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Palaeomagnetic Studies of Intrusives in the Deccan Trap Around Nandurbar Area, South of Tapti Valley, District Dhule, Maharashtra

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Abstract: The area around Nandurbar consists of compound lava flows (basalts) of Deccan Trap which are intruded by numerous prominent dykes. These dykes are mainly dolerites and some are quite massive and extensive. One major dyke was traced for over 50 km, from north of Dondaicha, westwards as far as Umaj, near the Gujarat - Maharashtra border. Petrochemical studies indicate tholeiitic nature of the magma. There is also an indication of two distinct magma types represented by high Ti and low Ti varieties. These two magma types have intruded as distinct phases with the high Ti dykes being cut across by the low Ti dykes.

The palaeomagnetic work centers around these dykes. In addition a few lava flows were studied for comparison. The older set of dykes show normal magnetization whilst the younger set shows reverse directions. The lava flows are also reversely magnetized. It is thus evident that both the dyke phases are younger than the surrounding lava flows. The older phase of dykes could have been feeders to the younger lava flows of the Deccan Volcanic Province but the younger phase is distinctly post Deccan Trap.

Keywords: Palaeomagnetism, Deccan Trap, Dykes, Tapti valley, Maharashtra.

INTRODUCTION

The area of study is around Nandurbar, a small town situated to the northwest of Dhule (Maharashtra) and to the south of Tapti River. The country rock here consists of fine grained, vesicular Deccan Trap basalts, which form compound lava flows (Walker, 1972). These lava flows are intruded by numerous dykes (Deshmukh and Sehgal, 1988; Baride et al. 1993) that form the focus of the present study. The area of study lies between Latitude 21° N to 21°25' N and Longitude 74°E to 74°37' E and is covered by Survey of India Topographic Sheet Nos. 46 K/3, 46 K/4, 46 K/7, 46 K/8 and 46 K/11. Fig 1 shows the geology of the area under investigation and also some of the prominent towns.

Recent stratigraphic studies (Beane et al. 1986; Bodas et al. 1985, 1988; Khadri et al. 1988) have not covered the area under investigation and thus the stratigraphic position of these Deccan Trap flows is not yet known. The lava flows are invariably weathered, while the dykes in comparison are quite fresh and more resistant to weathering. Most of the dykes encountered are medium-grained dolerites, but one very coarse grained gabbroic dyke has also been observed. Generally they are equigranular though a few show porphyritic texture.

The dykes in the study area form very prominent ridges, many of which are quite extensive in length. One particular dyke (D 13) runs for more than 50 km starting somewhere north of Dondaicha and can be traced westwards into Maharashtra-Gujarat border. The trend of the dykes is practically east-west, more or less parallel to the Narmada-Son lineament as pointed out by Auden (1949) and Deshmukh and Sehgal (1988). The field geological and petrological aspects pertaining to the dykes of this area have already been studied (e.g., Sethna et al. 1996; Melluso et al. in press). The trends

