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New Palaeomagnetic evidences about Deccan Trap Volcanic activity from the magmatic bodies of Kachchh Basin, Northwest India

***Mamilla Venkateshwarlu[1], Bindhyachal Pandey[2], G. Papanna[1], Deo Brat Pathak[2], Jai Krishna[2]**
[1] CSIR-National Geophysical Research Institute, Uppal Road, Hyderabad -500 007, India
[2] Department of Geology, Banaras Hindu University, Varanasi – 221005, India
*Corresponding author: mamila_v@rediffmail.com

ABSTRACT

New Palaeomagnetism results have been obtained from twelve dyke samples that are intruded into the litho units exposed in three different localities, namely, Jumara (Mainland), Kaladongar (Patcham Island) and Kantkote (Wagad, outside the Mainland) in the Kachchh Basin of Gujarat, North West India. The study shows that the dykes from two of the three localities have normal directions while the third has a reverse direction (similar to the Deccan Volcanic Province directions). The combined Virtual Geomagnetic Pole (VGP) provides 34.8 °N and 83.8 °W (dp/dm = 5.12/8.13). This pole is similar to that of the Deccan Super Pole (36.9 °N; 78.7 °W). The findings suggest that wide spread distribution of magmatic activity in the Kachchh basin is coeval with the Deccan lava eruption.

INTRODUCTION

The effusion of Deccan Flood Basalts is considered to be the result of reactivated rifting on a pre-existing (Palaeozoic?) Narmada-Son rift system when material from a hot spot source impinged on the Indian lithosphere (Courtillot et al., 1986). Dyke swarms cover areas of 32,500 km^2 and 87,000 km^2 in the Narmada-Tapti and West Coast belts, respectively. These dykes are mainly dolerites of tholeiitic character. Based on the analyses of available field data (Deshmukh, S. S. and Sehgal, M. N, 1988) suggest that the N-S dykes in the West Coast belt are the youngest intrusives, while the E-W, NW-SE and NE-SW dykes represent older intrusive phases in this belt. In order to find out the intrusive phase event of this eruption in the northern most region palaeomagnetic study was undertaken on the dykes from Kachchh basin, Gujarat.

The Deccan Traps cover an area of about 500,000 Sq Km in the Western India. Deccan Trap flows are found to extend over the continental shelf. The flows cut across the Gulf of Kachchh and extend up to the southern part of Kachchh district of Gujarat. The magmatic rocks of Kachchh mark the northern limit of the Deccan Trap volcanic activity that took place during the Late Cretaceous – Early Paleocene period across K–T boundary (Shukla et al., 2001), when the Indian plate passed over the Reunion hot spot. With time the Trap cover got eroded exposing several feeder plugs, other intrusives and a few volcanic vents.

Palaeomagnetic investigations have been carried out previously on mafic dykes in the Narmada-Tapti (Nandurbar) and West Coast tectonic belts (Saurastra) of the Deccan Volcanic Province (Prasad et al., 1996; Sethna et al., 2001) and a comprehensive detailed review on Continental Flood Basalts was given by Poornachandra Rao et al., (2003). Biostratigraphic studies based on the sedimentary record of the Kachchh Mesozoics have provided interesting results (Krishna et al., 1996; Krishna and Ojha, 1996; Krishna, et al., 2009). Preliminary results of palaeomagnetic studies of Kachchh Jurassic sediments have added useful information (Venkateshwarlu et al., 2008). The dykes investigated in the present study cover different parts of the basin, viz, Kantkote (Wagad) in the east, Jumara (Mainland) representing a distal locality of the NW part of the basin and Kaladongar the exposed margin in the north (Figure 1). We conceive two separate phases of magnetic activities, the early one related to rifting/drifting between India and Madagascar during 80 Ma and the later one related to the event of spreading India

