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Rock magnetic and Palaeomagnetic Study of the Archaean Granites from Hyderabad, India

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ABSTRACT
Samples from Hyderabad granitic region are studied for their rock magnetic and palaeomagnetic behaviour. There are considerable differences between the pink and gery granites in the rock magnetic properties such as Intensity of natural remanent magnetization (J_n), magnetic susceptibility (χ) and Koenigsberger's ratios (Q_n) and indicates that these granites are of two different origins. Average values of NRM intensity, χ and Q_n are found to be 488 and 637 Am^{-1}; 1689 and 1780; and 9 and 19.7 for pink and gray granites respectively. Two different mean palaeomagnetic directions were obtained for these rocks after af demagnetization which are D/I = $159^o/-25^o$ and $268^o/-40^o$. The corresponding palaeomagnetic poles lie at 69S/160E and 8S/327E respectively. Based on the statistics former direction $159^o/-25^o$ is considered as the palaeomagnetic direction of Hyderabad granitic region.

INTRODUCTION

Though the Precambrian palaeomagnetic results from India are not convincing to draw conclusions about geodynamics, these studies are however useful for geological applications and in pointing out directions for future palaeomagnetic research. In Peninsular India the rocks suitable for palaeomagnetic studies are available in the form of sedimentary basins and mafic dykes intruding the Archaean metamorphic basement. Palaeomagnetic investigations on the sedimentary formations of different basins and the mafic dykes are already in progress in the country. On the other hand, Palaeomagnetic research on the acid igneous rocks such as granite of older age is very scanty anywhere in the world. This is because of their complex geological nature, their longtime exposure to high grade metamorphism and weathering as well as the antiquity in terms of geological age. In the present study an attempt has been made to understand the rockmagnetic and palaeomagnetic behaviour of the Archaean granite samples of part of the Hyderabad granitic region (HGR) to evaluate their magnetic properties as a pilot work for future research.

GEOLOGICAL SETUP

The Hyderabad granitic region (HGR) forms part of the Eastern Dharwar Craton (EDC) of southern India and is covered by unclassified granites and granite gneisses of Achaean age (Crawford 1969), which are locally classified into numerous varieties. Sitaramayya (1971) classified the rocks of the study area into three main varieties like pink, grey and leuco-granites besides the presence of pyroxene bearing granodiorites and charnockite assemblages at places. Plagioclase feldspar is predominant along with mafic minerals in grey granite while potash feldspar is main mineral in pink granites. Pink granites show relatively low magnetic response compared to grey granite indicating the presence of more ferromagnesian minerals in grey granite (Madhusudhan Rao et al. 2002). Within the grey variety the color ranges from grey to grayish pink. According to Balakrishna (1964) pink granite is derivative of metasomatism of potash feldspar from grey granite. Similar conclusion was drawn by Kanungo et al., (1975) stating that the pink granite has formed due to feldspathization of the grey granite. Grey granite is predominant variety in the sampling area. The grain size ranges from medium to coarse grained and at places fine grained nature observed in grey granite and display, in general, equigranular to porphyritic texture. The boundary between grey and pink granite is transitory and gradational in both lateral and in vertical directions, the origin being the same for both the rock types (Madhusudhan Rao et al., 2002). However, supergene alterations (interaction between meteoric or groundwater and rocks) commonly lead to a change in rock color from white-gray to pinkish or reddish (Tarling & Hrouda 1993). Alteration by late magmatic or hydrothermal fluids can also affect the primary magmatic mineral assemblage and result in formation of more oxidized iron oxides. Besides the above mentioned reasons, constant exposure to weathering and to tectonic disturbances of these rocks might have caused the change in the physical properties as well as the development of structural features like faults, fractures and joints. Balakrishna, Christopher & Vijaya Raghava (1962) opined that these structural features are responsible for the development of pseudo contacts between pink and grey granites at some places. However, the grey granite is reported (Crawford 1969) to be older than the pink variety and is considered to be equivalent of Closepet granite (2500 Ma).

Epidote veins and veinlets are common secondary minerals found along the weak planes like joints in the study area. Pegmatite and quartz veins are also present in some areas. Several independent works have been employed to get the geological and geophysical picture of the study area. Significant among them are Balakrishna & Raghava Rao (1961), Rambabu, Kameswara Rao & Vijay Kumar (1991). Madhusudhan Rao et al., (2006) have employed magnetic studies to delineate the lithology and subsurface structures in the study area.

