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Rock magnetic and palaeomagnetic studies on the alkaline complexes of western Rajasthan, India

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Forty-five oriented block samples were collected from 12 sites of Mundwara and Sarnu-Dandali alkaline complexes of western Rajasthan for palaeomagnetic and rock magnetic investigations to constrain the timing of the emplacement of alkaline suites in relation to the time-frame of main Deccan volcanism. The rock magnetic studies indicated (titano) magnetite as the main magnetic carrier of stable remanence. The Lowrie–Fuller (L–F) test revealed SD and PSD type magnetic carrier in samples. AF and thermal demagnetizations were piloted on the samples to isolate Characteristic Remanent Magnetisation (ChRM) directions. The samples exhibited stable remanence between 5 and 35 mT during AFD. Thermal demagnetizations unblocked remanence between 350° and 500°C. The mean ChRM directions with $Decl_m = 342$, $Incl_m = -35$ ($\alpha_{95} = 4.39$, K = 121, N = 9) corresponds to paleopole position at 42°N and 274°E with a palaeo-latitude of 24.5°S is coincident with the Deccan Super pole position. The comparison of ChRM in alkaline complexes with those documented in DVP implies coeval emplacement of alkaline suites with Deccan eruption. Further, the ChRM marked largely by normal polarity suggests that alkaline intrusions were accomplished within the magnetic Chron C30N, during the onset of Deccan volcanism. The results also indicate that Deccan volcanism extended far beyond the present day boundaries of the traps, especially in the north.

Keywords. Alkaline complexes; Indian plate; reunion hotspot; deccan super pole, paleomagnetism.

1. Introduction

The Indian plate during its 'northward drift' following the breakup of Gondwana landmass transgressed over various hotspots. The interactions of hotspots with the moving Indian plate are manifested as reactivation of mobile belts, subsurface magmatic underplating, as well as large-scale eruption of flood basalts (Mahoney *et al.* 2002; Raval 2003). The extensive Deccan Volcanic Province (DVP) covering a large portion of western and northwestern parts of India is an outstanding example of the outburst of Reunion hotspot (Morgan 1981; Vandamme *et al.* 1991). Combination of palaeomagnetic, geochronology and geochemical data continue to refine our understanding on the role of lithospheric extension, plume–lithosphere interaction, and outburst of plume head, on timing and duration of extensive DVP (Basavaiah *et al.* 2018). On the northwestern fringe of the DVP, number of alkali basalts and alkaline rocks outcrop along two or three volcanic belts (Bose 1980). The Mundwara and Sarnu-Dandali alkaline complexes in western Rajasthan,

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following the trend of Cambay graben (inset figure 1), have received larger attention of the researchers to trace the geological events and processes involved in their emplacements (Roy 2003; Poornachandra Rao *et al.* 2003). Based on the intrusive relationship of alkaline rocks to the Cretaceous sandstones, Srivastava (1989) suggested probable Paleocene age for the Mundwara alkaline complex. Since these alkaline complexes lie on the proposed track of the Reunion plume head, starting from Karakoram Range to the Laccadive–Maldive island (Mahoney *et al.* 2002; Roy 2003), there was a tendency to relate the alkaline magmatism and regional dyke injections along the western Rajasthan, Kachchh and the Gulf of Khambat with the mantle metasomatism above an arriving mantle plume and small scale lithospheric mantle melting (Simonetti *et al.* 1998; Jerram and Widdowson 2005). Also, Basu *et al.* (1993) dated the alkaline rocks from Mundwara and Sarnu-Dandali ($^{40}Ar/^{39}Ar$ dates of 68.53 ± 0.16 and 68.57 ± 0.08, respectively) and assigned an age of 3 Ma prior to Deccan volcanism. However, afresh questions on the timings of alkaline magmatism have arisen by the additional isotopic ages ranging between 70 and 64 Ma, obtained using $^{40}Ar/^{39}Ar$ method on the Mundwara and Sarnu-Dandali alkaline complexes (Rathore *et al.* 1996; Rathore and Venkatesan 1996). These additional isotopic ages warrant longer interval ranging between 70 and 64 Ma for the alkaline magmatism, embodying the period of main Deccan volcanism at $\sim$66 Ma (Pande *et al.* 1989) and as well encompassing events contemporaneous with Cretaceous–Tertiary (K–Pg) boundary (Raval 2003; Roy 2003). With an objective to provide independent constraints on the timing and possible mode of emplacement, in the present communication, the results of rock magnetic and palaeomagnetic studies carried out on a variety of alkaline rocks from the Mundwara and Sarnu-Dandali region of Rajasthan are reported. The comparison of polarity of Characteristic Remanent Magnetization (ChRM) and corresponding palaeopole position with Apparent Polar Wander Path (APWP) of the Indian plate and available isotopic ages may provide insight into the timing of alkaline magmatism, specially its relation with the regional scale Deccan volcanism.

2. Geology and sampling

The western and northwestern parts of India following the track of interaction of the Indian plate with Reunion Plume head provided a unique tectonic framework for emplacement of alkaline volcanic complexes (Poornachandra Rao *et al.* 2003). Outcrops of variety of alkaline intrusive are spread all

