The terrace like feature in the mid continental slope region off Trivandrum and a plausible model for India-Madagascar juxtaposition in immediate pre-drift scenario

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Abstract

Bathymetry of the southwestern continental margin of India reveal the presence of an anomalous terrace like feature in the mid continental slope region off Trivandrum. The genesis of this terrace of large areal extent (~9000 sq. km.) is yet to be established. Based on exercises with several existing paleogeographic reconstruction models and updated compilation of identified offshore tectonic elements, this study attempts to identify a plausible model of India–Madagascar juxtaposition in immediate pre-drift scenario, which provides idea about genesis of this terrace. It is inferred that the terrace off Trivandrum and an anomalous bathymetric notch located in the northern Madagascar Ridge are conjugate features related to India-Madagascar separation and the rifted and sheared segments of the pre-drift plate boundary have shaped their outlines. The drifting of India from Madagascar is suggested to have commenced at about 86.5 Ma.

Key words: Terrace, Madagascar Ridge, India-Madagascar juxtaposition, Paleogeographic reconstruction, shear zones

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1. Introduction

The continental shelf of west coast of India (Fig. 1), limited by the 200 m isobath, has variable width. Towards north this shelf is relatively wider, being more than 300 km in the areas north off Mumbai coast, whereas towards south this width gradually narrows down to about 50 km off Trivandrum. As compared to the continental shelf, the continental slope in most of this region is relatively narrow and parallels the trend of the continental shelf edge. However, the continental slope region off Trivandrum (Fig. 1) interestingly depicts the presence of an anomalous broad terrace like feature, which has not drawn much attention of the researchers so far. The western continental margin of India, to which this terrace belongs, is considered to be a passive continental margin (Biswas, 1982, 1987), which evolved during the process of rifting and drifting of Madagascar, Seychelles and India. Even though researchers agree on the concept of a welded Madagascar–Seychelles–India continental block, but opinion differs regarding their immediate pre-drift juxtaposition and consequential early post drift positions. Probably lack of distinct and dependable "piercing points" such as onshore tectonic lineaments, which could have constrained this juxtaposition, is one of the reasons for those varied inferences. The other reason could be the absence of India-Madagascar break-up related magnetic isochrons, which could have allowed arriving at consistent rotation parameters for constraining early India–Madagascar separation, as that break-up took place during Cretaceous long normal superchron.

It was also observed that the outline of this terrace appears in the post anomaly 34 paleogeographic reconstructions of Norton and Sclater (1979) as well as of Besse and Courtillot (1988). However, those studies, apparently due to their emphasis on broader perspective, did not pay specific attention to this terrace or looked for its conjugate feature. Rao and Bhattacharya (1975) analyzed magnetic and seismic data in the northern part (off Quilon) of this terrace and attributed its genesis to block faulting of the basement. As mentioned by Storey et al. (1995), the eastern part of the northern Madagascar Plateau and a bathymetric high on the west side of the southern tip of India was inferred by Dyment (1991) to be conjugate with respect to the Mascarene Basin spreading ridge. However, subsequent researchers could not identify those inferred conjugate features and make their use to constrain India-Madagascar juxtaposition, since they were not depicted in publication. In view of this, an attempt has been made in this paper to identify those conjugate features distinctly through exercises with several available paleogeographic reconstruction models and use those conjugate features to arrive at a close fit model of India-Madagascar juxtaposition in their immediate pre-drift scenario.

2. The topography of the terrace like feature off Trivandrum

The bathymetry contour map (Fig. 1), shows a conspicuously wide low gradient zone in the mid continental slope region off Trivandrum. This zone broadly lies between 1000 m and 2000 m isobaths and covers an area of about 9000 sq. km. Available eight bathymetric transects (Fig. 2 and Fig. 3) across this zone suggest this terrace as a relatively flat zone bounded by a steep ascending (by about 1000 m) seafloor to the adjacent continental shelf on easterly side and a comparable steep descending seafloor towards the deep sea in the westerly side. This topography appears to be anomalous as compared to the general topography depicted by contours and two bathymetric transects (Fig. 3) across the normal shelf-slope configuration in the north. This wide zone is considered to qualify well as a 'terrace' following the definition of Lapedes (1978) and for further reference in this study we denote this feature as 'Terrace off Trivandrum (TOT)'.

3. India-Madagascar juxtaposition at anomaly 34 time – varied inferences

For tracing the India-Madagascar separation one need to start with India-Madagascar juxtaposition. The aspect of paleogeographic juxtaposition of India and Madagascar have been directly addressed or indirectly depicted in number of studies. The qualitative juxtaposition models (Crawford, 1978; Katz and Premoli, 1979; Agrawal et al., 1992; Windley et al., 1994; Menon and Santosh, 1995; Dissanayake and Chandrajith, 1999; Pradeepkumar and Krishnanath, 2000; Torsvik et al., 2000; Anilkumar et al., 2001) are based on colinearity of inferred comparable onshore shear zones, geological domains or continental scale MAGSAT and gravity anomalies. On the other hand quantitative models are based on estimated finite rotation parameters. Based on the evaluation of those qualitative models by Yoshida et al. (1999) and other recent studies (Chetty and Bhaskar Rao, 2004; Radhakrishna et al., 2004) it appears that there is broad agreement about the comparable geological units and shear zones of southern India and Madagascar, however precise conjugate correspondence of these features is still awaited. According to Norton and Sclater (1979) separation of India and Madagascar started shortly before anomaly 34 time. Therefore, in the following paragraph, we briefly discuss some of those quantitative models (Norton and Sclater, 1979; Morgan, 1981; Besse and Courtillot, 1988; Muller et al., 1993) with focus on India–Madagascar relative position for the time of this anomaly 34 and show that the relative position of India and Madagascar vary in different models.

