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CARBON ISOTOPE STRATIGRAPHY OF THE PALAEO-NEOPROTEROZOIC VINDHYAN SUPERGROUP, CENTRAL INDIA: IMPLICATIONS FOR BASIN EVOLUTION AND INTRABASINAL CORRELATION

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ABSTRACT

To establish the carbon isotope stratigraphy of the Vindhyan Supergroup fifty two bulk samples of the carbonate rocks were analysed for total carbon content, organic carbon content, δ^{13}Corg, δ^{13}C and δ^{18}O. In addition 35 samples were also analysed for δ^{13}C and δ^{18}O. Three regions were selected for sampling viz., Chopan area, Uttar Pradesh, Maihar area, Madhya Pradesh and Kota – Chittorgarh area, Rajasthan. The carbonate content of the rocks varies from 24 to 99% but generally it is more than 70%. The organic carbon is present in very small quantities and is generally less than 0.05%. Over the whole Vindhyan profile δ^{13}Corg shows a wide range from –24 to -34‰ (PDB). The mean value (-29.0‰) for the Semri Group is slightly lower in comparison to the mean value (-26.8‰) for the Upper Vindhyan (the Rewa and Bhander Groups). δ^{13}Ccarb varies between –5.9 and 4.4‰. In the Semri Group, it is around zero per mil with 2‰ variation to either side. In the Maihar area, δ^{13}Ccarb variation for the Bhander Group is bracketed within 2.6 and 4.4‰, whereas in Rajasthan it shows a wide range from –5.9 to 3.4‰, implying a total spread of about 9‰. The Lakheri Limestone of Rajasthan gives the mean value of δ^{13}Ccarb as –5.4‰ where as the mean value for the Bhander Limestone of Maihar area is 3.9‰. Thus, both the limestone horizons are not correlatable on the basis of isotope signatures. It is also suggested that the Lakheri Limestone is stratigraphically older than the Bhander Limestone. The negative values for the Lakheri Limestone may indicate colder climate and the sedimentation of this limestone may coincide with Sturtian glaciation. However, the field evidence for the glacial event is yet to be established. δ^{18}Ocarb values for the entire Vindhyan succession varies quite widely between –2.3 and –15.5‰ (PDB). It is concluded that isotopically the successions in the western and eastern parts of the Vindhyan Basin differ considerably. However, the carbon isotope values matches well with the global trend.

There is no evidence to suggest that the Precambrian/Cambrian boundary exists within the Vindhyan Supergroup. It appears that the sedimentation in the Vindhyan Basin ceased around ca. 700 Ma. and the Vindhyans are in no way related to the Krol–Tal succession of the Lesser Himalaya.

Key words: Carbon isotope, Vindhyan Supergroup, Palaeo-Neoproterozoic, Central India, Stratigraphy

INTRODUCTION

In recent years, isotope geochemistry, especially of the stable isotopes, has been used to improve high resolution stratigraphy (Knoll *et al.*, 1986; Kaufmann and Knoll, 1995; Saltzman *et al.*, 1998; Lindsay and Brasier, 2000; Kumar *et al.*, 2002; Glumac and Spivak-Birndorf, 2002; Ray *et al.*, 2003). It has proved its utility in intra and interbasinal correlations for sequences which often attain thickness measurable in kilometers where both radiometric and palaeontological data are not available or poorly available as is the case with many Precambrian sequences of both peninsular as well as Lesser Himalayan successions of India. The Vindhyan Supergroup in Central India represents a sequence of Palaeo-Neoproterozoic (ca. 1800 to 600 Ma) succession which attains a thickness of ca. 4000m in an intracratonic setting (fig. 1). The rocks are developed in two different areas and the lithostratigraphic succession of the eastern part differs completely with the succession developed in the western part of the Vindhyan Basin. In general, the lithostratigraphic horizons of the eastern part can not be traced in the western part as there is no continuity of outcrops. This has created serious limitation for the lithostratigraphic correlation in absence of much needed radiometric dates. The intercalated carbonate beds constitute significant litho-units especially in the lower and upper parts of the Vindhyan succession; many of them are stromatolitic (Auden. 1933; Valdiya, 1969; Kumar, 1976; Prasad, 1984, Kumar and Gupta, 2002). Well marked differences between lower and upper Vindhyan stromatolite assemblages have been successfully used in intrabasinal and interbasinal correlations by a number of workers (Kumar, 1980, 1982, 1984; Raha and Sastry, 1982; Valdiya, 1969, 1989) but recently this attempt has been supplemented by using carbon isotope geochemistry (Kumar, 1999b; Kumar *et al.*, 2002; Ray *et al.*, 2003). Here we submit data pertaining to secular variation of carbonate carbon, carbonate bound oxygen and organic carbon isotopes of the well defined profile through the Vindhyan carbonates and evaluate their utility in intrabasinal and interbasinal correlations in the light of perturbances in the global carbon cycle. Attempts have also been made to address problems of Precambrian – Cambrian boundary and presence of cap carbonate within the Vindhyan Basin.

PREVIOUS WORK

Pandey *et al.* (1970) were the first to analyse two samples of the Bhander Limestone (Upper Vindhyan of the Maihar area, Madhya Pradesh), two samples of the Fawn Limestone

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and six samples of the Kajrahat Limestone of Son Valley area for carbon and oxygen isotopes. Krishnamurthy *et al.* (1986) have generated data for three samples of the carbonaceous matter from the basal part of the Semri Group of the Son Valley area for the organic carbon isotope while Banerjee *et al.* (1992) analysed carbon isotope of carbonaceous shales and pyritic shales of the Kaimur Group. Kumar (1991) studied the Bhander Limestone for carbon and oxygen isotopes exposed near Satna, Madhya Pradesh. Friedman *et al.* (1996) have published carbon and oxygen isotope ratios of 14 samples of the Vindhyan carbonates exposed between Maihar and Dhanwahi section, Madhya Pradesh. The same data was again published by Friedman and Chakraborty in 1997 who suggested Precambrian-Cambrian boundary within the Bhander Group. Kumar and Schidlowski (1999) presented analysis of 21 samples of the Rohtas carbonates for carbon and oxygen isotopes and have noted that there is no excursion in δ^{13}Ccarb which can support Precambrian-Cambrian boundary within the Rohtas Formation as suggested by Azmi (1998). Kumar (1999b) has given isotope data for the Lakheri, Sirbu and Balwan limestones of Rajasthan and noted that there is a very strong negative excursion for δ^{13}Ccarb with in the Bhander Group. Recently, Kumar *et al.* (2002) and Ray *et al.* (2003) have analysed a large number Vindhyan samples for carbon, oxygen and strontium isotopes of the Vindhyan carbonates and have discussed their utility in interbasinal and intrabasinal correlation and in suggesting age.

GEOLOGICAL SETTING

The Vindhyan Supergroup covers an area of more than one hundred thousand square kilometers in central India stretching from Dehri on Son in Bihar to Chittorgarh in Rajasthan (fig. 1). It unconformably overlies the Bundelkhand Granites (ca. 2500 Ma) and metamorphic rocks of the Bijawar Group (the Mahakoshal Group) (ca. 2600 – 2400 Ma). The dominant lithology is represented by sandstones, shales, limestones, dolostones and minor conglomerates and porcellanites. Following Auden (1933), the Vindhyan Supergroup has been subdivided into four groups. In stratigraphic order these are the Semri Group, the Kaimur Group, the Rewa Group and the Bhander Group (Table 1). Traditionally the Semri Group is being referred to as the Lower Vindhyan and

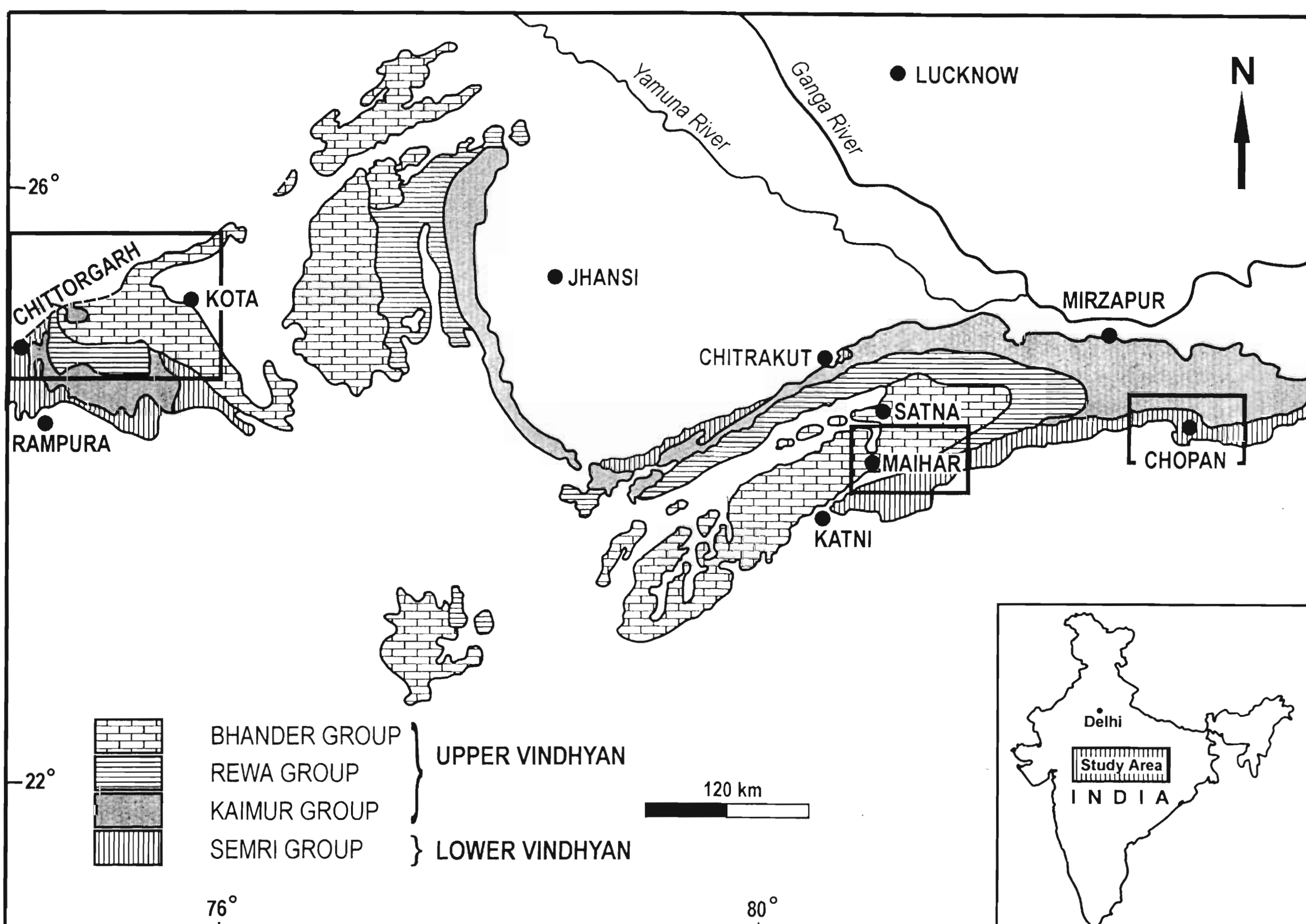

Fig. 1. Geological map of the Vindhyan Basin and location of the study area on the Indian subcontinent (inset). The three framed windows indicate the Kota-Chittorgarh, Maihar and Chopan areas which have furnished the samples for this investigation (after Krishnan and Swaminath, 1959).