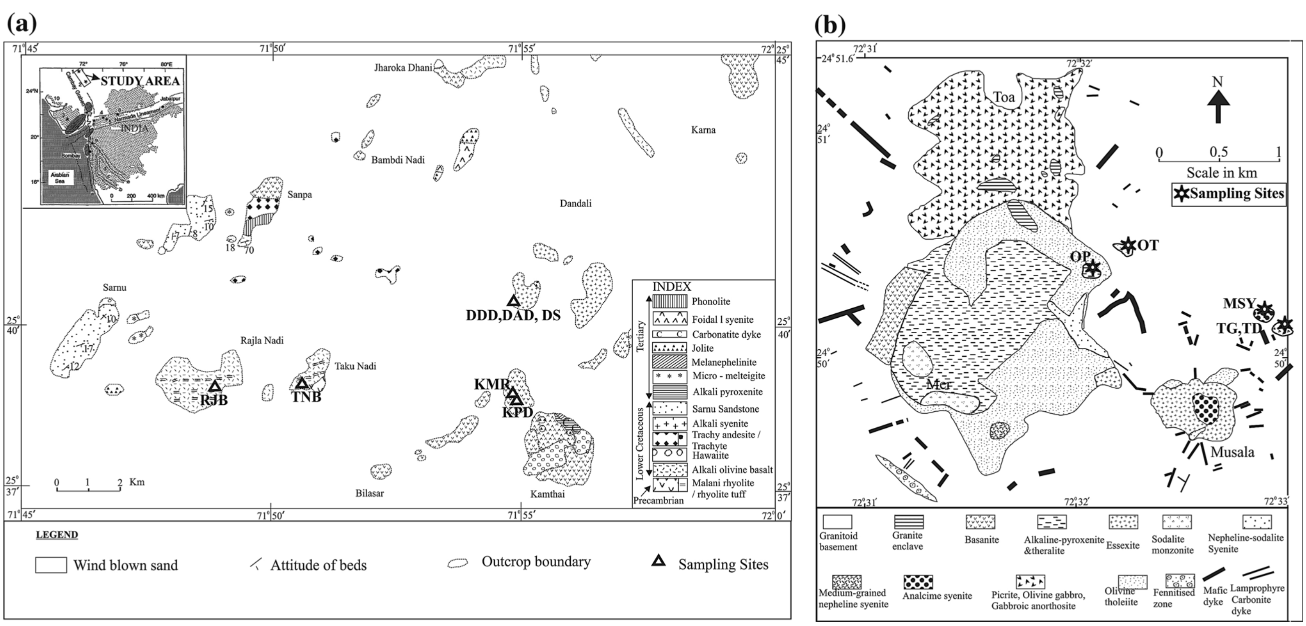

Figure 1. Geological map of **(a)** Sarnu-Dandali and **(b)** Mundwara alkaline complexes along with sampling sites (after Roy and Jakhar 2002). Inset shows the location of Sarnu-Dandali and Mundwara alkaline complexes in relation to tectonics and similar other alkaline suites in peninsular India (after Basu *et al.* 1993).

along the Narmada–Son Lineament, Kachchh Rift, Gulf of Khambat and Panvel flexure (figure 1), encompassing large parts of the northwestern and western India (Basu *et al.* 1993; Poornachandra Rao *et al.* 2003). Sarnu-Dandali and Mundwara complexes in Rajasthan are identified for the present study. Geology and geochemistry of the rocks is extensively discussed in Chandrasekaran *et al.* (1990) and Basu *et al.* (1993). The rocks occurring at Mundwara and Sarnu-Dandali complexes are the product of nepheline–carbonatite suite of rocks.

The Sarnu-Dandali alkaline complex is located at the eastern edge of the 'Barmer Graben'. The sequence of alkaline intrusion in the Sarnu-Dandali region in relation to country rocks is shown in figure 1(a). The region contains a variety of acidic, intermediate and alkaline rocks ranging from rhyolite, rhyolite tuffs, alkaline olivine basalts, hawaiites, trachy-andesite, trachyte to alkali syenites (figure 1a). In the Mundwara complex, alkaline rocks occur in an area of about 12 km^2 as three main plutons, namely, Musala, Mer and Toa (Bose 1980; Subrahmanyam and Leelanandam 1991; Srivastava 1989). Among them, Musala is a plug-like body, and Mer and Toa are two concentric ring-like bodies. Geological map with sampling sites is given in figure 1(b).

The sampling for present study is restricted to the core parts of the alkaline outcrops. A total of 45 oriented block samples were collected from 12 sites distributed over the Sarnu-Dandali and Mundwara alkaline complexes (figure 1a, b). Among 45 samples, 26 samples of intrusive rocks were collected from seven sites in Sarnu-Dandali complex include alkali syenite (Dandali Syenite – DS), tinguaite (Dandali Dyke – DDD and Dandali Alkali Dyke – DAD), phonolite (Kamthai Phonolite Dyke – KPD), rhyolite (Kamthai Rhyolite – KMR) and basalt (Taku Nadi Basalt – TNB and Rajla Nadi Basalt – RJB) for rock magnetic and palaeomagnetic characterization. Totally, 19 samples were collected from five sites in Mundwara complex covering gabbro (Toa Gabbro – TG), dolerite (Toa Dolerite – TD), camptonite (Toa camptonite – OT and OP) and syenite (Musala Syenite – MSY) near Musala pluton. The number of samples from each rock type and location is given in table 2.

3. Laboratory experiments

Standard cylindrical specimens of 2.2 cm length and 2.5 cm diameter were obtained by laboratory drilling. The specimens were measured for magnetic susceptibility at low frequency (0.465 kHz) using the Bartington MS-2B sensor (sensitivity 2×10^{-6} SI units). JR-5A Spinner magnetometer (Agico, Czech Republic) and Minispin magnetometer (Molspin, UK) were used for measurements of remanence directions and intensities. Alternating field (AF) demagnetization was carried out using Molspin AF demagnetizer and thermal demagnetization was done using Magnetic Vacuum System (MAVACS), (Geofyzica, Brono) and TD-700 (Magnon International, Germany).

Representative samples from each site were selected for rock magnetic studies to identify the magnetic mineralogy and properties. The IRM acquisition and backfield measurements were carried out using a pulse magnetizer with a maximum field of 1T (Molspin, UK). The L–F test is used to ascertain domain state of the magnetic carrier (Lowrie and Fuller 1971).

