

# Rock Magnetic properties of Proterozoic mafic dykes from the southern margin of Cuddapah Basin

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## ABSTRACT

Seventeen basic dykes of Proterozoic age intruding the Archaean basement from the southern margin of the Cuddapah Basin were studied from five sites for their magnetic characters. NRM intensity ( $J_n$ ) of the dykes range between 1793 and  $57 \times 10^{-3} \text{ Am}^{-1}$  while magnetic susceptibility ( $\chi$ ) ranges from 31 to  $303 \times 10^{-6}$  CGS units. Koenigsberger's ratio ( $Q_n$ ) varies from 1 to 55 for most of the specimens. All the above parameters are indicative of retaining the original magnetization in most of the dykes sampled. Based on the above mentioned rock magnetic properties along with hysteresis studies and low temperature (-196°C) magnetic studies, it is inferred that the main magnetic carrier in these dykes is magnetite in multi domain and mixed domain states. Dykes from Tirupati area seems to be magnetically altered.

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## INTRODUCTION

Dykes intruding into the Archaean metamorphic basement in southern India have been studied palaeomagnetically and petrologically from many areas.

However there have been only a few attempts on the magnetic study of the dykes intruding into the basement granites around the Cuddapah Basin. The earliest attempt was by Anjanappa (1972) who reported stable directions from three dykes and interpreted them to be emplaced at the end of Archaean Era.

From palaeomagnetic study of dykes from the SW margin of the Cuddapah Basin, Kumar & Bhalla (1983) concluded that they are older than the Cuddapah Formations. Reviewing the available data on the dykes, they suggested that there were at least three episodes of igneous activity. Based on the tectonic, petrochemical and geophysical studies of the dykes within 20 to 50 km around the margin of the Cuddapah Basin Murthy et al., (1987) suggested that there were at least five sequences of dyke emplacement between 2100 and 600 Ma. Further they suggested that the oldest dyke groups are oriented N-S, E-W and WNW to NW and that they are all tholeiitic and older than 1700 Ma. The remaining dyke groups are oriented WNW to NW, NNE to ENE and N-S and found to be either tholeiitic or alkaline with possible ages of 1700 to 600 Ma. In the present work rockmagnetic properties of the Proterozoic mafic dykes from the southern margin of the Cuddapah Basin were reported.

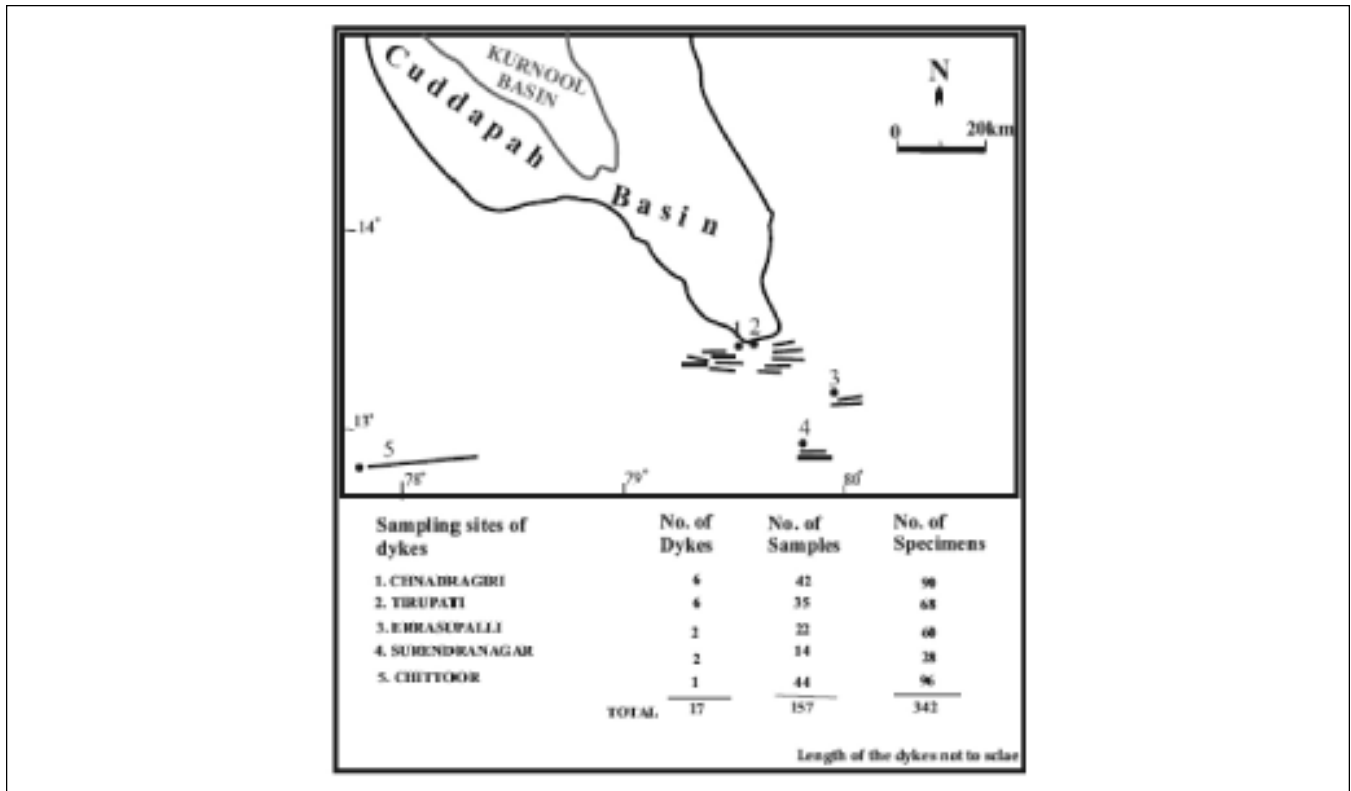
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## GEOLOGY & FIELD CHARACTERISTICS

