



DECIPHERING DETAILED PLATE KINEMATICS OF THE INDIAN OCEAN AND DEVELOPING A UNIFIED MODEL FOR EAST GONDWANALAND RECONSTRUCTION: AN INDIAN- AUSTRALIAN-FRENCH INITIATIVE

V. YATHEESH¹, J. DYMENT²,
G.C. BHATTACHARYA¹, R.D. MULLER³
¹CSIR-National Institute of Oceanography, Dona Paula,
Goa-403 004, India

²Institut de Physique du Globe de Paris & CNRS,
Paris Sorbonne Cite, France

³School of Geosciences, University of Sydney,
NSW 2006, Australia

E-mail: yatheesh@nio.org

ABSTRACT

The Indian Ocean formed as a result of the fragmentation and dispersal of Gondwanaland since the Jurassic. The deep ocean basins in the Indian Ocean contain the imprints of this plate tectonic history, which is related with several major tectonic events. A broad model for evolution of the Indian Ocean was proposed in the early 1980s. Subsequently, Indian, French and Australian scientists acquired large amount of sea-surface magnetic data in different sectors of the Indian Ocean and their independent magnetic anomaly investigations provided better plate tectonic evolution models for different sectors of the Indian Ocean. Indian and French scientists, under two Indo-French collaborative projects, carried out detailed magnetic investigations in the northwestern and central Indian Ocean by combining the available magnetic data from conjugate regions and provided a detailed understanding of plate tectonic evolution of Indian-Antarctic and Indian-African plate boundaries. Those projects were complemented by additional area-specific studies in the Mascarene, Wharton, Laxmi and Gop basins, which are characterized by extinct spreading centres. During the same period, Australian scientists carried out investigations in the southeastern part of the Indian Ocean and provided an improved understanding of the plate tectonic evolution of the Indian-Australian and the Antarctic-Australian plate boundaries. Any improved model of plate kinematics of the Indian Ocean region should be compatible with the motions that are evident at all the above-mentioned plate boundaries and should also be able to explain the

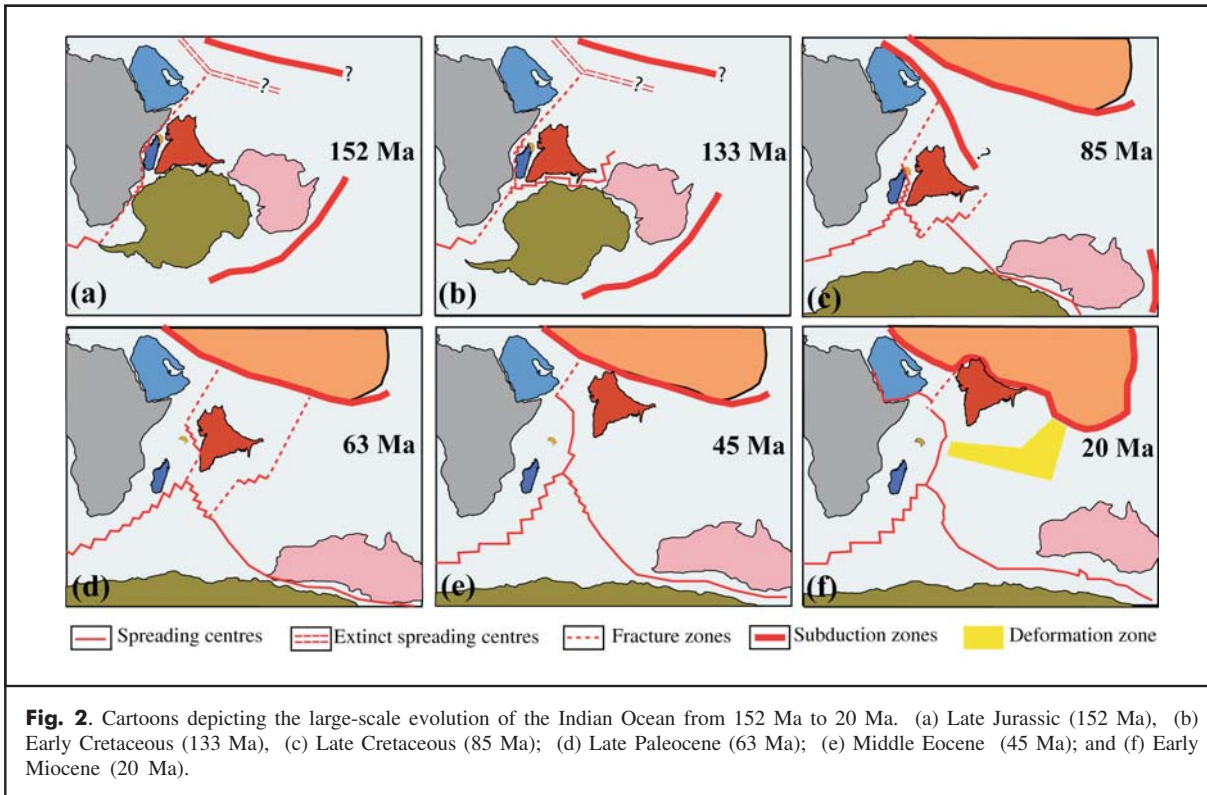
identified complexities. With an aim to develop such a unified model for the plate tectonic evolution of the Indian Ocean in high resolution, a project was initiated, under the auspices of an Indian-Australian-French collaboration, for the synthesis of all data available with the Indian, Australian and French scientists and work towards a unified high resolution plate tectonic model of the Indian Ocean.