Sampling

A total number of 70 oriented block samples from 19 sites are collected from the basement granite from the unweathered portion of the outcrops using Brunton compass. Sampling localities are shown in Fig.1. A minimum of five samples from each site are collected. While collecting the oriented samples care has been taken to see that there is no effect of the ferromagnetic content of the rocks on the magnetic compass.

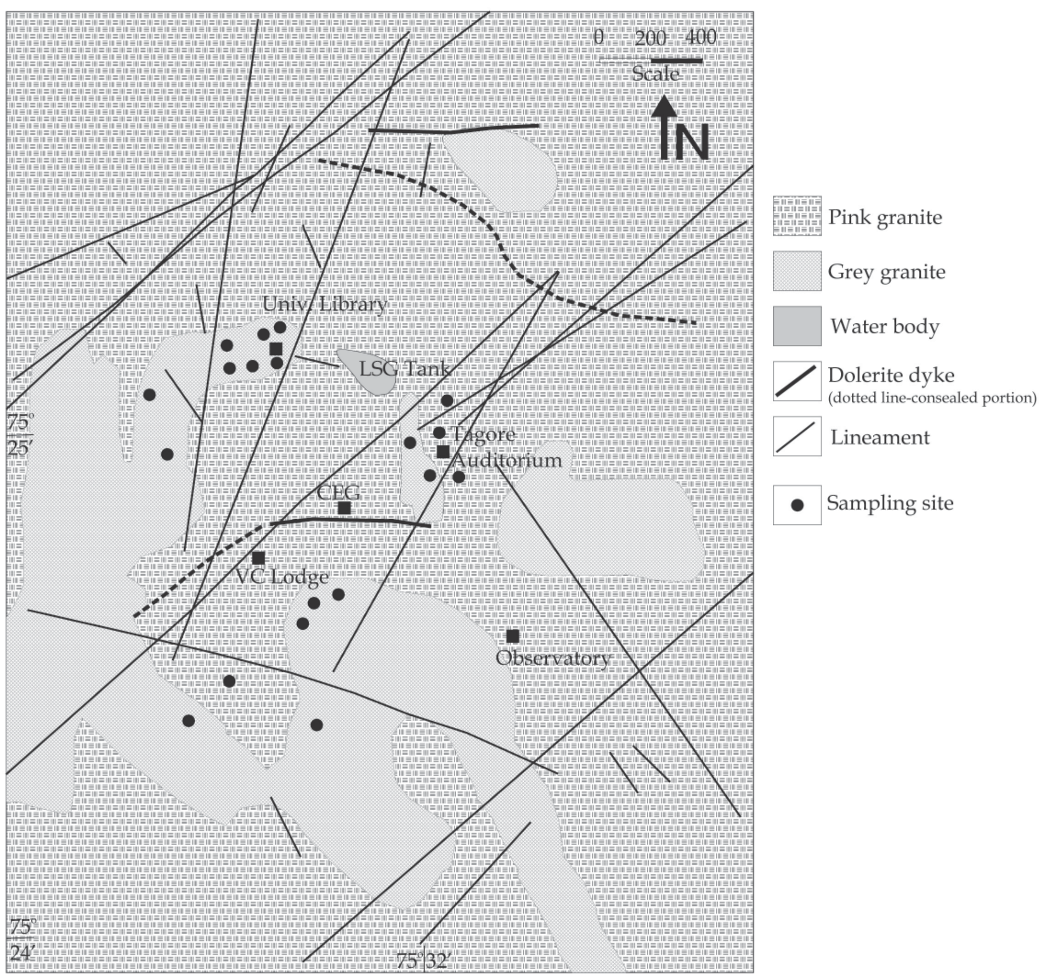

Figure 1. Geological map of the study area with sampling locations

METHODS OF STUDY

Nearly 450 cylindrical specimens of 2.2 cm diameter are obtained from all the collected samples. All the specimens are initially subjected to rockmagnetic studies to verify their suitability for palaeomagnetic studies. These studies include measurement of NRM intensity (J_n), Koenigsberger (Q_n) ratio, Susceptibility (χ) and Isothermal Remanent Magnetization (IRM). NRM measurements are made using spinner magnetometer of Molspin make (UK) while for the susceptibility measurement Bartington Susceptibility apparatus (MS2) is used. Q_n ratio, which is the ratio of remanent intensity to the induced intensity, is calculated from the measured J_n values. Specimens are progressively demagnetized to test the stability of NRM and to isolate Characteristic Remanent Magnetization (ChRM) using a Molspin alternating field (AF) demagnetizer. Results of demagnetization are analyzed using orthogonal vector diagrams (Zijderveld 1963), stereographic projections and normalized intensity plots. Site mean directions are calculated using Fisher (1953) statistics. IRM is imparted on the representative specimens using pulsed field magnetometer of Molspin make, for determination of magnetic carriers and their domain character. .

