An Overview of Vindhyan Supergroup Palaeomagnetism

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Abstract

Palaeomagnetic results of the Vindhyan Supergroup Formations are summarized in terms of the palaeogeography drift history and magnetostratigraphy considerations during the Meso Neoproterozoic eras which cover the sedimentation period of the basin .The basal Semri Group Pandwafall Sandstone Formation results reveal that the subcontinent has occupied a geographic position that is similar to the present day situation with a palaeolatitude of 21° N and an orientation of 1° W of present north. The Gangau tilloid results negate the existence of glacial conditions during Meso- Neo Proterozoic times in India a well debated point until now. A large latitudinal drift of 60 between the Malani Rhyolite and Rewa Sandstone period was supplemented by intermediate palaeoposition obtained from the Kaimur Group Baghain Sandstone Formation. The end of the sedimentation period was provided by the Rewa and Bhander Groups by an agreement of their palaeomagnetic data with that of the Lower Palaeozoic rocks from the Salt Range which are well constrained by fossil evidence. The palaeomagnetic data from several sites of the different Vindhyan. Groups provide magnetozones from several formations that help to construct a geomagnetic polarity timescale during the Vindhyan sedimentation period which can be used for correlation purpose. There is however plenty of scope to refine our understanding in terms of the above aspects from rest of the exposed rocks from other regions.With this background an exhaustive sampling of Vindhyan Supergroup rocks has been undertaken in recent times by collecting 550 oriented block samples from 100 sites to better under stand the evolutionary history of the Vindhyan basin and studies on these samples are underway. Available results on some of these formations are presented.

Introduction

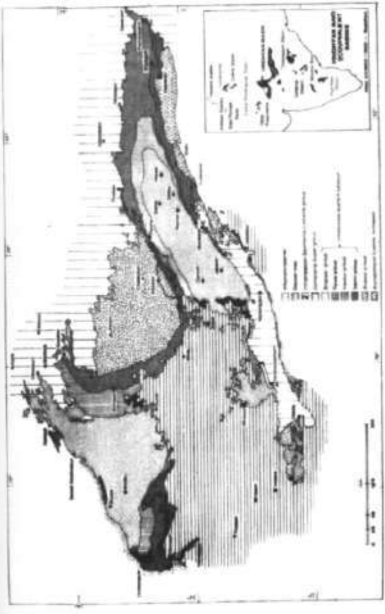
The Vindhyan basin in Central India is an intracratonic sedimentary basin with a sandstone shale limestone sequence of deposition without any metamorphic and tectonic effects. It contains the geological and evolutionary history of the

Indian subcontinent hidden in these rocks covering a very long period of Meso-Neoproterozoic eras in geological history. Systematic studies on these rocks were initiated as long ago as 1856 (Oldham, 1856), still we know very little about them. In recent times some advances are made with the development of new methods to date the rocks and sensitive instruments to measure their remanent magnetic directions even in limestone formations. An overview of these results of radiometric dating and palaeomagnetic measurements on some of these Vindhyan Supergroup rocks is presented that bring in to light some salient features with regard to the geological history, evolution of the Indian sub-continent and nature of the geomagnetic field during this Meso-Neoproterozoic eras.

Geology

The Vindhyan basin is an intracratonic sedimentary basin in Central India in the states of Bihar, Uttar Pradesh, Madhya Pradesh and Rajasthan occupying an area of 1,04, 000 sq. km. This Vindhyan Supergroup rocks cover an important period of geological evolution during late Palaeo-Neoproterozoic eras of the Indian sub-continent.. These rocks range in thickness from 4000-5000 m comprising mainly sandstone-shale-limestone formations of shallow-water marine origin. The Vindhyan Supergroup rocks are divided in to four major groups namely the Semri, Kaimur, Rewa and Bhander (Sony et. al. 1987; Bhattacharya, 1996). However, on the basis of presence of a local major unconformity these are often referred to as the Lower and Upper Vindhyans. The Semri Group rocks are referred to as Lower Vindhyan overlain by the Upper Vindhyans consisting of Kaimur, Rewa and Bhander Groups. Most of the Vindhyan Supergroup rocks are flat lying to gently dipping and unmetamorphosed. A geological map of the Vindhyan basin after Sony et. al. (1987) is shown in Fig. 1.

The age of the Vindhyans was not known with certainty due to lack of suitable material for radiometric dating and absence of fossil occurrences (Haldar and Ghosh, 1981; Mathur, 1981). The fossil record of the Vindhyan rocks indicates an age ranging between 1400-400 Ma (Venkatachala et. al. 1996; De, 2003). The K-Ar dating of glauconite from the Semri and Kaimur Groups (Tugarinov et. al. 1965; Vinogradov et. al. 1966) and K-Ar and Rb-Sr dating of kimberlites intrusive in to these Groups (Crawford and Compston, 1970; Paul et. al. 1975) suggest that the base of the Semri Group is at least 1200 Ma and perhaps as much as 1400 Ma and that the Kaimur Group is at least 910-940 Ma and possibly > 1150 Ma. On the basis of lithological correlations the Rewa Sandstone is correlated with the Jodhpur Sandstone of Marwar Supergroup



Fg 1 *Geological map of MesoNeo Proerozoc Vndhyan Basin Central Inda after Sony e al (1987)*

in Trans-Aravalli Vindhyan. These Jodhpur Sandstones overlie the Malani Rhyolites which are well constrained with palaeomagnetic and Rb-Sr date assigning an age of 745+10 Ma (Crawford and Corapston, 1970) and 771-751 Ma (Torsvik et. al. 2001) to the Rewa Group of rocks.

