

INTEGRATED GEOPHYSICAL STUDIES OVER THE 85°E RIDGE - EVALUATION AND INTERPRETATION

M.V.RAMANA, T. RAMPRASAD, MARIA DESA
AND V. SUBRAHMANYAM

National Institute of Oceanography, Dona Paula, Goa 403 004

Ship-borne magnetic, gravity, bathymetry and multichannel seismic reflection studies made so far on the linear subsurface ridge known as the 85°E Ridge in the northeastern Indian Ocean are reviewed. The extent and boundaries of the ridge are well reflected on the GEOSAT derived free-air gravity anomaly mosaic. It trends N 10°W between 6°N and 16°N latitudes in the Bay of Bengal. The two divergent opinions on its origin are discussed and the need to get petrological or chemical information on the rocks of the ridge is stressed to enlist support eitherway. One school favours a hotspot origin, while the other advocates that the ridge was formed due to volcanic emplacement during the major plate reorganization in the middle Cretaceous. The latter argument is primarily based on the marked geophysical anomaly signatures associated with the 85°E Ridge. Such a feature is not present in the other two-hotspot traces, namely, the Chagos-Laccadive Ridge and the Ninety east Ridge. Also the linear topographic trace of the 85°E Ridge south of equator is virtually absent unlike the long (~5000 Km) Ninety east Ridge trace. The positive magnetic and negative gravity anomalies between 5° and 16°N latitude associated with the 85°E Ridge strengthen the suggestion of emplacement origin rather than a trace of hotspot. Combined with the above, magnetic model studies on the 85°E Ridge favour a single polarity throughout the length of the ridge indicating a shorter span of time, which is unlikely if it is a trace of hotspot trace, but possible in an intrusion.

Introduction

The breakup of greater India from the eastern Gondwanaland during the early-Cretaceous and subsequent events resulted in the evolution of a number of features in the Indian Ocean (Fig. 1), such as the most pronounced Ninety east Ridge, the submerged 85°E Ridge, several fracture zones and major unconformities (McKenzie and Sclater, 1971; Curray et al., 1982; Ramana et al., 1994a,b; 1997 a, b; Gopala Rao et al., 1997). The Ninety east Ridge extends over a length of about 5000-km with an average width of 200 km between 33°S and 17°N latitudes. Results of the recent Ocean Drilling Program (ODP) revealed that the Ninety east Ridge was a trace of the Kerguelen hotspot when the Indian plate moved northward over it (Klootwijk et al., 1992; Duncan and Storey, 1992). But such Ocean Drilling Programme to get the rock samples of the 85°E Ridge is not yet made.

A subsurface basement rise-like feature (Fig.2) approximately parallel to 85°E meridian has been identified by Curray et al., (1982) on the long-range E-W seismic reflection profiles in the Bay of Bengal. This feature has been named as the 85°E Ridge. This submerged ridge trends N10°W between 6° and 16°N latitudes. Off southeast coast of Sri Lanka, the ridge takes an arcuate shape and appears to abut the northward extension of the Afanasy Nikitin seamounts situated around 2°S latitude. The ridge appears as an intrusive peak and broad basement rise around

