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Palaeomagnetic results from the Cretaceous Bagh Group in the Narmada Basin, central India: evidence of pervasive Deccan remagnetization and its implications for Deccan volcanism

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SUMMARY

A palaeomagnetic study of 115 samples (328 specimens) from 22 sites of the Mid- to Upper Cretaceous Bagh Group underlying the Deccan Traps in the Man valley (22° 20′N, 75° 5′E) of the Narmada Basin is reported. A characteristic magnetization of dominantly reverse polarity has been isolated from the entire rock succession, whose depositional age is constrained within the Cretaceous Normal Superchron. Only a few samples in the uppermost strata have yielded either normal or mixed polarity directions. The overall mean of reverse magnetization is $D_m = 144°$, $I_m = 47°$ ($\alpha_{95} = 2.8°$, $k = 152$, $N = 18$ sites) with the corresponding S-pole position 28.7°S, 111.2°E ($A_{95} = 3.1°$) and a palaeolatitude of 28°S ± 3°. The characteristic remanence is carried dominantly by magnetite. Similar magnetizations of reverse polarity are also exhibited by Deccan basalt samples and a mafic dyke in the study area. This pole position falls near the Late Cretaceous segment of the Indian APWP and is concordant with poles reported from the Deccan basalt flows and dated DSDP cores (75–65 Ma) of the Indian Ocean. It is therefore concluded that the Bagh Group in the eastern part of the Narmada Basin has been pervasively remagnetized by the igneous activity of Deccan basalt effusion. This overprinted palaeomagnetic signature in the Bagh Group indicates a counter-clockwise rotation by 13° ± 3° and a latitudinal drift northwards by 3° ± 3° of the Indian subcontinent during Deccan volcanism.

Key words: Bagh Group, Cretaceous, Narmada Basin, palaeomagnetism, remagnetization.

1 INTRODUCTION

Cretaceous palaeomagnetic data from the Indian shield are sparse. Apart from the extensively studied Deccan Traps of Cretaceous–Tertiary Boundary (KTB) age (Courtillot *et al.* 1986, 1988) and Deep Sea Drilling Programme (DSDP) results from the 90°E ridge of the Indian ocean (Klootwijk 1979), palaeomagnetic studies of four Cretaceous formations from the Indian shield have been reported so far. They are the Middle Cretaceous Rajmahal Traps (Clegg, Radhakrishnamurty & Sahasrabudhe 1958; Radhakrishnamurty 1963; McDougall & McElhinny 1970; Klootwijk 1971; Poornachandra Rao & Mallikharjuna Rao 1996), the Lower Cretaceous (?) Sylhet Traps (Athavale, Radhakrishnamurty & Sahasrabudhe 1963), the Lower Cretaceous Tirupati Sandstone Formation (Verma & Pullaiah 1967; Pullaiah & Verma 1970) and the Satyavedu Sandstone Formation (Mital, Verma & Pullaiah 1970). The results of three of these studies (Sylhet Traps and Satyavedu and Tirupati Red Beds) are not regarded as useful (Klootwijk & Radhakrishnamurty 1981; Klootwijk 1984) because of poorly constrained radiometric or magnetization ages. The Cretaceous segment of the well-documented Indo-Pakistan apparent polar wander path (APWP) (Klootwijk 1984) therefore comprises only three reliable results from the Indian shield—the Rajmahal Traps (117 Ma) (Baksi 1995), the Deccan Traps (66–68 Ma) (Duncan & Pyle 1988) and the DSDP cores (65–75 Ma) (Klootwijk 1979). The rest of the points on the APWP (Klootwijk 1984 and references therein) are derived from rocks of extrapeninsular regions after corrections for inferred rotations of sampled areas with respect to the Indian shield. The present study was intended mainly to fill, partly, the existing gap in the Cretaceous palaeomagnetic data from the stable Indian craton. However, as the age span inferred for the present rock succession on the basis of fossils

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falls in the Cretaceous Normal Superchron, it is of obvious interest to observe the compatibility of the magnetic polarity of the rock strata with the standard Geomagnetic Polarity Time Scale (GPTS). This compatibility of magnetic polarity assumes importance in inferring the primary nature of magnetization, as in the Narmada valley; a complex history of remagnetization has been reported in the sediments, as well as in the Deccan Traps, with a well-documented N–R–N magnetostratigraphic sequence (Vandamme & Courtillot 1992 and references therein). As part of a broader study of the Cretaceous sedimentary rock successions, we present here the first report of our palaeomagnetic investigation of the Middle to Upper Cretaceous sediments of the Bagh Group occurring in the Man River valley (22° 20′N, 75° 5′E) of the eastern Narmada Basin in the Dhar district, Madhya Pradesh (Fig. 1a).

2 GEOLOGICAL SETTING

The geological evolution of the Narmada Basin is related to the ENE–WSW-oriented Narmada–Son lineament, which is a major tectonic boundary dividing the Indian shield into a southern peninsular block and a northern foreland block. The Precambrian Narmada geofracture was reactivated during the Cretaceous Period (Biswas 1987; Acharyya & Lahiri 1991). As the Greater Indian continent broke away from Gondwanaland during the Early Cretaceous, the Narmada rift opened up and received marine sediments, which are deposited over the granites, gneisses and other Precambrian metamorphics with distinct angular unconformity. A large part of the basin is covered by the Deccan Traps, obscuring its deeper geology. The underlying Bagh Group is exposed in some parts along the Narmada River. The infratrappean sediments of the Lameta Group of Maastrichtian age (Prasad & Sahni 1988) overlie the Bagh Beds, followed by the Deccan Traps. In places, as in the sampling areas of this study, the Deccan Traps directly overlie the Bagh Beds. The lithostratigraphic classification for the present sampling area (Dassarma & Sinha 1975; Sastri *et al.* 1982; Tripathi 1995) envisages a three-tier grouping (Fig. 1b): the Nimar Sandstone, the Nodular Limestone and the Coralline Limestone Formations in ascending order. The Nimar Sandstone Formation represents a thick continental facies, becoming influenced by a marine environment in its upper levels. The overlying Nodular Limestone Formation shows a sharp contact with the Nimar Sandstone. It is a 2–10 m thick monotonous succession of greyish-white medium-bedded limestone with rippled bedding and microcross-lamination. The Coralline Limestone Formation, up to 3 m thick, is rich in bryozoan fossils and is well developed in the Man valley, but pinches out further west in the Basin. Some basaltic dykes trending E–W are seen to intrude the sedimentary sequence at a few places in the valley.