However, with the recent report of small shelly fossils of Cambrian affinity in Rohtasgarh Limestone (Semri Group) by Azmi (1998) there is a spurt in the radiometric dating of Semri Group rocks (Kumar et. al. 2001; Rassmussen et. al. 2002; Ray et. al. 2003). Several U-Pb and Zircon dating results of the Semri Group rocks extend the lower limit of the Vindhyan Basin to 1650-1600 Ma. The palaeomagnetic study of the Khairmalia Andesite Formation from the western part of the Vindhyan basin in Rajasthan also support an age of 1650 Ma for the beginning of the Vindhyan sedimentation (Poornachandra Rao et. al. 2004a). The C, O, Sr and Pb isotopic systematics of carbonate sequences of the Vindhyan Supergroup suggest that the Lower Vindhyans were deposited during the Mesoproterozoic era and the Upper Vindhyans were deposited during the Neoproterozoic era (Ray et. al. 2002, 2003; Kumar and Schidlowski, 1999; Kumar et. al. 2002). Therefore, it suggests that the Vindhyan sedimentation lasted over a very long period of 1650-400 Ma.

Palaeomagnetic study of the Vindhyan rocks is launched on a major scale at the National Geophysical Research Institute in order to recover the palaeomagnetic signatures of the geomagnetic field during this period to understand some of the problems associated with the evolution of the Indian subcontinent. There is a complete sequence of Vindhyan rock formations exposed in Son Valley as well as in Rajasthan from where we have sampled for palaeomagnetic study. The stratigraphy of the Vindhyan Supergroup rocks proposed by Sony et. al. (1987) from these areas is given in Table 1. Table 2 gives details of oriented block samples collected for palaeomagnetic studies from the Son Valley, Rajasthan, Guna-Shivpuri regions and Bhopal Inlier as well as Marwar Basin in Trans-Aravalli Vindhyan region under the above programme.

Table 1: Stratigraphy of Vindhyan Supergroup in Son Valley and Rajasthan

Group	Son Valley	Rajasthan
	Maihar Sandstone	-
	Sirbu Shale	-
Bhander		- Tilsava Sandstone
	Nagod Limestone	Singoli Limestone
	Simraval Shale	-
	Gahadra Sandstone	Umar Sandstone
Rewa	Jhiri Shale	Ratangarh Shale
	-	Dehpur Sandstone
	-	Deopura Shale
	Upper Kaimur Sandstone	Dicken Sandstones
Kaimur	Bijaigarh Shale	Panoli Shale
	-	Morwan Sandstone
	-	Suket Shale
	Hinauti Limestone	Nimbahera Limestone
	-	Bari Shale
		Jiran Sandstone
Semri	-	Khori-Mala Conglomerate
	Deonar Porcellinite	Palri Shale
	-	Sawa Sandstone
	Kuteswar Limestone	Bhagwanpura Limestone
	Kanwar Shale	Bandki Shale
	Deoland Sandstone	Khardeola Sandstone
	-	Khairmalia Andesite

Table 2: Samples collected from Vindhyan Supergroup Formations for palaeomagnetic study

Formation	Age	Index	Sites	Samples
	SON VALLEY			
Formation	Age	Index	Sites	Samples
Nagod Limestones	Lower Bhander	7	4	24
Govindgargh Sandstones	Upper Rewa	6	5	32
Dhandraul Sandstones	Upper Kaimur	4	4	27
Rohtasgarh Limestones	Upper Semri	2	9	53
Fawn Limestones	Lower Semri	1	2	16
	RA.TASTHAN			
Formation	Age		Sites	Samples
Tilsava Sandstone	Lower Bhander	7	6	30
Smgoli Limestones	Lower Bhander	7	2	10
Umar Sandstones	Upper Rewa	6	3	18
Ratangarh Shales	Upper Rewa	6	1	6
Dehpur Sandstones	Lower Rewa	5	4	27
Dicken Sandstones	Upper Kaimur	4	5	26
Nimbahera Limestones	Upper Semri	2	5	25
Jiran/Sawa Sandstones	Middle Semri	1	4	22
Khardeola Sandstones	Lower Semri	1	2	11
Khairmalia Andesites	Lower Semri	1	12	62
	GUNA - SHIVPURI			
Formation	Age		Sites	Samples
Sanwara Sandstones	Upper Rewa	6	4	20
Dudauni Sandstones	Upper Kaimur	4	4	20
	BHOPAL INLIER			
Formation	Age		Sites	Samples
Nurganj Sandstones	Upper Bhander	8	3	15
Salkanpur Sandstones	Lower Bhander	7	5	25
Nazarganj Sandstones	Upper Rewa	6	2	10
	MARWAR BASIN (RAJASTHAN)			
Formation	Age		Sites	Samples
Jodhpur Sandstones	Upper Rewa	6	14	70