4. Results and analysis

4.1 *Rock magnetic measurements*

The NRM intensities (M_o) at the Sarnu-Dandali sites range from 4.1×10^{-3} to 9.04×10^{-1} A/m, whereas in the Mundwara complex, intensities vary from 188.5×10^{-2} to 223.5×10^{-1} A/m. The corresponding susceptibility values (k) in the Sarnu-Dandali and Mundwara regions ranged from 24.9 to 953.1 ($\times 10^{-5}$ SI) and from 5069.5 to 10688.2 ($\times 10^{-5}$ SI), respectively. The *Q*-ratio (*Q*-ratio = M_o/kH) is close to 1, for both Sarnu-Dandali and Mundwara alkaline complexes, is a clear pointer of stable remanence (Stacey 1963; Dunlop and Ozdemir 1997).

The SIRM values of these samples are ranging from 10.22 to 27625.88 $\times 10^{-5}$ Am^2 kg^{-1} (table 1). The SIRM/χ_{lf} value showed uniform variation in grain-size of ferrimagnetic mineral phase as per the rock type of the alkaline complexes with the exception of TD site which showed higher values. The samples, except KMR and TNB sites, saturate at 200–300 mT (figure 2), indicate the presence of magnetite. KMR and TNB samples do not saturate even at 1T, a characteristic of the anti-ferromagnetic component (figure 2). The B_{OCR} for the alkaline rocks varied from 27 to 522 mT, while the basalts from sites TNB, RJB in Sarnu-Dandali and TD in Mundwara register B_{OCR} values uniformly higher than 100 mT (table 1). These differences are critical as the lower B_{OCR} values indicate ferromagnetic components and higher values mark the presence of

Table 1. *Rock magnetic parameters for Sarnu-Dandali and Mundwara alkaline complexes, Rajasthan.*

				Concentration				Grain size	Composition		
Alkaline complexes of Rajasthan	Site name (code)	Rock type	Samples	$\chi_{lf} \times 10^{-8}$ (m^3 kg^{-1})	SIRM (A m^2 kg^{-1})	$IRM_{-0.1T}$ (A m^2 kg^{-1})	$IRM_{-0.02T}$ (A m^2 kg^{-1})	$SIRM/\chi_{lf}$ $\times 10^3$ (Am^{-1})	IRM_{soft} in %	B_{OCR}	S-ratio
Sarnu–Dandali	Kamthai (KMR)	Rhyolite	KMR1.2b1	102.12	2701.62	–614.67	1275.76	26.46	26.389	63	–0.23
Alkaline Complex	Dandali (DDD)	Tinguaite dyke	DDD2.1c1	16.98	37.44	–9.34	16.28	2.21	28.261	48	–0.25
	Dandali (DAD)	Tinguaite dyke	DAD2.4a1	8.25	11.30	–7.30	2.20	1.37	40.262	27	–0.65
	Dandali (DS)	Alkali Syenite	DS2.6a1	61.67	1148.46	–304.11	757.14	18.62	17.037	61	–0.26
	Taku Nadi (TNB)	Basalt	TNB3.4a2	425.30	12967.86	–6489.52	5400.68	30.49	29.177	196	–0.50
	Rajla Nadi (RJB)	Basalt	RJB4.3a1	23.11	471.19	395.44	466.14	20.39	0.5356	522	0.84
	Kamthai (KPD)	Phonolite dyke	KPD5.5a1	9.11	10.22	–8.75	3.19	1.12	34.404	32	–0.86
Mundwara	Toa (TG)	Hornblende Gabbro	TG6.2a1	1000.11	27625.88	–18674.52	20407.25	27.62	13.065	52	–0.68
Alkaline complex	Toa (TD)	Dolerite dyke	TD7.3a1	404.77	24805.99	4647.83	24140.68	61.28	1.341	114	0.19
	Mer (OT)	Camptonite	OT8.4a1	2030.51	26729.02	–17021.39	25463.66	13.16	2.367	62	–0.64
	Mer (OP)	Camptonite	OP9.2a1	1927.38	24314.60	–14700.84	17989.55	12.62	13.007	43	–0.60
	Musala (MSY)	Syenite	MSY10.1a1	1411.18	17807.50	–15365.80	5197.17	12.62	35.407	30	–0.86

χ_{lf}: Low frequency magnetic susceptibility (mass specific); SIRM: saturation isothermal remanent magnetization; IRM_{soft} = ($SIRM\text{-}IRM_{-0.02T}$)/2; $IRM_{soft\%}$,=(IRM_{soft}/SIRM) × 100; B_{OCR}: Coercivity; S-ratio = $IRM_{-0.01T}$/SIRM.

anti-ferromagnetic components (Thompson and Oldfield 1986; Evans and Heller 2003). The deduction on the magnetic mineralogy and grain type is independently provided by the index IRM_{soft}, simplified as ($SIRM\text{-}IRM_{-0.02T}$)/2, such that higher IRM_{soft} values signify higher ferromagnetic content, whereas low values imply the presence of anti-ferromagnetic minerals such as Hematite (Kumaravel *et al.* 2005). Given this complimentary nature, the samples possessing low B_{OCR} values are invariably characterized by higher IRM_{soft} values, while samples possessing B_{OCR} higher than 45 mT are characterized by lower IRM_{soft} values (<30%) (table 1). Analogous to IRM_{soft}, the S-ratio, i.e., $IRM_{-0.3T}$/SIRM, for these locations also varied between –0.86 and –0.23 except for the RJB and TD sites which yield positive S-ratio indicating the presence of anti-ferromagnetic component in them (table 1). The S-ratio close to unity suggests the presence of ferromagnetic minerals as dominant magnetic carriers, while the lower values indicate the presence of anti-ferromagnetic minerals (Dekkers 2007).

The L–F plots of DS, KPD and TG sites show a gradual decrease of NRM and SIRM for each step of demagnetization (figure 3), which suggest the presence of PSD to SD type of magnetic minerals.