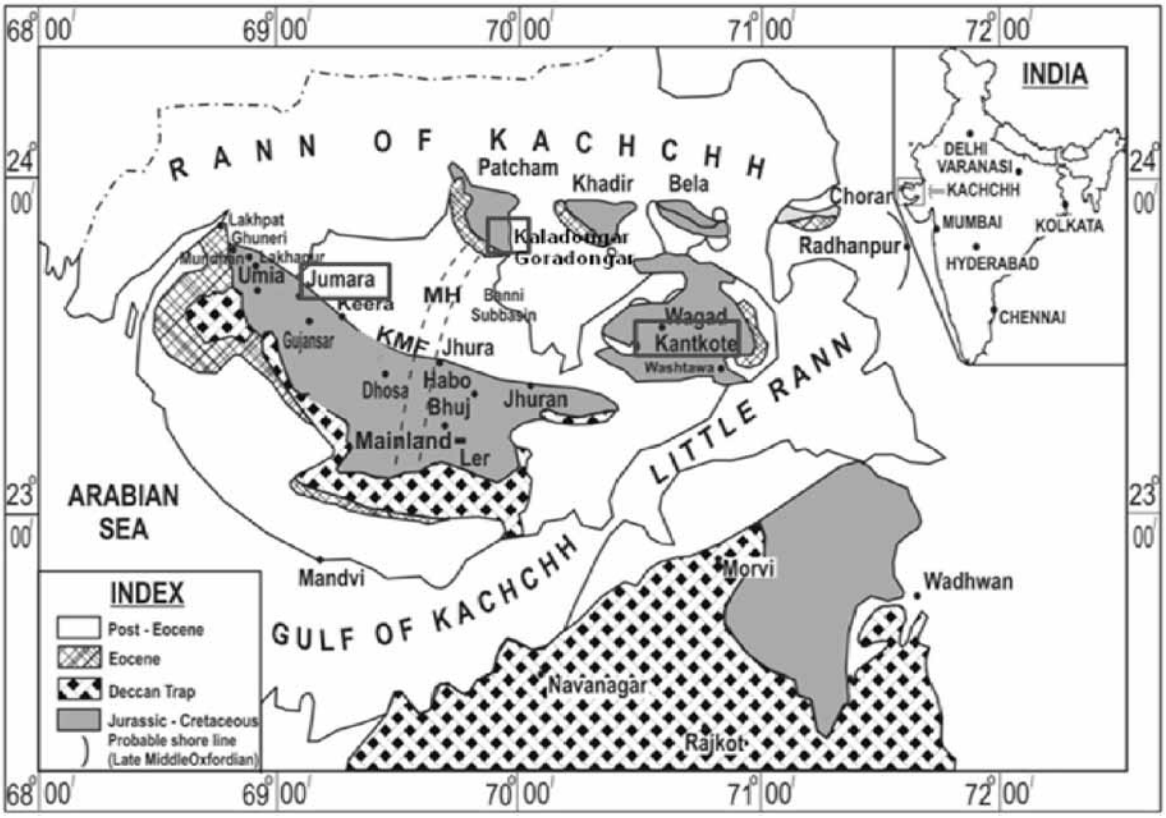

Figure 1. Simplified Geological Map of the Kachchh basin (modified after Wynne, 1872) along with study areas marked over it in boxes.

passing on the "Reunion Hot Spot" during 66 Ma. The present study is related to the later.

GEOLOGY

The Kachchh Basin located at the western margin of the Indian shield is an east-west trending pericratonic rift basin (Biswas, 2002), which was evolved during separation of Africa from India during the Middle Triassic Aniasian Kellenites Zone (Krishna, 2012). The rift basin is featured by intra-basin tilted fault blocks and intervening half-grabens. The rifting basin prior to Late Cretaceous magmatism received about 1500m thick Mesozoic sediments of Toarcian – Maastrichtian age (Krishna, 2012). Three uplifts occur along parallel strike faults forming ridges of varying dimensions. These east west trending uplifts are: the Island Belt Uplift (IBU) to the north, the Kutch Mainland Uplift (KMU) in the south with the Wagad Uplift (WU) in the central part. The Island Belt Uplift along the E–W master fault consists of four smaller uplifts separated by NE–SW wrench faults, viz., Pacham Uplift (PU), Khadir Uplift (KU), Bela Uplift (BU) and Chorar Uplift (CU) forming a chain of "islands". The highland representing the largest uplift and the southern segment of the rift basin adjacent to the Gulf of Kutch is known as the "Kutch Mainland". The Jumara (Mainland) dyke has intruded into the sediments of Chari Formation of Callovian – Early Oxfordian. The Kantkote dyke has intruded into the late Middle and Late Oxfordian sediments of Chari Formation. The Kaladongar dykes are intruded into the sediments of Toarcian – Bathonian age (Ray et al., 2006; Krishna, 2012; Rai and Jain, 2012). The Mesozoic rocks of the Kachchh Basin were affected by intense magmatic activities that left signatures in the form of dykes, sills, plugs, laccoliths and ring dykes. Magmatic rocks are fairly common in all the uplifted areas. Gravity-magnetic data indicate the presence of igneous intrusives beneath the recent sediment cover in the structural lows (Biswas, 1980). The maximum density of magmatic activity is present in the north western part of Kachchh Mainland Uplift, west of the Median High and in the northern part of Patcham

