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Rock magnetism and palaeomagnetism of the Oddanchatram orthosite, Tamil Nadu, South India

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SUMMARY

Rock magnetic and palaeomagnetic data are reported on the Proterozoic massif-type anorthosite body from Oddanchatram, on the northern slopes of the Kodaikanal (Palani) Ranges, Tamil Nadu. Alternating field demagnetization treatment indicated a very stable direction of magnetization. Progressive heating revealed a remanence that became unblocked at 580°C. The demagnetization analysis yields a characteristic component with a mean direction: $D_m = 97.3°$ $\mathrm{Im} = -28.8°$ ($k = 51, \alpha_{95} = 7.2°$ and $N = 9$ sites). In addition to this characteristic component, specimens from a few sites show the presence of a low coercivity component with a mean palaeomagnetic direction of $D = 36.7°$; $I = -29.4°$ ($k = 63, \alpha_{95} = 4.4°$ and $N = 18$). The isothermal remanent magnetization acquisition curves indicate magnetite as the main carrier of the stable remanence. The direction of the characteristic component corresponds to a pole position at 9.7°N, 1.7°E ($d_p = 4.4°, d_m = 7.9°$). The location of this pole is comparable to palaeomagnetic poles reported for the period of 1100–1000 Ma for a range of formations from the Indian shield. The pole for the secondary component (45°S, 23°E) fits well with poles for 550 Ma, associated with the Pan-African thermal event that extensively caused granulite grade metamorphism in the Southern Granulite Terrain. Despite the high temperature (>700 °C) that prevailed during the Pan-African event, the remanence magnetization of 1100–1000 Ma is preserved in the Oddanchatram anorthosite. It is inferred that the northern boundary of the terrain affected by the dominant 550 Ma granulitic metamorphism lies close to the southern margin of the Oddanchatram anorthosite body. Thus Oddanchatram anorthosite escaped the high temperatures metamorphism. The weak secondary magnetization found in a few specimens is attributed to hydrothermal activity associated with the intrusion of pink granites, immediately south of the Oddanchatram anorthosite body. A mid-Proterozoic magnetization age of the Oddanchatram anorthosite supports the view that this body was emplaced/remobilized during the Eastern Ghat Orogeny (~1000 Ma) and this body can be seen as a western extension of the string of massif-type anorthosites in the Eastern Ghat Mobile Belt.

Key words: Eastern Ghat Mobile Belt, Oddanchatram anorthosite, Palaeomagnetism, Pan-African thermal event, rock magnetism, Southern Granulite Terrain (SGT).

1 INTRODUCTION

In order to study the magnetic properties of the lower crust, the authors selected the Kodaikanal Ranges that expose granulitic facies lithologies dominated by charnockitic rocks with enclaves of meta-sedimentary lithologies and associated igneous plutons, such as anorthosite and syenite bodies. The rocks underwent high-grade granulite metamorphism at pressures of 7–10 Kbars and temperatures of 700–1000 °C, conditions typical for continental middle–lower crust (Janardhan 1998). The dominant charnockitic anhydrous rocks, with a density of 2.9 g cc^{-1}, point to their lower continental crustal origin (Janardhan 1999). The exhumed sections of lower crust permitted us to study their physical properties. Various rock types such as charnockites, cordierite-bearing pelitic gneisses and pink granites were collected but only the anorthosite pluton appeared to be suitable for palaeomagnetic research. Rock magnetic and palaeomagnetic results are reported for the Oddanchatram anorthosites exposed in the Palani Hills, on the northern slopes of the eastern Kodaikanal Ranges (Fig. 1a). Here, an anorthosite body occurs in the vicinity of the small township of Oddanchatram (Fig. 2). Palaeomagnetic studies of anorthosite rocks are important because the remanence direction in the massif-type anorthosites from different parts of the world have played a key role in the Proterozoic continental reconstructions (Piper 1974, 1976, and references therein).

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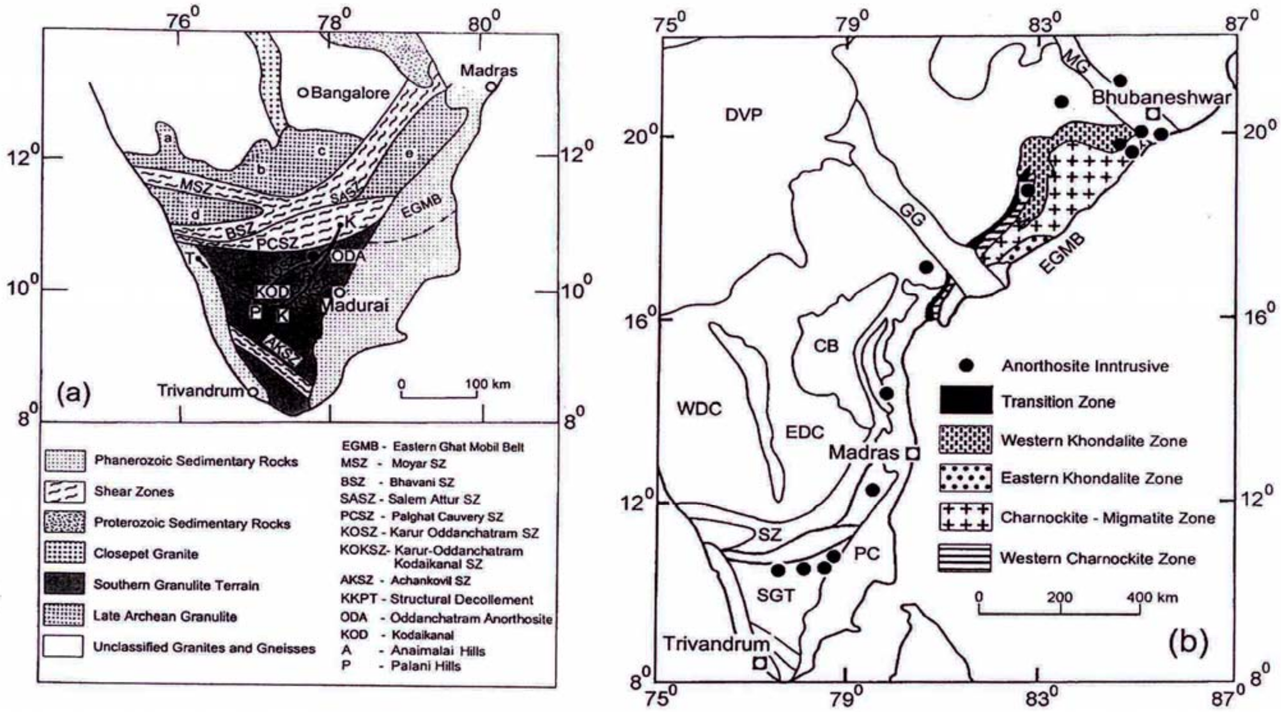


Figure 1. (a) A generalized map showing the geology and structural elements of peninsular India (redrawn from Drury *et al.* 1984; Valdiya 2002; Bhaskar Rao *et al.* 2003). The location of the Oddanchatram anorthosite body (filled circle) in relation to the various shear zones (PCSZ, KOSZ, KOKSZ) is also marked. (a)–(e) denote the granulite terrains referred to in the text: (a) Coorg, (b) Biligirirangan, (c) Shevaroys, (d) Nilgiri and (e) Madras. KKPT denotes the structural decollement passing through Karur, Kambam, Painavu and Trichur (Ghosh *et al.* 1998). (b) A map showing the location of various anorthosite bodies along the EGMB and south of the PCSZ (De 1969; Kanungo & Chetty 1978) in the major geological/tectonic blocks of South and Eastern India: EDC, Eastern Dharwar Craton; WDC, Western Dharwar Craton; SGT, Southern Granulite Terrain; EGMB, Eastern Ghats Moblile Belt; CB, Cuddapah Basin; GG/MG, Godavari/Mahaṇadi Graben; SZ, shear zones; DVP, Deccan Volcanic Province; PC, Phanerozoic Cover. The lithological subdivisions of the EGMB are from Ramakrishnan *et al.* (1998).