The paleogeographic reconstructions (Fig. 4a-d) prepared for this study are for the time of younger bound of anomaly 34 (i.e. anomaly 34ny). These reconstructions have been prepared using finite rotation parameters of different published models (Norton and Sclater, 1979; Morgan, 1981; Besse and Courtillot, 1988; Muller et al., 1993). Since the age corresponding to various magnetic isochrons in those studies are based on different geomagnetic timescales, therefore, for using those finite rotation parameters in this study, we have re-assigned the ages according to Cande and Kent (1995) geomagnetic time scale. It is generally agreed that the magnetic anomaly 34 identified in the southern Mascarene Basin represents the oldest anomalies formed shortly after India-Madagascar separation. Therefore, the paleo-ridge positions at anomaly 34ny and paleo-transforms have been marked using the available (Schlich, 1982; Dyment, 1991; Bernard and Munschy, 2000) magnetic anomaly identifications close to Madagascar in the Mascarene Basin and considered them fixed to African plate while generating reconstruction maps. We considered the 2000 m isobath obtained from recent GEBCO digital data set (Intergovernmental Oceanographic Commission et al., 2003) to define the continent-ocean boundary off India and Madagascar.

In the reconstruction (Fig. 4a) following Norton and Sclater (1979) model, we observed that the 2000 m isobaths off Indian coast as well off Madagascar coast are symmetric about the anomaly 34ny time ridge position and there is not much offset between the southern tips of India and Madagascar. The reconstruction following Morgan (1981) model provides a close fit (Fig. 4b) for India and Madagascar without any intervening gap at 83.0 Ma itself and the paleo-ridge overlaps Indian landmass at places. Further, in this reconstruction, we also observed that the southern tip of Madagascar is much south of the southern tip of India and the 2000 m isobath off Indian coast overlaps the Madagascar mainland. Reconstructions following model of Besse and Courtillot (1988) depict (Fig. 4c) the 83.0 Ma paleo-ridge positions closer to 2000 m isobath off Madagascar as compared to the same off Indian coast. The reconstruction model (Fig. 4d) following Muller et al. (1993) shows that the 2000 m isobaths off India as well off Madagascar are more or less symmetric about the paleo-ridge position, but towards north Madagascar is much closer to India. It appears that the models of Besse and Courtillot (1988) and Morgan (1981) are not appropriate for India-Madagascar relative motion as they place the anomaly 34ny time ridge axis asymmetrically with respect to the conjugate 2000 m isobaths. Based on our exercise, we believe that the model of Norton and Sclater (1979) provides a better approximation of India-Madagascar pre-anomaly 34ny time relative motion as it can accommodate the microcontinental fragments in the pre-drift India-Madagascar juxtaposition model.

4. Terrace off Trivandrum in a close fit India-Madagascar configuration

The Fig. 5a presents a reconstruction map of India-Madagascar juxtaposition for anomaly 34ny time (83.0 Ma), which we prepared using rotation parameters of Norton and Sclater (1979). As evidenced from this reconstruction map, we believe the shape of the 2000 m bathymetry contours off southwest Indian coast and southeast Madagascar coast strongly suggest the conjugate nature of the terrace off Trivandrum and the bathymetry notch in the northern Madagascar Ridge. As mentioned earlier, it is generally believed that separation of India and Madagascar started shortly before anomaly 34ny time and based on dated onshore volcanics this separation is considered to have been initiated around 88-91 Ma (Storey et al., 1995; Torsvik et al., 2000; Pande et al., 2001; Anil Kumar et al., 2001). If that is the case, then India and Madagascar were much closer as compared to their position in anomaly 34ny time reconstruction (Fig. 5a). In view of this we tried to reconstruct Madagascar and India for a pre-anomaly 34ny time close fit configuration. Since the finite rotation parameters to describe this motion are not readily available in Norton and Sclater (1979) model, so we tried to bring a closer fit of India and Madagascar by extrapolation, considering the same pole and rate of rotation as of anomaly 34ny time. This exercise provided a closer fit of India and Madagascar at 86.5 Ma and interestingly depicted a near fit (with slight overlap) of the terrace off Trivandrum with the bathymetric notch of the northern Madagascar Ridge. We tried to improve this fit by trial and error and believed to have obtained a reasonably good fit (Fig. 5b) of those terrace and notch for the same 86.5 Ma using a slightly modified Euler pole (Table 1) of Norton and Sclater (1979). In view of this, we are tempted to believe that this terrace off Trivandrum (TOT) and the bathymetric notch (BN) of northern Madagascar Ridge are the conjugate features inferred by Dyment (1991). It may be mentioned here that so far not enough anomaly 34ny magnetic isochrons have been mapped in the vicinity of northern Madagascar Ridge but published map do suggest the existence of traces of several fracture zones. Considering the disposition of this terrace (TOT) and bathymetric notch (BN) with respect to the trends of paleo-ridge and paleo-transform segments in the reconstruction map (Fig. 4a) it may not be unreasonable to believe that the shape of those conjugate features were controlled by the ridge and transform segments of the paleo-ridge which existed at 86.5 Ma.