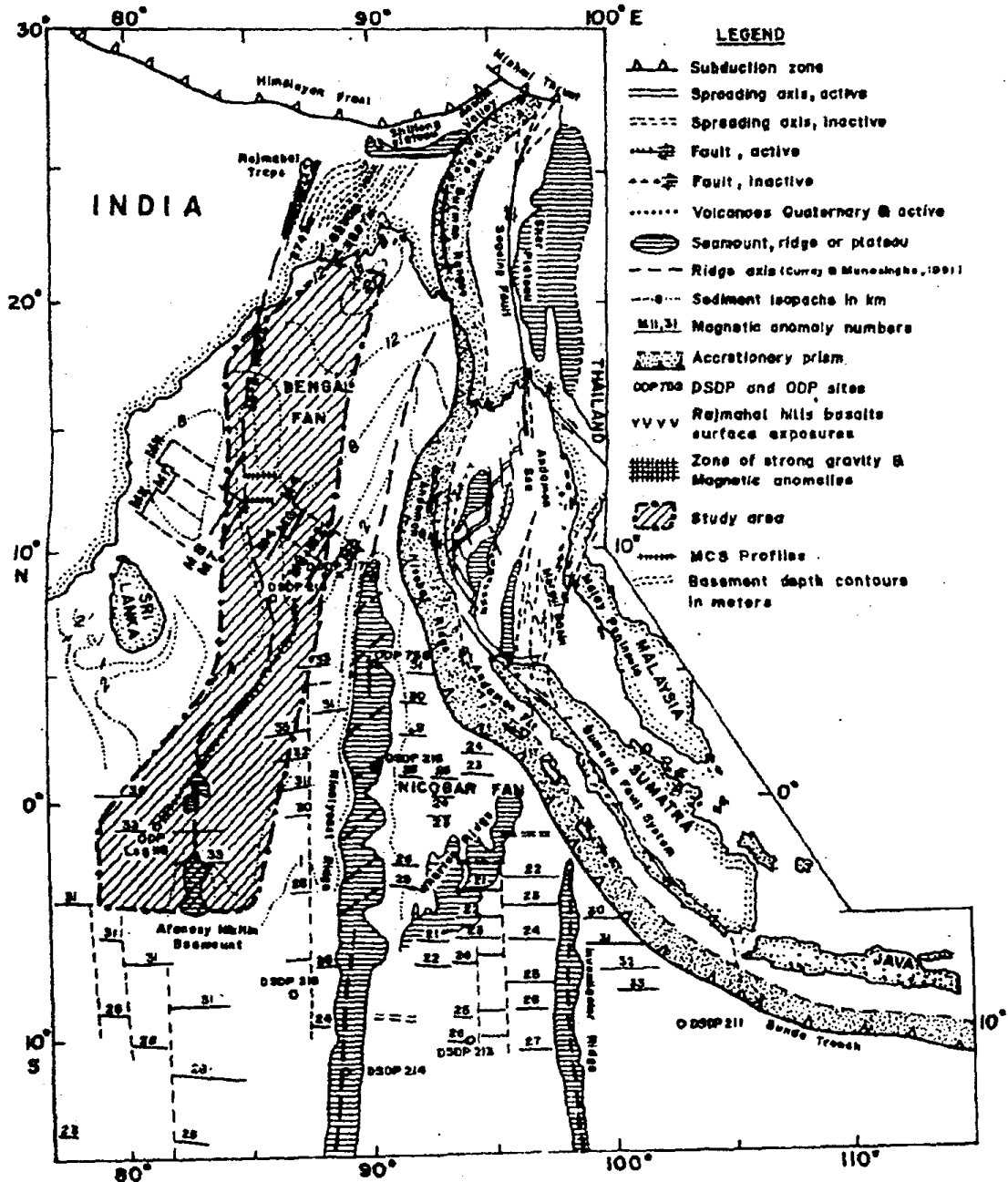


Fig. 1. Map showing various physiographic and tectonic features of the part of the north-eastern Indian Ocean and the Bay of Bengal (modified after Curray and Munasinghe, 1991; Ramana et al., 1994b.) The zone of strong gravity and magnetic anomalies and the basement contours (in meters) of the western onshore Bengal Basin are incorporated from the studies of Sengupta (1966). Study area is shown in a closed box with hatching.

10°N (Curray et al., 1982) and as a double humped feature around 13°N and 12°N latitudes (Gopala Rao et al., 1994, Ramana et al., 1997b). The 85°E ridge is characterized by positive magnetic (100-400 nT) and negative free-air gravity (~ -60 mGal) anomalies with variable widths of 100-180 km.