Index Denotes the position of the Rock Formation in the Vmdhyan Supergroup Stratigraphy

Palaeomagnetism

Ever since the formation of the Earth it is surrounded by its own magnetic field which has been protecting the life and atmosphere on it over the last 4.5 Ga. Rocks get magnetized at the time of their formation and serve as record of the geomagnetic field over the geological time. The study of this geomagnetic field recorded in rocks is termed as palaeomagnetism and a study of this geomagnetic field can be used to understand the evolution of different tectonic regions through geological time period (Athavale et. al. 1963; Klootwijk, 1976, 1979). A palaeomagnetic study involves recovering the magnetic signatures in rocks through a detailed study of representative rock samples of a geological formation from several sites. In-situ and un-metamorphosed samples collected from the rock formations are subjected to critical laboratory demagnetizations using AF, thermal and chemical fields to recover the magnetic signature from these rock formations. The remanent magnetic signatures thus recovered from some formations of the Vindhyan Supergroup rocks are provided below as listed in Table 3. These remanent magnetic signatures recovered from the Vindhyan Supergroup rock formations are used in understanding the evolutionary history of the subcontinent (Poornachandra Rao et. al. 1993, 1997) and nature of the geomagnetic field (Khramov, 1987; Poornachandra Rao and Bhalla, 1996) during their sedimentation period in the geological past as shown in Figures 2A and 2B.

(A)

Fig.2.(a). *Schematic diagram showing the migration of the Indian subcontinent derived from palaeomagnetic results of Palaeo-Peterozoic to Early Palaeozoic periods.*

Table 3 : Palaeornagnetic Data of Vmdhyan Supergroup Formations

formation	N	Dm Im K a_{95}	lp Lp	Reference
Upper Bhander	3	049- 19 200. 0 5 .7	31.5S 10.0E	Athavale et .al . 1972
Sandstones	7	108+10 137.5 5.5	48.5S 34.5E	Klootwijk, 1973
Bhander Group	6	200+11 36. 5 11.2	51.3S 42.7E	McElhinney et al. 1978
Upper Rewa	1	032- 37 15. 0 13. 7	35. 7S 42 .OE	Athavale et. al. 1972
Sandstones	1	222- 08	45. OS 11. 3E	MeElhiney et al. 1978
Gonvindgarh	3	029- 24 75. 9 9. 30	60. 3S 08. 6 E	Poornachandra Rao
Sandtones Rewa Rewa roup	2	017+ 31 12. 4 28. 1	44.8S 59. 5E	2004b ; 2004c
(Neo Proterozoic)				
Jodhpur Sandstone	3	020+46 206.2 5 .6	32.4 S 51.3 E	Poornachandra Rao et al . 2004b
Ghagar Quartzites	20	357+31 - 6 0	81.0 N 77.0W	Sahasrabudhe & Mishra, 1966
Bagham Sandstone	10	002 +39 51.0 6 0	72.0N 20.0W	Poornachandra Rao et al. 1997
(Meso Proterozoic)	6	355 -43 37. 0 10. 0	40.1N 266.2E	-do-
Pandwafall	5	359+42 374. 0 3. 0-	89. ON 34 .0W	Poornachandra Rao et al . 1993
Gangau Tilloids	7	161+63 - 13. 0	18. 2N 86. 6W	Williams & Schmidt, 1996
Semri Group (Meso -Proterozoic)				

N= Number of sites Dm, Im = Mean Declination and Inclination;
K,a_{95} = Precision Parameter and Radius of Circle of Confidence;
lp, Lp = Latitude and Longitude of the VGP

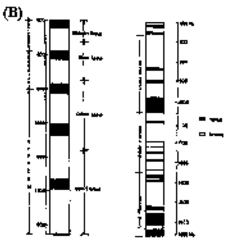


Fig.2(b). *Geomagnetic Polarity Time Scale (GPTS) constructed from the magnetozones recovered from the Vindhyan Supergroup formations from several regions of the Vindhyan Basin . The GPTS of the Russian platform after Khramov (1987) is also show for comparison that also covers the Vindhyan sedimentation period.*