RESULTS AND DISCUSSION

Rockmagnetism

a) NRM intensity (J_n):
The remanant magnetic intensity (J_n) of the specimens shows a large variation and ranges from 103 to 4613 Am^{-1} with a mean value of 637 Am-$^{-1}$ for grey granites; and from 56 to 2014 Am^{-1} with a mean value of 488 Am^{-1} for pink granites (Table 1). By and large, the specimens show a strong magnetization representing that they have retained their magnetization. Few specimens show very high value of J_n which are out of the sensitivity range of the instrument even at high attenuation. These can be attributed to the lightning strikes or thunderbolts.

b) Susceptibility (χ)
Magnetic susceptibility of the specimens also varies over a wide range between 630x10^{-5} and 6790.5 x10^{-5} SI units with an average value of 1780 x10^{-5} SI units; and from 54 x10^{-5} to 3480 x10^{-5} SI units with an average of 1689 x10^{-5} SI units for grey and pink granites respectively. This distribution shows that grey variety is more magnetic than pink variety.

Globally, the magnetic susceptibility values reported for granites range widely from 10^{-6} SI units in leucocratic granites up to 10^{-1} SI units in some granodiorites and tonalites (e.g., Rochette, Jackson & Aubourg, 1992; Tarling & Hrouda, 1993). However, these values exhibit a bimodal distribution with two distinct values around 10^{-3} to 10^{-2} and 10^{-5} to10^{-4} SI units. The existence these values has lead to the classic definition of ilmenite-series and magnetite-series granites (Ishihara 1977 and Gregorova, Hrouda & Kohut 2003).

As the megascopic appearance reveals, the rocks under investigation consists of diamagnetic minerals, such as quartz and feldspars, paramagnetic minerals, such as hornblende and biotite, and ferrimagnetic mineral magnetite. The contribution of diamagnetic minerals to the magnetic susceptibility is negligible because their intrinsic magnetic susceptibility is small (on the order of –14 x 10^{-6} SI units) compared to that of other minerals (Rochette 1987). Conversely, magnetic susceptibility may change with the grade of metamorphism with depth (Hrouda 1982, Shive, Frost & Peretti 1988). This may be the reason for the wide range of susceptibilities as shown above.

c) Koenigsberger's ratio (Q_n)
Koenigsberger's ratio (Q_n), which is the ratio of NRM intensity and induced intensity, is calculated from the measured J_n values. This distribution of Q_n ratio (2.2

Table 1. Comparison of rockmagnetic properties of pink and grey granites.

Type of granite	NRM (Am^{-1} units)			Susceptibility (SI Units)			Qn ratio		
	Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum	Average
Pink	56	2014	488.5	54	3480	1689.2	0.3	34	8.9
Grey	103	4613	637.3	630	6790.5	1780.4	2.2	343	19.7

