

Palaeomagnetism and rock magnetism of the Deccan traps

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Abstract. Extensive work on the palaeomagnetism of the Deccan traps by several workers has revealed only one reversal (normal-reverse-normal) of the geomagnetic field during the period of eruption of these flows. The scatter in the natural remanent magnetic directions of different flows in a sequence of these traps is rather large and it persists even after magnetic cleaning. Generally this large scatter of directions is attributed to the geomagnetic secular variation during formation of the traps. Recent studies of the magnetic properties of the trap samples indicate that the presence of multidomain magnetite in a lava sequence differs from locality to locality in the Deccan trap province and so the stability of their natural remanent magnetization. While these features can be clearly perceived, an understanding of the same seems to be quite difficult. However, it appears that part of the scatter in directions could be due to the alteration of the magnetic minerals in the Deccan traps and hence it would not be proper to relate the entire scatter to the secular variation.

Keywords. Palaeomagnetism; Deccan traps; domian states; rock magnetism.

1. Introduction

Palaeomagnetism is the study of the natural remanent magnetization (NRM) of rocks which they acquire in the ambient geomagnetic field at the time of their formation. The NRM direction of rocks of age less than a million years generally coincides with that of the local geocentric dipole field, but that of older rocks differs considerably. Also, some rocks show an NRM almost antiparallel to that of the others of the same rock unit and this is taken to indicate that the geomagnetic field reversed its polarity during the formation of the unit. Thus, palaeomagnetism could be useful to investigate a number of geophysical problems like polar wandering and continental drift on a global scale and correlation of geological strata, tectonic disturbances etc on a regional scale.

The first palaeomagnetic measurements on Deccan traps (DT) carried out by Irving (1964) on a few samples obtained by him from India showed a mean direction of N 155°E, 55°. The next detailed work on DT samples from Khandala and Linga areas by a group of British scientists (Clegg *et al* 1956) more or less confirmed the first results. Then a laboratory for palaeomagnetic work was set up at the Tata Institute of Fundamental Research (TIFR), Bombay, during 1955 as part of a collaboration project between the groups at the Imperial College (London, England) and TIFR. The first work carried out at this new laboratory was on the sequence of lava flows of DT at Amba and Nipani and at both these places normally magnetized flows were encountered by Deutsch *et al* (1958). An important indication of this study was that

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the underlying reversely magnetized flows showed a steeper inclination (+ 60°, down) compared to the overlying normal ones (− 32°, up), suggesting a gradual northward movement of the Indian landmass, referred to Bombay from 39°S to 14°S, during the period of eruption of the DT. In an attempt to verify if such was the case, a thick pile of lava flows at Mahabaleshwar was investigated twice and the results belied the earlier fortuitous indication. From then on, several other groups have extended and even repeated the palaeomagnetic work on the flows from the vast expanse of the DT but the final outcome is still not clear. However, the rock magnetic investigations carried out on samples from different localities of DT seem to indicate a different line of evolution of the magnetic minerals in these flows. One significant point emerging from these investigations is that the multidomain (MD) magnetite, occurring as a component of the magnetic minerals in DT, varies from place to place and this seems to affect the stability of the natural remanent magnetization (NRM) of the lavas concerned. Although the presence of MD has a negative effect on the stability of NRM, it does provide a possible clue for the problems, relating to palaeomagnetism, encountered with the DT. In the light of this fact, a cautious approach for the interpretation of the palaeomagnetic results from different areas of the DT is advocated and some intractable features highlighted.