1993) and Khairmalia Andesites (Rajasthan) (Poonachandra Rao et. al. 2004a). Willaims and Schmidt (1996) analysed 91 drill core samples from 7 sites and encountered 3 components, a low-temperature early Tertiary component, an intermediate steep downward pointing component and more rarely a high-temperature less steep component in these rocks. After bedding correction it is having a direction of magnetization that yielded a palaeolatitude of 44.7 + 15.8 °S to the subcontinent negating glaciation during their formation. 25 oriented samples of Pandwafall Sandstones were collected from 5 sites and subjected to AF, thermal and chemical demagnetization studies by Poonachandra Rao et al. (1993). These results indicate that during this period the subcontinent was situated in almost identical position of present time with a palaeolatitude of 20.6 °N for the reference town Nagpur (Fig. 2A). The basal Khairmalia Andesite formation of Semri Group from Rajasthan had been studied by Poonachandra Rao et. al., (2004a) by collecting 62 oriented samples from 12 sites. These samples resulted in a well grouped ChRM direction with reverse magnetization with downward inclination as shown in Figure 3A. The VGP corresponding to this ChRM after Euler rotation is located at 1650 Ma on the Australian APWP (Idnurm and Giddings, 1988) corresponding to an East Gondwanaland reconstruction proposed by Veewers et. al., (1991). Thus the location of the Khairmalia Andesite VGP on the Australian APWP confirms the radiometric dating results of other Semri Group rocks and the beginning of the Vindhyan sedimentation as early as 1650 Ma (Fig. 3B).

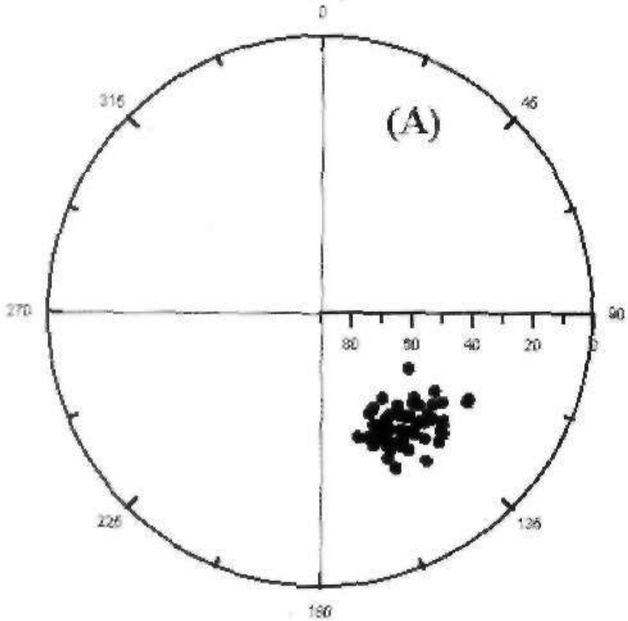


Fig 3(a). *Stereographtc plot of ChRM directions of basal Semrt Group Kluiirmaha Andesites Formation. Western Vmdhyan Basin. Rajasthan.*

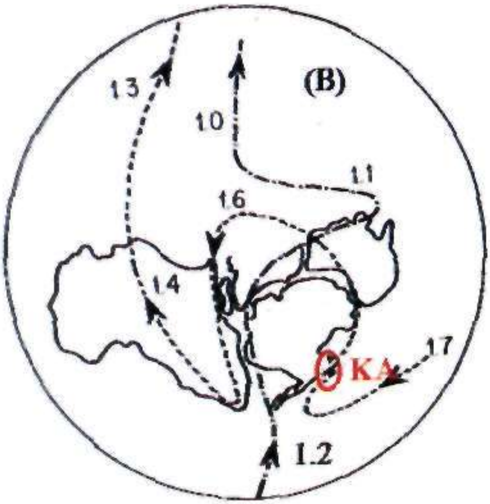


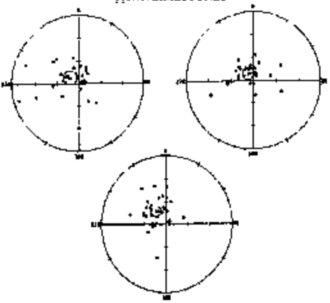
Fig.3(b) *Plot of Elder rotated VGP derived from the ChRM direction of Khairmalta Andesite Formation on the Australian APWP after Idnurm and Giddings (1988) as per the Gondwanaland reconstruction proposed by Veewers et al. (1991). The fChatrmalta Andesite VGP, KA. is located at 1650 Ma.*