Geologically the area consists of granites and granite gneisses of Archaean age (Murthy et al., 1987). These granites are of coarse grained and show equigranular texture. There are innumerable dyke swarms and isolated dykes in the study area. These dykes intrude into the granites and granite gneisses which form the basement to the Cuddapah Group of formations. The dykes occur as prominent outcrops, which run nearly in E-W direction. All of them are parallel or nearly parallel to each other. The width of the dykes ranges from few centimeters to about hundred meters with varying lengths. All the dykes have a sharp contact with the country rock. Generally they are doleritic and tholeiitic in character. The grain size varies from medium to coarse grained. They are distinctly dark in colour suggesting their mafic nature. Fresh exposures are available for collection of oriented samples due to quarrying of some of the dykes for dimensional stone.

## Sampling

A total number of 157 oriented block samples from 17 dykes intruding into the basement granite at the southern margin of the Cuddapah Basin are collected from five sites namely Chandragiri, Tirupati, Errasupalli, Surendranagar and Chittoor (Fig.1) within 50 to 70 km radius around Tirupati. These areas are selected due to availability of dyke swarms and good



**Figure 1.** Location map of the sampling sites of the dykes from the southern margin of the Cuddapah Basin.

exposures as shown in Fig.1 of Murthy (1995). All the collected dykes nearly trend in E-W direction with steep vertical inclinations. A minimum of five samples from each dyke is collected. Sampling details are given as an inset table in Fig. 1.

**METHODS OF STUDY**

342 cylindrical specimens are drilled out from 157 samples and are subjected to rockmagnetic studies including NRM intensity ( $J_n$ ), Koenigsberger ( $Q_n$ ) ratio, Susceptibility ( $\chi$ ), relative susceptibility (RS), Hysteresis and Isothermal Remanent Magnetization (IRM). For the measurement of  $J_n$ , Spinner magnetometer of Molspin make is used while for the susceptibility measurements a susceptibility apparatus developed by Likhite & Radhakrishnamurty (1965) and Bartington Susceptibility apparatus (MS2) are used.  $Q_n$  ratio, which is the ratio of remanent intensity to the induced intensity, is calculated from the measured  $J_n$  values of the dykes. IRM studies have been carried out on representative specimens using pulsed field magnetometer, of Molspin make, to identify the magnetic carriers. Besides, Lowrie -Fuller (L-F) test is carried out on representative specimens to understand the domain character.