Table 1: Lithostratigraphic subdivision of the Vindhyan Supergroup (Modified after Auden, 1933; see Bhattacharyya, 1993)

	Group	Formation	Member
Upper Vindhyan	Bhander Group	Maihar Sandstone Sirbu Shale Bhander Limestone Ganurgarh Shale	
	Rewa Group	Upper Rewa Sandstone Jhiri Shale Lower Rewa Sandstone Panna Shale	
	Kaimur Group	Dhandhraul Quartzite Scarp Sandstone Bijaigarh Shales Upper Quartzite Susanai Breccia Silicified Shales Lower Quartzite	
		-------Unconformity----	
Lower Vindhyan	Semri Group	Rohtas Formation	
		Kheinjua Formation	Glauconitic Sandstone Fawn Limestone Olive Shale
		Porcellanite Formation	Porcellanites
		Basal Formation	Kajrahat Limestone Basal Conglomerate
		----Unconformity--------	
Bijawar Group		Schists and phyllites	

the Kaimur, Rewa and Bhander Groups as the Upper Vindhyans. The rocks show considerable variation in facies as well as in thickness. This is well displayed when lithostratigraphic succession of the eastern part of the Vindhyan Basin is compared with the western part (fig. 8). In both the areas the lithostratigraphy differs considerably (see Table 1 & 2). Prasad (1984) has subdivided the Lower Vindhyans of the Kota - Bundi area, Rajasthan into four groups viz., the Satola Group, the Sand Group, the Lasarwan Group and the Khorip Group. However, Bhattacharyya (1996) and Kumar (2001) have given them the rank of a subgroup and included these subgroups under the Semri Group (Table 2). As such these four subgroups correspond to the four formations of the Semri Group as defined in the Son Valley (Table 3).

The Vindhyan rocks do not show any effect of metamorphism and are virtually undeformed in most of the areas. In general, the rocks are lying flat, showing gentle dips except in Rajasthan where the deformation is more pronounced.

The Vindhyan rocks were deposited in intracratonic setting and are interpreted as a coastal sand-tidal flat-lagoon complex (Lahiri, 1964; Singh, 1973, 1976, 1980a, b; Bhattacharyya *et al.* 1980; Prasad, 1984). Most of the Vindhyan carbonates are formed in subtidal to supratidal environment.

Semri Group

The Semri Group constitutes the oldest group of the Vindhayn Basin and is best exposed in the Son Valley area, central India where it unconformably overlies the phyllites of the Bijawar Group (Mohakoshal Group). It has been subdivided into four stratigraphic units by Auden (1933) (Table 1). The Basal and the Kheinjua Formations have been further subdivided into different members.

The Kajrahat Limestone, as the oldest carbonate horizon in the Son Valley area, constitutes the youngest member of

Table 2: Lithostratigraphic succession of the Vindhyan Supergroup in Kota-Chittorgarh area, Rajasthan (Prasad, 1984; modified by Kumar, 2001).

	Group	Subgroup	Formation
Upper Vindhyan	Bhander Group		Dholpura Shale Balwan Limestone Maihar Sandstone Sirbu Shale Bundi Hill Sandstone Somria Shale Lakheri Limestone Ganurgarh Shale
	Rewa Group		Govindgarh Sandstone Jhiri Shale Indargarh Sandstone Panna Shale
	Kaimur Group		Akoda Mahadev Sandstone Badanpur Conglomerate Chittorgarh Fort Sandstone
Lower Vindhyan	Semri Group	Khorip Subgroup	Suket Shale (including Kotastone) Nimbahera Limestone Bari Shale Jiran Sandstone
		Lasrawan Subgroup	Binota Shale Kalmia Sandstone
		Sand Subgroup	Palri Shale Sawa Sandstone
		Satola Subgroup	Bhagwanpura Limestone Khairdeola Sandstone Khairmalia Andesite
		--Unconformity--	
		Berach Granites/Bhilwara Metamorphics	Granites/Metamorphic Rocks

the Basal Formation (Table 1). It attains a total thickness of more than 600m and is made up of micritic limestone and dolostone. Stromatolites are developed in the upper part where *Conophyton, Kussiella, Platella* and *Colonnella* occur as thin biostromes in the upper part (Kumar, 1976, Kumar and Gupta, 2002). These represent the oldest stromatolite buildups of the Vindhyan Supergroup.

The next carbonate horizon, the Fawn Limestone, constitutes the middle part of the Kheinjua Formation and thickness varies from ca. 40 to 70m. The micritic dolostone, stromatolitic dolostone and intraclastic dolostone represent main lithology. Silicification is quite common. Stromatolites are abundantly recorded. Different morphologies of coniform stromatolites (*Siren, Ephyaltes, Cyathotes*) along with *Colonnella* show excellent development and some forms attain a height of about 1.5 m (Kumar and Gupta, 2002). This horizon has also yielded a well preserved microbial community dominated by cyanobacteria (McMenemin *et al.*, 1983; Kumar and Srivastava, 1995).

The Rohtas Formation is the youngest unit of the Semri Group in the Son Valley and is exclusively made up of limestone and grey to black carbonaceous shales. It attains a thickness of ca. 200m. The carbonates are nonstromatolitic but a few thin algal mat horizons are developed in the middle part of the succession. Carbonaceous megafossils *Chuaria* and *Grypania* have been recorded from the uppermost part of this formation (Kumar, 1995) and this *Grypania*-bearing carbonate horizon has recently been dated by Sarangi *et al.* (2004) as 1599 ± 48 Ma by Pb-Pb method

In the western part of the Vindhyan Basin (eastern Rajasthan), the Semri Group shows a different lithologic succession as compared to the Son Valley (Table 2). In this sector three carbonbate horizons in the Semri Group have been identified. Traditionally the lowermost is considered to be corresponding to the Kajrahat Limestone and the upper two horizons are bracketed with the Rohtas Formation of the Son Valley. The lowermost carbonate horizon is the Bhagwanpura Limestone. It is dominantly made up of micritic limestone, stromatolitic limestone, intraclastic limestone and minor shales with local evidence of silicification. *Colonnella* sp. and *Conophyton* spp. are abundantly developed (Prasad, 1984). Kumar and Srivastava (1992) have also described coccoid and filamentous microfossils from the Bhagwanpura Limestone.

In the Khorip Subgroup there are two carbonate bearing units; the lower is designated as the Nimbahera Limestone and the upper is locally referred as the Kotastone and is included in the Suket Shale (formation) as the lower stratigraphic unit. Both these limestone horizons are nonstromatolitic. The Suket shales (Table2) have yielded carbonaceous megafossils including *Chuaria circularis* and *Tawuia dalensis* (Mathur, 1983; Kumar, 2001).

Kaimur Group

This is an arenaceous succession represented by sandstones with minor shales and conglomerates. In the Son Valley area it also shows development of carbonaceous shales which have been analysed for organic carbon isotopes by Banerjee *et al.* (1992). In the Rampura-Chittorgarh area of Rajasthan, the Kaimur sandstones are glauconitic which have been dated by Vinogradov *et al.* (1964) as 910 – 940 ± 30 Ma. No carbonate horizon has been recorded from any part of the Kaimur Group.

Rewa Group

This is also an areno-argillaceous succession represented by sandstones and shales. However, in Rajasthan it shows thin horizons of micritic carbonates within the Panna shales and Jhiri shales (Table 2). Carbonaceous megafossils *Chuaria circularis* and *Tawuia dalensis* have been recorded from the shales of this group (Rai *et al.*, 1997; Srivastava, 2004)

Bhander Group

This youngest group of the Vindhyan Supergroup with several carbonate units is well developed in the Maihar area of Madhya Pradesh, but attains maximum thickness in the Kota – Chittorgarh area of Rajasthan. In the Maihar area, the Bhander Group has been subdivided into four formations (Table 1). The well developed carbonate horizon, the Bhander Limestone is exposed in the low lying areas around Maihar and Satna townships. Bioherms of *Baicalia* are abundantly seen over the entire succession of the Bhander Limestone. It is overlain by the Sirbu Shale. It is basically an areno-argillaceous formation but near Maihar township it shows a thin lenticular carbonate horizon with development of stromatolites. This horizon constitutes the youngest stromatolite buildup of the Vindhyan Supergroup in the Maihar area, M.P. However, in Rajasthan, the Bhander Group attains a maximum thickness of about 1200m and accommodates four carbonate horizons. The lowermost is 150m thick Lakheri Limestone which is completely devoid of stromatolites. The next carbonate band is a thin algal dolostone unit within the Samria Shale (Table 2). Thick carbonate lenses measuring some few tens of meters are also present within the Sirbu Shale, generally showing good development of biostromes of *Baicalia* and *Patomia* (Misra, 2004) mostly around Kota township and adjoining areas. The uppermost carbonate unit is represented by 120m thick Balwan Limestone It also displays bioherms and biostromes of *Baicalia* and *Patomia* (Misra, 2004).

AGE OF THE VINDHYAN SUPERGROUP

The Vindhyan rocks are not well dated. Glauconite bearing beds were dated more than four decades ago by the K/Ar method (Vinogradov *et al.*, 1964). The dates given by them were recalculated by Kreuzer *et al.* (1977) using latter recommended constants and gave radiometric dates as 1080 ± 40 Ma for the Kheinjua Formation and 890 ± 40 Ma for the Kaimur sandstones. A kimberlite pipe which has intruded the Kaimur sandstone has been dated by Crawford and Compston (1970) by K/Ar method as 1140 ± 12 Ma and by Kumar *et al.* (1993) by Rb/Sr method as 1067 ± 31 Ma. Glauconies of the Lower Vindhyan sediments of Chitrakut area were dated by Rb/Sr method by Kumar *et al.* (2001) who suggested that the on set of the earliest Vindhyan sedimentation was not later than 1600 ± 50 Ma. Rasmussen *et al.* (2002) dated the zircons separated from the silicified tuff by SHRIMP U-Pb zircon method which is bounding the Chorhat Sandstone (the Semri Group) and suggested that the Chorhat Sandstone must have deposited between 1628 ± 8 and 1599 ± 8 Ma. At the same time Ray *et al.*, (2002) have estimated the age of the zircons of the silicified volcanic rock of the Porcellanite Formation by U-Pb method as 1632 Ma. On the basis of the $^{87}Sr/^{86}Sr$ ratio of 0.70599 they have suggested a broad Neoproterozoic age to the Bhander Group. Recently, Ray *et al.* (2003) have dated Rohtasgarh Limestone (Rohtas Formation) by Pb-Pb method and gave the age as 1601 ± 130 Ma while on the basis of Sr isotope stratigraphy they have suggested Mid-Neoproterozoic age (750 – 650 Ma) for the carbonates of the Bhander Group. More recently, Sarangi *et al.* (2004) dated the upper part of the Rohtas Formation by Pb-Pb method and suggested 1599 ± 48 Ma age.

In Rajasthan, the Khairmalia andesitic flows form the base for the Vindhyan sedimentation and have been dated by Crawford (see Prasad, 1984) as ca. 1250 Ma. Stromatolites are abundant in the Vindhyan carbonates and have been used in correlation as well as for suggesting ages. The Semri Group is characterised by *Conophyton, Colonnella* and *Kussiella* while the Bhander Group shows abundant development of *Baicalia* and *Tungussia* with complete absence of *Conophyton.* Using these criteria Kumar (1984) had suggested a Lower to Middle Riphean age for the Semri Group and an Upper Riphean age for the Bhander Group.

Abundance of carbonaceous megafossils *Chuaria* and *Tawuia* in the Bhander Group (Kumar and Srivastava, 1997; Srivastava, 1998) and complete absence of Cambrian fossils suggest that the youngest bed of the Bhander Group is definitely older than the Cambrian. Discovery of sponge spicule like structures (Kumar, 1999a) from the Bhander Limestone of the Maihar area suggests that the upper age limit of the Vindhyan sedimentation may be ca. 600 Ma. Suggestion of the Precambrain /Cambrian boundary in the upper part of the Rohtas Formation by Azmi (1998) on the basis of the disputed assemblage of small shelly fossils and brachiopod and the similar suggestion of the same boundary within the Bhander Group by Friedman and Chakarborty (1997) on the basis of the carbon isotope data is not tenable (for discussion see Bhargava and Srikantia, 2000; Kumar, 2001). The discovery of Ediacaran megafossil *Spriggina* by Kathal *et al.*, (2000) from the Semri carbonates is again a matter of misidentification (see Kumar, 2001). Similarly, recent discovery of *Ediacaria* (Sprigg, 1947) by De (2003) from the Bhander Group can be placed under the category of pseudofossil. Thus, considering the available data the suggested age of the Vindhyan Supergroup can be bracketed between ca. 1800 and 600 Ma.