The report of small shelly fossils of Cambrian affinity in Rohtasgarh Limestones of Semri Group by Azmi (1998) has attracted the attention of several workers towards the Vindhyan stratigraphy. It has created lot of interest in the radiometric dating of several formations of the Lower Vindhyan Semri Group rocks (Kumar et. al., 2001; Ray et. al., 2002, 2003; Rasmussen, 2002). Samples from a number of formations of Semri Group from both Son Valley and Rajasthan regions were collected for palaeomagnetic study as listed in Table 2. The rock formations collected from the Semri Group include Fawn Limestone (16 samples from 2 sites) and Rohtasgarh Limestone (53 samples from 9 sites) Formations from Son Valley and Khairmalia Andesites (62 samples from 12 sites), Khardeola Sandstones (11 samples from 2 sites), Jiran Sandstones (22 samples from 4 sites) and Nimbahera Limestone (25 samples from 5 sites) Formations from Rajasthan. NRM results on these formations are available which can confirm their stratigraphy after detailed demagnetization studies on these rocks. The Fawn Limestones of lower Semri Group and the Rohtasgarh Limestones of upper Semri Group exhibit very good grouping with steep downward inclinations with normal magnetization as shown in Figure 4. However, two sites in Rohtasgarh Limestone also exhibit SW declination with steep downward inclination. The upper Semri Nimbahera Limestones from Rajasthan also exhibit normal magnetization with steep downward inclinations as shown in Figure 5. However, there are some samples that also show scattered magnetization. The middle Semn Jiran Sandstones from Rajasthan reveal westward pointing declinations with intermediate to steep downward pointing inclinations (Figure 5). The identical remanent magnetic directions of upper Semri Rohtasgarh Limestones from Son Valley and Nimbahera Limestones from Rajasthan provide very good opportunity to confirm their correlation from the two regions.

Kaimur Group

The Kaimur Group is the lowermost group of the Upper Vindhyans and dated to be at least 1200 Ma on the basis of K-Ar and Rb-Sr dating of kimberlites intruding the Baghain Sandstone Formation around Majhgawan (Crawford and Compston, 1970. Paul et. al. 1975). Palaeomagnetic study of the Vindhyan Supergroup rocks has begun with the study of Ghaghar Quartzites around Mirzapur by Sahasrabudhe and Mishra (1966) who studied 60 samples from 20 sites. These results suggested two groups of ChRM directions with normal and reverse polarities indicating a geomagnetic field reversal and yielded a palaeolatitude of 14 °N to the subcontinent. The other investigation is on Baghain Sandstones of Upper Kaimur Group from the Panna region by Poornachandra Rao et. al. (1997). ChRM directions isolated from 60 samples collected at 14 sites around Panna region revealed both normal and reverse magnetic directions with upward and downward inclinations that imply two

FAWN LIMESTONES



ROHTASGARH LIMESTONES

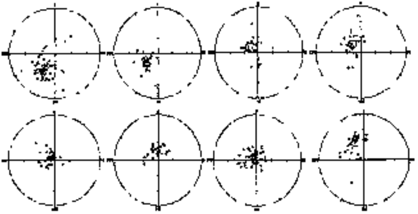


Fig. 4. *Stenographic plot of NRM vectors of specimens from Fawn Limestones (Lower Semri) and Rohtasgarh Limestones (Upper Semri) from Son Valley of the Vindhyan Basin . The specimen NRM vectors are shown site-wise with their circles of confidence at each site. All inclinations are downward pointing*