**RESULTS AND DISCUSSION**

**NRM intensity ( $J_n$ ):**

The remanant magnetic intensity ( $J_n$ ) of the specimens shows a large variation and ranges from  $1793 \times 10^{-3}$  to  $57 \times 10^{-3} \text{ Am}^{-1}$  (Table 1). By and large, the specimens show a strong magnetization indicating that they have retained their magnetization. Some of these dykes have shown low intensity suggesting that they have lost their original magnetization. Few others show very high value of  $J_n$  which can be attributed to the lightning strikes or thunderbolts.

Representative samples from each site are subjected to thermal demagnetization and the results are presented in Fig. 2. Most of the specimens lost their magnetization around  $600^\circ\text{C}$  except the samples from Tirupati area. This indicates that the main magnetic mineral carrying remanence in these samples is magnetite as they lost intensity around  $600^\circ\text{C}$ , which is close to the Curie temperature of Magnetite ( $580^\circ\text{C}$ ). Samples from Tirupati area lost their magnetization near  $350^\circ\text{C}$  and picked up some intensity in further temperature steps (Fig. 2). The loss of intensity around  $350^\circ\text{C}$  can be ascribed to the presence of either pyrrhotite or greigite (iron sulfides) in these rocks as the Curie temperature of these

minerals is 320°C and 330°C respectively. Pyrrhotite is a reasonably common accessory mineral in rocks especially igneous rocks, where as greigite occur in sediments formed under anoxic conditions (McFadden & McElhinny 2000). Therefore, in this case pyrrhotite seems to be the carrier of magnetization. However, variations in titanomagnetite content will also

produce the same result. At relatively high temperatures pyrrhotite transforms irreversibly to magnetite. Increase in intensity at higher temperatures, as mentioned above, is probably due to alteration of magnetic minerals in these rocks. This alteration is reflected in IRM and L-F studies also (Figs. 5b and 6c)