Table 3: General lithostratigraphic succession in the Chopan-Maihar and Kota-Chittorgarh areas (after Auden, 1933; Prasad, 1984 and Kumar, 2001).

	Chopan-Maihar area		Kota-Chittorgarh area
Upper Vindhyan	Bhander Group Rewa Group Kaimur Group		Bhander Group Rewa Group Kaimur Group
-----Unconformity-----			
Lower Vindhyan	Semri Group	Rohtas Formation Kheinjua Formation Porcellanite Formation Basal Formation	Khorip Subgroup Lasrawan Subgroup Sand Subgroup Satola Subgroup
-----Unconformity-----			
	Metamorphics and Granites		

SAMPLING

To cover the representative areas for sampling of the carbonates and calcareous shales from the Vindhyan Supergroup three areas were selected (fig. 1). The three areas are grouped under two sections:

1. Son Valley Section - Chopan area (Uttar Pradesh) and . Maihar area (Madhya Pradesh)
2. Chambal Valley Section - Kota-Chittorgarh area (Rajasthan)

Although carbonate bearing beds in all the three areas were sampled but only one litholog (fig. 2) for the Chopan and Maihar areas (Son Valley section) is prepared as in the former only Semri and Kaimur Groups are exposed and the Bhander Group is developed in the latter. In the Kota-Chittorgarh area complete succession of the Vindhyan Supergroup is sampled (fig. 3). Dolostones and limestones were differentiated before isotope analysis.

METHODOLOGY

About 100 gm of cleaned and crushed sample was pulverized to less than 2 mμ with the help of an agate grinder. The total carbonate content of the samples was determined using a Karbonate Bomb (Müller and Gastner, 1971).

To remove the inorganic carbonate, the sample was treated with 100% pure phosphoric acid and heated at 50° C on the sand bath till the reaction ceased. The samples were washed and dried at 60° C and then subjected to the determination of the total organic carbon with the help of Carlo-Erba Elemental Analyser. Organic carbon isotopes of the carbonate free samples were determined by heating in pre-evacuated tubes at 900° for 15 minutes with flakes of cuprous oxide. The CO_2 so released was trapped and analysed in a V.G. Prism Mass Spectrometer. Some of these carbonate free samples were also analysed for organic carbon as well as inorganic carbon isotopes on the online system of an Elemental Analyser CE1110 connected by Conflo Interface to a Finnigan 252 Mass Spectrometer.

For the determination of carbon and carbon bound isotope values the rock samples were processed following McCrea (1950) and the CO_2 was trapped after one hour of the beginning of the reaction with phosphoric acid for the determination of carbon and oxygen isotope values for calcite. For dolomite the reaction time was extended to 70 hours. The results are reported as values per mil relative to PDB. The data was corrected by using factor described by Craig (1957). The precision of the data is ± 2%.

Table 4: Comparative mean values of $\delta^{13}C$ and $\delta^{18}O$ for the Vindhayn carbonates.

	Bhander Group			Semri Group			References
	Sirbu Shale	Bhander Limestone	Lakheri Limestone	Rohtas Formation	Fawn Limestone	Kajrahat Limestone	
$\delta^{13}C$ ‰ (in PDB)		+2.9 (N=2)			-1.0 (N=2)	-0.8 (N=4)	Pandey *et al.*, 1970
		+4.3 (N=8)					Kumar, 1991
	+2.7 (N=1)	+4.2 (N=4)		-0.8 (N=4)	+0.9 (N=1)	+0.1 (N=4)	Friedman & Chakraborty, 1997
			-5.4 (N=5)				Kumar, 1999
				-1.0 (N=18)			Kumar & Srivastava, 1999
		+4.2 (N=27)	-4.42 (N=10)	-0.4 (N=19)	-0.6 (N=4)	-1.0 (N=17)	Kumar *et al.*, 2002
		+3.0 (N=41)	+1.8* (N=38)	-1.2 (N=34)	+0.6 (N=6)	+0.96 (N=33)	Ray *et al.*, 2003
	+3.3 (N=10)	+3.9 (N=15)	-4.9 (N=24)	-0.7 (N=19)	-0.6 (N=9)	-0.6 (N=14)	Present work
$\delta^{18}O$ ‰ (in PDB)		-8.5 (N=2)			-6.4 (N=2)	-5.6 (N=4)	Pandey *et al.*, 1970
		-7.9 (N=8)					Kumar, 1991
	-5.8 (N=1)	-7.1 (N=4)		-6.0 (N=4)	-3.4 (N=1)	-10.6 (N=4)	Friedman & Chakraborty, 1997
				-6.4 (N=18)			Kumar & Schidlowski, 1999
		-7.0 (N=27)	-9.7 (N=10)	-6.8 (N=19)	-6.3 (N=4)	-13.6 (N=17)	Kumar *et al.*, 2002
		-7.2 (N=41)	-9.8 (N=38)	-6.8 (N=34)	-8.2 (N=6)	-10.2 (N=33)	Ray *et al.*, 2003
	-9.6 (N=10)	-8.8 (N=15)	-8.0 (N=24)	-7.7 (N=19)	-5.1 (N=9)	-11.5 (N=14)	Present work

*The value could not be interpreted in the absence of stratigraphic position of the samples with respect to lower or upper contact of the Lakheri Limestone.

Table 5: Lithology, carbonate content, organic carbon, carbon and oxygen isotopes for the samples in the Chopan-Maihar area.

S. No.	Sample No.	Lithology	Total organic content in %	Total Carbonate in %	$\delta^{13}C$ organic	$\delta^{13}C$ calcite	$\delta^{13}C$ dolomite	$\delta^{18}O$ calcite	$\delta^{18}O$ dolomite	Stratigraphic horizons
1.	CM29	Domal stromatolite	0.03	82	- 26.8	4.3	-	- 9.2	-	Sirbu Shale
2.	CM28	Micritic limestone	0.03	94	- 27.0	3.9	3.9	- 12.7	- 11.7	Bhander Limestone
3.	CM27	Micritic limestone	0.03	97	- 28.2	4.2	4.2	- 9.0	- 8.3	Bhander Limestone
4.	CM26	Micritic limestone	0.02	97	- 27.6	4.0	4.0	- 7.8	- 6.5	Bhander Limestone
5.	CM25	Micritic limestone	0.11	78	- 28.2	3.5	3.4	- 7.6	- 6.8	Bhander Limestone
6.	CM24	Micritic limestone	0.05	80	- 26.6	3.9	-	- 7.8	-	Bhander Limestone
7.	Rh1	Micritic limestone	0.05	89	- 31.7	- 1.0	- 1.2	- 8.7	- 7.8	Rohtas Formation
8.	Rh2	Micritic limestone	0.05	95	- 31.2	- 1.0	- 0.9	- 7.3	- 6.5	Rohtas Formation
9.	Rh3	Micritic limestone	0.12	90	- 31.6	- 0.8	- 1.0	- 7.9	- 7.6	Rohtas Formation
10.	Rh4	Calc. shale	1.12	24	- 32.6	- 1.6	- 1.1	- 10.3	- 8.5	Rohtas Formation
11.	Rh5	Micritic limestone	0.02	88	- 32.1	- 0.2	- 0.5	- 7.4	- 7.1	Rohtas Formation
12.	Rh6	Micritic limestone	0.15	81	- 30.9	- 0.5	- 0.6	- 8.3	- 7.1	Rohtas Formation
13.	Rh7	Calc. shale	0.20	34	- 26.9	- 2.3	- 1.4	- 8.2	- 5.6	Rohtas Formation
14.	C1	Calc. shale	1.00	42	- 33.5	-	0.8	-	- 6.3	Rohtas Formation
15.	C2	Calc. shale	0.04	41	- 30.7	0.7	- 0.4	- 8.2	- 7.2	Rohtas Formation
16.	CM14	Micritic limestone	0.02	79	- 32.0	0.1	- 1.0	- 9.4	- 7.4	Rohtas Formation
17.	CM13	Micritic limestone	0.01	92	- 30.1	- 0.4	- 0.4	- 5.5	- 4.7	Fawn Limestone
18.	CM12	Micritic limestone	0.01	88	- 30.3	- 0.9	- 0.4	- 5.6	- 5.0	Fawn Limestone
19.	CM11	Stromatolitic limestone	0.05	85	- 29.1	-	- 2.0	-	- 6.1	Fawn Limestone
20.	CM10	Micritic limestone	0.01	99	- 27.0	0.2	0.7	- 4.9	- 4.0	Fawn Limestone
21.	CM9	Micritic limestone	0.02	84	- 26.2	0.2	0.1	- 5.5	- 4.9	Fawn Limestone
22.	CM8	Stromatolitic dolostone	0.06	92	- 27.5	-	0.7	-	- 12.1	Kajrahat Limestone
23.	CM7	Stromatolitic dolostone	0.01	99	- 27.5	- 0.1	0.0	- 11.8	- 12.1	Kajrahat Limestone
24.	CM6	Stromatolitic dolostone	0.02	92	- 24.8	-	0.2	-	- 10.4	Kajrahat Limestone
25.	CM5	Micritic limestone	0.05	99	-	- 0.8	- 0.1	- 11.6	- 11.1	Kajrahat Limestone
26.	CM4	Micritic limestone	0.02	93	- 32.2	- 1.6	- 1.2	- 11.4	- 9.5	Kajrahat Limestone
27.	CM3	Micritic limestone	0.03	93	- 29.9	- 1.4	- 1.5	- 11.7	- 10.8	Kajrahat Limestone
28.	CM2	Micritic limestone	0.02	90	-28.1	- 0.2	0.3	- 10.5	- 8.8	Kajrahat Limestone
29.	CM1	Micritic limestone	0.02	87	- 27.1	- 1.1	- 1.0	- 15.5	- 13.5	Kajrahat Limestone

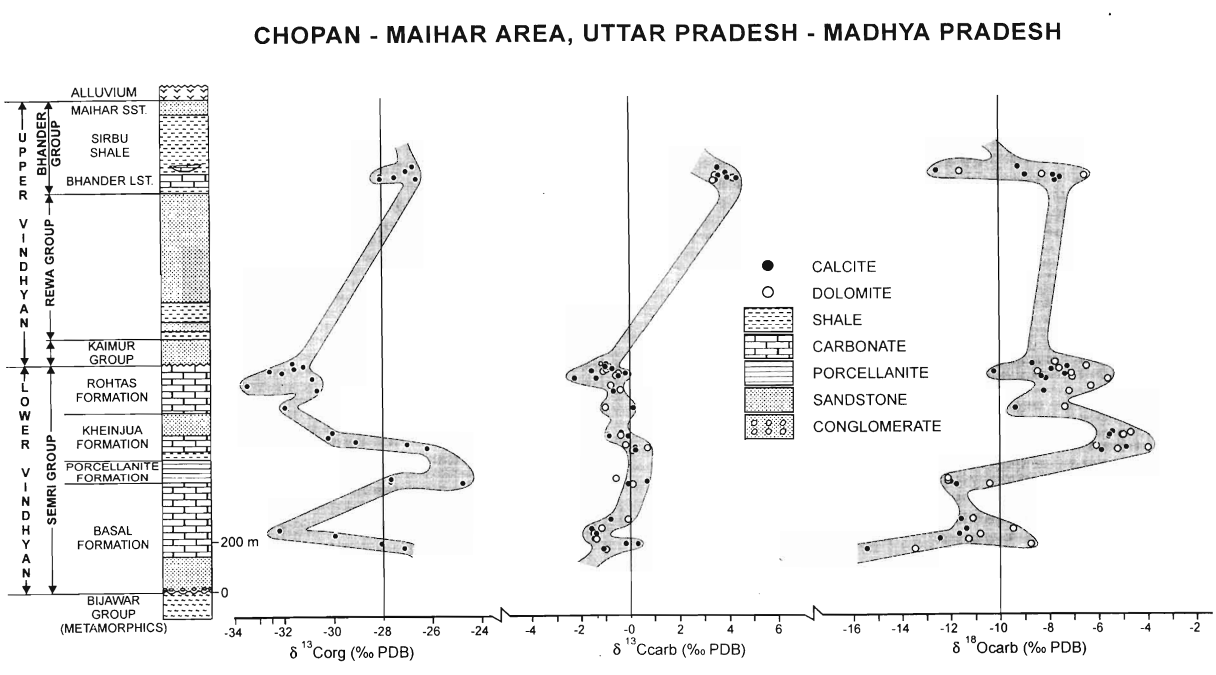

Fig. 2. Lithostratigraphic succession of the Vindhyan Supergroup in the Maihar-Chopan region as reflected by the isotope stratigraphy of organic carbon (δ^{13}Corg), carbonate carbon (δ^{13}Ccarb) and carbonate-bound oxygen (δ^{18}Ocarb).