From the fossil assemblage in the marine limestones, which contain a rich faunal assemblage of bivalves, gastropods, echinoids, ostracods, bryozoans, foraminifera and pisces (Dassarma & Sinha 1975; Sastri *et al.* 1982), the inferred age of the Bagh Group is in the range (Late?) Albian to Turonian (Chiplonkar 1987). A recent study (Rajshekhar 1995; private communication, 1996) of the foraminiferal assemblage, however, indicates the age of the Bagh Group to be dominantly in the range Cenomanian to Turonian (*ca.* 98–89 Ma).

3 SAMPLING AND LABORATORY PROCEDURE

The following two sections of the Bagh Group in the Man valley were sampled for palaeomagnetic study (Fig. 1a):

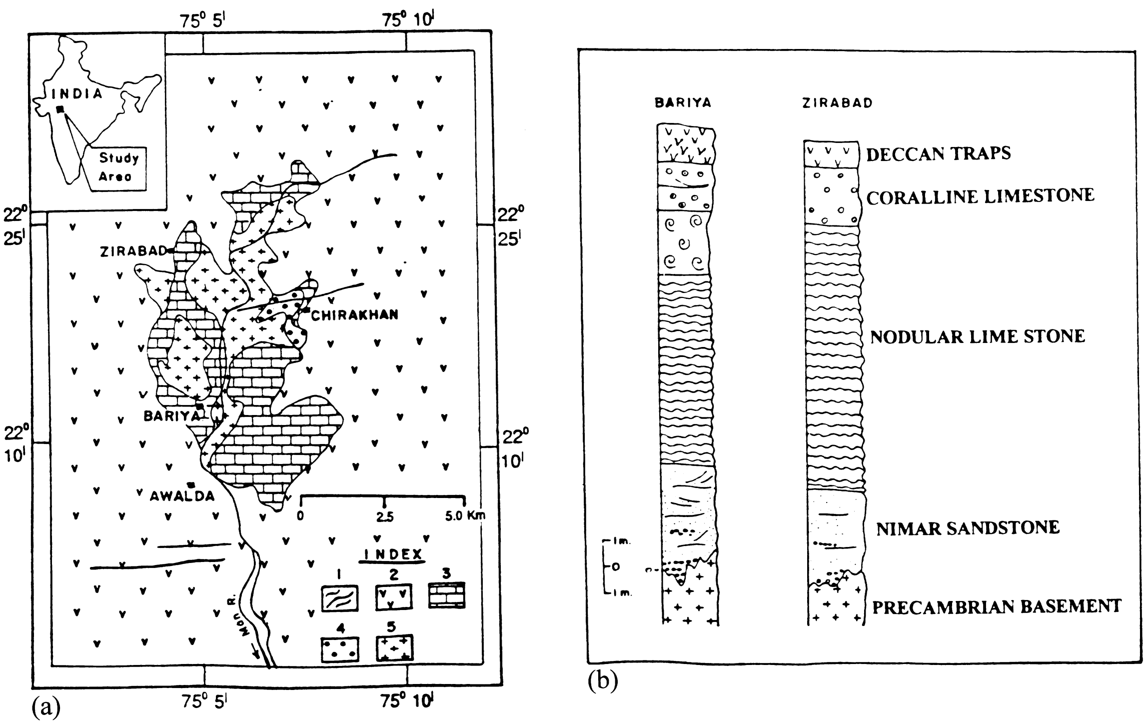

Figure 1. (a) Generalized geological map of the Man valley, Dhar district, Madhya Pradesh, India. 1, Basaltic dykes; 2, Deccan Traps; 3, Nodular and Coralline Limestone Formations; 4, Nimar Sandstone Formation; 5, granites and gneisses. (b) Lithosections of the sampling sites.

(i) 0.5 km east of Zirabad, with poor fossil content, and (ii) 0.5 km east of Bariya, showing well-developed macrofossils. In all, 115 oriented block samples were collected from 22 sites: 89 samples (16 sites) of the Nodular Limestone Formation; 18 samples (four sites) of the Coralline Limestone Formation; and four samples each at two sites of the Nimar Sandstone Formation. Limestone samples were collected from newly excavated quarries which did not show evidence of basaltic dyke intrusion. The Nimar Sandstone samples were obtained from stray exposures near the Bariya section whose overlying limestone sequence is eroded. In addition to the above collection, five samples each were collected from a basaltic dyke and from a very thin patch of Deccan Basalt flows close to the sampling areas.

In the laboratory, cylindrical specimens of standard size (2.2 cm length and 2.5 cm diameter) were drilled from each sample. A minimum of two specimens, more frequently three to four specimens, per sample were used in the palaeomagnetic measurements. Remanence, including the natural remanent magnetization (NRM), was measured with a JR-4 spinner magnetometer, whose sensitivity is 3×10^{-12} T (2.4×10^{-6} A m^{-1}). The noise level recorded in the laboratory on the most sensitive range of this magnetometer is below 5×10^{-11} T (4×10^{-5} A m^{-1}). Thermal demagnetization was carried out by using a magnetic vacuum control system (MAVACS) from Geofyzika, Brno (Prihoda *et al.* 1989). For alternating-field (AF) demagnetization, a Molspin AF demagnetizer was used. In order to monitor production of new magnetites due to the thermal treatment, the susceptibility of some representative specimens was measured with a Bartington susceptibility meter (model MS 2) after the NRM measurement, and after each remanence measurement during the thermal treatment.