Uplift. Only dykes and sills are present in other uplifted areas located in the eastern Kachchh. The Kachchh Mainland Fault marks the northern limit of the volcanic field.

Sampling

In this paper, we present the paleomagnetic results on the magmatic rocks of Kachchh basin with a view to explore the relationships among the magmatic rocks from the three regions. Twelve oriented block samples were collected from four sites covering Mainland, Patcham Island and Wagad region of the Kachchh basin. 65 specimens of standard size (2.5 cm diameter x 2.2 cm height) were obtained from twelve samples by drilling and cutting in the laboratory.

PALAEOMAGNETIC RESULTS

NRM and Demagnetization

The Natural Remanent Magnetization (NRM) of all the 65 specimens was measured on JR-6 spinner magnetometer (AGICO, Czech Republic). The intensities are in the range of 0.25 to 2.85 A/m (mean 1.25 A/m). Magnetic susceptibilities of the specimens were measured on MS-2 susceptibility meter (Bartington, UK). The values observed were in the range of 2.33 to 44.48 x 10^{-3} SI with a mean of 22.08 x 10^{-3} SI units. Koenigsberger ratios (Q= NRM/kH) were calculated and found to be in the range from 1.13 to 8.13 with a mean of 3.39, indicating the suitability of the rocks for paleomagnetic investigations. Figure 2 gives the stereo plots of NRM directions from the three locations. These directions from 12 oriented samples were distributed in all the quadrants of the stereonet with shallow to steeper positive and negative inclinations, indicating overprints of the present earth field (PEF) direction.

Out of the 12 samples, 9 samples representing all the sections were subjected to stepwise Alternating Field (AF) demagnetization using Molspin AF demagnetizer (Magnetic Measurements, UK) in the fields of 2.5, 5, 7.5, 10, 15, 20, 25, 30, 40, 60, 80, 100, 120, 140 and 150 mT for isolating the Characteristic Remanent Magnetization (ChRM)