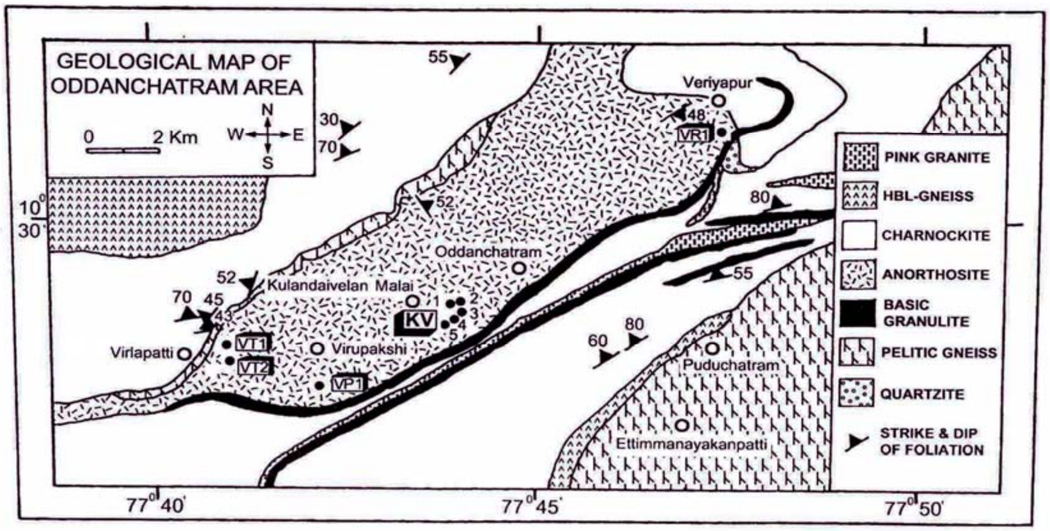


Figure 2. Geological map of the Oddanchatram anorthosite massif (modified from Sivasubramanian 1993). Numbered solid circles indicate the sampling sites in four localities.

he Oddanchatram anorthosite body (ODA) is located near to the uthern margin of the broad Palghat–Cauvery shear zone (PCSZ) at divides the composite granulite belt of southern India into two stinct terrains (Drury *et al.* 1984). The Late Archaean (2500 Ma) oorg (a) Biligirirangan, (b) Shevaroys, (c) Nilgiris, (d) Madras and) blocks sutured along the Moyar, Bhavani, Attur, Palaghat and uvery shears collectively represent the northern granulite terrain GT). The southern granulite terrain (SGT) extending southward om the PCSZ down to southern tip of the Peninsula is further vided into Madurai and Trivandrum Blocks by the Achankovil ear zone (Fig. 1a). The NGT towards the east coalesces with the 00 Ma Eastern Ghat Mobile Belt (EGMB), whilst the connection the SGT with the EGMB is not clear. The protolith ages of the T are between 2100 and 2400 Ma, though the dominant granite grade metamorphism took place at 550 Ma (Jayananda *et al.* 95; Bartlett *et al.* 1998). The PCSZ was considered to denote the rchaean–Neoproterozoic terrain boundary (Harris *et al.* 1994), but w field and chronometric data suggest complex terrain assembly relocation of the boundary (Bhaskar Rao *et al.* 2003; Chetty *al.* 2003). Establishment of the magnetization age of the Oddanatram anorthosite may provide new insights into the make-up and olution of the high-grade metamorphic terrain of southern India.

In India, massif-type anorthosites occur mainly in the EGMB ig. 1b). A genetic relationship with the Oddanchatram anorthosite s been pursued only on the basis of lithological, textural and ructural similarities (De 1969; Leelanandam & Narashima Reddy 988). In recent years, however, geochronological data have proided new insights into the emplacement of anorthosites in relation the tectonothermal evolution of the EGMB (Bhattacharya *et al.* 998; Mezger & Cosca 1999; Raith *et al.* 1999). U–Pb zircon dating n the ferrodiorites associated with the anorthosite crystallization Chilka Lake and Bolangir in the EGMB gave an age of 780 ± and 870 ± 10 Ma (Krause *et al.* 1998). Constraining the magtization age of the Oddanchatram anorthosite that has not been ated by radiometric methods, may help to understand the space–mporal relationship between the massif-type anorthosite bodies the EGMB and to the south of the Palghat–Cauvery shear zone ig. 1b).

IELD SETTING ND PETROGRAPHY

he Oddanchatram anorthosite body, in composition and in texture milar to other Proterozoic anorthosites, occurs as an intrusive plun in deformed supracrustal rocks (cordierite-bearing pelites, calclicate rocks and two pyroxene granulites). The elliptically shaped orthosite body forms part of an essentially charnockitic terrain d is associated with younger pink granites (Fig. 2). The intrusive aracter of the anorthosite is well displayed at the contact zones, ch as at the Virupakshi hillock and at Veriyapur, near the SW and E margins of the body, respectively.

The Oddanchatram anorthosite rocks contain more than 0 per cent plagioclase (~An 55 per cent) with a few pods that are a w metres thick and rich in Fe–Ti oxides (Wiebe & Janardhan 1988). he textures are highly variable. As a result of the high-grade metaorphism the anorthosites exhibit the common assemblage of plaioclase and hornblende locally. Parts of the anorthosite massif that ave escaped the metamorphism display primary igneous textures ith subhedral plagioclase, up to 2 cm in length, and clinopyroxne. Strongly foliated rocks are common near the contact zones, but e only sporadically seen in the interior. Plagioclase is variably dermed and recrystallized. In some outcrops, strongly foliated bands, several cm thick, are found in alternation with coarser-grained massive anorthosite. Elsewhere, in the more mafic varieties, mafic-rich layers define the foliation.

3 SAMPLING AND LABORATORY PRACTICE

The elliptical Oddanchatram anorthosite body, bounded by basic granulites in the east and south and by pelitic gneisses to the west and north, covers roughly an area of approximately 40 km^2. In the central part of the massif exposures of fresh anorthosite are scarce. Oriented block samples were collected at four localities on the southern and eastern margins of the anorthosite body (Fig. 2), where fresh exposures are abundant: namely Veriyapur (VR), Kulandaivelan Malai (KV), Virupakshi (VP) and Virlapatti (VT). At nine sites, a total of 31 oriented block samples were collected (Fig. 2; Table 1). In the laboratory, up to four cores were drilled from each block sample. From each core, 2–3 cylindrical specimens of standard size, 2.54 cm in diameter and 2.2 cm in length, were cut. Each specimen is identified with a two-letter locality code and site number within each locality, a core specification (A, B, C or D) and a specimen identifier (1 or 2).

The instruments used for rock magnetic and palaeomagnetic studies include a Kappabridge (KLY2) for room temperature low-field susceptibilities, a JR-5A spinner magnetometer for magnetic remanence measurements, a Molspin demagnetizer and a magnetic vacuum control system (MAVACS) for alternating field (AF) and thermal demagnetization, respectively. A Molspin pulse magnetizer was used to impart isothermal remanent magnetization (IRM).

4 ROCK MAGNETIC RESULTS

4.1 Magnetic susceptibility and natural remanent magnetization

Bulk susceptibility and initial NRM were measured on all 159 specimens. The mean values for individual sites are listed in Table 1. The NRM intensity ranges from 0.01 to 1.20 A m^{-1}, with a mean of 0.27 A m^{-1}. The magnetic susceptibilities are between 32 and 2516 × 10^{-6} SI units with a mean of 370 × 10^{-6} SI. The majority of the specimens are characterized by a low susceptibility; high values are an exception. The Koeningsberger ratios (Q-values) are uniformly very high (Table 1). Low susceptibility high-Koeningsberger values point to the abundance of Fe–Ti oxide in igneous plutons (Schlinger & Veblen 1989). A Q-value >0.5 is considered to be a first-order indicator that the remanence is predominantly carried by the PSD to SD size grains (Stacey 1967). However, in our study more than 70 per cent of the specimens have Q-values of more than 15, indicating that the remanence could be mainly carried by SD magnetite (Dunlop & Ozdemir 1997, p. 239).

4.2 Isothermal remanent magnetization acquisition

14 anorthosite specimens from different sites were subjected to progressive DC fields in seven steps up to 1000 mT; and after each step the IRM was measured. The resulting IRM acquisition curves are shown in Fig. 3(a). Five specimens were also subjected to backfields until the saturated IRM (SIRM) was reduced to zero, providing the remanent coercive force (H_{cr}). In Fig. 3(b) partial remanent hysteresis curves are shown. Usually, the IRM acquisition curves rise steeply and acquire saturation magnetization at fields of 200–300 mT (Figs 3a and b). This distinctive pattern suggests that magnetite is the main carrier of remanence. The recorded H_{cr} values of ~80–100 mT are characteristic for magnetite-rich rocks. This is consistent

Table 1. Summary of rock magnetic and palaeomagnetic measurements on the Oddanchatram anorthosite specimens.