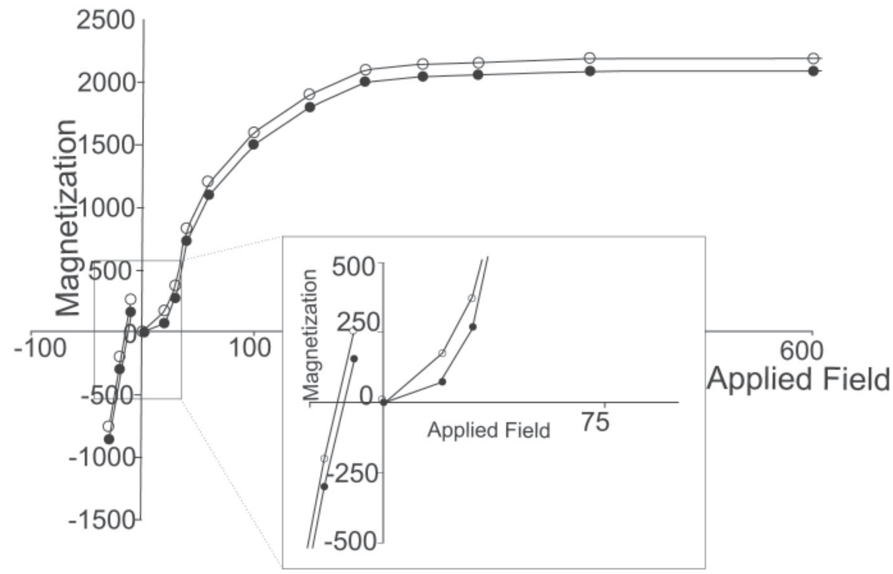

Figure 2 Results of IRM acquisition for representative specimens. Inset: Blown up portion of the curve to show the Coercive force. X and Y axes represents Applied Field in mT and Magnetization in mA/m respectively.

to 343 with an average of 19.7 for grey granites; and 0.3 to 34 with an average of 8.9 for pink granites) in large number of specimens is suggestive of their strong magnetic nature. In general, for granites the Q_n ratio ranges from 0.1 to 28 (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, 1993). However, these high Q_n values failed to yield stable magnetic directions for many of the samples.

d) Isothermal Remanent Magnetization (IRM) results

For the determination of minerals carrying the magnetic remanence in the rocks under study, specimens representing all the sites are subjected to Isothermal Remanent Magnetization (IRM) studies in the increasing forward magnetic fields from 20mT to 1000 mT in different steps and the induced magnetization acquired by the specimens is measured after each step of induction. Then the specimens are subjected to reverse field to get the coercivity of remanence (J_r). All the specimens seem to saturate around 150 mT suggesting magnetite is the carrier of remanence and the remanent coercive force (Hc) is very low (<20)(Fig 2 inset) suggesting the dominant multidomain nature of the samples. This is true for all the specimens studied.

PALAEOMAGNETISM

The palaeomagnetic results of slowly cooled igneous rocks, particularly in plutons (such as in the present study), are complex in nature and its interpretation poses challenges similar to the study of magnetic directions of deeply exposed metamorphic basement (Piper 2007). The analysis and interpretation of such results is influenced mainly by two reasons. Firstly, enormous time involved in the cooling of the rocks which will be far beyond the cycles of secular variation and thereby representing palaeomagnetic record rather than geomagnetic record; secondly, variations in cooling history of the rocks from place to place in giving rise to different magnetic directions and therefore, the analysis should aim at the directional similarity rather than magnetic properties of individual samples (Piper 2007).

A close scrutiny of the results shows that these are samples having with-in sample consistency of direction though there is no with-in site consistency. Therefore, the directions are widely scattered over the equal area projection. As the present study is restricted to limited area, probably, with-in site consistency can be achieved, if more number of samples is collected from each site covering the entire area of the HGR. By and large, the preliminary NRM direction of these granites show reversed magnetization with respect to the present day magnetic field, although there is no grouping in any hemisphere when plotted on an equal area projection-