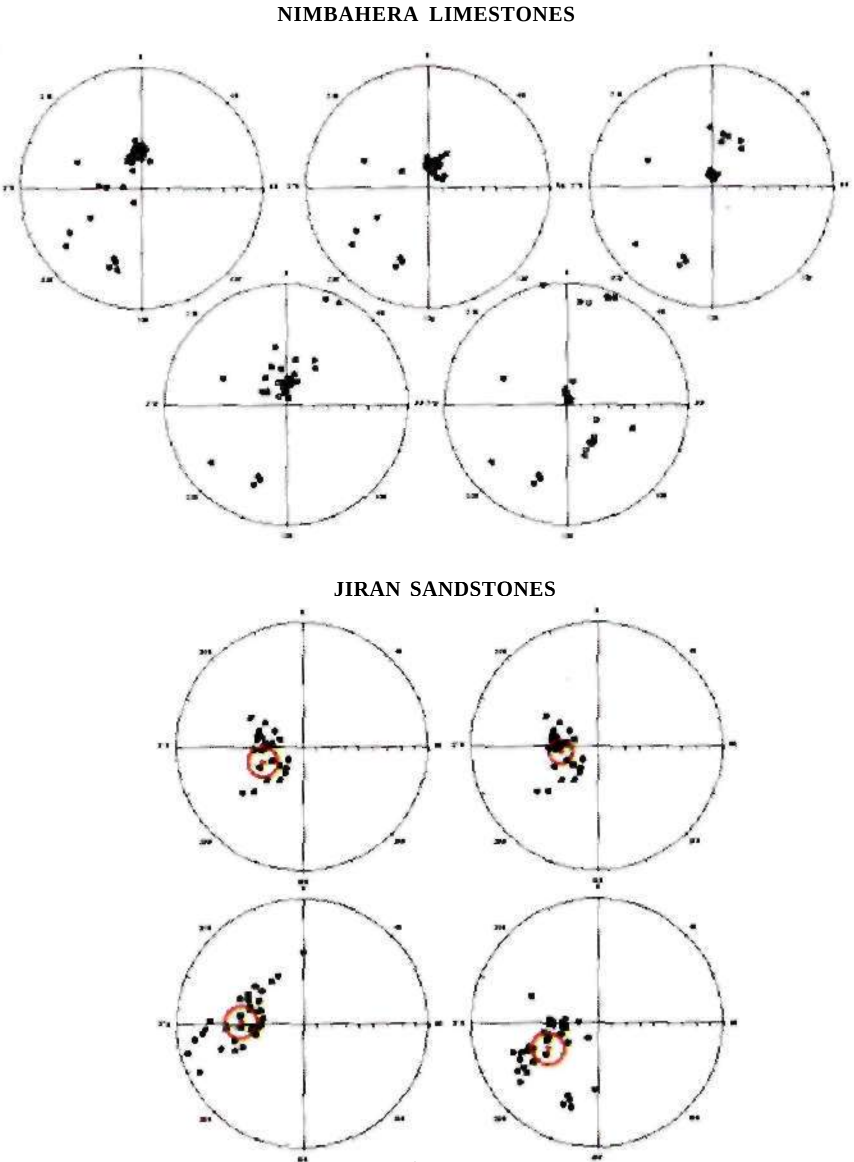


Figure 5

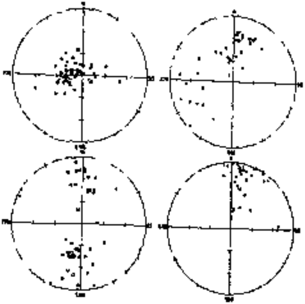
Pig.5. *Site-wise specimen NRM directions plotted on stenographic projection from Jiran Sandstonei (Middle Semn) and Nimbahera Limestones (Upper Semri) of Western Vindhyan Basin in Rajasthan. Site mean directions for the Jiran Sandstones are also shown with circles of confidence. Closed (Open) circles denote downward (Upward) pointing inclinations.*

reversals of the geomagnetic field (Fig. 2B) and palaeolatitudes of 18 °N and 28 °S to the subcontinent (Fig. 2A). These palaeolatitudes from the Kaimur Group rocks indicate smooth passage of the Indian plate from northern hemisphere to the southern hemisphere between the Malani Rhyolite and Rewa- Bhander periods to form Gondwanaland/Pangaea along with other continents by early Palaeozoic era.

In a recent programme dealing with palaeomagnetic study of Vindhyan sediments, Dhandraul Sandstones from Son Valley and its equivalent Dicken Sandstones from Rajasthan were investigated. 27 oriented samples from 4 sites of Dhandraul Sandstones and 26 samples from 5 sites of Dicken Sandstones were collected and subjected to detailed palaeomagnetic tests (Poornachandra Rao et. al. 2003). The NRM directions of Dhandraul Sandstones exhibit very good grouping with normal and reverse directions of magnetization from these sites (Figure 6). NRM directions of Dicken Sandstones reveal only normal direction of magnetization with steep downward inclinations. It can be seen from these NRM directions shown in Figure 6 that these two rock formations can be correlated, which suggest inter-basinal correlation of sedimentation among the Vindhyan sub-basins. The Dhandraul Sandstones exhibiting both normal and reverse magnetic directions of magnetization indicate a reversal of the geomagnetic field (Fig. 2B).

Rewa Group

The Rewa Group occupies the middle position in the Upper Vindhyans and on the basis of lithological correlations with the Jodhpur Sandstones of Marwar Supergroup in Rajasthan, the base of this Group has been extended up to 750 Ma from the radiometric dating of the Malani Rhyolites underlain by the Jodhpur Sandstones. Not many formations of Rewa Group were investigated and only the Upper Rewa Sandstones from two areas were studied by Athavale et. al. (1972) and McElhinny et. al., (1978) (one site each) (Table 3). These studies result in normal and reverse polarities with upward inclinations with palaeolatitudes of 24 °S and 0.4 °N respectively. However, recently 25 samples from 5 sites of Govindgarh Sandstones representing the Upper Rewa Sandstones around Rewa town were investigated by Poornachandra Rao et. al. (2003). These studies reveal normal magnetic directions with upward and downward inclination identical to other studies (Fig. 7) implying two reversals of the geomagnetic field during their deposition (Fig. 2B). The Jodhpur Sandstones in Marwar Basin in Trans-Aravalli Vindhyans in Rajasthan, lying above the Malani Rhyolites dated at 771-751 Ma and correlated with the Upper Rewa Sandstones, from 14 sites were investigated by Poornachandra Rao et. al. (2004b). These studies also reveal similar ChRM directions as that of the Son valley Rewa Sandstones confirming their correlation and assigning a lower age between 771 and 751 Ma for the Rewa Group.