Sample	N	NRM A m^{-1}	K 10E−6 SI	Q-ratio	REM	MDF mT	J/Jn at 80 mT	J/Jn at 560 °C	J/Jn at 580 °C
Locality: Veriyappur; 1 site									
VR1.1	6	0.2330	126	46.4	0.0138	50	0.14	0.91	0.35
VR1.2	5	0.0300	207	3.7	0.0190	65	0.32	0.88	0.16
VR1.3	7	0.0300	36	21.3	0.0570	60	0.24	0.86	0.11
VR1.4	5	0.2390	406	14.8	0.0250	50	0.22	0.52	0.08
VR1.5	4	0.0880	96	23.0	0.0090	20	0.19	0.74	0.11
VR1.6	4	0.0230	32	17.8	0.0116	65	0.30	0.78	0.76
Locality: Kulandaivelan Malai; 5 sites									
KV1.1	7	0.0013	335	0.1	0.0020	Not stable			
KV1.2	6	0.0990	94	26.5	0.0260	80	0.46	0.99	0.26
KV1.3	5	0.4130	1333	7.8	0.0470	70	0.36	0.97	0.07
KV1.4	5	0.2830	479	14.8	0.0430	65	0.37	0.96	0.08
KV1.5	4	0.4670	391	30.0	0.0250	70	0.43	0.85	0.06
KV2.1	5	0.2940	146	50.5	–	70	0.33	0.9.0	0.13
KV2.2	6	1.1280	2516	11.3	0.0690	40	0.12	0.91	0.11
KV2.3	5	1.1960	1616	18.6	0.0730	40	0.12	0.94	0.08
KV3.1	5	0.1700	100	43.0	0.0065	70	0.35	1.00	0.05
KV3.2	4	0.0760	77	24.8	–	70	0.37	Not stable	
KV4.1	5	0.2390	155	38.7	0.0397	75	0.46	0.96	0.06
KV4.2	5	0.2080	163	32.1	0.0480	70	0.43	0.96	0.17
KV5.1	4	0.0060	98	1.6	0.0039	>90	0.72	Not stable	
KV5.2	4	0.0008	140	0.2	0.0014	70	0.35	Not stable	
Locality: Virupakshi Temple; 1 site									
VP1.1	6	0.2430	99	61.3	0.0020	50	0.19	0.89	0.12
VP1.2	5	0.5680	192	74.5	0.0647	50	0.23	0.91	0.08
VP1.3	5	0.3200	49	163.6	0.0450	65	0.31	0.97	0.10
VP1.4	7	0.0330	149	5.5	0.0080	20	0.04	0.87	0.14
VP1.5	6	0.2920	83	88.5	0.0750	50	0.21	0.93	0.17
Locality: Virlapatti; 2 sites									
VT1.1	6	0.0130	1297	0.3	0.0008	50	0.29	1.00	0.18
VT1.2	5	0.4180	198	53.0	0.0330	70	0.38	1.00	0.14
VT1.3	4	0.9200	406	57.0	0.0290	50	0.22	0.76	0.03
VT1.4	5	0.0300	120	6.5	0.0270	60	0.28	0.98	0.07
VT2.1	4	0.2720	145	47.1	0.0330	30	0.13	0.88	0.04
VT2.2	5	0.0550	119	11.6	0.0130	60	0.27	0.88	0.07

N denotes the total number of specimens subjected to initial NRM, low-field magnetic susceptibility (K) and palaeomagnetic measurements. Q-ratio denotes the Koeningsberger ratio; REM denotes the ratio of NRM to SIRM; MDF denotes the median destructive field; J/Jn denotes the NRM intensity (J) at specified alternating field (mT) or temperature (°C) normalized to the initial NRM (Jn).

with the thermal demagnetization curves (see Fig. 6 in Section 5.2) showing unblocking temperatures between 560 and 580 °C.

The ratios of NRM to saturation remanence (SIRM), referred to as REM values by Wasilewski & Warner (1988), are listed in Table 1. They show that rocks acquiring remanence during continuous cooling passing the Curie point (TRM) generally have REM values ranging from 0.01 to 0.08. In the metamorphic rocks thermal blocking takes place over a long period of time and blocking may take place below the Curie point as magnetic minerals are formed. In such cases, the resulting REM values are generally below 0.008 (Wasilewski & Warner 1988). From the 29 specimens studied, 24 REM values were between 0.01 and 0.07 (NRM is at most 7 per cent of SIRM) indicating a TRM origin. The remaining five specimens have REM values ranging from 0.0008 to 0.004, which may be due to metamorphism of the anorthosites.

4.3 Lowrie fuller test

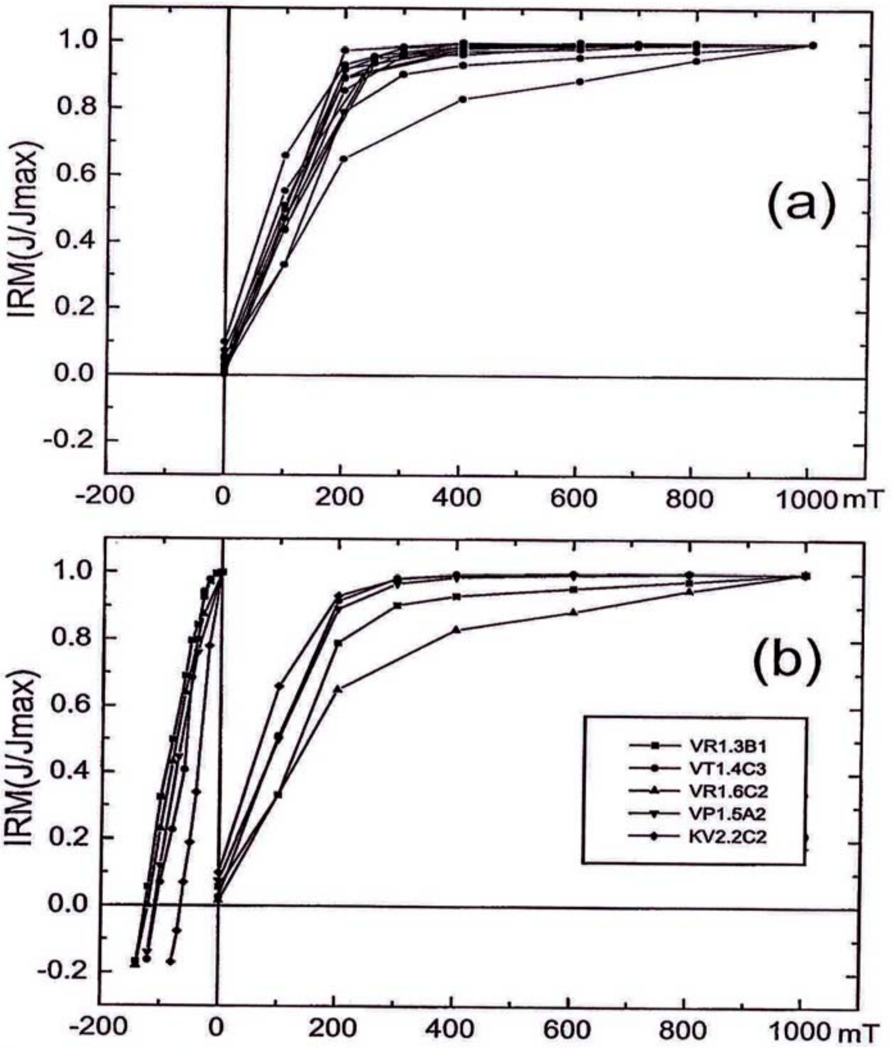
A total of seven specimens were subjected to progressive AF demagnetization up to 80 mT peak values. Then the specimens were saturated for SIRM at 1T, and again subjected to progressive AF demagnetization up to 80 mT. The resulting AF and SIRM decay curves are shown in Fig. 4 with the NRM curves invariably above the SIRM curves. The observed trends are indicative for the dominance of SD grains as a carrier of remanence (McElhinny & McFadden 2000, p. 133). Only specimen VR1.5C3 exhibits a curve that is characteristic for the presence of SD and MD grains.

5 PALAEOMAGNETISM

5.1 AF demagnetization

The representative examples of pilot AF demagnetization in steps of 20, 40, 60 and 80 mT carried out on one specimen each from the 31 block samples are shown in Fig. 5. Specimens of the four localities show similar characteristics. Generally, the NRM decay patterns have a sigmoidal shape. Comparison of these sigmoidally shaped curves with the AF demagnetization curves for the broad range of grain sizes (see fig. 11.13 of Dunlop & Ozdemir 1997) suggests that fine SD grains are the dominant carrier of the remanence.

The median destructive field (MDF) is always above 50 mT with a substantial part (~30 per cent) of NRM left at 80 mT (Fig. 5 and



gure 3. (a) IRM acquisition curves, (b) back-field demagnetization curves for selected anorthosite samples. J/J_{max} denotes the IRM intensity normalized th respect to the intensity at the maximum applied field.

Table 1). In addition, 23 specimens were subjected to progressive AF demagnetization in 11 steps with peak field strengths of 2.5, 5, 7.5, 10, 15, 20, 30, 40, 60, 80, 100 mT. The resulting normalized AF curves resemble those described above. The detailed AF demagnetization procedures, however, show the presence of a low-coercivity component that is eliminated at peak fields of 10–20 mT (discussed hereafter). The significant part of the stable remanence prevails up to the maximum applied fields of 100 mT. A high coercivity remanent component appears to be characteristic of massif anorthosite intrusives (Murthy *et al.* 1968, 1971; Irving *et al.* 1974; Piper 1974).