According to Storey et al. (1995) the Madagascar Ridge is believed to be volcanic emplacement related to the motion of the African plate over Marion hotspot since 90 Ma. However, based on the difference in the nature of the crust, the Madagascar Ridge is considered to be divided, roughly by a transition zone along 32°S latitude, into a northern domain and a southern domain (Goslin et al., 1980; Schlich, 1982; Bhattacharya and Chaubey, 2001). The velocity-depth distribution of the southern domain is closely related to that of a mean oceanic crust, but the crust underlying the northern domain is considered to be anomalous as it is neither purely continental nor of oceanic affinity. Perhaps the terrace off Trivandrum also have a similar nature of crust as its conjugate areas of the northern Madagascar Ridge and probably represents areas of thinned continental crust on which at places Marion hotspot related volcanics might have been emplaced.

Several authors (Barron, 1987; Lawver et al., 1999) considered the unusual steep and straight edge of eastern Madagascar as an evidence of transform motion between India and Madagascar, which believed to have taken place between 160 and 105 Ma. It is therefore necessary to examine the compatibility of our proposed model of juxtaposed conjugate TOT and BN and the transform motion between India and Madagascar, because a locked-in TOT and BN would have prevented such a transform motion. It may be noted that the inferred transform motion between India and Madagascar had taken place about 18 m.y. prior to the locked-in TOT and BN model which we have proposed for an India–Madagascar immediate pre-drift scenario at about 86.5 Ma. The region which later developed into TOT and BN might have existed simply as adjacent crusts across the transform boundary subsequent to the transform motion. Later, this area probably thinned when it came under the influence of Marion hotspot, and the bathymetric protrusion (TOT) and notch (BN) were formed by the initial geometry of the spreading axis when spreading was initiated between India and Madagascar. Assumption of such an initial spreading geometry in this region appears to be reasonable based on disposition of the TOT with respect to the reconstructed Mahanoro and Mauritius Fracture zones along with their intervening magnetic anomaly 34 (Fig.4a).

Our proposed close fit (Fig. 5b) depicts the existence of a wide gap between the conjugate 2000 m isobaths in the areas north of TOT. On the other hand we have not shown the disposition of Seychelles microcontinent in this model and we also need to provide space for accommodation of Laxmi Ridge, Saya de Malha Bank, and Laccadive Plateau, in case they are microcontinental slivers as believed by some authors (Krishnan, 1968; Naini and Talwani, 1982; Plummer and Belle, 1995; Todal and Eldholm, 1998; Talwani and Reif, 1998; Bhattacharya and Chaubey, 2001; Collier et al., 2004; Lane et al., 2005), which existed between India and Madagascar in pre-drift scenario. We feel accommodation of these features is possible in our 86.5 Ma India-Madagascar close fit model and to depict that possibility we presented a schematic map (Fig. 6) where major portion of these features (outlined by the simplified surrounding present 2000 m isobath) have been accommodated in the gap available between the conjugate reconstructed 2000 m bathymetric contours. Since these features are inferred as thinned continental crust, therefore, their present extents perhaps are much larger than their original pre-thinning state. Therefore, we feel they could be more conveniently accommodated in the gap in their pre-thinning dimension. As mentioned earlier, perhaps there was some crustal extension in the regions of the TOT and BN before the spreading event, and therefore, the unstretched TOT and BN would have fitted slightly better and closer, but the overall scenario would have remained the same.

5. Summary and conclusions

We believe to have presented a better constrained model for a close fit juxtaposition of India and Madagascar in the immediate pre-drift tectonic scenario. This model suggests that the bathymetric protrusion of the terrace like feature off Trivandrum (TOT) fits well in shape and size with the bathymetric notch (BN) located in the northern Madagascar Ridge and they lock well in a close fit India-Madagascar configuration. This fit can be obtained for an 86.5 Ma reconstruction using a slightly modified finite rotation parameters of Norton and Sclater (1979) for relative motion of India with Africa. This model also appears to accommodate Seychelles, Laxmi Ridge, Saya de Malha Bank and Laccadive Plateau as intervening microcontinental slivers. In view of these, it is inferred that the terrace off Trivandrum and the bathymetric notch of the northern Madagascar Ridge represent scars related to India–Madagascar break-up, the outlines of which were shaped by the rifted and transforms segments of the initial spreading geometry and the drifting of India from Madagascar was initiated around 86.5 Ma.

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References

Agrawal, P.K., Pandey, O.P., Negi, J.G., 1992. Madagascar: A continental fragment of the paleo-super Dharwar craton of India. Geology, 20, 543-546.

Anil Kumar, Pande, K., Venkatesan, T.R., Bhaskar Rao, Y.J., 2001. The Karnataka Late Cretaceous dykes as products of the Marion hotspot at the Madagascar - India breakup event: evidence from $^{40}Ar/^{39}Ar$ geochronology and geochemistry. Geophysical Research Letters, 28, 2715-2718.

Barron, E.J., 1987. Cretaceous plate tectonic reconstructions. Palaeogeography, Palaeoclimatology, Palaeoecology, 59, 3-29.

Bernard, A., Munschy, M., 2000. Le bassin des Mascareignes et le bassin de Laxmi (océan Indien occidental) se sont-ils formés à l'axe d'un même centre d'expansion ?: Comptes Rendus de l'Académie des Sciences - Series IIA - Earth and Planetary Science, 330, 777-783.