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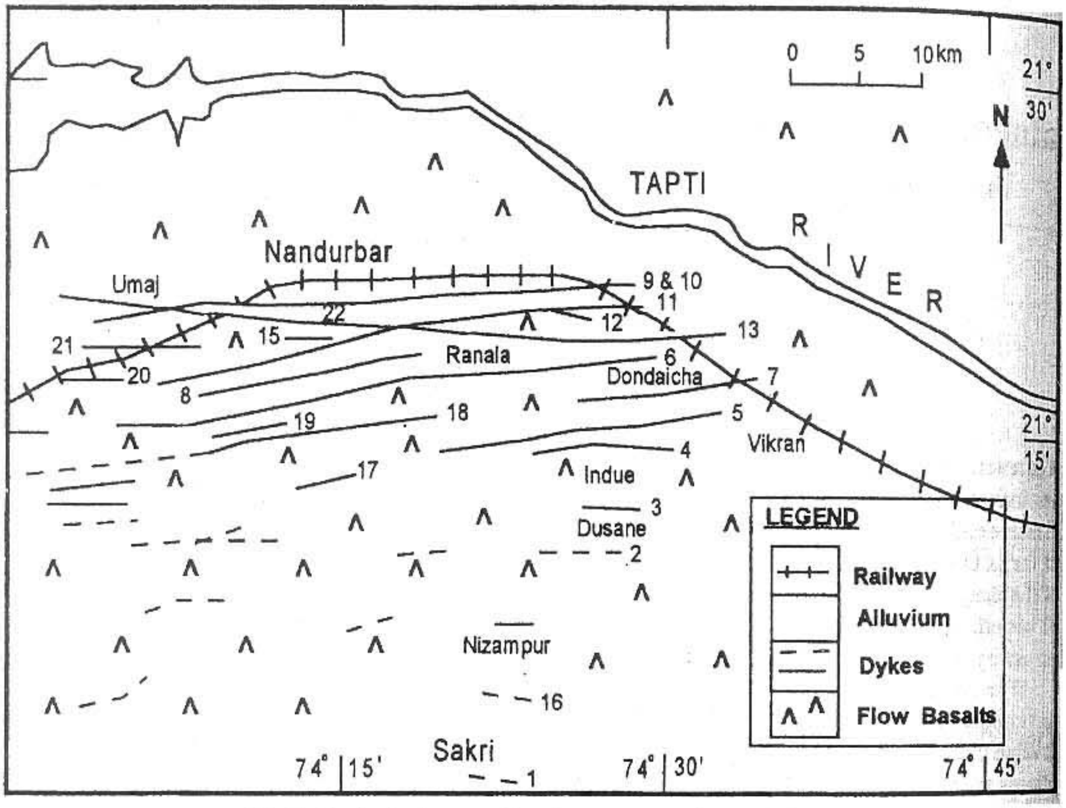

Fig.1. Geological map of study area around Nandurbar.

of the dykes range from N 75° E to nearly through E-W to S 85° E. The major dyke (D 13), that extends for more than 50 km, appears to change its trend from S 85° E to E-W and back to S 85° E as one moves towards the west.

A very interesting and peculiar feature seen in a few dykes (e.g. D 11, D 12 and D 6) is vertical layering. In these dykes plagioclase rich layers are found alternating with pyroxene rich layers. The individual layers are 1-2 cm. in width. The light coloured plagioclase rich layers being more resistant to weathering, form minor ridges while the pyroxene rich layers form minor depressions.

Earlier palaeomagnetic studies have been carried out on the Deccan Trap lava flows mainly to find out the number of magnetic reversals within the vertical section of the lava pile (Sahasrabudhe, 1963). Subsequently many workers have carried out magnetostratigraphic, palaeomagnetic and rock magnetic studies on the Deccan Trap lava flows (Athavale, 1970; Pal, 1975; Sreenivasa Rao et al. 1985; Khadri et al. 1988; Radhakrishnamurty and Subbarao, 1990; Vandamme et al. 1991; Navaneethakrishnan et al. 1994).

As compared to the lava flows, very little palaeomagnetic study has been carried out on the intrusives which are associated with the Deccan Trap, except the work on the dykes of Mandaleswar region (Subbarao et al. 1988). Palaeomagnetic study on the intrusives south of Tapti has therefore been undertaken as it could throw some light on the relation that these dykes have with the Deccan lavas into which they intrude.

Oriented samples were collected in the field from 13 dykes and 6 lava flows. As the stratigraphic position of the lava flow samples could not be ascertained, it is possible that some samples taken from different locations might belong to the same flow. An initial magnetic susceptibility reading was taken in the field for the rock by using a Kappameter. This was done to ensure the suitability of the rock samples for the palaeomagnetic work. Wherever possible the samples were taken from the unweathered portion of the rock. The dykes yielded good unweathered samples but the country rocks on the other hand showed some amount of weathering. The palaeomagnetic work was carried out at the IIG laboratory at Alibagh.