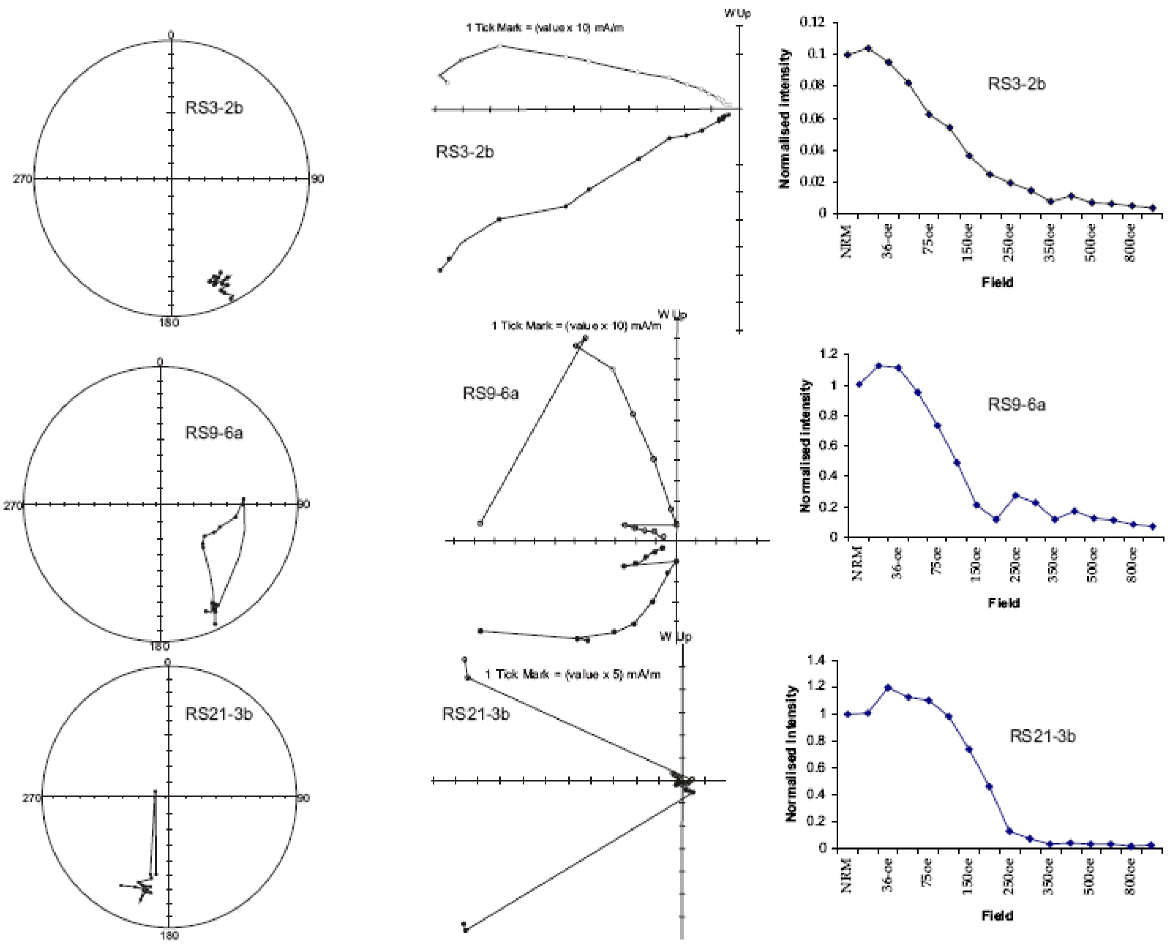

Figure 3. Demagnetization results of the representative specimens.

lower hemisphere. This assumption was made based on the distribution of the specimens in second and third quadrants of the projection with a wide scattering among them. However, to test the stability of the NRM directions AF demagnetization is carried out and the results are shown in Fig. 3 along with Zijderveld diagram, stereo net and the intensity decay curve for representative specimens. Furthermore, thermal demagnetization is not effective in igneous rocks, which will cause the chemical alteration of the sample during heating and therefore not attempted.

A batch of 28 specimens have been selected for AF demagnetization to test the stability of NRM directions in the applied fields of 3.6, 5.0, 7.5, 10, 15, 20, 25, 30, 35, 40, 50, 60, 80 and 100 mT. The results of demagnetization are presented in Table 2 and Fig. 3. It is evident from the intensity decay curves that the intensity has dropped down to minimum around 250 Oe for most of the specimens.

From the demagnetization data, it is observed that 11 sites show consistent mean magnetic direction of D/I = $159^{o}/-25^{o}$ and 4 sites show D/I = $268^{o}/-40^{o}$. The statistical parameters of the above directions are shown in Table 2. Both pink and grey varieties show this distribution and the direction shown here are obtained by combining the directions of both the varieties. The corresponding palaeomagnetic poles for the above directions are calculated to be 69S/160E and 8S/327E respectively. The palaeomagnetic poles obtained for the study area are plotted in the Fig 6 of Poornachandra Rao & Mallikharjuna Rao, (2006) in which poles of some late Archaean Palaeoproterozoic- Mesoproterozoic formations of Indian subcontinent are plotted and is shown in Fig. 4. One of the two poles of the study area plots at the present day south pole while other plots close to the late Archaean BHJ2 which corroborates with its age. However, the direction of $159^{o}/-25^{o}$ seems to be the palaeomagnetic direction of these samples as statistically more number of sites shows this distribution.

Table 2. Mean magnetic direction of the granite samples along with statistical parameters.