Besse, J., Courtillot, V., 1988. Paleogeographic maps of the continents bordering the Indian Ocean since the Early Jurassic. Journal of Geophysical Research, 93, 11791-11808.

Bhattacharya, G.C., Chaubey, A.K., 2001. Western Indian Ocean - a glimpse of the tectonic scenario. In: Sengupta, R., Desa, E. (Eds.), The Indian Ocean - a perspective. Oxford & IBH, New Delhi, 691-729.

Biswas, S.K., 1982. Rift basins in western margin of India and their hydrocarbon prospects with special reference to Kutch Basin. American Association of Petroleum Geologists Bulletin, 66, 1497-1513.

Biswas, S.K., 1987. Regional tectonic framework, structure and evolution of the western marginal basins of India. Tectonophysics, 135, 307-327.

Cande, S.C., Kent, D.V., 1995. Revised calibration of the geomagnetic polarity time scale for the Late Cretaceous and Cenozoic. Journal of Geophysical Research, 100, 6093-6095.

Chetty, T.R.K., Bhaskar Rao, Y. J., 2004. Structural framework of south India and the significance of major shear zones. Joint AOGS 1st Annual Meeting & 2nd APHW Conference, Asia Oceania Geosciences Society, Singapore, Abstracts, I, 54-55.

Collier, J.S., Minshull, T.A., Kendall, J.M.., Whitmarsh, R.B., Rümpker, G., Joseph, P., Samson, P., Lane, C.I., Sansom, V., Vermeesch, P.M., Hammond, J., Wookey, J., Teanby, N., Ryberg, T., Dean, S.M., 2004. Rapid continental breakup and microcontinent formation in the Western Indian Ocean. EOS, Transactions, American Geophysical Union, 85, 481.

Crawford, A.R., 1978. Narmada-Son lineament of India traced into Madagascar. Journal of Geological Society of India, 19, 144-153.

Dissanayake, C.B., Chandrajith, R., 1999. Sri Lanka - Madagascar Gondwana linkage: evidence for a Pan-African mineral belt. Journal of Geology, 107, 223-235.

Dyment, J., 1991. Structure et évolution de la lithosphère océanique dans l'océan Indien: apport des données magnétiques. Doctorate Thesis, Université Louis Pasteur.

Goslin, J., Segoufin, J., Schlich, R., Fischer, R.L., 1980. Submarine topography and shallow structure of the Madagascar Ridge, Western Indian Ocean. Geological Society of America Bulletin, 91, 741-753.

Intergovernmental Oceanographic Commission, International Hydrographic Organization, British Oceanographic Data Centre, 2003. General Bathymetric Chart of the Oceans (GEBCO) Digital Atlas (CD ROM). British Oceanographic Data Centre, Birkenhead.

Katz, M.B., Premoli, C., 1979. India and Madagascar in Gondwanaland based on matching Precambrian lineaments. Nature, 279, 312-315.

Krishnan, M.S., 1968. Geology of India and Burma. Higgin-Bothams, Madras.

Lane, C.I., Minshull, T.A., Collier, J.S., Whitmarsh, R.B., Sansom, V., Evans, M.M., 2005. Extensive magmatism during the formation of the Laxmi Ridge rifted margin, NW Indian Ocean. Geophysical Research Abstracts, 7, 04954.

Lapedes, D.N., 1978. McGraw-Hill Dictionary of Scientific and Technical Terms. McGraw-Hill Book Company, New York.

Lawver, L.A., Gahagan, L.M., Dalziel, I.W.D., 1999. A tight fit – Early Mesozoic Gondwana, a plate reconstruction perspective. Memoirs of National Institute of Polar Research Special Issue, 53, 214-229.

Meissner, B., Deters, P., Srikantappa, C., Kohler, H., 2002. Geochronological evolution of the Moyar, Bhavani and Palghat shear zones of southern India: implications for east Gondwana correlations. Precambrian Research, 114, 149-175.

Menon, R.D., Santosh, M., 1995. A Pan-African gemstone province of East Gondwana. In: Yoshida, M., Santosh, M. (Eds.), India and Antarctica during the Precambrian. Geological Society of India Memoir, 34, 357-371.

Morgan, W.J., 1981. Hotspot tracks and the opening of the Atlantic and Indian Oceans. In: Emiliani (Ed.). The Sea. Wiley Interscience, New York, 443-487.

Muller, R.D., Royer, J.Y., Lawver, L.A., 1993. Revised plate motions relative to the hotspot from combined Atlantic and Indian Ocean hotspot tracks. Geology, 21, 275-278.

Naini, B.R., Talwani, M., 1982. Structural framework and the evolutionary history of the continental margin of

Western India. In: Watkins, J.S., Drake, C.L. (Eds.). Studies in continental margin geology. American Association of Petroleum Geologists Memoir, 34, 167-191.

National Geophysical Data Centre, 1998. GEODAS CD-ROM, Worldwide Marine Geophysical Data. National Oceanic and Atmospheric Administration, US Department of Commerce, Washington, DC.

Norton, I.O., Sclater, J.G., 1979. A model for the evolution of the Indian Ocean and the break-up of Gondwanaland. Journal of Geophysical Research, 84, 6803-6830.