2. Palaeomagnetism of the Deccan traps

The main basis of the palaeomagnetic method is that rocks acquire magnetization during their formation due to the action of the ambient geomagnetic field and retain the same over geological periods. An underlying assumption of this method is that the magnetic minerals in the rocks do not change with time, or if they do, such a change would not radically affect the original magnetization. Basalts conform to these assumptions very closely. Thus, some of the classic palaeomagnetic results were obtained on basalts and the credibility of the method was enhanced by the pioneering studies on the lavas of Mt. Etna by Chevalier (1925). Nagata (1953), based on the work of Konigsburger, summarized the points relating to the suitability of basalts for palaeomagnetic studies. However, the most important criterion is the consistency of the direction of magnetization of samples obtained from a flow or a sequence of flows of a volcanic province. Palaeomagnetic results obtained prior to 1958 mainly depended on this consistency criterion, as other stability tests were not perfected till then. Even after the stability tests based on alternating field demagnetization (AFD) and thermal demagnetization (TD) were perfected and used, it was found impossible to recover the primary component of magnetization from some samples of DT and no clear-cut explanation could be offered to this anomaly, except to omit the results from such samples and sometimes those of even entire flows. Such a situation provided an opportunity to different workers to manipulate the results best suited to their opinion. It is interesting to record chronologically how different authors investigated DT and interpreted the results.

TIFR group's work on DT came to a final stage by 1963 and the results were summarized by Sahasrabudhe (1963) who included the results of both flows and dykes. Most of the consistent directions of magnetization of individual dykes or flows are in the range, declination N 150° ± 25°E (reversed—R) or 330° ± 25°E (normal—N)

and inclination $50^\circ \pm 25^\circ$ (down) or $-50^\circ \pm 25^\circ$ (up) for reversed and normal cases respectively. However, some odd directions of magnetization, either for individual samples from a single flow or for samples from an entire flow, were omitted for computing the mean directions. Another important result is that in the high Western Ghat sections south of Pune, the lower 300 m is reversely magnetized while the upper portions are normally magnetized. Thus only one R to N transition could be detected. But the flows in Bombay region, even at sea level, are normal and are considered either (i) to be separate central volcanic type eruptions at the close of the DT activity or (ii) represent faulted blocks.

During 1966–71, a group at the Osmania University, Hyderabad, carried out palaeomagnetic investigations on DT from a few different localities. The results of this group (Pal *et al* 1971) were essentially similar to those reported by Sahasrabudhe (1963), except that a few short-term reversals, meaning one flow showing N polarity among the otherwise R sequence, were reported. Comments on this aspect are given in § 4.

For about a decade, 1964–74, the palaeomagnetic group at the National Institute of Geophysical Research, Hyderabad, also devoted considerable efforts to the study of DT. This group's main contributions are the results obtained from Mt. Girinar (Verma and Mittal 1972) and Mt. Pavagadh (Verma and Mittal 1974), which are considered to represent the last phases of DT (Verma and Mittal 1974). The results from both these areas show a number of N flows overlying a few R flows. Another important observation reported (Verma *et al* 1973) is the occurrence of N flows underlying R flows at Kundam and Malwa areas. This result implies that during the eruption of DT, the geomagnetic field underwent a complete N–R–N inversion, although this full transition has not been represented by any one vertical sequence of flows in this area. However, such a transition is present in the Narmada region (Sreenivasa Rao *et al* 1985).

While the above extensive studies of DT were completed or were in progress, overseas groups, Netherlands (Wensink and Klootwijk 1971), Japan (Kono *et al* 1972) and more recently France (Courtillot *et al* 1986), essentially re-investigated some of the areas already covered by the Indian scientists. The overseas investigators' main plea was that the work of the Indian groups was not reliable enough due to inadequate sampling and stability tests and hence a repeat of the work was in order. It would be interesting to see how far this plea was correct or sustainable.

Wensink and Klootwijk (1971): "There are a number of reports on the palaeomagnetism of the DT (Clegg *et al* 1956; Deutsch *et al* 1959; Sahasrabudhe 1963). In these publications the results are not based on a consistent and detailed sampling of lava sequences." These authors collected 600 samples from 97 different flows during the winter of 1967–68, whereas on a conservative estimate the Indian scientists (three groups) might have studied several thousands of specimens from a few hundred flows, as these were obtained from many more areas, including those covered by the former. However, it could be conceded that more magnetic cleaning work might have been done by the Netherlands' group. Unfortunately, the extra cleaning effort had not rewarded them in any way when they obtained the final result, as they state "The pole position deviates only slightly from the earlier published combined Deccan trap pole (Irving 1964)." Needless to add that the result computed by Irving was mainly based on the results of the TIFR-Imperial College collaboration project.