5.2 Thermal demagnetization

Ten specimens from different sites were subjected to progressive thermal demagnetization in seven steps up to a maximum temperature of 600 °C (Fig. 6). Another 28 specimens were subjected to thermal demagnetization with maximum temperatures of 530, 560, 570 and 580 °C. These experiments show that the remanence drops rapidly between 560 and 580 °C, indicating that magnetite is the dominant carrier of the remanence. The ratio of NRM at 560 °C to initial NRM (room temperature) in most specimens is more than 0.9 and less than 0.15 at 580 °C (see last two columns of Table 1). This very discrete blocking temperature indicates the NRM to be a weak-field TRM (Dunlop & Ozdemir 1997). Anorthosite from the Morin Complex (Irving *et al.* 1974) also showed similar discrete blocking temperature spectrum.

5.3 Determination of characteristic palaeomagnetic directions

To determine the remanence directions of the anorthosite intrusives, data of stepwise AF and thermal demagnetizations have been used. With progressive demagnetization, results shown in Zijderveld (1967) diagrams, one can often distinguish one or more remanence components. Representative specimen examples are shown in Fig. 7. For the majority of anorthosite specimens, the vector plots indicate the presence of a single component of magnetization. The intensity of this characteristic component decreases gradually (Fig. 5), but its direction does not change with increasing steps of AF demagnetization (Fig. 7, KV1.4B1). In the case of thermal demagnetization, both direction and intensity remain nearly constant until temperatures of 560 °C, followed by an intensity drop to almost zero at 580 °C. The thermal and AF demagnetization curves indicate near

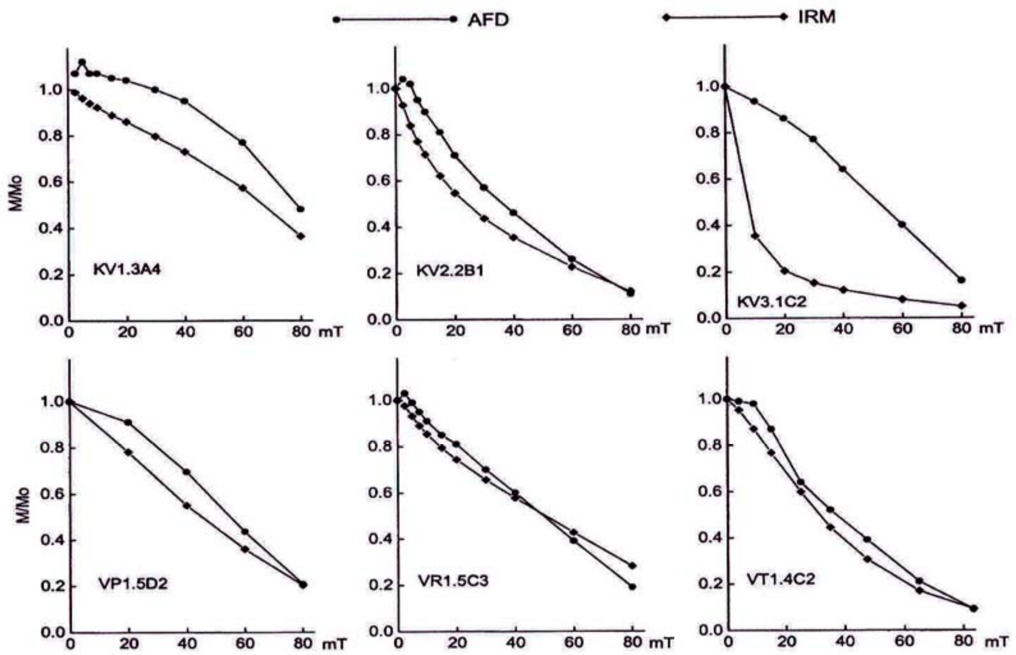


Figure 4. Normalized alternating field demagnetization (AFD) curves for NRM and saturated remanence (SIRM). The samples were imparted SIRM at 1 T field.

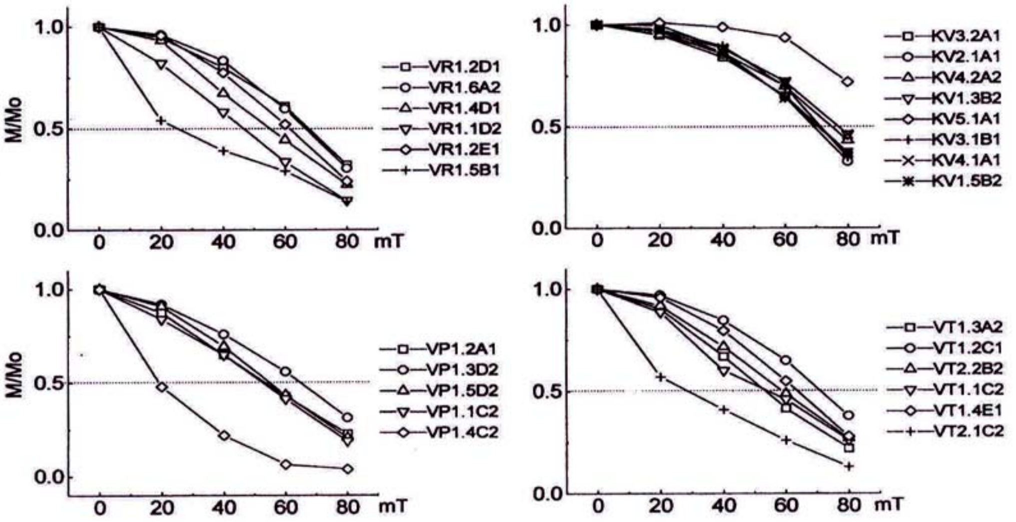
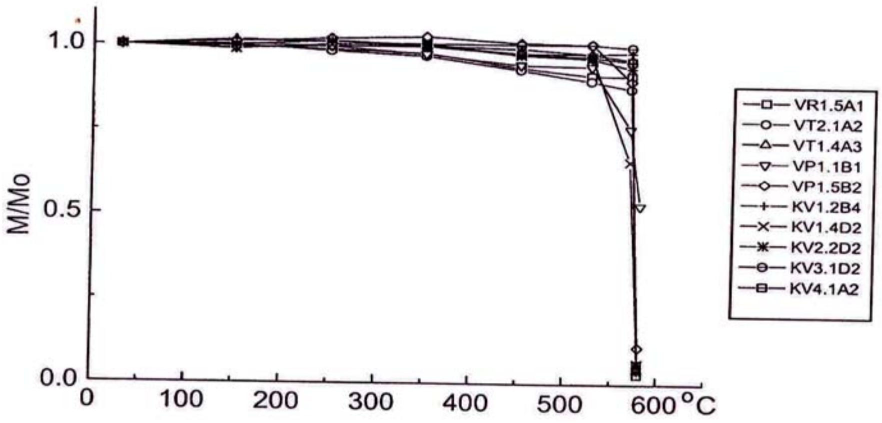


Figure 5. Normalized alternating field demagnetization curves for anorthosites from four different localities.

identical directions of the characteristic component of remanence. The components have easterly declinations and shallow to intermediate upward inclinations.

Apart from the characteristic component of remanence, some specimens contain a secondary component as well. The secondary component is identified by the linear alignment of vectors at low AF fields, particularly in the horizontal plane (shown by enlarged segments in Fig. 7). This low coercive component is completely removed at fields of 10–20 mT (e.g. in samples VR1.5C3, KV3.1C2, VP1.1C1 and VT1.3E1 in Fig. 7). The secondary component has a NE–SW declination as opposed to the near eastward declination of the characteristics component. The thermal demagnetization does not unambiguously detect the secondary component of magnetization.

The demagnetization data for each specimen were analysed by principal-component analysis, using PMAGIC software (Rehacek 1994). The vast majority, 153 out of 159 specimens subjected to AF and thermal demagnetization, yielded characteristic directions (see column N/n in Table 2) with maximum angular deviation generally below 2°. The direction of the characteristic remanence of individual specimens is plotted in Figs 8(a) and (b). The site-mean directions together with α_{95} circles are presented in Fig. 8(c) and related statistics are given in Table 2. The site-mean directions of the characteristic component at different sites are indistinguishable as their α_{95} circles intersect. The characteristic site-mean directions were combined vectorially into a mean-site direction (Fig. 8c) at $D_{\mathrm{m}} = 97.3°$, $I_{\mathrm{m}} = -28.8°$ ($k = 51.4$, $R = 8.8$, $\alpha_{95} = 7.2°$ and $N = 9$ sites) (Table 2). This corresponds to a palaeomagnetic pole



ure 6. Representative thermal demagnetization plots for Oddanchatram anorthosites.

ion at 9.7°N, 1.7°E ($d_p = 4.4°$, $d_m = 7.9°$) and a palaeolatitude .4°. The mean-site direction for the low coercivity compo- t was similarly obtained by combining vectorially the directions rded in a few specimens (18) at $D = 36.7°$ and $I = -29.4°$ $= 63.4$, $R = 17.7$, $\alpha_{95} = 4.4°$ and $N = 18$ specimens) with a responding pole position at 45.2°S, 23°E (Table 2).

