pseudofossil. Subsequently, De (2006a) has described nine coelenterate genera, one arthropod genus and a few unnamed new forms belonging to sponge and coelenterate. These also fall under the category of

pseudofossils as their morphology appears doubtful biogenically and can therefore be ignored. Thus, megafossils which can be confidently accepted as true fossils are the carbonaceous megafossils which have algal affinity. These fossils can be grouped under *Tawuia* – *Chuar* – *Grypania* assemblage. Thus, in the absence of any typical Cambrian fossils, the carbonaceous megafossils of the Vindhyan Supergroup point to the Precambrian age for the entire Vindhyan succession. Ultrastructure studies on *Chuar circularis* established algal origin of its wall structure (Dutta *et al.*, 2006; Sharma *et al.*, 2010).

Microbial Mats

Recently, well-preserved microbial mat structures and microbial mat-mediated structures have been recorded from the Vindhyan rocks. Kumar and Pandey (2008) have recorded well developed *Arumberia banksi*, *A. vindhyanensis* and *Rameshia rampurensis* from the Maihar Sandstone, the youngest horizon of the Vindhyan Supergroup in the Son Valley Section. Based on the presence of *Arumberia banksi*, they favoured Ediacaran age to the Maihar Sandstone (Shikao-da Sandstone). Algal mat-mediated structures were also noted in the Bundi Hill Sandstone of the Chambal Valley Section by Kumar and Pandey (2007a). Sarkar *et al.* (2006) have noted the macroscopic signatures of microbial mat related structures within the Rampur Formation (= Chorhat Sandstone) of the Semri Group. Sur *et al.* (2006) have discussed the possibility of the role of microbial mats at the

time of deposition of the Rampur Shale and the Bijaigarh Shale on the basis of petrographic observations.

Isotope Chemostratigraphy

In recent years, chemostratigraphy has quite successfully been used in correlation of strata in the absence of radiometric dates and reliable index fossils. Not much data are available on stable isotopes for the Vindhyan sediments. Pandey *et al.* (1970) were the first to analyse two samples of the Bhandar Limestone for carbon and oxygen isotopes. Krishnamurthy *et al.* (1986) provided carbon isotope ratio of the coaly matter from the basal part of the Proterozoic Vindhyan Supergroup. Kumar (1991) gave a detailed account of geochemistry of the upper part of the Bhandar Limestone of the Satna area, M.P. He gave $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values for the carbonates as 4.33‰ (PDB) and – 7.88‰ (PDB) respectively and suggested deposition in normal sea water with some enrichment in ^{13}C . The Precambrian/Cambrian boundary has been proposed by Friedman *et al.* (1996) and Friedman and Chakraborty (1997) within the Bhandar Group on the basis of carbon isotope values. Kumar (1999b), however, disagreed with their suggestion and remarked that no excursion in the carbon isotope values which can be compared with global excursion near Precambrian/Cambrian boundary, is seen in the data given by them. Kumar *et al.* (1998b) have analysed 21 samples of the Rohtasgarh Limestone of the Maihar–Chopan area (M. P. – U. P.) and argued that there is no perceptible

variation in $\delta^{13}\text{C}$ values and hence no Precambrian-Cambrian boundary is indicated on the basis of carbon isotope values.

Robust data on the carbon, oxygen and strontium isotopes were generated by Kumar B. *et al.* (2002, 2003). They analysed 98 carbonate samples belonging to both the Semri and Bhandar Groups covering both the eastern as well as the western parts of the Vindhyan Basin for $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values. It was argued that the sedimentation patterns in the Rajasthan and the Son Valley areas are totally different. They concluded that the Lower Vindhyan sediments were deposited during the Mesoproterozoic Eon and the Upper Vindhyan represented a Neoproterozoic interval of deposition. They have also contended that the Lakheri Limestone of Rajasthan can be termed the 'cap carbonate' as it overlies a glacial deposit. However, Kumar S. (2003) has questioned the validity of this conclusion and argued that there is no evidence that the Lakheri Limestone overlies a glacial deposit. Kumar, S. *et al.* (2005) have analysed 52 samples for $\delta^{13}\text{C}_{\text{org}}$ and 87 samples for $\delta^{13}\text{C}_{\text{carb}}$ from three regions of the Vindhyan Basin. These are the Chopan area, U. P., the Maihar area (M. P.) in the Son Valley Section and the Kota – Chittorgarh area, Rajasthan in the Chambal Valley Section. According to them, the mean value for $\delta^{13}\text{C}_{\text{org}}$ for the Semri Group is -29.0‰ (PDB) and for the Upper Vindhyan (Rewa and Bhandar Group) it is -26.8‰ (PDB). In the Semri Group, $\delta^{13}\text{C}_{\text{carb}}$ is around zero per mil with 2‰ variation and in the Bhandar Group of the Maihar and the Bundi areas there is a wide variation in the $\delta^{13}\text{C}_{\text{carb}}$

values. In the Maihar area, for the Bhandar Group it is bracketed between 2.6 and 4.4‰ and for Bundi, the variation is quite large and it ranges from -5.9 to 3.4‰ . The Lakheri Limestone of Rajasthan which is traditionally correlated with the Bhandar Limestone of the Maihar area shows $\delta^{13}\text{C}_{\text{carb}}$ mean value as -5.4‰ but the mean value for the Bhandar Limestone is 3.9‰ . On this basis they have suggested that the Lakheri Limestone should not be correlated with the Bhandar Limestone. They have suggested that isotopically the eastern part of the Vindhyan Basin differs considerably from the western part. They have also contended that there is no evidence to suggest that the Precambrian-Cambrian boundary exists within the Vindhyan Supergroup. Banerjee *et al.* (2005) analysed the Rohtas Limestone exposed in the Rampur area for stable isotope and concluded that $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values are compatible with early Mesoproterozoic open sea water composition.

Structure and Tectonic Framework

The Vindhyan Basin is developed on the northern margin of the peninsular shield and extends under the Gangetic alluvium. A large area underlies the Deccan traps of Cretaceous – Palaeocene age (69-62 Ma). It is semicircular in shape with Bundelkhand Granite (~ 2500 Ma) dividing it into two parts, the eastern part is exposed in the Son Valley area (Bihar–Uttar Pradesh–Madhya Pradesh) and the western part is developed in the Chambal Valley area (Madhya Pradesh–Rajasthan).

Chakraborty and Bhattacharyya (1996b) have summarised the status of the Vindhyan Basin on the basis of the available data up to 1995.

Generally, the Vindhyan Supergroup is considered as an undisturbed sequence of rocks. However, at a few places, the Lower Vindhyan sediments are noted to be severely folded (Auden, 1933; Crawford and Compston, 1970; Choubey, 1971b; Pandey, 1973; Sharma, 1979; Mishra, 2006) (Fig. 13). On the western and southern margins, the rocks of the Semri Group show evidence of deformation against the Aravalli-Delhi Mobile belt and Satpura Mobile belt (Choubey, 1968; Banerjee and Sinha, 1981; Sinha-Roy *et al.*, 1986). The Vindhyan rocks are down-warped into a gentle syncline with its axis running parallel to the arcuate thrust belt. The syncline plunges towards west resulting in easterly closure of the parabolic outcrop belt. Its southern margin is marked by the Son-Narmada lineament and north-western margin is marked by a lineament known as the Great Boundary Fault separating it from the Aravalli Supergroup. Deep Seismic Sounding (DSS) profiles have revealed the existence of several deep fractures underlying the Vindhyan and the Mahakoshals (Bijawars). The fractures are interpreted to have formed during the Archaean and vertical movements have been inferred at different periods during the deposition of the Vindhyan. The horst and graben tectonics played a major role in the development of the basin which resulted in the creation of sub-basins in which the Vindhyan sediments were deposited (Narain and Kaila, 1982; Mishra, 2011).

The maximum thickness estimated for the Vindhyan sediments under the Gangetic alluvium is ~ 4.5 km. Prasad and Rao (2006), on the basis of deep seismic reflection profiling, have suggested that there is a basement ridge which separates the Son Valley Vindhyan from the Chambal Valley Vindhyan.

Chakraborty and Bhattacharyya (1996a) have discussed the validity of three models for the evolution of the Vindhyan Basin. These are: (i) continental interior basin, (ii) intra-continental rift basin and (iii) peripheral foreland basin. According to them, the Vindhyan Basin could be a peripheral foreland basin. However, Ram *et al.* (1996) have inferred that the Vindhyan Basin initiated as intra/pericratonic rift (half graben) with well-defined pre-, syn-, post-rift phases of development in contrast to simple interior basin concept. According to them, a post-compressive event led to intense deformation, forming most of the observed structures such as folds, arches and structural inversions.

There are two impact structures associated with the Vindhyan Supergroup that have modified the sedimentary rocks in the vicinity. The famous Dhala structure in the Madhya Pradesh, central India is considered as an eroded large Palaeoproterozoic impact structure that is overlain by the post-impact sediments of the Vindhyan Supergroup (Pati *et al.*, 2008). Another impact structure known as the Ramgarh structure is recorded within the Vindhyan Supergroup sediments in Rajasthan. It is 4 km in diameter and 250 meters high rim in the Baran district of Rajasthan. It is considered to be of im-



Fig. 13-Folded Rohtasgarh Limestone, the Semri Group, Murli Pahar area, Rohtas District Bihar.

pact origin (Sisodia *et al.*, 2006) and rocks cropping out in the crator belong to the Bhandar Group. Bose *et al.* (2001) suggested that in spite of its origin in stable intracratonic basin, the Vindhyan Supergroup incorporates tectonic-driven depositional cycles of various orders. Recently Mishra (2011) suggested that the Lower Vindhyan rocks were deposited on the rifted platform of Bundelkhand Craton, whereas the Upper Vindhyan rocks were deposited as a foreland basin during the convergence. On the basis of trace element and Nd isotope studies, Chakrabarti *et al.* (2007) suggested that the boundaries between the Semri and Kaimur Groups as well as the Rewa-Bhandar Groups are characterised by abrupt changes in Nd isotopic composition indi-

cating multiple changes in the provenance of the Vindhyan sediments. It also indicates that the basin was tectonically active during the entire span of the depositional period.

Gupta *et al.* (2003) suggested that the Semri Group sedimentation experienced pulsating tectonism resulting in recurrent sea level fluctuation. Andesite dykes intruding the basal lithounits are exposed in Pataudh area. Basic intrusives in the Kajrahat Limestone and overlying porcellanite indicate tectonism/syn depositional tectonism in the basin. Synsedimentary seismic signatures have been recorded in the Koldaha Shale of the Semri Group (Sarkar *et al.*, 1995; Bose *et al.*, 1997). Sarkar *et al.* (2011) recorded palaeotsunami from the Upper Bhandar Sandstone in Central India.

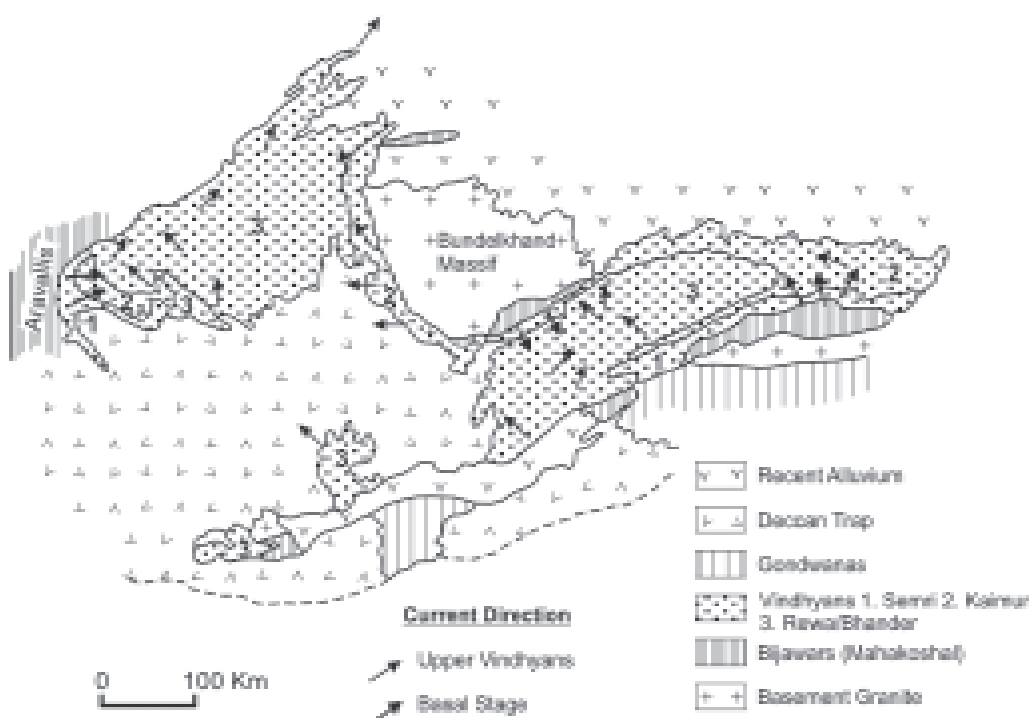


Fig. 14-Map showing dominant directions of the palaeocurrent and sediment dispersal across the Vindhyan Basin (After Raza and Casshyap, 1996).

Palaeocurrent Analysis

According to Akhtar (1996), the Vindhyan Basin is characterised by the dominance of unimodal westerly to north-westerly directed palaeocurrent pattern which is seen all over the basin and also persists through time (see also Fig. 14). For the Kaimur Sandstone in the Chitrakut area which constitutes the northern part of the Vindhyan Basin the dominant current direction is northwesterly (Kumar and Singh, 1978). The uniformity of palaeocurrent direction was variously attributed to stable tectonics and persistence of palaeoslope (Banerjee and Sengupta, 1963) or an omnipresent northwesterly wind drift current that reinforced tidal and

/oceanic currents (Chanda and Bhattacharyya, 1982). The westerly palaeocurrent was recognized as a longshore current in the shallow marine deposits of the Bhandar and Rewa basins which have E-W shore line and northerly slope. It is further stated that in the case of shallow marine deposits it is difficult to assume westerly palaeoslope. Further, the fluvial units also show westerly slope during the emergent stages. Chakraborty and Chaudhari (1990) suggested that contemporaneous tectonism brought about a change in the palaeoslope direction from the north during the early Rewa marine sedimentation phase (Fig. 15). It appears that change in the palaeoslope occurred repeatedly during the Vindhyan sedimentation. Akhtar

(1996) has opined that the dominant westerly to northwesterly palaeocurrent direction is enigmatic. Singh (1985) has also opined that in the eastern and central part of the Vindhyan Basin, northwesterly directed waves and westerly directed waves (corresponding to ebb current) were present during the deposition of the Kaimur sediments. At the same time, the Rewa Sandstone and the Shikaoda Sandstone (Maihar Sandstone) also exhibit a dominant northwesterly palaeocurrent direction. This suggests that the palaeogeographic setting, including palaeowind and palaeocurrent directions, was constant throughout the sedimentation in the Vindhyan Basin.

Environment of Deposition

Banerjee (1974) proposed a barrier coastline model for the sedimentation of the Vindhyan sediments and assigned tidal flat, lagoon and barrier coastline, beach dune environments to different lithounits. Safaya (1975a) analysed the Semri Group of rocks of the Banda area and proposed that various units laterally juxtaposed the environmental belts. However, Singh (1976, 1985) suggested that the environment of deposition of the Vindhyan sediments fluctuated between tidal flat, lagoon and shoal complex and the succession formed mainly due to syn-sedimentary sinking of the basin and lateral shifting of the shallow marine environments. He also

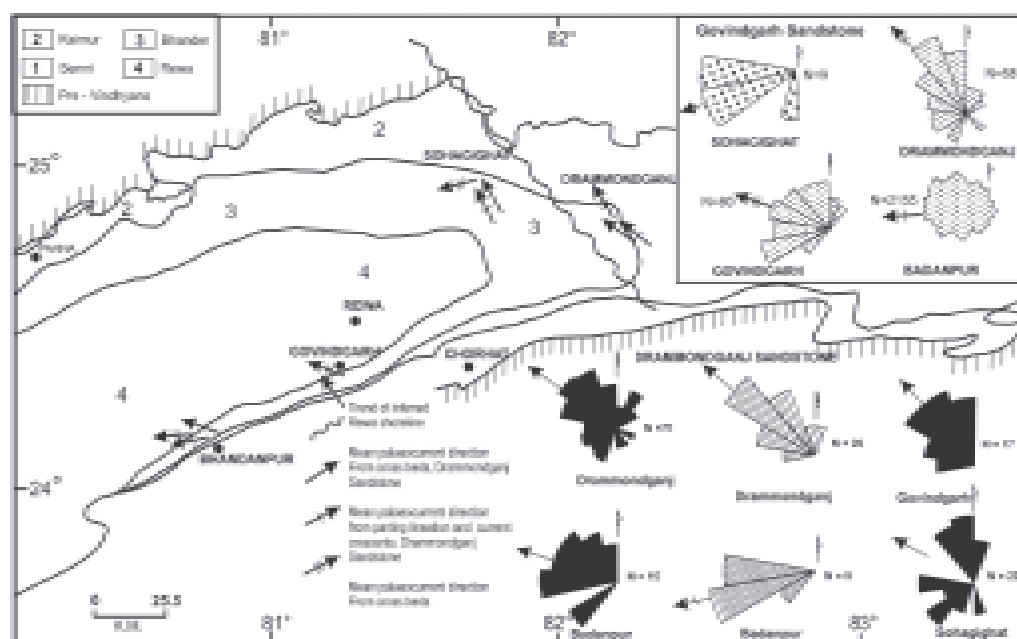


Fig. 15 – Map showing current flow direction in the Son Valley Basin during Rewa sedimentation and inferred trend of shoreline of the marine basin. Rose diagrams are constructed following the method of Chenney (1983). Stippled Roses are for the Govindgarh Sandstone, striped ones for parting lineation and current crescent data and dark ones for cross-bed data from the Drammondganj Sandstone (after Chakraborty and Chaudhari, 1990).

emphasized that there are no progradational offshore-coastal sequences. The Vindhyan sediments are the product of deposition in a shallow littoral embayment, roughly following the distribution of the present-day Vindhyan outcrops. The eastern limit of the embayment was not far from Son Valley, while the open sea may have existed in the west. The environment of deposition of the different stratigraphic horizons in the Rajasthan area has been summarized in Tables-10 & 11. Banerjee and Jeevankumar (2007) presented facies analysis of the Rohtas Limestone exposed in the eastern part of the Son Valley and concluded that it is bounded by a con-

densed zone below and unconformity above, and overall it is a prograding and High Stand System Tract (HST). Detailed analysis of the upper part of the Sirbu Shale of the Bhandar Group by Sarkar *et al.* (2002b) revealed that it was deposited in a storm dominated shelf and lagoonal palaeoenvironment and evolved as a High Stand System Tract on a storm-dominated siliciclastic shelf. There are a few poorly argued and inconclusive reports of glaciation during the deposition of the Vindhyan Supergroup (Dubey and Chaudhary, 1952; Ahmad, 1955a, b; Lakshmanan, 1969; Williams and Schmidt, 1996).

Table 10-Lithostratigraphy of the Vindhyan Supergroup in the eastern part of the basin (after Sastry and Moitra, 1984 in Akhtar, 1996) and depositional environment (after Akhtar, 1996).

Group	Formation	Depositional Environment	
		Singh, 1973	Banerjee, 1974
Bhander Group	Shikaoda Sandstone	Tidal Flat-Shoal Complex	Tidal Flat
	Sirbu Shale	Lagoon	Tidal Flat (Supratidal)
	Bundi Hill Sandstone	-----	Tidal Flat
	Lakheri Limestone	Carbonate Tidal Flat	Carbonate Tidal Flat
	Ganurgarh Shale	-----	Lagoon and Tidal Flat
Rewa Group	Govindgarh Sandstone	Shoal –Beach Complex	Barrier Beach Dune
	Jhiri Shale	Lagoon	Lagoon
	Asan Sandstone	-----	-----
	Panna Shale	Lagoon	Lagoon
Kaimur Group	Dhandraul Sandstone	Shoal Complex	Barrier Beach Dune wash over flat(?)
	Mangesar Formation	Shoal Complex	Barrier Beach Dune wash over flat(?)
	Bijaigarh Shale	Lagoon/Lagoonal Beach	Lagoon
	Ghaghar Sandstone	Tidal Flat (Subtidal to Intertidal)	Barrier Bar to Tidal Flat
	Susnai Breccia		
	Sasaram Formation		
	Bhagwar Shale	Carbonate Lagoon	-----
	Rohtasgarh Limestone	Carbonate Tidal Flat (Subtidal to Intertidal)	Lagoon
	Rampur Formation	Tidal Flat (Intertidal)	Longshore Bar(?)

Table 11-Stratigraphic sequence and depositional environment of the Upper Vindhyan in southeastern Rajasthan (western part of the Vindhyan Basin) (after Akhtar, 1996).

Group	Formation	Depositional environment	
		Mandalgarh-Singoli Area	Kota-Rawatbhata Area
		(Akhtar, 1973, 1975, 1976; Akhtar and Srivastava, 1976)	(Bhardwaj, 1970, 1973, 1977)
BHANDER GROUP	Shikaoda Sandstone	Upper Part: tidal channels and inlets Middle Part: beaches and bars Lower Part: low tidal flat	Fluvial
	Sirbu Shale	Upper Part: mid intertidal flat Middle Part: high intertidal flat Lower Part: supratidal and high intertidal flat	Supratidal flat
	Lakheri Limestone	Upper Part: subtidal lagoon Middle Part: low supratidal to high intertidal flat Lower Part: high supratidal to low supratidal flat	Upper Part: Broad submerged shelf of low relief Lower Part: Supratidal flat
	Ganurgarh Shale	Upper Part: supratidal flat Lower Part: high intertidal flat	Upper Part: Intertidal or supratidal Lower Part: Low intertidal flat
	Govindgarh Sandstone	-----	Upper Part: Delta fringe (Wave zone) Lower Part: Upper Prodelta (transition Zone)
REWA GROUP	Jhiri Shale	-----	Upper Part: Prodelta (below wave zone) Lower Part: distal prodelta (below wave zone)
KAIMUR GROUP	Dhandraul Sandstone	-----	Beach and sandy intertidal flat

Traverses

Description of sections

The field work can be subdivided under the following sections:

- A. Chitrakut–Sajjanpur–Satna Section
- B. Rewa–Drummondganj Section
- C. Rewa–Govindgarh–Chorhat–Koldaha Section
- D. Maihar–Badanpur–Dhanwahi–Chhoti Mahanadi Section
- E. Maihar–Nagod–Panna–Majhgawan–Khajuraho Section
- F. Varanasi–Robertsganj–Markundi–Dala–Renukoot Section.

A. Chitrakut–Sajjanpur–Satna Section

(Chitrakut, also known as Chitrakoot, is a religious place and the Kamadgiri and Hanuman Dhara hillocks are considered sacred. The township is partly in U. P. and partly in M. P. It is believed that Lord Rama stayed here during exile from Ayodhya. To honour the sentiments and religious feelings of the local people, any damage to stones and collection of the samples by application of hammer or undertaking geological studies should be avoided.)

This section can be covered preferably from Chitrakut (Uttar Pradesh–Madhya Pradesh) or Satna (M. P.).