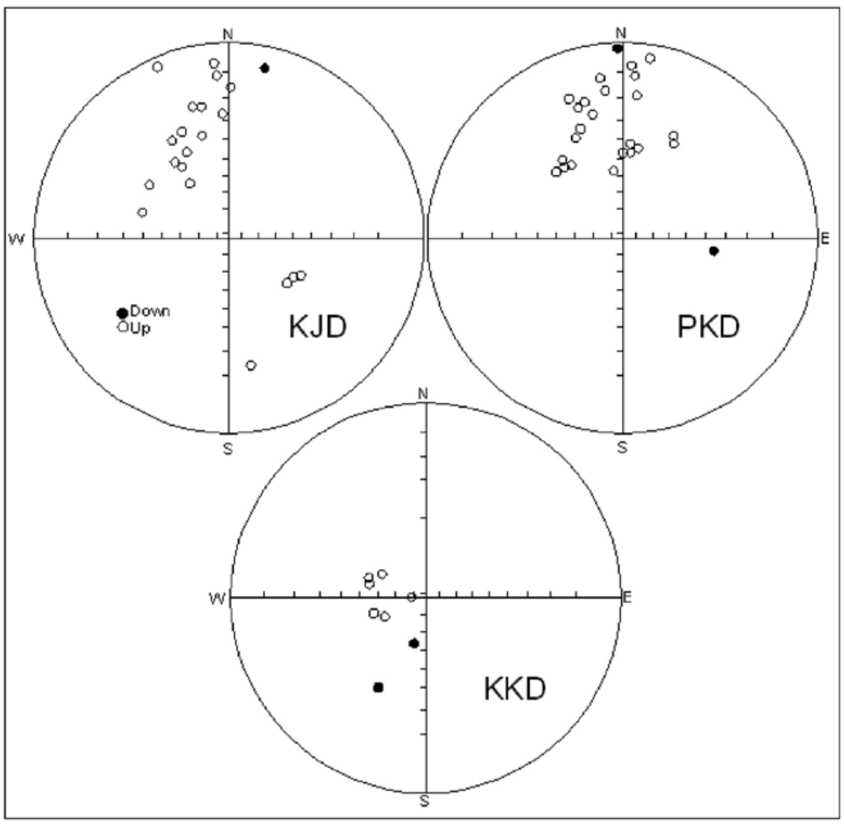

Figure 2. Specimen NRM directions of Kachchh Jumara dyke (KJD); Pacham Kaladongar dyke (PKD); Kachchh Kantkot dyke (KKD).

component. Figure 3 shows the vector end point diagrams (Zijderveld, 1967) depicting the behavior of the specimens during AF (a) and thermal (b) demagnetizations. During the AF demagnetization, a low coercivity component of viscous origin having mostly PEF directions was erased by the application of a 15 mT field for Jumara dyke and 20-30 mT AF field for Kaladongar dykes. Further demagnetization steps, particularly within the steps of 50–80 mT, yielded north westerly and south easterly declinations along with intermediate negative and positive inclinations, representing the high coercivity ChRM component in the samples.

Another set of 9 samples were treated thermally using thermal demagnetizer (MMTD-80, U.K) in steps at 100, 150, 200, 300, 350, 400, 425, 450, 475, 500, 520, 540, 560, 560, 580 and 600 °C. A low blocking temperature component containing the viscous remanence was removed by the application of thermal demagnetization steps at around 250–400 °C and the ChRM component was recovered by the application of 450–600 °C thermal steps. From the thermal demagnetization spectra (intensity decay curves), it could be observed that titano-magnetite (sudden drop in intensity at 450 °C) was the major remanence carrier with an influence of magnetite. Principal component analysis (PCA) was applied using REMA-4 software to obtain the ChRM component from the AF and thermal demagnetization data sets. The ChRM directions plotted on the stereonet of the studied samples are shown in Figure 4. Fisher Statistics (Fisher, 1953) was applied to find the mean ChRM directions which was noticed as Dm= 336, Im= - 45 (α_{95} = 6.45; k = 21.14). Table 1 gives the Palaeomagnetic results of the magmatic bodies of Deccan Volcanic Province, Kachchh Basin.

Rock magnetism

The Molspin Pulse magnetizer (Magnetic Measurements, MMPM - 9, U. K) having a maximum field of 9 T, was used for the acquisition of the isothermal remanent magnetization (IRM). The samples were magnetized by increasing fields in the steps from 50 to 1000 mT, and the intensity of IRM was measured after each step using the Molspin Spinner magnetometer. Reverse fields were also applied to reduce the magnetization to zero and for