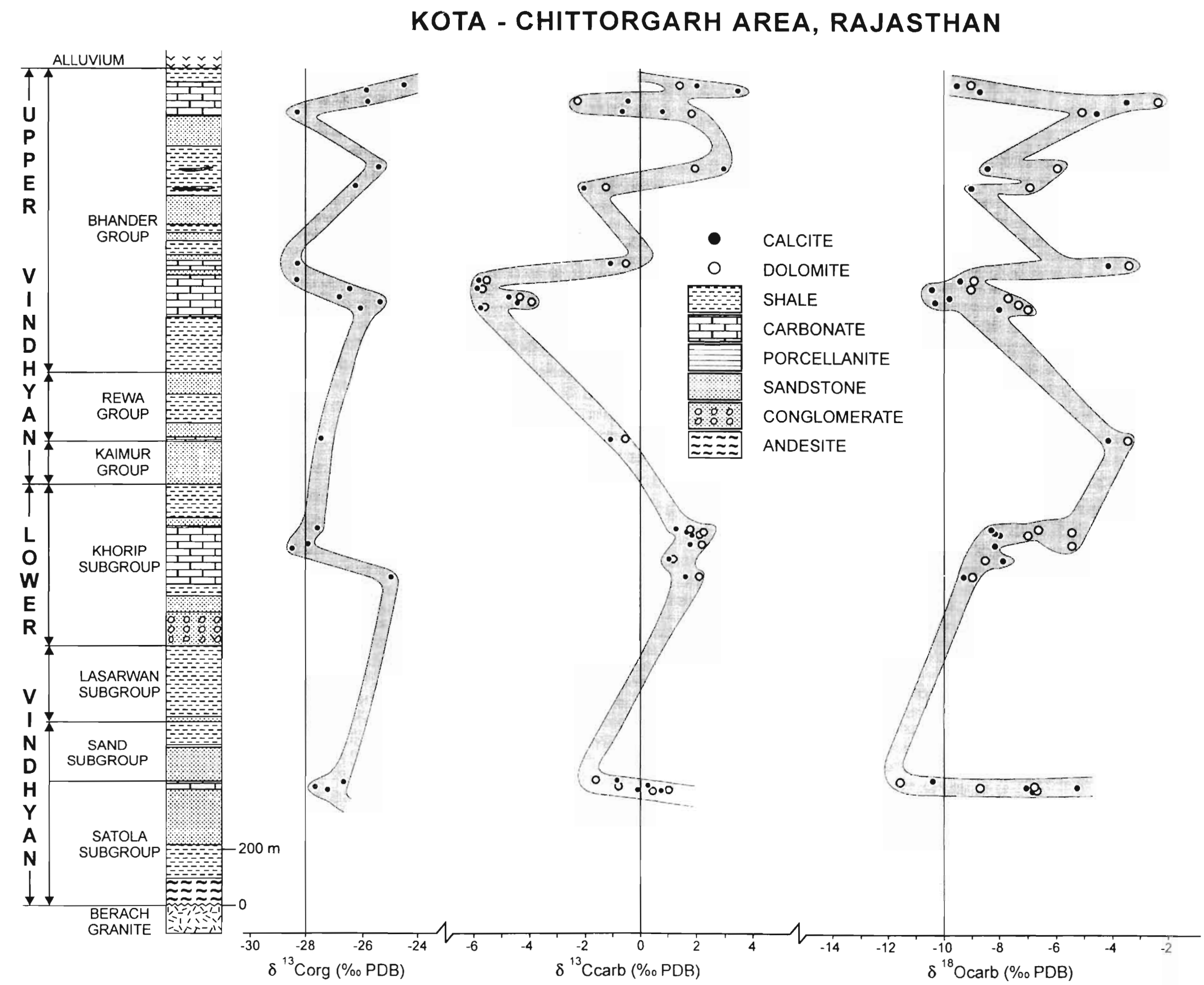

Fig. 3. Lithostratigraphic succession of the Vindhyan Supergroup in the Kota-Chittorgarh region (Rajasthan) along with relevant isotope stratigraphy (δ^{13}Corg, δ^{13}Ccarb and δ^{18}Ocarb).

EVALUATION OF THE DATA

Various methods have been used to identify the pristine character of the isotope signatures in the carbonate rocks. Sr/Ca ratio and relative abundance of Mn and Fe (Viezer, 1983a, b), assumption of an apparent constancy in δ^{13}C fractionation between coexisting carbonate-kerogen pairs (Knoll *et al*, 1986) and sample selection for primary rock fabric on the basis of petrography (Tucker, 1982; Aharon *et al.*, 1987) have been used for this purpose. Kumar *et al.* (2002) have discussed the post depositional alteration of the Vindhyan carbonates and have concluded that δ^{13}C values have remained largely unaffected though δ^{18}O values in few samples might have been modified. Ray *et al.* (2003) have also dealt in detail about the evaluation of the primary isotope signature in the Vindhyan carbonates and used different cross plots using Mn/Sr ratio, ^{87}Sr/^{86}Sr values, δ^{13}C and δ^{18}O data. They concluded that δ^{13}C values are near original but δ^{18}O values show a shift of ~2‰ due to diagenesis. An evaluation of δ^{13}C and δ^{18}O data generated by different workers (Table 4) for the Vindhyan carbonates for the bulk rock and its various components show unanimity in this interpretation. In Table 4 it is quite apparent that δ^{13}C values are more or less comparable except for the Lakheri Limestone where the analytical results of Ray *et al.* (2003) are substantially different and are not comparable to the analytical data of other workers. This anomalous situation is difficult to explain as the stratigraphic position of the Lakheri samples of Ray *et al.* (2003) which cover only 6m thick succession against the total thickness of more than 100m is not known with respect to the base or top of the Lakheri Limestone (see Kumar, 2004). Ray and Viezer (2004) have admitted that the exact position of their samples with respect to the stratigraphic position is not known. Because of this reason we have ignored the data as given by Ray *et al.* (2003) for the Lakheri Limestone. Since the rocks were collected from the different areas, the comparable values for δ^{13}C suggest that these values are original and not modified during diagenesis. However, δ^{18}O values show variation and there is a possibility that some of the δ^{18}O values are modified during diagenesis. In addition the isotope data has been evaluated on the following reasoning:

Table 6: Lithology, carbonate content, organic carbon, carbon and oxygen isotope for the samples in Kota-Chittorgarh area.

S. No.	Sample No.	Lithology	Total organic content in %	Total Carbonate in %	$\delta^{13}C$ organic	$\delta^{13}C$ calcite	$\delta^{13}C$ dolomite	$\delta^{18}O$ calcite	$\delta^{18}O$ dolomite	Stratigraphic horizons
1.	KC23	Stromatolitic dolostone	0.03	82	- 24.6	2.0	1.3	- 9.5	- 9.0	Balwan Limestone
2.	KC22	Micritic limestone	0.24	78	- 25.9	3.4	-	- 8.7	-	Balwan Limestone
3.	KC21	Micritic limestone	0.03	68	- 25.8	- 0.5	- 2.3	- 3.4	- 2.3	Balwan Limestone
4.	KC20	Micritic limestone	0.01	99	- 28.4	- 0.7	1.8	- 4.5	- 5.0	Balwan Limestone
5.	KC19	Micritic limestone	0.03	89	- 25.5	2.9	1.9	- 8.4	- 5.9	Sirbu Shale
6.	KC18	Micritic limestone	0.01	99	- 26.3	- 2.1	- 1.3	- 9.0	- 6.9	Sirbu Shale
7.	KC17	Micritic limestone	0.03	71	- 28.4	- 1.1	- 0.6	- 4.1	- 3.4	Somria Shale
8.	KC16	Micritic limestone	0.04	84	- 28.4	- 5.9	- 5.6	- 9.4	- 8.9	Lakheri Limestone
9.	KC15	Micritic limestone	0.02	84	- 26.5	- 5.9	- 5.7	- 10.4	- 9.0	Lakheri Limestone
10.	KC14	Micritic limestone	0.02	83	- 26.9	- 4.8	- 4.4	- 9.8	- 7.7	Lakheri Limestone
11.	KC13	Micritic limestone	0.03	80	- 25.4	- 4.5	- 4.0	- 10.3	- 7.3	Lakheri Limestone
12.	KC12	Micritic limestone	0.04	84	- 26.1	- 5.8	- 5.7	- 8.6	- 9.1	Lakheri Limestone
13.	KC11	Micritic limestone	0.03	71	- 27.5	- 1.1	- 0.6	- 4.1	- 3.4	Panna Shale
14.	KC10	Micritic limestone	0.02	72	- 27.3	1.2	1.7	- 8.3	- 6.6	Kota Limestone
15.	KC9	Micritic limestone	0.02	60	- 27.9	1.6	2.2	- 8.2	- 5.4	Kota Limestone
16.	KC8	Micritic limestone	0.04	71	- 28.4	1.8	2.1	- 8.0	- 7.0	Kota Limestone
17.	KC7	Micritic limestone	0.07	73	- 28.5	1.7	1.5	- 9.1	- 9.4	Nimbahera Limestone
18.	KC6	Micritic limestone	-	76	-	1.0	1.1	- 7.9	- 8.5	Nimbahera Limestone
19.	KC5	Micritic limestone	0.01	74	- 25.0	1.8	1.6	- 9.3	- 9.0	Nimbahera Limestone
20.	KC4	Micritic limestone	0.04	86	- 26.7	- 0.9	- 1.6	- 10.4	- 11.6	Bhagwanpura Limestone
21.	KC3	Micritic limestone	0.01	76	- 27.7	- 1.0	- 0.9	- 11.0	- 8.7	Bhagwanpura Limestone
22.	KC2	Micritic limestone	0.04	99	- 27.3	- 0.1	0.3	- 7.0	- 6.8	Bhagwanpura Limestone
23.	KC1	Micritic limestone	-	79	-	0.7	1.0	- 6.8	- 6.7	Bhagwanpura Limestone

1. The Vindhyan rocks are completely unmetamorphosed with no evidence of deep burial
2. They show least effect of deformation and at many places the rocks are completely undeformed.
3. The level of preservation of primary sedimentary structures is exceptionally good.
4. Only unfractured micritic carbonates were selected.

RESULTS AND STRATIGRAPHIC TRENDS

In all 52 bulk carbonate rich rock samples were analysed for determination of total carbonate, organic carbon, $\delta^{13}C$ org, $\delta^{13}C$ carb and $\delta^{18}O$ carb. The area wise analytical data is summarized in Tables 5 & 6. Both $\delta^{13}C$ and $\delta^{18}O$ are given as parts per thousand relative to the PDB standard. Graphically $\delta^{13}C$ and $\delta^{18}O$ values are plotted against corresponding lithologs (figs. 2 & 3). Additional 19 samples of the Lakheri Limestone and two dolomitic limestone samples of the Somria Shale from the Satur area about 12 kms from Bundi on Bundi-Jaipur motor road have also been analysed to study the carbon isotope variation within the Lakheri Limestone. Due to the controversy of the Precambrian –Cambrian boundary within the Bhander Group as suggested by Friedman and Chakraborty (1997), close samples of the Sirbu limestone and the Bhander Limestone in Maihar area have also been analysed for carbon and oxygen isotopes.

The carbonate content in these rocks varies from 24% to 99% but generally it is more than 70%. The carbonate content decreases with the increase in the argillaceous matter. The organic carbon is generally less than 0.05% except two samples where it is more than 1%. Mineralogy suggests a range from ca. 100% calcite to ca. 100% dolomite.