INTRODUCTION

The configuration of continents, continental fragments and the deep-sea regions in the Indian Ocean (Fig. 1), as we see it today, results from the fragmentation and dispersal of Gondwanaland since the Jurassic ~ 152 million years ago. In this framework, the Indian Ocean was formed by the rifting and subsequent drifting of Africa, Antarctica, Australia, and India, to cite only the main continental blocks. The deep ocean basins in the Indian Ocean contain the imprints of this plate tectonic history, which is further affected by several major events such as Kerguelen, Marion and Reunion hotspots volcanism, the India-Eurasia collision and the compressive deformation of the Central Indian and Wharton basins.

A first general model for evolution of the whole Indian Ocean was proposed by McKenzie and Sclater (1971, *Geophys. J. R. Astron. Soc.*, v. 25, 437-528) mainly based on widely spaced geophysical data acquired during the International Indian Ocean Expedition (IIOE). Many subsequent studies (see Appendix-1) enriched the database, improved magnetic anomaly and fracture zone identifications and offered gradually better models for the plate tectonic evolution of this region, bringing into focus the tectonic complexities of this ocean basin. However, these models were developed separately for different regions and their combination does not provide a consistent evolutionary model for the whole Indian Ocean. Some inconsistencies result from the fact that the finite rotation parameters, computed by different studies across the present and past ridges of the Indian Ocean spreading system, are of different vintage resulting from identified magnetic anomalies using different geomagnetic polarity reversal time scales. It is therefore important to revisit the magnetic anomaly identifications and the evolution of the Indian Ocean in a common framework using the most reliable geomagnetic timescale to date and with several modern tools for better-constrained magnetic anomaly identifications and finite rotation parameter estimations.

With such an objective, under the auspices of two Indo-French collaborative projects funded by the Indo-French Centre for the Promotions of Advanced Research (ICPAR / CEFIPRA), New Delhi, a group of Indian and



Basin off Antarctica, the Perth, Cuvier, and Gascoyne abyssal plains off Western Australia and the Bay of Bengal Basin (**stage 2, Fig. 2b**). Spreading ceased in the Somali Basin at about 115 Ma and the plate boundary probably transferred to a transform fault between Madagascar and India, resulting in the attachment of Madagascar to the African plate. As a result of the Marion hotspot influence spreading started between Madagascar and Seychelles-India block at ~85 Ma (Late Cretaceous), resulting in the opening of the Mascarene and Madagascar basins. This period marks the establishment of a three-plate system with a triple junction in the Western Indian Ocean. In the Eastern Indian Ocean, the onset of the Kerguelen hotspot at ~110 Ma was followed by a major reorganization between 100 and 90 Ma, with spreading reorientation off Australia leading to the formation of the Wharton Basin, reorientation of the Indian-Antarctic plate boundary resulting in the opening of the Central Indian and Crozet basins, and initial seafloor spreading between Australia and Antarctica after a long period of continental rifting. The formation of this new spreading centre in the Australian-Antarctic Basin also marks the establishment of a three-plate system with a triple junction in the Eastern Indian Ocean, (**stage 3, Fig. 2c**). After its separation, the Seychelles-India block continued its northward drift and, at ~65 Ma (Late Cretaceous), was

affected by widespread volcanism at the origin of the Deccan Trap continental flood basalt province, resulting from the onset of the Reunion hotspot activity. As a consequence, spreading gradually ceased in the Mascarene Basin and was initiated between the Seychelles and India, opening the Carlsberg Ridge and forming the conjugate Arabian and Eastern Somali basins (**stage 4, Fig. 2d**). At ~50-55 Ma (Middle Eocene) a slowing down of the spreading rates was observed at the Carlsberg, Central Indian and Southeast Indian ridges. This slowing down is believed to be the consequence of collision of India (including its continental margin in the north) with an intra-oceanic island arcs system. Around ~45 Ma a severe reorientation of the spreading direction at these ridges was noticed. During this reorientation, spreading in the Wharton Basin ceased and spreading between Australia and Antarctica was accelerated. As a result Australia and India became part of the same plate (**stage 5, Fig. 2e**). At about 40 Ma the plate boundaries in the Indian Ocean began to assume the present day configuration. It should be mentioned, however, that the timing of contact between continental India and Eurasia is still a matter of scientific debate; some recent studies proposed that such a contact took place around ~34 Ma (Atchison *et al.*, 2007, *J. Geophys. Res.*, v. 112, doi:10.1029/2006JB004706). At ~30 Ma, under the influence of the