DICKEN SANDSTONES

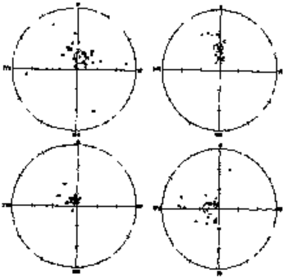


Fig. 6. *Specimen NRM directions on stereographic projection for four sites each of Upper Kaimur Dhandraul Sandstones, Son Valley (easternmost part of the Vindhyan Basin) and Dicken Sandstones, Rajasthan (Western Vindhyan Bonn) Site mean directions are shown with circle of confidence .Closed (Open) circles denote downward (Upward) pointing inclinations.*

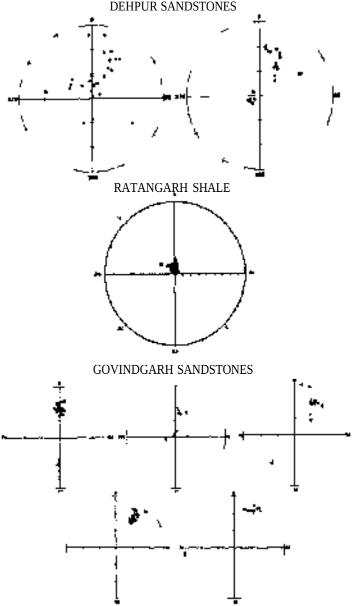


Fig. 7. *Stenographic plot of specimen NRM directions of Dehpur Sandstones and Ratangarh Shale (Middle Rewa) ,Rajasthan (Western Vindhyan Basin) ,and Upper Rewa Govindharh Sandstones, Son Valley (Eastern Vindhyan Basin). Closed (Open) circles denote downward (Upward) pointing inclinations.*

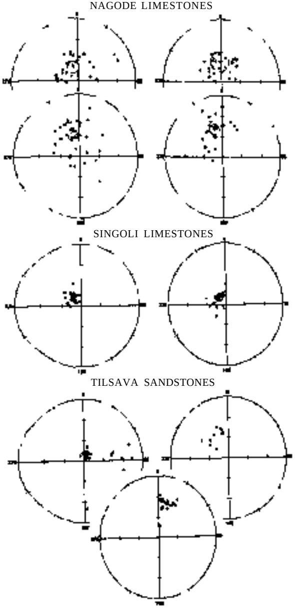


Fig. 8 . *Plot of specimen NRM vectots on stenographic projection of Nagod Limestones (Son Valley) and Singoli Limestones (Rajasthan) of Lower Bhander Group and Tilsava Sandstones (Rajasthan) from Middle Bhander Gioup .All inclinations are positive and downward pointing and site mean directions are shown with confidence circles.*

Under the Vindhyan palaeomagnetic study programme undertaken recently, Upper Rewa Govindgarh Sandstones from 5 sites (32 samples) from Son Valley and Upper Rewa Umar sandstones (18 samples from 3 sites) and middle Rewa Dehpur Sandstones (27 samples from 4 sites) from Rajasthan were studied. ChRM directions from all the 5 sites of Govindgarh Sandstones reveal normal directions with both downward and upward pointing inclinations implying two reversals of the geomagnetic field (as mentioned above) during their deposition similar to that of upper Kaimur Baghain Sandstones around Panna region and Banganapalle Quartzites of Cuddapah Supergroup far south (Poornachandra Rao et. al. 1997 and Goutham et. al. 2004). The Dehpur Sandstones from Rajasthan reveal normal magnetization with mostly downward pointing inclination (Fig. 7), which may also result in similar ChRM directions as that of the other upper Rewa Group sandstones. The Umar Sandstones being more quartzitic needed better coring bits that delayed their coring operation and studies on these rocks are in progress.

Ratangarh Shales were collected from Rajasthan whose NRM directions exhibit very good grouping with very steep downward inclination and normal magnetization. The ChRM direction obtained after laboratory demagnetization studies reveal normal magnetization with steep positive inclination (Fig. 7) similar to that of Malani Rhyolites with a VGP close to around 800 Ma. Further studies on them are in progress. In general shales are very difficult to sample for laboratory studies, However, we are successful in collecting samples from one site for laboratory studies from Ratangarh Shale Formation that proved to be very useful. This study may result in very good correlation with Jhiri Shale exposed in almost all the sub-basins of the Vindhyan basin, an advantage available from palaeomagnetic studies.

Bhander Group

The uppermost group of the Upper Vindhyans is represented by the Bhander Group and widely studied among the Vindhyan rocks. The Upper Bhander Sandstones were investigated by Athavale et. al. (1972), Klootwijk, (1973) and Mc Elhinny et. al. (1978) from a total of 16 sites (Table 2). While Athavale et. al, (1972) reported normal magnetic directions with upward inclinations from 3 sites Klootwijk (1973) reported reverse magnetic directions with upward and downward pointing shallow inclinations from 7 sites. The studies undertaken by McElhinny et. al. (1978) show both results of Athavale et. al. (1972) and Klootwijk (1973). Thus the studies on Bhander Group rocks reveal two reversals of the geomagnetic field with southern palaeolatitudes to the Indian subcontinent.