Kono *et al* (1972): "Because of the great thickness of the traps and importance of India in the continental drift hypothesis, the lavas of the Western Ghats have been the objectives of many palaeomagnetic studies (Clegg *et al* 1956; Deutsch *et al* 1958, 1959; Sahasrabudhe 1963). However, these classic studies have several drawbacks in regard to the reliability of data; they are not based on detailed sampling of lavas and the stability of natural remanent magnetization (NRM) was not investigated properly." These authors took great care in the orientation of samples, spent more effort in demagnetizing and remeasuring the samples and performed a methodical statistical analysis of the data. But the end result is "The mean pole position (Table 3) is almost the same as Sahasrabudhe's (1963)."

The French group (Courtilot *et al* 1986) mounted a joint palaeomagnetic, palaeontological and geochronological investigations on the DT on the plea "despite decades of extensive geological work still relatively little is known about the internal structure, age, total duration and ultimately origin of the Deccan volcanism." As far as the palaeomagnetic result is concerned they state that 18 out of 21 sites, i.e. 85% of the total have reversed magnetization which confirms previous findings that the remanent magnetization of DT is predominantly reversed.

It is clear from the above quotes that no matter how much effort and care were taken for the palaeomagnetic study of DT by latter workers, they could not improve over the first results obtained by simple techniques. Also, the overseas groups decried the work of Indian scientists mainly to justify their repetition of the work. Actually the latter's investigations of DT were more elaborate and accurate enough to draw out the main features. Over the past five years, a group at the Indian Institute of Technology, Bombay, has undertaken geochemical and magnetic work with some geochronological support, as part of a major project work on Deccan traps. In these investigations the magnetic properties of the samples, especially the domain state aspects of the magnetic mineral grains, were investigated in detail. Before coming to the rock magnetism of the DT, the palaeomagnetic results from some thickest lava sequences may be looked into to draw some essential points.

Table 1 shows the palaeomagnetic directions obtained by different groups for some thick sections of the DT. The mean directions of flows for the different areas have been tabulated against the mean elevation above sea level. The elevation has been rounded off to the nearest ten meters and each flow in a sequence is placed at the nearest 20m interval. Such a simplification is not expected to distort the picture unduly, since the average thickness of the lavas in DT is about 20m. The dashes indicate that no sampling could be done at these levels either due to non-availability of suitable outcrops or inaccessibility. Only in the case of Amarkantak/Dindori sequence, the superposition of the flows is not certain, especially between 380 and 680m, as was recorded by Verma *et al* (1973) and the sequence is built up by combining the sections studied by Verma *et al* (1973) and Athavale (1970). In all the sections, a few odd directions shown by some flows have been omitted by the investigators themselves, but some, like the one at 960 m in Amarkantak/Dindori and the ones at 200 and 220 m in the Pavagadh section, have been retained. This was done by both Indian and foreign scientists and the details of these can be found in the original papers. The essential point emerging from this data is that the scatter in the directions is much larger than expected. Sahasrabudhe (1965) was the first to comment on this aspect, soon after he studied the Mahabaleshwar section. Kono *et al* (1972) re-investigating the Mahabaleshwar section and subjecting the data to

Table 1. Palaeomagnetic directions for flows in a few thick sections of Deccan traps.