3.1 Pilot study

Initially, 25 samples representing all the sites were selected for a pilot study. Two specimens from each sample were investigated palaeomagnetically—one each, through stepwise thermal and stepwise AF demagnetizations. The thermal treatment was in 10–12 steps (from 100 to 680 °C). About one-quarter of the specimens lost 85–97 per cent of their NRM intensity by 200 °C. The AF treatment was also in 10–12 steps (2.5 to 100 mT), but more than half of the specimens could not be demagnetized completely by the 100 mT step, where quite often more than 50 per cent of the NRM intensity remained. Samples which had lost a substantial portion of their NRM intensity below 200 °C were characteristically more resistant to AF treatment. Realizing that the dominant remanence carrier in such samples might probably be geothite, which is characterized by high coercivity and low blocking temperature, we thermally pre-treated a third specimen from these samples at 120 °C before subjecting them to further AF demagnetization. We found this to be a useful exercise, which was later adopted for many of the remaining samples, mostly from the Bariya section. However, in most pilot samples, the thermal treatment was found to be the most effective technique for isolating the characteristic magnetization. Accordingly, at least two specimens each from the remaining samples were thermally demagnetized, mostly in six to eight steps, ensuring almost total demagnetization at the highest temperature step. Also, on the basis of the pilot study results, some fresh specimens, as well as some thermally pre-treated specimens from selected sites, were treated by AF. Thus 197 specimens were demagnetized thermally, 43 specimens were demagnetized by AF alone, and 74 specimens were AF demagnetized after thermally pre-treating them to 120 °C. This makes a total of 314 specimens (115 samples) investigated palaeomagnetically. An additional 14 specimens were used for rock magnetic studies.

4 RESULTS AND ANALYSIS

The NRM intensity ranges from 8×10^{-2} to 8 A m^{-1} for 6 per cent of the specimens, 8×10^{-4} to 8×10^{-2} A m^{-1} for 74 per cent of the specimens and 1.5×10^{-4} to 8×10^{-4} A m^{-1} for 20 per cent of the specimens. As the noise level of the magnetometer is less than 4×10^{-5} A m^{-1}, all but the weakest specimens remained measurable when demagnetized to 1–3 per cent of the NRM intensity. Most untreated specimens were in the susceptibility (K) range 1.2×10^{-5} to 2.1×10^{-3} SI. Remeasurement of K after each thermal demagnetization step showed a gradual decrease in its value up to the 540 °C step, after which a marginally increasing trend was observed. However, no pronounced increase in K was seen up to 650 °C. As will be seen later, the magnetic remanence generally becomes unblocked between 500 and 580 °C. Thus mineralogical changes, if any, are not serious enough to affect the isolation of characteristic magnetizations.

4.1 The Nodular Limestone Formation

Demagnetization of Nodular Limestone samples from the Zirabad area (symbol JN) led to the isolation of a stable reverse component with southeasterly declinations and intermediate downward inclinations (Fig. 2). The characteristic remanence is stable either in the temperature range 100–580 °C or in the AF range 10–80 mT. The remanence is effectively destroyed beyond 580 °C or 100 mT peak field. The unblocking temperature and coercivity spectra of the characteristic remanence therefore suggest magnetite to be the remanence carrier in the above specimens. The unblocking temperature in a few JN samples, however, exceeds 580 °C, suggesting that the remanence resides in part in haematite. The characteristic directions in these samples are similar to those isolated from other samples having unblocking temperatures below 580 °C.

The NRM intensities of samples from the Bariya village locality (symbol BN) were found to be one to two orders of magnitude less than the samples from the Zirabad area and were more often strongly overprinted by the present Earth's field (PEF). Thermal and AF demagnetizations of thermally pre-treated (at 120 °C) specimens led to the isolation of a characteristic magnetization of reverse polarity similar to that exhibited by the JN samples. Samples from the uppermost strata (site BN 6), however, showed a trend of directional migration towards normal polarity after 200 °C. Two examples (Fig. 3) show that for both specimens (from different samples), the steep, downward NRM direction migrates to the southeast quadrant before swinging to normal polarity at 200 °C. The recovery of normal magnetization in one specimen (Fig. 3a) is associated with an increase in the remanent intensity above 100 °C, indicating preferential removal of an anti-parallel component. Out of four samples in this site, two samples yielded a normal characteristic magnetization, and specimens from the other two samples exhibited the presence of both reverse and

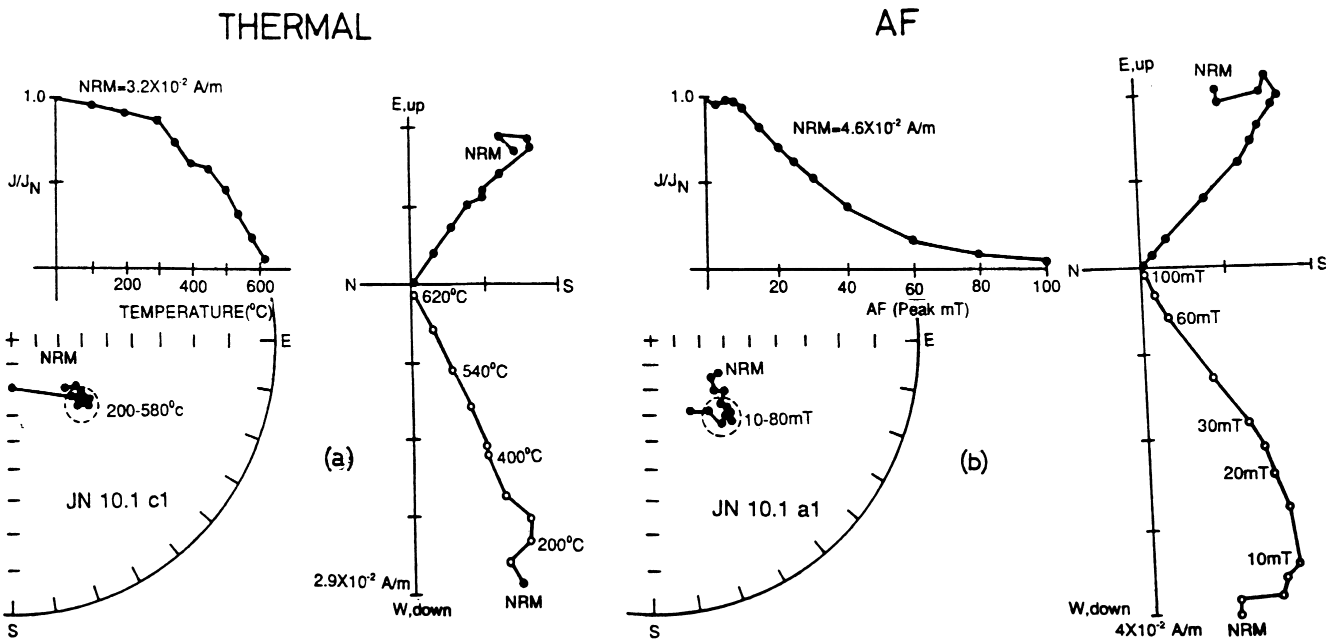

Figure 2. Demagnetization results of specimen pairs of a Nodular Limestone sample from the Zirabad section after thermal demagnetization (a) and AF demagnetization (b). Solid and open circles denote projections on the lower and upper hemisphere respectively on a stereographic (Wulff) net. Dashed outlines indicate directions in the temperature or field intervals shown and have no statistical significance. On Zijderveld (1967) diagrams (to the right of the stereographic plots), the open circles are projections of endpoints of the demagnetization vectors on a north–south vertical plane; solid circles, on the horizontal plane. In the intensity decay curves (above the stereographic plots), J/J_N denotes the normalized intensity.