RESULTS AND DISCUSSION

Age estimation for the characteristic anence component

grating the available Precambrian palaeomagnetic vector data of ous igneous intrusives scanning the entire southern Indian shield, hakrishna & Joseph (1993) identified six distinct clusters cor- onding to discrete ages ranging between 2000 and 800 Ma. The racteristic palaeomagnetic directions in each group were quite ilar both in Dharwar Craton and the SGT. This led Radhakrishna seph (1993) to infer that neither any large-scale rotational mo- nor major displacement have occurred between the constituent ks of the southern Indian shield since Late Proterozoic times 0 Ma). Table 3 lists the characteristic remanence directions and sponding pole positions from a number of formations of Pro- oic age from peninsular India (Radhakrishna & Joseph 1993) help to constrain the magnetization age of the Oddanchatram thosite intrusives. Our palaeomagnetic direction for the Oddan- am anorthosite intrusives is in reasonable agreement with the tions derived for the Wajrakarur Kimberlite pipes of the East- harwar Craton (Table 3, no 2) and the Tiruvannamalai dykes e SGT (Table 3, no 3). The other formations show roughly site direction with respect to the Oddanchatram anorthosite 4–8 in Table 3). K–Ar ages of the Wajrakarur Kimberlite were rted earlier in the range of 840–1170 Ma (Hargraves & Bhalla) with an Rb–Sr age of 1090 ± 20 Ma (Kumar *et al.* 1993). equivalence with the Tirupati dykes (Table 3, no 4) is assumed e basis that these Tirupati dykes are coeval with dolerite intru- dated at 980 ± 110 Ma (Crawford & Compston 1973). The apah sandstone (Table 3, no 5) and shales (Table 3, no 6) have dated to 1400–1160 Ma (Aswathanarayana 1964). Given these metric constraints and clustering of pole positions, the forma- from peninsular India listed in Table 3 were taken to have ages 00–1000 Ma (Radhakrishna & Joseph 1993). The agreement en the pole position of the Oddanchatram anorthosite with of the formations from the SGT, Dharwar Craton, Cuddapah Basin and EGMB (Table 3) is taken as an age of magnetization is the period 1100–1000 Ma.

6.2 Age estimation for the secondary remanence component

The local magnetic field direction ($D = 358°$ and an $I = 6°$) differs from the secondary component, ruling out a present-day viscous remanent magnetization as the source of the secondary component in the Oddanchatram anorthosite body. The pole position derived for the secondary component of remanence reasonably conforms with the pole positions for a number of formations across the Indian Shield (Table 4) the magnetization ages of which correspond to the ~550 Ma Pan-African thermal event. It is likely therefore, that the secondary magnetization detected in the Oddanchatram anorthosite relates to a thermal imprint of the 550 Ma Pan-African thermal events.

6.3 Tectonic implications

It follows from the above discussion that the estimated magnetization age for the anorthosite represents the cooling age following the metamorphic episode of Grenvillian time (1100–1000 Ma) that primarily gave rise to the Eastern Ghat Orogeny. Although the Oddanchatram anorthosite has not been dated by radiometric techniques, the U–Pb zircon dating on the ferrodiorites suites associated with the anorthosites at Chilka Lake and Bolangir in the EGMB, respectively, provides ages of 780 ± 2 and 870 ± 10 Ma (Krause *et al.* 1998). These radiometric data in conjunction with assumption that the anorthosites in the Oddanchatram region and in the EGMB have contemporaneous history, the emplacement or reset magnetization age for the Oddanchatram anorthosites may range at most between 1000–800 Ma, but definitely earlier than the 550 Ma Pan-African tectonothermal event. This sharply contrasts with views that the entire Southern Granulite Terrain has undergone granulitic grade metamorphism in association with the Pan-African thermal event (Santosh *et al.* 1993; Jayananda *et al.* 1995; Bartlett *et al.* 1998). Under the pressure conditions (~10 Kbars) attained during Pan-African granulitic metamorphism, the Curie temperatures for magnetite would be in the order of 600 °C (Schult 1970). Given that temperatures during the granulitic metamorphism (700–1000 °C) were clearly in excess of this elevated Curie temperature or blocking temperature recorded in anorthosite specimens, thermal overprinting of

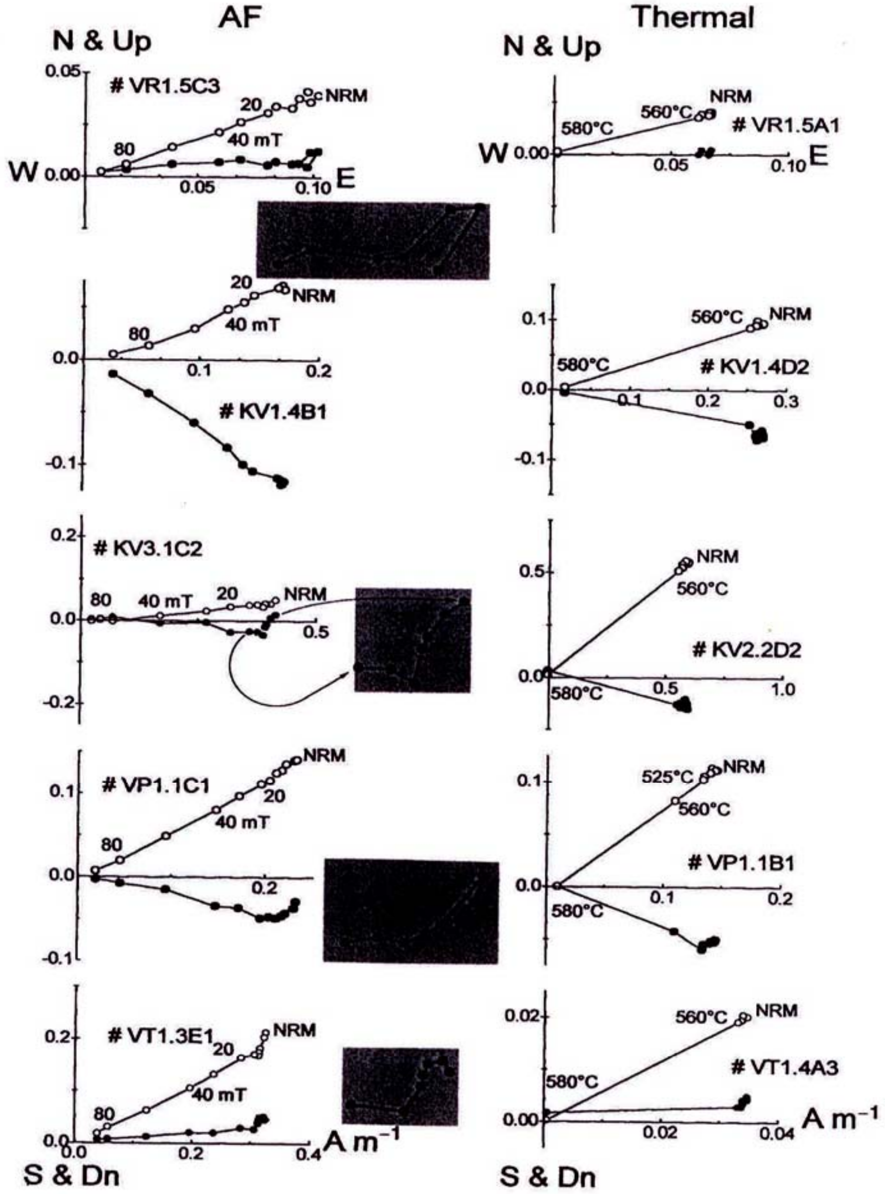


Figure 7. Orthogonal vector plots (Zijderveld diagrams) of AF (left) and thermal (right) demagnetization for the representative Oddanchatram anorthosite specimens. Solid and open circles are, respectively, the horizontal and vertical projections of remanent magnetization vector at various steps of demagnetization. The shaded areas show four times enlarged segments of vector plots in horizontal plane at low AF fields (0–20 mT).

the initial magnetization of the Oddanchatram anorthosite would be a natural consequence. Sm–Nd garnet–whole rock isochron ages suggest that the peak metamorphism in the Kodaikanal Massif at 553 ± 15 Ma was followed by an isothermal uplift up to 459 ± 16 Ma (Jayananda *et al.* 1995). Pullaiah *et al.* (1975) have shown that if rocks remain exposed to certain higher temperatures, even though below the Curie temperature, for prolonged periods, the rocks acquire a thermoviscous magnetization. Based on this thermal relaxation criterion, the period of isothermal uplift in the Kodaikanal Massif was certainly long enough to destroy the original remanence in the anorthosite intrusive. Despite the favourable temperature conditions, the fact that the remanence in the Oddanchatram anorthosite have escaped the thermal effects of the Pan-African event can only be reconciled by considering that the northern boundary of 550 Ma granulitic metamorphism did not extend northward beyond northern fringes of the Anaimalai–Kodaikanal Ranges, as initially envisaged by Janardhan (1998, 1999). Such an inference has a major implication in constraining the location of the Archaean–Neoproterozoic terrain boundary that has been considered to coincide with the PCSZ. However, it is now well known that part of the Archaean crust north of the PCSZ has been intensely reworked along a number of narrow shear belts during 800–500 Ma (Bhaskar Rao *et al.* 1996; Raith *et al.* 1999). These terrains are also intruded by numerous plutons of granite, alkali granite, synite and carbonatite emplaced during the 700–500 Ma (Roy & Dhana Raju 1999; Nathan *et al.* 2001). Meissner *et al.* (2002) also report ages of ≪1200 and 550 Ma to be common in the rocks of Moyar and Bhavani shear zones, bounding the 2510 Ma Niligiri charnockite massif, which does not show any of the effects of the 550 Ma event at all. This evidence goes to prove that the 550 Pan-African tectonothermal event in the NGT is more confined to the shear zones and is not a pervasive one. On the other hand, there is growing field evidence that the Archaean

Table 2. Site-mean and mean-site palaeomagnetic directions for the characteristic magnetization component as well as mean-site direction for secondary component.