S No	NRM		After demag	
	D	I	D	I
1	152.9	-4.5	151.5	-25.2
2	155.6	-4.6	152.1	-20.3
3	134.4	-54.5	185.3	-37.5
4	321.5	44.1	141.6	-9.9
5	149.3	54.9	167.9	-35.2
6	227.5	5	189	-17.6
7	342.3	51.6	147.6	-26.6
8	164.9	-58.2	150.1	-29.7
11	191.1	38.6	150.4	-14.8
D_m= 159, I_m= -25, α_{95}=12, k=20, d_p/d_m=7/13; λ_p/ϕ_p =-69/160				
1	299	0	266	-67
2	281	44	270	-19
3	270	74	277	-56
4	243	18	263	-19
D_m= 268, I_m= -40, α_{95}=30, k=10, d_p/d_m=22/36; λ_p/ϕ_p =-8/327				

Dm=Mean Declination, Im=Mean Inclination, α_{95}=radius of circle of confidence, dp/dm=semi major and minoe ellipse of confidence respectively; $\lambda p/\phi p$=latitude and longitude of palaeomagnetic pole

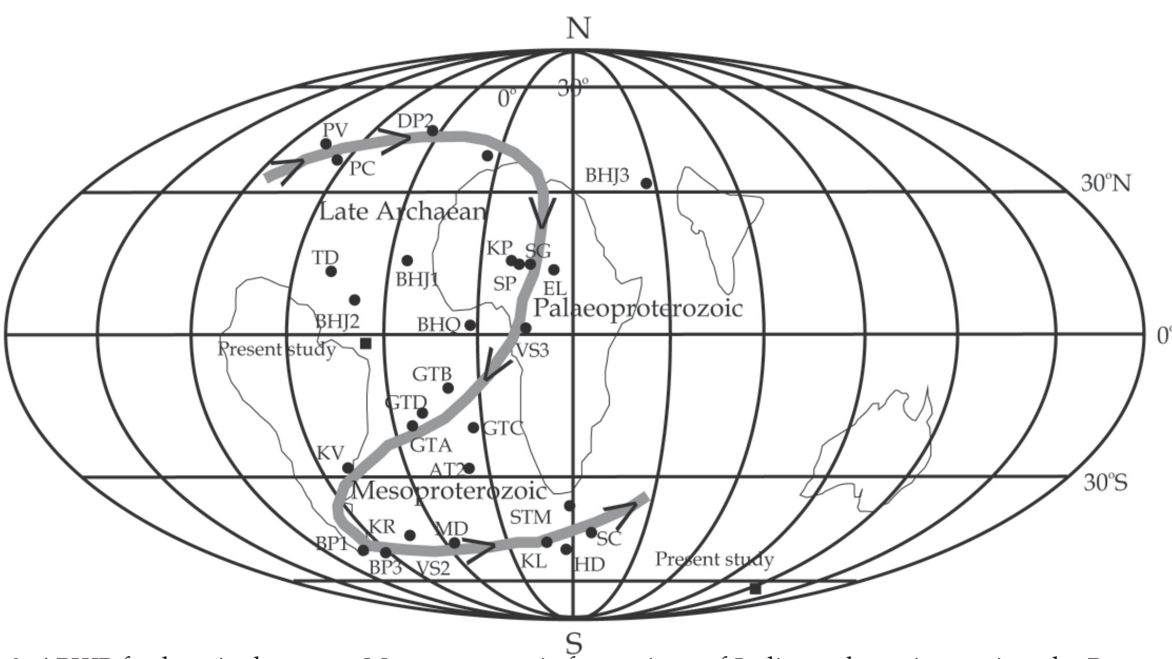

Figure 4. APWP for late Archaean to Mesoproterozoic formations of Indian subcontinent given by Poornachandra Rao & Mallikharjuna Rao (2006) on which poles of the present study are plotted. For legend and data see Poornachandra Rao & Mallikharjuna Rao (2006).

CONCLUSIONS

The palaeomagnetic investigations on the part of the HGR along with magnetic stability tests yield a reversed magnetization direction compared to the present day magnetic direction. However, the results reported here are from the samples restricted to the limited area of the HGR and based on only AF demagnetization, Though two directions are obtained, we consider that the D/I = 164/-23 is the direction for the rock under study. The wide range of rockmagnetic properties shown by these rocks may be the expression of the grade of metamorphism to which they are exposed. The magnetic mineralogy of the granites on the study area is dominated by multi domain magnetite as the IRM study indicates. These directions may be improved a lot by carrying out a detailed sampling of the entire region and by applying comprehensive magnetic stability tests.

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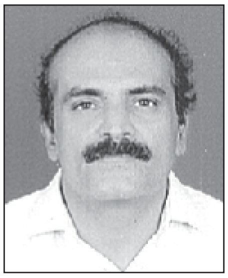

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