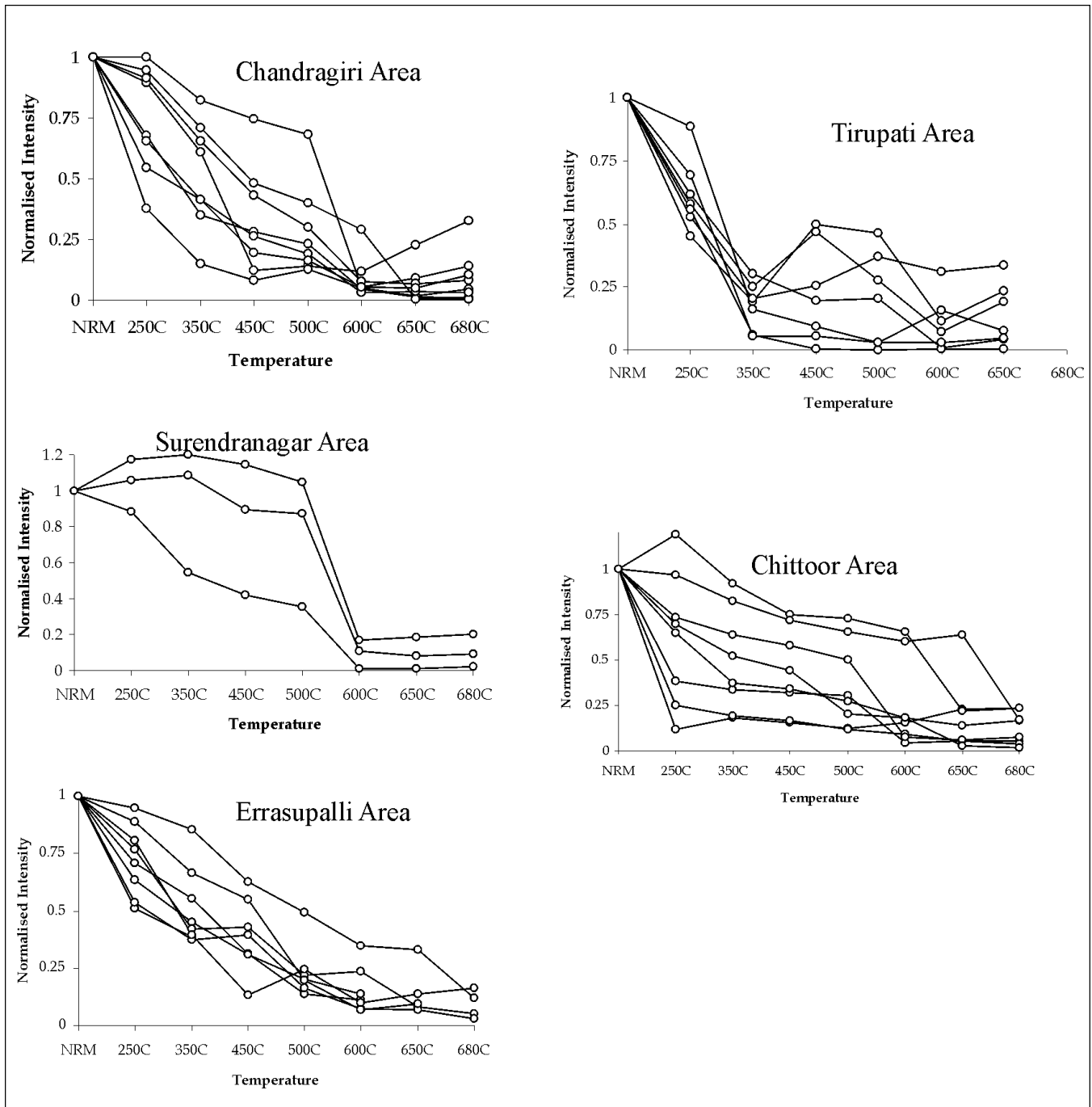


Figure 2. Intensity decay curves of the dykes.

**Table 1.** Table showing rockmagnetic properties of dykes sampled. All the values shown are average values of the dykes.

Dyke No.	NRM $J_n$ ( $\times 10^{-3}$ )	$Q_n$	$\chi$ ( $\times 10^{-6}$ ) cgs units	RS ( $\chi_{-196}/\chi_{25}$ )
D1	257	1.3	131	0.56
D2	170	10.3	32	0.7
D3	445	2.03	118	0.54
D4	388	4.84	289	0.56
D5	552	3.9	225	0.56
D6	866	1.6	303	0.7
D7	753	5.6	248	0.51
D8	321	2.8	31	0.58
D9	350	3.8	353	0.58
D10	188	14.8	276	0.51
D11	109	1.9	94.8	0.52
D12	57	1.38	320	0.53
D13	362	3.8	247	0.47
D14	72	1.3	110	0.61
D15	590	2.6	117	0.52
D16	155	2.2	280	0.9
D17	1793	9.8	204	0.7

$Q_n$  = Koenigsberger Ratio,  $J_n$  =NRM Intensity,  $\chi$ =Susceptibility, RS = Relative Susceptibility

**Susceptibility ( $\chi$ )**

Magnetic susceptibility of the specimens also varies over a wide range between  $31 \times 10^{-6}$  and  $325 \times 10^{-6}$  CGS units (Table 1). Samples are studied for susceptibility at room temperature initially. Then the specimens are immersed in the liquid nitrogen to attain a temperature of  $-196^\circ\text{C}$  and susceptibility at this temperature is measured. The relative proportions of magnetic domains such as multi-domain (MD) and single domain (SD) fraction in magnetite can be evaluated from the difference between the ratios of susceptibility at  $-196^\circ\text{C}$  and  $-150^\circ\text{C}$  to the susceptibility at room temperature (Thomas 1993). According to Radhakrishnamurty (1993) pure MD grains of magnetite can be identified by the presence of a sharp peak of  $\chi$  at  $-150^\circ\text{C}$ . Samples with dominantly SD grains which may be titanomagnetite with 60%  $\text{TiO}_2$  will have RS ( $\chi_{-196}/\chi_{25}$ ) values around 0.4 with high coercive force and Relative remanence ( $J_r/J_s$ ) of about 0.5.

A close scrutiny of the data indicates that large number of specimens shows a peak at  $-150^\circ\text{C}$  while warming up to the room temperature and show RS value ( $\chi_{-196}/\chi_{25}$ ) of about 0.5 (Fig 3 & Table 1). These characters are typical of multi domain (MD) magnetite, which generally results in unstable magnetization in very old rocks. Those specimens with no peak but with high RS values of more than 1 are suggestive of a mixed domain character (Radhakrishnamurty 1993).

