Palaeomagnetism of the Cretaceous Lamproites from Gondwana basin of the Damodar Valley in India and migration of the Kerguelen plume in the Southeast Indian Ocean

T. Radhakrishnaa,⁎, G.S. Soumyaa, K.V.V Satyanarayanaab

a National Centre for Earth Science Studies, Trivandrum 695011, India
b Indian Institute of Geomagnetism, Navi Mumbai 410218, India

ARTICLE INFO

Keywords:
Palaeomagnetism
Cretaceous
Lamproite
Kerguelen plume
Damodar valley India

ABSTRACT

The paper presents new palaeomagnetic results and reassesses complete set of published palaeomagnetic results on the lamproite intrusions in the Gondwana formations of the Eastern India. Altogether eleven sites register reliable characteristic magnetisations corresponding to the c. 110 Ma emplacement age of the lamproites. A mean ChRM is estimated with D = 331.3°; I = −62.4° (α95 = 6.2°, k = 55; N = 11). The palaeomagnetic pole of λ = 14.9°: Φ = 287.6° (A95 = 8.4°) is established for the lamproites and it averaged the secular variation and confirms to the Geocentric Axial Dipole (GAD). The pole compares remarkably well with the grand mean pole reported for the Rajmahal traps that are attributed to represent location of the Kerguelen mantle plume head. The paleolatitudes transferred to Rajmahal coordinates (25.05°: 87.84°) are situated ∼6° north of the present location of the Kerguelen hotspot location. The interpretations are consistent with earlier suggestions of southward migration of the plume based on palaeomagnetic results of Site 1138 of the ODP Leg 183 and with the predictions of numerical models of global mantle circulation.

1. Introduction

The genetic link between the large igneous provinces (LIPs), hot spots (mantle plumes) and continental breakup is widely accepted (Ernst, 2014). On the eastern continental margin of India, its breakup from Gondwana was triggered by the initiation of the Kerguelen mantle plume in the mid-Cretaceous (c. 115–120 Ma; Mahoney et al., 1983; Kent, 1991; Frey et al., 2000). Large outpourings of magma that form the Rajmahal traps in eastern India, Bunbury basalts in SW Australia, and basalts on Ninetyeast Ridge, Broken Ridge complex and Kerguelen Plateau in the southern Indian ocean are attributed to the hotspot related LIP of the Kerguelen plume (Frey et al., 1996; Frey et al., 2000; Coffin et al., 2002; Kent et al., 2002; Zhu et al., 2009; Ghatak and Basu, 2013; Sushchevskaya et al., 2016 and many others). The reconstructed position of these volcanic features are inconsistent with the present day position of the Kerguelen plume (Gaina et al., 2003 Müller et al., 1993; O’Neill et al., 2003 Zhao and Ernesto, 2014). An explanation to the inconsistency has come from models of hotspot motion using numerical experiments of mantle flow in deep interior of the earth and reconstructions based on Ninety degrees East Ridge (Royer et al., 1991 Steinberger and O’Connell, 1998; O’Neill et al., 2003 etc). These models predicted 3–10° southward motion of the plume. Palaeomagnetism data of characteristic remanent magnetization (ChRM) of LIP related igneous rocks is recognized to have potential to offer explanations to these inconsistencies. Antretter et al. (2002) have lend explanation based on palaeomagnetic inclination data from ODP Leg 183 basalts samples from Kerguelen plateau. Our present study deals with palaeomagnetcism of igneous intrusions from the Indian continental region. These intrusive rocks belong to lamproite clan and dolerites in the Gondwana Basins of Damodar Valley in the eastern India and are linked to the Kerguelen plume igneous activity (Kent, 1991; Coffin et al., 2002; Paul, 2005; Ghatak and Basu 2013; Chalapathi Rao 2014). We carried out detailed investigations on some of the intrusions of lamproite clan. In light of our results, the previously published data have been critically evaluated and a palaeomagnetic pole for the lamproite dykes has been established. The pole is remarkably similar to the grand mean pole reported for the Rajmahal traps. The combined results are used to evaluate whether or not the Kerguelen mantle plume migrated southward as predicted by numerical experiments.