A brief description of the different stratigraphic horizons (see Table-12 and 13) is given below:

Bundelkhand Granite-Gneiss Complex—The Bundelkhand granite-gneiss complex (BGGC) forms the north-

ern part of Precambrian Central Indian shield, occurring as a semi-circular outcrop. It is represented by pink, coarse, medium and fine grained granites which are intruded by pegmatitic veins (Jhingran, 1958). At a few places, these are also intruded by dolerite dykes. It is overlain in the south and southeast by the Bijawar Group (Mahakoshal Group) of sedimentary rocks and associated volcanics, to-

Table 12-Lithostratigraphic successions exposed around the Chitrakut area, M. P. and U. P.

		After Singh and Pal (1970)	After Auden (1933)
Kaimur Series (Group)		Sandstone, sandy shales and grit	Quartzite and sandstone
-----Unconformity-----			
		Tirohan Limestone Member	Tirohan Limestone
		Muradpur Member	Pellet Limestone
Semri Series (Group)	Chitrakut Formation	Glaucconitic Sandstone Member	Glaucconitic Sandstone
		Kamtanath Member	Pellet Limestone
			Limestone with glauconite
-----Unconformity-----			
		Granite with xenoliths of amphibolites	

wards northwest by the Gwalior Group of rocks and towards southeast, south, southwest and west by the sedimentary rocks of the Vindhyan Supergroup (Auden, 1933). The northern margin of the complex is covered by the Gangetic alluvium. The BGGC is truncated towards south by the Son-Narmada Lineament and towards west by the Great Boundary Fault. The Archaean-Palaeoproterozoic BGGC comprises mainly of three types of lithological assemblages: (1) Highly deformed Archaean greenstone-gneiss assemblage with relicts of older supracrustals in association with ultramafic rocks, amphibolites, fuchsite quartzite, Banded Iron Formation, schist, marble and calc-silicate rocks (3.3 Ga to 2.5 Ga); (2) Large bodies of massive/deformed granitoids (2.5 Ga) intruding the pre-existing greenstone

gneiss assemblage and (3) Mafic dyke swarms (2.0 Ga). The older supracrustals and enclaves occur in the form of WNW-ESE to E-W trending linear fold blocks and are linear to irregular lensoidal bodies of considerable length and aerial extent with magnetite bearing quartzite as a common feature and Banded Iron Formation (BIF) of sedimentary parentage. These supracrustal rocks are exposed along E-W trending crustal-scale brittle ductile shear zone, known as Bundelkhand Tectonic Zone (BTZ). The granitoids emplacement in BGGC was followed by extensive fracturing, trending generally ENE-WSW and NE-SW accompanied by shearing and sinistral displacement of earlier elements, which led to generation of extensive mono-mineralic quartz reefs, fine-grained granite (porphyry) and felsite

Table 13-Lithostratigraphic succession in the Chitrakut area as followed in the field-guide book.

along these pre-existing tensional fractures. The mafic dykes emplacement within the Bundelkhand Granitic massif marks the end of intrusive phase, predominantly along the NW-SE, NNW-SSE directions along the pre-existing fractures. Geomorphologically, the area is generally undulatory with inselberg and piedmont with long serrated prominent ridges. Mafic dykes form smooth and linear mounds. The intersection zones of mafic dykes with quartz reefs are demarcated by geomorphic depression, whereas the meeting of two quartz reefs form the high ridges. Three generations of gneisses (3.3 Ga, 2.7 Ga and 2.5 Ga) have been reported from different parts of the complex around Mahoba, Kabrai, Kuraicha, Babina, Karera and Panchwara. Older (3.3 Ga and 2.7 Ga) gneisses are of tonalite, trondhjemite and granodiorite (TTG) composition, where-

nants of which are present with present day diameter of 11 Km at Dhala in the Shivpuri district of Madhya Pradesh. However, many workers consider it as a volcanic crater.

The lithostratigraphy of the Bundelkhand craton (Table-14) is given below:

The Chitrakut area (Uttar Pradesh and Madhya Pradesh) constitutes a part of the northern limb of the Vindhyan Syncline. Auden (1933) gave the stratigraphy of the area and identified only three stratigraphic levels, viz. the Bundelkhand Granite, the Semri Group and the Kaimur Group. The Semri Group in this area has been designated as the Chitrakut Formation by Singh and Pal (1970). Singh and Kumar (1978) have suggested that the Semri Group in this area represents a condensed sequence. The thickness of the Semri Group varies from 10 m to about 80 m. The thickness increases only where the thickness of the Tirohan Limestone increases. The Tirohan Limestone attains a maximum thickness of ~100 m (Narain, 1975; Safaya, 1975a). The Semri Group shows an excellent contact with the underlying Bundelkhand granites. The Vindhyan succes-

Stratigraphic Horizon	Age and method	Reference
Vindhyan Supergroup	calc-alkaline nature. The granitoids are (1.8 Ga, Rb-Sr)	Crawford, 1970
Gwalior mafic dykes and sills	calc-alkaline in composition and were emplaced at ~2.5 Ga. According to Pati <i>et al.</i> , 2008, the Bundelkhand Craton experienced large impact structures between ~2.5 Ga and >1.7 Ga age. Eroded rem-	Mondal <i>et al.</i> , 2002
Gwalior Group	(2.5 Ga by $^{207}\text{Pb}/^{206}\text{Pb}$)	Mondal <i>et al.</i> , 2002
Bijawar Group	(2.5 Ga by $^{207}\text{Pb}/^{206}\text{Pb}$)	Mondal <i>et al.</i> , 2002
Mafic Dyke Swarms	(2.5 Ga by $^{207}\text{Pb}/^{206}\text{Pb}$)	Mondal <i>et al.</i> , 2002
Quartz Veins	(2.5 Ga by $^{207}\text{Pb}/^{206}\text{Pb}$)	Mondal <i>et al.</i> , 2002
Granitoids	(2.5 Ga by $^{207}\text{Pb}/^{206}\text{Pb}$)	Mondal <i>et al.</i> , 2002
Gneisses	(3.3 Ga, 2.7 Ga and 2.5 Ga by $^{207}\text{Pb}/^{206}\text{Pb}$)	Mondal <i>et al.</i> , 2002
Table 14-Lithostratigraphy of the Bundelkhand Craton.		
Metasediments (quartzite, marble), Banded Iron Formation, tremolite-actinolite and biotite schists, amphibolite, ultramafics and metabasalts.		

sion is seen overlying the weathered surface of the granite, and pebbles & cobbles of granite can be seen within the overlying sediments (Fig. 16). The Chitrakut Formation has been subdivided into four members by Singh and Pal (1970) and the youngest is the Tirohan Limestone Member (Table-12). The lithology of the Chitrakut Formation is represented by pellet limestone, micritic limestone, glauconitic sandstone, siltstone and shale. The Tirohan Limestone is represented by dominantly micritic dolostone and limestone. In the Janaki-Kund area, the Tirohan Limestone also shows development of columnar stromatolites that are phosphatic (Kumar, 1977b). Stromatolites have also been reported from the Lodhwara hill, north-north-east of Chitrakut Township. Kumar (1976b) has described *Kussiella kussiensis* and *Colonnella* spp. and compared the stromatolite-bearing horizon with the Kajrahat Limestone of the Son Valley Section.

Singh and Kumar (1978) have observed that the lithological successions in the various hills are different and the stratigraphic units suggested by Singh and Pal (1970) cannot be traced in the different hills as such the stratigraphy suggested by them has no regional validity. The Chitrakut Formation has been subdivided into different informal units (Table -12).

Chitrakut Formation - Singh and Pal (1970) have designated the rocks underlying the Kaimur Sandstone as the Chitrakut Formation belonging to the Semri Group. At the Sangrampur hillock, possibly a complete succession of the Semri Group and its contact with the underlying Bundelkhand granites and the overlying Kaimur Sandstone can be seen. However, in the present work the rocks of the Semri Group in the Chitrakut area have been subdivided into the Chitrakut Formation and the Tirohan Limestone. The Tirohan Limestone Member of Singh and



Fig. 16-The contact of the Bundelkhand Granite and the Pellet Limestone of the Chitrakut Formation, the Semri Group, Chitrakut area, Chitrakut District, Uttar Pradesh.

Pal (1970) has been given the rank of a formation.

The dominant lithologies of the Chitrakut Formation are as follows:

Pellet Limestone - It is a characteristic lithology of the Chitrakut Formation but is seen at different stratigraphic positions in different hillocks of the Chitrakut area. It is represented by 5 to 7 m thick unit made up of pellets seen in a micritic matrix.

Glaucinitic Sandstone - It is also an important lithology of the Chitrakut Formation and attains a thickness of ~ 13 m. Abundant presence of glauconite is well seen in the sandstones which gives greenish colour to the rock. Small-scale cross bedding, wavy and current ripples, mud cracks and ripple bedding are well developed.

Conglomerate - It is developed at the base of the Chitrakut Formation in which pebbles, cobbles of granites are seen cemented together by micritic limestone.

Micritic Limestone - It is seen at different stratigraphic positions at different hillocks. It is grey to light ash grey.

Stromatolitic Limestone - It is seen only at Lodhwara hill where it attains maximum thickness of 2.5 m. Kumar (1993) has described two stromatolite forms from this horizon.

Tirohan Limestone

The dominant lithologies of the Tirohan Limestone are:

Micritic Limestone - The Tirohan Limestone is characterised by micritic limestone.

Stromatolitic Limestone - Stromatolitic Limestone is developed only in the Janaki Kund area in the valley section of the Paisuini River where the columnar stromatolites dominated by *Colonnella columnaris* are exposed (Fig. 17). Some of the stromatolites are phosphatic in nature (Kumar, 1993).

An unconformable contact of the Semri Group can be seen with the underlying Bundelkhand Granite at a number of hillocks around Chitrakut Township. In the Pasuini River Section at Janaki Kund, the Tirohan Limestone is exposed which shows development of stromatolites. Outer margins of the stromatolites as well as stromatolite laminae are phosphatic. Phosphatic clasts are also seen as infilling material between the stromatolite columns.

About 15 km SW of Chitrakut Township, underlying the Kaimur Sandstone, a thick succession of the Tirohan Limestone (=Rohtasgarh Limestone) is well exposed near Gupt Godavari, which is the point of emergence of the river. This place is famous for cavernous limestone geomorphological setting. The Tirohan Limestone thins out towards north and perhaps becomes a part of a condensed succession represented by the Chitrakut Formation of Singh and Pal (1970) belonging to the Semri Group developed around Chitrakut Township. However, Singh and Kumar (1978) have doubted the regional validity of the lithostratigraphy given by Singh and Pal (1970) as these members cannot be traced in different hillocks. It shows un-

conformable contact with the underlying Bundelkhand Granite (~2,400 Ma) and can be seen in a number of hillocks like Bihara, Sangrampur, Muradpur and Lodh-wara hills.

The rocks of the Rewa Group are poorly developed between Chitrakut and Satna and much of the area up to Satna is occupied by the Kaimur Sandstone.

From about 6 km before Satna township, the exposures of the Bhandar Limestone can be seen in the low-lying areas. The Satna township is situated on the Sirbu Shale whose exposures can be seen in the Satna River valley. In the mines of the Satna Cement Factory, a good section of the Bhandar Limestone can be studied.

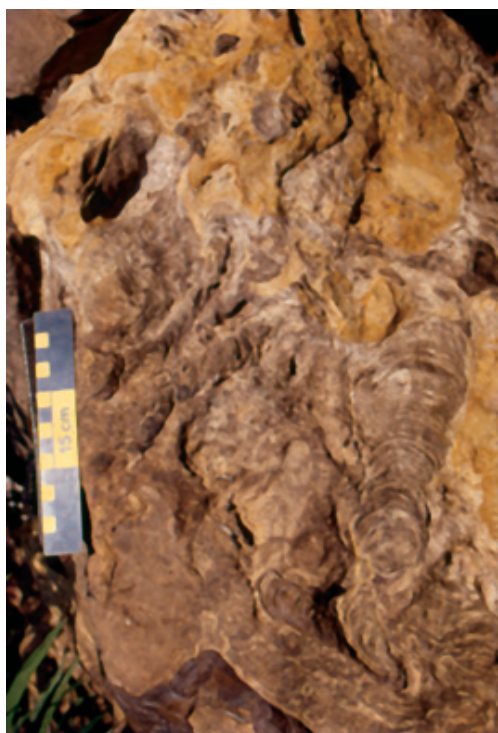


Fig. 17-Stromatolite *Colonnella columnaris* in the Tirohan Limestone of the Semri Group exposed in the Janki Kund area of Chitrakut, Satna District, Madhya Pradesh.

Anbarasu (2001b) has studied the Chitrakut Formation in detail and divided it into seven members (Fig. 18, 19). Singh and Pal (1970) have correlated the Semri sediments with Koldaha Shale/Rampur Formation of the Son Valley Section, while Singh and Kumar (1978) considered that the entire succession of the Son Valley is represented by these sediments. They have considered that during a long interval of time only a thin sediment veneer accumulated forming an extreme case of condensed deposits. These sediments are characterized by rich occurrence of glauconite. These are the deposits of shallow tidal sea. Kumar *et al.* (2001) have dated the glauconites of these sediments by Rb-Sr method and contended that the onset of earliest Vindhyan sedimentation should not later be than 1600 Ma.

Kumar and Srivastava (1991a) and Anbarasu (2001a) have reported micro-biota from the chert veins associated with the micritic limestone at the base of Chitrakut Formation. Earlier, Kumar (1993) also reported the occurrence of intraclast associated with the phosphatic stromatolites of the Tirohan Limestone showing microstructure comparable to filamentous cyanobacteria. Report of calcareous algae of the earliest Cambrian age from the Tirohan Limestone by Joshi *et al.* (2006) and Azmi *et al.* (2007) could not be confirmed by Bengtson *et al.* (2009) who demonstrated that the published assignment to Cambrian taxa of skeletal fossils are disputable. They confirmed a Palaeoproterozoic age for the Tirohan Limestone.

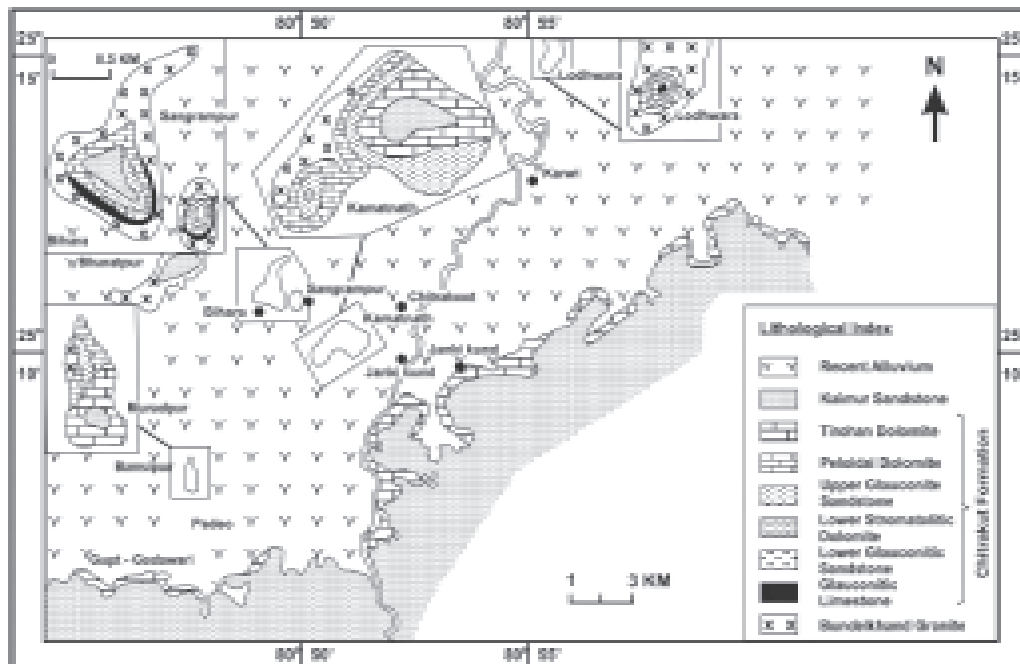


Fig. 18-Geological map of the Chitrakut Formation (after Singh and Pal, 1970; Anbarasu, 2001b).

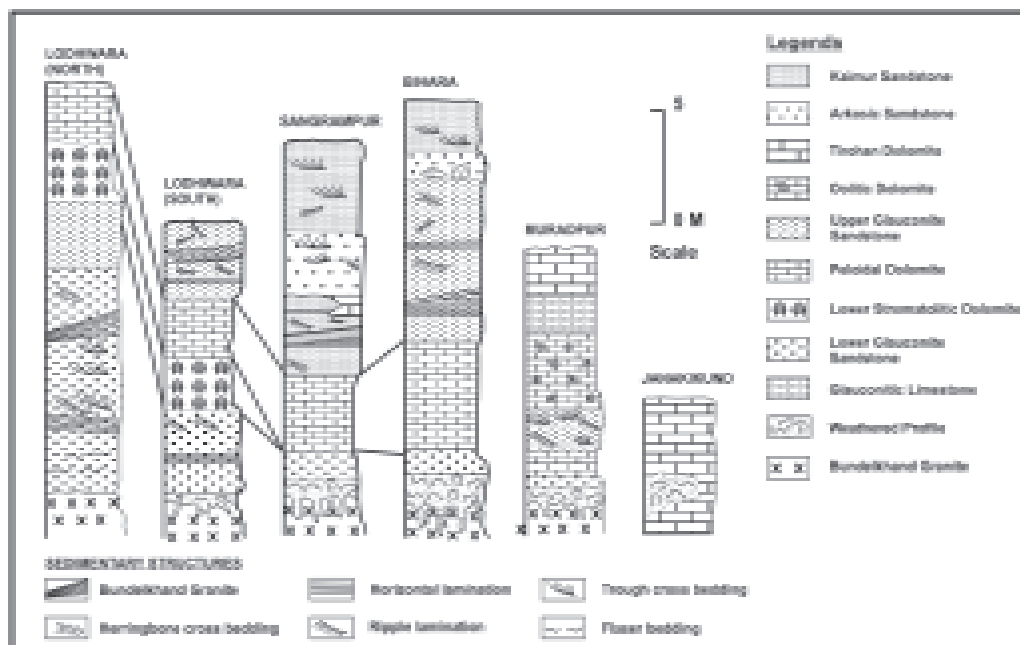


Fig. 19-Stratigraphic columns showing correlation among lithologies of the Chitrakut Formation (Anbarasu, 2001b).

B. Rewa–Drummondganj Section

This section can be covered either from Rewa (Madhya Pradesh) or from Robertsganj (Uttar Pradesh) via Drummondganj on National Highway 7.

Robertsganj is situated on the rocks of the Kaimur Group. Northward, the area between Robertsganj and Mirzapur is covered by thick soil and lateritic cover. Around Mirzapur, the Dhandraul Sandstone (Dhandraul Quartzite) is well exposed. The general trend of the rocks is ENE-WSW with low to moderate dips towards north or south. Near Ghorawal, one crosses over the core of the Vindhyan Syncline. The area between Lalpur to Drummondganj through Baraundha is again occupied by the Dhandraul Sandstone showing southerly dip. Close to about 2.0 km north of Drummondganj, the rocks of the Rewa Group are seen overlying the Dhandraul Sandstone. The contact is concealed under the soil.

If one covers this section from Rewa, one can see the exposures of the Bhandar Group. Only two horizons, viz. the Ganurgarh Shale and the Bhandar Limestone can be seen in the river valley and in a few hillocks, especially near Ramnai, north of Rewa city. Drummondganj is basically a Ghat Section. South of Drummondganj at the base are exposed the Panna Shale. It comprises reddish brown, purple and khaki coloured, thinly laminated and evenly bedded shale with intercalations of thin siltstone. A few bands also show presence of salt pseudomorphs. This horizon is about 100–150 m thick. *Chuaria circu-*

laris can be collected from the soft thinly laminated shales. The Panna Shale is overlain by 8–10 m thick greenish grey glauconitic sandstone with lenticular bedding and thin shale and siltstone partings, exhibiting profuse development of ripple marks, mud-cracks, load casts, etc. Thin bands of gritty and granular pebbly conglomerate comprising granules of red jasper, vein quartz are present. These are considered the equivalent of the Asan Sandstone (Lower Rewa Sandstone) of the Panna area. The overlying Jhiri Shale is represented by khaki and yellowish brown shales with thin lenticular fine sandstone interbeds exhibiting flaser bedding. Siltstone and fine sandstone interbeds exhibit flute casts, ripple marks, mud cracks, current lineations as most common sedimentary structures. The khaki shales are followed upwards by a thick sequence of purple shales with 5–10 cm thick siltstone interbeds. A few bands of glauconite bearing sandstone are present. Thickness of the Jhiri Shale is estimated from 90 to 100 m. *Chuaria circularis* and *Tawuia dalensis* have been recorded from these shales.

The Jhiri Shale is overlain by the massive current bedded sandstone belonging to the Govindgarh Sandstone (Upper Rewa Sandstone). It comprises reddish brown, purple to whitish grey, massive, thickly bedded and current-bedded sandstone. The thickness of this horizon is about 100–125 m. The contact between the Govindgarh Sandstone (Upper Rewa Sandstone) and the overlying Ganurgarh

Shale is generally not exposed. In the quarries at Ramnai hill near Rewa on Rewa–Varanasi motor road where more than 8 meters of the Ganurgarh Shale is well exposed, the gradational contact of the Ganurgarh Shale with the overlying Bhandar Limestone can be observed (Fig. 20). The Ganurgarh Shale is represented by red-

dish shales with light coloured calcareous shales and siltstones. Thin bands showing salt pseudomorph can be seen. Presence of gypsum is also recorded. The upper reaches of the hillock at Ramnai are occupied by the Bhandar Limestone. *Baicalia baicalica* is well developed in these limestones as biostromes.



Fig. 20-White line marks the contact of the Ganurgarh and the Bhandar Limestone exposed in Ramnai quarry, Rewa District, Madhya Pradesh.

C. Rewa–Govindgarh–Chorhat–Koldaha Section

This section can be covered from Rewa (Madhya Pradesh) along the Govindgarh-Sidhi Road.

From Rewa up to Govindgarh, the area is generally covered by thick soil. Close to south of Govindgarh near the Ghat Section, the Govindgarh Sandstone (Upper Rewa Sandstone) is exposed as a

linear ENE-WSW trending ridge, sloping northwards. From the ridge up to the base towards Sidhi, the rock successions are undifferentiated and different formations of the Rewa and Kaimur Groups are not demarcated. Near the base of the ridge, the exposures of the Bhagwar Shale and further south the Rohtasgarh Limestone can

be seen. A good section of the Rohtasgarh Limestone is now well exposed in the newly opened mines of the Jaypee Cement Factory. Further south up to the Chorhat Township, the area is occupied by the Rampur Formation (=Chorhat Sandstone/Glauconitic Sandstone). From this section, Seilacher *et al.* (1998) reported the trace fossils of triploblastic animals. However, majority of the workers have disagreed with their identification. The Koldaha Shale (=Olive Shale) can be seen between the Chorhat Township and the Son Valley. The Deonar Formation (Porcellanite) is well exposed in the Son River Valley.

A brief description of the different litho-units is given below:

Semri Group: The rocks of the Semri Group are exposed at the base of the escarpment and extend further south.