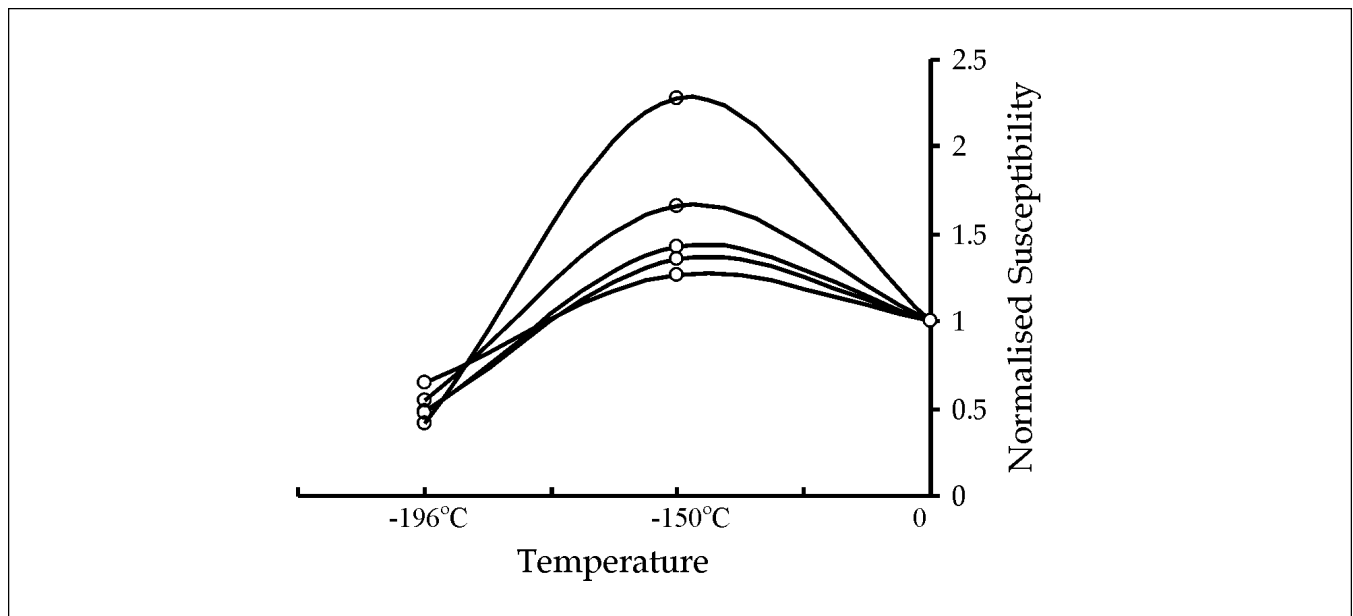


Figure 3. Representative susceptibility variation curves with temperature for dyke samples.