⁎ Corresponding author.
E-mail address: tradha1@rediffmail.com (T. Radhakrishna).
2. Geological setting

Geological descriptions of these lamproites are given by many authors and most recently in a review article by Chalapathi Rao et al. (2014). Only the salient aspects are presented here. The Gondwana sedimentary basins in the Damodar valley of eastern India constitutes the east–west trending linear intracratonic basin developed over the Chotanagpur gneissic complex to the north of Singbhum craton (Fig. 1). These basins host thick pile of Gondwana sedimentary rocks formed through Upper Carboniferous to Lower Cretaceous. A number of coal fields are known from these sedimentary basins and the Raniganj coal field basin is the easternmost one in the Damodar valley. Ultrapotassic-ultramafic lamproite clan intrusions (lamprophyres, lamproites and orangeites) and mafic (dolerite) suite of rocks occur as dykes and sills.

The precise 40Ar/39Ar isotope dating yielded ages of 109–115 Ma for intrusions of lamproite clan (Kent et al., 1997; Kent et al., 1998; Coffin et al., 2002; P.R. Renne, Berkeley in Ghatak and Basu, 2013; see Table 1). At the same time, the mafic (dolerite) dykes have yielded ages of c. 115 Ma and c. 65 Ma (Kent et al., 2002). The lamproite dykes are only a few meters long and < 5 m in width (mostly < 1–2 m) and fresh in-situ exposures are very limited. Lamproite intrusions unearthed recently in fresh quarries were collected from vertical sections for the present study (Fig. 1).

Petrographic study shows that the lamproite samples are mainly composed of phlogopite, olivine, carbonates and Fe-Ti oxides (Fig. 2). The phlogopite is the major mineral constituent and it occurs as large lath-shaped phenocrysts ranging in size up to 1.5 mm and as groundmass. It is generally fresh without any visible alteration. Occasionally the phlogopite laths have near parallel arrangement that may be described as flow structure. Olivine also occurs as phenocrysts ranging in size up to 0.5 mm and as groundmass. It is altered mostly forming serpentine and iddingsite. Carbonate mostly occurs as groundmass. The Fe-Ti oxides occur as small discrete grains (< 40 μm size) and as alteration product along grain boundaries or within micro-fractures of olivine. Reflected light studies identify that the opaque minerals are mostly titanomagnetite.

3. Palaeomagnetism

3.1. Methods

A total of 21 oriented core samples were collected from three sites of lamproite intrusions in the Gondwana Basin of the Damodar valley. Oriented core samples were drilled in the field using Pamroi handheld drill (ASC Scientific; USA) and orientations were carried out in the field using magnetic compass and an in-house built orientation stage. Orientation markings were always made by keeping the magnetic compass over orientation stage at about twenty cm above the sampling surface. Thus the errors due to the rocks own magnetization are eliminated despite the use of a magnetic compass only. The oriented cores were sliced into one inch long specimens for palaeomagnetic measurements.

Thermomagnetic measurements (susceptibility as a function of temperature) were carried out on crushed sample from each site using Temperature-Susceptibility System (Bartington Ltd; UK). Heating experiments were carried out between 40 °C and 640 °C and then cooled back to 100 °C (at a rate of 5 °C/min) in air to estimate the Curie temperatures of major magnetic phases. Isothermal Remanent Magnetization (IRM) measurements were carried out for forward and reverse fields by Impulse magnetizer (ASC Scientific; USA model IM-10-30) by applying fields up to 1 T. Lowrie Fuller tests (Lowrie and Fuller, 1971) were conducted by demagnetizing the samples in successive steps up to 80 mT by applying 1 T field for acquisition of saturation isothermal remanent magnetisation (SIRM).

The natural remanent magnetisations (NRM) measurements were carried out on one specimen from each core sample and the same specimens were subjected to step-wise alternating field demagnetisations from 2.5 mT up to a field of 40 mT at 2.5 mT intervals or until demagnetisation is reduced by 95%. Magnetisation after each step was measured using the JR6 Spinner magnetometer (AGICO; Czech Republic) and the alternating field demagnetizer (ASC Scientific Ltd; USA) was employed for AF demagnetisations. Step-wise progressive incremental thermal demagnetization was also carried out on
The susceptibility to a ferrimagnetic mineral like magnetite at 550 °C, reflecting the transformation of weakly paramagnetic mineral to a ferrimagnetic mineral like magnetite above the NRM curve. In the IRM measurements (Fig. 5), the samples from GL-1 and GL-2 sites while the site GL-3 site has the IRM curve shown in Fig. 3a–c. The susceptibility finally drops down steeply indicating a Curie temperature of nearly 580 °C that corresponds to Tpoor titanomagnetite. The NRM and SIRM decay curves for representative samples using MMTD Thermal Demagnetiser (Magnetic Measurements; UK). Thermal demagnetisations were performed at 50 °C incremental steps from 150 to 500 °C and 20 °C incremental steps at 500–580 °C. Stereographic projections and orthogonal vector plots were employed to analyse the progressive AF and thermal demagnetisation data. Principle component analysis (PCA) by Kirschvink (1980) was used to isolate characteristic remanent magnetisation (ChRM) from steps constituting linear trajectories of consecutive points with angular uncertainty of < 1°. Fisher statistics (Fisher 1953) was employed for computing mean-site directions, radius of cone of confidence (α95) and the precision parameter (k).