Pande, K., Sheth, H.C., Bhutani, R., 2001. ^{40}Ar - ^{39}Ar age of the St. Mary's Islands volcanics, southern India: record of India - Madagascar break-up on the Indian subcontinent. Earth and Planetary Science Letters, 193, 39-46.

Plummer, Ph.S., Belle, E.R., 1995. Mesozoic tectono-stratigraphic evolution of the Seychelles microcontinent. Sedimentary Geology, 96, 73-91.

Pradeepkumar, A.P., Krishnanath, R., 2000. A Pan-African 'Humite Epoch' in East Gondwana: implications for Neoproterozoic Gondwana geometry. Journal of Geodynamics, 29, 43-62.

Radhakrishna, T., Joseph, M., Mathai, J., 2004. Southern granulite terrain of India and constraints for the Precambrian continental assemblies, Joint AOGS 1st Annual Meeting & 2nd APHW Conference, Asia Oceania Geosciences Society, Singapore, Abstracts, I, 55-56.

Rao, T.C.S., Bhattacharya, G.C., 1975. Seismic profiler and magnetic studies off Quilon, south-west India. Indian Journal of Marine Sciences, 4, 110-114.

Schlich, R., 1982. The Indian Ocean: aseismic ridges, spreading centres, and oceanic basins. In: Nairn, A.E.M., Stehli, F.G. (Eds.), The Ocean Basins and Margins. Plenum Press, New York, pp. 51-147.

Storey, M., Mahoney, J.J., Saunders, A.D., Duncan, R.A., Kelley, S.P., Coffin, M.F., 1995. Timing of hotspot-related volcanism and the breakup of Madagascar and India. Science, 267, 852-855.

Talwani, M., Reif, C., 1998. Laxmi Ridge - a continental sliver in the Arabian Sea. Marine Geophysical Research, 20, 259-271.

Todal, A., Eldhom, O., 1998. Continental margin off western India and Deccan large igneous province. Marine Geophysical Research, 20, 273-291.

Torsvik, T.H., Tucker, R.D., Ashwal, L.D., Carter, L.M., Jamtveit, V., Vidyadharan, K.T., Venkataramana, P., 2000. Late cretaceous India - Madagascar fit and timing of breakup related Magmatism. Terra Nova, 12, 220-224.

Wessel, P., Smith, W.H.F., 1995. New version of the Generic Mapping Tools released. EOS, Transactions, American Geophysical Union, 76, 329.

Windley, B.F., Razafiniparany, A., Razakamanana, T., Ackermand, D., 1994. Tectonic framework of the Precambrian of Madagascar and its Gondwana connections. Geologische Rundschau, 83, 642-659.

Yoshida, M., Rajesh, H.M., Santosh, M., 1999. Juxtaposition of India and Madagascar: a perspective. Gondwana Research, 2, 449-462.

Figure Captions

Fig. 1. Generalized map of the southwestern continental margin of India along with selected (200 m, 1000 m and 2000 m) bathymetric contours obtained from recent GEBCO digital data set (Intergovernmental Oceanographic Commission et al., 2003). The dashed box indicates the area of the terrace like feature located off Trivandrum.

Fig. 2. Map showing location of selected bathymetry profiles across the southwestern continental margin of India along which the sectional views have been presented in Fig. 3. These bathymetry profiles have been obtained from the National Geophysical Data Centre (1998) and National Institute of Oceanography (NIO) databases. Other details as in Fig. 1.

Fig. 3. Selected bathymetric profiles across the southwestern continental margin of India showing the distinct sectional view of the terrace off Trivandrum as compared to the normal shelf-slope configuration along the northern profiles (SK22-02 and SK22-03). The locations of these profiles are shown in Fig. 2. and the depth levels of 1 and 2 kms. are labeled on the profiles.

Fig. 4. Various paleogeographic reconstruction models to show the varied juxtaposition of India with Madagascar at anomaly 34ny (83.0 Ma). Models a, and c are in fixed Africa reference frame while models b and d are in fixed hotspot reference frame. Locations of anomaly 34ny time paleo-spreading ridge segments are shown as thick black lines and transform segments by dashed lines. The 200 m and 2000 m isobaths surrounding India and Madagascar are shown by thin lines.

Fig. 5. Paleogeographic reconstruction of India and Madagascar in fixed Africa reference frame; (a) at 83.0 Ma following Norton and Sclater (1979) rotation parameters, (b) a plausible close fit at 86.5Ma following the additional rotation parameters suggested in this study (Table 1). Madagascar is in its present position. Land portions of India and Madagascar are shaded, surrounding 200 m isobaths are shown by thin lines and 2000 m isobaths are shown by thick lines. Locations of onshore shear zones simplified after Meissner et al. (2002) and Windley et al. (1994). TOT: Terrace off Trivandrum, BN: Bathymetric notch;

NMR: Northern Madagascar Ridge, ASZ: Achankovil Shear Zone, PCSZ: Palghat-Cauvery Shear Zone, MSZ: Moyar Shear Zone, RSZ: Ranotsara Shear Zone, AXSZ: Axial Shear Zone

Fig. 6. A schematic model showing possibility of accommodating Seychelles Bank [SEY] and other probable microcontinental slivers (Laccadive Plateau [LP], Laxmi Ridge [LR], Saya de Malha Bank [SM]) in the gap between the 2000 m bathymetry contours in a close fit India-Madagascar configuration at 86.5Ma. BH: Bombay High. Other details are as in Fig. 5.