Deoland Sandstone: This is the basal unit of the Vindhyan Supergroup which has an unconformable contact with the basement granitoids. It comprises of sandstone, pebbly sandstone and conglomerate set in a fine sandy to gritty matrix. It is light pink and brownish white in colour, hard and compact. Cross bedding and imbrications are profusely developed.

Kanwari Shale: The Kanwari Shale overlies the Deoland Sandstone and comprises greenish white, brown flinty shales with interbeds of greenish white and dirty green limestone. It is overlain by the Deonar Porcellanite.

Deonar Porcellanite: The Deonar Porcellanite is considered as the equivalent of the Porcellanite Formation of the

Chopan area (U.P). It comprises of compact silicified porcellanites, porcellanitic shales with flinty fracture patterns. Inter-calations of feldspathic sandstone and coarse-grained gritty sandstone are common. The porcellanites are dark grey, black, ash grey, khaki green to olive green in colour. The sedimentary structures such as small-scale cross lamination, slump structures, clay-gals and liesegang rings are common.

Koldaha Shale: It is sandwiched between the Deonar Porcellanite and the Rampur Formation (=Chorhat Sandstone). It comprises purple, olive green, khaki green and ash grey, paper-thin finely laminated shale. The shales have splintery appearance. Inter-beds of light pink, dirty yellow siltstone and fine sandstone are present. Sedimentary structures include ripple marks, cross lamination, desiccation cracks and clay-gals.

Rampur Formation (=Chorhat Sandstone): The Rampur Formation comprises a rhythmic assemblage of sandstone and shale. It is light pink, dirty white, purple in colour. It is a fine- to medium-grained, occasionally gritty sandstone. Glauconite content is also recorded. Ripple lamination, flaser and lenticular bedding, wavy bedding, wave and current ripples, rib and furrow structure, wrinkle marks, flute casts, bounce marks, clay gals and desiccation marks are profusely recorded. From this horizon, Seilacher *et al.* (1998) have recorded the supposed trace fossils of triploblastic animals. However, the majority of the workers have rejected the identification of the trace fossils.

Rampur Shale: The Rampur Shale conformably overlies the Rampur Formation and comprises black paper-thin shale, porcellanitic shales with thin intercalations of dirty yellow limestone.

Rohtasgarh Limestone: The Rampur Shale shows an upward gradational contact with the overlying Rohtasgarh Limestone. It comprises argillaceous limestone in the lower part and a dolomitic limestone in its upper part. The argillaceous limestone is dirty yellow, ash grey, occasionally light pink. The dolomitic limestone is light grey, greenish grey, dirty white, thinly to thickly bedded, massive and compact. Sedimentary structures such as intra-formational conglomerate, ripple marks, cross bedding, desiccation cracks and algal laminites are seen. A southwesterly palaeocurrent direction has been recorded.

Bhagwar Shale: This horizon conformably overlies the Rohtasgarh Limestone and comprises a lower porcellanite member and upper mainly light grey and greenish grey micaceous splintery shale and siltstone. Sedimentary structures such as small-scale cross bedding, ripple marks, wrinkle marks, flute casts, load casts, clay galls and desiccation cracks are present.

Kaimur Group: The contact between the Semri Group and the Kaimur Group is largely covered by scree. However, close to the Ghat section, south of Govindgarh a distinct conformable contact has been recorded. In this section, the Kaimur Group is represented by a single sandstone horizon.

Dhandraul Sandstone: It is a light pink, dirty white and brownish sandstone. The contact with the underlying Bhagwar Shale is gradational. It comprises thickly bedded, massive and lenticular sandstone exhibiting current bedding in profusion. Large scale planar and tabular cross bedding indicates WNW to NW palaeocurrent direction.

Rewa Group: The contact between the Kaimur and the Rewa Groups is conformable and is represented by two formations in this part of the Vindhyan Basin, viz. the Jhiri Shale and the Govindgarh Sandstone with thin inter-beds of siltstone.

Jhiri Shale: It is represented by purple, khaki, olive green greyish black and blackish green splintery shale intercalated with greenish grey sandstone beds varying in thickness from a few tens of centimeters to about 1 meter. An impersistent thin conglomerate horizon is recorded between this shale and the underlying Dhandraul Sandstone. A WNW palaeocurrent direction is recorded in the sandstones.

Govindgarh Sandstone: This horizon forms a gentle northerly sloping plateau and escarpment trending ENE-WSW. It comprises light pink, steel grey, white, coarse grained to medium grained sandstone. It is thickly bedded, massive and cross-bedded with tabular tangential and trough type current bedding indicating NW palaeocurrent direction. Ripple marks, current lineations, rib and furrow structures and convolute bedding are common sedimentary structures displayed.

Bhander Group: As has already been discussed, the plateau portion and the generally peneplained area around Rewa Town is occupied by the rocks belonging to the Bhander Group. It is represented by two formations, viz. the Ganurgarh (Simrawal) Shale and the Bhander (Nagod) Limestone.

Ganurgarh (Simrawal) Shale: Surface exposures of the Ganurgarh Shale are rare and its presence has been recorded in the river sections and dug wells. The contact with the underlying Govindgarh Sandstone is gradational and conformable. It comprises an alternating sequence of reddish brown and chocolate shale and siltstone with thin calcite and gypsum partings. Inter-beds of fine sandstone exhibit small scale cross lamination, desiccation cracks and ripple marks. The general trend

of the formation is ENE-WSW with shallow northerly dips between 5° to 15°.

Bhander Limestone (Nagod Limestone): Exposures of the Bhander Limestone first appear in the area close to the east of Rewa Town, forming the closure of the Vindhyan Syncline. The contact with the Ganurgarh Shale is conformable and gradational. Lithologically, it comprises dark bluish grey, ash grey and greenish grey limestone and dolomitic limestone. Stromatolites are abundantly recorded. Chert lenses and stringers are frequently seen with dolomitic limestone. The sedimentary structures include cross lamination, intraformational conglomerate, ripple marks, flute casts, mud cracks, syaerensis cracks, gas escape structures and load structures.

D. Maihar-Badanpur-Dhanwahi-Chhoti Mahanadi Section

This section can be covered from the Maihar Township.

The rocks of the Vindhyan Supergroup around the Kaimur-Badanpur area form the southern limb of the Vindhyan Syncline. A complete succession starting from the Bhander Group in the north to the Semri Group in the south is exposed between Maihar and Dhanwahi. The Maihar Sandstone is exposed near Maihar Town and occupies the core of the Basin. All the ridges and escarps in the north-eastern part are occupied by the Maihar Sandstone, which constitutes the youngest lithostratigraphic horizon of the Vindhyan Supergroup in the Son Valley Section. The Maihar Sandstone is underlain by the

Sirbu Shale, which is exposed along the hill slopes and recognized from its gully erosion. The Bhander Limestone (Nagod Limestone) outcrops are exposed south-east of Maihar in the low-lying areas especially in the Tamas River Valley near Emaliya and Dulni. The Bhander Limestone is underlain by the Ganurgarh Shale, distinguished from the red soil and is rarely exposed. Its lower portion can be seen in the Tamas Valley on the Maihar-Badanpur Road.

Massive, thickly bedded and current bedded sandstone with reddish brown and purple sandstone underlying the Ganurgarh Shale, close to the Maihar Cement Factory, represents the Upper Rewa Sand-

stone or Govindgarh Sandstone. Good exposures of this sandstone unit can be seen in the Hathi Nala cutting at Sarla Nagar. Further south, greenish grey and khaki shales are exposed near a sharp road bend, under the Govindgarh Sandstone. It may be equivalent of the Jhiri Shale. As one descends the scarp, the road cuts across the Dhandraul Sandstone (Kaimur Sandstone). The rocks of the Semri Group occupy the peneplained area south of the escarpment. The Bhagwar Shale is exposed just at the base of the scarp from where Azmi (1998) has reported small shelly fauna which was rejected by majority of workers. The Rohtasgarh Limestone can be studied in the mines of the Maihar Cement Factory. On way to Dhanwahi, the sandstone belonging to Rampur Formation (=Glaucinitic Sandstone) and the Salkhan Limestone (=Fawn Limestone) can be studied. A good exposure of the Kajrahat Limestone is seen in the Chhoti Mahanadi River Section.

A brief description of the different lithounits is given below:

Semri Group: The Kajrahat Limestone is the oldest rock exposed in the section up to Dhanwahi.

Kajrahat Limestone: It is more than 130 m thick. Its upper part is stromatolitic. Three distinct stromatolite zones have been recognized. The lower is characterized by *Colonnella*, the middle by *Calypso* and the upper by *Thyssagetes*. The upper part also shows the presence of *Jacutophyton* and *Externia*.

Deonar Formation (Porcellanite Formation): It is exposed in the south-

eastern part of the section and is characterised by pale brown weathering, bleached and cream-coloured porcellanites with interbeds of friable clay, tuff, sandstone and siltstone. Interbeds of autoclastic conglomerate comprising grey to black coloured orthoquartzites are occasionally seen.

Koldaha Shale (Olive Shale): The top part of the Formation is predominated by an alternate sequence of shale, siltstone and arenite with individual sandstone beds up to 15 m thick, below which some limestone interbeds have been recorded. It is about 120 m thick. The Koldaha Shale is generally khaki, greenish grey to black, splintery needle/pencil shales. The general trend is ENE-WSW with moderate to steep northwesterly dips. Folding and faulting are common with axial trends in ENE-WSW to NNW-SSE of varying amplitude. Cross bedding, ripple marks, clay-gals, rare rain prints and trough cross bedding are common sedimentary structures indicating a NNE to NW palaeocurrent directions. The sandstone/clastic dykes have been recorded within the shale bands. A total cumulative thickness of about 500 m has been estimated for this formation.

Salkhan Limestone (Fawn Limestone): It conformably overlies the Koldaha Shale. The upper part is again characterised by the presence of limestone horizon overlain by shale-siltstone and sandstone alternation. Glauconite-bearing fine sandstone and siltstone chert and clay interbeds are occasionally present. Clay-gals, desiccation cracks, ripple marks and rain prints are common. The sandstone

interbeds show cross bedding. The limestone exhibits ripple marks, cross bedding and stromatolitic structures. Maximum thickness of this formation has been estimated around 200-250 m.

Rampur Formation: A flinty hard and compact sandstone/orthoquartzite exposed in a nala section east of Badera marks the lower part of the formation, conformably overlying the Fawn Limestone. The formation comprises a se-

quence of shale-siltstone and fine sandstone with a persistent limestone horizon in the lower middle part. The non-calcareous shales associated with these assemblages are pale grey to black in colour and are highly fissile. Glauconite bearing sediments are common. Ripple marks, cross bedding, clay-gals, desiccation cracks, rain prints and load cast structures have been recorded. The thickness of this formation has been estimated between 100-150 m.

E. Maihar-Nagod-Panna-Majhgawan-Khajuraho Section

This section can be covered from Maihar via Panna township, M. P.

The area north of Maihar represents the northern limb of the Vindhyan Basin. Rocks belonging to the Bhander, Rewa, Kaimur and Semri Groups are exposed between Maihar and Khajuraho via Panna and Majhgawan overlying the Bundelkhand Granitoid basement. The lateral northwards variations in the lithologies of these could be appreciated in this section.

A brief description of the different lithounits is given below:

The Maihar Sandstone exposed near Maihar occupies the core of the syncline. The area between Maihar to Nagod is covered by the Sirbu Shale. The Bhander Limestone is exposed in the lowlying areas only. The area from Nagod to the south of Panna is generally covered by limestone and the underlying Ganurgarh Shale. Exposures of the Ganurgarh Shale are scanty. The Govindgarh Sandstone, as one follows, underlies the Ganurgarh Shale westward from Nagod towards Panna. The general trend of the formations is ENE-

WSW. The sandstone forms a linear southerly sloping ridge. The Govindgarh Sandstone forming an escarpment near Panna town is underlain by the Jhiri Shale, the Asan Sandstone (=Itwa Sandstone) and the Panna Shale. The Kaimur Group is represented in the area by the Dhandraul Sandstone (=Baghain Sandstone) with diamond bearing conglomerate at the top. The Semri Group underlies the Dhandraul Sandstone (=Baghain Sandstone) with a gradational contact. The Semri Group is divided into three distinct formational units, viz. the Deoland Formation (=Pandwafall Sandstone), the Kajrahat Limestone (=Ken Limestone) and the Deonar Formation (=Palkawan Shale), in the ascending order. The Majhgawan pipe is an intrusive emplaced along a well-marked ENE-WSW lineament intruded in the Dhandraul Sandstone (Kaimur sandstones) (Chatterjee and Rao, 1995) (Fig. 21).

A brief description of the different lithounits is given in Table-15.

Bundelkhand Granite: It is represented by the granites and granite gneisses which have been dated by Rb/Sr method as 2550 ± 50 Ma (Sarkar *et al.*, 1990).

Semri Group: The Semri Group representing the basal most facies of the Vindhyan Supergroup rests unconformably over the Bundelkhand Granites. It has been subdivided into the Deoland Formation (=Pandwafall Sandstone), the Kajrahat Limestone (=Ken Limestone) and the Deonar Formation (=Palkawan Shale).

Deoland Formation (Pandwafall Sandstone): It comprises greenish grey to olive green coloured medium to fine sandstones. Bedding is thin, flaggy to slabby

and lenticular in nature. The middle member is an ash grey to light grey pinkish chert-dolomite. The sedimentary structures include cross bedding, asymmetrical ripples, desiccation cracks, etc. which indicate NE to WSW current directions.

Kajrahat Limestone (Ken Limestone): A pelletic and nodular limestone horizon occurs at the base of the Deonar Formation (Palkawan Shale) with variable thickness between 5-20 m. This limestone is very unevenly developed and lenticular in nature and has been designated as the Ken Limestone.

Deonar Formation (Palkawan Shale): The Deonar Formation (=Palkawan Shale) is exposed along the under-cliff portions of the Kaimur escarp-

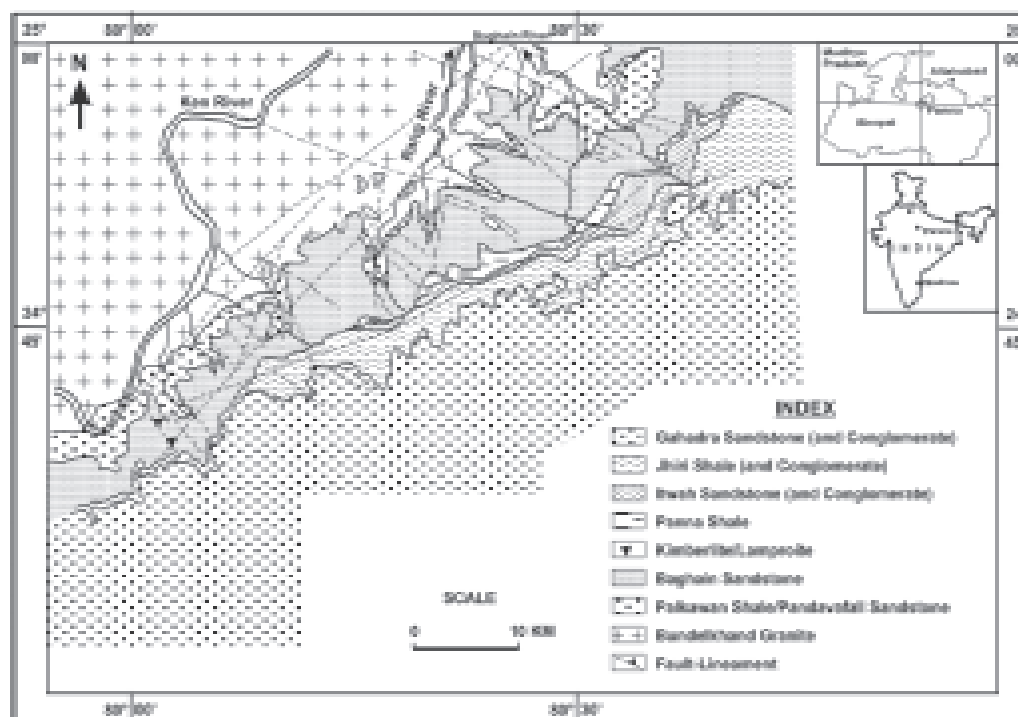


Fig. 21-Geological map of the Majhgawan area, Panna District, Madhya Pradesh (redrawn after Chatterjee and Rao, 1995).

Table 15-The stratigraphic succession in the Panna area (After Chatterjee and Rao, 1995).

Group	Formation
Rewa Group	Sandstone, shale and conglomerate Ultrabasic diatreme Kimberlite/lamproites
Kaimur Group	Baghain Sandstone Pipartola Conglomerate
-----Unconformity-----	
Semri Group	Palkawan Shale Ken Limestone Pandwafall Sandstone
-----Unconformity-----	
Bundelkhand Granite Complex	Granites and gneisses

ment. The thickness of this formation is between 15-60 m. It comprises thinly laminated, evenly bedded ash grey, yellow bleached porcellanitic shales.

Kaimur Group: The Kaimur Group is represented by massive sandstone, forming an escarpment over the Deonar Formation (Palkawan Shale) with a gradational and conformable contact. It is designated as the Dhandraul Quartzite (Baghain Sandstone). Lithology is represented by pink, light pink, white coloured compact sandstone. It shows overlapping contact with the underlying Bundelkhand Granitoid basement towards north. WNW to NW palaeocurrent direction has been inferred.

Rewa Group: The Rewa Group has been subdivided into the Panna Shale, the Asan Sandstone (Itwa Sandstone), the Jhiri Shale and the Govindgarh (Gahadra) Sandstone. Lithological details are as follows:

Panna Shale: The Panna Shale conformably overlies the Dhandraul Quartzite (Baghain Sandstone) and is best developed in the area east of Panna Town. It is poorly developed and completely absent westwards. It mainly comprises purple to olive green (khaki), thinly laminated flaggy shale with thin siltstone and fine sandstone. A 2.0 m thick pink and yellowish brown flaggy argillaceous limestone bed occurs towards its top. The average thickness of the formation is of the order of 20-25 m. Ripple marks, rill marks, clay-gals and pellets of psilomelane are seen at places.

Asan Sandstone (Itwa Sandstone): The Asan Sandstone (Itwa Sandstone) conformably overlies the Panna Shale with a gradational contact. It forms a prominent stratigraphic division between the Panna Shale and the overlying Govindgarh Sandstone (Gahadra Sandstone). The Asan Sandstone comprises dirty green, greenish grey and variously coloured medium to fine grained sandstone with thin shale and siltstone partings. It is thickly bedded, lenticular and cross-bedded sandstone with diamond-bearing conglomerate towards the top. The diamondiferous conglomerate comprises pebbles and cobbles of fine feldspathic quartzite, black chert, red and yellow jasper, vein quartz and porcellanitic shale set in a coarse sandy and ferruginous matrix. Sedimentary structures include cross bedding, ripple marks and clay-gals. The palaeocurrent direction is generally towards south to south-south-east. There is a marked reversal in palaeocurrent direction with those found in the overlying Govind-

garh Sandstone (Gahadra Sandstone) and the underlying Dhandraul Quartzite (Baghain Sandstone) Formations. This lithounit is between 5-15 m thick between Panna and Paharikhera and is obscure west of Panna town. The conglomerates are being quarried for the recovery of diamonds.

Jhiri Shale: The Jhiri Shale underlies the Govindgarh Sandstone (Gahadra Sandstone) characterised by erosional gullies. It unconformably overlies the Asan Sandstone (Itwa Sandstone); contact being marked by the conglomerate. However, towards west of Panna town it is exposed over Dhandraul Quartzite (Baghain Sandstone) with a conglomerate horizon continuing westwards. The size of the clasts belonging to this diamondiferous conglomerate ranges from granules to as big as boulders. The Jhiri Shale is purple, greenish grey, khaki and chocolate coloured, thinly laminated with wavy to lenticular bedding. Sedimentary structures such as halite casts, load casts, flute casts, bounce marks, small scale cross bedding and ripple marks are commonly exhibited by silty and sandy units. An estimated thickness ranges from 80 to 120 m.

Govindgarh (Gahadra) Sandstone: The Govindgarh (Gahadra) Sandstone conformably overlies the Jhiri Shale with a gradational contact and forms a conspicuous escarpment south of Panna town, extending in a linear ENE-WSW direction. The dips of the formation are low, between 4-8° in amount. The Govindgarh (Gahadra) Sandstone comprises a thickly bedded, current bedded and massive sandstone succession. It is compact and

pink, light reddish brown and purple coloured, medium to fine grained, rarely gritty. A conglomerate (oligomictic type), comprising pebbles, cobbles and even boulder size fragments of vein quartz and sandstone, has yielded diamonds in the Sakaria area. Sedimentary structures commonly associated include cross bedding, parting lineations, ripple marks and clay-gals. The cross bedding is tabular tangential and trough types, indicating NNW to westerly palaeocurrent direction.

Bhander Group: The Bhander Group is represented by the argillo-calcareous facies divisible into the Ganurgarh (Simrawal) Shale, the Bhander Limestone, the Sirbu Shale and the Maihar Sandstone.

Ganurgarh Shale: The Ganurgarh Shale comprising reddish brown and chocolate shales with subordinate siltstone and fine sandstone rests conformably over the Govindgarh Sandstone. However, due to the paucity of outcrops, the exact nature has been ascertained from dug wells and sections exposed in small rivulets. Sedimentary structures recorded include ripple marks, desiccation cracks and rarely salt pseudomorphs. The general trend is ENE-WSW with low 2-6° dips.

Bhander Limestone (Nagod Limestone): The limestone is grey to greyish black with bioherms of columnar stromatolite *Baicalia* with thin intercalation of shales.

The Sirbu Shale and the Maihar Sandstone have already been described in the stratigraphy section.

Kimberlite Pipe: The pipe is a pear-shaped body with a typical carrot-shaped

diatreme the walls of which are inclined steeply at $70^{\circ} - 80^{\circ}$ towards the centre. Surface outcrop is 500 m long and 320 m wide (Chatterjee and Rao, 1995) (Fig. 22 and 23). Scott Smith (1992) has suggested that the Majhgawan rock represents a lamproitic lapilli tuff (volcaniclastic) of crater facies. The pipe varies in lithology and different lithologic units are arranged in concentric manner. The rock is tuffaceous and often vesicular. Towards the centre of the pipe, the rock is a dark, massive compact, medium grained, tuffaceous with coarse xenoliths of olivine (serpentine), phlogopite and red coloured lapilli. It also contains cognate and accidental xenoliths. The accidental xenoliths are made up of sandstone, shale and rarely granite that occur towards the contact with invaded rocks. Phenocrysts are mostly serpentinised olivine, pervoskite, phlogopite, enstatite, pyrope, chromite and spinel and

the groundmass is made up of serpentinised olivine, phlogopite, spinel, apatite, rutile etc. Olivine generally contains inclusions of chromite and spinel. According to Chatterjee and Rao (1995), geochemically the Majhgawan pipe shows normal Group- I Kimberlite composition and does not indicate lamproitic affinity.

Kharkiv *et al.* (1991) observed that the Majhgawan rocks differ in composition from typical kimberlite in several essential characteristics in having higher TiO_2 and P_2O_5 content, presence of high titanium phlogopite and low content of indicator minerals. It also contains little K_2O and no clinopyroxene and potassic richterite. According to Chatterjee and Rao (1995), the pipe rock is intermediate between typical kimberlite and lamproites. Shanker *et al.* (2001) have suggested that the Majhgawan rock is similar to orangeites.