### 3.2. Results

Temperature susceptibility spectra of representative samples are shown in Fig. 3a–c. The samples are characterised by irreversible thermomagnetic curves with higher levels of susceptibility during cooling cycle. The magnetic susceptibility remains constant while heating up to 400–450 °C, beyond which susceptibility increases up to 550 °C, reflecting the transformation of weakly paramagnetic mineral (high Ti-titanomagnetite) to a ferrimagnetic mineral like magnetite (Dong et al., 2014). The susceptibility finally drops down steeply indicating a Curie temperature of nearly 580 °C that corresponds to Tpoor titanomagnetite. The NRM and SIRM decay curves for Lowrie Fuller tests (Fig. 4a–c) shows the NRM curves going above the IRM curves for GL-1 and GL-2 sites while the site GL-3 site has the IRM curve above the NRM curve. In the IRM measurements (Fig. 5), the samples from GL-1 and GL-2 sites saturated within 300 mT, with S ratio (IRM-0.3T/SIRM) close to unity (0.98) while the GL-3 site sample doesn’t reach saturation even at 1000 mT, and its S-ratio is about half the unity (0.49). At the same time softIRM (SIRM-IRM-0.03T) is greater than hardIRM (SIRM-IRM-0.3T) and the remanent coercive force values are in the range of 11–31 mT for all the samples. These results suggest the dominance of single domain magnetite in GL-1 and GL-2 sites where as the GL-3 site contains mixture of multidomain magnetite, hematite and SD magnetite.

NRM directions from the lamproites are highly scattered and intensities are generally low (< 1 mA/m–328 mA/m). During AF demagnetisations, the initial NRMs have decreased drastically by 5–10 mT steps and viscous components are removed and characteristic magnetisations were recovered in the steps between 5 and 40 mT. Thermal demagnetisations show scatter of directions beyond 400–450 °C that correspond to temperatures where phase changes were noticed in thermomagnetic experiments. Steps up to 400 °C either show gradual decrease of intensities (particularly for site GL-2) or remain near constant and suddenly fall at the unblocking temperature. The samples may attain directions similar to ChRMs derived from AF demagnetisations in steps between 250 and 400 °C, but robust ChRMs can be determined using AF demagnetisations.

Typical examples of the response to AF and thermal demagnetisation are shown as Zijderveld and stereographic plots (Figs. 6 and 7). The ChRM directions are determined using 3–8 successive AF demagnetisation steps (Table 2). All the three sites of lamproites yielded moderately steep upward northwesterly ChRM directions (Fig. 8). Sites GL-1 and GL-2 obtained coherent within-site directions (α95 < 11.5°) and the GL-3 directions are less coherent (α95 = 18.1°). However, confidence circle of the GL-3 site shows significant overlap with the confidence circles over the mean of other two sites and the mean of GL-3 site is distributed within the confidence circle of the overall mean. The mean directions from the three sites obtained a between-site mean direction of D = 330.6°; I = -59.3° (α95 = 13.2° k = 88; N = 3). There have been a few other reports of paleomagnetic results on the lamproite clan of rocks in the eastern India. We critically evaluate these results in the following section on the basis of our present study and in light of more precise isotope age data to estimate the best paleomagnetic pole for the lamproite intrusions within the Gondwana Basins in India.
Fig. 2. Photomicrographs of the lamproite from Damodar valley showing (a) euhedral phlogopite laths and altered olivine set in a groundmass matrix (plane polarised light) and (b) disseminated grains of titanomagnetites (reflected light).

Fig. 3. Thermomagnetic plots depicting susceptibility-temperature variations for the representative lamproite samples in eastern India. Heating and cooling curves are indicated by forward and backward arrows.
the eastern India.