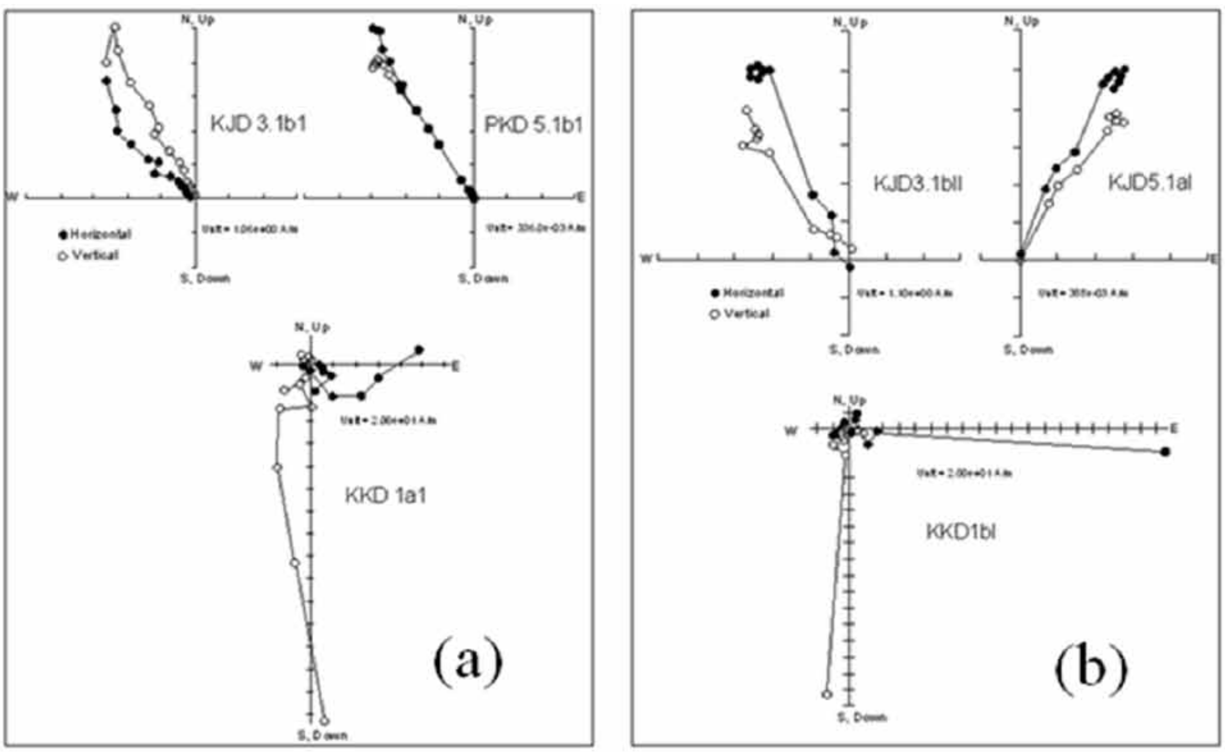

Figure 3. Graphical representation of vector end point diagrams during alternating field (a) and thermal (b) demagnetization of specimens from the Kachchh basin. Solid circles represent horizontal plane and open circles represent vertical plane.

Table – 1. Palaeomagnetic results of the magmatic bodies of Deccan Volcanic Province, Kachchh Basin

Location/ Site No.	Dm	Im	α_{95}	k	Plat. (°N)	Plong (°W)	dp	dm	Polarity
Kantkote									
KKD1	136	53	36.8	48.2	19.3	72.3	-	-	Reversal
Kaladongar dome									
PKD5	334	-38	25.8	23.9	38.5	78.3	-	-	Normal
PKD6	339	-32	33.0	14.9	44.4	81.5	-	-	Normal
Jumara dome									
KJD3	327	-50	24.2	108.2	27.1	77.7	-	-	Normal

Dm= mean declination; Im= mean inclination; α_{95} = circle of cone of confidence at 95% probability level; k= precision; Plat.= pole latitude; Plong.= pole longitude; dp and dm= error limits.

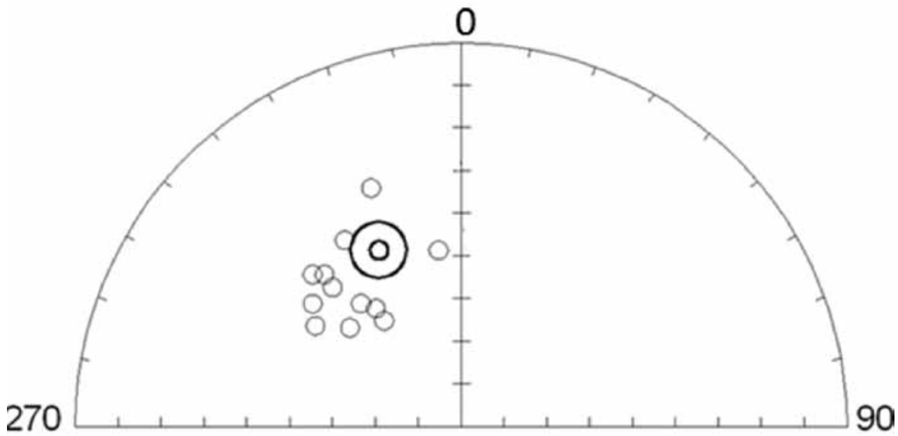

Figure 4. Stereo plot of Sample mean Characteristic Remanent Magnetization (ChRM) directions from magmatic bodies of Kachchh basin. Thick circle (small) indicates the overall mean and the confidence circle around the mean ChRM directions.