Elevation above MSL (m)	Amarakantak/ Dindori		Girinar		Pavagadh		Kalsubai		Mahaba- leshwar	
	D	I	D	I	D	I	D	I	D	I
1620							132	67		
1580							160	61		
1540							137	47		
1480							168	67		
1380							250	24		
1320							141	51		
1240							91	24		
1220							151	72		
1200							148	77		
1160							154	71		
1100							158	71	338	-33
1080							—	—	349	-48
1000	326	-38					149	50	—	—
980	328	-31					153	56	338	-54
960	47	36					—	—	—	—
940	220	53					184	30	—	—
920	155	35					—	—	352	-39
900	162	51					—	—	—	—
880	149	50					163	57	—	—
860	151	56					—	—	—	—
840	138	43					139	60	—	—
820	321	35					141	10	353	-47
800	143	38					165	50	—	—
780	—	—			344	-24	148	51	—	—
760	—	—	337	-35	333	-35	114	82	—	—
740	145	43	338	-43	—	—	171	53	284	-74
720	—	—	339	-47	—	—	150	63	—	—
700	144	46	—	—	—	—	114	82	—	—
680	158	49	343	-29	335	-43	—	—	298	-71
660	—	—	350	-27	334	-28	—	—	—	—
640	163	68	—	—	—	—	119	13	—	—
620	—	—	349	-44	—	—	—	—	140	57
600	345	-29	—	—	—	—	—	—	136	59
580	338	-35	—	—	334	-35	—	—	133	53
560	338	-41	—	—	342	-42	—	—	151	48
540	161	53	—	—	331	-36	—	—	166	45
520	152	42	340	-35	324	-43	—	—	175	66
500	166	53	—	—	337	-63	—	—	158	29
480	159	38	—	—	320	-21	163	45	—	—
460	338	-13	335	-42	348	-50	—	—	—	—
440	150	-45	—	—	—	—	—	—	182	45
420	—	—	—	—	—	—	—	—	159	65
400	—	—	—	—	—	—	120	48	147	28
380	133	62	333	-45	329	-19	—	—	136	62
360	—	—	—	—	329	-44	—	—	—	—

(Continued)

Table 1. (Continued)

Elevation above MSL (m)	Amarakantak/ Dindori		Girinar		Pavagadh		Kalsubai		Mahaba- leshwar	
	D	I	D	I	D	I	D	I	D	I
340	—	—	315	-47	327	-44	215	41	—	—
320	—	—	—	—	—	—	—	—	—	—
300	—	—	323	-37	339	-26	155	51	157	53
280	—	—	—	—	335	-43	151	5	187	60
260	—	—	—	—	—	—	165	48	—	—
240	—	—	—	—	—	—	178	45	159	54
220	—	—	—	—	295	28	161	31	—	—
200	—	—	333	-50	343	23	—	—	—	—
180	—	—	—	—	270	-46	—	—	155	53
160	—	—	—	—	—	—	—	—	—	—
140	—	—	334	-13	224	-29	—	—	—	—
120	—	—	134	47	—	—	—	—	160	29
100	—	—	150	49	—	—	—	—	144	57
80	—	—	—	—	—	—	—	—	147	47
60	—	—	111	64	—	—	—	—	161	36

D—Declination given in degrees measured 0 to 360 east of north.

I—Inclination in degrees, + down, and - up.

elaborate statistical tests stated that the secular variation of the geomagnetic field at the time of Deccan volcanism might have been much greater than the present trend. However, it is doubtful if all such scatter could be attributable to geomagnetic secular variation and not to some changes in the magnetic mineralogy of the samples belonging to some of the flows concerned.

3. Rock magnetism of the Deccan traps

While palaeomagnetic work by several groups in the world progressed rapidly during the period 1948–65, the investigations of the basic magnetic properties of rocks lagged far behind, mainly because suitable instruments and techniques were lacking. When this deficiency was covered up by the TIFR group with the development of simple instruments ideally suited for rock magnetic studies and used extensively on basalts, several unexpected results were obtained (Radhakrishnamurty *et al* 1970). It took another ten years of detailed investigations to get a reasonable understanding of the complex magnetic behaviour of basalts. Even now, it has not become a common practice to investigate and give due weightage to the magnetic properties of rocks in the interpretation of their palaeomagnetic results. However, the TIFR group has been engaged in the study and reporting of the basic properties of basalts despite stiff and unwarranted opposition by anonymous referees from other groups. The noteworthy fact is that the results reported by the TIFR group can be checked using the techniques described.