In the recent study of Vindhyan palaeomagnetism, samples were also collected from Lower Bhander Nagod Limestone Formation (24 samples from 4 sites) from Son Valley, Singoli Limestone Formations (10 samples from 2 sites) from Rajasthan and middle Bhander Tilsava Sandstone Formation (30 samples from 6 sites) from Rajasthan were also collected. The Nagod Limestones lesult in a NNW pointed declinations with steep downward inclinations (ChRM) and the Singoli Limestones exhibit well grouped NW pointed declinations with very steep positive inclination as shown in. Figure 8. The Tilsava Sandstones from Rajasthan show well grouped normal magnetization with steep to very steep positive inclinations (Fig. 8). Therefore it can be inferred that this provides very good correlation of lithological units (Nagod Limestones and Singoli Limestones) in these Vindhyan sub basins when the ChRM directions are established.

The Vindhyan Inliers

Apart from the main Vindhyan basin in central India, the Vindhyan Supergroup rocks are also available and exposed as Bhopal and Harda Inliers For the first time palaeomagnetic studies were extended to the Bhopal Inker that may provide very good information with regard to depositional history, environment correlation of lithological units and their tectonic relation with the main basin and the inhere. There exists a difference of opinion about the stratigraphy and tectonic relation of the rocks in the Inliers with the main Vindhyan basin From Guna Shivpuri region Upper Kaimur Dudauni Sandstones (20 samples from 4 site) and Upper Rewa Sanwara Sandstones (20 samples from 4 sites) were collected. From the Bhopal Inker Upper Rewa Nazarganj Sandstones (10 samples from 2 sites), Lower Bhander Salkanpur Sandstones (25 samples from 5 sites) and Upper Bhander Nurganj Sandstones (15 samples from 3 sites) were

Table 4: Inter Basinal Correlation of Vindhyan Supergroup Rocks

Son Valley	Rajasthan	Guna-Shivpuri	Bhopal Inlier
—	—	—	Nurganj S. St.
—	Tilsava S. St.	—	—
Nagod L. St	Singoli L. St.	—	Salkanpur S . St.
Govindgarh S. St.	Umar S. St.	Sanwara S. St.	Nazarganj S. St
Dharmondganj S. St.	Dehpur S. St.	—	—
Jhiri Shale	Jhiri Shale	Ratangarh Shale	Jhiri Shale
Baghain S. St.	Dicken S. St.	Dudauni S. St.	—
Dhandraul S. St.	—	—	—
Rohtasgarh L. St.	Nimbahera L .St.	—	—
—	Jiran/Sawa S. St.	—	—
Fawn L. St.	Khardeola S. St.	—	—
Pandwafall S. St.	Khairmalia Andesite	—	—

collected. Oriented samples from the Guna-Shivpuri area adjacent to the Bundelkhand Granite Massif were also collected. Laboratory studies on these samples are in progress and are expected to result in very useful information from these formations. If once the ChRM directions from all these rock formations are available it would provide a wonderful opportunity to correlate lithounits across the Vindhyan sub-basins as shown in Table 4.

Conclusions

Though the palaeomagnetic studies on the Vindhyan rocks were initiated four decades ago not many formations were studied because of certain limitations such as their weak magnetic nature and non-availability of sensitive instruments for their laboratory investigations until recently. Palaeomagnetic studies on Vindhyan rocks were restricted to only red sandstones of Upper Rewa and Upper Bhander Groups. A review of the available results from these rocks was provided by Poornachandra Rao et. al. (2000). Subsequently a major programme of palaeomagnetic study of Vindhyan sediments has been initiated at NGRI under which a large number of samples were collected representing the complete stratigraphic column of the Vindhyan Supergroup from Son valley and Rajasthan regions. Preliminary results on some of these formations are available and are very much encouraging. The following are some of the salient results that have emerged as a result of palaeomagnetic study of Vindhyan Supergroup rocks over the last four decades.

1) The Vindhyan basin started evolving during the late Palaeo-Proterozoic Era with the effusion of Khairmalia Andesites and deposition of sediments.

2) During the initial stages of Vindhyan sedimentation the subcontinent occupied a palaeoposition just similar to that of the present day location of 21 °N (palaeolatitutde of leference town Nagpur) and orientation just 1 °W of present north (with a declination of 359°) in the equatorial latitudes and thus negating existence of glacial conditions as proposed by some.

3) The subcontinent drifted to the southern hemispheric latitudes during the Rewa and Bhander periods in Neo-Proterozoic Era and formed Gondwanaland/Pangaea with other continents.

4) During most of the Vindhyan period the geomagnetic field was of reverse polarity which is more dominating during the Riphean Era as can be seen from the Russian geomagnetic polarity time scale also (Khramov, 1987). The geomagnetic field changed its polarity at least once during each period of Semri, Kaimur, Rewa and Bhander Groups. These reversals can be used as marker horizons for correlation of lithological units across the entire basin.

5) In Kaimur rocks as many as six mangetozones (three each of normal and reverse polarity) were observed that suggest as many as three reversals of the geomagnetic field.

6) The preliminary results on many of the Vindhyan formations from the Son valley and Rajasthan regions would provide a very good opportunity of correlating the litho units across several sub basins on the basis of their remanent magnetic directions and magnetic field reversals.

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