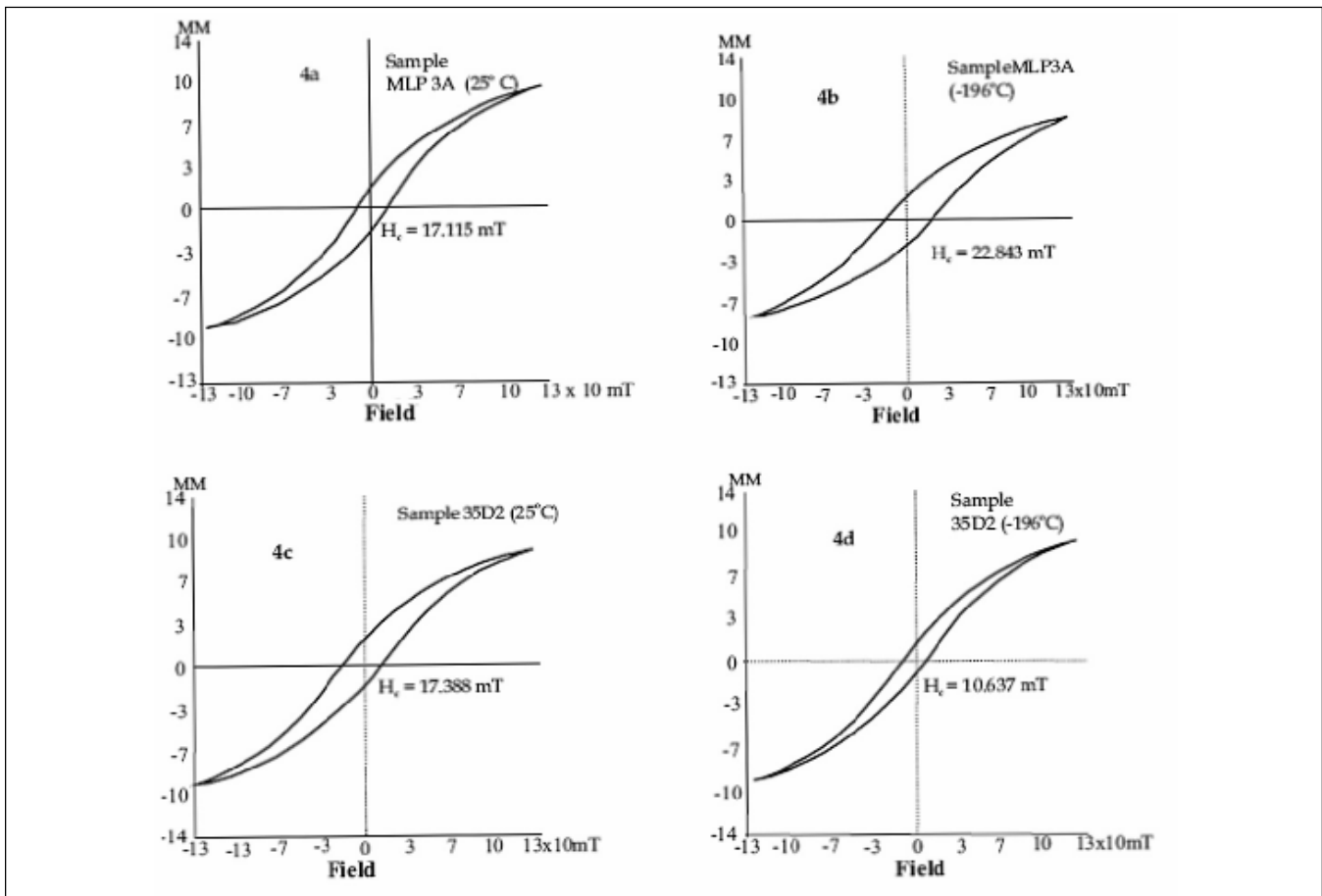
### Koenigsberger's ratio ( $Q_n$ )

Koenigsberger's ratio ( $Q_n$ ), which is the ratio of NRM intensity and induced intensity, is calculated from the  $J_n$  values. In Table 1 the average  $Q_n$  values for each dyke are presented. The large number of specimens, when taken individually, show  $Q_n$  ratio between 1 and 55 forming 71% of the total number of specimens. Specimens with lower  $Q_n$  ratio of less than 1 are suggestive of some loss of original magnetization in the specimens. Such specimens constitute 28 percent of the total number of specimens. There are only 2 specimens with  $Q_n$  ratio between 55 and 250. These two specimens are not included for averaging out  $Q_n$  ratio. This distribution of  $Q_n$  ratio (between 1 and 55) in large number of specimens is suggestive of retaining of the original magnetization in most of the dykes. In general, for dolerite the  $Q_n$  ratio ranges from 2 to 3.5 (Sharma 1986) and for an igneous rock on an average it lies between 1 and 40 (Carmichael 1989). It is generally considered that a value of  $Q_n > 1$  indicates the presence of

stable directions in the specimens, although very high values may indicate the effect of lightning strikes (Radhakrishnamurty 1966).