The magnetic properties of any material depend to a large extent on the domain state of grains forming the bulk. The hysteresis behaviour of the three domain states,

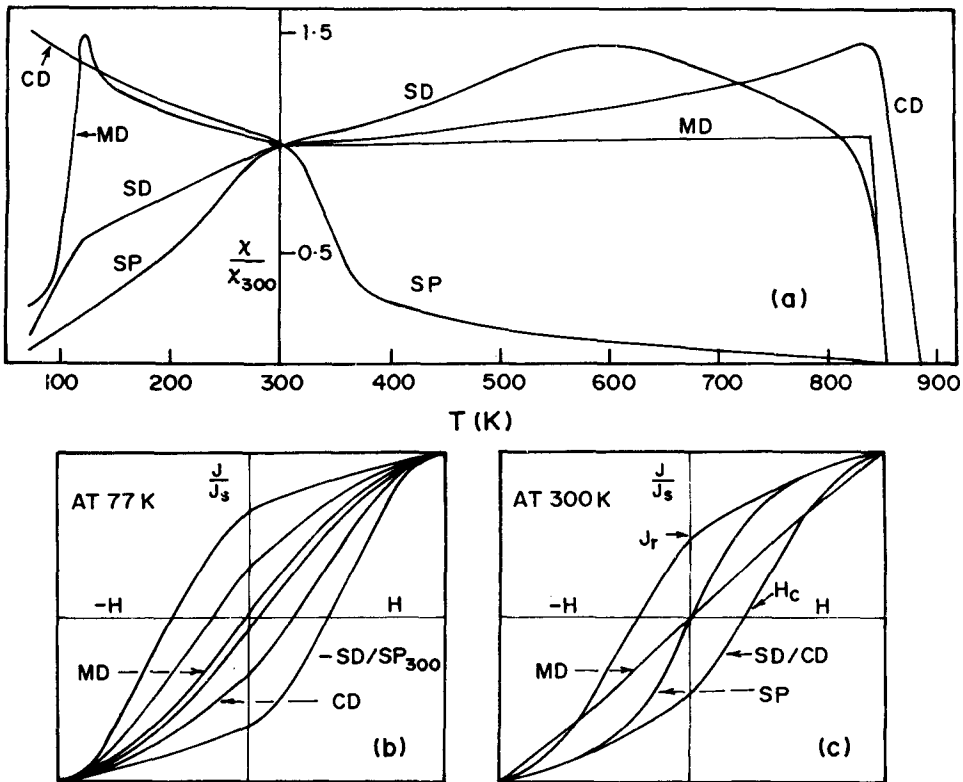


Figure 1. Idealized schematic curves showing thermal variation of susceptibility (a) and hysteresis loops at 77 and 300 K (b and c respectively) for three domain states, multidomain (MD), single-domain (SD) and superparamagnetic (SP), and one cation-deficient (CD) state of magnetite.

multidomain (MD), single-domain (SD) and superparamagnetic (SP), has been described by Bean (1955) and the thermal variation of susceptibility ($\chi - T$) by Radhakrishnamurty *et al* (1982). While these features can be verified easily for synthetic materials and single-phased magnetic minerals, it would be difficult to do so for basalt samples due to the mixed nature of the domain states of the magnetic grains. Additional complications can arise due to the presence of more than one phase of the magnetic mineral grains in basalts. These problems were discussed at length earlier (Radhakrishnamurty *et al* 1981, 1982; Radhakrishnamurty 1985).

The idealized behaviour of the three domain states for pure magnetite and one of its special oxidation states, referred to as cation deficient (CD) state, which is single-domain and having a composition close to $\gamma\text{-Fe}_2\text{O}_3$ but showing anomalous hysteresis and susceptibility variations at low temperatures, is depicted in figure 1. The essential features to be noted are: (i) the characteristic χ -peak for the MD at 120 K, its suppression for SD and the 50% increase in χ at 77 K for CD case (see figure 1a); (ii) the high values of coercive force (H_c) and J_r/J_s for SD/CD, compared to the small or negligible values for MD and SP at 300 K (see figure 1c); (iii) considerable increase in H_c for SD, the SP grains at 300 K behaving like SD at 77 K, and decrease in H_c for CD at 77 K (see figure 1b).