Chopan -Maihar area

A composite litholog was prepared for the stratigraphic succession of the Vindhyan Supergroup in the Chopan and Maihar areas (fig.2). In the Chopan area only Semri and Kaimur Groups are developed while the Upper Vindhyans i.e., the Kaimur, Rewa and Bhander Groups are well exposed in the Maihar area.

δ^{13}Corg varies from -33.5 to –24.8 ‰. One sample of the Kajrahat Limestone and three samples of the Rohtas Formation yielded values lighter than -32‰. Only five values are less than -27‰. From the base to top there is a definite trend in the variation of δ^{13}Corg. In the middle part of the Kajrahat Limestone there is a well marked negative trend which is followed upwards by a positive trend. It is reversed in the Fawn Limestone and this negative trend continues also in the Rohtas Formation. The Rohtas limestones mostly show fairly negative values. Most of the values are around –32 ‰ except one which is nearer to -27‰. There is no carbonate horizon in the Kaimur and Rewa Groups and so no data is available for them. The Bhander Group has yielded values ranging between -29 to -26‰ and thus, shows a positive shift. Similar trends are also noted in the variation of δ^{13}Ccarb. In this section there exists a covariation in δ^{13}Corg and δ^{13}Ccarb. There is a marked shift of 6‰ between the Rohtas Formation and the

Bhander Group in which the $\delta^{13}C$ values range from 3.5 to 4.3‰ where as in the Rohtas Formation the values vary from -2.3 to 0.1‰.

$\delta^{18}O$carb in this section ranges from -15.5 to -4‰. The Kajrahat Limestone has yielded the most negative values and the Fawn Limestone has given the most positive values. There is one positive shift within the Kajrahat Limestone which is reversed in the next carbonate horizon of the Fawn Limestone. In the Rohtas Formation one minor positive and two negative excursions are present while in the Bhander Group one negative excursion has been observed.

Chittorgarh-Kota area

In all, 21 analyses of $\delta^{13}C$org are available for this area and the values range from -28.5‰ to -24.6‰ (PDB) showing a spread of about 4‰. Generally, most values lie around -27‰. There is no specific variation through the stratigraphic succession except for minor oscillations. Four positive and three negative shifts have been noted (fig. 3). $\delta^{13}C$carb varies from -5.9‰ to 3.4‰ and thus demonstrate the maximum spread seen in the carbonates of the Vindhyan Supergroup. At the base of the Bhagwanpura Limestone, $\delta^{13}C$carb is positive but shifts to negative values at the top of the unit. The values range up to +2.2‰ in the Nimbahera Limestone (including the Kotastone of Prasad, 1984). In the Rewa Group it again drops back into the negative field, shifting to around -4‰ in the Lakheri Limestone. In the Somria Limestone, however, it again oscillates towards zero but returns to -2.1‰ in lower lenticular carbonate intercalations within the Sirbu Shale. In the upper carbonate horizon of this shale unit it swings up to 2.9‰, but falls back to negative values just to acquire a positive shift at the top. Thus, at least one positive excursion in the Semri Group and a pronounced negative excursion in the Lakheri Limestone are well recognised. In the upper part of the Bhander Group, three positive and three negative oscillations are present.

The most negative $\delta^{18}O$ values are recorded in the Bhagwanpura Limestone (-11‰) and the large positive values are yielded by the Panna limestone with -3.4‰ (fig. 3). At the top of the succession in the Bhagwanpura Limestone it is -11.6‰. It is followed upwards by a negative excursion. But there is a slight shift in positive direction in the Nimbahera Limestone (including the Kotastone). Subsequently it oscillates towards positive value in the Panna limestone. The overlying Lakheri Limestone is again marked by negative values around -9‰. With some minor oscillations it acquires a maximum positive shift of -2.3‰ in the Balwan Limestone, but falls back to -9.5‰ at the top.

DISCUSSION AND CONCLUSIONS

1. In spite of the very low content of organic carbon in most of the rocks a secular variation of $\delta^{13}C$org for over the complete profile of the Vindhyan Basin both for the eastern as well as for the western part is discernable. The $\delta^{13}C$org shows a wide range from -24 to -33‰. The mean value (-29.0‰) for the Lower Vindhyan (the Semri Group) is slightly lower in comparison to the mean value of –26.8‰ for the Upper Vindhyan (the Rewa and Bhander Groups). Strauss *et al.* (1992) have plotted variation of $\delta^{13}C$org of Proterozoic rocks against time and noted that there is a global trend of enrichment in ^{13}C between 800 and 600 Ma. Here we also report an increase in $\delta^{13}C$org mean values in the Bhander Group with respect to the underlying Semri Group (fig. 4). Thus, the above observation of global shift towards mean positive value over the above mentioned periods is also supported by our data.

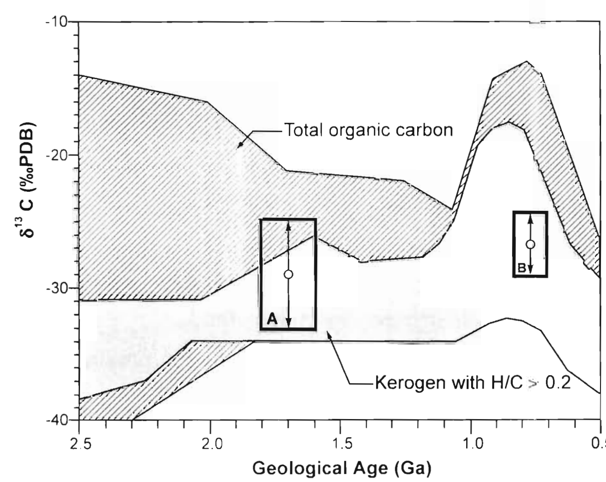

Fig. 4. Principal isotope spread of sedimentary organic carbon ("kerogen") over the time interval 2.5 - .5 Ga (Strauss et al., 1992). Framed windows A and B within this envelop mark $\delta^{13}C$org distributions in the Semri (Lower Vindhyan) and Bhander Groups (Upper Vindhyan), respectively (mean values marked as circles) Note that both spreads basically conform with the global trend.

2. $\delta^{13}C$carb was shown to vary in the whole Vindhyan profile between -5.9 and +4.4‰. In the Semri Group it is found to be around zero per mil line with about 2‰ variation to either side. In the Maihar area $\delta^{13}C$carb values for the Bhander Group are bracketed within +3.5 and +4.4‰, however, in Rajasthan it shows a wide range from -5.9 to +3.4‰ implying a total spread of about 9‰. The Lakheri Limestone of the Kota-Bundi area and the Bhander Limestone of the Maihar area occupy similar stratigraphic position as both represent oldest carbonate horizon of the Bhander Group but significantly both give different $\delta^{13}C$carb values. For the Lakheri Limestone $\delta^{13}C$carb mean value is -4.9‰ where as the mean for the Bhander Limestone is 3.9‰. Both carbonate horizons have been correlated

on the basis of their stratigraphic position, though the Lakheri Limestone is nonstromatolitic while the Bhander Limestone is characterised by the ample presence of stromatolitic ecosystems dominated by *Baicalia* spp. Our data reveal that the isotope signatures of these contrasting lithounits differ considerably. Similar differences have also been noted by Kumar *et al.* (2002). This difference in isotope signatures can be explained in two ways:

i. That the two horizons are isochronous and represent two distinct facies. This possibility can be ruled out because in the Bhander Limestone, the columnar stromatolites, oolitic limestone and shallow marine sedimentary structures like current and wave ripples, current bedding , mud cracks as well as flaser and lenticular bedding with occasional development of gypsum suggest a typical tidal flat environmental setting. At the same time the Lakheri Limestone also shows evidence of a tidal flat environment of deposition like flaser and lenticular bedding, wave and current ripple bedding, mud cracks, intraformational conglomerates and breccias, teepee structures and ripple marks. It seems therefore that both the Bhander Limestone and Lakheri Limestone were deposited in tidal flat environmental setting and represent two different stratigraphic horizons.

ii. That they belong to two diachronous facies and represent different geological time plane. The Bhander Limestone has a profuse development of stromatolites while in the Lakheri Limestone these are totally absent. At the same time both show totally different isotope signatures. The mean δ^{13}Ccarb value for the Lakheri Limestone is -4.9‰ while it is 3.9‰ for the Bhander Limestone. There is a difference of about 9‰ and thus they are not correlatable on the basis of carbon isotope data. It is suggested that the Bhander Limestone was formed in a tidal flat –lagoonal setting which occasionally developed evaporitic conditions. As is typical for evaporitic environments, we observe a pronounced ^{13}C enrichment in the Bhander Limestone and also in the Sirbu limestone of the Maihar area, while the Lakheri Limestone was obviously deposited in a tidal flat environment but belongs to different stratigraphic position. A very strong negative values for δ^{13}Ccarb of the Lakheri Limestone has been explained by Kumar (1999b) by presuming very cold climate and by Kumar *et al.* (2002) by suggesting it to be a cap rock. This means that the Lakheri Limestone was deposited after a glacial event. In support of this they have identified a tilloid at the base the Lakheri Limestone with a remark that it needs confirmation. We have studied this tilloid and identified it as a diamictite exposed at 9.5 km from Lakheri on Lakheri – Bundi motor road. It is only two meters thick in which pebbles and cobbles of sandstone and limestone are seen floating in a ferruginous matrix. The sandstone and limestone clasts are angular to subangular. In XRD analysis of the diamictite sample only calcite and quartz could be identified. Calcite in some clasts shows recrystallisation. Matrix is made up of iron oxide and clay minerals. A very cold climate can be presumed for the deposition of the Lakheri Limestone which did not support the growth of algal mat ecosystem which is so profusely developed in the rest of the Upper Vindhyan carbonates. Because of the low organic productivity, the local marine pool of dissolved inorganic carbon (DIC) remained enriched in ^{12}C and was consequently precipitated as carbonate with δ^{13}Ccarb values ranging between -2.9 and –5.9 ‰. Thus, the δ^{13}Ccarb values for the Lakheri Limestone can be taken as an evidence for cold climate during its deposition and can be linked to Neoproterozoic glacial event possibly of Sturtian glaciation. However, no field evidence has yet been recorded to support the glacial event at the base of the Lakheri Limestone except the presence of a thin discontinuous diamictite horizon which could not be traced in the adjoining areas. Prasad (1984) has remarked that there is a 2 m thick persistent horizon of an intrformational conglomerate at the base of the Lakheri Limestone. This horizon can be termed as an extension of the diamictite horizon exposed on Lakheri – Bundi motor road.

iii. B. Kumar *et al.* (2002) have considered the Lakheri Limestone as a cap carbonate. They had sampled only 9 m thick section (see B. Kumar *et al.*, 2003) towards the base of the Lakheri Formation (Limestone) which shows strong negative excursion. The entire thickness of ca. 100 m of the Lakheri Limestone exposed at Satur, on Bundi – Jaipur highway was resampled with close intervals from where B. Kumar *et al.* (2002) had collected the samples of the Lakheri Limestone to see the variation of δ^{13}Ccarb for the entire thickness. We analysed 19 samples of the Lakheri Limestone and two samples of the stromatolitic limestone belonging to the overlying Somria Shale (Table 7). δ^{13}Ccarb values range from –5.7‰ to –2.9‰. About 60 m thick succession of the Lakheri Limestone shows δ^{13}Ccarb values around –5.5‰ and then it gradually shifts towards -3‰ (fig. 5). Thus, around 60 m thick succession shows very strong negative values (around –5.5‰) and not a very small thickness as asserted by Kumar *et al.* (2003). In our opinion the Lakheri Limestone differs completely in isotope signature with the Bhander Limestone and thus not correlatable as has been done by Sarkar *et al.* (1996) and Bhattacharya (1996). It appears that the Lakheri Limestone represents a distinctly different horizon and is possibly older than the Bhander Limestone (see fig. 8).

iv. For the Maihar area, Friedman *et al.* (1996) and Friedman and Chakarborty (1997) have reported carbon and oxygen isotopes of 14 samples covering both the Semri and Bhander Groups. They have noted a sharp drop of 2.1‰ in δ^{13}Ccarb within the Bhander Group and on this basis have identified Precambrain/Cambrian boundary between the Bhander Limestone and a carbonate horizon that is intercalated within the

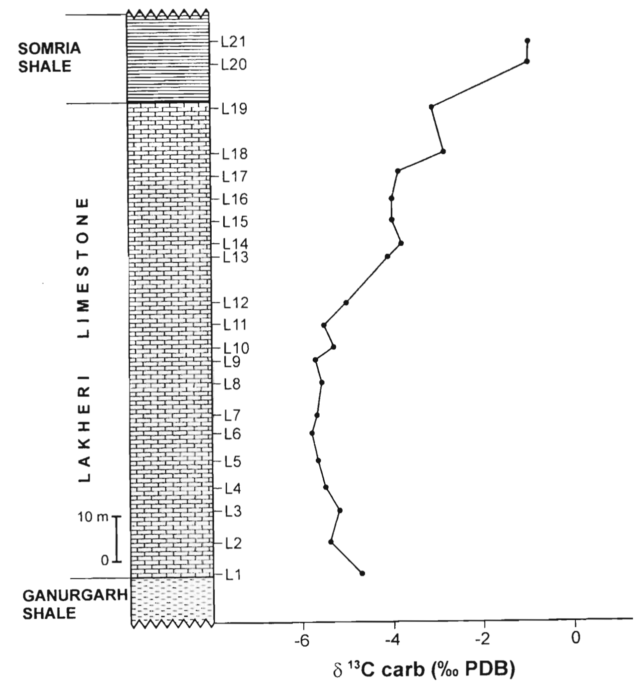

Fig. 5. Detailed litholog of the Lakheri Limestone and Somria Shale with δ^{13}Ccarb trends in this section.