PALAEOMAGNETIC MEASUREMENTS

The initial NRM measurement was taken for about 203 specimens representing the 13 dykes and 6 lava flow samples. The measurements were taken by using an astatic magnetometer (LAM-24) and a spinner magnetometer (JR4) both manufactured by GEOFYZIKA n.p. BRNO, Czechoslovakia. The intensity in case of astatic magnetometer was measured in nT/Kg (nano Tesla per Kg) and in the case of the spinner magnetometer it was measured in Tesla.

Thermal Cleaning

In order to test the stability of the NRM of the specimens, thermal cleaning was carried out for 57 pilot specimens which represented the 13 dykes and 6 lava flows. The thermal cleaning was carried out in a magnetic vacuum using MAVACS (Magnetic Vacuum Control System), starting at 50°C and going upto 600°C, in increments of 50° to 100° C. After each step of the thermal cleaning, measurements were taken on the astatic magnetometer or the spinner magnetometer.

The NRM measurements of the specimens showed less amount of scatter for the dykes and a very large scatter for the country rocks. The measurements on the pilot samples were used to plot Zijderveld and vector migration diagrams, which indicated that the temperature for obtaining stable directions generally ranged from 300°C to 500°C. Stable directions are found in those temperature ranges, wherein the Zijderveld plots (orthogonal projection of the magnetization vector on the horizontal and meridian vertical planes during demagnetization) show the decay of intensity components along straight lines moving towards the origin and directions show clustering in the vector migration plots (stereographic projection showing behaviour of magnetization vector on demagnetization). Typically, samples would show some amount of fluctuation in palaeomagnetic directions in the initial steps of the thermal cleaning. The palaeomagnetic direction would later on stabilize as the thermal cleaning progressed in the range of 300° to 500°C. Some specimens were also subjected to blanket cleaning at 350°C for the dyke samples and at 400°C for the country rock samples.

From the Zijderveld (Figs. 2 and 3) and vector migration plots (Figs. 4 and 5) it becomes evident that the dykes show a better stability in palaeomagnetic directions when compared to the country rocks. The flows are compound lava flows and are therefore more susceptible to weathering. The weathering can lead to formation of magnetites which have multi-domain character. The multi-domain constituents affect the stability of the NRM directions as they can acquire random magnetization which will interfere with the primary magnetization of the rock (Subbarao et al. 1989; Navaneethakrishnan et al. 1994). The flow samples also showed high inclinations. This could be due to the presence of a strong secondary magnetization component (directed northwards) which is opposed to the primary component (directed southwards). The vector migration plots for the flows show zig zag patterns (e.g. Fig. 4) which suggest that there were several secondary magnetization imprints or indicate random magnetization acquired by the multi-domain constituents.

Most of the dykes showed good stability of palaeomagnetic directions. From the Zijderveld and vector migration plots, it becomes clear that the NRM inclinations are quite shallow which gradually and systematically increase on demagnetization until stability is achieved. This suggests that some secondary magnetization component is being gradually removed until it has been completely eliminated.