The magnetic minerals in basalts, however, generally belong to the solid solution series known as titanomagnetites ($\text{Fe}_{3-x}\text{Ti}_x\text{O}_4$, $0 < x < 1.0$) and the properties of these were reported earlier (Radhakrishnamurty *et al* 1981, 1982). It is possible that each of these minerals could occur in the three domain states and their higher oxidation states, known as titanomeghemites (O'Reilly and Readman 1971) as well. A rock sample can thus, in principle, show a very complex behaviour depending upon its magnetic grain constitution. However, in practice, it appears impossible to resolve the exact composition and domain states of the magnetic mineral grains, if they are complex mixtures. But some simple schemes to represent the nature of the grains can be resorted to, based on the overall behaviour of a rock sample. Two such schemes have been proposed (Radhakrishnamurty *et al* 1977; Radhakrishnamurty 1985). The presence of certain compositions or domain states, if present in sufficient proportion of the total, can be deciphered quite correctly due to their characteristic features. Thus, the presence of MD magnetite grains can be inferred by observing the susceptibility peak at low temperature (about 120 K). The presence of mineral grains of compositoin like $\text{Fe}_{2.4}\text{Ti}_{0.6}\text{O}_4$ (abbreviated as TM60, the number after TM indicating the atomic percent of Ti present) by the tremendous increase in coercive force (from about 10 mT at 300 K to 80 mT at 77 K) or by a drop in susceptibility (one tenth of the room temperature value at 77 K).

The variation of susceptibility with temperature for some members of the titanomagnetite series is shown in figure 2. The important point to be noted is that the relative susceptibility, χ_{77}/χ_{300} , gradually decreases from 1.3 to 0.1 as the composition changes from TM10 to TM60, apart from the lowering in their Curie temperatures. The change in H_c values for these TMs was depicted elsewhere (Radhakrishnamurty 1985).

The above magnetic granulometry techniques, particularly, the study of low temperature susceptibility variation, have been used to study over 4000 specimems of DT from different localities. Based on the $\chi - T$ behaviour, most of the DT samples

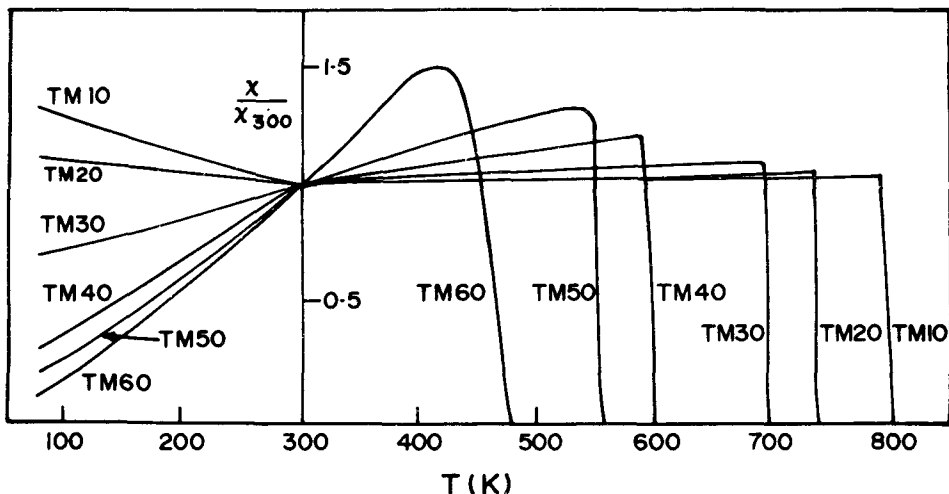


Figure 2. Schematic curves showing thermal variation of susceptibility for some members of the titanomagnetite (TM) series. The number besides TM indicates the atomic percent of Ti in $\text{Fe}_{3-x}\text{Ti}_x\text{O}_4$. (e.g. TM10 = $\text{Fe}_{2.9}\text{Ti}_{0.1}\text{O}_4$).