F. Varanasi–Robertsganj–Markundi–Dala–Renukoot Section

This section can be studied by staying at Varanasi or Robertsganj or Obra. However, if the section is covered from Varanasi via Robertsganj the following outcrops will be noticed:

The Older Alluvium of the Quaternary Period covers the area around Varanasi. First outcrop of the Vindhyan Supergroup is exposed near Adalhat, about 24 km from Varanasi. Close to south of Ahr-aura (about 32 km from Varanasi) the regular ENE-WSW trending escarpments can be seen which are formed by the rocks of the Kaimur Group. The Dhandraul Sandstone comprising dirty white and buff,

medium to fine grained sandstones exhibit profuse development of tabular and trough megacross bedding. It is underlain by brownish red massive sandstone belonging to the Scarp Sandstone (the Mangesar Formation of Sastry and Moitra, 1984). The Dhandraul Sandstone occupies the plateau area of Robertsganj, the district headquarters of Sonbhadra. Thick soil and laterites cover large areas of the plateau. Further south, the Son River has exposed excellent sections of both the Kaimur and Semri Groups by cutting the Kaimur plateau. About 150 m thick Dhandraul Sandstone is exposed in the section,

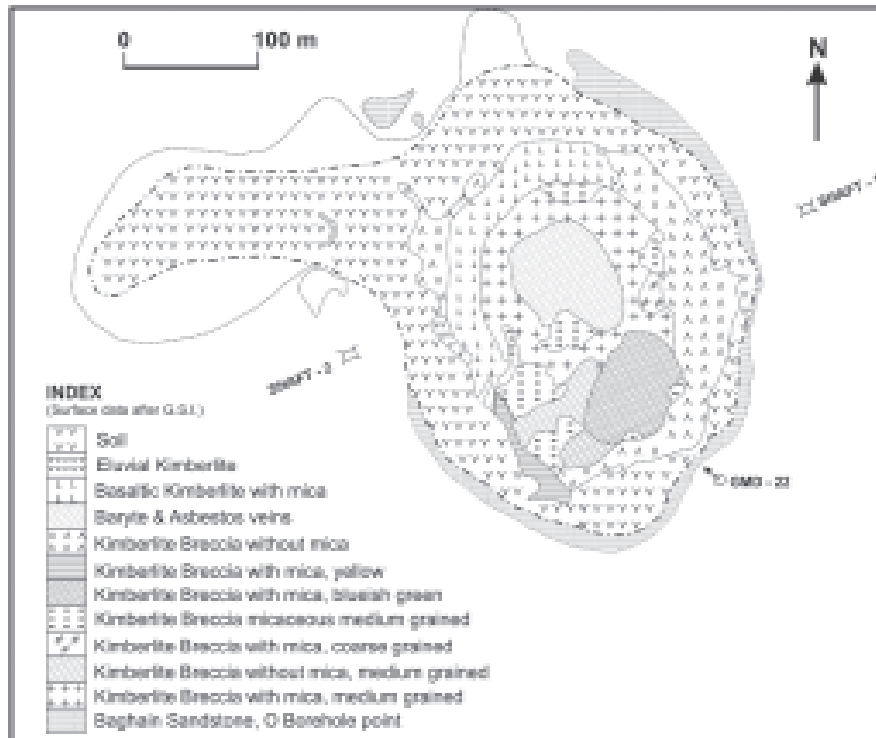


Fig. 22-Geological map of the Majhgawan pipe (redrawn after Chatterjee and Rao, 1995).

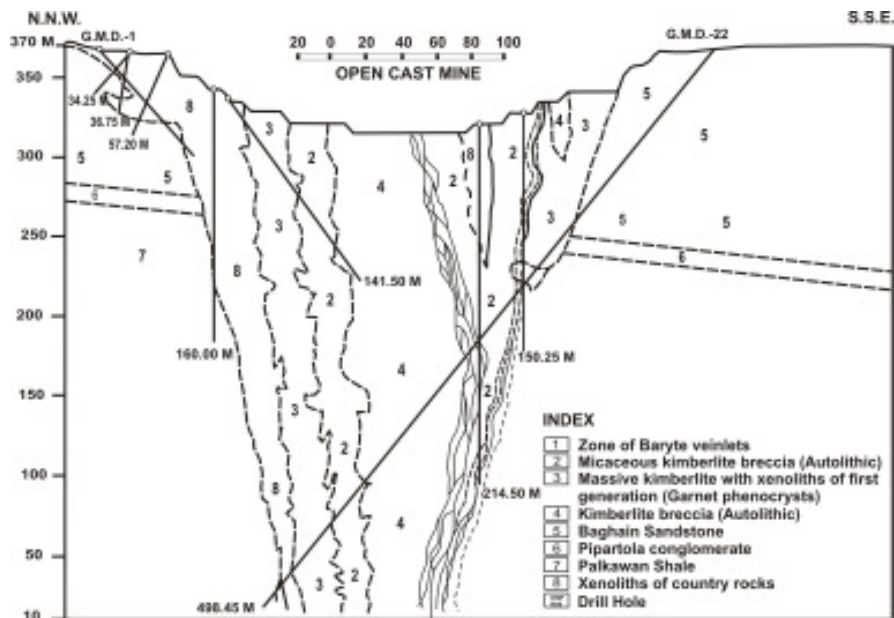


Fig. 23-Cross section of the Majhgawan pipe along drill holes (redrawn after GSI, 1989 in Chatterjee and Rao, 1995).

as one descends from the top of the scarp. It is underlain by the Scarp Sandstone (Mangesar Formation). The uppermost part of the Bijaigarh Shale is exposed at the base of the scarp. The rocks of the Semri Group occupy the centre of the broad amphitheatre marked by the surrounding Kaimur escarpment. The Semri Group is folded here as an easterly plung-

ing antiform. Towards south, between Markundi and Kajrahat, the complete succession of the Semri Group is exposed. Near residential colony of the Dala Cement Factory, the faulted contact of the Semri Group and the Bijawar phyllites can be seen. From Dala to Renukoot, the area is occupied by the Bijawar phyllites.

Field Stops

For field observations, the selected sites are referred as *stops*. The field work can be started from Chitrakut area (U. P.-M. P.)

[Abbreviations: District Resource Map (DRM) of the Geological Survey of India; Topo Sheet (TS); Degree Sheet (DS) of the Survey of India].

Stop 1

Kamtanath Hill Section (Chitrakut)

Location—N 25°10' 26.5"; E 80°50' 30.9". DRMs of Satna and Banda.

Approach—Best access point to this hill is on the Kamtanath-Sangrampur metalled road. There is a temple of *Prakat Bhaye Hanuman* on the *Kamtanath parikrama* (circular path) near Khohi, access the hill from this side to the top.

Key observations—Good exposures of the Bundelkhand Granite-Gneissic Complex (BGGC) can be seen on the Kamtanath and also in the Sangrampur and Lodhwara hills. On each hillock, at the base, the Bundelkhand granite is exposed and at the top of it the rocks of the Semri Group with variable thickness are seen. On the Kamtanath hillock, the top part of the basement granite shows weathered profile in the form of fissures and cracks filled with peloidal dolomite followed by the Upper Glauconitic Sandstone and Tirohan Limestone of the Semri Group. Peloids are poorly sorted, rounded to subrounded, polylobate and sickle shaped often chertified (Fig. 24). The lower horizons are enriched in glauconitic pellets (Anbarasu, 2001b). The Upper Glauconitic Sandstone shows herringbone cross bedding, horizontal bedding along with small current and wave ripples as the prominent sedimentary structures. The Tirohan Limestone is extensively exposed in the hillock followed by the arkosic sandstone and sandstone of the Kaimur Group.



Fig. 24-The Pellet Limestone of the Chitrakut Formation exposed in the Sangrampur Hill of the Chitrakut area, Chitrakut District, Uttar Pradesh. Note the size variation in pellets (coin=2.2 cm).



Fig. 25-A view of the Sangrampur Hill in the Chitrakut area, Chitrakut District, Uttar Pradesh. The Bundelkhand Granite is seen below the White line whereas the Semri Group is noted above it. The lower succession of the Kaimur Group is exposed on the top of the hill.



Fig. 26—An exposure of the Pre-Vindhyan Dolerite Dyke piercing the Bundelkhand Granite at the Sangrampur Hill, the Chitrakut area, Chitrakut District, Uttar Pradesh.



Fig. 27—Black bedded non-stromatolitic chert in the Peloidal Limestone, the Chitrakut Formation at the Sangrampur Hill, Chitrakut area, Chitrakut District, Uttar Pradesh.

Stop 2

Sangrampur Hill Section (Chitrakut)

Location—N 25°10' 46.3"; E 80°49' 50.5". DRMs of Satna and Banda.

Approach—Easily accessible from the Kamtanath-Sangrampur metalled road. Local people have made temporary access up to the hill.

Key observations—BGGC is exposed on the 2/3 part of the hill (Fig. 25). An angular unconformable contact of the Semri Group and the Bundelkhand granite is well exposed. There is a pre-Semri dolerite dyke present on the eastern face of the hillock which pierce in the Bundelkhand Granite and terminates before the sedimentary succession of the Semri Group (Fig. 26). Uppermost part of the granite shows fissures and cracks filled with peloidal limestone. The pebbles and cobbles of the granites are seen in glauconite bearing limestone. Black bedded non-stromatolitic chert is also present near the base of the Peloidal Limestone (Fig. 27). The palaeocurrent directions for the Semri Group at Sangrampur, Bihara, Muradpur and Lodhwara hills are given in Fig. 28 and 29. The Glauconitic Limestone, Peloidal Limestone, Upper Glauconitic Sandstone and Tirohan Limestone of the Semri Group and arkosic sandstone and sandstone of the Kaimur Group are seen near the top of the hillock. Black bedded chert has yielded organically well preserved microfossils (Kumar and Srivastava, 1991; Anbarasu, 2001a).

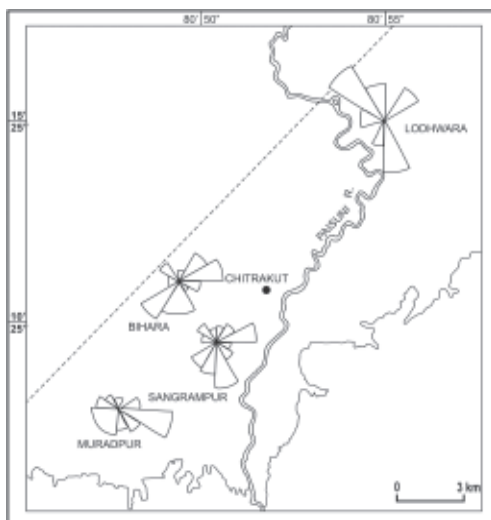


Fig. 28-The rose diagram for the current bedding in the Lower Glauconitic Sandstone in the Semri Group, Chitrakut area (after Kumar and Singh, 1978).

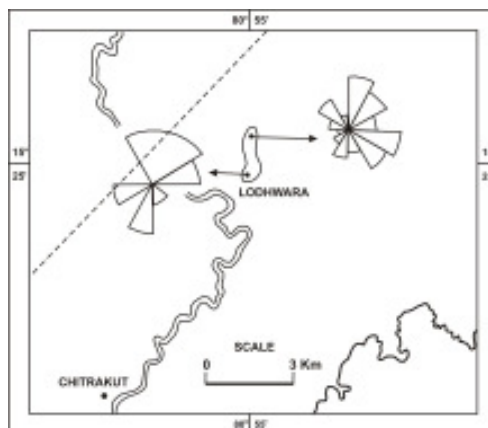


Fig. 29-The rose diagram for the current bedding in the Upper Glauconitic Sandstone in the Semri Group of the Chitrakut area (after Kumar and Singh, 1978).

Stop 3

Janaki Kund Section (Chitrakut)

Location—N 25°09' 35.1"; E 80°51' 57.6". DRMs of Banda and Satna.

Approach—An easy access to the Janaki Kund area is through the *Arogya Dham* (a local clinic) gate on the Chitrakut-Satna Road. Within the stretch of 500 meters one can notice good exposures of the Tirohan Limestone.

Key observations—This is the most debatable spot of the Vindhyan Supergroup for controversial age diagnostic fossil record. Good exposures of the Tirohan Limestone are seen in the Mandakini River Section (Paisuni River) where phosphatic stromatolites are well exposed on the right bank and in the stream of the Mandakini River. Kumar (1977b) described columnar stromatolite, *Colonnella columnaris* from this section. The intercolumnar spaces of the stromatolites are filled with phosphatic pellets and neomorphic dolomite patches (Fig. 30, Fig. 31). Joshi *et al.* (2006), Azmi *et al.* (2007) and Bengtson *et al.* (2009) have described a variety of small shelly fossils and mineralized floral elements from the phosphorites of the Janaki Kund. However, there is a debate about the taxonomic status of these fossils. Radiometric dating of this unit has yielded the Palaeoproterozoic age (Bengtson *et al.*, 2009).

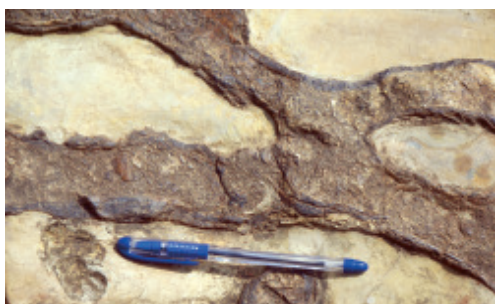


Fig. 30—Infilling of the black coloured phosphatic pellets in the inter columnar spaces of the columnar stromatolites developed in the Tirohan Limestone (=Rohtasgarh Limestone) exposed in the Janki Kund of the Chitrakut area, Satna District, Madhya Pradesh.



Fig. 31—Phosphatic stromatolite *Colonnella columnaris* in the Tirohan Limestone (=Rohtasgarh Limestone) exposed in the Janki Kund of the Chitrakut area, Satna District, Madhya Pradesh.

Stop 4

Tarahuwan—Dadri Section (Chitrakut)

Location—N 25°09' 13.1"; E 80°55' 07.7". DRMs of Banda and Satna.

Approach—A good section is exposed on Hanuman Dhara—Dadri Reserve Forest Road. The Tirohan Limestone and Kaimur Sandstone can be studied on the metalled road leading to Dadri Air-strip.

Key observations—The type area of the Tirohan Limestone is in the Tarahuwan Village (N 25°12'; E 80°54') of Chitrakut area (M. P.). The Tirohan Limestone is exposed at the base of the hillock. Pink to grey, fine to coarse-grained crystalline Tirohan Limestone is seen in the southeastern part of the Chitrakut area U. P. and north-eastern part of the Satna District. The autoclastic Tirohan breccia overlies the Tirohan Limestone, which is composed of varied sizes of angular fragments of pure white chert and banded yellow and white chert. The Tirohan Limestone is slightly dolomitised and therefore it is also known as Tirohan Dolomite. Small scale ripples and cross beddings and parallel beddings, laminoid fenestrae filled with internal sediments are noticed in lower part of the Tirohan Limestone. In the upper part, it shows parallel lamination, stylolites and chert lenticles. The topmost part is made up of greenish grey, hard, compact dolomite consisting of small glauconitic pellets (Anbarasu, 2001b).

Hanuman Dhara, a temple complex of Lord Hanuman, is constructed around a spring. On way to the temple site and up to Dadri Air-strip, good exposures of Kaimur Sandstone showing large-scale cross bedding are seen.

Stop 5

Gupt-Godavari Section (Chitrakut)

Location— N 25°06.035'; E 80°46.189'. DRM Satna.

Approach—15 kms south west of Chitrakut town on Chitrakut-Satna road.

Key observations—It is a spectacular religious/tourist-spot famous for a pair of caves seen in the Tirohan Limestone. One of the caves has high and wide entrance while other has long and narrow entrance with a stream of water flowing from the cavernous limestone. The cavernous Tirohan Limestone is well exposed in both the caves (Fig. 32). Small-scale ripples, cross beddings, parallel beddings and laminoid fenestrae can be noticed in the caves.



Fig. 32-Gupt Godavari stream forming well developed cavernous cave within the Tirohan Limestone, Gupt Godavari area, Satna District, Madhya Pradesh.

Stop 6

Sajjanpur Section (Satna – Rewa Road)

Location— N 24°33' 23.6"; E 80°58' 29.7". DRM Satna, TS 63 D/14, 63 H/2.

Approach—22 Km east of Satna on Satna-Rewa road.

Key observations—Upper part of the Bhandar Limestone is exposed in the river valley. Large bioherms and biostromes of the stromatolites are noticed (Fig. 33). Columnar stromatolites *Baicalia* sp. and *Tungussia* sp. were reported by Kumar (1976a) (Fig. 34). Synaeresis cracks (Fig. 35), small scale ripples, wrinkle marks and molar tooth structures are commonly noticed in this section.

Additional Locality A-

Rao *et al.* (1977) reported stromatolites in the limestone member of the Sirbu Shale exposed around Loharaora, Chakdahi and along Magardha River between

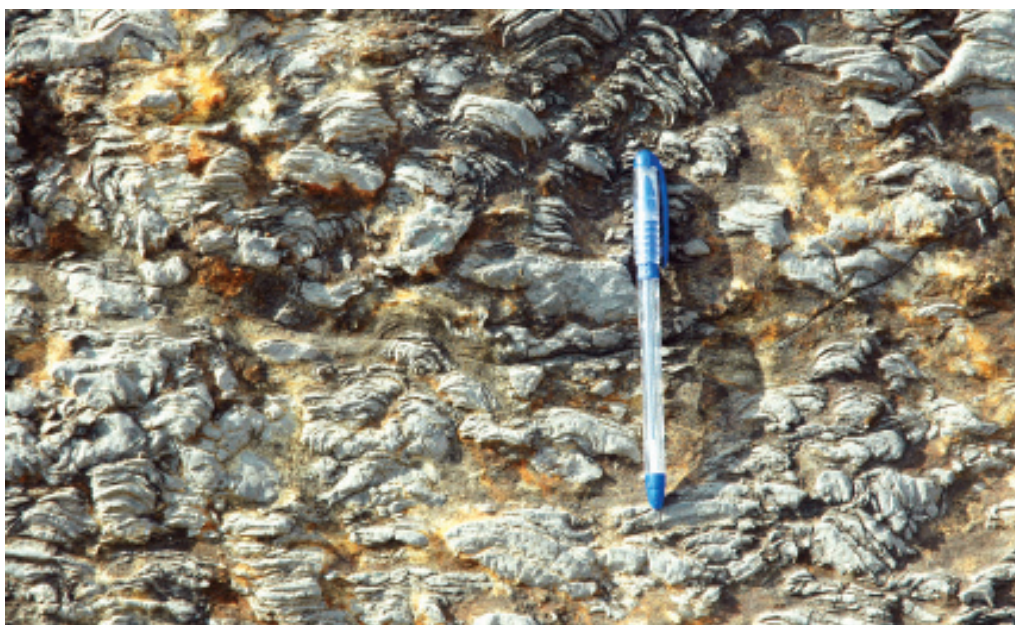


Fig. 33-*Baicalia burra*, a columnar stromatolite in the upper part of the Bhandar Limestone, Sajjanpur area, Satna District, Madhya Pradesh.



Fig. 34-*Tungussia* sp., a columnar stromatolite developed in the upper part of the Bhandar Limestone, Sajjanpur area, Satna District, Madhya Pradesh.



Fig. 35-Synaeresis cracks in the upper part of the Bhandar Limestone, exposed in Sajjanpur area, Satna District, Madhya Pradesh.

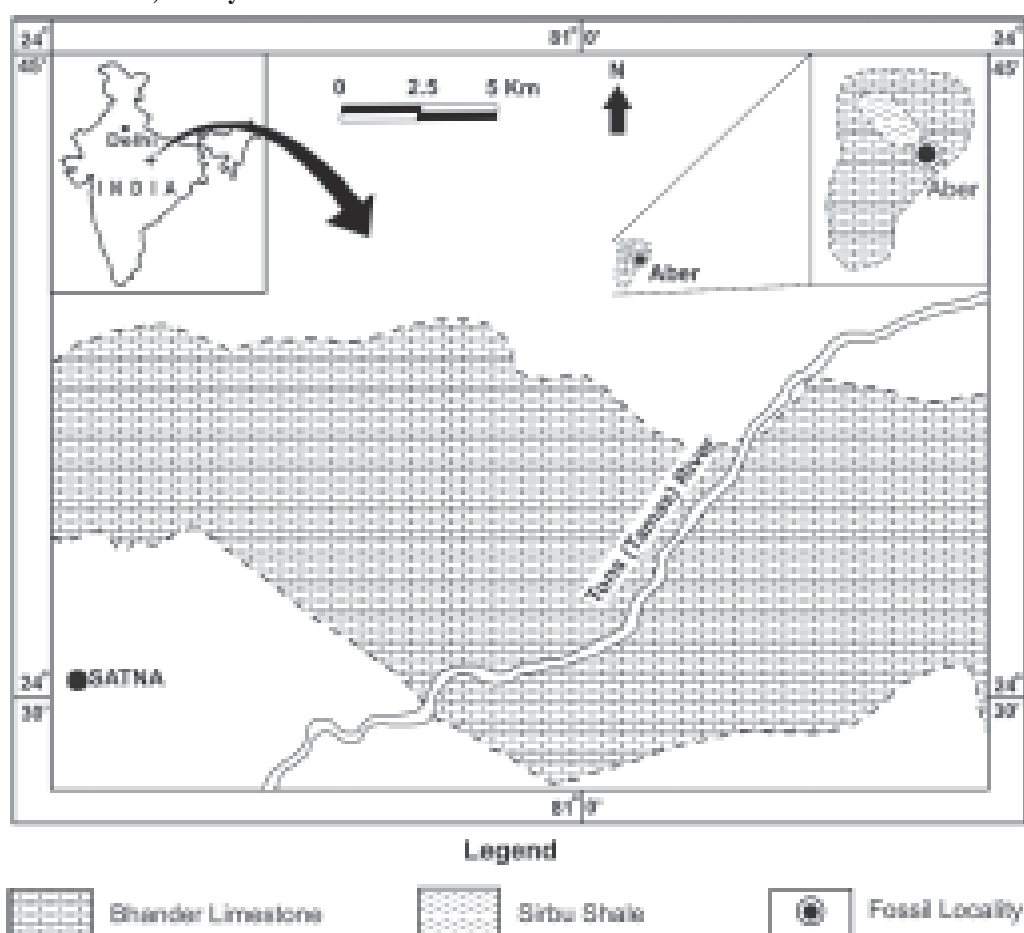


Fig. 36-Geological map of the Aber area, Satna District, Madhya Pradesh (modified after Rao *et al.* 1981).



Fig. 37A-Columnar stromatolite *Baicalia baicalica* from the Bhandar Limestone, Aber area, Satna District, Madhya Pradesh.



Fig. 37B-*Cryptozoon* sp. in the Bhandar Limestone exposed in the Aber area, Satna District, Madhya Pradesh.

Parkhuri and Baghunda villages and close to north-east of Purwa in Satna District M. P.. All these localities are situated on the southern side of the Rewa-Panna Highway near Sajjanpur.