### Hysteresis

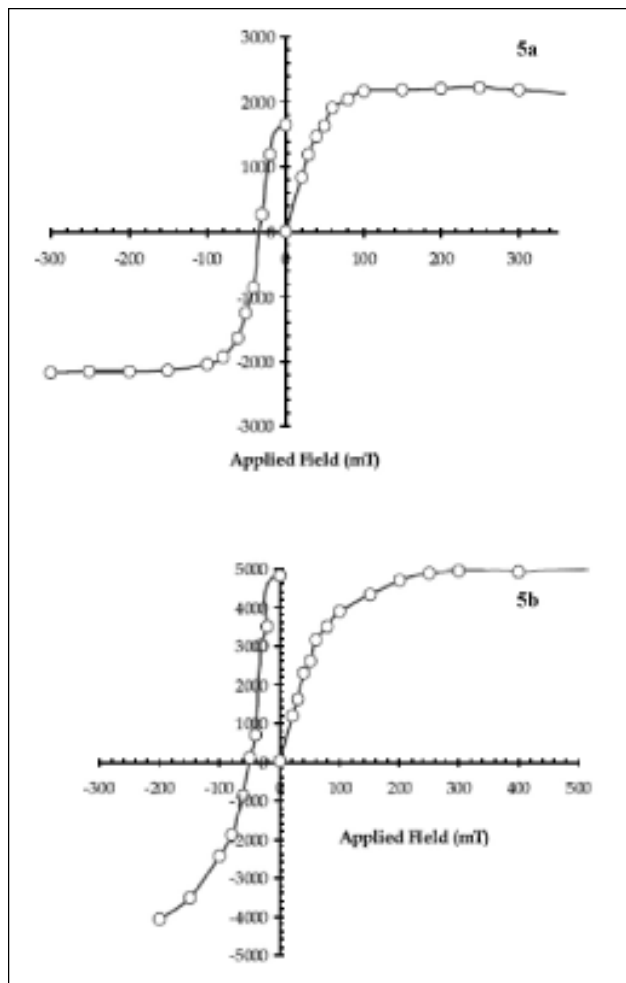
Representative samples of different dykes are studied for hysteresis loop at room temperature (25°C) and at low temperature (-196°C) by applying high field (130 mT). Two types of hysteresis behaviour have been noticed. One type shows increase in Coercive force ( $H_c$ ) at -196°C compared to that of room temperature. It can be noticed from Fig 4a that the  $H_c$  is 17.115 mT at room temperature (25°C) where as Fig.4b shows an increased  $H_c$  of 22.843 mT when cooled to -196°C. The other kind is opposite to the previous case which shows  $H_c$  of 17.388 mT and 10.637 mT at room temperature and liquid nitrogen temperature respectively (Figs. 4c & 4d). Former (Fig.4b) is representative of a combination of CD+SD grains while the later (Fig. 4d) characterizes the presences of SD+MD grains (Radhakrishnamurty 1990).



**Figure 4.** Hysteresis loops of representative samples a & c are at room temperature, b & d are at -196°C temperature.  $H_c$ : Coercive force;  $J_r$ : remanent magnetization;  $J_s$ : saturation magnetization.