Locality	Site	*N*/*n*	*D*	*I*	*R*	*k*	α_{95}
VR	1	37/37	88.3	−26.4	36.0	38.0	3.9
KV	1	18/20	92.3	−20.2	17.6	45.0	5.2
KV	2	15/15	102.6	−29.8	14.5	27.0	7.5
KV	3	7/7	88.0	−20.0	6.9	69.0	7.3
KV	4	10/10	97.0	−31.0	9.6	24.7	9.9
KV	5	3/5	115.8	−23.0	2.9	18.0	29.7
VP	1	27/29	106.9	−32.6	26.7	96.0	2.8
VT	1	28/28	90.8	−28.9	26.9	24.0	5.7
VT	2	8/8	94.1	−44.8	7.8	30.0	10.2
Mean-site: Characteristic component		9*	97.3	−28.8	8.8	51.4	7.2
Mean-site: Secondary component		18	36.7	−29.4	17.7	63.4	4.4

Localities as in Table 1; site number within each locality.
N/*n*: number of specimens used in computing the mean/total number of specimens demagnetized.
D, *I*, site-mean declination, inclination (deg); *R*, vector length, *k*, precision parameter; α_{95}, semi-angle (deg) of the 95 per cent confidence cone.
*Number of sites.

crustal style continues further south of the PCSZ (Naha & Srinivasan 1996). Ghosh *et al.* (1998) have identified a major structural decollement, termed the KKPT shear zone in this part (see Fig. 1), separating the terrains with contrasting structural style and lithological association. The more recent field observations carried out as a part of the multidisciplinary studies along the N–S geotransect from Kuppam to Palani have indicated that the region south of the PCSZ is traversed by other prominent shear zones such as the Karur–Oddanchatram shear zone (KOSZ) and the Karur–Oddanchatram–Kodaikanal shear zone (KOKSZ) as shown in Fig. 1(a) (Chetty *et al.* 2003). Between the Karur and the Palani Hill Ranges, the northern part of the KOSZ and KOKSZ matches well with the KKPT structural decollement. Bhaskar Rao *et al.* (2003), based on the extensive new Sm–Nd and Rb–Sr whole rock data along the Kuppam–Palani Geotransect, have come to the conclusion that the shear zone lying along the Karur–Oddanchatram–Kodaikanal zone (KOKZ) may represent an important decollement zone separating basement complexes of contrasting Neoproterozoic thermal activity, though with a very similar pre-Neoproterozoic history. More recently, Santosh *et al.* (2003), while working on the lithologies of the terrain south of the Kodaikanal block, found widespread imprints of the 550 Ma Pan-African tectonothermal event, and further noted that the terrain has witnessed strong tectonic or metamorphic events at 800 Ma. Bartlett *et al.* (1998) had also reported a scattered cluster of ages between 900–1000 Ma. A common conclusion from these studies, what is pertinent to the present paper, is that there are enough indications of both the 1000–800 and 550 Ma metamorphic events but the 550 Ma granulite metamorphism connected with the Pan-African tectonothermal event was not pervasive north of the KKPT or the KOKZ decollement zone. This then can explain why the Oddanchatram anorthosite body located along the northern margins of the Palani ranges had escaped the full impact of the 550 Ma event.

The charnockite rocks, immediately to the south of the Oddanchatram anorthosite body (Fig. 2), are traversed by innumerable pink veins, which are considered to be intruded in association with the pink granite emplacement between 650–592 Ma (Jayananda *et al.* 1995). The detailed petromineragraphic studies of the Sankari

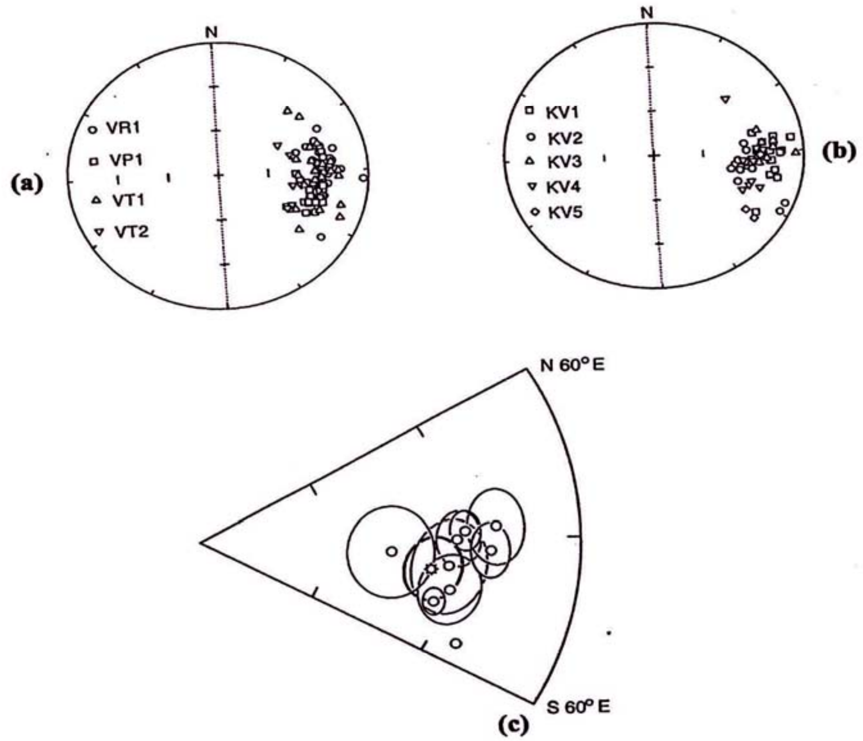


Figure 8. Equal area projections of the upward dipping magnetization vectors for individual anorthosite specimens from localities VR, VP, VT (a) KV (b). (c) gives the corresponding site-mean and mean-site (⋆) directions (listed in Table 2) with a 95 per cent confidence limit (except for site KV5) for the characteristic component of magnetization.

Table 3. Palaeomagnetic directions and pole positions for the southern Indian formations[1] corresponding to the age of 1100 Ma.

Sr. no	Formation		Site location		Magnetic direction			Pole position		Age, Ma
			Lat. (°N)	Long. (°E)	*D*	*I*	α_{95}	Lat. (°N)	Long. (°E)	
1	Oddanchatram anorthosite (present study)	SGT	10.5	77.7	97	−29	7	9.7	1.7	1100–1000
2	Wajrakarur Kimberlite	EDC	15.0	77.4	104	−39	11	18.3	6.1	1090 ± 20[2]
3	Tiruvannamalai dyke (over print)	SGT	12.2	78.8	97	−1	6	6.5	347.8	~1000[3]
4	Tirupati dykes	CB	14.0	79.0	278	−22	4	4.8	335.9	980 ± 110[4]
5	Cuddapah Metamorphosed Shale	CB	14.8	78.1	295	−10	5	22.6	336.1	1400–1160[5]
6	Cuddapah sandstone	CB	14.9	78.5	294	−6	8	22.3	338.8	1400–1160[5]
7	Visakhapatnam Charnockites	EGMB	17.5	83.0	280	35	15	14.8	9.0	1100–1000[1]
8	Tiptur dykes	WDC	13.4	76.0	287	−21	12	13.6	331.1	1100–1000[1]

SGT, Southern Granulite Terrain; CB, Cuddapah Basin.
EGMB, Eastern Ghat Mobile Belt; WDC, Western Dharwar Craton; EDC, Eastern Dharwar Craton.

[1] Information extracted from the compilation of Radhakrishna & Joseph (1993).
[2] Age after Kumar *et al.* (1993).
[3] Age after Radhakrishna & Joseph (1993).
[4] Age after Crawford & Compston (1973).
[5] Age after Aswathanarayana (1964).

Table 4. Palaeomagnetic directions and pole positions of formations corresponding in age with the ≈550 Ma Pan-African thermal event.