Finally, $SIRM/\chi_{lf}$ vs. B_{OCR} plot (Peters and Dekkers 2003) is used for assessing magnetic mineralogy of the samples (figure 4). Values from the alkaline complexes fall into three groups, viz.,

(i) $SIRM/\chi_{lf}$ values of less than 4×10^3 A/m at sites DDD, DAD and KPD indicate the presence of titanomagnetite;

(ii) High coercivity (>114 mT) and high $SIRM/\chi_{lf}$ ratios (>20×10^3 A/m) at TNB, RJB and TD sites indicate dominance of hematite; and

(iii) Sites like KMR, DS, DG, OT, OP and MSY, though the coercivities values are higher, still fall within the range to be grouped as titanomagnetites as principal magnetic mineral (Poornachandra Rao *et al.* 2003).

4.2 *Palaeomagnetism*

After the initial NRM measurements, 48 specimens were subjected to detailed AF demagnetization in 14 progressive steps. A few examples from representative specimens are shown in figure 5. Once the secondary components are removed, intensities decrease gradually with increasing applied AF fields. Zijderveld diagram (Zijderveld 1967)

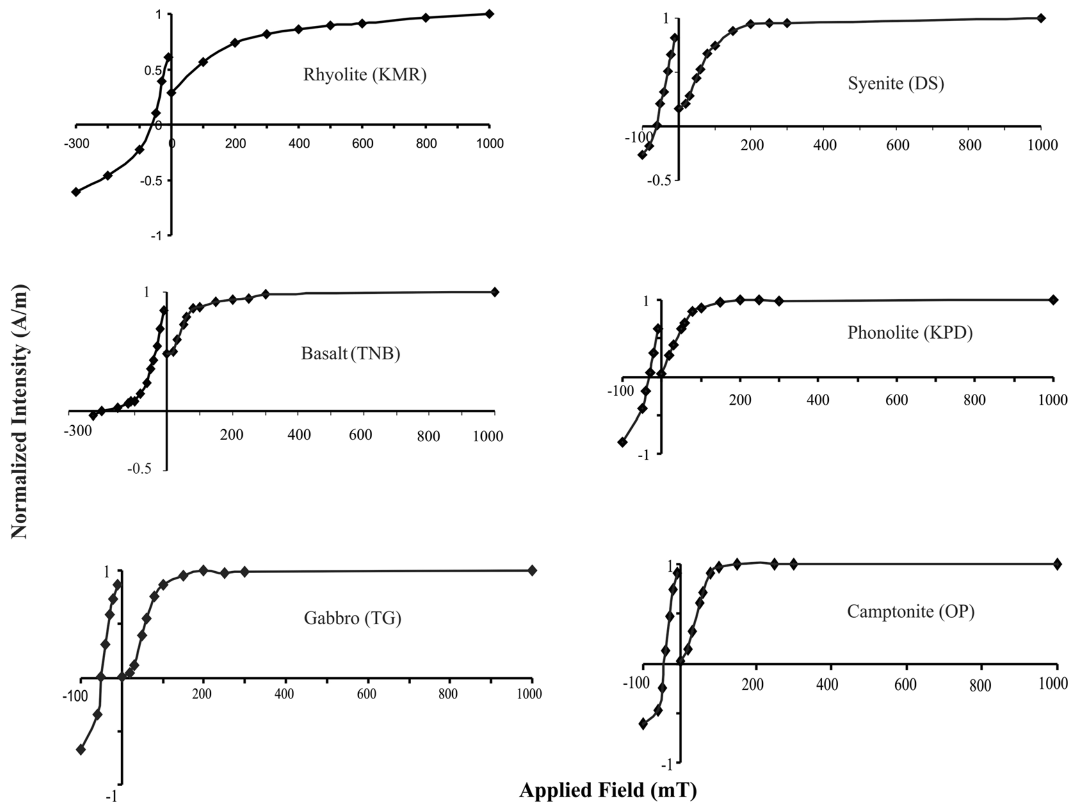

Figure 2. Isothermal Remanent Magnetization (IRM) acquisition curves together with backfield coercivity plots for the representative sites in the Sarnu-Dandali and Mundwara alkaline complexes.

portray the stable direction of ChRM in the site KPD at Sarnu-Dandali (figure 5a) and in the Mundwara complex sites at TG (figure 5c). The ChRM with NW declinations and negative inclinations at higher AF fields indicate normal polarity. In comparison, the alkali syenite site (DS) from Dandali region shows reverse polarity with SE declinations and positive intermediate inclinations (figure 5b).

A set of 36 specimens of alkaline suites were subjected to detailed thermal demagnetization. The behaviour of two representative samples of thermal demagnetizations are shown in figure 6(a and b). The plots show that thermal demagnetizations unblocked remanence between 350° and 500°C. After 500°C, the ChRM directions got randomized.

After pilot studies, blanket demagnetization measurements, both AF and thermal, were carried out on 28 additional specimens. Since the magnetization intensities drop to extremely low values above the applied fields of 50 mT, the blanket AF demagnetization steps were restricted to lower peak fields of 5, 10, 20, 30, and 35 mT. Analogously, since the ChRM directions randomize during thermal demagnetization at 350°–400°C, blanket thermal demagnetization was limited to only 200°, 300° and 350°C steps.

The results of both AFD and thermal demagnetizations of the alkaline complexes were subjected to the Principal Component Analysis (PCA) (Kirshvink 1980) to obtain more robust estimate of ChRM parameters using the Fisher's (Fisher 1953) statistics. The mean ChRM directions obtained from the Sarnu-Dandali and Mundwara alkaline complexes are summarized in table 2.