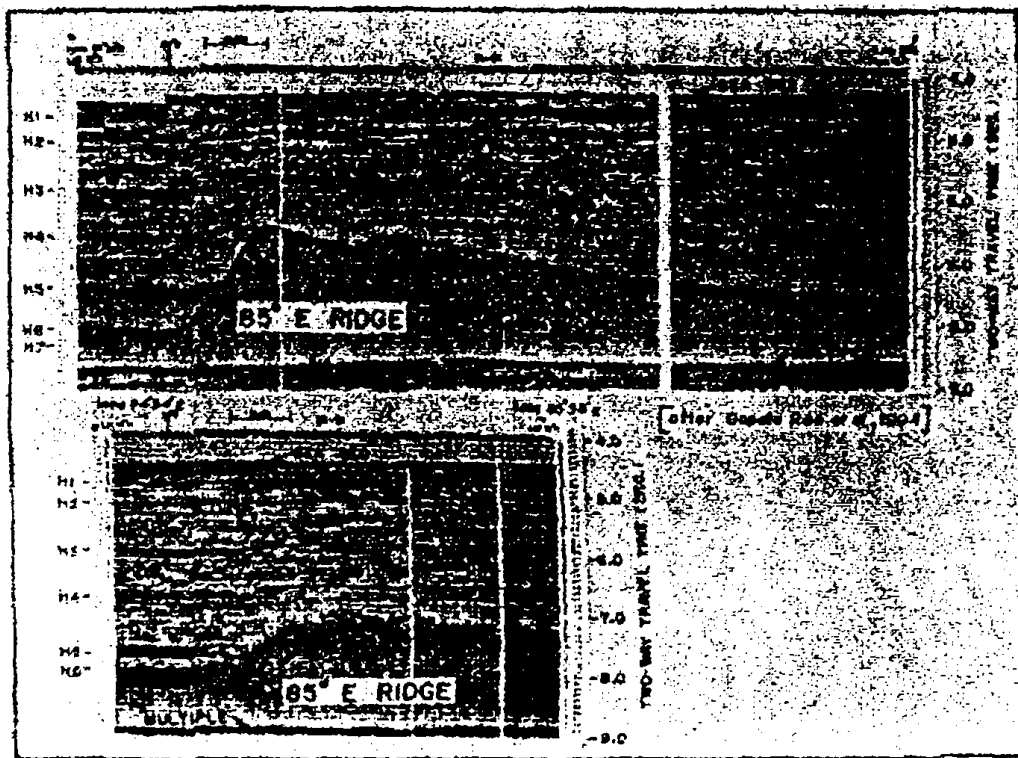


Fig. 2. Seismic reflection section across the 85°E Ridge.

The free air gravity anomaly mosaic derived from GEOSAT and ERS-1 satellite altimeter (Sandwell and Smith, 1997) is incorporated in this present study to define more accurately the physical boundaries and extent of the 85°E Ridge along with the conclusions derived from the earlier model studies using the potential field data under the constraint of seismic reflection data. The conclusions are primarily based on the compilation of large volume of marine geophysical data collected onboard RV Gaveshani, ORV Sagar Kanya and DSV Nand Rachit and the data from NGDC by Ramana et al., (1997b) to study the structure and origin of the 85°E Ridge. A synthesis of the results from different studies has been highlighted in this article.

Interpretation following Curray's Work

Seismic reflection data (Curray et al., 1982, and Ramana et al., 1997b and others) in the Bay of Bengal reveal that (i) the 85°E Ridge divides the main Bengal Fan longitudinally into two basins with more than 8 Km thick sediments, (ii) the ridge is buried under more than 3 km thick sediments in the north (around 13°N latitude) and relatively thin (less than 2 km) sediments in the south (~10°N latitude), and (iii) the western flank of the ridge (along 13°N latitude) is steeper while the eastern flank dips gently. A thin sediment cover blanketed the ridge since at least early Tertiary and the ridge was in existence prior to the lower Eocene (P) unconformity (Curray et al., 1982).

The observed steep gradient of the negative free-air gravity anomaly associated with the 85°E Ridge was modeled and interpreted in terms of lithospheric flexure (Liu et al., 1982). Subsequently, Mukhopadhyay and Krishna (1991) suggested that the ridge comprised of thick oceanic crustal material with its underlying root in the lithosphere. Different opinions prevail about the origin of the ridge. It was suggested by Curray and Munasinghe (1991) that the 85°E Ridge was a trace of the Crozet hotspot, which also formed the Rajmahal, traps. Muller et al., (1993) on the other hand believed that the 85°E Ridge between 10°N and Afanasy Nikitin seamounts may have been formed by a hotspot now located underneath the eastern Conrad Rise, now situated on the Antarctica plate. Mishra, (1991) considered the ridge as an abandoned spreading center, while, Chaubey et al., (1990) interpreted the ridge as a result of volcanism through a weak zone within a short span of time. Kent et al., (1992) suggested the ridge to be a northward continuation of the 86°E fracture zone. Studies of Murthy et al., (1993), Gopala Rao et al., (1997) mostly confine to the concept of hotspot model of Curray and Munasinghe (1991). A common belief, however, is that the ridge was evolved during the Cretaceous long normal polarity epoch (K-T superchron, 118-84 Ma).