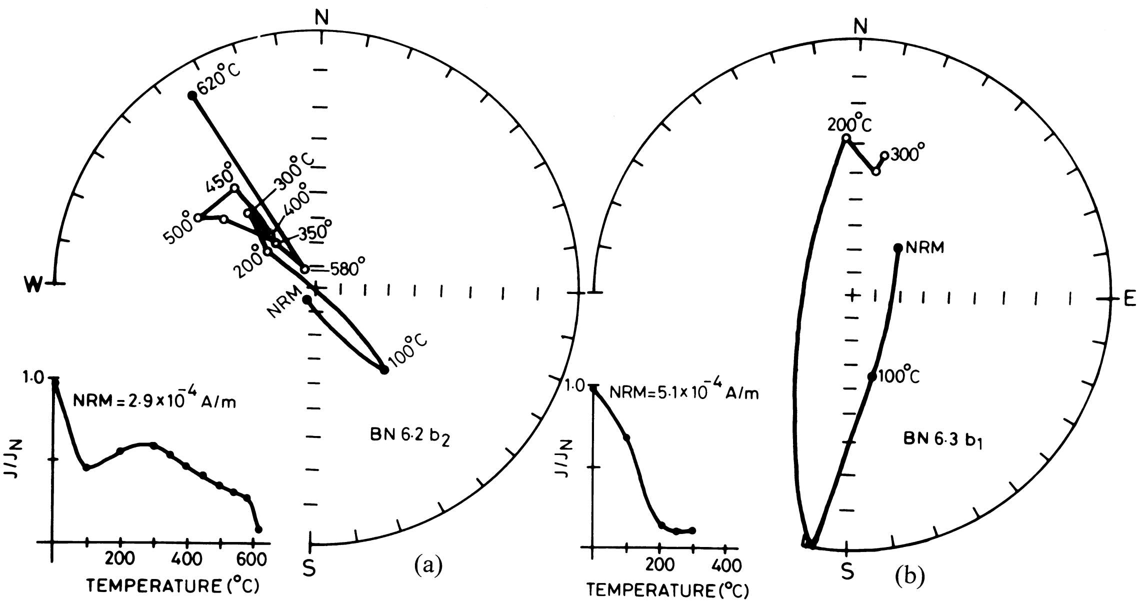

Figure 3. Thermal demagnetization results of two specimens from the uppermost strata of the Nodular Limestone Formation of the Bariya section exhibiting normal-polarity magnetization. Stereographic projections, with symbols as in Fig. 2.

normal polarities, in which no stable component could be identified.

4.2 Coralline Limestone Formation

Samples from the Zirabad area (symbol JC) yielded a southeasterly stable component after thermal treatment, residing possibly in magnetite (Fig. 4). This component is similar to that isolated from the Nodular Limestone Formation. Samples from the only site in Bariya village (symbol BC), on the other hand, revealed normal characteristic directions, with northwesterly declinations and upward-directed inclinations (Fig. 5) above 200 °C. The demagnetization behaviour often becomes noisy, perhaps as a result of the intensity becoming too low. The inclinations observed at this site are relatively shallower than those of other sites yielding reverse polarity.

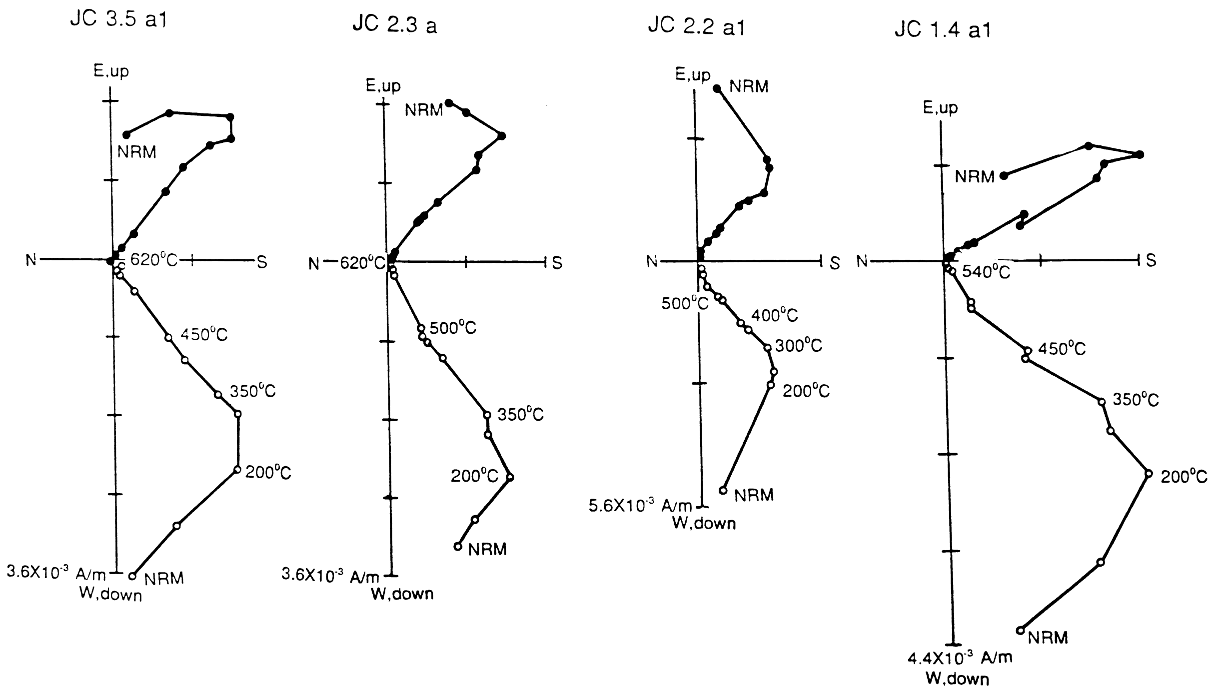

Figure 4. Zijderveld diagrams of thermal demagnetization results for four representative specimens of the Coralline Limestone Formation from the Zirabad section. Symbols as in Fig. 2.