Afar hotspot in the East African region, continental rifting was initiated in the East African Rift, the Red Sea, and the Gulf of Aden. Seafloor spreading started at ~20 Ma on the Sheba Ridge and rapidly propagated westward in the Gulf of Aden (~15 Ma), then in the Red Sea (~5 Ma). Another important event that may have started at ~20 Ma and is still ongoing is the development of a wide deformed area in the Central Indian and Wharton basins, which isolates three rigid plates - India, Australia, and Capricorn - separated by what has been named "diffuse plate boundaries" (Stage 6, Fig. 2f).

MAGNETIC INVESTIGATIONS IN THE NORTHWEST INDIAN OCEAN

The Arabian and the Eastern Somali basins, in the northwest Indian Ocean, are conjugate basins formed at the Carlsberg Ridge. Indian scientists carried out magnetic investigations (Bhattacharya *et al.*, 1992, *Oceanography of the Indian Ocean, Oxford-IBH, 503-509*; Chaubey *et al.*, 1995, *Mar. Geol.*, v. 128, 105-114; Chaubey *et al.*, 1998, *Earth Planet. Sci. Lett.*, v. 154, 41-52) in the Arabian Basin using sea-surface magnetic profiles collected by the National Institute of Oceanography, India, complemented by magnetic profiles available from the GEODAS Marine Geology and Geophysics database of National Geophysical Data Centre (NGDC), USA. Their studies revealed the existence of several paleo-propagating ridge segments in the Arabian Basin. Independently, French scientist Jerome Dymont (1998, *J. Geophys. Res.*, v. 103, 24067-24084) carried out magnetic investigations in the northwest Indian Ocean and made similar inferences about the existence of paleo-propagating ridge segments in the northwest Indian Ocean. Though the evidence for ridge propagation were put forward, the data available with Indian and French scientists were not adequate to carry out independently the detailed mapping of magnetic lineations and the associated tectonic fabric such as pseudofaults and fracture zones from these conjugate basins.

The data available with the Indian and French scientists were complementary and a joint collaborative project was initiated in 1999 under the aegis of the Indo-French Centre for the Promotion of Advanced Research (IFCPAR / CEFIPRA), New Delhi. Under this project, an up-to-date and quality controlled sea-surface magnetic profiles database was created by integrating all the magnetic data available with the Indian (23 cruises) and French (13 cruises) scientists complemented by the magnetic profiles available through GEODAS Marine Geology and Geophysics database of NGDC (54 cruises). These data were used to identify magnetic lineations based on several conventional and modern techniques. For clearly

identifiable magnetic anomalies, the interpretation was carried out based on the conventional method of inter-profile correlation and comparison with synthetic anomaly models. In the regions where magnetic anomalies are ambiguous, magnetic anomalies were identified with the additional use of "magnetic tiny wiggles", which are second-order, correlatable detailed features of the magnetic anomalies. Having identified the magnetic anomalies, boundaries of these magnetized blocks (i.e., magnetic anomaly picks that represent estimate of age of the oceanic crust at that location) were delineated. **This study (Bhattacharya, Dymont and IFCPAR1911-1 team, 2003, IFCPAR project completion report, 32p.; Chaubey *et al.*, 2002, *Geol. Soc. London Sp. Pub. 195, 71-85*; Royer *et al.*, 2002, *Geol. Soc. London Sp. Pub. 195, 7-23*) could derive about 800 magnetic anomaly picks, which were used for detailed mapping of magnetic lineations and the associated tectonic fabric (Fig. 3) in the conjugate Arabian and the Eastern Somali basins between Chrons 28ny (~62.3 Ma) and 20ny (42.5 Ma). The updated finite rotation parameters**