**Isothermal Remanent Magnetization (IRM) results**

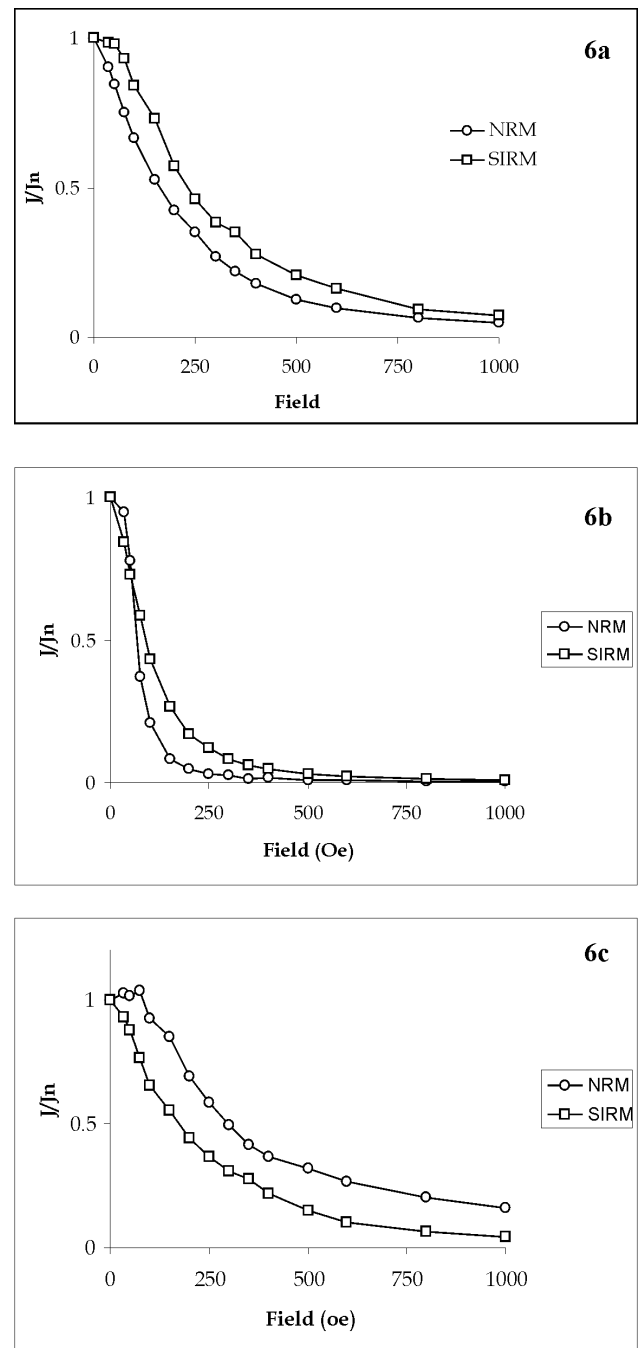
To determine the magnetomineralogy, representative specimens covering all the dykes sampled are subjected to Isothermal Remanent Magnetization (IRM) studies in the magnetic fields of 20, 30, 40, 50, 60, 80, 100, 150, 200, 250, 300, 400, 600, 800 and 1000 mT and the induced magnetization acquired by the specimens is measured after each step of induction. Then the specimens are subjected to opposite field to get the coercivity of remanence ( $J_r$ ). All the specimens seem to saturate around 100 mT and the remanent coercive force ( $H_c$ ) is around 35 mT (Fig 5a) suggesting that the magnetic carrier in these rocks is magnetite. This is true for all the specimens studied except for Tirupati area. In the case of Tirupati dykes  $J_r$  and  $H_c$  are around 5000 mA/m and 35mT respectively and the saturation takes place in relatively higher fields (500mT) indicating the alteration of magnetic minerals in these rocks (Fig 5b).



**Figure 5.** Typical examples of IRM acquisition in dyke samples

**Lowrie – Fuller Test (L-F test)**

To identify the domain character representative samples are subjected to L-F test (Lowrie & Fuller 1971), though this test has its own limitations (Dunlop, Hanes & Buchan 1973, Johnson, Lowrie & Kent 1975, Heider, Dunlop & Soffel 1992). The specimens are first subjected to AF demagnetization



**Figure 6.** Comparison of NRM and SIRM intensity after AF demagnetization.

with increasing peak fields up to 100mT and then Saturated Isothermal Remanence Magnetization (SIRM) at 1T (1 Tesla) is imparted on these specimens and the AF demagnetization is repeated with the similar steps. The response of the NRM intensity to the applied field is compared with that of SIRM intensity. Typical examples are shown in Fig.6. It is revealed from this study that in some specimens, the SIRM intensity is found harder than the NRM intensity indicating multi domain magnetite as the major magnetic mineral carrying the characteristic remanent magnetization in these rocks. In some specimens there found a crossover between the two curves at the beginning. But, the samples from Tirupati area show that the NRM is harder than SIRM indicating the single domain nature (Fig 6c). In general, single domain minerals gives stable magnetic directions. However, this is not resulted in yielding stable direction in case of Tirupati dykes (magnetic directions are reported elsewhere). This is probably due to the alteration of magnetic minerals present in the rock.

## CONCLUSIONS

Rockmagnetic studies like NRM intensity ( $J_n$ ), Koenigsberger ( $Q_n$ ) ratio, Susceptibility ( $\chi$ ), relative susceptibility (RS), Hysteresis and IRM studies on the dykes under study collectively reveal that most of the dykes from the southern margin of the Cuddapah Basin retain strong magnetization and the main magnetic carrier in these rocks is magnetite which is multidomain and mixed domain in character. The dykes from Tirupati seem to be altered magnetically as the intensity decay curves and IRM studies and other rockmagnetic studies reveal.

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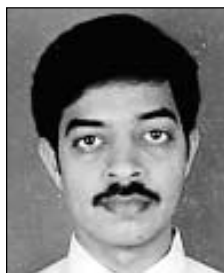
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