4.3 Basaltic dyke and lava flow

Samples from one dyke and one site of the lava flow exhibited only reverse polarity directions. Out of 10 samples, stable directions could be obtained from only four samples, two each from the flow and the dyke, with strikingly similar declinations and inclinations (within $\pm 15^\circ$) as isolated from the sediments.

On the basis of the above results of magnetic cleaning for the Nodular and Coralline Limestone Formations, the characteristic directions were obtained from the orthogonal vector diagrams for the linear segments directed to the origin at higher temperatures or fields. The site-level characteristic directions together with their statistical parameters (Fisher 1953) are summarized in Table 1. The sample and site characteristic directions are shown in Fig. 6. The overall *in situ* mean direction corresponding to the reverse component, calculated from the site unit vectors, is $D_m = 144^\circ$, $I_m = 47^\circ$ ($k = 152$, $\alpha_{95} = 2.8^\circ$, $N = 18$ sites). The beds being horizontal (dip $< 2^\circ$), no tilt correction is required. The characteristic directions of normal polarity obtained from one site (BC 1) have been excluded from the final statistics, as the α_{95} confidence circle of this site mean is significantly displaced from the confidence circle of the antipode of the reverse-polarity mean, thus failing the reversal test. The S pole corresponding to the overall mean is 28.7°S, 111.2°E ($A_{95} = 3.1^\circ$). The palaeolatitude is $28^\circ S \pm 3^\circ$. Very similar pole positions have been reported from the Deccan Traps and from dykes in the Narmada valley and adjoining areas. Therefore we have listed (Table 2) and plotted (Fig. 7) all such poles and other published Cretaceous poles from Peninsular India, for a comparison and interpretation of the present results with reference to the standard APWP (Klootwijk 1984). We have also included two Cretaceous poles (Nos 6 and 8) from the extrapeninsular region, which are plotted after correction for the inferred rotation of the area.

5 ROCK MAGNETISM

For the identification of magnetic minerals, the variation of susceptibility with temperature (*K–T* curves), and isothermal remanence magnetization (IRM) acquisition and decay curves were studied. Thermal changes of magnetic susceptibility were measured by a CS-2 apparatus and a KLY-2 Kappa bridge. Fig. 8 shows the heating and cooling curves of two specimens. A clear Hopkinson peak and Curie temperature in the vicinity of 600 °C (Fig. 8a) and below 700 °C (Figs 8a and b) indicate the presence of magnetite and haematite respectively. IRM was studied using equipment similar to that of Carmichael (1961), in which specimens could be magnetized to a maximum field of 600 mT. Some results of IRM acquisition and thermal demagnetization of acquired IRM are shown in Fig. 9. The steep initial increase in intensity followed by a sharp flattening-off of the slope above 100 mT (Fig. 9a), but falling short of saturation at higher fields, is diagnostic of magnetite coexisting with a minor component of harder-coercivity grains (Lowrie & Heller 1982). The initially convex nature of the acquisition curve (Fig. 9b) suggests the predominance of goethite grains and the curves depicted in Figs. 9(c) and (d) indicate the coexistence of magnetite with goethite or/and haematite. The thermal demagnetization of acquired IRM (Figs. 9e–h) suggests the presence of two phases of magnetic grains in each individual specimen. One of these phases has a maximum unblocking temperature of about 450 °C, which is common to all four specimens. This is consistent with magnetite exhibiting a lower unblocking temperature, due possibly to the volumetric dominance of multidomain (MD) grains, which may not carry remanence (Jackson 1990). The second phase has a maximum unblocking temperature of about 580 °C (Fig. 9g), 150 °C (Fig. 9f) or above 620 °C (Figs. 9e and h). The magnetic grains inferred are magnetite, goethite and haematite respectively.