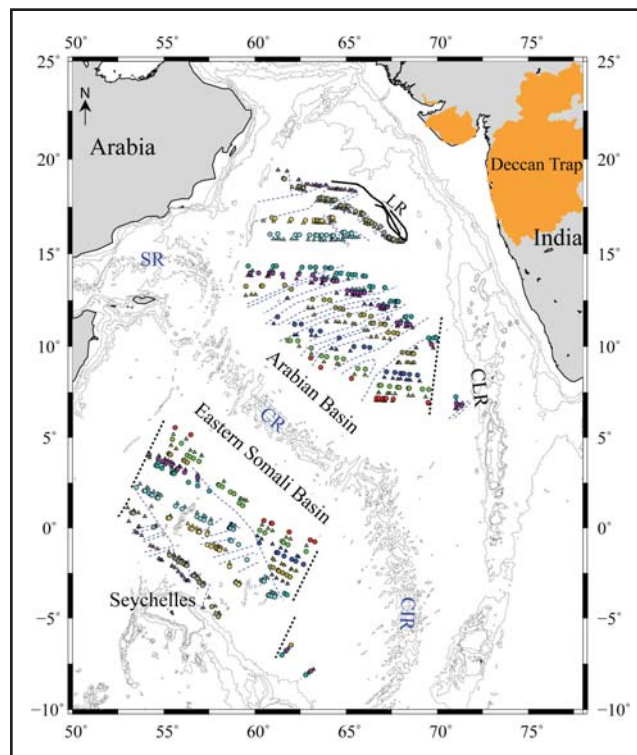


Fig. 3. Map showing updated magnetic anomaly picks in the conjugate Arabian and Eastern Somali basins, between Chrons 28ny (~62.5 Ma) and 20ny (~42.5 Ma). [Modified after Bhattacharya, Dymont and IFCPAR1911-1 team, 2003, IFCPAR project completion report, 32p]. Thick dashed black lines represent fracture zones and thin dashed blue lines represent pseudofaults. Abbreviations are as in Fig. 1.



derived from the above studies enabled to provide improved model of relative motion between Indian and African (now Somalian) plate boundaries in high-resolution.

MAGNETIC INVESTIGATIONS IN THE CENTRAL INDIAN OCEAN

The Central Indian, Crozet and Madagascar basins, located in the Central Indian Ocean, were formed as a result of rifting and subsequent drifting of India, Antarctica and Madagascar. The diverging relative motions among these Gondwanaland fragments since the Late Cretaceous created the Crozet Basin and its conjugate, the eastern part of the Central Indian Basin, at the Southeast Indian Ridge, and the Madagascar Basin and its conjugate, the western part of the Central Indian Basin, at the Central Indian Ridge. The trace of the Indian Ocean triple junction on the Indian plate defines the boundary between the eastern and western parts of the Central Indian Basin. The oceanic crust created in these basins carries the imprints of several major tectonic events such as (i) intense crustal deformation (observed in the Central Indian Basin and participating to the India-Capricorn diffuse plate boundary, formed during the last 20 Ma), (ii) the India-Eurasia collision (observed in all basins with, successively, decreasing spreading rates and a major spreading reorientation ~45 Ma), (iii) the onset of volcanism and further evolution of the Kerguelen, Marion, and Reunion hotspots since 110, 90, and 65 Ma, respectively (marked by the Ninetyeast Ridge and Kerguelen Plateau, the Madagascar and Crozet plateaus, and the Chagos-Laccadive Ridge and Mascarene Plateau, respectively). Subsequent to the magnetic anomaly investigation of Fisher *et al.* (1974, *Geol. Soc. Am. Bull.*, v. 85, 683-702), French scientists collected many data sets in the Crozet and Madagascar basins while Indian scientists acquired large amounts of data in the conjugate regions of the Central Indian Basin as a part of the Polymetallic Nodule Programme of India. The independent magnetic investigations by Indian scientists in the Central Indian Basin (Kamesh Raju and Ramprasad, 1989, *Earth Planet Science Lett.*, v. 95, 395-402; Kamesh Raju, 1993, *Mar. Geol.*, v. 109, 195-201) and French scientists in the Central Indian, Crozet and Madagascar basins (Schlich, 1982, *The Ocean Basins and Margins*, 51-147; Dymont, 1993, *J. Geophys. Res.*, v. 98, 13863-13877) improved understanding of the plate tectonic evolution of this part of the Indian Ocean significantly.

The complementary data available with the Indian and French scientists in the Central Indian Ocean were gathered to initiate in 2006 a second joint Indo-French collaborative magnetic anomaly investigation project, focused on this area, supported by IFCPAR, New Delhi.