Table Captions

Table 1. Suggested addition to the finite rotation parameters of Norton and Sclater (1979) to obtain a closer fit India and Madagascar in fixed Africa reference frame.

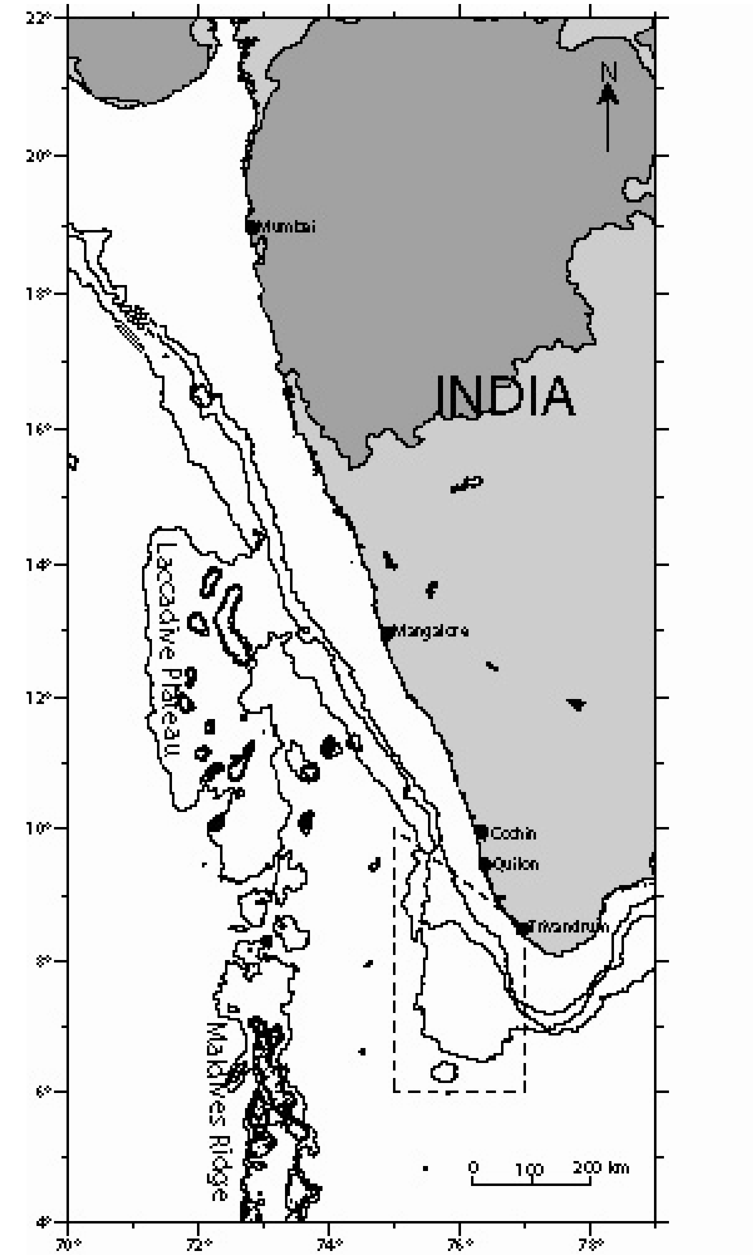

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Fig. 1

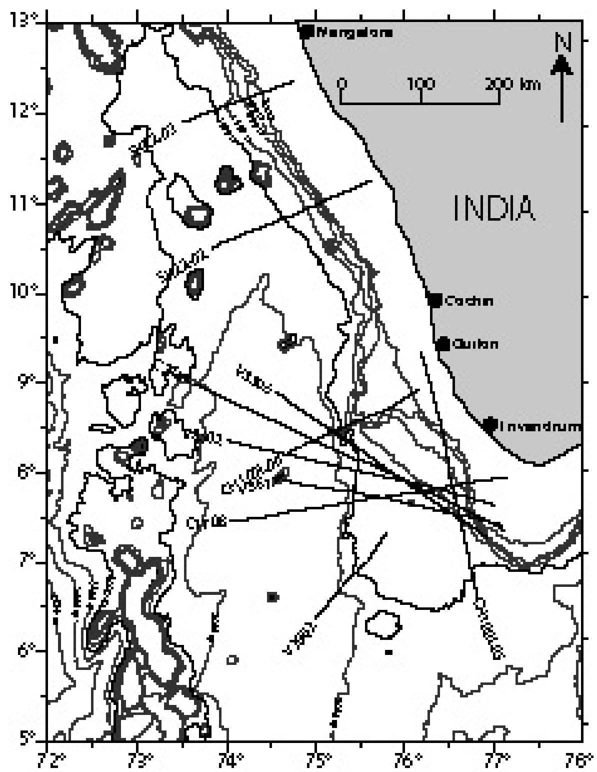
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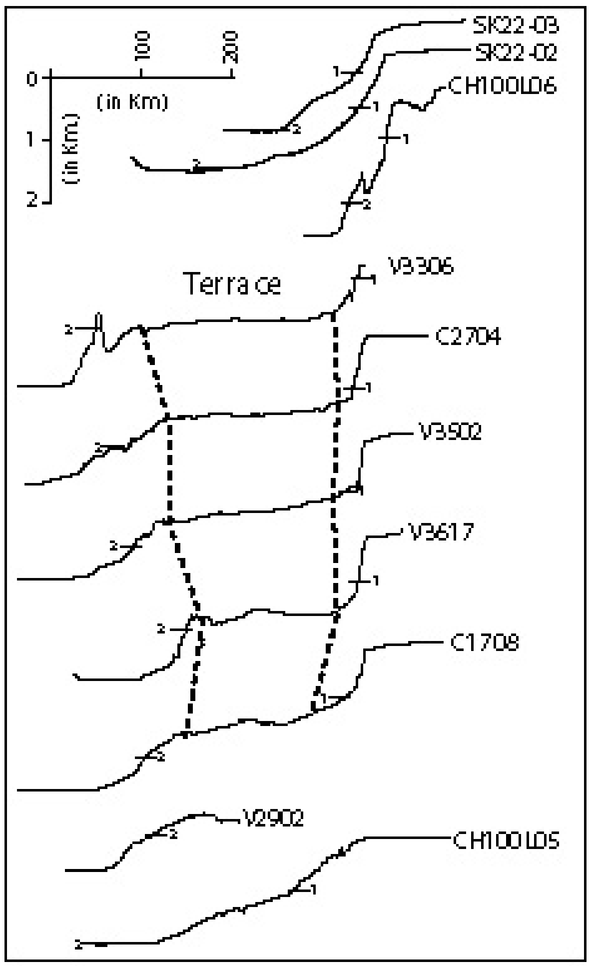
Fig. 2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CH100L05