5. Discussion and conclusions

The rock magnetic results on the alkaline outcrops in Rajasthan indicate SD/PSD titano-magnetite as the chief carrier of remanent magnetization in majority of samples. However, samples from the sites KMR, RJB and TNB in Sarnu-Dandali alkaline complex and from site TD in Mundwara alkaline complex, are showing mixed SD+MD characteristics and possess high coercivity values of >100 mT (table 1). The PCA analysis has yielded consistent ChRM component from AF and

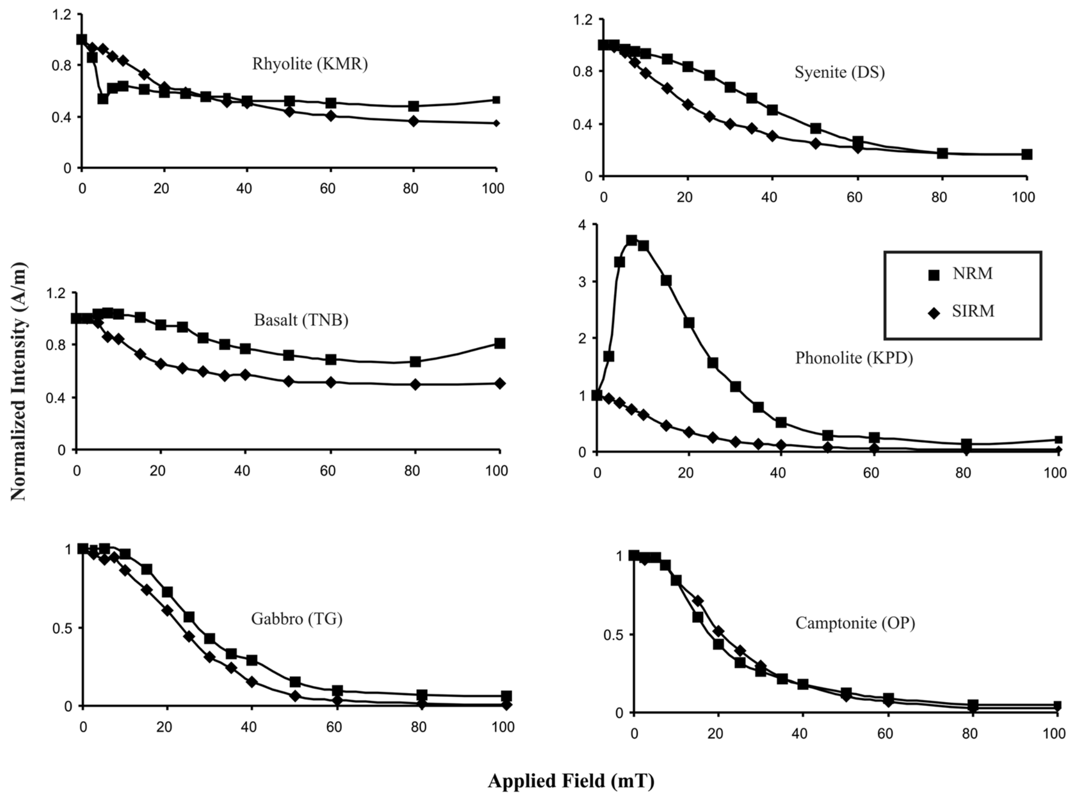

Figure 3. Lowrie–Fuller test plots for four sites in Sarnu-Dandali complex and at two sites in Mundwara complex.

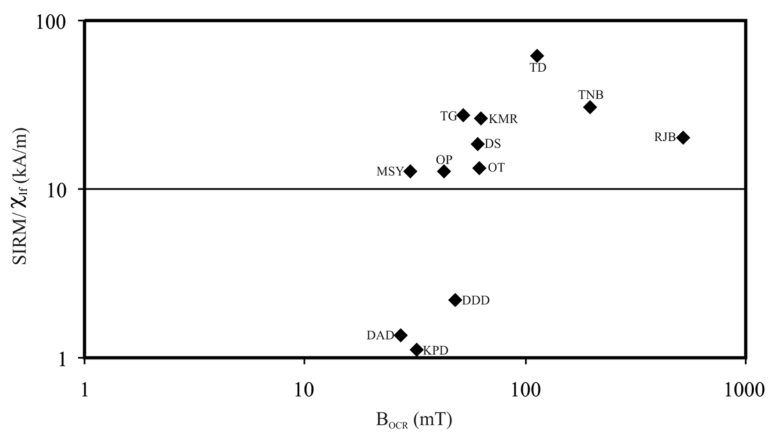

Figure 4. Biplot of ratio of saturation remanent magnetization to susceptibility vs. remanent acquisition coercivity (SIRM/X_{lf} Vs. B_{OCR}) for all 12 sites of Sarnu-Dandali and Mundwara alkaline complexes (after Peters and Dekkers 2003).

thermal demagnetization datasets. The individual specimen mean and site mean are given in table 2 and the ChRM directions plotted on the stereonet for alkaline complexes are shown in figure 7(a). Among 12 sites distributed over two alkaline complexes, eight sites show normal polarity. The samples from Syenite of Musala pluton (MSY) in the Mundwara complex did not show a stable remanance. Also the basalts from the sites TNB and RJB belonging to the Sarnu-Dandali region show directions significantly different from the closely clustered group of eight sites. Due to the above suspicious results, the sites TNB, RJB and MSY are not included in the estimation of mean