The aim of this project was to compile and reinterpret the magnetic data available with the Indian and French scientists from the conjugate regions of the Central Indian Ocean and improve our understanding of the plate tectonic evolution of this area, including events such as timing of India-Eurasia collision and the Central Indian Basin deformation. With such an objective, as done in the case of first Indo-French collaborative project in the northwest Indian Ocean, a sea-surface magnetic profiles database was created by integrating all the magnetic data available with the Indian (11 cruises) and French (43 cruises) scientists complemented with the magnetic profiles available at NGDC (97 cruises). These magnetic profiles were interpreted using the conventional and modern techniques of inter-profile correlation, comparison with synthetic anomaly models and analytic signal approach, as used in the northwest Indian Ocean project. **This study (Dymont, Bhattacharya and IFCPAR3307-1 team, 2010, IFCPAR project completion report, 48p; Yatheesh *et al.*, 2008, *Am. Geophys. Union Fall Meeting abstract and poster T51B-1879*; Yatheesh *et al.*, 2009, *European Geosci. Union Meeting abstract and poster EGU2009-13589*) could derive 1399 magnetic anomaly picks (846, 287 and 266 picks from the Central Indian, Crozet and Madagascar basins, respectively), which were used for detailed mapping of magnetic lineations and the associated tectonic fabric in the Central Indian, Crozet and Madagascar basins between Chrons 34ny (83 Ma) and 20ny (42.5 Ma). The updated finite rotation parameters derived from the above studies enabled to provide improved model of relative motion of Indian-African (now Capricorn-Somalian) and Indian-Antarctic (now Capricorn-Antarctic) plate boundaries in high-resolution.**

MAGNETIC INVESTIGATIONS IN THE COMPLEMENTARY REGIONS - MASCARENE, WHARTON, LAXMI AND GOP BASINS

The adjacent Mascarene, Wharton, Gop and Laxmi basins were also investigated for obtaining additional information about the evolution of the Indian-African, Indian-Antarctic and Indian-Australian plate boundaries. The Wharton Basin is located between the Sunda Trench in the northeast, the Ninetyeast Ridge in the west, and the Broken Ridge in the south. It includes an extinct spreading centre which was the former plate boundary between Indian and Australian plates (Liu *et al.*, 1983, *Earth Planet. Sci. Lett.*, v. 65, 331-342; Krishna *et al.*, 1995, *J. Geophys. Res.*, v. 100/B10, 20011-20024). Recently, Jacob *et al.* (2009, *European Geosci. Union Meeting abstract and poster EGU2009-6417*) revisited the Wharton Basin to carry out detailed mapping of the magnetic lineations using an up-to-date compilation of sea-surface magnetic profiles. Their study provides updated finite



rotation parameters to constrain the Indian-Australian plate boundaries between Chrons 34ny (83.0 Ma) and 20ny (42.5 Ma). Similarly, followed by the earlier investigations of Dyment (1991, *Ph.D. Thesis, Université Louis Pasteur, 374p.*) and Bernard and Munsch (2000, *C. R. Academie Sci. Earth Planet. Sci., v. 330/11, 777-783*), the Mascarene Basin magnetic anomalies were revisited by Bissessur et al., (2009, *European Geosci. Union Meeting abstract and poster EGU2009-6383*) and they provided updated tectonic chart for the Mascarene Basin region. The picks derived from this study were further used to estimate finite rotation parameters to constrain the relative motion between Madagascar and India-Seychelles continental blocks between Chrons 34ny (83.0 Ma) and 27ny (60.920 Ma).

The Laxmi Ridge is a small continental sliver located off the India/Pakistan continental margin, separated from the Indian continent by the Laxmi Basin to the east and the Gop Basin to the north. Paleogeographic reconstruction models of the Indian-Somalian plate boundary at Chron 28ny (62.499 Ma) show that these basins represented a wide, deep offshore region between the Seychelles-Laxmi Ridge continental block (Greater Seychelles) and the India/Pakistan continental slope at that time and suggest that they were formed by the motion of Greater Seychelles away from India/Pakistan mainland. Bhattacharya et al. (1994, *Earth Planet. Sci. Lett., v. 125, 211-220*) showed that the Laxmi Basin contains sea-floor spreading type magnetic lineations and thus inferred that the Laxmi Basin is underlain by oceanic crust. Subsequent study of Yatheesh (2007, *Ph.D. Thesis, Goa University, 212p.*) provided finite rotation parameters and deciphered the plate tectonic evolution of this region. A similar study carried out by Yatheesh et al. (2009, *Earth Planet. Sci. Lett., v. 284/1-2, 399-408*) established that the Palitana Ridge is the extinct spreading axis of the oceanic Gop Basin region. They further inferred that the prominent but short sequence of fairly linear magnetic anomalies in the Gop Basin does not allow a unique identification but can be reasonably explained either as A31r–A25r (~69.3-56.4 Ma) or as A29r–A25r (~64.8-56.4 Ma) sequences.