Additional Locality B-

Another good section of the Bhandar Limestone is exposed in the Aber area (Fig. 36) where stromatolites are found in abundance. The area can be reached from Satna by a vehicle. It is 22 km from Satna on Satna-Semaria Motor Road. The contact of the Bhandar Limestone and the overlying Sirbu Shale is well exposed. The stromatolites in the Bhandar Limestone are profusely developed. *Baicalia baicalica*, *B. burra*, *Tungussia* sp. *Colonnella columnaris* and *Cryptozoon* have been recorded (Fig. 37A, Fig. 37B). The overlying Sirbu Shale shows good preservation of *Chuarina* and *Tawuia*.

Stop 7

Drummondganj Ghat Section

Location—N 24°52' 28.5"; E 82°09' 57.9". DRMs Rewa and Mirzapur, TS 63 L/1.

Approach— It can be accessed either from Rewa or Mirzapur on National Highway-7. Drummondganj is a township near Ghat section close to the borders of Uttar Pradesh and Madhya Pradesh.

Key observations— It is a type section of the Rewa Group exposed in Drummondganj Ghat escarpment where most complete section is available for examination. The thick succession of the Panna Shale is seen along the road section. At the base of the hillock, parallel-bedded Panna Shale with intercalated sandstone are exposed. The shale facies is red, reddish brown to greenish yellow and characterised by the persistent thin laminations. In some parts, sand-intercalated shale facies have well laminated shale units. The sandstone, present as impersistent stringers and thin lenticles, are constituted of fine to medium grained sandstone. It is followed by the Asan Sandstone (=Lower Rewa Sandstone). However, the exposures are covered with scree. Exposed portions of the sandstone show large scale cross bedding, flute casts (Fig. 38), load casts and prod marks. It is overlain by the grey and red coloured fissile Jhiri Shale. Chakraborty and Chaudhuri (1990) recorded salt pseudomorphs in the sequence pointing to restricted, mud depositing coastal environment. Rai *et al.* (1997) and Srivastava (2004) reported carbonaceous megafossils from the Jhiri Shale and Panna Shale respectively. *Chuarina* and *Tawuia* can be collected from the Panna and Jhiri shales. The scarp is made up of the Govindgarh Sandstone (=Upper Rewa Sandstone).



Fig. 38—Flute cast in the Govindgarh Sandstone, Drummondganj Ghat Section, Rewa District, Madhya Pradesh.

Stop 8

Drummondganj—Rewa Road Section

Location—N 24°51' 39.7"; E 82°08' 47.7". DRM of Rewa, TS 63 L/1.

Approach—It can be accessed either from Rewa or Mirzapur on National Highway-7. Mid-way of the ghat section shows the Govindgarh Sandstone of the Rewa Group. Best part of the section can be seen between 105-104 km milestone towards Rewa.

Key observations—Upper part of the Govindgarh Sandstone is exposed on the dip slopes. Chakraborty and Chaudhuri (1990) considered that the Panna Shale and the Asan Sandstone units are absent in this section and the Upper Rewa Sandstone is divisible into the lower Drummondganj Sandstone and the upper Govindgarh Sandstone. The Drummondganj Sandstone shows extensive parting lineations that suggest deposition in upper flow regime at very shallow depth. There are sigmoidal fore-sets that are slightly thicker and are upwardly convex near the brink point and often merge with the top set (Chakraborty and Chaudhuri, 1990). Litholog of the Drummondganj

section is given in Figs. 39 & 40. A palaeocurrent map for this section of the Rewa Group is given in Fig. 15. The Govindgarh Sandstone shows poor sorting, extensive trough cross-stratification and planar erosional surfaces bounding sand bodies with fining and thinning upward trends that indicate fluvial depositional environment. Pene-contemporaneous overturning of cross-beds are very common in the Govindgarh Sandstone. It also supports fluvial origin (Chakraborty and Chaudhuri, 1990).

However, at several places it is difficult to differentiate the Drummondganj Sandstone from the Govindgarh Sandstone. It is, therefore, suggested that these two lithounits

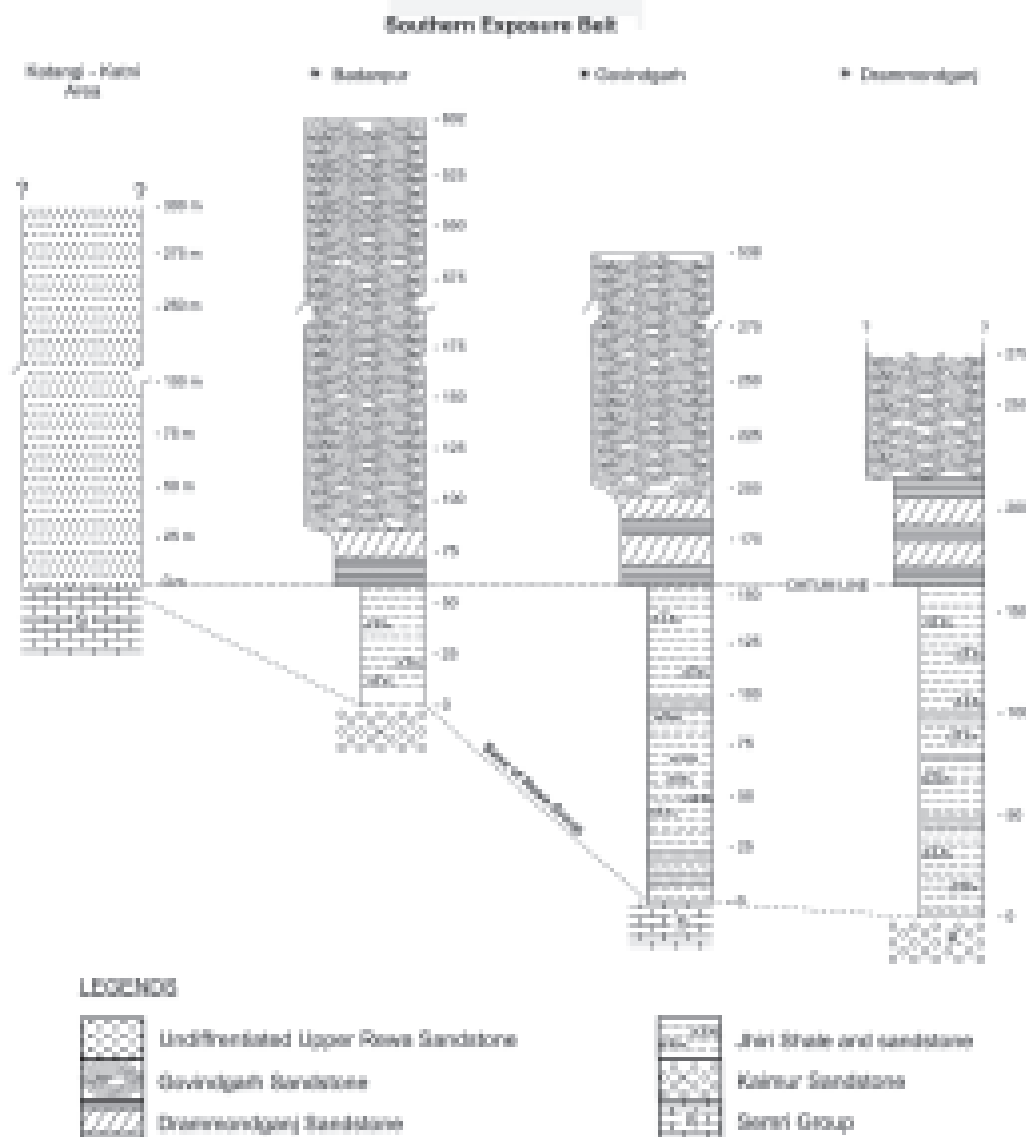


Fig. 39-Lithostratigraphic correlation and division of the Rewa Group as noted along the southern flank of the Son Valley (redrawn after Chakraborty and Chaudhari, 1990).

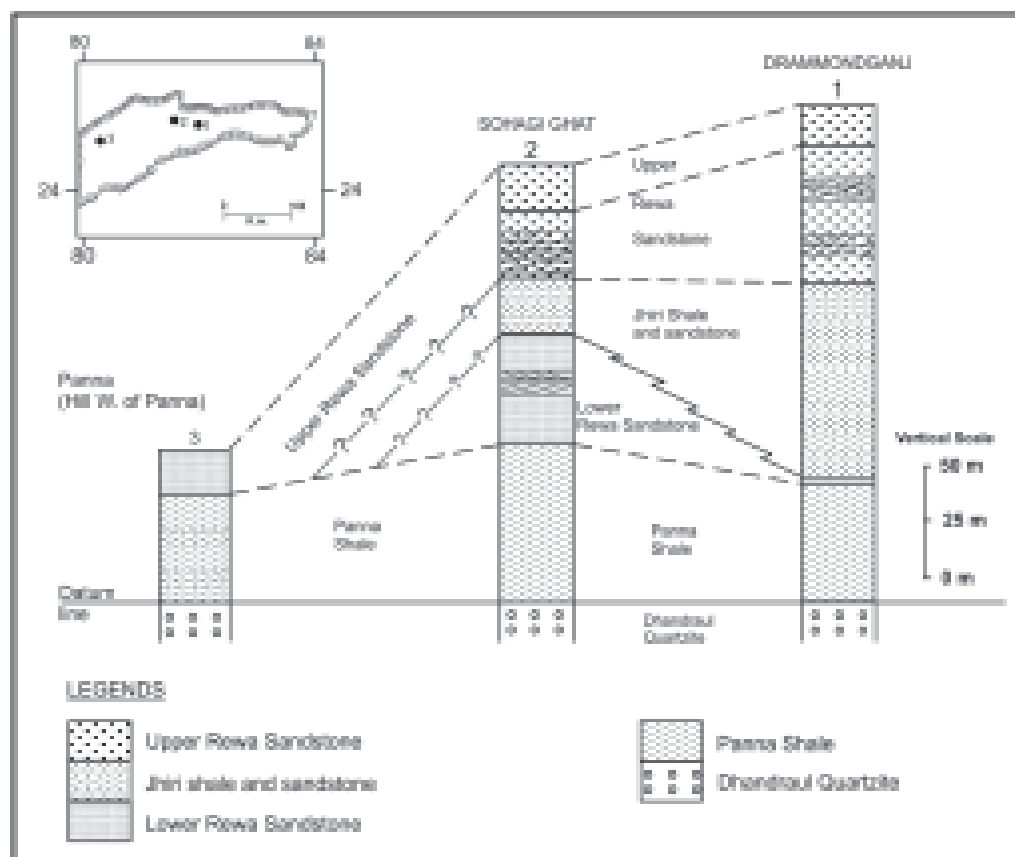


Fig. 40-Lithostratigraphic correlation and division of the Rewa Group as noted along the northern flank of the Son Valley (redrawn after Banerjee and Sengupta, 1963).

should be merged and the original designation of the Upper Rewa Sandstone should be retained. In this section, all the four lithounits, *viz.* the Panna Shale, the Lower Rewa Sandstone, the Jhiri Shale and the Upper Rewa Sandstone can be recognized.

Stop 9

Ramnai Section (Rewa)

Location—N 24°33' 31.1"; E 81°24' 41.5". DRM of Rewa, TS 63 H/6.

Approach—It is 14 km east of Rewa on National Highway-7.

Key observations—It is a good section where contact of the Ganurgarh Shale and the overlying Bhandar Limestone is exposed in an open cast mine. Fine parallel laminated shales (Fig. 41) are exposed which grade into the Bhandar Limestone. The

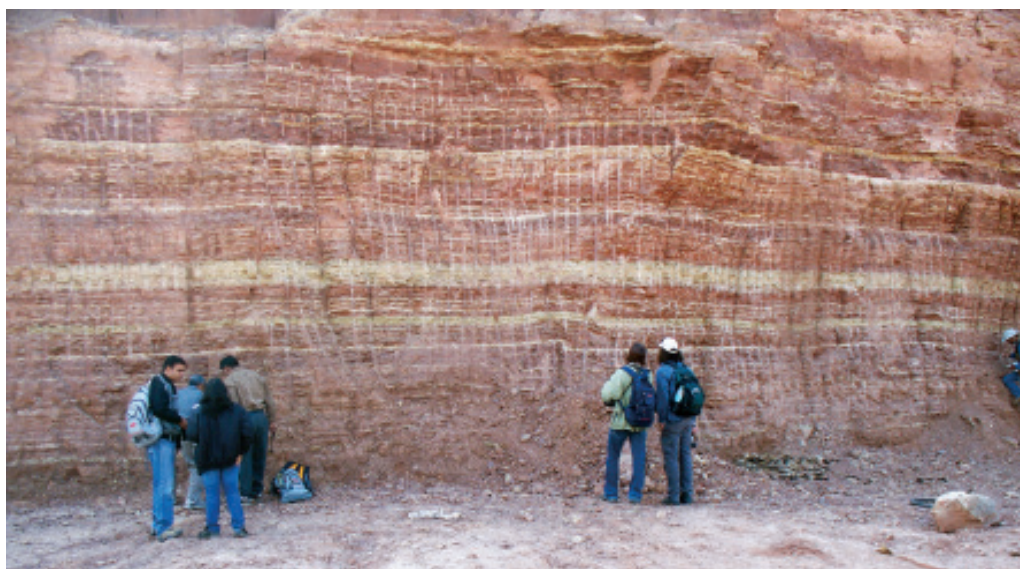


Fig. 41-A section of the Ganurgarh Shale exposed in the Ramnai quarry, Rewa District, Madhya Pradesh. Note the fine parallel laminated shales.

shales also show salt pseudomorph (Fig. 42) and presence of gypsum lenses. The limestone is grey, black to light coloured and there are some pockets of stromatolitic limestone. Bedded and lensoid cherts are present near the transition zone of the Ganurgarh Shale and the Bhandar Limestone. Irregular chert nodules in Bhandar Limestone are also noticed in this area (Fig. 43).

Stop 10

Govindgarh Section (Rewa)

Location—N 24°22' 02.3"; E 81°20' 17.6". DRM of Rewa, DS 63 H.

Approach—The Rewa city is situated on the Bhandar Limestone, and the Govindgarh section is 22 km south of Rewa city on Rewa-Sidhi State Highway.

Key observations—It is a type section of the Govindgarh Sandstone and the dip slope exposes the Govindgarh Sandstone with excellent development of large planar and trough cross bedded horizons (Fig. 44). It is underlain by the thinly laminated greenish-yellow to deep red coloured Jhiri Shale with sandstone interbeds. Thinner sand beds have sheet-like tabular morphology whereas thicker ones display low angle cross-laminations, cross beds, ripples and mud cracks (Chakraborty and Chaudhuri, 1990). Poor sorting, extensive trough cross stratification, profuse planar erosional surfaces indicate fluvial depositional regime for the Govindgarh Sandstone.



Fig. 42-Salt pseudomorphs recorded in the Ganurgarh Shale, Ramnai quarry, Rewa District, Madhya Pradesh. Note the cuboidal casts of the salt on the sole of the Ganurgarh shale.



Fig. 43-Irregular chert bands present in the lower part of the Bhandar Limestone, Ramnai quarry, Rewa District, Madhya Pradesh. Chert is encircled with white line.



Fig. 44—The plan view of the large trough sets in the type area of the Govindgarh Sandstone, Govindgarh area, Rewa District, Madhya Pradesh.

Stop 11

Chhuyia Ghati Section

Location—N 24°21' 11.57"; E 81°21' 08.93". DRM Satna; DG 63 H.

Approach—Chhuyia Ghati Section is mid way on the ghat section south of the Rewa city on the Rewa-Sidhi State Highway.

Key observations—An alternation of sandstone and shale underlies the Govindgarh Sandstone (Upper Rewa Sandstone). Differentiation between the Kaimur Sandstone and the Govindgarh Sandstone is not clearly marked. After crossing the ridge, the Kaimur Sandstone and shales are exposed but their lithostratigraphic subdivisions are not established. In the lower reaches of the ridge, the Bhagwar Shale is well exposed. It is underlain by the Rohtasgarh Limestone (Hinaoti Limestone). The limestone confirms the presence of the Semri Group.



Fig. 45—Large size molar-tooth structures recorded in an exposure of the Rohtasgarh Limestone on the Rewa-Sidhi State Highway near Toll Gate/Jaypee Cement Factory gate.

Stop 12

Toll Gate Section

Location—N 24°20' 23.14"; E 81°21' 02.00". DRM Satna; DG 63 H.

Approach—South of the Rewa city on the Rewa-Sidhi State Highway, 1 km before the toll gate and Jaypee Cement Factory gate.

Key observations—On the lower reaches of the ridge, the Bhagwar Shale is well exposed. It is underlain by the Rohtasgarh Limestone (Hinaoti Limestone). Thick bedded Limestone is exposed on the road. It is devoid of stromatolites. The limestone confirms the presence of the Semri Group that shows well-developed mud cracks, intraclasts, molar tooth structure and small scale ripple on the bedding (Fig. 45).

Stop 13

Chorhat Section

Location—N 24°24' 17.23"; E 81°36' 08.50". DRM Sidhi; DG 63 H.



Fig. 46-Double crested wave ripples in the Rampur Formation, Semri Group exposed in a section near Chorhat on the Rewa-Sidhi State Highway, Madhya Pradesh.



Fig. 47-Interference or ladder ripples in the Rampur Formation, Semri Group exposed in a section near Chorhat on the Rewa-Sidhi State Highway, Madhya Pradesh.

Approach—South of Rewa city on the Rewa-Sidhi State Highway, 22 km before Chorhat township. Good exposures are present along the road leading to Chorhat.

Key observations—Near Chorhat, on either side of the township, the road follows the strike of the Rampur Formation (=Chorhat Sandstone) which has been correlated with the Glauconitic Sandstone of the Chopan area, U. P.. The sandstones show profuse development of both current and wave ripples (Fig. 46 and 47). They also show abundant development of mud cracks and synaeresis cracks along with wave and current and interference ripples. Seilacher *et al.* (1998) have described trace fossils representing triploblastic animals. However, these trace fossils have been considered pseudofossils (Hofmann, 2005) and may simply be the mud cracks or synaeresis cracks. Chakrobarti (2001) has also reviewed the occurrence of trace fossils reported by Seilacher *et al.* (1998) and considered them to be synaeresis cracks.

Stop 14

Chorhat Rest House Section

Location—N 24°25' 02.74"; E 81°40' 41.87". DRM Sidhi; DG 63 H.

Approach—One and a half kilometer after Chorhat Rest House towards the Koldaha Bridge on Chorhat-Sidhi Road.

Key observations—In the Son Valley, southeast of Chorhat Rest House, good exposures of the porcellanite can be seen. This sequence of rocks belongs to the Deonar Formation and the Koldaha Shale of the Semri Group. It is constituted of alternating succession of silicified, unsilicified shale, sandstone and tuffs. Typical porcellanite is hard and of varying colours and show conchoidal fracture. Various types of joints are prominently present.

Stop 15

Koldaha Shale—Son River Section

Location—N 24°24' 38.7"; E 81°42' 08.1". DRM Sidhi; DG 63 H.

Approach—Near Koldaha Bridge on Chorhat-Sidhi Road.

Key observations—It is the type section and type area of the Koldaha Shale. It is olive green coloured, fine-grained laminated shale with cuboidal to pencil cleaved fracture pattern. At a few places, it is interbedded with pockets of fine-grained limestone, sandstone and porcellanite. Sharma (2003) has reported a variety of millimetric carbonaceous films from the Koldaha Shale exposed in the Newari area in Sonbhadra District, Uttar Pradesh. The right bank of the Son River shows good exposures of the Deonar Formation.

Stop 16

Girgita—Emaliya Quarry Section (Maihar)

Location—N 24°14' 704"; E 80°47' 826". DRM Satna; TS 63 D/16. Fig. 48, 49.

Approach—7 km southeast of Maihar Township on NH-7 on the banks of Tons (Tamas) River.

Key observations—Very good outcrops of the Bhandar Limestone are exposed in the Tons (Tamas) River section near Emaliya (Fig. 50). In the upper part, profuse development of *Baicalia baicalica* and poor development of *Colonnella columnaris* can be seen. From the nearby mine, Kumar (1999b) has recorded the occurrence of (?) sponge spicule-like forms and microstromatolites from the black-bedded cherts associated with the upper part of the Bhandar Limestone. In the Girgita Mines, one can notice profuse development of stylolites, synaeresis cracks, intraformational and edge-wise conglomerates (Fig. 51), molar tooth structures (Fig. 52), flat ellipsoidal black chert nodules. The basal part of the Bhandar Limestone exposed in the Tons River section shows parallel laminated and ripple laminated facies. Cherts normally represent

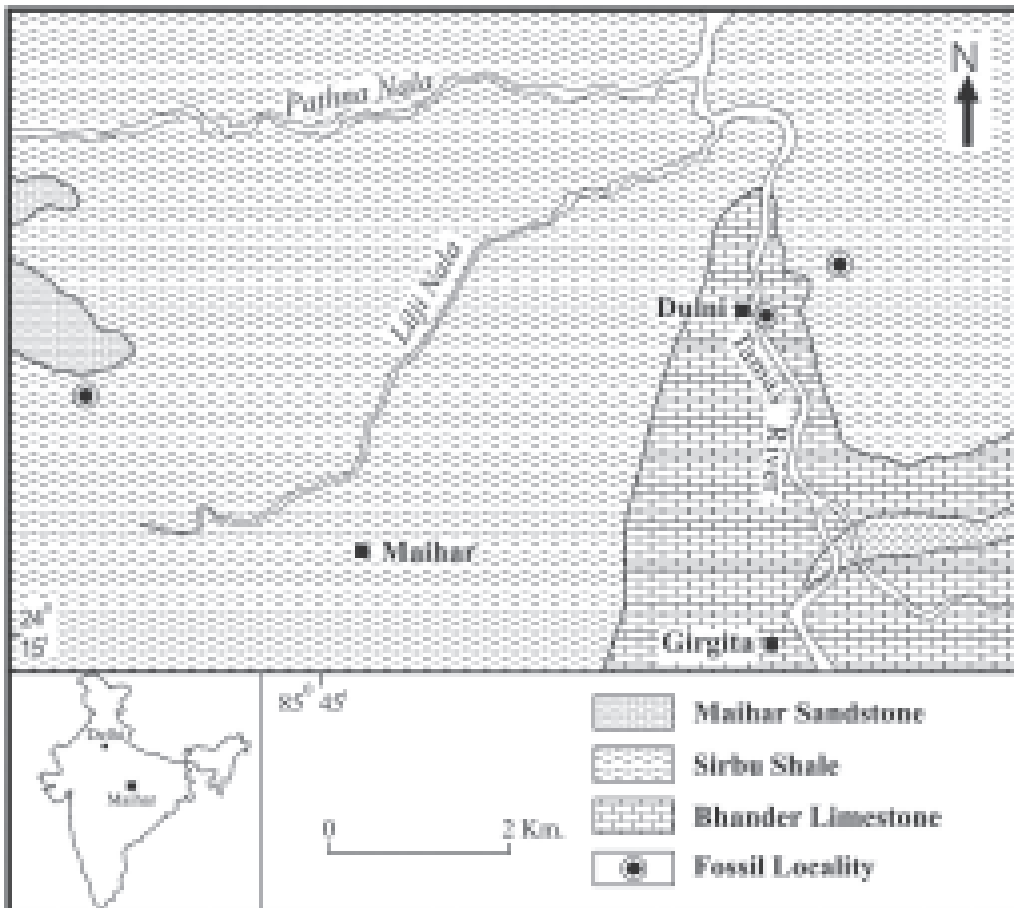


Fig. 48-Geological map of the Girgita, Emaliya and Dolni areas in Maihar, Satna District, Madhya Pradesh (modified after Bhattacharyya, 1993).