Interpretation of GEOSAT free-air gravity mosaic

The satellite derived free air gravity anomaly map (Fig.3) (Sandwell and Smith, 1997) depicts a linear feature corresponding to the submerged 85°E Ridge, which is characterized by an approximately N10°W trending gravity low between 6 and 16°N latitudes. The extent and the boundaries of this subsurface tectonic linear feature are well resolved. The width of the ridge varies between 80 and 180 km and is within the limits as could be seen on the seismic reflection sections (Curray et al., 1982; Gopala Rao et al., 1994 and Ramana et al., 1997b). The width of the ridge widens marginally towards north and is maximum up to 180 km around 15°N latitude. Towards south, it tapers maintaining roughly a uniform width of about 90 km. The satellite gravity mosaic is seen with a major dislocation around 16°N latitude probably suggesting the northern limit of the ridge. However, the observed north-south trend between 17° and 19°N latitudes parallel to the local meridian surmises to be the northward extent of the 85°E Ridge. The gap/dislocation on the gravity mosaic perhaps represents a submerged fracture zone devoid of any appreciable topographic relief. The linear portion of the ridge appears to align with the 86°E fracture zone symbiotically around 6°N latitude and giving rise to a pseudo appearance as if these two features (ridge and the fracture zone) are inter-linked. A deviation from the north-south trend of the ridge can be seen conspicuously around 5°N latitude on the satellite gravity mosaic (Fig3). Further, the ridge is seen offset by few tens of kilometers by two approximately NNW-SSE trending fracture zones around 5° and 6° N latitudes. The arcuate extent of the ridge east of Sri Lanka further south, appears to abut the northern extent of the Afanasy Nikitin seamounts. The satellite gravity mosaic also supports the observation made by Ramana et al., (1997b) about the deep seated nature of the ridge response as seen by a broad gravity anomaly low of the order of -120 mGal across the ridge at places.



Fig. 3. Gravity anomalies derived from GEOSAT and ERS-1 Satellite Altimetry data (after Sandwell and Smith, 1997) of the Bay of Bengal region showing the imprints of various tectonic features

Interpretation of Potential field observations

A close examination of the gravity and magnetic anomalies (Figs.4&5 a,b) reveals that the subsurface ridge is associated with a continuous string of ($\sim 40\text{-}60$ mGal) negative free-air gravity and positive magnetic anomalies with $\sim 100 - 400$ nT amplitude between 16°N and 2°N . Ramana et al., (1997b) have therefore considered a combination of negative free-air gravity and positive magnetic anomalies as the diagnostic characteristics of the 85° E Ridge. The width of the ridge determined from magnetic and gravity anomaly profiles in general varies between 80 and 180 km. The widths derived from the potential field data exhibit a difference of the order of 5-10 km, which is due to the individual response of potential field over the ridge (Ramana et al.,1997b). The inferred axis of the 85°E Ridge is based on the width of the ridge derived from potential field data sets along different profiles, which corroborates with the GEOSAT gravity observation.

The magnetic anomalies over the ridge are asymmetric, which is due to phase shift that occurred during the northward drift of the Indian plate as interpreted by McKenzie and Sclater (1971) elsewhere. The magnetic data deskewed with the phase shift algorithm of Schouten and McCamy (1972) depicted bell-shaped positive anomaly signatures over the ridge (Fig.5c). This phase shift angle ($=70^\circ\pm 5^\circ$) may corresponds the to paleo inclination of the Indian plate during the breakup from Antarctica-Australia.

Interpretation of model studies of magnetic anomaly

The 85°E Ridge, as mentioned earlier, is believed to evolve during the Cretaceous long normal polarity epoch, and Curray and Munasinghe, (1991) linked it to the Rajmahal traps. Dating results of the Rajmahal traps show the age variation between 107 ± 3 Ma and 118 ± 2 Ma (exceptions 88 ± 2 Ma and 128 ± 7 Ma) with a mean age of 117 Ma (Baksi et al., 1987). Unlike the Deccan traps, the spatial extent of the Rajmahal traps is narrowly confined between $25^\circ\text{-}24^\circ\text{N}$ latitudes and $87^\circ 30'\text{-}87^\circ 50'\text{E}$ longitudes, and covers a very small area of about 4000 km^2 (Pascoe, 1964). Paleomagnetic studies (MacDougall and McElhinny, 1970 and Klootwijk, 1971) indicate that the Rajmahal traps are normally magnetized without any reversals. If the 85°E Ridge has a genetic link with that of the Rajmahal Traps, the rocks of the ridge should also possess similar paleomagnetic parameters i.e., mean paleo inclination of $I = -67^\circ \pm 6^\circ$ (normal polarity) and declination, $D = 310^\circ \pm 5^\circ$, as measured by MacDougall and McElhinny (1970).