4. Discussion

4.1. Reassessment of previous results and the mean ChRM of the lamproites in the eastern India

The initial report of paleomagnetism on intrusive rocks in the Gondwana Basins dates back to 1970 (Athavale and Verma, 1970). These authors interpreted the results suggesting that the dykes constitute part of a single prolonged igneous event covering the eastern Rajmahal and the western Deccan traps. Rigorous reevaluation of K-Ar results (Baksi, 1994) and subsequent 40Ar/39Ar isotope age determinations clearly distinguish the Deccan and Rajmahal episodes as two distinct large igneous provinces within a short time span at c. 65–70 Ma and c. 110–115 Ma respectively (Vandamme et al., 1991; Chenet et al., 2009; Baksi, 1995; Ray et al., 2005; Kent et al., 1997, 2002). The early palaeomagnetic results were obtained by more nascent in-house built Astatic magnetometers using limited steps of alternating field de-magnetisations. In view of such inherent weakness, these results are not considered here for further analysis.

The precise 40Ar/39Ar isotope dating of phlogopite/biotite minerals of the lamproite clan of rocks from the Gondwana formations in the Damodar valley yielded 109–116 Ma ages (Kent et al., 1998; Coffin et al., 2002; P.R. Renne, Berkeley in Ghatak and Basu, 2013; see Table 1). At the same time, the mafic (dolerite) dykes have yielded ages of 112–115 Ma and c. 65 Ma that correspond to both Rajmahal and Deccan LIPs respectively (Kent and Pringle in Kent et al., 1997; Kent et al., 2002; Table 1). It follows that the lamproite clan rocks are clearly of c. 109–115 Ma whereas the mafic dykes relate to either of the events. Patil and Arora (2008) reported palaeomagnetism results from the dykes of lamproite clan, Salma mafic dyke and sedimentary formations in the Damodar Valley. In calculating the mean direction, they combined a direction from Salma mafic dyke and two sites of sedimentary formations. The Salma dyke is included into the group arguing that palaeomagnetism of this dyke is similar to that of lamproites. Similarly, the remagnetisations in sedimentary formations were attributed to Rajmahal event. However, the Salma dyke yielded a high precision 40Ar/39Ar plateau age of 65.4 ± 0.3 (Kent et al., 2002); it is petrologically very distinct from lamproites and genetically linked to the Deccan traps (Paul, 2005). The reported magnetisation of this dyke has a very steep upward inclination (−83.5°) that is not known from Rajmahal/Deccan traps or from coeval intrusive rocks in the eastern India. The measured direction is likely to have recorded some spurious magnetisation or, less likely, it may represent extreme levels of secular variation in the Deccan activity. Thus, we do not incorporate this dyke into lamproite group. Similarly it is not possible to relate unambiguously the remagnetisations in sedimentary formations to the Rajmahal event. We consider the directions from 6 other sites of lamproite only to correspond to c. 109–115 Ma with certainty. Among them, VGP of their site 2 is remotely placed at 30° away from the mean VGP and is considered as an outlier. Comparable directions were also reported from three sites of the intrusive rocks in the Raniganj/Bokaro basins (Basu Mallik et al., 1999). Combining results from these three studies, an overall mean direction of the lamproite intrusions is calculated as $D = 331.3°; l = -62.4°$ ($\alpha q = 6.2°; k = 55; N = 11$). The corresponding paleopole is situated at $\lambda = 14.9°; \Phi = 287.6°$ ($\alpha q = 8.4°$). The confidence circle over the mean calculated from the combined results and the mean of our present results are almost indistinguishable (Fig. 8). The combined results show improved precision and the mean direction from all sites are considered to represent the mean direction of these lamproite intrusions. The angular standard deviation of $14.5° \pm 7.3°/−4.0°$ is calculated from the virtual geomagnetic poles of our and other quality results from the coeval intrusive rocks in the eastern India. It is comparable with the scatter of the geomagnetic poles predicted (McFadden and McElhinny, 1990) at the latitude positions during the period of lamproite intrusion and thus average out secular variations and the mean pole is in conformity with the GAD model.
4.2. Comparison with synthetic APWP and implications to kerguelen plume event