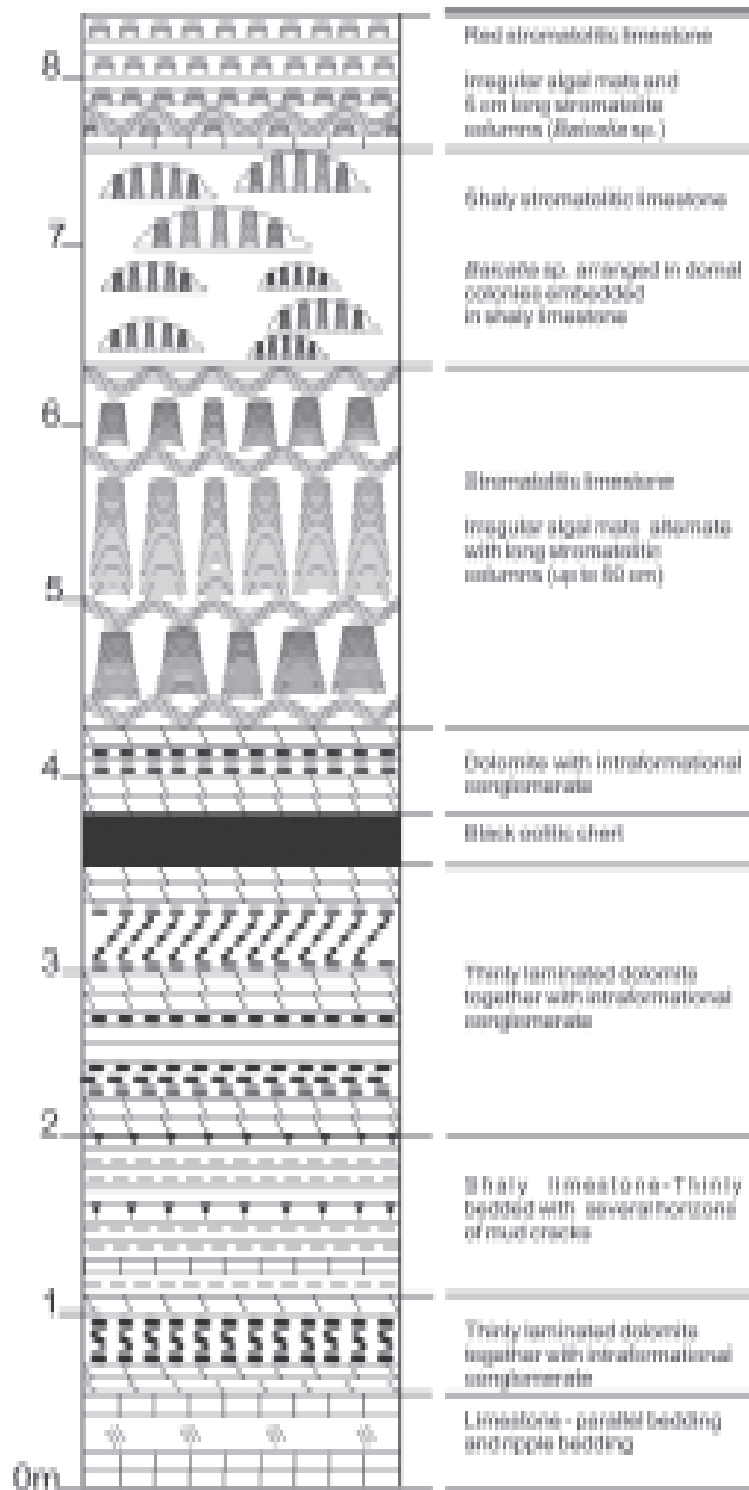


Fig. 49-Succession of sedimentary structures in the Bhandar Limestone, Tons River near Emaliya quarry, Maihar, Satna District, Madhya Pradesh (redrawn after Singh, 1976).

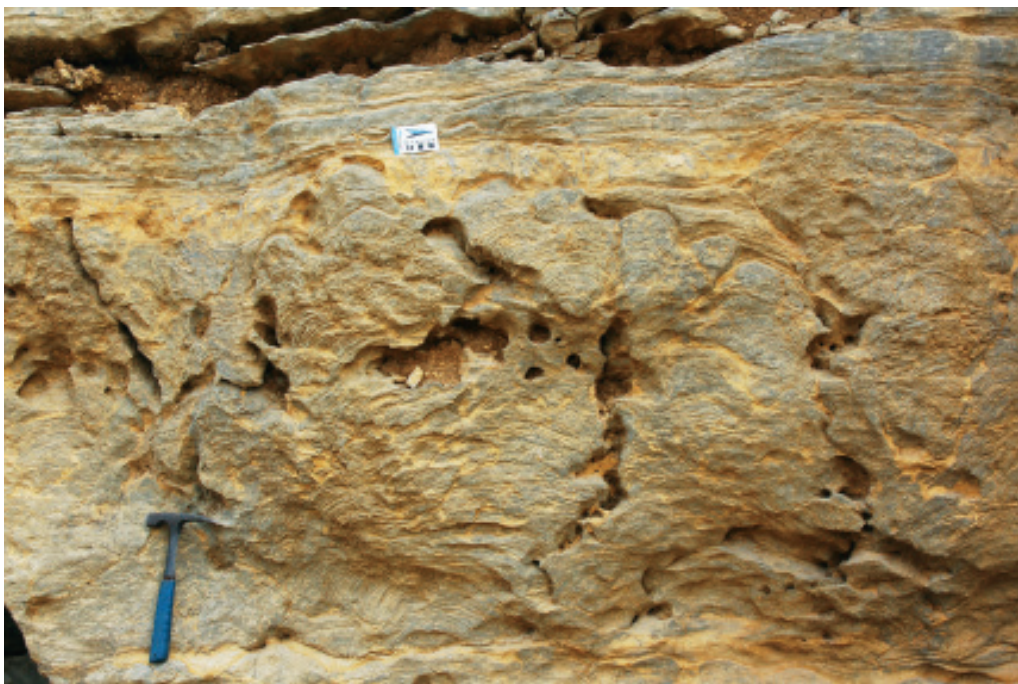


Fig. 50- Columnar stromatolite *Baicalia baicalica* in the Bhander Limestone, Tons river valley near Girgita quarry, Satna District, Madhya Pradesh.

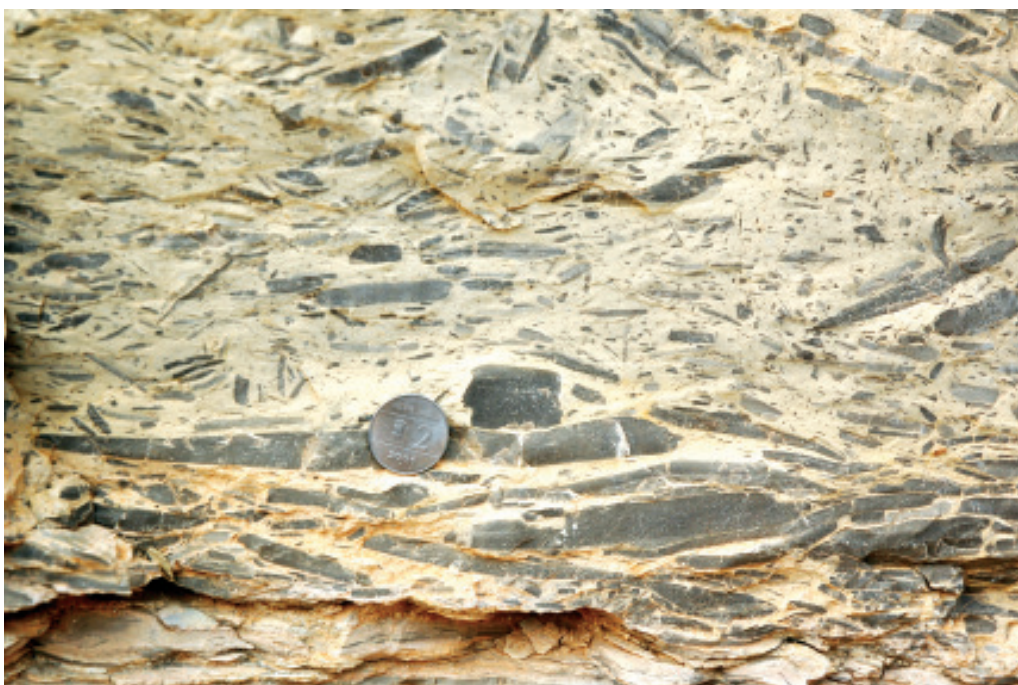


Fig. 51-Edgewise conglomerate in the upper part of the Bhander Limestone in the Tons River valley in Emaliya quarry, Maihar area, Satna District, Madhya Pradesh.



Fig. 52- Molar-Tooth structure recorded in the Bhandar Limestone, Girgita quarry, Maihar area, Satna District, Madhya Pradesh.

silicified oolitic horizon. Chertified oolites facies is underlain and overlain by stromatolites. Middle part of the Bhandar Limestone is exposed in Girgita and Emaliya quarries. Flaggy limestone beds show ripple and ripple cross lamination, climbing ripple lamination and occasionally herringbone-like cross lamination and mud cracks. A siltstone facies divides the middle and upper part of the Bhandar Limestone which is exposed 1 km east of Emaliya in Pahari Village.

Stop 17

Tons (Tamas) River—Dulni Village Section (Maihar)

Location—N 24°17' 27.8"; E 80°48' 05.2". DRM Satna; TS 63 D/15. Fig. 53.

Approach—5 km northeast of Maihar Township, the left bank of Tons (Tamas) River can be accessed through Dulni (Dolni) Village on the Maihar-Satna Road, whereas the right bank can be accessed through the Siddnath Temple Road on NH-7. During dry season, water remains very low and river can be crossed on foot.

Key observations—Upper part of the Bhandar Limestone is exposed in the cuttings of Tons River. Different facies can be easily demarcated in this section. Dark muddy oolitic limestone facies constitutes the base of the upper part of the Bhandar Limestone. The black limestone facies is characterized by plane laminations, small scale-cross bedding and ripple marks. Symmetrical and asymmetrical ripples, stylolites and

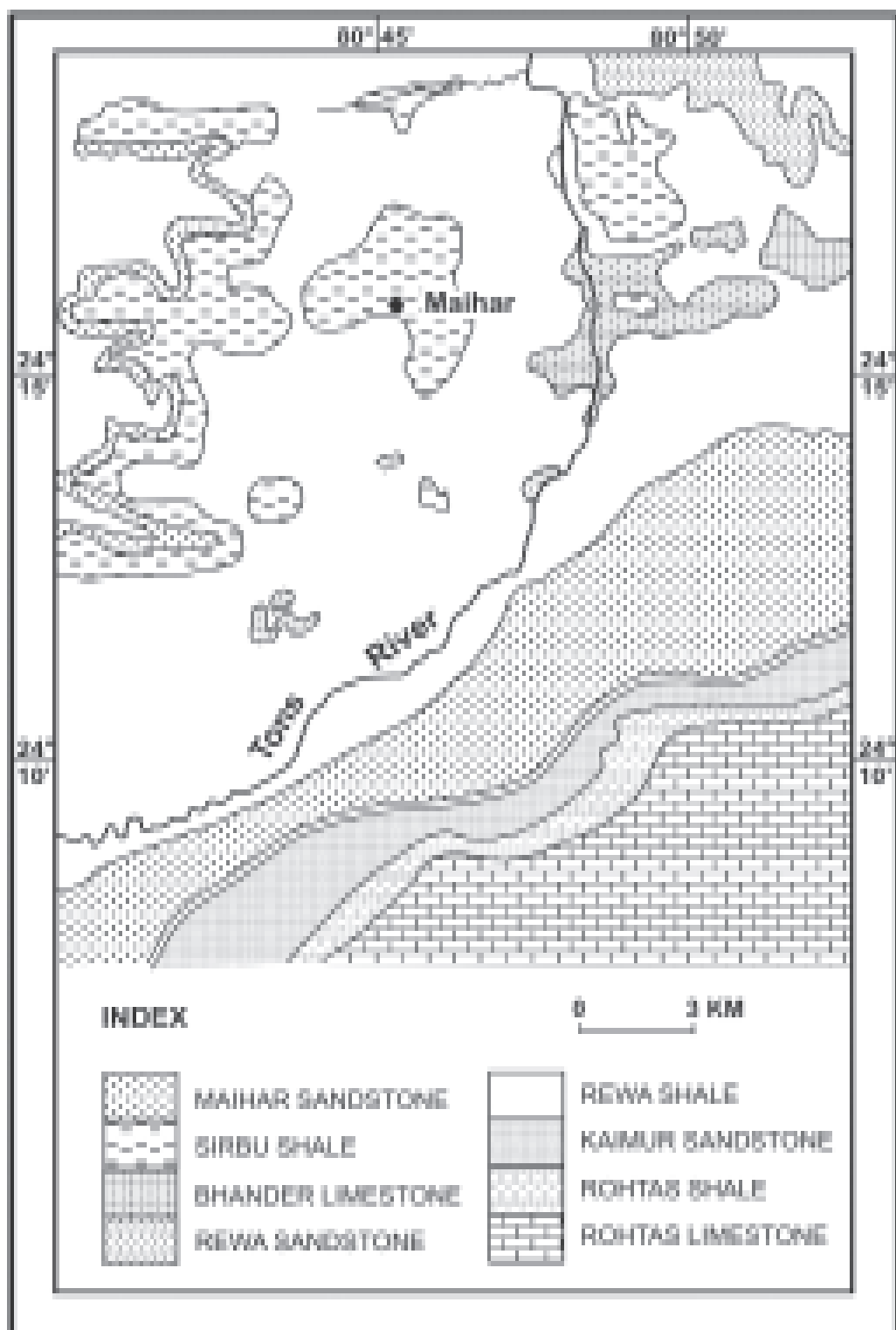


Fig. 53-Geological map of the Maihar area, Satna District, Madhya Pradesh (redrawn after Rao, 1949 in Kumar, 1978e).

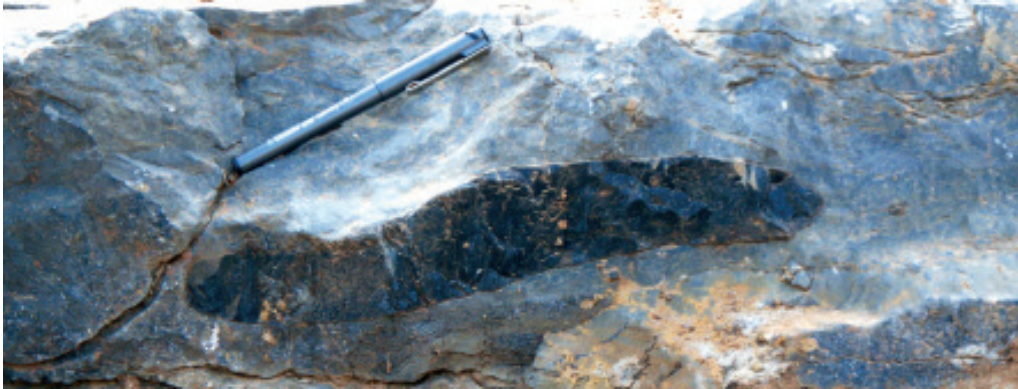


Fig. 54-Chert lens in the oolitic facies of the Bhandar Limestone, Dulni village section, Maihar area, Satna District, Madhya Pradesh.



Fig. 55-Yellow coloured cross bedded oolitic limestone facies of the Bhandar Limestone, Dulni village section, Maihar area, Satna District, Madhya Pradesh.



Fig. 56-Convolute lamination and ball and pillow structures in the upper part of the Bhandar Limestone, Dulni village section, Maihar area, Satna District, Madhya Pradesh.



Fig. 57-Convolute zone showing abrupt truncations in the upper part of the Bhandar Limestone, Dulni village section, Maihar area, Satna District, Madhya Pradesh.

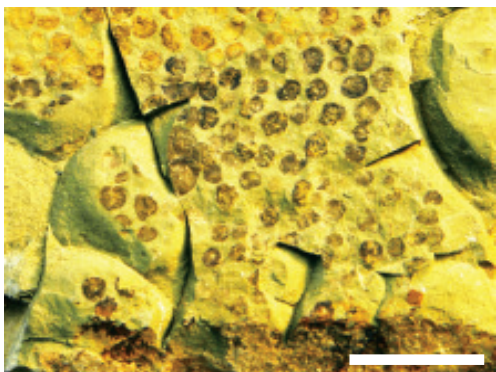


Fig. 58—An assemblage of carbonaceous megafossil *Chuaria* in the shale unit of the upper part of the Bhandar Limestone, Dulni village section, Maihar area, Satna District, Madhya Pradesh (Scale bar = 1 cm).

synaeresis cracks are common. Chert nodules occur as lenses (Fig. 54). Chanda *et al.* (1977) noted under the microscope that the oolites in the cherts are undeformed, whereas those occurring closely in nearby limestones are deformed. Black limestone facies is overlain by yellow coloured thin-bedded oolitic limestone facies (Fig. 55). This facies is characterized by ripples and cross stratification, swarms of chert nodules and intraclasts of varying sizes. Intraclasts show graded beddings. In the upper part, these beddings show convolute laminations and load structures (Fig. 56). At many places, the upper surfaces

of the convolute zone show abrupt truncations (Fig. 57). This facies gradually becomes more shaly with greenish shales and impure limestone that changes to the Sirbu Shale. Kumar and Srivastava (2003) recorded carbonaceous remains from the shale unit of the Bhandar Limestone exposed in the Tons river beds (Fig. 58).

Stop 18

Lilji Creek (Nala) Section, (Maihar)

Location—N 24°16' 52.0"; E 80°45' 37.3". DRM Satna; TS 63 D/15.

Approach—Good exposures of the Sirbu Shale can be seen in the north of Maihar on Maihar–Satna Motor Road. One has to walk for half a kilometer to reach the Lilji creek.

Key observations—The Maihar Township is situated on the rocks of the Sirbu Shale. Good exposures of the Sirbu Shale can be seen in the Lilji Creek. The lithology is represented by thinly laminated greenish coloured shale and siltstone. The siltstone layers in the basal part are rippled and mudcracked (Fig. 59). Excellent preservation of salt pseudomorph bearing shales has been noted from these outcrops (Fig. 60).

Stop 19

Pathera Creek (Nala) Section, (Maihar)

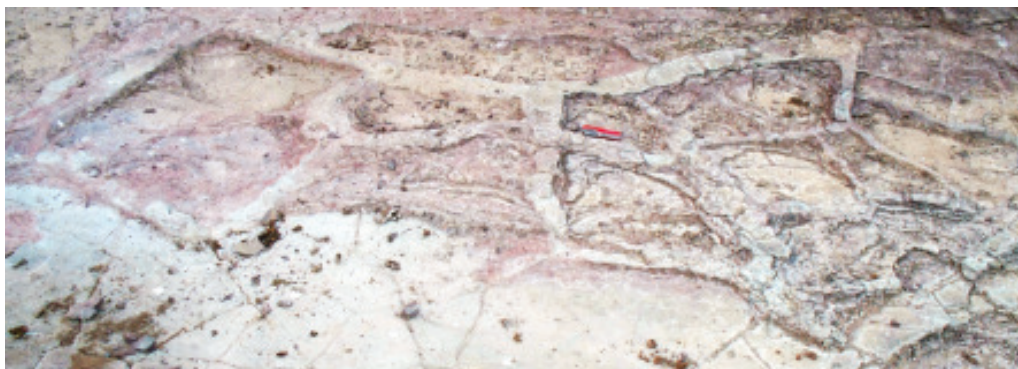


Fig. 59—Large sized mud-cracks in the Sirbu Shale exposed in Lilji creek, Maihar area, Satna District, Madhya Pradesh.



Fig. 60—Salt pseudomorphs recorded in the Sirbu Shale, Lilji creek, Maihar area, Satna District, Madhya Pradesh. Note the cuboidal casts of the salt on the sole surface of the Sirbu Shale.

Location—N 24°18' 36.3"; E 80°46' 10.2". DRM Satna; TS 63 D/15.

Approach—It is 5 km north of Maihar on Maihar-Satna Road. Section is easily accessible at the crossing of Pathera Creek and Maihar-Satna Road. It is also known as Pathna Creek.

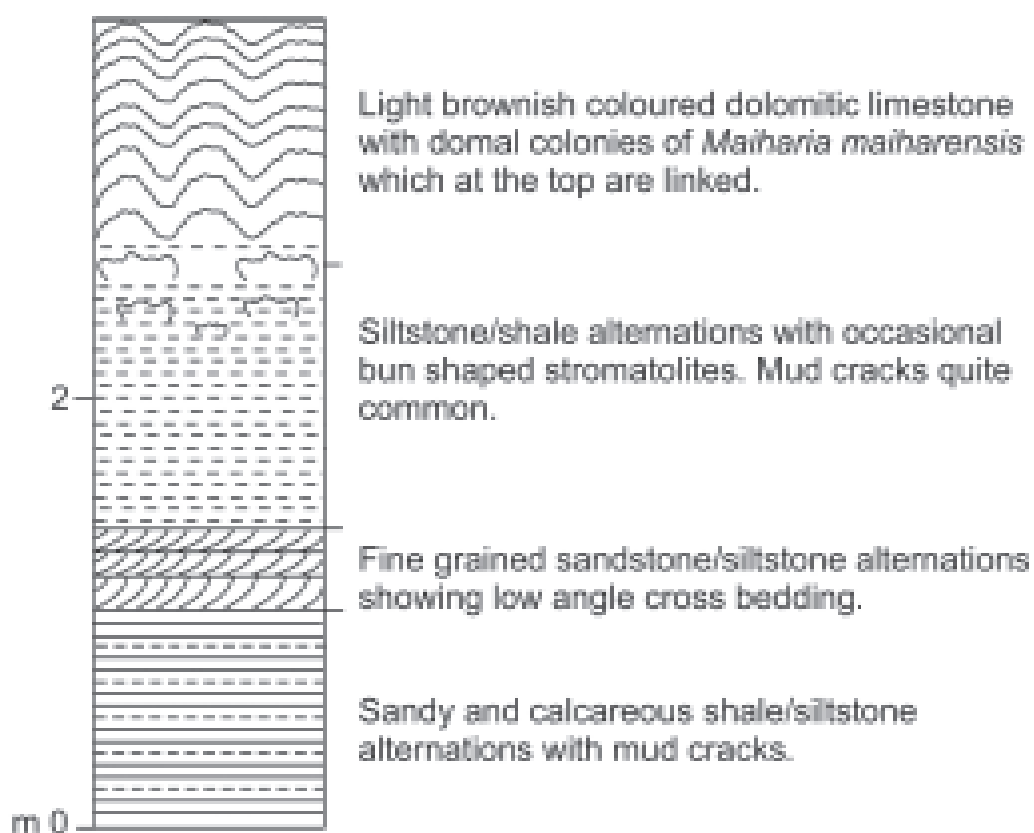


Fig. 61-Generalized litholog of the Sirbu Shale exposed in Pathera creek, Maihar area, Satna District, Madhaya Pradesh (redrawn after Kumar, 1976a).