Formation	Age Ma	Site location		Magnetic direction		Pole		Reference
		Lat. °N	Long. °E	Decl.	Incl.	Lat. °S	Long. °E	
Oddanchatram anorthosite, Tamil Nadu		10.5	77.7	36.7	−29.4	45.2	23.0	Present study
Upper Bhander Sandstone, M.P.	505–620*	23.7	79.6	49.0	−19.0	31.8	19.0	Athavale *et al.* (1972)
Upper Bhander Sandstone, Gwalior	505–620*	26.5	78.0	208.0	10.0	48.4	34.0	Klootwijk (1973)
Upper Bhander red beds, M.P.	505–620*	27.0	77.5	182.0–205.0	−0.6–18.0	51.3	42.7	McElhinny *et al.* (1978)
Khewra Sandstone	550–590	32.2	71.0	203.0	31.5	36.0	43.5	Klootwijk *et al.* (1986)
Rewa Sandstone	500–750+	23.8	78.9	32.0	−37.0	35.7	41.2	Athavale *et al.* (1972)
Rewa Sandstone	500–750+	24.5	81.0	221.6	−8.0	45.0	11.3	McElhinny *et al.* (1978)
Jutana Fm.	530–554*	32.2	71.0	202.5	53.5	20.5	51.0	Klootwijk et al. (1986)
Salt Pseudomorph beds (Baghanw)	523–570*	32.2	73.0	218.0	36.0	27.0	34.0	Wensink (1972)
Purple (Khewra Fm.) Sandstone, Salt Range	540–570*	32.7	73.0	218.0	31.5	28.0	32.0	McElhinny (1970)

*Age after Vander Voo (1993).
+Age after Poornachandra Rao & Bhalla (1996).

Granitoid at Kullampatti along the Bhavani–Attur shear has shown that the intrusion of granitoid bodies is accompanied by intense hydrothermal activity (Roy & Dhana Raju 1999). The weak secondary remanence component found in a few Oddanchatram anorthosite specimens may then be a consequence of the similar hydrothermal activity accompanying pink granite intrusion at the southern margin of the Oddanchatram anorthosite body.

As mentioned earlier, a string of massif-type anorthosite bodies occurs in the EGMB, all along the eastern coast of India (Fig. 1b). Based on the relative abundance of certain rock types, the belt is subdivided into four major lithologic units (Fig. 1b) that run approximately N–S and parallel to the contact with the Dharwar craton (Ramakrishnan *et al.* 1998). Isotopic data from the EGMB show pronounced differences in mineral ages and grade of metamorphism among the different lithologic units (Mezger & Cosca 1999). All hornblende ^{40}Ar/^{39}Ar data indicate ages of ca. 1110 Myr for the Western Chanockite zone, the western most unit of EGMB (Fig. 1b), is approximately contemporaneous with the estimated magnetization age of the Oddanchatram anorthosite body. This similarity of lithology and age between the Western Charnockite zone and the belt hosting the Oddanchatram anorthosite importantly suggests that the narrow sliver of formation embedded between the northernmost margin of the Kodaikanal Ranges and the Palghat–Cauvery shear zone may represent the vestiges of the EGMB. This supports the view that the Oddanchatram anorthosite body can be considered as the western extension of the extended string of massif-type anorthosites in the EGMB (Janardhan & Wiebe 1985), originated by plutonic intrusions during the Eastern Ghat Orogeny (Kaila & Bhatia 1981). Rock magnetic and palaeomagnetic measurements initiated recently on the anorthosites in the Chilka Lake and Bolangir areas of the EGMB will help to test this hypothesis and trace the linkage with the global distribution of anorthosite bodies on the reconstructed Proterozoic super-continent (Piper 1976).

7 CONCLUSIONS

Extensive rock magnetic research clearly establishes single domain magnetite grains as the main carriers of remanence in the Oddanchatram anorthosite. The anorthosite retains a significant fraction of magnetization after progressive AF demagnetization at high fields. The high coercivity of the Oddanchatram anorthosite magnetite indicates its suitability to determine the characteristic of a palaeomagnetic direction.

The direction and pole position of the characteristic magnetization indicate that the Oddanchatram anorthosite body acquired an initial or a reset magnetization at approximately 1100–1000 Myr, possibly related to the Eastern Ghat Orogeny. The pole position derived from another, secondary, component of magnetization indicates that this component may be due to the hydrothermal effects associated with ~600 Ma granite intrusions, evidence of which is seen by the profuse pink granite veins traversing the country rock bordering the anorthosite body at its southern margins. However, the secondary component was rather weak and found only in a few specimens. This coupled with the main result that the characteristic magnetization component relates to the age of 1100–1000 Ma is interpreted to indicate that the northern boundary of the Pan-African thermal event, that has affected the Southern Granulite Terrain extensively, is located along the southern margin of the Oddanchatram anorthosite body. The ages of 1100–1000 Ma are still preserved in the Oddanchatram anorthosite body support the earlier suggestion of Kaila & Bhatia (1981) and Janardhan & Wiebe (1985) that the Eastern Ghats anorthosite bodies and the magmatic activity associated with these intrusions continue westwards well into the granulite grade terrain south of the Palghat–Cauvery shear zone.

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REFERENCES

Aswathanarayana, U., 1964. Isotopic ages from the Eastern Ghats and Cuddapah Basin of India, *J. geophys. Res.*, **69,** 3479–3486.

Athavale, R.N., Asha Hansraj & Verma, R.K., 1972. Palaeomagnetism and age of Bhander and Rewa Sandstones from India, *Geophys. J. R. astr. Soc.*, **28,** 499–509.

Bartlett, J.M., Dougherty, J.S., Harris, N.B.W., Hawkesworth, C.J. & Santosh, M., 1998. The application of single zircon evaporation and model Nd ages to the interpretation of polymetamorphic terrains: an example from the Proterozoic mobile belt of south India, *Contrib. Mineral. Petrol.*, **131,** 181–195.

Bhaskar Rao, Y.J., Chetty, T.R.K., Janardhan, A.S. & Gopalan, K., 1996. Sm-Nd and Rb-Sr ages and P-T history of the Archaean Sittampundi and Bhavani layered meta-anorthosite complexes of the Cauvery shear zone, south India: evidence for Neoproterozoic reworking of the Archaean crust, *Contr. Mineral. Petrol.*, **125,** 237–250.

Bhaskar Rao, Y.J., Janardhan, A.S., Vijay Kumar, T., Narayana, A.M., Dayal, A.M., Taylor, P.N. & Chetty, T.R.K., 2003. Sm-Nd model ages and Rb-Sr isotopic systematics of charnockites and gneisses across the Cauvery shear zone, Southern India: Implications for the Archaean–Neoproterozoic terrain boundary in the Southern Granulite Terrain, *Mem. Geol. Soc. India*, **50,** 297–317.

Bhattacharya, A., Raith, M., Hoernes, S. & Banerjee, D., 1998. Geochemical evolution of the massif-type anorthosite complex at Bolangir in the Eastern Ghats Belt of India, *J. Petrol.*, **39,** 1169–1195.

Chetty, T.R.K., Bhaskar Rao, Y.J. & Narayana, B.L., 2003. A structural cross-section along Krishnagiri-Palani corridor, southern Granulite Terrain of India, *Mem. Geol. Soc. India*, **50,** 255–278.

Crawford, A.R. & Compston, W., 1973. The age of Cuddapah and Kurnool Systems, South India, *J. Geol. Soc. Australia*, **19,** 453–464.

De Anrudha, 1969. Anorthosites of the Eastern Ghats, India, in *Origin of Anorthosites and Related Rocks,* Vol. 18, ed. Isachsen, Y.W., NY State Mus. Sci. Serv., Mem.

Dunlop, D.J. & Ozdemir, O., 1997. Rock magnetism fundamentals and frontiers, *Cambridge Studies in Magnetism,* Cambridge University Press, Cambridge.

Drury, S.A., Harries, N.B.W., Reeves-Smith, G.J. & Wightman, R.T., 1984. Precambrian tectonics and crustal evolution in South India, *J. Geol.*, **92,** 3–20.

Ghosh, J.G., Zartman, R.E. & De Wit, M.J., 1998. Re-evaluation of tectonic framework of southernmost India: new U-Pb geochronological and structural data, and their implication for Gondwana reconstruction, Gondwana 10: Event stratigraphy of Gondwana, *J. Afican Earth Sci.*, **27,** 86.

Hargraves, R.B. & Bhalla, M.S., 1983. Precambrian palaeomagnetism in India through 1982: a review, *Mem. Geol. Soc. India,* **4,** 491–524.

Harris, N.B.W., Santosh, M. & Taylor, P.N., 1994. Crustal evolution in south India: constraint from Nd isotopes, *J. Geol.*, **102,** 139–150.

Irving, E., Park, J.K. & Emslie, R.F., 1974. Palaeomagnetism of the Morin complex, *J. geophys. Res.*, **79,** 5482–5490.

Janardhan, A.S., 1998. Evolution of granulite facies charnockites of Southern India, International symposium on charnockite and granulite facies rocks, *Geol. Assoc. Tamil Nadu,* 15–26.