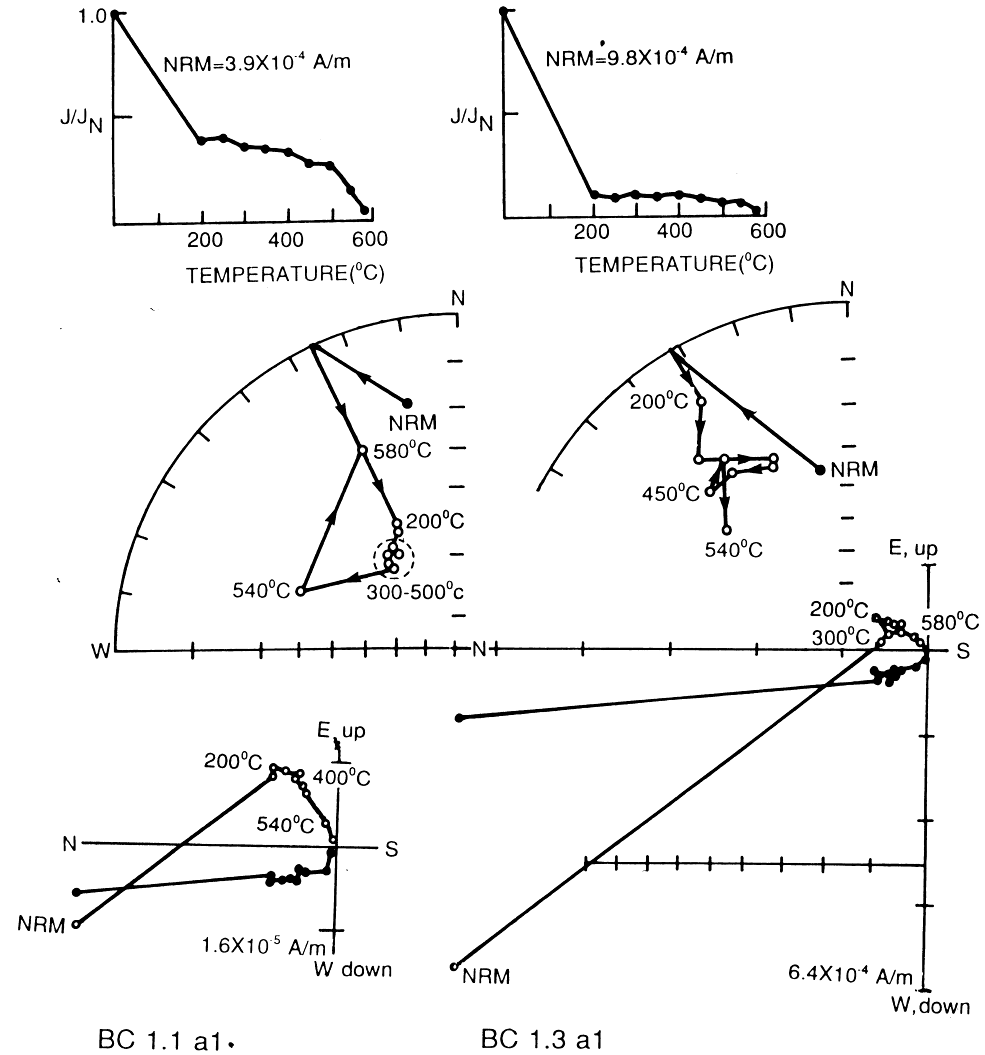

Figure 5. Thermal demagnetization results of two Coralline Limestone specimens from the Bariya section exhibiting a normal-polarity characteristic magnetization. Stereographic projections (middle), intensity decay curves (top) and vector diagrams (bottom). Symbols as in Fig. 2.

Thus, either the presence of magnetite alone, or the coexistence of magnetite with either goethite or haematite is indicated. The IRM and K–T results support our earlier conclusions from the thermal demagnetization results, where magnetite was indicated to be the dominant remanence carrier, and haematite as the remanence carrier in a few samples. Also, the presence of goethite was suspected in the pilot study as the carrier of a viscous PEF component. However, we rule out the possibility of goethite being a serious contaminant in the characteristic directions.

6 DISCUSSION

Magnetizations of both normal and reverse polarities have been isolated in the present study, none of which appear to be of primary origin. Normal polarity directions are exhibited only by samples in the uppermost strata of the Bariya section. In this section, mixed polarity directions are also exhibited, in discordance with the purely reverse polarity directions of the corresponding strata in the Zirabad section. These normal polarity directions appear to be an overprinting by the igneous activity of the overlying, normally magnetized first basaltic flows of the N–R–N magnetostratigraphic sequence (Courtillot *et al.* 1986; Sreenivasa Rao *et al.* 1985; Vandamme *et al.* 1991). A very similar kind of remagnetization induced by Deccan volcanism, in the Maastrichtian Lameta Beds at one site in the Narmada valley, has also been reported by Vandamme & Courtillot (1992). The ubiquitous reverse-polarity magnetizations, on the other hand, yield a pole position that falls far off its expected position on the Indian APWP (Fig. 7). The present pole falls close to a cluster of poles reported from the Deccan Traps of the Narmada and adjoining areas, Late Cretaceous DSDP cores from the Indian Plate and Maastrichtian-age sediments from the extrapeninsular regions. Of particular interest is the pole (No. 10 in Fig. 7) from the Deccan lava flows in the Dhar area (Poornachandra Rao & Bhalla 1981), 10–20 km west of our sampling localities. The Dhar pole, based dominantly on the reverse-polarity characteristic directions, is almost coincident with the present pole. The palaeolatitude (28°S ± 3°) obtained in this study is also very similar to the values (about 30°S) reported from the Deccan Traps. Thus, it appears that the primary magnetization of these sediments has been completely reset along the Deccan magnetization in the study area. This Deccan-induced remagnetization may

Table 1. Palaeomagnetic results from the Bagh Group in the Narmada Basin.

Site	n/n_0	n'/n'_0	Characteristic directions				VGP			
			Dm	Im	k	α_{95}	Lat. (°S)	Long. (°E)	dp	dm
JN 1	5/6	16/22	155	49	44.2	11.6	32.4	100.8	10.1	15.3
JN 2	7/8	15/27	150	59	40.0	9.6	21.8	99.5	10.7	14.4
JN 3	6/9	13/27	151	56	47.1	9.8	25.0	100.5	10.1	14.1
JN 4	6/6	15/18	150	46	34.8	11.5	32.4	106.8	9.4	14.7
JN 6	7/7	20/22	139	41	62.6	7.7	29.2	118.7	5.7	9.3
JN 7	6/6	13/14	143	40	60.4	8.7	32.2	116.1	6.3	10.5
JN 8	5/5	12/13	150	44	328	4.2	33.7	107.9	3.3	5.2
JN 9	6/6	9/9	138	46	34.0	11.6	25.8	116.4	9.5	14.8
JN 10	5/5	16/16	140	42	46.6	11.3	29.3	117.3	8.5	13.9
JN 11	4/5	8/10	140	44	33.1	16.2	28.2	116.1	12.7	20.3
BN 1	3/4	5/11	135	48	30.7	22.6	22.9	117.2	19.3	29.5
BN 2	5/5	15/16	145	44	88.3	8.2	31.1	112.3	6.4	10.3
BN 3	5/5	11/12	141	50	74.7	8.9	25.1	111.8	7.9	11.9
BN 4	4/4	10/12	148	49	59.9	12.0	29.5	106.9	10.5	15.8
BN 5	4/4	11/12	142	49	870	3.1	26.3	111.6	2.7	4.1
BC 1*	5/5	15/21	337	−35	21.0	17.1	42.8	105.3	11.3	19.7
JC 1	4/4	8/10	155	46	126	8.2	34.7	102.2	6.7	10.5
JC 2	5/5	10/10	134	46	146	6.3	23.3	119.9	5.1	8.0
JC 3	4/4	10/10	144	42	61.6	11.8	31.7	114.1	8.9	14.5
Mean			144	47	152	2.8	28.7	111.2	$K=128$ $A_{95}=3.1$ s.d. = 7.2° $N=18$	

Notes: Sites JN and JC are in the Zirabad section: BN and BC are in the Bariya section (see Fig. 1).
n/n_0: number of sample characteristic directions used in computing the site mean/number of samples demagnetized; n'/n_0': number of specimen characteristic directions from n samples/number of specimens from n_0 samples demagnetized; Dm, Im: site mean declination, site mean inclination; k, K: Fisherian precision parameter; α_{95}: radius of the cone of 95% confidence about the site mean; VGP: Virtual Geomagnetic Pole; dp, dm: semi-axes of the oval of 95% confidence for the VGPs; A_{95}: Radius of the 95% confidence circle about the calculated mean pole; N: number of site mean VGPs; Mean: Fisherian means of site characteristic directions and VGPs calculated from all the sites except the site with *; Samples from site JN 5 were lost and site BN 6 yielded mixed polarity directions and are therefore excluded from the Table.