Fig. 3

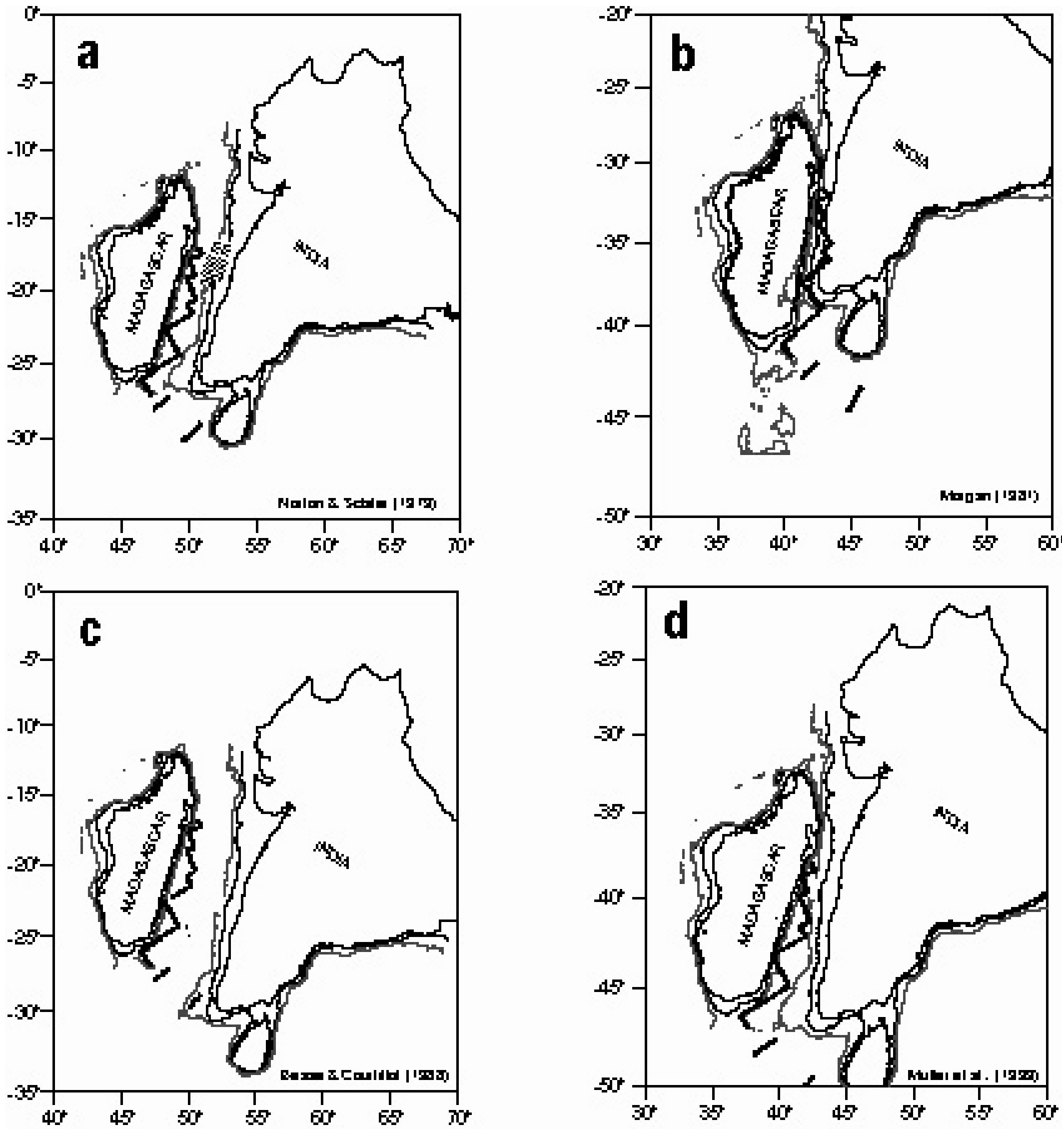
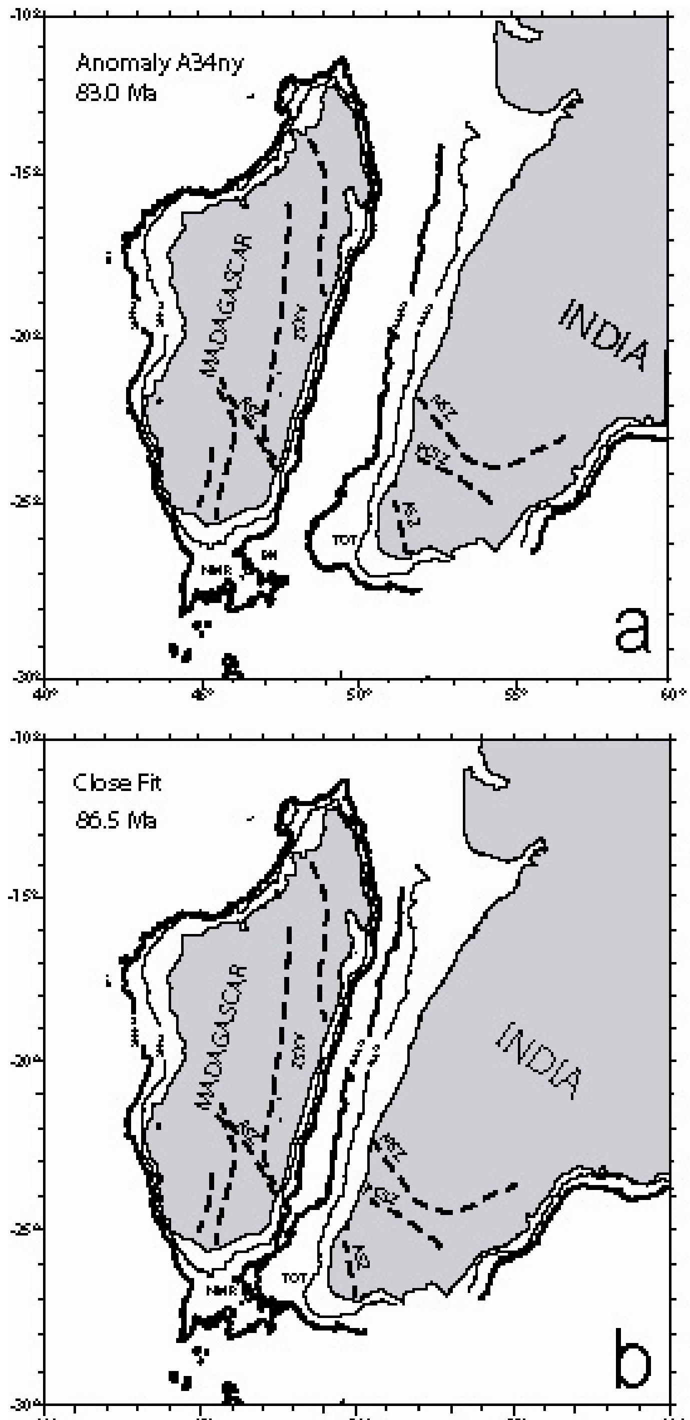