Fig. 62-Stromatolite *Maiharia maiharensis* in the limestone unit of the Sirbu Shale exposed in the Pathera Creek, Maihar area, Satna District, Madhya Pradesh.



Fig. 63-Stromatolite *Maiharia maiharensis* in the limestone unit of the Sirbu Shale exposed in the Pathera Creek, Maihar area, Satna District, Madhya Pradesh as noted on the bedding surface.



Fig. 64-Stromatolite *Maiharia maiharensis* in the limestone unit of the Sirbu Shale exposed in the Pathera Creek, Maihar area, Satna District, Madhya Pradesh as noted at right angle to the bedding plane.

Key observations—A thin limestone bed within the Sirbu Shale, showing domal stromatolites *Maiharia maiharensis*, is exposed in the Pathera Creek (Fig. 61-64). The stromatolitic facies of the Sirbu Shale is sandwiched between heterolithic facies of shale and siltstone. The stromatolites are large dome shaped. Weathered surface of the stromatolites show concentric rings. From this section, Friedman and Chakraborty (1997) have recorded carbonate excursion of 2.1 ‰ PDB between this horizon and the underlying Bhandar Limestone. However, this excursion is not accepted by Kumar *et al.* (2005). Chakrabarti (1990) has recorded vertical burrows from this section from the Sirbu Shale horizon but their biogenicity could not be confirmed. The siltstone layers in the basal part are rippled and mudcracked. Presence of domal stromatolites suggest that water depth was never more than a meter during the formation of these stromatolites.

Stop 20

Maihar Temple—Rampura Road Section (Maihar)

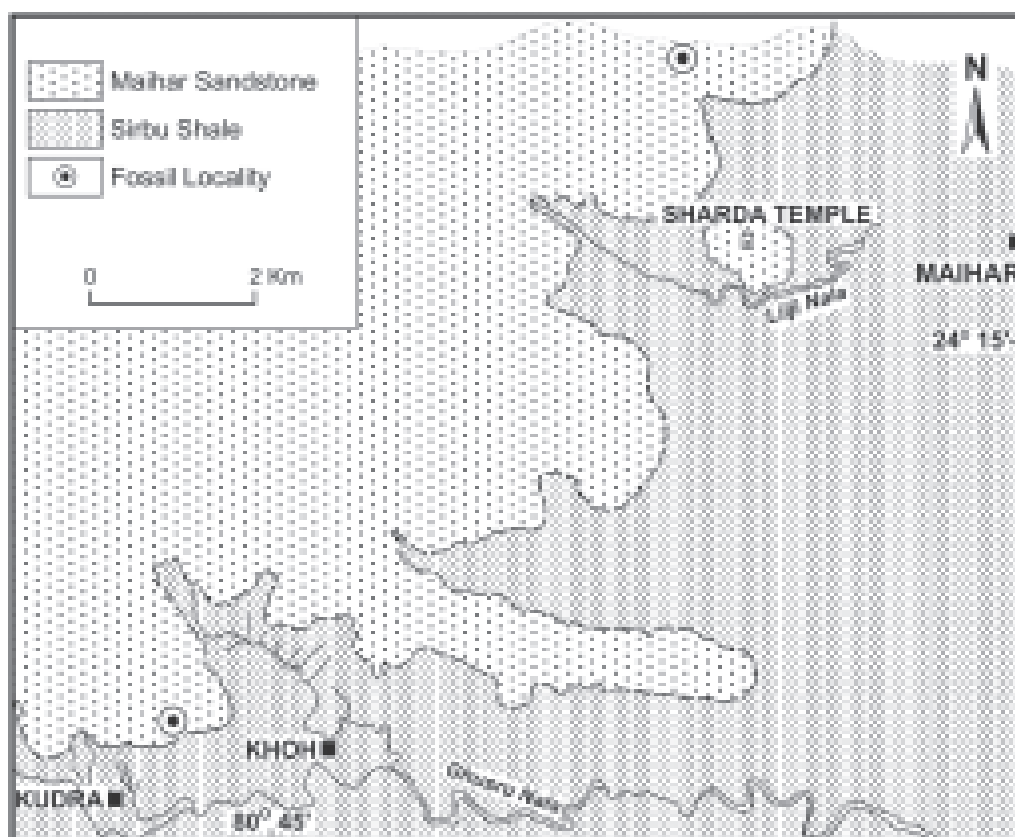


Fig. 65-Geological map of the area around the Maihar Temple, Satna District, Madhya Pradesh (after Kumar and Pandey, 2008).



Fig. 66—Inter laminated sequence of sandstone-shale near the contact of the Sirbu Shale and Sikaoda Sandstone (Maihar Sandstone) on the Maihar-Rampur road section, Maihar area, Satna District, Madhya Pradesh.

Location—N 24°16' 32.3"; E 80°42' 55.9". DRM Satna; TS 63 B/11. Fig. 65.

Approach—2 km west of Maihar, on the foothills of Sharda Temple, a metalled road bifurcates to Rampur Hill that exposes upper part of the Sirbu Shale.

Key observations—Good outcrops of the Sirbu Shale can be seen all along the motor road. In the upper part of the Sirbu Shale, siltstone and shale ratio gradually decreases upward turning into greenish-coloured thinly laminated, varve-like shale for considerable thickness. The Sirbu Shale near the contact with the Maihar Sandstone once again turns into inter-laminated siltstone-fine sandstone sequence (Fig. 66). Occasionally, very flat, scour surfaces carpeted by siltstone or fine sandstone have been recorded (Bhattacharyya, 1993). In an exposed section at 6 km stone, Kumar and Srivastava (1997, 2003) have reported *Chuarina* - *Tawuia* assemblage and a number of additional carbonaceous megafossils (see Fig. 67).

Stop 21

Rampur Road Ghat Section, (Maihar)

Location—N 24°16' 54.5"; E 80°42' 42.0". DRM Satna; TS 63 B/11.

Approach—2.5 km west of Maihar, on the foot-hills of Sharda Temple, a metalled road bifurcates to Rampur Hill that exposes the Maihar Sandstone.

Key observations—This section forms a typical Vindhyan scarp. Good exposures can be seen on the Maihar-Rampur Motor Road. The Maihar Sandstone occurs

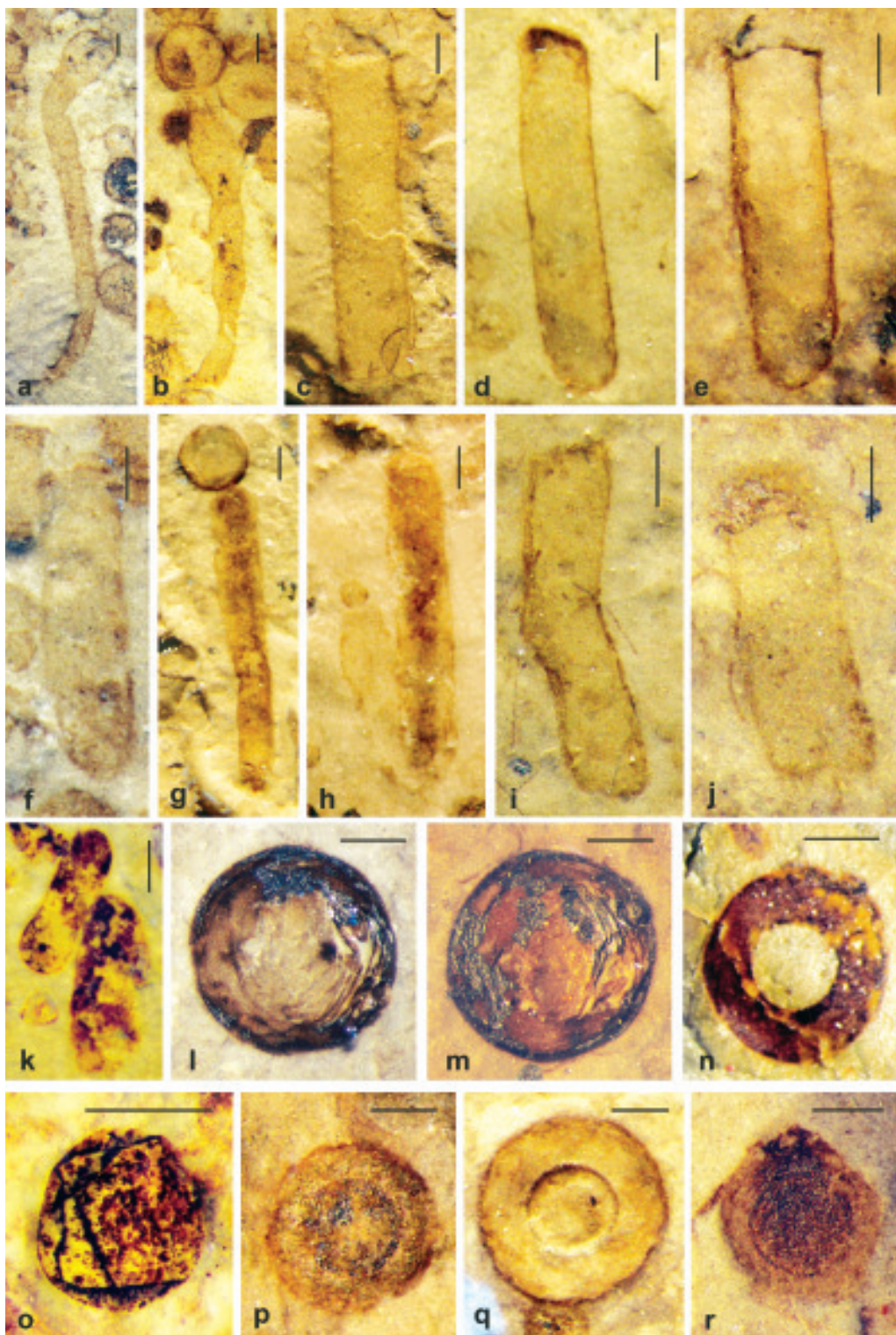


Fig. 67-Carbonaceous megafossils from the Vindhyan Supergroup. a-j: *Tawuia dalensis* Suket Shale, Rampur, Neemuch, M.P.; k: *Tawuia dalensis* Bhandar Limestone, Maihar area, M.P.; l, m: *Chuaria circularis* Suket Shale, Rampur, Neemuch, M.P.; n: *Bhanderia maiharensis* Bhandar Limestone, Dulni, Maihar area, M.P.; o: *Chuaria circularis* Sirbu Shale, Rampur road, Maihar area, M.P.; p-r: *Suketia rampurensis* Suket Shale, Rampur, Neemuch, M.P. (Scale=1mm).



Fig. 68—*Arumberia banksi* in the Sikaoda Sandstone (Maihar Sandstone), on the Maihar-Rampur road section, Maihar area, Satna District, Madhya Pradesh.

as a capping on the Sirbu Shale on the northwestern part of the Maihar Township. The lower part of the sandstone unit is characterized by alteration of red and brown shale and flaggy sandstone, whereas the upper part is made up of sandstone and complete absence of shale. Variety of sedimentary structures and microbial mat structures in siliciclastic rocks are noticed in the Maihar Sandstone. The sandstones are parallel laminated and cross bedded. Ripple marks are common and range from sharp crested ripples, flat-topped ripples, interference ripples, wave ripples with tuning fork junctions. Mud cracks, flute casts and load structures are also noticed. Kumar and Pandey (2008) have described the algal mat textures in the rippled surface of brownish red coloured sandstones. They have described *Arumberia banksi* and *Beltanelliformis* from this horizon (Fig. 68).

Stop 22

Chhoti Mahanadi—Kuteswar Mine Section, (Maihar)

Location—N 23°56' 29.9"; E 80°48' 32.7". DRM Satna; TS 64 A/13.

Approach—30 km southeast of Maihar on Maihar-Dhanwahi Road.



Fig. 69-Longitudinal section of *Thyssagetes* sp. in the Kajrahat Limestone exposed in the Chhoti Mahanadi Section, Maihar area, Satna District, Madhya Pradesh.



Fig. 70-Transverse section of *Thyssagetes* sp. in the Kajrahat Limestone exposed in the Chhoti Mahanadi Section, Maihar area, Satna District, Madhya Pradesh.

Key observations—The Kuteswar Mines of the Steel Authority of India are situated on the Maihar-Dhanwahi section on either side of the Chhoti Mahanadi River. Mishra *et al.* (1990) have given the thickness of the Kajrahat Limestone in this area as ca. 300 m. They have subdivided the Kajrahat Limestone into three members as Low-



Fig. 71-Longitudinal section of *Calypso* sp. in the Kajrahat Limestone exposed in the Chhoti Mahanadi Section, Maihar area, Satna District, Madhya Pradesh.

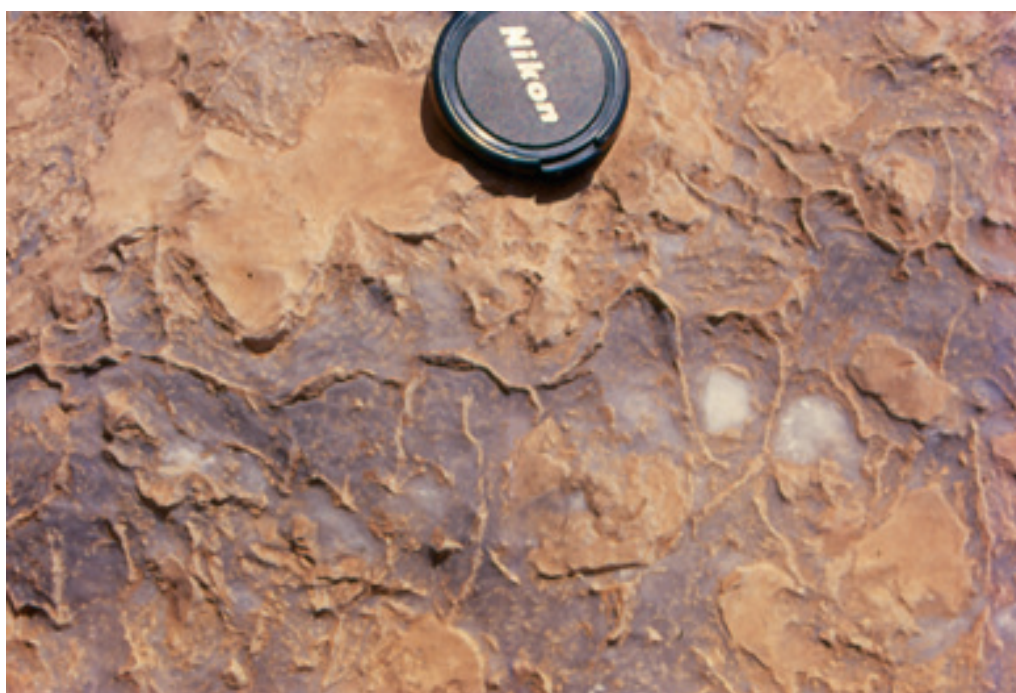


Fig. 72-Transverse section of *Calypso* sp. in the Kajrahat Limestone exposed in the Chhoti Mahanadi Section, Maihar area, Satna District, Madhya Pradesh.

er Flat Bedded Limestone, Middle Biohermal Limestone and Upper Flat Bedded Limestone. They were the first to record the repeated cycles of *Conophyton* from the middle part of the Kajrahat Limestone. Good exposures of the middle part of the Kajrahat Limestone can be seen on either banks of Chhoti Mahanadi River. Extensive carbonate mounds are exposed on the banks of the Chhoti Mahanadi under the newly constructed bridge. Many forms of *Conophyton* along with *Colonnella* can be seen.

Calypso and *Thyssagetes* have been reported (Kumar, 1999a) (Figs. 69-72). Presence of *Jacutophyton* and *Externia* has also been noted. There are repeated stromatolite cycles starting with *Conophyton* then changing to *Jacutophyton*. In our opinion, each cycle represents shallowing upward sequence. Carbonate fan fabrics have also been noted in this section. Such fabrics are typical of the Palaeoproterozoic and early Mesoproterozoic carbonate sequences world over.

Stop 23

New Banjariya Village Section, (Maihar)

Location—N 24°03' 51.1"; E 80°49' 51.1". DRM Satna; TS 63 D/16.

Approach—15 km southeast of Maihar on Maihar-Dhanwahi Road. From this road further 3 km towards new Banjariya Village by taking unmetalled road.

Key observations—The thinly bedded Salkhan Limestone is exposed on the surface that shows chertified laminites and massive limestone which is excavated for building material by the local peoples. Equivalent horizons in Salkhan (U. P.), Jaradag (Bihar) and near Amrapatan (Maihar) have yielded extensive microfossils (McMenamin *et al.*, 1983; Kumar and Srivastava, 1995; Sharma, 2006b and Sharma unpublished).

Stop 24

Badanpur Mine Section, (Maihar)

Location—N 24°10' 20.6"; E 80°51' 20.3". DRM Satna; TS 63 D/16.

Approach—Badanpur Mines of Birla Cement Factory are situated in the south of Maihar township on Maihar-Dhanwahi Road. The Rohtasgarh Limestone is being mined for the manufacture of cement in the area.

Key observations—Good section of the Rohtasgarh Limestone can be seen in the mines of the Maihar Cement Factory. The upper horizon of the Rohtasgarh Limestone represented by the shales, calcareous shales and silicified shales (the Bhagwar Shale Member) is also exposed in the mines. The contact between the Rohtasgarh Limestone and the overlying Kaimur Sandstones can be studied. *Grypania* and *Chuarina* can be collected from the upper most part of the Rohtasgarh Limestone.

Stop 25**Maihar—Dhanwahi Road Section (Between Sarla Nagar and Badanpur)**

Location—N 24°10' 41.8"; E 80°48' 44.7". DRM Satna; TS 63 D/16.

Approach—11.1 km south of Maihar on Maihar-Dhanwahi Road near the hump.

Key observations—North of Badanpur in the nala cuttings, the silicified Bhagwar Shale is exposed. From this horizon, Azmi (1998) has reported the presence of small shelly fauna, which could not find favour with the majority of the workers. It is followed by the Kaimur sandstones which can be studied on either sides of the road cuttings. It is overlain by the rocks of the Rewa Group. Only two litho-units of the Rewa Group have been identified, one represented by sandstone and the other by the shales.

Stop 26**Maihar—Dhanwahi Road Section (Between Sarla Nagar and Badanpur)**

Location—N 24°10' 49.0"; E 80°48' 41.7". DRM Satna; TS 63 D/16.

Approach—11.1 km south of Maihar on Maihar-Dhanwahi Road near the hump.

Key observations—The Dhandraul Sandstone, the topmost stratigraphic unit of the Kaimur Group is exposed along the hill ranges to the south of Maihar. It unconformably overlies the tightly folded Bhagwar Shale of the Semri Group. Small thickness of the Kaimur Group is noteworthy in the Maihar area. In other areas, this stratigraphic unit is very thick (200-300 m). Singh (1976) and Bhattacharyya (1993) showed the presence of dunes of varied dimensions, ripples, reactivation surfaces, ripple cross-laminae, flute casts and large-scale cross stratification.

Stop 27**Maihar--Dhanwahi Road Section (Between Sarla Nagar and Badanpur)**

Location—N 24°11' 11.0"; E 80°48' 46.8". DRM Satna; TS 63 D/16.

Approach—South of Maihar, the hill ranges on the northern slopes expose the Rewa Group on the road leading to Dhanwahi.



Fig.73-Hump back dunes of the transitional flow regime in the Govindgarh Sandstone on the Maihar-Dhanwahi Road Section, Maihar area, Satna District, Madhya Pradesh.



Fig. 74-Large scale concave up cross strata constituting the dunes in the Govindgarh Sandstone, Sarla Nagar-Badanpur Road, Satna District, Madhya Pradesh.

Key observations—In Maihar, the Rewa Group is represented by two upper lithostratigraphic units, i.e. Jhiri Shale and Govindgarh Sandstone (Upper Rewa Sandstone). Its contact with underlying Kaimur Group is conformable. Dips are sub-horizontal. A very good section is exposed in a road quarry on Maihar-Dhanwahi Road. The basal section is constituted of buff coloured, well-sorted, fine to medium-grained parallel-laminated sandstone; it has excellent parting lineations and current crescents on the bedding plane (Bhattacharyya, 1993). Dunes of lower flow regime and hump back dunes of transitional flow regime characterize the upper part of the basal section (Fig. 73). Large-scale concave-up cross strata constitute the dunes (Fig. 74). At several places the cross-strata are locally overturned and present recumbent fold-like geometry.



Fig. 75—Overturned cross-strata in the Govindgarh Sandstone in the Hathi Nala section, Sarla Nagar, Satna District, Madhya Pradesh.

Stop 28

Hathi Nala Section (Sarla Nagar, Maihar)

Location—N 24°12' 15.4"; E 80°48' 42.46". DRM Satna; TS 63 D/16.

Approach—South of Maihar, 200 meters east of cement factory, hill range on the northern slopes exposes the Rewa Group on the road leading to Sarlanagar compound.

Key observations—Good exposers of the Govindgarh Sandstone (Upper Rewa Sandstone) are seen in the compound of the Sarla Nagar in the Hathi Creek (Nala). It is a coarsening upward sequence with granules and pebbles in its upper part. Large trough sets are common in the Upper Rewa Sandstone. Curved and concave down-current fore-sets of trough are prominent in contrast to straight fore-sets in tabular type. Simple cross stratification and compound stratification occur at several places in the Hathi Creek. Penecontemporaneous deformation has modified the cross stratification. At several places, the cross-strata are locally overturned and present recumbent folds like geometry (Fig. 75). It is considered that cross-stratified sets were produced by migration of trains of asymmetric dunes (Bhattacharyya, 1993). Ripple drift cross laminations are also very common with several reactivation surfaces.

Stop 29

Bistara Mine Section (Maihar – Katni Road)

Location—N 23°58' 27.7"; E 80°27' 10.8". DRM Katni.

Approach—50 km southwest of Maihar on NH-7 (Maihar- Katni Road); and 17 km northeast of Katni.



Fig. 76-*Katnia singhii* helically coiled fossil recorded from the Rohtasgarh Limestone, Tikaria locality, Katni District, Madhya Pradesh.



Fig. 77-High angle dipping Rohtasgarh Limestone in the Bistra Mines, Katni District, Madhya Pradesh.

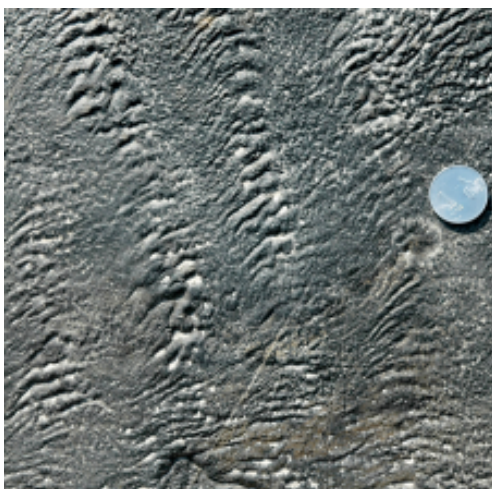


Fig. 78-Microbially induced sedimentary structure (MISS) developed on the bedding surface, Rohtasgarh Limestone, Semri Group exposed in the Bistara Mines, Katni District, Madhya Pradesh.