The 85°E Ridge has been interpreted by Ramana et al., (1997b) as the manifestation of the emplacement through the sheared lithosphere. The ocean floor on either side of the ridge in the Bay of Bengal is characterized by early Cretaceous crust associated with the Mesozoic anomaly sequence M11 through M0 (133.5-118 Ma). Hence, different combinations of polarity reversals have been considered for magnetic model study. These combinations are: (i) the normal, normal and normal polarity, (ii) normal, reverse and normal polarity, (iii) the normal, reverse and reverse polarity and (iv) reverse, normal and normal polarity for the adjacent ocean floor and the ridge. Besides, the weak/strong magnetization to the ridge in com-

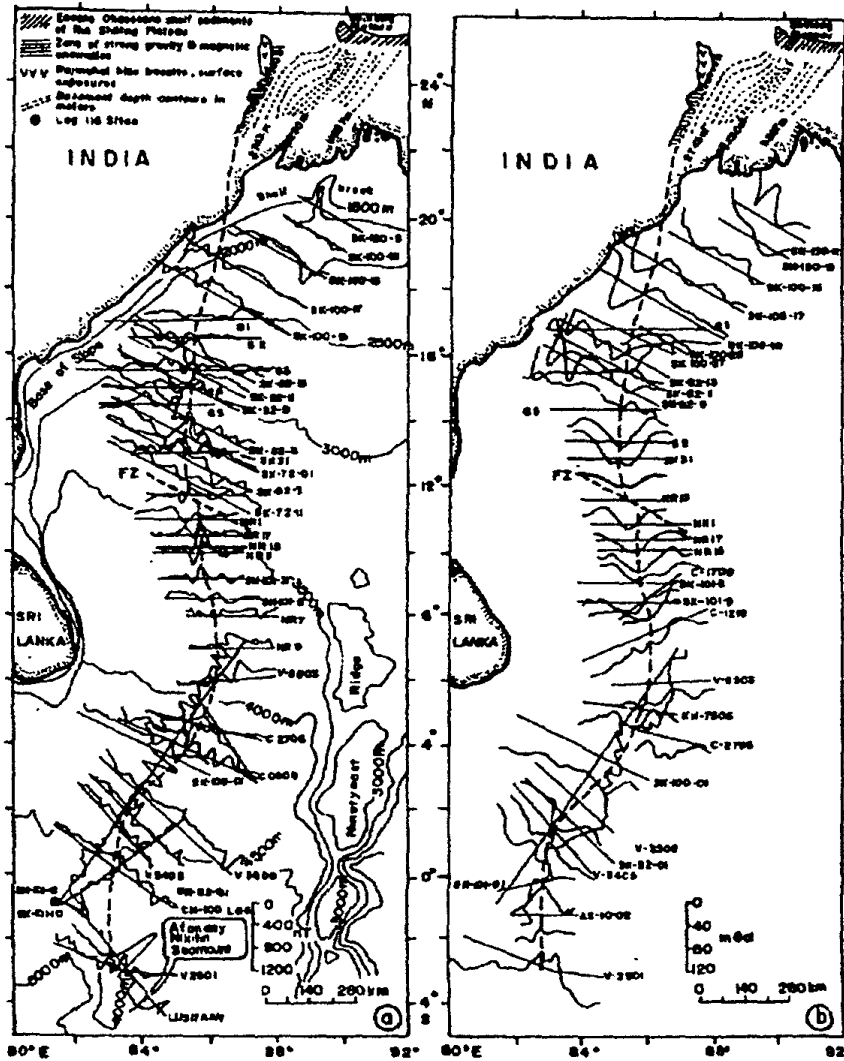


Fig. 4: (a) Total intensity magnetic anomaly profiles, and (b) free-air gravity anomaly profiles plotted along the cruise tracks. The dashed line represents the inferred axis of the 85°E Ridge. The axis of the ridge has been determined based on the identification of inflection points on the gravity and magnetic anomaly curves (after Ramana et al., 1997b).