Fig. 4



Anomaly A34ny
83.0 Ma
MADAGASCAR
INDIA
a
Close Fit
86.5 Ma
MADAGASCAR
INDIA
b

Fig. 5

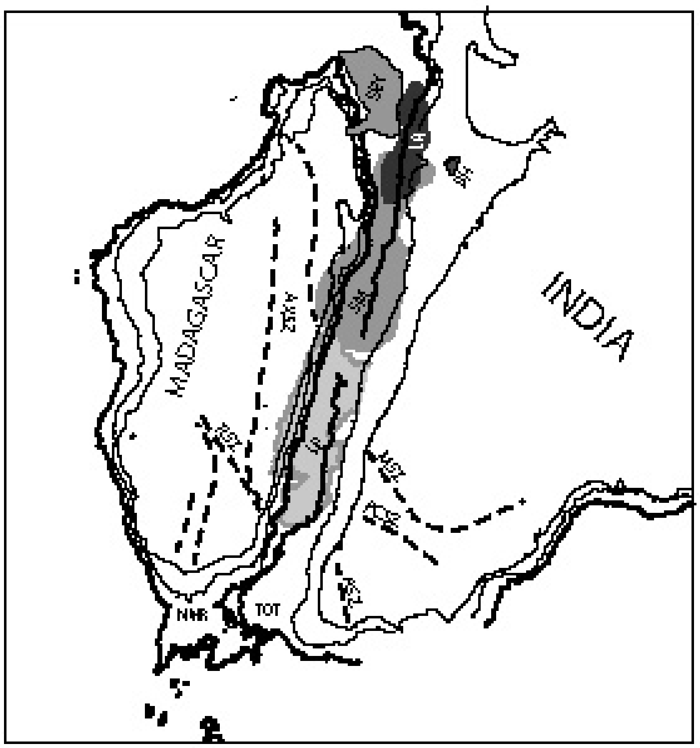


Fig. 6

Table 1.

Anomaly	Age (Ma)	Finite rotation parameters		
		Latitude (Deg.)	Longitude (Deg.)	Angle (° CCW)
34ny	83.0	18.7	25.8	-56.00
Close fit	86.5	18.7	26.4	-58.36

CCW: Counter Clock-Wise