Sirbu Shale. Their conclusion can not be accepted as we do not find supporting evidence for the drop of 2.1‰ between the Bhander Limestone and the Sirbu limestone intercalations. We did a more detailed sampling (Table 8, fig. 6) in the limestone pocket preserved with the Sirbu Shale to check this drop in the isotope values. δ^{13}Ccarb values ranges from 2.6‰ to 4.4‰. A slight decline is recorded but is within the Sirbu Shale and is within the normal variation recorded in the Maihar area and can not be taken as an excursion (fig. 6). It may be pointed out that Kumar (1991) had recorded a drop of 2.35‰ within the Bhander Limestone in adjoining Satna area.

Table 7: δ^{13}C and δ^{18}O values for the carbonates of the Lakheri Limestone and Somria Shale, Satur area, Bundi district, Rajasthan.

S. No.	Sample No.	Lithology	δ^{13}C‰ (PDB)	δ^{18}O‰ (PDB)	Stratigraphic Position
1.	L20	Algal Limestone	-1.0	-4.6	Somria
2.	L21	Algal Limestone	-1.0	-4.2	Shale
3.	L1	Interclastic Limestone	-4.7	-7.5	
4.	L2	Micritic Limestone	-5.4	-9.6	
5.	L3	Micritic Limestone	-5.2	-9.6	
6.	L4	Micritic Limestone	-5.6	-9.3	
7.	L5	Micritic Limestone	-5.7	-8.7	
8.	L6	Micritic Limestone	-5.7	-9.2	
9.	L7	Micritic Limestone	-5.7	-9.3	Lakheri Limestone
10.	L8	Micritic Limestone	-5.6	-8.1	
11.	L9	Micritic Limestone	-5.7	-8.6	
12.	L10	Micritic Limestone	-5.3	-8.5	
13.	L11	Micritic Limestone	-5.5	-9.6	
14.	L12	Micritic Limestone	-5.0	-9.1	
15.	L13	Micritic Limestone	-4.1	-7.5	
16.	L14	Micritic Limestone	-3.8	-8.0	
17.	L15	Micritic Limestone	-4.0	-8.7	
18.	L16	Micritic Limestone	-4.0	-8.5	
19.	L17	Micritic Limestone	-3.9	-8.1	
20.	L18	Micritic Limestone	-2.9	-8.3	
21.	L19	Micritic Limestone	-3.1	-8.6	

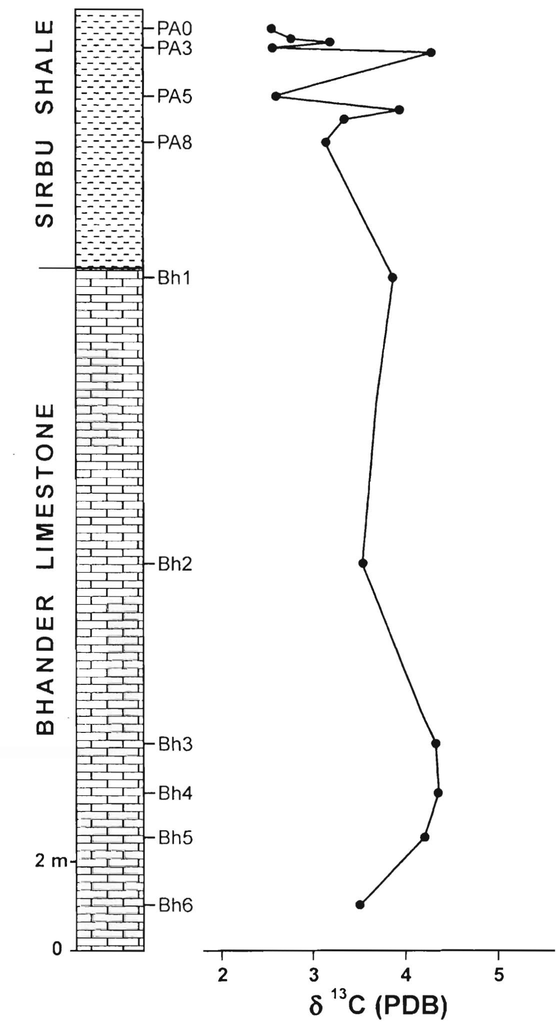

Fig. 6. Litholog of the Bhander Limestone and overlying Sirbu Shale with δ^{13}Ccarb trends over this section.

Table 8: δ^{13}C and δ^{18}O values for the carbonates of the Sirbu Shale and the Bhander Limestone, Maihar area, Madhya Pradesh.

S. No.	Sample No.	Lithology	δ^{13}C in ‰ (PDB)	δ^{18}O in ‰ (PDB)	Stratigraphic position
1.	PA0	Micritic Limestone	2.6	- 8.7	
2.	PA1	Calc. Shale	2.8	- 7.8	
3.	PA2	Infilling between domal	3.2	- 10.0	
4.	PA3	stromatolite	2.6	- 7.4	
5.	CM29	Stromatolitic Limestone	4.3	- 9.2	Sirbu Shale
6.	PA5	Stromatolitic Limestone	2.6	- 10.6	
7.	PA6	Calc. Shale	3.9	- 11.6	
8.	PA7	Calc. Shale	3.4	- 10.3	
9.	PA8	Calc. Shale	3.2	- 10.7	
10.	Bh1	Micritic Limestone	3.6	- 9.4	Bhander
11.	Bh2	Stromatolitic Limestone	3.6	-9.3	Limestone
12.	Bh3	Stromatolitic Limestone	4.3	-9.0	
13.	Bh4	Micritic Limestone	4.4	-6.8	
14.	Bh5	Micritic Limestone	4.2	-7.8	
15.	Bh6	Micritic Limestone	3.5	-7.6	

v. Frank *et al.* (1997) have plotted δ^{13}Ccarb values of marine carbonate successions for which good evidence for the preservation of primary δ^{13}C values are available (fig. 7). It is noted that the variation in the δ^{13}Ccarb values for the Vindhyan Supergroup matches well with the global age trend.

vi. As discussed earlier there is no compelling evidence to accept a Cambrian age for the upper part of the Bhander Group as suggested by Friedman and Chakraborty (1997) because no trace fossil, megabody fossil and microfossils of the Cambrian age have so far been recorded from the Vindhyan sediments. Friedman and Chakraborty (1997) have also contented that the horizon which shows drop in carbon isotope values is unfossiliferous but this is not true. Well preserved *Chuaria-Tawuia* association along with other carbonaceous megafossils, presence of sponge spicules like forms and abundance of stromatolites have been recorded from the Bhander Limestone (Kumar and Srivastava, 1997, Kumar, 1976, 1999a) The Sirbu shales have yielded microfossils dominated by Leiosospherids and filamentous forms (unpublished data of S. Kumar), well preserved algal mat horizons and carbonaceous megafossils (Kumar *et al.*, 2002; Kumar and Srivastava, 2003).

vii. Friedman and Chakraborty (1997) have also assumed that the Vindhyan and Krol sediments were formed in the same sea way without presenting evidence. It may be pointed out that these two deposits do not show any continuity of exposures. In other words, there is no field evidence to suggest this, as these are separated by a wide physiographic division, the Indo-Gangetic alluvium. The Vindhyan Supergroup is situated on the northern part of a shield of peninsular India while the Krol Formation constitutes a part of the Lesser Himalaya. The age of the Krol - Tal succession is now well settled on the basis of trilobites, brachiopod, trace fossils and microfossils (Singh and Rai, 1983; Rai and Singh, 1983, Azmi, 1983, 1987; Tripathy *et al.*, 1984; Tiwari and Knoll, 1994). The Precambrian/Cambrain boundary is now firmly established by high resolution chemostratigraphy based on C isotope study and the isotope trends recorded in the Krol-Tal succession matches well with the well studied sections in the other areas of the world. (Aharon *et al.*, 1997).

The stromatolite assemblage of the Krol succession is also not comparable with the stromatolite assemblage of the Bhander Group. The stromatolite assemblage of the Bhander Group is characterised by abundance of *Baicalia* spp. and a complete absence of *Conophyton* where as stromatolites are very rare in the Krol Formation but shows rare presence of *Conophyton* (Singh and Rai , 1977). It may be pointed out that the *Conophyton* spp. are very rare in the Upper Riphean but appears commonly in Vendian. In our opinion the Krol Formation is younger than the uppermost Vindhyan horizon. Possibly the Vindhyan sedimentation ended close to the lower part of the Vendian. Thus, the contention of Friedman *et al.*

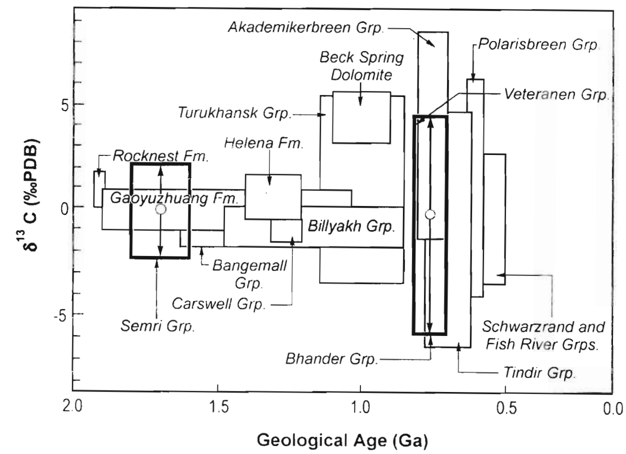

Fig. 7. Spread of δ^{13}Ccarb in the calcite fraction of selected marine carbonate formations of Proterozoic (2.0 – 0.5 Ga) age (after Frank et al., 1997). Superimposed on this compilation are the corresponding field for the Semri and Bhander Groups of the Vindhyan Supergroups (strong frames with mean values marked as circles within the windows).