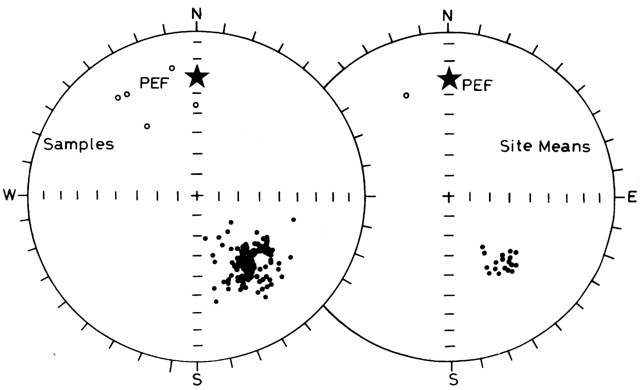

Figure 6. Characteristic sample and site mean directions. Equal-area plot on the lower hemisphere (solid circles) and the upper hemisphere (open circles).

have been caused by fluids related to reverse-polarity flows in the overlying Deccan Traps. The reverse-polarity magnetizations in the rocks belonging to the Cretaceous Normal Superchron and the presence of only reverse-polarity magnetizations in a dyke and lava flows in the sampling areas further strengthen our conclusions of complete remagnetization. It may, however, be noted that the cluster of poles with which the present pole is consistent is significantly displaced from either the Deccan 'Superpole' or the poles from the synchronous Deccan dyke swarms (Subbarao, Ramasubba Reddy & Prasad 1988; Prasad *et al.* 1996). The secular variation in our data appears to be considerably averaged as is evident from the angular standard deviation of the pole (7.2°), which is one-half of that expected for a palaeolatitude of about 30° (McFadden, Merril & McElhinny 1988). Our results do not show any evidence of multicomponent characteristic magnetizations. We therefore interpret the discrepancy between the present pole and the Deccan Superpole as due to the apparent polar wandering (APW). This Deccan overprint in the Bagh Group then offers an opportunity to compute a reasonable estimate of polar wandering during the period of volcanism. Previous estimates of the APW are based on the studies of the Deccan Traps alone and suggest a counter-clockwise rotation of India as large as 37° and a northward drift of 18° in latitude (Poornachandra Rao & Bhalla 1981), in apparent contradiction with estimates of not more than 5° latitudinal drift (Klootwijk 1979) and 3.5° along the polar path (Vandamme *et al.* 1991). Choosing the Deccan Superpole as the reference pole, the present result indicates a counter-clockwise rotation of India by 13° ± 3° and a latitudinal drift of 3° ± 3° during the period of Deccan volcanism, the uncertainties being calculated according to Demarest (1983).

In conclusion, this study reveals the pervasive remagnetization in the sedimentary sequence of the Narmada Basin

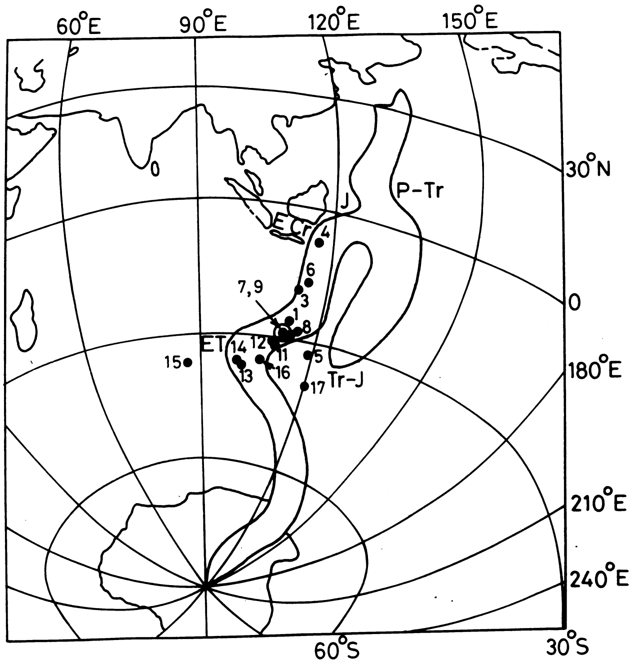

Figure 7. Palaeopole from this study (point 7, with A_{95} circle) plotted with other Cretaceous poles (see Table 2). The swath in the figure is the Mesozoic part of the standard Indo–Pakistani APWP proposed by Klootwijk (1984).

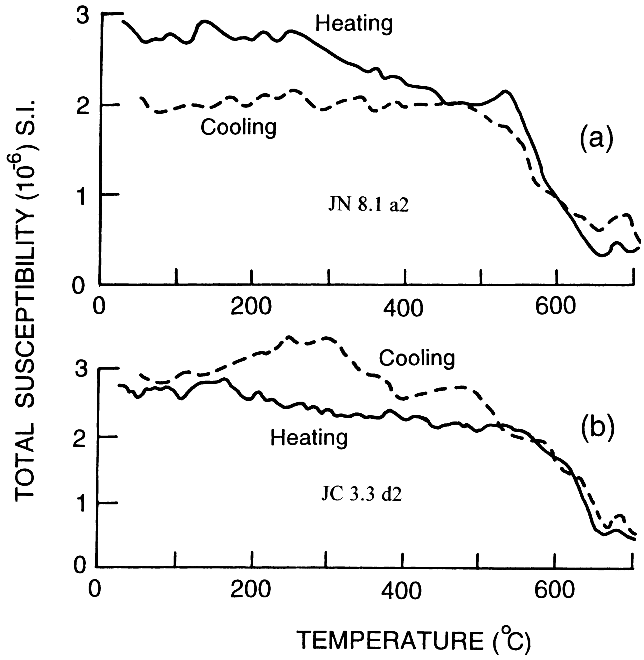

Figure 8. Variation of susceptibility with temperature for two Nodular Limestone samples.

caused by the igneous activity of Deccan volcanism. Further palaeomagnetic and rock-magnetic studies of other Mesozoic and older formations, including the Bagh Beds exposed in the western Narmada Basin, are required to understand the extent and mechanism of remagnetization in the Narmada Basin.