The palaeopole is plotted (Fig. 9) over a 0–120 Ma synthetic apparent polar wander path of India derived from Global Apparent Polar Wander Path (GAPWaP) of Torsvik et al. (2012). For comparison, the Deccan superpole determined along E-W Nagpur-Bombay and N-S Nasik-Mahabaleswar traverse (Vandamme et al., 1991; Chenet et al., 2009), grand mean poles of the Rajmahal (Basu Mallik et al., 1999) and the 85–90 Ma west coast igneous units (Radhakrishna and Joseph, 2012) are also plotted. The lamproite pole confidence circle does not incorporate either of the Deccan poles and only peripherally overlaps the A95 circle of the 85–90 Ma pole. It incorporates A95 circle of the Rajmahal pole completely. The A95 circle of the lamproite intrusions overlaps the circles over 100 Ma (window of 90–110 Ma), 110 Ma (Window of 100–120 Ma) synthetic poles with their mean pole distributed between the 100 and 110 Ma poles. Hence based on the weighted ages of the two synthetic poles, a palaeomagnetic age of 104 ± 9 Ma is interpreted based on GAPWaP of Torsvik et al. (2012) and the synthetic APWP of Besse and Courtillot (2002). Acton (1999) adopted a different method of generating APWP of India by predicting palaeomagnetic poles using Palaeomagnetic Euler Pole (PEP) that defines a small circle track for the 0–80 Ma Indian palaeomagnetic data and extrapolated out to 120 Ma. The PEP predicted pole of Acton...
The lamproite pole is in the closest proximity (2.4°) to the 100 Ma PEP predicted pole. These ages, within the limits of uncertainties, are in agreement with the c. 109–116 Ma 40Ar/39Ar ages on the lamproites. All the sites of present and previous study of lamproites are unipolar, with normal polarity magnetizations, in contrast to the bipolarity and dominance of reverse polarity in the Deccan volcanics (cf; Chennet et al., 2009). The normal polarity in the lamproites and Rajmahal and the palaeomagnetic and isotopic age estimates link this LIP event with the 34N Cretaceous superchron (83–117 Ma; Cande and Kent, 1995).

N = number of samples yielded stable directions constituting the group; D and I are declination and inclination (in degrees) respectively of the characteristic remanent magnetic directions; k = precision parameter; \( \alpha_{95} \) = radius of the 95% confidence; \( \lambda \) and \( \Phi \) are respectively the latitude and longitude of the VGPs calculated. Superscripts a and b denote the data from Basu Mallik et al. (1999) and Patil and Arora (2008).

Fig. 8. Equal-area projection showing the mean characteristic magnetisations with \( \alpha_{95} \) confidence circles of the lamproite intrusions in Gondwana basins of eastern India. The site mean directions of present study and combined with previous studies are shown in blue and red. Directions plotted in broken lines as they all fall in upper Hemisphere. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Fig. 9. Mean palaeomagnetic pole data of the lamproite intrusions along with synthetic apparent polar wander path based on Torsvik et al. 2012 GAPWaP model. Deccan-1 is the overall mean pole of E-W Nagpur-Bombay traverse (\( \lambda = 36.9, \Phi = 281.3; \alpha_{95} = 2.4; \) Vandamme et al., 1991). Deccan-2 is the overall mean pole of N-S Nasik-Mahabaleswar traverse (\( \lambda = 37.8, \Phi = 282.6; d_{p}, d_{m} = 3.2, 5.1; \) Chennet et al., 2009). The grand mean pole of 85–90 Ma igneous rocks (\( \lambda = 24.0, \Phi = 293.0; \alpha_{95} = 5.9; \) Radhakrishna and Mathew Joseph, 2012) and the Rajmahal traps (\( \lambda = 11.2, \Phi = 296.0; \alpha_{95} = 2.0; \) Basu Mallik et al., 1999) are also plotted for comparison. The PEP predicted pole for India at 100 Ma which is in close proximity to the palaeopole estimated for the lamproites is shown in red with \( \alpha_{95} \) circle. Detailed explanation is given in text. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

(1999) at 100 Ma is also plotted in Fig. 9. The lamproite pole is in the closest proximity (2.4°) to the 100 Ma PEP predicted pole. These ages, within the limits of uncertainties, are in agreement with the c. 109–116 Ma 40Ar/39Ar ages on the lamproites. All the sites of present and previous study of lamproites are unipolar, with normal polarity magnetizations, in contrast to the bipolarity and dominance of reverse polarity in the Deccan volcanics (cf; Chennet et al., 2009). The normal polarity in the lamproites and Rajmahal and the palaeomagnetic and isotopic age estimates link this LIP event with the 34N Cretaceous superchron (83–117 Ma; Cande and Kent, 1995).