Janardhan, A.S., 1999. Southern Granulite Terrain, South of the Palghat–Cauvery shear zone: implications for India–Madagascar connection, *Gondwana Res.*, **3,** 463–469.

Janardhan, A.S. & Wiebe, R.A., 1985. Petrology and geochemistry of the Oddanchatram anorthosite and associated basic granulites, Tamilnadu, South India, *J. Geol. Soc. India,* **26,** 163–176.

Jayananda, M., Janardhan, A.S., Sivasubramaniam, P. & Peucat, J.J., 1995. Geochronologic and isotopic constraints on granulite formation in the Kodaikanal area, Southern India, *Mem. Geol. Soc. India,* **34,** 373–390.

Kaila, K.L. & Bhatia, S.C., 1981. Gravity study along the Kavali–Udipi deep seismic sounding profile in the Indian Peninsula Shield: some inferences about the origin of anorthosites and the Eastern Ghats Orogeny, *Tectonophysics*, **79,** 129–143.

Kanungo, D.N. & Chetty, T.R.K., 1978. Anorthosite body in the Nellore mica-pegmatite belt of eastern India, *J. Geol. Soc. India,* **19,** 87–90.

Klootwijk, C.T., 1973. Palaeomagnetism of upper Bhander sandstones from central India and implications for a tentative Cambrian Gondawanaland reconstruction, *Tectonophysics,* **18,** 123–145.

Klootwijk, C.T., Nazirullah, R. & De Jong, K.A., 1986. Palaeomagnetic constraints on formation of the Mianwali reentrant, Trans-Indus and Western Salt Range, Pakistan, *Earth planet. Sci. Lett.*, **80,** 394–414.

Krause, O., Mezger, K. & Raith, M.M., 1998. Age constraints on the emplacement of Massif-type anorthosites in the Eastern Ghats Belt, India., *Proc. Int. Seminar on Precambrian Crust in Eastern and Central India,* pp. 121–123, Geological Survey of India, Bhubaneshwar.

Kumar, A., Padma Kumari, V.M., Dayal, A.M., Murthy, D.S.N. & Gopalan, K., 1993. Rb-Sr ages of Proterozoic Kimberlites of India: evidence for contemporaneous emplacement, *Precambrian Res.*, **62,** 227–237.

Leelanandam, C. & Narashima Reddy, M., 1988. Precambrian anorthosites from Peninsular India—problems and perspectives, *J. Geol. Soc. India*, **60,** 111–136.

McElhinny, M.W., 1970. The palaeomagnetism of the Cambrian Purple Sandstone from the Salt Range, West Pakistan, *Earth planet. Sci. Lett.*, **8,** 149–156.

Mc Elhinny, M.W. & McFadden, P.L., 2000. Paleomagnetism, Continents and Oceans, *International Geophysics Series,* Vol. 73, p. 133, eds Dmowska, R., Holton, J.R. & Rossby, H.T., Academic Press, San Diego.

McElhinny, M.W., John A. Cowley & Edwards, D.J., 1978. Palaeomagnetism of some rocks from Peninsular India and Kashmir, *Tectonophysics,* **50,** 41–54.

Meissner, B., Deters, P., Srikanatppa, C. & Kohler H., 2002. Geochronological evolution of the Moyar, Bhavani and Palghat shear zones of southern India: implications for East Gondwana correlation, *Precamb. Res.*, **114,** 149–175.

Mezger, K. & Cosca, M.A., 1999. The thermal history of the Eastern Ghats Belt (India) as revealed by U-Pb and ^{40}Ar/^{39}Ar dating of metamorphic and magmatic minerals :implications for the SWEAT correlation, *Precambrian Res.*, **94,** 251–271.

Murthy, G.S., Fahrig, W.F. & Jones, D.L., 1968. The palaeomagnetism of the Michikamau Anorthosite Intrusion, Labrador, *Can. J. Earth Sci.*, **5,** 1139–1144.

Murthy, G.S., Evans, M.E. & Gough, D.I., 1971. Evidence of single-domain magnetite in the Michikamau Anorthosite, *Can. J. Earth Sci.*, **8,** 361–370.

Naha, K. & Srinivasan, R., 1996. Nature of the Moyar and Bhavani shear zones, with a note on its implication on the tectonics of the southern Indian Precambrian shield, *Proc. Indian Acad. Sci. (Earth Planet Sci.),* **105,** 143–189.

Nathan, N.P., Balasubramanian, E., Ghosh, S. & Roy Barman, T., 2001. Neoproterozoic acid magmatism in Tamil Nadu, south India: geochemical and geochronologic constraints, *Gondwana Res.*, **4,** 714–715.

Piper, J.D.A., 1974. Magnetic properties of the Cunene Anorthosite Complex, Angola, *Phys. Earth planet. Inter.*, **9,** 353–363.

Piper, J.D.A., 1976. Palaeomagnetic evidence for a Proterozoic supercontinent, *Phil. Trans. R. Soc. Lond.*, A, **280,** 469–490.

Poornachandra Rao, G.V.S. & Bhalla, M.S., 1996. Magnetostratigraphy of Vindhyan supergroup, *J. Geol. Soc. India,* **47,** 29–32.

Pullaiah, G.E., Irving, E., Buchan, K.L. & Dunlop, D.J., 1975. Magnetization changes caused by burial and uplift, *Earth planet. Sci. Lett.*, **28,** 133–143.

Radhakrishna, T. & Joseph, M., 1993. Proterozoic palaeomagnetism of South Indian Shield and tectonic constraints, *Mem. Geol. Soc. India,* **25,** 321–336.

Raith, M., Srikantappa, C., Dieter Buhl & Kohler, H., 1999. The Nilgiri Enderbites, South India: Nature and age constraints on protolith formation, high grade metamorphism and cooling history, *Precambrian Res.*, **95,** 129–150.

Ramakrishnan, M., Nanda, J.K. & Augustine, P.F., 1998. Geological evolution of the Proterozoic Eastern Ghats Mobile Belt, *Geol. Surv. Ind. Spec. Pub.*, **44,** 1–21.

Rehacek, J., 1994. *PMAGIC Software for Paleomagnetic Calculations, Version 1.2,* Department of Geology, Washington State University, Pullman.

Roy, M. & Dhana Raju, R., 1999. Petrogenetic model of A-Type granitoids of the Kullampatti area, Salem District, Tamil Nadu, India, *Gondawana Res.*, **2,** 127–135.

Santosh, M., Kagami, H., Yoshida M. & Nandakumar, V., 1993. Pan-African, Charnockite formation in East Gondwana: Geochronologic (Sm-Nd and Rb-Sr) and petrogenetic constraints, *Bull. Indian Geol. Assoc.*, **25,** 1–10.

Santosh, M., Yokayama, S., Biju-Sekhar & Rogers J.J.W., 2003. Multiple tectonothermal events in the granulite blocks of southern India revealed from EPMA dating: implications on the history of supercontinents, *Gondwana Res.*, **6,** 29–64.

Schlinger, C.M. & Veblen, D.R., 1989. Magnetism and transmission electron microscopy of Fe-Ti oxides and pyroxenes in a granulite from Lofoten, Norway, *J. geophys. Res.*, **94,** 14 009–14 026.

Schult, A., 1970. Effect of pressure of the Curie temperature of titanomagnetites $[(1-x)\mathrm{Fe_3O_4}\text{-}x\mathrm{TiFe_2O_4}]$, *Earth planet. Sci. Lett.*, **10,** 81–86.

Sivasubramanian, P., 1993. Geology and metamorphic history of parts of Kodaikanal ranges, *PhD thesis*, University of Mysore.

Stacey, F.D., 1967. The Koeningsberger ratio and the nature of thermoremanence in igneous rocks, *Earth planet. Sci. Lett.*, **2,** 67–68.

Valdiya, K.S., 2002. Tectonic resurgence of the Mysore plateau and surrounding regions in cratonic Southern India, *Current Sci.,* **81,** 1068–1089.

Vander Voo, R., 1993. *Paleomagnetism of the Atlantic, Tethys and Iapetus Oceans,* Cambridge University Press, Cambridge.

Wasilewski, P. & Warner, R.D., 1988. Magnetic Petrology of deep crustal rocks—Ivrea zone, Italy, *Earth planet. Sci. Lett.*, **87,** 347–361

Wensink, H., 1972. The palaeomagnetism of the salt pseudomorph beds of Middle Cambrian age from the Salt Range, West Pakistan, *Earth planet. Sci. Lett.*, **16,** 189–194.

Wiebe, R.A. & Janardhan, A.S., 1988. Metamorphism of the Oddanchatram Anorthosite, Tamilnadu, South India, *Mem. Geol. Soc. India,* **25,** 113–117.

Zijderveld, J.D.A., 1967. AC demagnetization of rocks: Analysis of results, in *Method in Palaeomagnetism,* pp. 254–286, eds Collinson, D.W., Creer, K.M. & Runcon, S.K., Elsevier, Amsterdam.