further saturation in the opposite direction. Figure 5 shows the response of IRM experiments on the samples of this study. The IRM saturations at the fields < 200 mT indicate that titano-magnetite is the major remanence carrier magnetic mineral in the samples, as also noted from thermal demagnetization intensity decay curves. The coercivity of remanence was noticed around 20–30 mT, indicating the magnetic mineral grain size as Single domain (SD) to *Pseudo-single* domain (PSD) type (Cisowski, 1981). Figure 6 shows the behavior of samples during Saturation IRM (Lowrie and Fuller, 1971) experiment. For this test, the representative samples were demagnetized by AF method with increasing fields reaching 150 mT and the remnant intensities were measured after each step, as was in the routine AF demagnetizations. Then they were saturated by applying 1Tesla field. Following the saturation, once again they were subjected to AF demagnetizations similar to those in the NRM demagnetizations. The relative intensity decay pattern between NRM and SIRM demagnetization curves indicates the grain size of the magnetic mineral in the samples. As can be seen from Figure 6, the NRM decay pattern is harder than those of the SIRM decay pattern, indicating the dominance of Single Domain (SD) type magnetic minerals in the samples. Lowrie-Fuller test and IRM data suggest that the major remanence carrier magnetic mineral is SD to PSD type titano-magnetite.

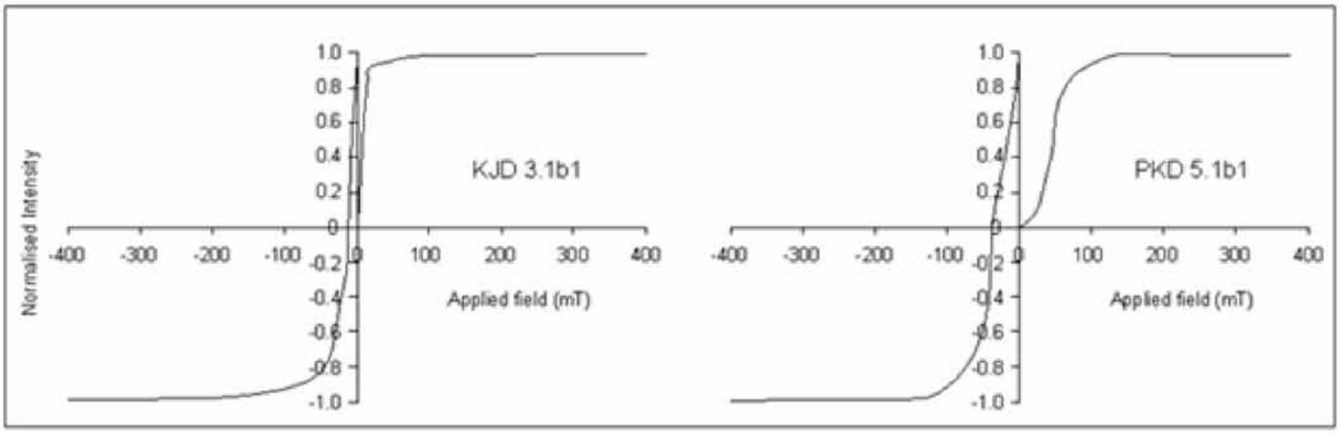

Figure 5. Isothermal remanent magnetization acquisition and back-field curves of the dykes from Kachchh Basin.