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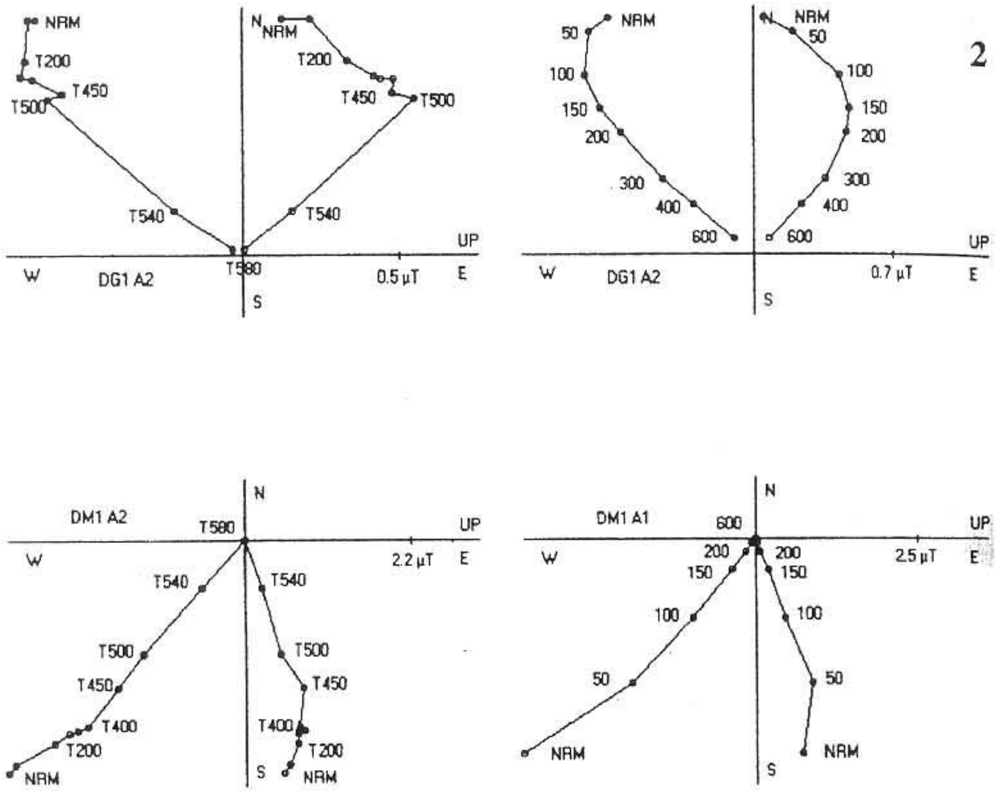

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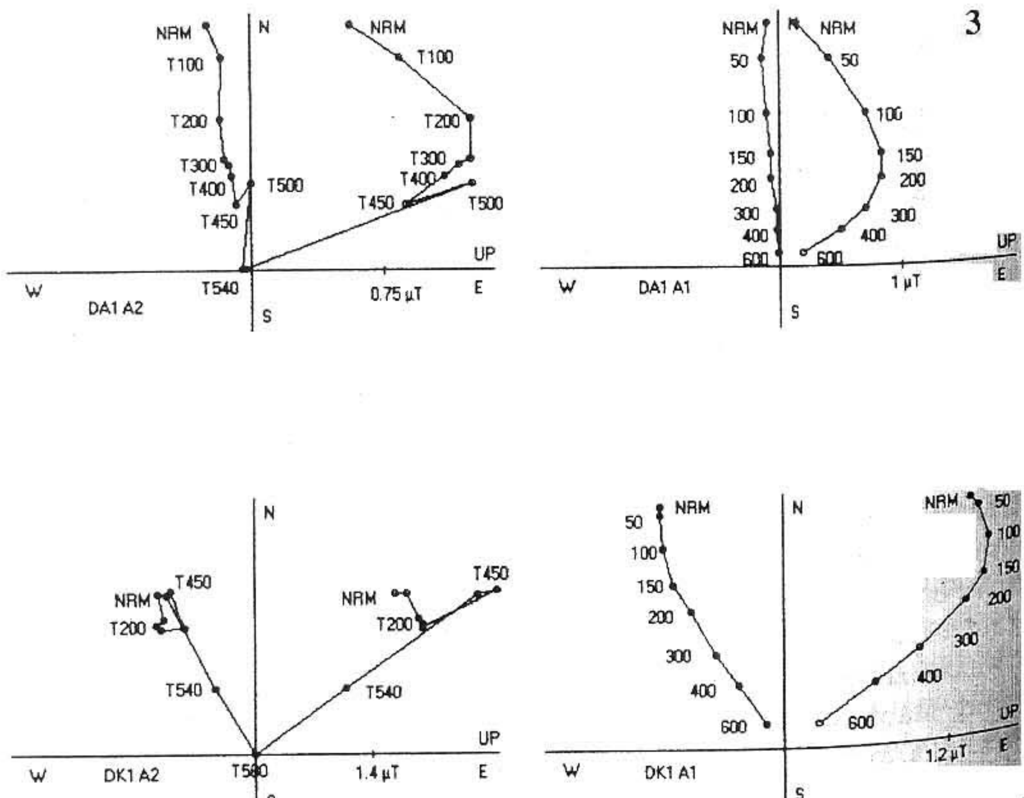