Near identical palaeomagnetic results, coeval isotope ages of the lamproite dykes and the Rajmahal traps and the proposed links between the Rajmahal traps and the Kerguelen plume permit us to draw inferences to the fixity/moving hotspot arguments (O’neill et al., 2003; Steinberger et al., 2004; Steinberger and Torsvik, 2008; Torsvik et al., 2012; Doubrovine et al., 2012; Zhao and Ernesto, 2013 and references therein). Fixed hotspot reference frame has been used as the basis to determine absolute plate motions and place the Kerguelen plume around 1000 km south of the Rajmahal at the time of their formation. Consequently it is difficult to establish genetic linkage between the Rajmahal traps and the Kerguelan mantle plume. Numerical experiments and a variety of tomographic models demonstrated the motion of...
hotspots in a convecting mantle (Steinberger and O’Neill, 1998; O’Neill et al., 2003; Steinberger et al., 2004; Torvik et al., 2008; Steinberger and Torvik, 2008; Torvik et al., 2012; Doubravine et al., 2012 and references therein) and some of them predicted at least 5° southward motion for the Kerguelen plume in the past 100 Ma. This scenario provides evidence for a genetic link between the Kerguelen plume and the Rajmahal traps. The combined palaeomagnetic data presented here on lamproite intrusions estimate a paleolatitude of 43.7° ± 7.7° S (transferred to Rajmahal coordinates: 25.05°: 87.84°) and it is consistent with the palaeolatitudes derived for the Rajmahal traps (44.8° ± 2.4° S) calculated from grand mean of 106 sites (Basu Mallik et al., 1999) and the 100.4 ± 0.71 Ma 40Ar/39Ar age; Duncan, 2002) Central Kerguelen lava flows (ODP Leg 183; Site 1138: 43.6° ± 4.2° S; Anttretter et al., 2002). Comparable palaeolatitudes (43.4°) are reported from basalt sequence at the ODP Site 565 of Leg 121 on the Ninetyeast ridge although a little higher palaeolatitudes were obtained (up to 50°S) from basalt sites at Sites 757 and 758 where tectonic disturbances or substantial overprinting occurred (Klootwijk et al., 1991). All these palaeopoles are at least 5° north of the present day Kerguelen plume activity. True polar wander may also contribute to this latitudinal discrepancy. Doubravine et al. (2012) demonstrated significant conflict of true polar wander in the time interval between 120 and 100 Ma based on moving hotspot models. A true polar wander motion indicates a further southward position than the present-day location for the Kerguelen hotspot (for example Fig. 4; O’Neill et al., 2003). Thus, the paleomagnetic results point out a southward migration for the Kerguelen mantle plume. Our recent studies on the Marian and the Reunion mantle plume related magmatic rocks in India (Radhakrishna and Joseph, 2012) suggested southward and northward migration of these plumes respectively. Thus, our results from the Indian Ocean region are in agreement with predictions from numerical models of global mantle circulation and suggest migration of mantle plumes is a reality.

5. Conclusions

Fixity vs migration of the mantle plumes is a topic of debate in recent years. It has significant implications for determining absolute plate motions. Numerical models and palaeomagnetism of the ODP sites suggest a southward motion for the Kerguelen plume in the southeast Indian Ocean region. We have carried out new palaeomagnetism study and reevaluated all existing data from the Kerguelen plume related lamproites (c.110 Ma) from continental segment in the eastern India. The study is aimed at determining a reliable palaeomagnetic pole of the lamproite intrusions and to test the models favouring southward motion for the Kerguelen plume. The results permitted us to establish a reliable pole for the lamproites and the pole is comparable remarkably with the grand mean pole of the Rajmahal LIP which represents the head of the Kerguelen plume. The paleopole estimated here for the eastern Indian Ocean region are in agreement with predictions from numerical models of global mantle circulation and suggest migration of mantle plumes is a reality.

Acknowledgments

This is a part of our ongoing research works under the grants (ESS/16/090/97 and SR/S4/ES-598/2011) from the Department of Science and Technology, Government of India. GSS also acknowledges research grant from University Grants Commission [Grant No.F.2-7/2010 (SA-I)]. NCES permitted to carry out this research and provided support. This paper is a contribution for the IGCP 597 and 648. Drs. Tapan Paul and Mathew Joseph from the Geological Survey of India extended valuable help in field for sample collection.

References