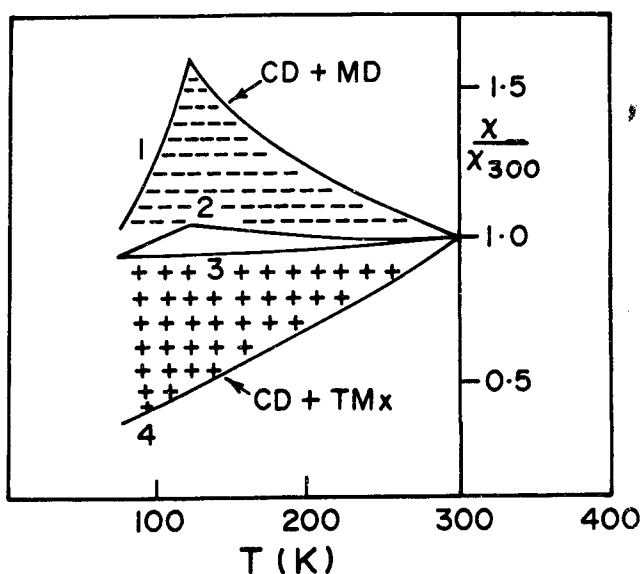


Figure 3. Low-temperature variation of susceptibility observed for some Deccan trap samples. See text for details.

can be divided into two groups, which are bound by curves 1 and 2 and 3 and 4, shown in figure 3. Each of these curves is an outcome of the mixed nature of the magnetic grains. Thus, curves 1 and 2 can be considered as those of a mixture of MD and CD/TM₁₀ (both these show a monotonous increase in susceptibility when cooled to 77 K, though to different extents, see figures 1 and 2), with different proportions of each component, while 3 and 4 could be a mixture of CD and a TM whose composition is not easy to decipher from this study alone. However, the important point emerging from the study of the DT samples is that rarely samples with a single mineral phase are encountered. Kono *et al* (1972) reported the Curie temperatures of samples from different flows at the Mahabaleshwar area, and most of the them showed two Curie points, one low (< 400°C) and one high (> 520°C), which also confirms the idea of mixed nature of magnetic grains in these basalts.

Another important result of this study is that the proportion of samples containing some amount of MD magnetite varies in different localities, so also the stability of NRM of the samples concerned (Subbarao *et al* 1989). In some cases, the NRM direction of some of the samples grossly differs from that of the others in the same flow. This feature indicates that the NRM of some samples, some times even of entire flows, has been changed, possibly by the alteration of the magnetic minerals in them. Also, such alteration seems to have brought about an addition of some MD magnetite, though it is not yet clear how this phenomenon takes place. Efforts are afoot to study this aspect in detail.

4. Discussion of results

Although basalts are best suited for palaeomagnetic studies, they do suffer from certain drawbacks which came to light somewhat late in the development of this

subject. It was soon after noticing the odd behaviour of some samples of DT from the Mahabaleshwar area that the Rock Magnetism group at TIFR concentrated its efforts on the study of the basic magnetic properties of basalts. Some laboratory techniques for ascertaining the suitability of basalts for palaeomagnetism were proposed on empirical grounds (Radhakrishnamurty 1970). Only on the basis of studies in the last ten years, a better understanding of the domain state aspects of the magnetic grains in basalts became possible. In the light of these studies, the following points may be emphasized for a better appreciation of the problems concerning the basalts in general and the Deccan traps in particular.