Figs.2 and 3. Comparison of Zijderveld plots for thermally demagnetized and alternating field demagnetized specimens from the same dyke sample. Closed circles represent projection on the horzontal plane while open circles represent projection on the N-S vertical plane. Figures on left represent specimens which have been thermally demagnetized and typically show stable directions in the range of 300°C to 400°C. Figures on the right specimens from the same dyke sample which have been demagnetized using alternating field and show stability in the range of 200 to 600 Oe. The AFD plots prove to be better than those produced by thermal demagnetization.

Alternating Field Demagnetization

The AFD cleaning shows that the palaeomagnetic directions are quite stable over a wide range of 200 to 600 Oe. This is significant, as generally for the Deccan Trap, alternating fields of less than 250 Oe are usually enough to cause demagnetization (Subbarao et al. 1988; Navaneethakrishnan et al. 1994). The Zijderveld and vector migration plots using the AFD are generally more reliable than those obtained using thermal cleaning and this is apparent inspite of there being fewer steps in the AFD cleaning than in the thermal cleaning (Figs. 2 and 3). The fact that directions are stable at such high fields as 600 Oe indicates the magnetic constituents have a high coercivity.

DISCUSSION

The stable directions obtained using thermal cleaning and AF demagnetization have been utilized to calculate the mean declinations, inclinations and other palaeomagnetic parameters summarized in Table 1. Some of the readings obtained by blanket cleaning have also been utilized for calculations after they were found to be in agreement with those obtained by thermal cleaning of the pilot specimens. There was fairly good agreement in the directions obtained within the same dyke using different samples and also within a sample for different specimens.

The palaeomagnetic results show that the dykes are predominantly normally magnetized showing negative inclinations. A couple of dykes also showed reversely magnetized character with positive inclinations. The flows were not found to give stable directions as were given by the dykes. The flows were found to be reversely magnetized with high positive inclinations. The mean declinations for the normally magnetized dykes ranged between 322° and 7° while the mean inclinations were found to vary from -30° to -64°. The mean declination for the entire set of normally magnetized dykes is 334°, and the mean inclination is -42° which gives an average palaeolatitude of 24°S with reference to Nagpur. For the reversely magnetized dykes, the mean inclinations and declinations were found to be 176° and 43° respectively. The mean palaeolatitude for the reversely magnetized dykes is 25°S.

Table 1. Average declinations and inclinations for dyke and country rock samples of Nandurbar

Dyke No.	N	D	I	$\alpha 95$	d_p	d_m	R	K	Palaeo-latitude	VGP Lat.	VGP Long.
D2	5	7	-55	6.71	6.75	9.52	7.9	69.18	36 S	33N	112 W
D3	2	324	-64	12.13	15.39	19.32	5.84	31.44	45 S	15N	80 W
D5	1	339	-39	3.97	2.82	4.74	4.99	372.40	22 S	42N	79 W
D18	2	322	-50	4.79	4.23	6.33	5.97	197.02	31 S	26N	69 W
D11	4	326	-34	6.56	4.28	7.50	10.80	49.46	19 S	38N	63 W
D12	4	338	-30	5.47	3.37	6.07	7.93	103.51	16 S	47N	74 W
D13	6	180	43	8.02	6.15	9.94	7.86	48.18	25 S	44N	106 W
D9 D22	3	329	-31	11.79	7.36	13.17	9.43	17.76	17 S	41N	65 W
Avg. Norm	21	334	-42	4.72	3.55	5.79	50.02	17.79	24 S	37N	75 W
D13 D6	7	176	43	7.03	5.40	8.71	9.81	48.18	25 S	43N	101 W
Avg. Flow	6	161	59	11.55	12.86	17.24	12.99	12.82	40 S	27N	90 W