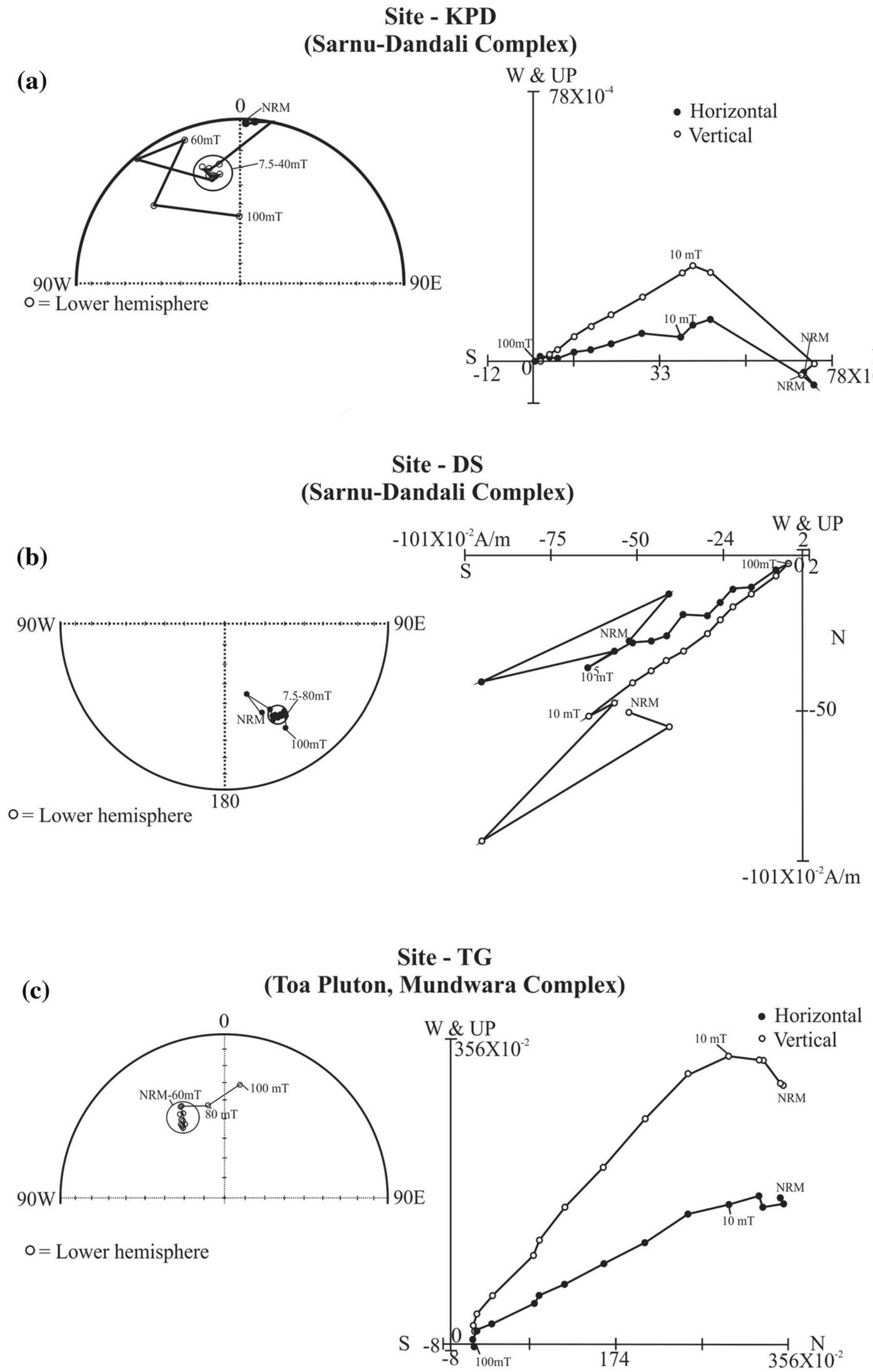

Figure 5. Stereo (left) and orthogonal vector diagram (Zijderveld) (right) plots during AF demagnetization. Sites KPD **(a)**, TG **(c)** are identified with normal polarity and DS **(b)** is marked by reverse polarity in the Sarnu-Dandali and Mundwara alkaline complexes.

direction and pole positions for the alkaline complexes. The Syenite samples (DS) from Dandali region is the only site that showed ChRM of reverse polarity (Decl=160°; Incl=43°). Inverting the characteristic directions of reverse polarity (Patil and Rao 2002; Lakshmi Narasimhan *et al.* 2008; Venkateshwarlu *et al.* 2014) of site DS, the Fisher's statistics is applied to all the nine sites that yielded a composite direction with $Decl_m = 342°$, $Incl_m = –35°$ ($\alpha_{95} = 4.39°$, K = 121, N = 9). The corresponding virtual geomagnetic pole (VGP) position is at 42°N and 274°E with palaeolatitude at 24.5°S. This VGP position when examined in relation to Indian apparent polar wander path (Besse and Courtillot 1991), the pole position for the alkaline rocks of Rajasthan falls close to the