- (i) Basalts containing a good proportion of single-domain titanomagnetite (TM50 to TM60) can be expected to show highly stable palaeomagnetic directions. Many such samples were encountered in the Rajmahal traps and for fewer in the Deccan traps (Radhakrishnamurty 1985).
- (ii) Cation-deficient (CD) magnetite, when present in sufficient proportion in a basalt sample, can impart good stability of NRM to the sample concerned and such samples are well suited even for palaeointensity work (Radhakrishnamurty 1986).
- (iii) Basalts in general contain magnetic grains in mixed domain states and compositions and hence not only are their magnetic properties complex but deciphering the proportions of individual states is difficult.
- (iv) The presence of multidomain (MD) magnetite grains can be inferred from an observation of the susceptibility peak at about 120 K for the samples. MD seems to be a later addition due to alteration in most cases of younger basalts (less than Cretaceous age) and hence considered as a contamination. It also affects the NRM directions of the samples (Subbarao *et al* 1989). MD magnetite is a predominant component in Precambrian basalts (Radhakrishnamurty *et al* 1978).
- (v) Among the Deccan trap flows of different regions, the proportion of the samples showing MD contamination as also the overall stability of their NRM vary (Sreenivasa Rao 1984; Ramasubba Reddy 1985).

In the light of the above points, a comparative study of the Rajmahal and Deccan traps revealed that whereas MD was undetectable in the former, it was present in 50% of the samples in the latter in the Mahabaleshwar area (Radhakrishnamurty 1985). Whereas a significant mean direction could be obtained from each site (or flow?) of Rajmahal traps from which samples were collected (Radhakrishnamurty 1963), the same could not be done for at least six out of 28 flows sampled at Mahabaleshwar even after subjecting them to cleaning techniques and these had to be disregarded (Kono *et al* 1972). The high scatter in the final mean directions of the flows of DT at any locality is not entirely due to the large secular variation of the geomagnetic field during the formation of these traps as proposed by Kono *et al* (1972). It is clear from the extensive rock magnetic studies carried out on DT at TIFR and IIT that the magnetic minerals in the traps might have been altered to a lesser or greater degree and this would have affected the NRM directions slightly or greatly as the case may be. It is possibly because of such an effect that no correlation between any two sections of flows could be deciphered from their NRM directions (see table 1), other than the zone of complete reversal. Obviously, it seems improper to attribute the irregular variation of the NRM directions observed in a flow sequence of DT to the secular variation of the geomagnetic field. Fortuitously, however, when the sampling is large enough, Deccan traps may show the same overall mean direction

of magnetization, especially when all the odd directions are omitted which necessarily is a must in the palaeomagnetic method. This could account for the tally of final results of DT obtained by different investigators. When a few samples in a flow show near N polarity among others showing R polarity, it seems prudent to leave such samples as altered and non-representative, rather than considering the flow as of N polarity in which case a short-term geomagnetic field reversal would have to be proposed. As short-term reversals during the period of DT formation was unlikely, according to any of the polarity time scale (e.g. Lowrie and Alvarez 1981), such indications, e.g. those reported by Pal *et al* (1971), may best be considered either as spurious or due to step-faulting (Dhandapani 1988).

Finally, the problems like duration of Deccan volcanism and whether any movement of the Indian landmass could be inferred from the palaeomagnetic directions of the lowest and upper most flows, seem to have been interlinked with the subtle alteration of the magnetic minerals. These must await a thorough study of this aspect for their solution. Until then, great caution must be exercised in the interpretation of palaeomagnetic results of the Deccan traps from different localities.

5. Conclusions

- (i) It seems possible that the large scatter encountered in the palaeomagnetic directions of the Deccan trap flows could be partly due to some subtle alteration of the magnetic minerals in the samples and the consequent change in the directions of magnetization.
- (ii) The varying amounts of multidomain magnetite present in samples of Deccan traps of different localities may be an outcome of alteration subsequent to formation and this aspect needs a thorough study. Till then, the palaeomagnetic results must be treated with caution.
- (iii) The future work on the Deccan traps must involve a thorough investigation of the magnetic properties of the samples, before their palaeomagnetic directions can be properly interpreted.

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