MAGNETIC INVESTIGATIONS IN THE SOUTHEAST INDIAN OCEAN

The southeast Indian Ocean is formed by seafloor spreading between Australia and Antarctica. The Australian scientists carried out detailed magnetic investigations (Fig. 4) in the Australian-Antarctic Basin, Enderby Basin (Gaina et al., 2007, *Geophys. J. Int., v. 170, 151-169*; Gibbons et al., 2013, *J. Geophys. Res., in press*) and the west Australian margin (Gibbons et al., 2012, *Geochem. Geophys. Geosyst., v. 13,*

Q05w13, doi: 10.1029/2011gc003919). Those studies were carried out mainly based on sea-surface magnetic profiles available from GEODAS database of NGDC, complemented by magnetic data collected during IFM-Geomar CHRISP research cruise in 2008.

A detailed magnetic investigation was carried out in the Enderby Basin by Australian researchers (Gaina et al., 2007, *Geophys. J. Int., v. 170, 151-169*), based on improved coverage of potential field and seismic data off the east Antarctic margin between the Gunnerus Ridge and the Bruce Rise. Their study revealed that the Enderby Basin exhibit an extinct spreading centre and was formed as a result of relative motion between Antarctica and India-Elan Bank continental blocks, between M9o (~130.2 Ma) to M2o (~124.1 Ma). Recently, based on the existing magnetic profiles and using the fracture zone constraints from the Wharton and Enderby basins, Gibbons et al. (2013, *J. Geophys. Res., in press*) re-interpreted the age of the Enderby Basin as M4 to M0 (126.7 to 120.0 Ma), which implies a younger age for the initiation and cessation of spreading within the Enderby Basin.

Recently, the Australian researchers (Gibbons et al., 2012, *Geochem. Geophys. Geosyst., v. 13, Q05w13, doi: 10.1029/2011gc003919*) carried out detailed investigations

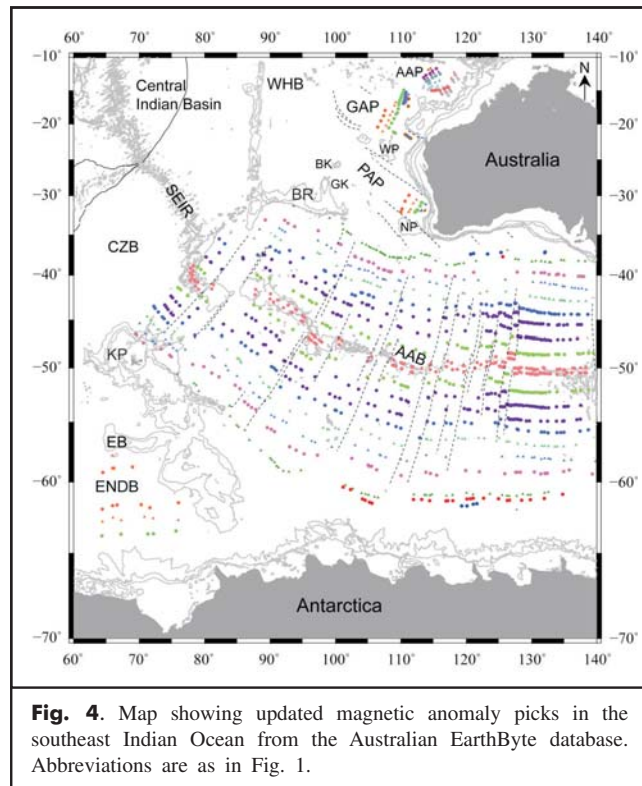


Fig. 4. Map showing updated magnetic anomaly picks in the southeast Indian Ocean from the Australian EarthByte database. Abbreviations are as in Fig. 1.



off the west Australian margin, i.e. the Argo, Cuvier, Gascoyne and Perth abyssal plains, based on analysis of sea-surface magnetic profiles and dredge samples recovered from the Batavia and Gulden Draak knolls. These studies revealed the existence of extinct Mesozoic spreading centres between west Australia and microcontinental slivers of Batavia and Gulden Draak knolls, Wallaby Plateau and Naturaliste Plateau. They identified two sequences of isochrons in the Argo Abyssal Plain, M26-M21 (155–147 Ma) and M14-M10N (136–131 Ma), while in the Gascoyne Abyssal Plain, the magnetic anomalies correspond to the M10-M0 (130–120.4Ma) sequence. In the Cuvier Abyssal Plain, they recognized two sets of conjugate anomalies separated by the Sonne Ridge, M10-M8 (130.5–128.2 Ma) east of the Sonne Ridge and M6-M4 (127.2–126.7 Ma) west of the Sonne Ridge. In the Perth Abyssal Plain, they correlated the magnetic anomalies to the M10N-M0 (131 Ma-124 Ma) sequence. Based on these results, *Gibbons et al.* (2012, *Geochem. Geophys. Geosyst.*, v. 13, Q05w13, doi: 10.1029/2011gc003919) proposed a new plate tectonic model for the break-up and early spreading history between India and Australia.