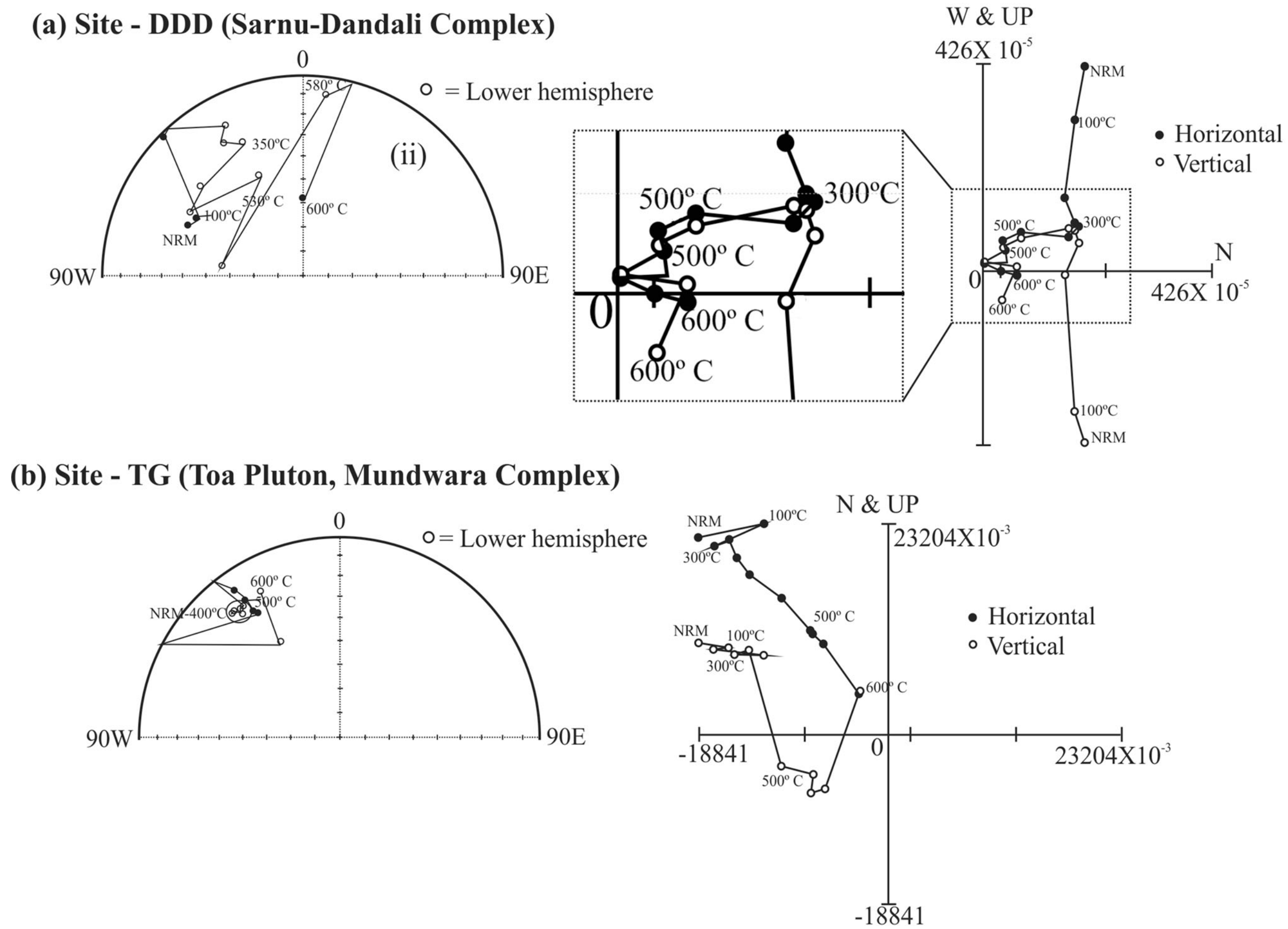

Figure 6. Stereo (left) and vector diagram (Zijderveld) (right) plots during thermal demagnetization for the sites **(a)** DDD and **(b)** TG from Sarnu-Dandali and Mundwara complexes. For site DDD, enlarged plot shown as inset indicates randomized directions after 350°C.

65 Ma old Deccan Super Pole (figure 7b). An age of 65 ± 2.5 Ma is assigned to the Deccan super pole by Vandamme *et al.* (1991), later Kuiper *et al.* (2008) reported an age of 65·96 ± 0·04 Ma for Deccan eruption.

The reported radiometric ages, 68.57 ± 0.08 Ma and 68.53 ± 0.16 Ma respectively from the alkali pyroxenite of the Sarnu-Dandali region and the primary biotite grains from an alkali olivine gabbro of the Mundwara region (Basu *et al.* 1993), had reinforced the earlier hypothesis that mantle plume–lithosphere interactions were considered to be leading mechanism for alkaline magmatism in Rajasthan and was initiated at least 3 Ma prior to the outburst of the main Deccan Volcanism (Devey and Stephens 1992).

However, Rathore *et al.* (1996) using $^{40}Ar/^{39}Ar$ method obtained age of 70 Ma for the mafic rocks and 64 Ma for syenite samples from the Mundwara region. Extending the $^{40}Ar/^{39}Ar$ dating to the Hawaiite basalts in the Sarnu complex, Rathore and Venkatesan (1996) obtained an age of 64 Ma for the basalts. The above studies brought out a wide age bracket of 70–64 Ma for the alkaline complexes. The longer duration of the Deccan eruption is much debated and the present study is aimed to compare the paleomagnetic ages between alkaline intrusion and Deccan eruption.

Synthesizing all the available palaeomagnetic measurements, primarily on Deccan lava flows, Courtillot *et al.* (2000) proposed two phase or

Table 2. *Paleomagnetic results of Sarnu-Dandali and Mundwara alkaline complexes, Rajasthan.*

Alkaline complexes of Rajasthan	Site name (code)	Geographic coordinates		Rock type	N(n)	Palaeomagnetic mean directions (AF+thermal)				Palaeopoles			
		Lat° N	Long° E			Decl.	Incl.	α_{95}	K	Lat° N	Long° E	dp	dm
Sarnu-Dandali alkaline complex	Kamthai (KMR)	25.647	71.913	Rhyolite	4(9)	350	−33	8	51	45	267	5.01	8.83
	Dandali (DDD)	25.675	71.913	Tinguaite dyke	3(8)	336	−25	8	38	44.93	285.6	4.55	8.48
	Dandali (DAD)	25.675	71.913	Tinguaite dyke	4(12)	339	−34	9	21	41.47	278.74	6.05	10.61
	Dandali (DS)	25.675	71.913	Alkali Syenite	4(11)	160	43	12	18	35	276	8.91	14.36
	Taku Nadi* (TNB)	25.650	71.843	Basalt	4(11)	44	−35	12	14	28	203	8.18	14.29
	Rajla Nadi* (RJB)	25.649	71.814	Basalt	3(7)	30	−13	12	23	46.82	204.90	6.0	11.8
	Kamthai (KPD)	25.645	71.914	Phonolite dyke	4(10)	343	−44	5	72	35.75	270.86	4.06	6.46
Mundwara alkaline complex	Toa (TG)	24.833	72.550	Hornblende Gabbro	4(9)	341	−32	9	37	43.97	278	5.84	10.35
	Toa (TD)	24.833	72.550	Dolerite dyke	4(9)	342	−32	8	35	44.35	277.14	5.24	9.33
	Mer (OT)	24.840	72.537	Camptonite	4(7)	346	−30	5	108	47	271.72	3.28	5.91
	Mer (OP)	24.838	72.534	Camptonite	3(11)	342	−41	5	84	39	274.19	3.48	5.76
	Musala (MSY)*	24.834	72.548	Syenite	4(7)	17	−38	41	3	45.38	251.61	39.2	63.23
Overall mean					9	342	−35	4.39	121	42	274	3.06	5.32

*Not included in calculation of pole; n: no. of specimens yielding stable directions; N: no. of samples from each site/rock type. Decl and Incl: declination and inclination (in degrees) of ChRM vectors; K: precision parameter for directions, α_{95}: radius of 95% confidence cone for mean directions; dp and dm: semi-axes of the oval of 95% confidence for the VGPs.