(1996) and Friedman and Chakraborty (1997) concerning the common sea way for the Krol and the Vindhyan and the presence of Precambrian/Cambrian boundary with in the Bhander Group are not supported by evidence.

viii. The intrabasinal correlation of the Vindhyan sediments is very difficult in absence of radiometric dates. Earlier attempts at correlation were simply based on the lithology and stromatolite assemblages. More recently carbonaceous megafossils *Chuaria* and *Tawuia* helped in suggesting ages. Though microfossils were also discovered from a number of horizons but they were not of much help in suggesting ages to the fossil bearing horizons. Now chemostratigraphy has given a new insight for the Vindhyan stratigraphy and has shown the limitation of the lithologic correlation. The isotope analysis may help in reaching better results for correlation. The earlier lithostratigraphic correlation for the Vindhyans is given in Table 3 . But if the isotope signatures are taken into account it convincingly shows that the carbon isotope signatures are different for both the Semri Group and the Bhander Group for the Son Valley area (Chopan-Maihar area) as well as for the Kota-Chittorgarh area, Rajasthan. In the Semri Group, the Bhagwanpura Limestone and the Kajrahat Limestone show more or less same isotope values as well as stromatolite assemblages. Both represent the oldest carbonate horizon of the Semri Group. But the Rohtas Limestone and the Nimbahera Limestone (including the Kotastone) have altogether different isotope signatures. In the lithocolumn both show different stratigraphic position with respect to the well recognised horizon of the Kaimur Group. And hence it is suggested that they are not correlatable. Similarly the Bhander Limestone is not correlatable with the Lakheri Limestone as both show different isotope signatures. The Bhander Limestone is stromatolitic while the Lakheri Limestone is nonstromatolitic. The Sirbu carbonates, the Balwan Limestone (the youngest car-

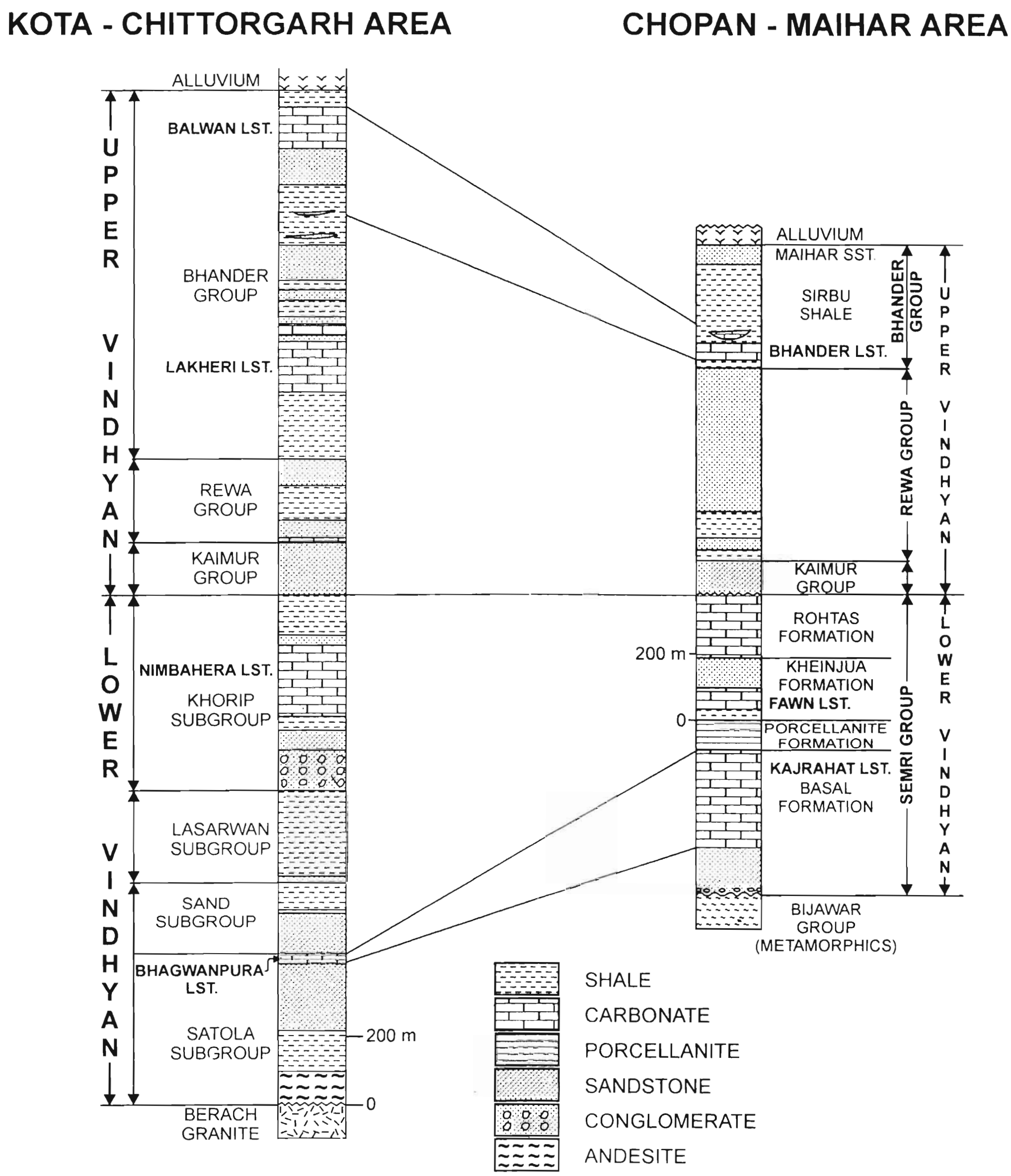

Fig. 8. Lithostratigraphic correlation between the Vindhyan successions of the Chopan-Maihar (Uttar Pradesh, Madhya Pradesh) and the Kota-Chittorgarh (Rajasthan) areas.

bonate unit of the Bhander Group of Rajasthan) and the Bhander Limestone show same stromatolite assemblage as well as similar isotope signature and hence can be correlated. Correlation based on isotope signature is attempted in Fig. 8. The carbonate successions in the Son Valley – Maihar area i.e., eastern part of the Vindhyan Basin and in Rajasthan, where the western part of the Basin is developed show different isotope signatures. In other words it can be said that the isotope signatures for the western and eastern parts of the Vindhyan Basin are different. It appears that the evolution of the Vindhyan Basin differ considerably for the eastern and western parts.

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REFERENCES

Aharon, P., Schidlowski, M. and Singh, I.B. 1987. Chronostratigraphic markers in the Precambrian Cambrian-isotope record of the Lesser Himalaya. *Nature*, **327**: 99 –102.

Auden, J.B. 1933. Vindhyan sedimentation in Son Valley, Mirzapur district. *Mem. Geol. Surv. India*, **62**: 141 - 250.

Azmi, R.J. 1983. Microfauna and age of Lower Tal phosphorite of Mussorie syncline, Garhwal Lesser Himalaya. *Him. Geol.* **11**: 373 – 409.

Azmi, R.J. 1987. Global prospects of small shelly fauna of Krol - Tal of Garhwal Lesser Himalaya, India. *Conf. Volume 'Geology of Krol Basin in Garhwal, Garhwal University*: 39 – 44.

Azmi, R.J. 1998. Discovery of lower Cambrian small shelly fossils and brachiopods from the Lower Vindhyan of Son Valley, Central India. *Jour. Geol. Soc. India*, **52**: 381 – 389.

Banerjee, D.M., Deb, M. and Strauss, H. 1992. Organic carbon isotopic composition of Proterozoic sedimentary rocks from India: Preliminary results, p. 232-240. In:. *Early Organic Evolution: Implications for Mineral and Energy resources* (Ed. Schidlowski, M. *et al.*). *Springer –Verlag, Berlin- Heidelberg.*

Bhargava, O.N. and Srikantia, S.V. 2000. Vindhyan Fossil Controversy. Jour. Geol. Soc. India. **55**: 675 – 680.

Bhattacharyya, A. 1993. *A field guide on the Upper Vindhyans of Maihar, Satna district, Madhya Pradesh.* Geol. Soc. India.

Bhattacharyya, A. 1996. Foreword, p. i-viii. *Recent Advances in Vindhyan Geology* (Ed. Bhattacharyya, A.), *Geol. Soc. India. Bangalore.*

Bhattacharyya, A., Sarkar, S. and Chanda, S.K. 1980. Storm deposits in the Late Proterozoic Lower Bhander Sandstone of Vindhyan Supergrooup around Maihar, Satna district, Madhya Pradesh, India. *Jour. Sed. Petrol.* **50:** 1327 – 1336.

Craig, H. 1957. Isotopic standards for carbon and oxygen and correlation factors for mass spectrometric analysis of carbon dioxide. *Geochim. et Cosmochim. Acta*, **3**: 133 – 149.

Crawford, A.R. and Compston, W. 1970. The age of the Vindhyan System of Peninsular India. *Jour. Geol. Soc. London*, **125**: 351 – 371.

De, C. 2003. Possible organisms similar to Ediacaran forms from the Bhander Group, Vindhyan Supergroup, Late Neoproterozoic of India. *Jour. Asian Earth Sci.* **21**: 387 – 395.

Frank, T. D., Lyons, T.W. and Lohmann, K.C. 1997. Isotopic evidence for the palaeoenvironmental evolution of the Mesoproterozoic Helena Formation, Belt Supergroup, Montana, USA. *Geochem. et Cosmochem. Acta*, **61**(23): 5023 – 5041.

Friedman, G.M. and Chakraborty, C. 1997. Stable isotopes in marine carbonates: their implications for the palaeoenvironment with special reference to the Proterozoic Vindhyan carbonates (Central India). *Jour. Geol. Soc. India*, **50**: 131 – 159.

Friedman, G.M., Chakraborty, C. and Kolkas, M. 1996. $\delta^{13}C$ excursion in the end of Proterozoic strata of the Vindhyan Basin (Central India): its chronostratigraphic significance. *Carbonate and Evaporites*, **11**: 206 – 212.

Glumac, B. and Spivak-Birndorf, M. L. 2002. Stable isotopes of carbon as an invaluable stratigraphic tool: an example from the Cambrian of the northern Applachians, USA. *Geol.* **30**: 563 - 566.

Kathal, P.K., Patel, D.R. and Alexander, P.O. 2000. An Ediacaran fossil *Spriggina* (?) from the Semri Group and its implication on the age of the Proterozoic Vindhyan Basin , Central India, *N.Jb. Geol. Palaönt. Mh.* **2000**(6): 321 – 332.

Kaufman, A.J. and Knoll, A. H. 1995. Neoproterozoic variations in the C isotopic composition of sea water: stratigraphic and biogeochemical implications. *Precamb. Res.* **73**: 27 – 49.

Knoll, A.H., Hayes, J.M., Kaufman, A.J., Swett, K. and Lambert, I.B. 1986. Secular variation in carbon isotope ratios from upper Proterozoic successions of Svalbard and East Greenland, *Nature*, **321**: 832 – 838.

Kreuzer, H., Harre, W., Kursten, M., Schnitzer, W. A., Murti, K.S. and Srivastava, N. K. 1977. K/Ar dates of two glauconites from Chanderpur Seris (Chhattisgarh/India). *Geol. Jahrb.* **B28**: 23- 26.

Krishnamurthy, R. V., Bhattacharya, S. K. and Mathur, S. M. 1986. Carbon isotope ratio of the coaly matter from the basal part of Proterozoic Vindhyan Supergroup. *Jour. Geol. Soc. India*, **27**: 119 – 120.

Krishnan, M. S. and Swaminath, J. 1959. The great Vindhyan Basin of northern India. *Jour. Geol. Soc. India*, **1**: 10 – 30.

Kumar, A., Gopalan K. and Rajagopalan, G. 2001. Age of the Lower Vindhyan sediments, Central India, *Curr. Sci.* **81** (7): 806 – 809.

Kumar, A., Padma Kumari, V. M., Dayal, A. M., Murthy, D. S. N. and Gopalan K. 1993. Rb – Sr ages of Proterozoic kimberlites of India: evidence of contemporaneous emplacement. *Precamb. Res.* **62**: 227 – 237.

Kumar, B., Das Sharma, Sreenivas, B., Dayal, A. M., Rao, M.N., Dubey, N. and Chawla, B.R. 2002. Carbon, oxygen and strontium isotope geochemistry of Proterozic carbonate rocks of the Vindhyan Basin, central India. *Precamb. Res.* **113**: 43 – 63.

Kumar, S. 1976. Stromatolites from the Vindhyan rocks of Son Valley-Maihar area, districts Mirzapur (U.P.) and Satna (M.P.) *Jour. Pal. Soc. India*, **18**: 13 – 21.