Key observations—A good section of the Rohtasgarh Limestone and Bhagwar Shale are exposed in the Bistara Mines in the Jukehi area of Katni District. The shales and limestone of this area have yielded very well-preserved megascopic carbonaceous forms, viz. *Grypania spiralis*, *Katnia singhii*, *Spiroichnus beerii* (Sharma and Shukla, 2009a) (Fig. 76). Tectonically disturbed, folded beds are dipping at high angle (Fig. 77). Calcite veins, microbially mediated structures (Fig. 78) and slicken-side like calcite sheets are very common in the limestone of this area. Certain beds are extremely dark black to brown due to excessive organic content. The Rohtasgarh Limestone gradually passes into the Bhagwar Shale, which is exposed at higher reaches of the section and on the road section to Kymore. This is capped by the Kaimur Sandstone and at places covered by the Deccan basalt.

Stop 30

Panna Diamond Mine Section (Panna)

Location—N 24°38' 44"; E 80°01' 59.4". DRM Panna.

Approach—16 km inside the Panna Tiger Reserve on Satna-Chhatarpur Road. For the access to the mine area, one has to take permission from the Headquarters of the National Mineral Development Corporation at Hyderabad.



Fig. 79-Open cast Majhagawan Diamond Mine, Panna District, Madhya Pradesh.



MAJHGWAN DIAMOND MINES NMDC LTD MAJHGWAN PANNA (M.P.) SALIENT FEATURES	
• DISCOVERY OF KIMBERLITE PIPE	1827 A.D.
• EXPLORATION BY NMDC	1959-1968 A.D.
• MINING LEASE	275.963 Ha.
• COMMENCEMENT OF PRODUCTION	1968 A.D.
• INCIDENCE	10 CARATS/100 Tc
• PRODUCTION TO DATE	(+) 10 LAKH CARATS
• PIT DIMENSIONS	370 M - 490 M (TOP) 75 M - 87 M (BOTTOM)
• R.L. TOP	376.00 M.
• R.L. BOTTOM	288.00 M.
• DEPTH	88 M
• ENVIRONMENTAL MEASURES	
▶ PLANTATION	137250 PLANTS
▶ CHECK DAM	9 Nos
• ACCREDITATION	ISO 14001: 2004

Fig. 80-Display board giving basic information about the Majhagan Diamond Mines, Panna District, Madhya Pradesh.

Key observations—Both the Kaimur Sandstone and the Kimberlite Pipe can be studied in the open-cast mine section. The Panna Diamond Field covers an area of about 4000 sq km, sandwiched between the Son and the Ken rivers, at the northern edge of the Vindhyan Plateau on the Bundelkhand craton of central India. The diamonds are recovered since antiquity in the Panna field and are confined to the old working in the Upper Vindhyan and the alluvium. However, primary sources (e.g. Kimberlitic Pipes) for some of these diamonds are also known to occur at Majhagan (Fig. 79, and 80), Hinota and Bunder (a new finding by the Rio Tinto). It is interesting to note that even though the diamonds were mined from the Majhagan pipe at least from 1830, its nature was recognised as Kimberlitic only in

1930s – which is some 60 years after the primary source rock for the diamond, was identified and named as Kimberlite, after the place Kimberley, in South Africa. There is a marked disagreement between the researchers as to the exact nomenclature of all the three pipes - whether they are a kimberlite or lamproite or even an orangeite. However, the fact remains that the Majhagan is the only diamond-producing mine in the country. All these diamondiferous ultramafic pipes intrude the Baghain Quartzite Formation of the Kaimur Group of the Vindhyan Supergroup. Their emplacement age at 1100 Ma imposes important constraint on the upper limit of sedimentation in the Upper Vindhyan rocks.

Stop 31

Pandav Fall Section (Panna)

Location—N 24°43' 51.0"; E 80°04' 02.6". DRM Panna.

Approach—Half a kilometer inside 'Pandav Fall Forest Park' on Satna-Chhatarpur Road.



Fig. 81-Contact of the Bundelkhand Granite with the overlying rocks of the Semri Group with in the premises of the Pandav Fall Forest Park. Rocks overlying the granite (marked by white line) belong to the Rampur Formation of the Semri Group.



Fig. 82-Large loose blocks of the Pipartola Conglomerate of the Kaimur Group are used as building material in making boundary wall of the Panna Tiger Reserve in Panna District, Madhya Pradesh. The conglomerate is constituted of feldspathic quartzite, black chert, red and yellow jasper, vein quartz and porcellanitic shale.

Key observations—In the lower reaches of the Pandav falls, the rocks of the Bundelkhand Granite Complex are exposed. Weathered pieces of granite are present in the lower most unit of the Semri Group followed by the Glauconitic Sandstone (=Rampur Formation) that is correlated with the Glauconitic Sandstone of the Sonbhadra area (Fig. 81). The sandstone is greenish grey to olive green coloured, medium to fine grained. Bedding is thin and flaggy to slaby and lenticular in nature. In the middle part, it is ash grey, pinkish to cherty. The sedimentary structures include cross bedding, asymmetrical ripples, dessicaion cracks, etc. In this area, the Kaimur Group is represented by two rock units namely conglomerate and quartzite. The Quartzitic unit is equivalent to the Dhandraul Sandstone of the Son Valley. The Conglomerate found in this locality, i.e. Bundelkhand area, is not noticed in the Son Valley. Good exposures of the conglomerate are seen in the Pipartola Village where it attains a thickness of 15 meters (Mathur *et al.*, 1978). Further east, it has been encountered in the Hinota Gorge and the Kamesan Nala, though reduced considerably in thickness to one meter and 15 cm respectively. The Lower Rewa Sandstone (Asan Sandstone) is locally called the Itwa Sandstone. It has diamond-bearing conglomerate towards the top. It comprises pebble and cobbles of fine feldspathic quartzite, black chert, red and yellow jasper, vein quartz and porcelanitic shale in a coarse sandy and ferruginous matrix. This conglomerate can be seen as a building material on the gates of the Panna Tiger Reserve (Fig. 82).

F. Varanasi–Chopan–Renukoot Section

(Following sections were covered during the Field Workshop in 2002 and were not a part of the Field Workshop organized in 2010. However, these are incorporated for the benefit of the researchers and students willing to see the eastern part of the Son Valley.)

This section can be covered from either Varanasi or Chopan / Renukoot (U. P.).

Stop 32 A & B



Fig. 83-A view of the Garai Falls, developed in the Mangesar Sandstone, the Kaimur Group, Sonbhadra District, Uttar Pradesh. The sandstone forms shelters which show rocks cave painting also.

Varanasi-Robertsganj Section

Location— A-Garai River Bridge on Varanasi-Robertsganj Motor Road.
N 24°57.531'; E 83°0.569'.

B-On the Varanasi-Robertsganj Motor Road, N 24°55.412';
E 83°02.732'.

Approach—Stops are located on the Varanasi-Robertsganj Motor Road and both the stops can be covered from Varanasi or Chopan.

Key observations—From Varanasi to Adalhat township, the Gangetic Alluvium covers the area. The sediments belong to the Older Alluvium of the Quaternary Period. First outcrop of the Vindhyan rocks is exposed near Adalhat about 24 km from Varanasi and regular ENE-WSW trending escarpments formed by the sandstones of the Kaimur Group are seen from Ahraura township about 36 km from Varanasi, constituting typical Vindhyan geomorphical setting. Good exposures can be seen on both the sides of the road. The Dhandraul Sandstone occupies the plateau region. In the valley region, the Scarp Sandstone (Mangesar Formation) is exposed. At places, there is poor development of a laterite.

The first stop is situated on the Scarp Sandstone (Mangesar sandstone). The tabular and trough large scale cross bedding is well exposed. The Garai River forms beautiful falls (Fig. 83) within the Mangesar Sandstone and ancient rock painting can also be seen in the rock shelters. The second stop is located on the Dhandraul Sandstone on the plateau region where well-preserved cross bedding is developed.

Stop 33 A, B & C

Robertsganj-Ghat Section

Location— A- N 24°37.286'; E 83°02.918' (TS-63P/2);
B- N 24°37.156'; E 83°02.392' (TS-63P/2);
C- N 24°37.139'; E 83°02.683' (TS-63P/2).

Approach—All the three stops are on the Robertsganj-Chopan Toad. The road from plateau region descends towards the Son Valley and this descent is referred to as 'Ghat' in the local language. First stop is on the newer road-cutting with lesser slope and is about 50 meters from *Vir Lorik Pathar Memorial Gate* towards Ghat. The second stop is about half way of the Ghat Section and the third stop is near the base of the Ghat Section where the two roads join, one with steep slope and other with relatively lower slope.

Key Observations—The first Stop (A) is situated on the Dhandraul Sandstone where large-scale cross bedding can be observed. The Mangesar Sandstone can be studied at Stop (B). At Stop (C), a small outcrop of the Bijaigarh shales is also exposed. In the Ghat section, the rocks show some deformation and small-scale folding can be seen.

Stop 34 A & B

Ghurma Mine Section

Location— A- N 24°35.903'; E 83°04.060' (TS-63P/2);
B- N 24°36.324'; E 83°05.041' (TS-63P/2).

Approach—This section can be approached from the Robertsganj-Chopan Motor Road from Markundi Village. It is about 2 km from the road. Near Ghurma Village, the road crosses the Ghaghar River. The Ghaghar River Bridge is the first stop (3A) of the Ghurma Mine Section. Further northward, the road leads to the Kaimur Scarp. There is a barrier near the old mining site of the Churk Cement Factory, which is now owned by Jaypee Cement Corporation. About one and half kms towards Makri-Bari



Fig. 84-A section of the Rohtasgarh Limestone, Ghurma Mine, Sonbhadra District, Uttar Pradesh. *Chuaria* can be collected from these mines. Some deformation is also seen.

from Ghurma Mine barrier, stop (3B) is located where a number of mines on the northeastern side can be seen.

Key Observations—In the Ghaghar River, the Rohats Limestone (Fig. 84) is exposed in which a sandstone dyke has intruded (Fig. 85). At Ghurma Mine, the contact of the Rohtas Limestone and Kaimur Sandstone can be studied which appears as normal. Carbonaceous mega-fossils *Chuarina* and *Tawuia* (?) can be collected from these limestone and shales.

Stop 35

Salkhan Hill Section

Location— N 24°35.225'; E 83°02.249' (TS-63P/2).

Approach—The site has been declared as a fossil park and can be approached by a motor road from the main Chopan-Robertsganj Motor Road near the Salkhan Village which is about 3 km from the Chopan-Robertsganj Road.

Key Observations—The hillock is made up of the Glauconitic Sandstone (Rampur Formation) and in the lower reaches the Salkhan Limestone (Fawn Limestone) is exposed on the northern side of the hillock (Fig. 86). However, the contact is covered with soil. The Salkhan Limestone shows beautifully preserved *Conophyton garganicus* (*Ephyaltes myriocranus*) (Fig. 87 & 88). In the upper part, small sized *Colonnella columnaris* is also developed. The associated



Fig. 85-A sandstone dyke in the Rohtasgarh Limestone near Ghurma Bridge, Sonbhadra District, Uttar Pradesh.



Fig. 86-A board on the entrance of the fossil park, Salkhan Hill, Sonbhadra District, Uttar Pradesh.

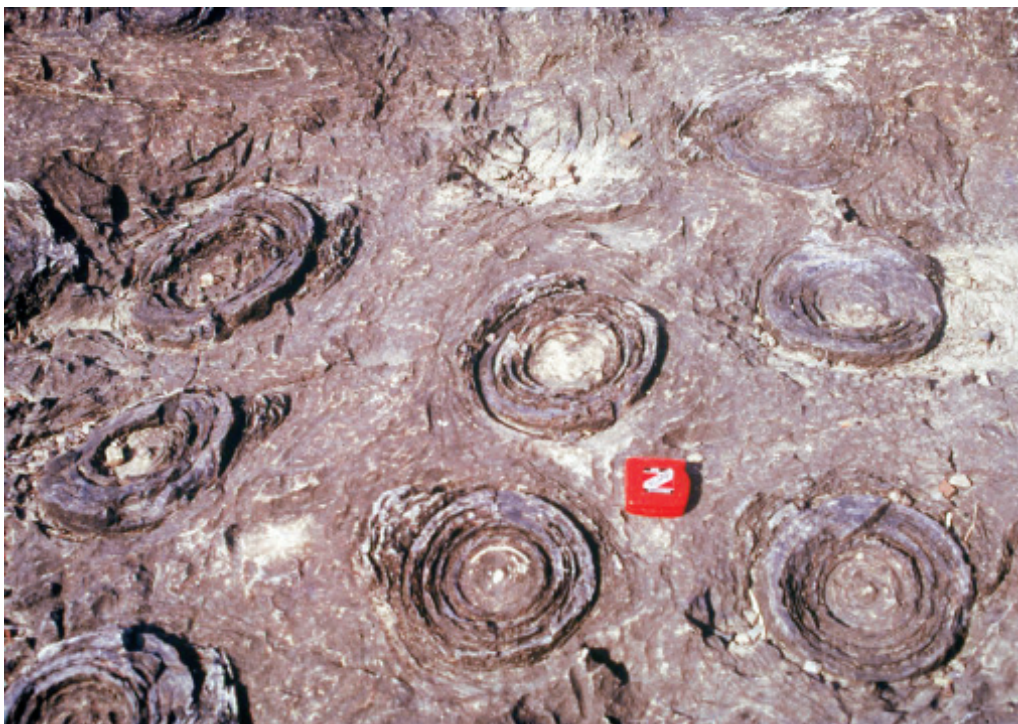


Fig. 87-A surface plan view of the stromatolite *Conophyton garganicus* (*Ephyaltes myriocranus*) in the Salkhan Limestone, Salkhan Hill, Sonbhadra District, Uttar Pradesh. Note the rounded cross section of the conical stromatolites.



Fig. 88-Longitudinal section of the stromatolite *Ephyaltes myriocranus* (*Conophyton garganicus*) recorded in the Salkhan Limestone, Salkhan Hill, Sonbhadra District, Uttar Pradesh.

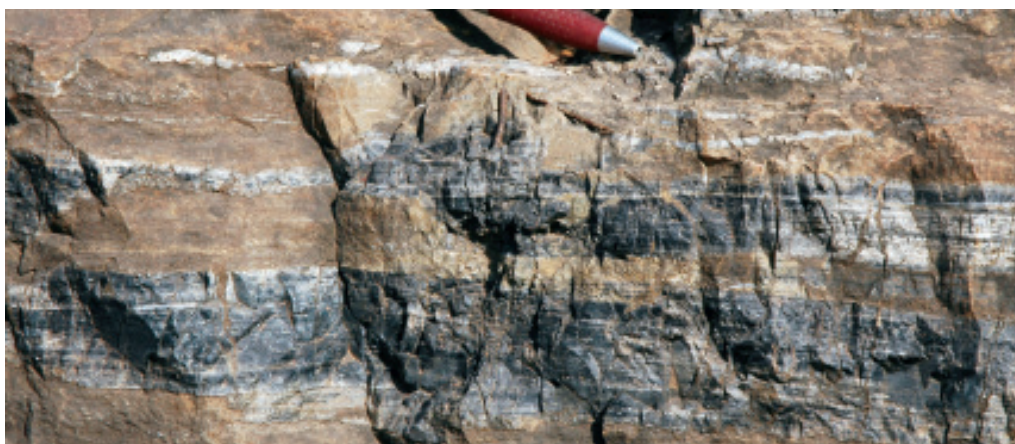


Fig. 89-Algal laminites and black bedded cherts are extensively developed in the Salkhan Limestone, Salkhan Hill, Sonbhadra District, Uttar Pradesh.

algal laminites are silicified and black bedded chert (Fig. 89) is extensively developed which shows excellent preservation of microbiota. From the thin sections of these silicified algal laminites and black cherts, Kumar (1978b), McMenamin *et al.* (1983) and Kumar and Srivastava (1995) have described well-preserved microbiota. The glauconitic sandstone shows excellent preservation of ripple marks and mud cracks.

Stop 36

Pataudh (Patwadh) Hill Section

Location— N 24°32.563'; E 83°02.443' (TS-63P/2).

Approach—The site can be approached by a road from the main Chopan-Robertsganj Highway near Kerwa Village which leads to the main Lift Canal Pump Station. It is about 2 km from the main road.



Fig. 90-Longitudinal polished cross-section of the stromatolite *Mistassinia* noted in Salkhan Limestone, Pataudh Hill section, Sonbhadra District, Uttar Pradesh. Scale is = 1 cm.

Key Observations—The small hillock is made up of the Salkhan Limestone in the lower part and the Rampur Formation (Glaconitic Sandstone) in the upper part. The contact can be observed in this hillock. In the upper part, the Salkhan Limestone shows development of columnar stromatolites *Mistassinia* and *Colonnella* (Fig. 90). Here, the Salkhan Limestone shows altogether different facies in comparison to the limestone developed in the Salkhan Hill.

Stop 37

Lift Canal Pumping Station Section

Location— N 24°31.144'; E 83°02.956' (TS-63P/2).

Approach—The site can be approached by a motor road from the Chopan-Robertsganj Highway from Kerwa Village. The road which leads to Pataudh Hill continues further south along the canal. The motor road ends at the pumping station near the bank of Son River.

Key Observations— At the pumping station, the Koldaha (Olive) Shale is exposed just at the end of a staircase. Well-developed graded bedding in the rhythmites can be seen. On the left hand-side, the Salkhan Limestone is exposed. Moving further west, the Rampur Formation (Glaconitic Sandstone) is exposed and a sharp contact with the underlying limestone horizon can be seen.

Stop 38

Bari Section

Location— N 24°28.143'; E 83°02.188' (TS-63P/3).

Approach—There is a hillock near Bari Village in front of a Bharat Petroleum (petrol pump) on the Dala–Chopan Motor Road which is about 2 km from Dala.

Key Observations— The uppermost part of the Kajrahat Limestone can be studied in this section. It shows profuse development of stromatolites. *Colonnella*, (Fig. 91A), *Platella* (Fig. 91B) and *Ephyaltes* (Fig. 92) can be identified. They occur as biostrome.



Fig. 91A-*Colonnella columnaris* in the upper part of the Kajrahat Limestone exposed near Bari Village, Sonbhadra District, Uttar Pradesh.



Fig. 91B-Surface plan view of the stromatolite *Platella* developed in the upper part of the Kajrahat Limestone exposed in a hillock near Bari Village, Sonbhadra District, Uttar Pradesh.

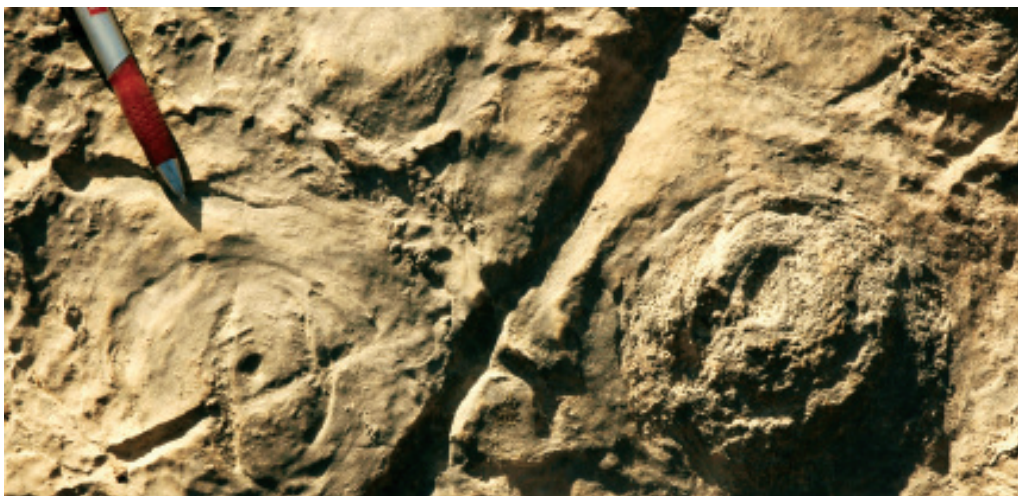


Fig. 92-Cross-section of *Ephyaltes* in the upper part of the Kajrahat Limestone exposed near Bari Village, Sonbhadra District, Uttar Pradesh.

Stop 39

Dala-Chopan Road Section

Location— N 24°29.002'; E 83°01.927' (TS-63P/3).



Fig. 93-Marked colour bandings in the Koldaha Shale (Porcellanite) exposed on both sides of the Dala-Chopan Motor Road, Sonbhadra District, Uttar Pradesh.

Approach—The stop is situated on the motor road which is about 300 m from the Obra tri-junction towards Dala. It is also near the railway overbridge.

Key Observations—The porcellanites are well-exposed on both the sides of the Motor Road. The rocks show well-marked colour banding and well-developed joints (Fig. 93).

Stop 40

Dala-Billi Road Section

Location—N 24°26.849'; E 83°02.091' (TS-63P/3).

Approach—About one and half km from Dala on Dala-Billi Road the stop is on the left side of a Hanuman Temple within the compound of a private residence.

Key Observations—At this site, the contact of the Bijawar phyllites and the Basal conglomerate (Deoland Formation) can be seen. It appears to be faulted.

Stop 41

Dala Limestone Mine Section

Location—N 24°27.182'; E 83°03.711' (TS-63P/3).

Approach—The mine can be approached through a motor road from Dala Cement Factory. This mine is referred to as Pit 1 by the miners and presently is now abandoned. It is about 2 km from Dala.

Key Observations—Outcrops of the lower and middle part of the Kajrahat Limestone can be best studied in this mine. Here, the limestone shows high dips (Fig. 94A, Fig. 94B). Dark grey, bluish grey, dirty yellow limestones are intercalated with black, grey, yellow and pink shales. These limestones show low angle discordance, small-scale cross bedding, cut and fill structure, lenticular and flaser bedding and parallel bedding.

In a small hillock between the Dala Mine Office and the Dala Cement Factory gradational contact between the Basal Conglomerate and the Kajrahat Limestone is exposed. Loose boulders of dolerite are abundantly recorded in the nearby nala section.

Stop 42**Dala-Renukoot Section**

Location— N 24°26.054'; E 83°03.545' (TS-63P/2).



Fig. 94A-High angle dipping Kajrahat Limestone in Pit-1 in the Dala Limestone Mines, Sonbhadra District, Uttar Pradesh.



Fig. 94B-High angle to vertical dipping Kajrahat Limestone near Kota Village, Sonbhadra District, Uttar Pradesh.

Approach—The site can be approached from Dala. It is about 3 km from Dala residential colony on Dala-Renukoot Motor Road.

Key Observations— Good exposures of the Bijawar phyllites can be seen on either side of the motor road (Fig. 95). Small-scale puckering is also seen. These phyllites are now included under the Mahakoshal Group. They seem to have acted as the basement rocks for the Vindhyan sediments in this area.



Fig. 95-A view of the Bijawar phyllites exposed on the Dala-Billi Road Section.

Bibliography

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

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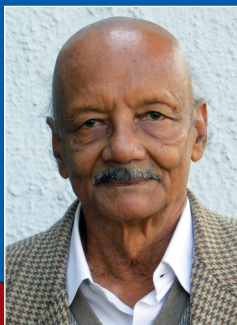
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