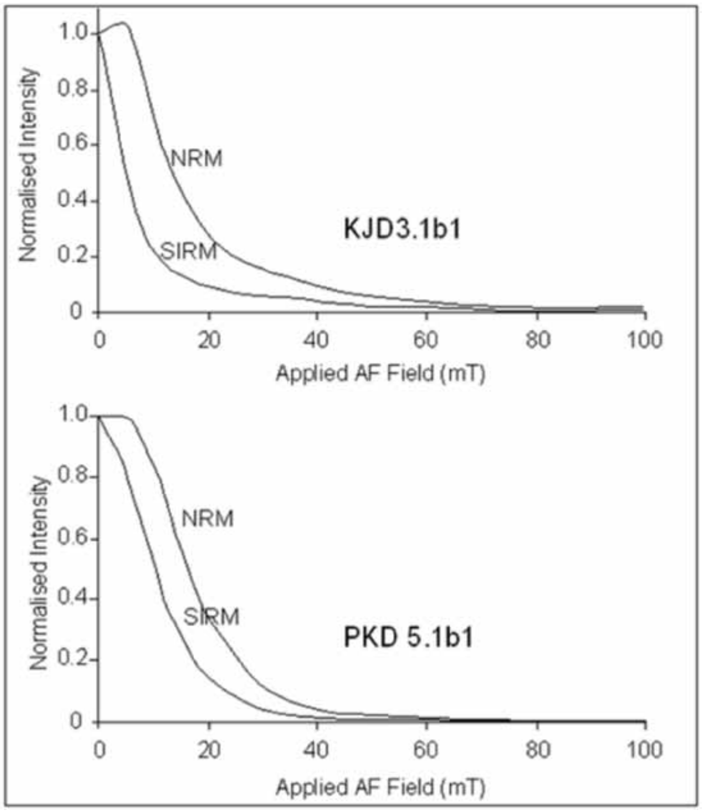

Figure 6. Normalized AF demagnetizations for the NRM and SIRM (L–F test).

DISCUSSION

Palaeomagnetic investigations consisting of detailed AF and thermal demagnetizations and rock magnetic experiments indicate that the mean ChRM direction obtained from the Kachchh magmatic bodies was of primary origin. Three intrusive bodies in Kaladongar and Jumara regions showed 'normal polarity' (north-west declinations associated with moderate negative inclinations) and another intrusive in Kantkote revealed a 'reverse polarity' direction (trending south–east declinations with moderate positive inclinations). The combined ChRM directions (antipodal) were noticed in the present study as Dm = 336 and Im = - 45 (α_{95} = 6.45; k = 21.14; N = 4) and the corresponding Virtual Geomagnetic Pole (VGP) at 34.8 °N and 83.8 °W (dp/dm = 5.12/8.13).

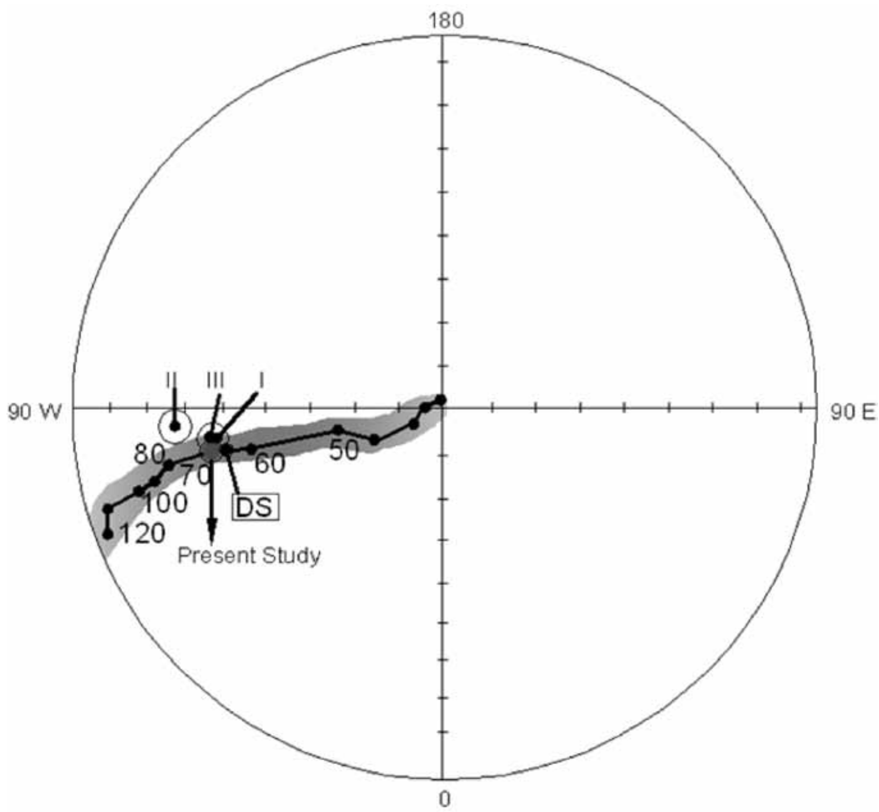

Figure 7. Kachchh dykes and Deccan Super pole (DS) VGP's are plotted along with the synthetic APWP for India (Vandamme et al., 1991). I, II and III are the pole positions obtained by Dalim et al., 2008.