Kumar, S. 1980. Stromatolites and Indian Biostatigraphy: A review. *Jour. Pal. Soc. India*, **23–24**: 166 – 183.

Kumar, S. 1982. Vindhyan stromatolites and their stratigraphic testimony, p. 102-112. In : *Geology of Vindhyanchal* (Eds. K.S.Valdiya, S.B.Bhatia and V.K. Gaur). Hindustan Publishing Corporation, New Delhi.

Kumar, S. 1984. Present status of stromatolite biostratigraphy in

India. *Geophytol.* **14**(1): 96 – 110.

Kumar, S. 1991. Lithostratigraphy, mineralogy and geochemistry of the Bhander Limestone (Upper Vindhyan Supergroup) Satna area, Madhya Pradesh. *Ind. Min.* **45**(3) : 139 – 148.

Kumar, S. 1995. Megafossils from the Mesoproterozoic Rohtas Formation (the Vindhyan Supergroup) Katni area, Central India. *Precamb. Res.* **72**: 171 – 184.

Kumar, S. 1999a. Siliceous sponge spicule like forms from the Neoproterozoic Bhander Limestone, Maihar area. Madhya Pradash. *Jour. Pal. Soc. India*, **44**:141 – 148.

Kumar, S. 1999b. Stromatolite biostratigraphy of the Vindhyan Basin: Utility and Significance. Workshop on Vindhyan Stratigraphy and Palaeobiology, Lucknow University:18 (Abstract)

Kumar, S. 2001. Mesoproterozoic megafossil *Chuaria – Tawuia* association may represent parts of a multicellular plant, Vindhyan Supergroup, Central India. *Precamb. Res.* **106**: 187 –211.

Kumar, S. 2004. C, O, Sr and Pb isotope systematics of carbonate sequences of the Vindhyan Supergroup, India: age, diagenesis, correlations and implications for global events- Comment. *Precamb. Res.* **129**: 191 – 193.

Kumar, S. and Gupta, S. 2002. International Field Workshop on the Vindhyan Basin, Central India. *Field Guide Book. Pal. Soc. India*, Lucknow: 1- 72.

Kumar, S. and Schidlowski, M. 1999. Carbon and Oxygen Isotopes of the Rohtas Formation, Son Valley – Maihar area, Central India: A preliminary report. Workshop on Vindhyan Stratigraphy and Palaeobiology, Lucknow University: 21. (Abstract),

Kumar, S. and Srivastava, P. 1991. Microfossils from the nonstromatolitic Middle Proterozoic Vindhyan Chert, Chitrakut area, Uttar Pradesh. *Jour. Geol. Soc. India*, **38**: 511 – 515.

Kumar, S. and Srivastava, P. 1992. Microfossils from the black chert of Bhagwanpura limestone (Middle Proterozoic), Vindhyan Supergroup, Chittorgarh area, Rajasthan, west India. *Curr. Sci.* **62**: 371 – 374.

Kumar, S. and Srivastava, P. 1995. Microfossils from the Kheinjua Formation. Mesoproterozoic Semri Group, Newari area, Central India. *Precamb. Res.* **74**: 91 – 117.

Kumar, S. and Srivastava, P. 1997. A note on the carbonaceous megafossils from the Neoproterozoic Bhander Group, Maihar area, Madhya Pradesh. *Jour. Pal. Soc. India*, **42**: 141 – 146.

Kumar, S. and Srivastava, P. 2003. Carbonaceous megafossils from the Neoproterozoic Bhander Group, Central India. *Jour. Pal. Soc. India*, **48**: 125 – 140.

Lahiri, D. 1964. Petrology of the Vindhyan rocks around Rohtasgarh, India. *Jour. Sed. Petrol.* **34** (2): 270 – 280.

Lindsay, J.F. and Brasier, M.D. 2000. A carbon isotope reference curve for ca. 1700 – 1575 Ma McArthur and Mount Isa Basins, Northern Australia. *Precamb. Res.* **99**: 271 – 308.

Mathur, S.M. 1982. Organic materials in Precambrian Vindhyan Supergroup, p. 125-131. In: "*Geology of Vindhyanchal*" (Eds. K.S.Valdiya, S.B.Bhatia and V.K. Gaur), *Hindustan Publishing Corporation*, New Delhi.

McCrea, J.H. 1950.On the isotope chemistry of carbonates and palaeotemperature Scale. *Jour. Chem. Phys.* **18**: 849 –857.

McMenemin, D.S., Kumar, S. and Awaramik, S. M. 1983. Mcrobial fossils from the Kheinjua Formation, Middle Proterozoic Semri Group (Lower Vindhyan), Son Valley area, Central India. *Precamb. Res.* **21**: 247 – 272.

Misra, Y. 2004. Stromatolite biostratigraphy of Vindhyan Basin. *Unpublished Thesis, Department of Geology, University of Lucknow, Lucknow*, p. 1-126, India.

Müller, G. and Gastner, M. 1971. The 'Karbonat-Bombe' a simple devise for determination of the carbonate content in sediments, soils and other materials. *Neues. Jahrb. Min., Monatsh.* **1972**: 466 – 469.

Pandey, G.C., Sharma, T. and Misra, R.C. 1970. O^{18}/O^{16} and C^{13}/C^{12} ratio variations in the limestones from the Vindhyan range. *Jour. Geol. Soc. India*, **11**: 397 – 399.

Prasad, V. 1984. Geology, sedimentation and palaeogeography of the Vindhyan Supergroup, Southeastern Rajasthan. *Mem. Geol. Surv. India*, **116**(I): 1 –107.

Raha, P. K. and Sastry, M.V.A., 1982. Stromatolites and Precambrian stratigraphy in India. *Precamb. Res.* **18**: 293 – 318.

Rai, V., Shukla, M. and Gautam, R. 1997. Discovery of carbonaceous megafossils (*Chuaria – Tawuia* assemblage) from the Neoproterozoic Vindhyan succession (Rewa Group) Allahabad – Rewa area. *Curr. Sci.* **73** : 783 – 788.

Rai, V. and Singh, I.B. 1983. Discovery of trilobite impression in the Arenaceous Member of Tal Formation, Mussoorie area, India. *Jour. Pal. Soc. India*, **28**: 114 – 117.

Rasmussen, B. Bose, P.K., Sarkar, S., Banerjee, S. Fletcher, I.R. and McNaughton, N. J. 2002. 1.6 Ga U –Pb zircon age for the Chorhat Sandstone, lower Vindhyan, India: Possible implications for early evolution of animals. *Geol.* **30**: 103 – 106.

Ray, J .S., Martin M.W., Veizer, J. and Bowring, S.A. 2002. U-Pb zircon dating and Sr isotope systematics of the Vindhyan Supergroup, India. *Geol.* **30**: 131 – 134.

Ray, J. S., Veizer, J. and Davis, W. J. 2003. C, O, Sr and Pb isotope systematics of carbonate sequences of the Vindhyan Supergroup, India: age, diagenesis, correlations and implications for global events. *Precamb. Res.* **121**:103 – 140.

Ray, J. S. and Veizer, J. 2004. C, O, Sr and Pb isotope systematics of carbonate sequences of the Vindhyan Supergroup, India: age, diagenesis, correlations and implications for global events - Reply. *Precamb. Res.* **129**: 195 - 196.

Saltzman, M. R., Runnegar, B. and Lohmann, K. 1998. Carbon isotope stratigraphy of Upper Cambrian (Stetoean Stage) sequence of the eastern Great Basin: Record of a global oceanographic event. *GSA Bull.* **110**(3) :285 – 297.

Sarangi, S., Gopalan, K. and Kumar, S. 2004. Pb – Pb age of earliest megascopic, eukarayotic alga bearing Rohtas Formation, Vindhyan Supergroup, India: implications for Precambrian atmospheric oxygen evolution. *Precamb. Res.* **132**: 107 – 121.

Sarkar, S., Chakraborty, P.P. and Bose, P. K. 1996. Proterozoic Lakheri Limestone, central India: Facies, Palaeogeography and Physiography, p. 5-26. In: *"Recent Advances in Vindhyan Geology"* (Ed. Bhattacharyya, A.), *Mem. Geol. Surv. India*, **36**.

Singh, I. B. 1973. Depositional environment of the Vindhyan sediments in the Son Valley area, p. 140-152. In : *Recent Researches in Geology. Hindustan Pub. Corp. New Delhi.* **1**.

Singh, I. B. 1976. Depositional environment of the Upper Vindhyan in Satna –Maihar area, Madhya Pradesh and its bearing on the evolution of the Vindhyan sedimentary basin. *Jour. Pal. Soc. India,* **19**: 48 – 70.

Singh, I. B. 1980a. Precambrian sedimentary sequences of India: their peculiarities and comparison with modern sediments. *Precamb. Res.* **12**: 411 – 433.

Singh, I. B. 1980b. The Bijaigarh Shale, Vindhyan System (Precambrian) India- An example of a lagoonal deposit. *Sediment. Geol.* **25**: 83 – 103.

Singh, I. B. and Rai, V. 1977. On the occurrence of stromatolites in the Krol Formation of Nainital area and its implications on the age of Krol Formation. *Curr. Sci.* **46**(21): 736 – 738.

Singh, I. B. and Rai, V. 1983. Fauna and biogenic structures in Krol-Tal succession (Vendian - Early Cambrian), Lesser Himalaya: their biostratigraphic and palaeoecological significance. *Jour. Pal. Soc. India,* **28**: 67 – 90.

Srivastava, P. 1998. Upper age limit of the Vindhyan Supergroup: New evidence from carbonaceous magafossils from the Dholpura Shales, Bhander Group, Rajasthan. 14th Indian Colloquium on Micropalaeontology and Stratigraphy, NIO, Goa: 201 –202. (Abstract)

Srivastava, P. 2004. Carbonaceous fossils from the Panna Shale, Rewa Group (Upper Vindhyans), Central India : A possible link between evolution from micro-megascopic life *Curr. Sci.* **86** (5) : 644 – 646.

Strauss, H., Des Marais, D. J., Hayes, J. M. and Summons, R .E. 1992. Proterozoic organic carbon–Its preservation and isotopic record, p. 203-211. In : *"Early organic evolution- Implication for Mineral and Energy Resources"* (Eds. Schidlowski, M. *et al.*), Springer Verlag, Berlin Heidelberg.

Tripathy, C. Jangpangi, B. S., Bhatt, D. K., Kumar, G. and Raina, B.K. 1984. Early Cambrian brachiopods from Upper Tal Mussoorie Syncline, Dehradun District, U.P., India. *Geophytol.* **14**(2): 221 – 227.

Tiwari, M. and Knoll, A.H. 1994. Large acanthomorphic acritarchs from the Infrakrol Formation of the Lesser Himalaya and their stratigraphic significance. *Jour. Him. Geol.* **5**(2) :193 – 201.

Tucker, M.E. 1982. Precambrian dolomites: Petrographic and isotopic evidence that they differ from Phanerozoic dolomites. *Geol.* **10**: 7 – 12.

Valdiya, K. S. 1969. Stromatolites of the Himalayan carbonate formations and the Vindhyans. *Jour. Geol. Soc. India,* **10**: 1 – 25.

Valdiya, K.S. 1989. Precambrian stromatolite biostratigraphy of India- A review. *Him. Geol.* **13**: 181 – 214.

Veizer, J. 1983a. Chemical diagenesis of carbonate rocks: theory and application of trace element technique, p. 111/1-11/100. In : *"Stable isotopes in Sedimentary Geology"* (Eds. M.A. Arthur, T.M. Anderson and R.Kaplan). *Society of Economic Palaeontologists and Mineralogists, Tulsa Okla, SEPM short course*, **10**:III/1- III/100.

Veizer, J. 1983b. Trace elements and isotopes in sedimentary carbonates. *Rev. Min.* **11**: 265 – 300.

Vinogradov, A. Tugarinov, A. Zhkov, C., Stapnikova, N., Bibikova, E., Khoree, K., 1964. Geochronology of the Indian Precambrian. *XXII Int. Geol. Congr.* Rept, New Delhi, Part **10** : 553 – 567.

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