The above studies in the Indian Ocean formed the basis of developing a consistent set of rotation parameters to describe the Indian-Australian, Australian-Antarctic and Indian-Antarctic plate boundaries. These rotation parameters were used by the Australian researchers to decipher stage-by-stage the plate tectonic evolution of the Southeast Indian Ocean.

AN INDIAN-AUSTRALIAN-FRENCH COLLABORATION FOR DETAILED UNDERSTANDING OF PLATE TECTONIC EVOLUTION OF THE INDIAN OCEAN

All the above studies, along with the published literature, reveals the tectonic complexity of the Indian Ocean, including extinct spreading centres, microcontinents, ridge propagation and deformation zones, which need to be resolved in order to decipher the plate kinematics of the Indian Ocean as a whole. Any acceptable ocean-wide plate kinematic model should be compatible with the constraints gathered at all the above-mentioned plate boundaries. The above-mentioned group of Indian, Australian and French scientists initiated a new project aimed to complete the synthesis of available data and develop such a unified model for the plate tectonic evolution of the Indian Ocean in high resolution, from the dislocation of East Gondwanaland to the present. This Indian-Australian-French collaboration is supported by the Australia-India Strategic Research Fund (AISRF) and the French-Australia Science and Technology (FAST) programmes.

As a part of this project, we created a digital magnetic anomaly picks database (**Fig. 5**) by integrating all the picks available with the project members from the above studies, complemented by the digital magnetic picks database from other sources in the regions older than Chron 34ny (83 Ma). Further work planned under the project are: (i) identifying and delineating magnetic anomaly picks in high resolution over the Southeast Indian, Carlsberg and Central Indian ridges for the period younger to Chron 20ny (42.5 Ma); (ii) testing the consistency of relative motions across the plate boundaries using different plate circuits and validating the available magnetic picks compiled; (iii) determining a self-consistent set of high-resolution finite rotation parameters for each pair of plate boundaries in the Indian Ocean and (iv) building a unified model for East Gondwanaland reconstruction and deciphering the detailed plate kinematics of the Indian Ocean by accommodating microcontinental slivers.

To visualize and manage plate tectonic and associated data through geological time, we are using the GPlates software, which is an open-source plate reconstruction software developed through collaboration of the University of Sydney, Australia, the California Institute of Technology, USA and the Norwegian Geological Survey, Norway. The use of GPlates (www.gplates.org) allows interactive testing of plate models based on a variety of geological and geophysical data as well as the evaluation of the simultaneous interaction of a mosaic of multiple plates, something beyond the capability of quantitative programs to derive finite rotations with uncertainties between 2 or a maximum of 3 plates. GPlates also allows the testing of models for terrane accretion and plate collision, embedded in a global plate framework. This is particularly relevant for relating models for Indian Ocean opening to the successive closure of the Tethys.

SUMMARY

Indian, French and Australian scientists acquired large amount of sea-surface magnetic data in different sectors of the Indian Ocean and their independent magnetic anomaly investigations provided better plate tectonic evolution models for different parts of the Indian Ocean. The Indo-French collaborations for the last decade provided a detailed plate tectonic evolution model of the northwest and central Indian Ocean. These studies, along with complementary investigations in the Mascarene, Wharton, Gop and Laxmi basins, better constrain the relative motions of the Indian-African, Indian-Antarctic and Indian-Australian plate boundaries. Similarly, the magnetic anomaly investigations carried out by the Australian scientists provided a better

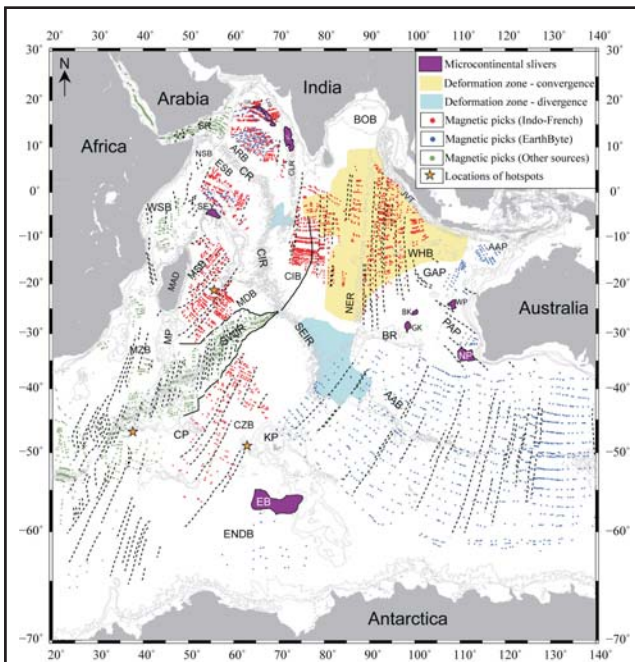


Fig. 5. Map of the Indian Ocean region showing the magnetic picks compiled under the Indian-Australian-French initiative. The red dots represent the magnetic picks derived from the Indo-French collaboration projects and related complementary studies. The blue dots represent the magnetic picks available with the Australian EarthByte database and the green dots represent the magnetic picks compiled from other publications. Abbreviations are as in Fig. 1.