Note: Avg. Norm is the average for the normally magnetized dykes and represents average values for normally magnetized dykes. D6 and D13 show reversely magnetized character. Avg. Flow is average value for the lava flows. N - No. of samples, D - Declination, I - Inclination, $\alpha 95$ represents semi-angle at 95% confidence, d_p, d_m are semi-axes of elliptical error at 95% probability level, K - Precision parameter, R - Resultant vector, VGP - Virtual geomagnetic pole position.

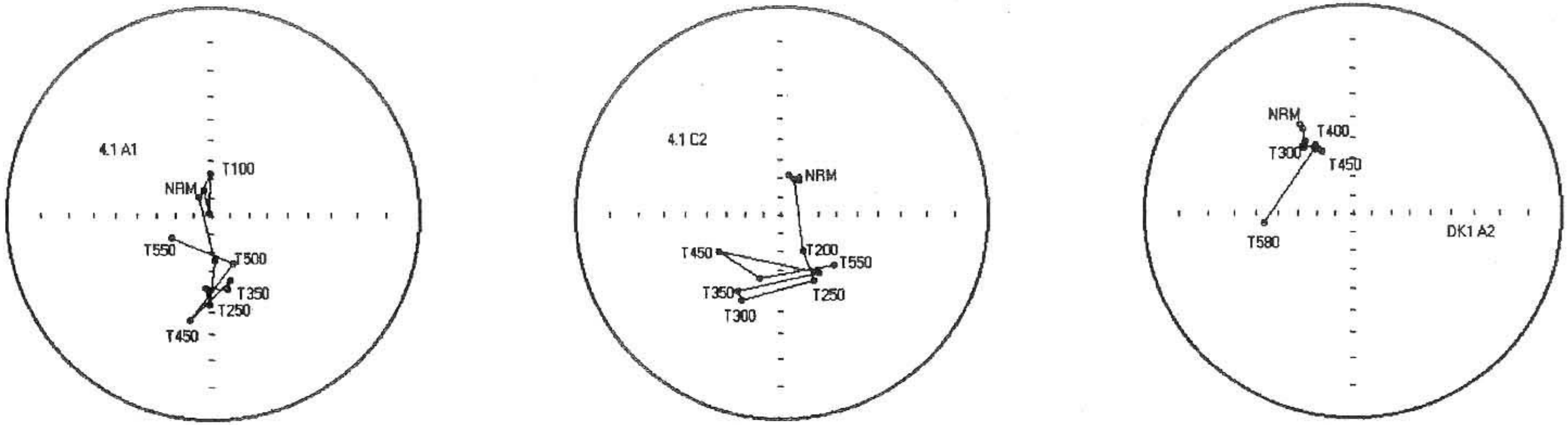

Fig. 4. Vector migration plots showing behaviour of the vectors on demagnetization for thermally demagnetized lava flow specimens (4.1A1 and 4.1C2) and dyke specimen (DK1A2). Open and closed circles represent negative and positive inclinations respectively. Dyke shows greater stability on demagnetization when compared to lava flow specimens.