three magnetic Chron model for the evolution of the Deccan volcanism; the first took place within the normal Chron C30N at 66.5/67 Ma, which was a relatively subdued phenomenon. The second phase which resumed after a short gap, during the reverse chron C29R at 65 Ma, was more vigorous in scale. More recent geochronological studies place the main bulk Deccan Volcanic eruption at ∼66 Ma (Renne *et al.* 2015; Schoene *et al.* 2015). Although inclusion of fresh palaeomagnetic measurements on the undated dyke swarms near Mumbai, western India, suggest additional reversals (Basavaiah *et al.* 2018), the 30N–29R–29N magnetostratigraphy still remains on the centre stage to the timing and duration of Deccan volcanism. The VGP position for the widely spread alkaline rocks in Rajasthan from the present study completely overlaps with Super Pole position of Deccan Volcanic Province (DVP), which implies that the intrusion of alkaline rocks are coeval with Deccan volcanism. Further, the prevalence of normal polarity both in the Sarnu-Dandali and Mundwara alkaline complexes favour their intrusions with the initial phase of Deccan volcanism corresponding to magnetic Chron 30N. A similar suggestion is in agreement with hypothesis of Khadri *et al.* (1988, 1989), who proposed that Deccan volcanism in the north of Narmada valley had started at C30N around at 66.5/67 Ma. Only the single evidence of reversed polarity, if proved with measurements at new sites, may warrant emplacement of alkaline rocks could have extended to Chron C29R in the N–R–N sequence of the Deccan volcanism.

It is concluded from the present rock and palaeomagnetic investigations on the alkaline complexes of western Rajasthan that these complexes were erupted in coeval with Deccan volcanism. It indicates the actual extent of the Deccan volcanism extended far beyond the present day boundaries of the traps, especially in the north. Further, the ChRM marked largely by normal polarity favours the view that large scale alkaline intrusions were accomplished within the magnetic Chron C30N that marked the onset of massive Deccan volcanism.

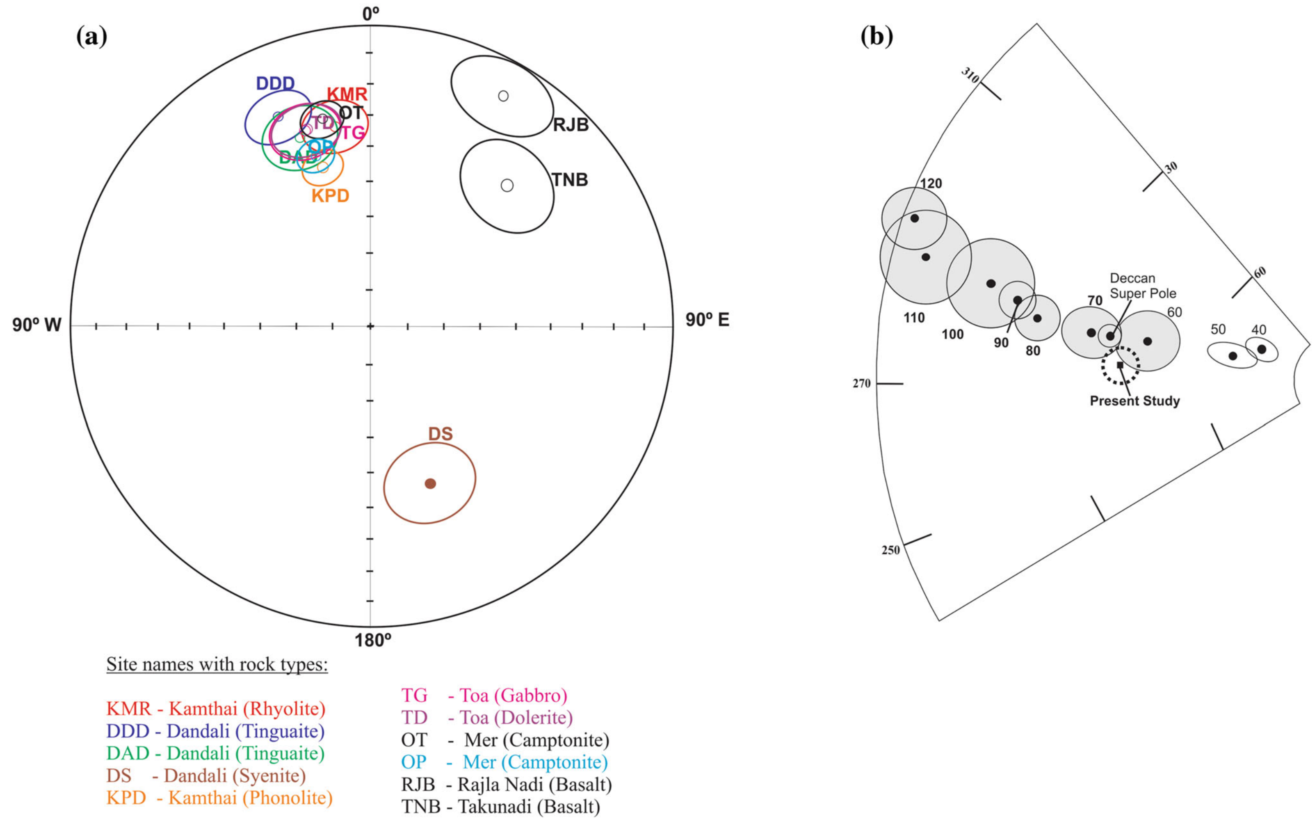

Figure 7. (**a**) The ChRM direction for each site from Sarnu-Dandali and Mundwara alkaline complexes are plotted in stereonet with confidence circles. (**b**) VGP position obtained in the present study for the Sarnu-Dandali and Mundwara alkaline complexes is superimposed on the APWP for Indian plate (Besse and Courtillot 1991). The position of Deccan Super pole is shown.

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