understanding of the southeast Indian Ocean, namely the Indian-Australian and Indian-Antarctic plate boundaries. The above studies revealed or better constrained several tectonic complexities of the Indian Ocean region, such as extinct spreading centres, microcontinents, ridge propagation and diffuse deformation zones, which need to be resolved in order to decipher the plate kinematics of the Indian Ocean as a whole. **Under the auspices of an Indian-Australian-French collaboration, we initiated the synthesis of all data available with the Indian, Australian and French scientists and work towards a unified high resolution plate tectonic model of the Indian Ocean.**

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Research (MESR) and the Ministry of Foreign and European Affairs (MAEE), Govt. of France and Indo-French Centre for the Promotion of Advanced Research (IFCPAR / CEFIPRA), New Delhi under various schemes. Bilateral Indo-French, Indo-Australian and French-Australian collaborations were supported under IFCPAR fund (Project Nos. 1911-1 and 3307-1), Australia-India Strategic Research Fund (DST/INT/AUS/P-41/2011) and French-Australia Science and Technology (FAST) schemes, respectively. We also thank the team members of the above IFCPAR, AISRF and FAST projects for their contributions in those projects. All figures were drafted with GMT software (Wessel and Smith, 1995, *EOS Trans. Am. Geophys. Union*, 329). This is NIO contribution number 5320 and IGP contribution number 3375.

Appendix - 1: List of selected references of magnetic investigations in the Indian Ocean

Besse and Courtillot, 1988, *J. Geophys. Res.*, v. 93/B10, 11791-11808; Bhattacharya et al., 1992, *Oceanography of the Indian Ocean, Oxford-IBH*, 503-509; Bhattacharya et al., 1994, *Earth Planet. Sci. Lett.*, v. 125, 211-220; Chaubey et al., 1995, *Mar. Geol.*, v. 128, 105-114; Chaubey et al., 1998, *Earth Planet. Sci. Lett.*, v. 154, 41-52; Desa et al., 2009, *Geophys. J. Int.*, v. 177/3, 1265-1278; Drolia and Demets, 2005, *Geochem. Geophys. Geosyst.*, v. 6, Q09009, doi:10.1029/2005GC000950; Dymant, 1993, *J. Geophys. Res.*, v. 98, 13863-13877; Dymant, 1998, *J. Geophys. Res.*, v. 103, 24067-24084; Gaina et al., 2007, *Geophys. J. Int.*, v. 170, 151-169; Gibbons et al., 2012, *Geochem. Geophys. Geosyst.*, v. 13, Q05w13, doi: 10.1029/2011gc003919; Gibbons et al., 2013, *J. Geophys. Res.*, in press; Kamesh Raju and Ramprasad, 1989, *Earth Planet Science Lett.*, v. 95, 395-402; Kamesh Raju, 1993, *Mar. Geol.*, v. 109, 195-201; Ramana et al., 1994, *Earth Planet. Sci. Lett.*, v. 121, 469-475; Krishna et al., 1995, *J. Geophys. Res.*, v. 100/B10, 20011-20024; Krishna et al., 2006, *Tectonics*, v. 25, TC1006, doi:10.1029/2004TC001747; Norton and Sclater, 1979, *J. Geophys. Res.*, v. 84/B12, 6803-6830; Patriat and Segoufin, 1988, *Tectonophysics*, 155, 211-234; Patriat, 1987, *Reconstruction de l'évolution du système de dorsales de l'océan Indien par les méthodes de la cinématique des plaques*, *Terr. Terres Aus. Ant. Franc., France*; Royer and Sandwell, 1989, *J. Geophys. Res.*, v. 94/B10, 13,755-713,782; Schlich, 1975, *Memoire hors serie 6, Societé Geologique de France*, 102p.; Schlich, 1982, *The Ocean Basins and Margins*, Plenum Press, 51-147; Sclater and Fisher, 1974, *Geol. Soc. Am. Bull.*, v. 85, 683-702; Sclater et al., 1976, *Geol. Soc. Am. Bull.*, 87, 371-378; Yatheesh et al., 2009, *Earth Planet Sci. Lett.*, v. 284/1-2, 399-408