Figure 7 shows the plot of the obtained VGP's of the present study with that of the Deccan Super Pole (Vandamme et al. 1991) on the synthetic Apparent Polar Wandering Path (APWP). The obtained paleopole of our study area is very much close to the Kaladongar dykes at 33.7° N and 81.2° W (dp/dm = 5.81/9.18) obtained by Dalim et al. (2008). The obtained poles were found statistically concordant with that of the Deccan Super pole (36.9 ° N; 78.7 ° W) as reported by Vandamme et al. (1991). Sadhara sill from Patcham region of Kachchh has been studied by Ray et al. (2006). They collected samples from eight sites representing the Kaladongar dyke swarm, Sadhara sill, Kuran, Raimarlo Hill and Nir Wandh of the "Island Belt". From the analysis of the collected samples they have reported higher magnetic susceptibilities (with a mean as 53,036 x 10^{-6} SI units). Whereas, our study has shown moderate values of susceptibilities. ChRM directions from these eight sites were recovered (Ray et al, 2006) using AF and thermal demagnetization method. Ray et al. (2006) reported that two of the four mentioned sites (Kuran and Kaladongar) showed reverse polarity, while the other six sites exhibited normal polarity. Both normal and reverse polarity signatures in the Kaladongar sites (Ray et al, 2006) indicate multiple intrusive events for the dykes in Kaladongar. The mean ChRM for these dykes was recorded as D = 336; I = − 40 (α_{95} = 10; k = 31.4; N = 8). Similar directions were obtained in the present study from Kaladongar. This suggests that the studied magmatic events of the Kachchh basin belong to chrons 30 N – 29 R – 29 N. However, older ages of the order of 1–2 Ma could be assigned to these magmatic bodies relative to the peak of the Deccan magmatic event of 65 Ma in view of a 3° difference between the VGP latitude of the samples studied by Dalim et al. (2008) and the Deccan Super Pole VGP latitude. The obtained pole position was compared with other studies in Deccan Volcanic Province of Kachchh and is given in Table 2.

Table – 2. Comparison of Kachchh Poles with the published results from Deccan volcanic Province of Kachchh and Deccan Traps.

Region	Dm	Im	α_{95}	P.Lat.	P.Long.	dp	dm	Reference
Kachchh magmatic bodies	336	-45	6.4	34.8 °N	83.8 °W	5.12	8.13	**This study**
Sadara intrusive	316	-43	9.8	25.0 °S	114.6 °W	6.61	1.6	Arjit Ray et al., 2006
Kachchh earliest magmatic rocks	335	−45	7.5	33.7 °N	81.2 °W	5.8	9.2	Paul et al.,2008
Deccan Super Pole (Bombay-Nagpur traverse)	156	47	2.4	36.9 °N	78.7 °W	2.4	2.4	Vandamme et al., 1991

From Figure 7 it can be observed that Kaladongar, Jumara and Kantkote dykes along with Group - l and Group – lll magmatic rocks representing tholeiites and gabbroic dykes of Kachchh mainland and the northern Island Belt, Dalim et al. (2008) and the Deccan Super (DS) pole were grouped at 65 Ma part of the synthetic APWP. The VGP of the alkali basalts of Kachchh Mainland (Group - ll rocks) (Dalim et al., 2008) match with the 70–75 Ma part of the APWP of Vandamme et al. (1991). From this, it has been inferred that the Kachchh Mainland alkali basaltic plugs are relatively older than those of the "Island Belt" and Kachchh Mainland tholeiites and gabbroic bodies. However, absolute age determinations of the Kachchh magmatic bodies will be helpful in determining the span of the magmatic episodes.

CONCLUSIONS

New palaeomagnetic data is generated from twelve dyke samples of Jumara, Kaladongar and Kantkote regions of Kachchh. Data analysis established that the Deccan dyke activity spread in different directions and extend even to the northern regions of India.

The main conclusions of our study are: (1) the dykes from three localities have shown both normal and reversed Deccan Trap directions, (2) Palaeomagnetic data indicate close temporal relation between the alkaline rocks and the tholeiitic basalts, (3) these dykes displayed that titano-magnetite was the major remanence carrier with an influence of magnetite and (4) the combined Virtual Geomagnetic Pole (VGP) gives 34.8 ° N; 83.8 ° W, which is similar to that of the Deccan Super Pole (36.9 ° N; 78.7 ° W).

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