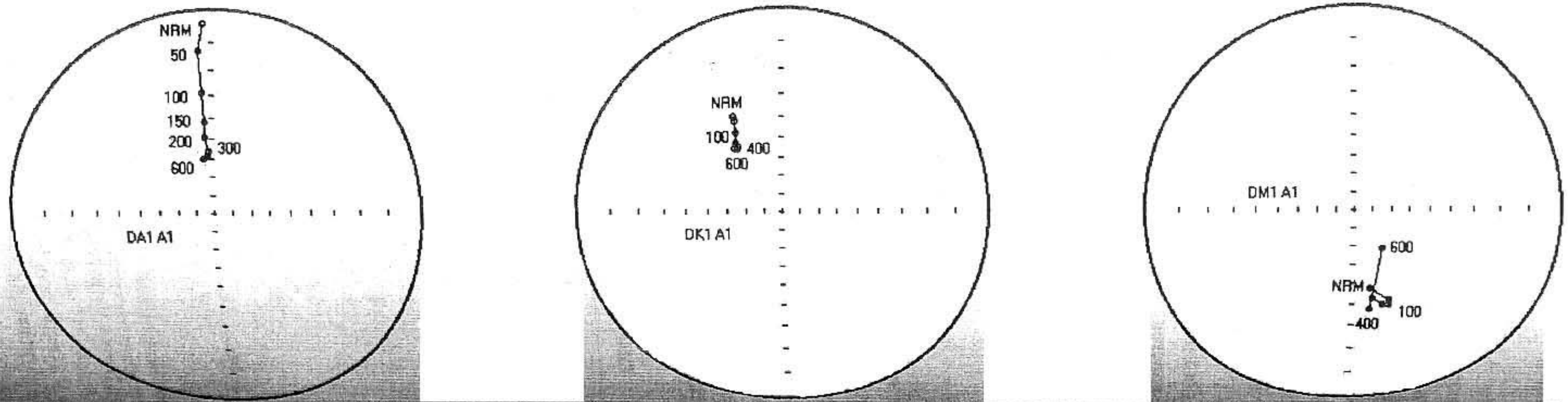

Fig. 5. Vector migration plots showing behaviour of the vectors on demagnetization using alternating field for dyke specimens. Open and closed circles represent negative and positive inclinations respectively.

The lava flows of the central part of the Deccan Trap Province are predominantly reversely magnetized. The Tapti dykes which intrude the Deccan flows are predominantly normally magnetized. The average palaeo-latitudes calculated for the dykes are also significantly lower than those of the Deccan flows in general. The dykes might therefore be post-Trappean in age though there is also a possibility of the normally magnetized dykes belonging to a younger phase of Deccan volcanism (normal polarity 29N epoch). The reversely magnetized dyke (D 13) is found to intersect a normally magnetized dyke (D 11) and must therefore be of still younger age than the normally magnetized dykes (perhaps 28R epoch or some still younger reverse epoch).

It is also significant to note that the reversely and normally magnetized dykes show significant petrochemical differences. The dykes showing reversely magnetized character are the ones which show low Ti content while the dykes which are normally magnetized are the high Ti varieties (Melluso et al. in press).

CONCLUSIONS

It is evident from the data presented above that the dolerite dykes have intruded the Deccan Trap lava flows as two distinct phases, the older phase of dykes being intersected by the younger phase of the dykes. These two intrusive phases show the following characters:

1. The older phase of dykes shows distinct high Ti contents.
2. The younger phase of dykes on the other hand shows low Ti contents.
3. The older dyke phase shows normal magnetic declination which averages at about 334° with a mean inclination of -42°.
4. The younger phase of dykes is reversely magnetized with average declination of 176° and a mean inclination of 43°.

As the lava flows of the area show reversed magnetization of the 29R epoch, the normally magnetized dykes are distinctly younger and may belong to the 29N epoch or an even younger epoch. The reversely magnetized dykes, being younger than the ones showing normal directions, cannot be considered to belong to the 29R epoch but should belong to either the 28R or an even younger epoch. It thus becomes evident that intrusive phase that shows normal magnetization could possibly be feeders to the younger lava flows or may be post-Deccan Trap, while the reversely magnetized phase is definitely younger than Deccan Trap in age.

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