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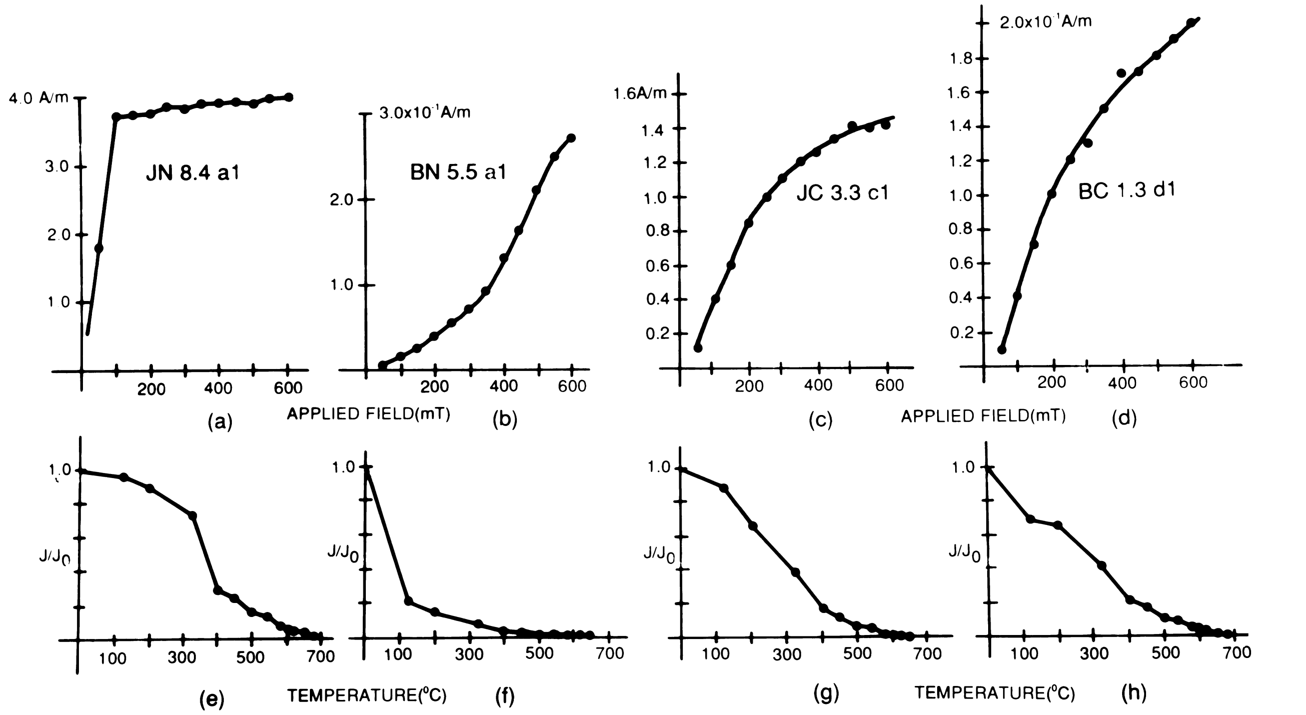

Figure 9. IRM acquisition (top) and thermal demagnetization of acquired IRM (bottom) curves of four specimens, J/J_0 denotes normalized intensity.

Table 2. Cretaceous pole positions of the Indian subcontinent.

Pole no.	Rock unit	Age	S-pole position		K	A_{95}	References
			Lat. (°S)	Long. (°E)			
1	Satyavedu Sandstone	Early Cretaceous	26.5	113.0	80.0	4:0	Mital, Verma & Pullaiah (1970)
2	Tirupati Sandstone	Early Cretaceous	33.5	109.5	52.5	11.0	Pullaiah & Verma (1970)
3	Sylhet Traps	Early Cretaceous (?)	16.0	120.0	—	7.0	Athavale *et al.* (1963)
4	Rajmahal Traps	117 Ma	9.0	117.0	106.0	2.0	Poornachandra Rao & Mallikharjuna Rao (1996)
5	Gondwana dykes	???	33.5	119.0	37.0	6.7	Athavale & Verma (1970)
6	Goru Formation + Parh Limestone	Aptian–Campanian	17.7	116.5	32.5	2.9	Klootwijk *et al.* (1981)
7	Bagh Group	Cenomanian–Turonian	28.7	111.2	152.0	3.1	This study
8	Fort Munro Formation	Maastrichtian	28.0	115.2	12.6	27.0	Klootwijk *et al.* (1981)
9	DSDP cores	75–65 Ma	29.0	111.5	—	—	Klootwijk (1979)
10	Dhar Traps	68–66 Ma	29.0	113.0	107.0	5.5	Poornachandra Rao & Bhalla (1981)
11	Deccan Traps	68–66 Ma	32.5	110.5	—	4.6	Courtillot *et al.* (1986)
12	Deccan Traps	68–66 Ma	31.0	109.0	20.8	9.7	Vandamme & Courtillot (1992)
13	Deccan Superpole	67 Ma	36.9	101.3	—	2.4	Vandamme *et al.* (1991)
14	Dhule dykes	67–64 Ma	37.2	99.5	—	9.7	Prasad *et al.* (1996)
15	Mandaleshwar dykes	67–64 Ma	37.0	86.0	—	5.0	Subbarao *et al.* (1988)
16	Mandaleshwar dykes	67–64 Ma	36.0	106.0	—	16.6	Subbarao *et al.* (1988)
17	DSDP cores	65–55 Ma	40.5	120.0	—	10.5	Klootwijk (1979)

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