parison with the adjacent blocks has also been considered for generating the synthetic models. The theoretical magnetic anomalies (Fig.6) generated with the paleomagnetic parameters of the Rajmahal traps using the forward modeling predicted a negative magnetic anomaly signature (Fig.6a) over the ridge. On the other hand, the theoretical curves (Fig. 6b) generated for reversed polarity ($I=67^{\circ}\pm 6$) resemble more closely with the observed positive magnetic anomaly signatures (Fig.6c). Similarity in the shape of the magnetic anomalies (observed and calculated) helped to infer that the ridge rocks were reversely magnetized through out the its length. This single polarity is possible only if the ridge evolves within a short span of time (1 to 2 million years). Had the ridge been a trace of a hotspot, the

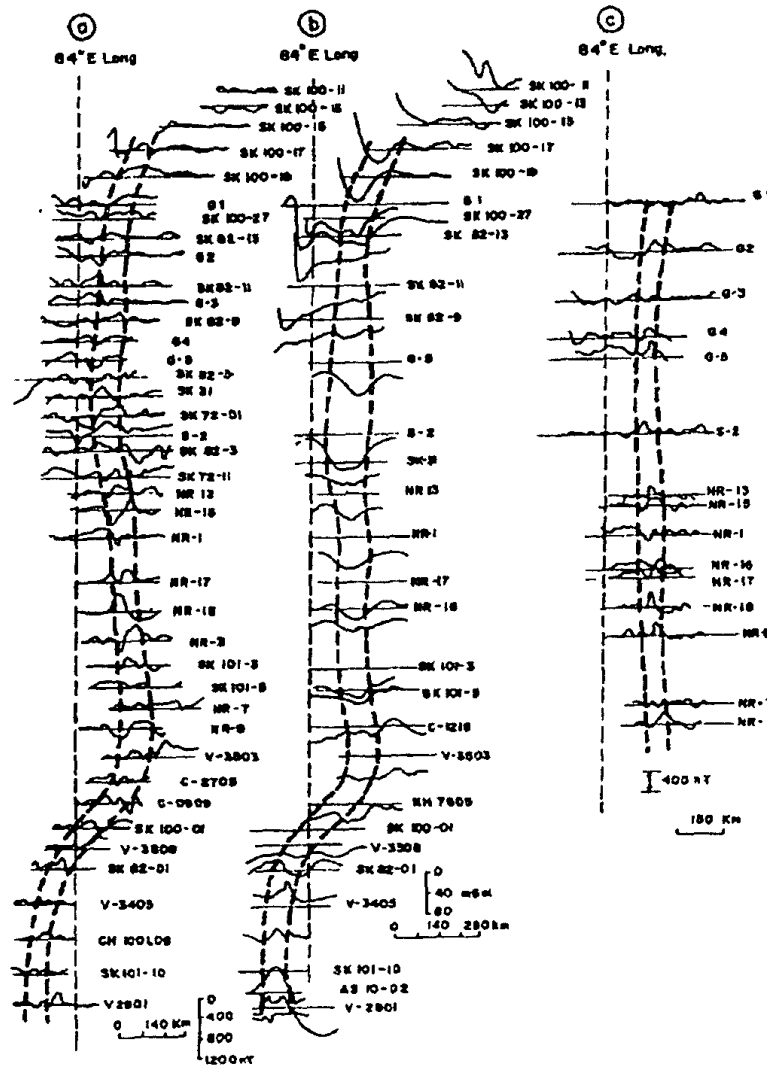


Fig. 5: Projected (a) total intensity magnetic and (b) free-air gravity anomalies across the 85°E Ridge with reference to 84°E longitude (c) The inverse phase-filtered magnetic data of selected profiles from north to south showing a positive magnetic anomaly associated with the 85°E Ridge. The eastern and western boundaries of the ridge have been demarcated based on the wavelength of the anomalies (after Ramana et al., 1997b).

retention of single polarity throughout its length is not possible. Magnetic model studies thus convincingly supports the concept of short span evolution of the ridge.

Hotspot trace vs. emplacement origin

Curry and Munasinghe (1991) proposed the ridge as a trace of Crozet hotspot that connects Rajmahal Traps (-117 Ma), and evolved during the Cretaceous long normal polarity epoch (118-84 Ma). If there were no reversals within this epoch, then the major portion of the ridge would have been characterized either by (i) ill

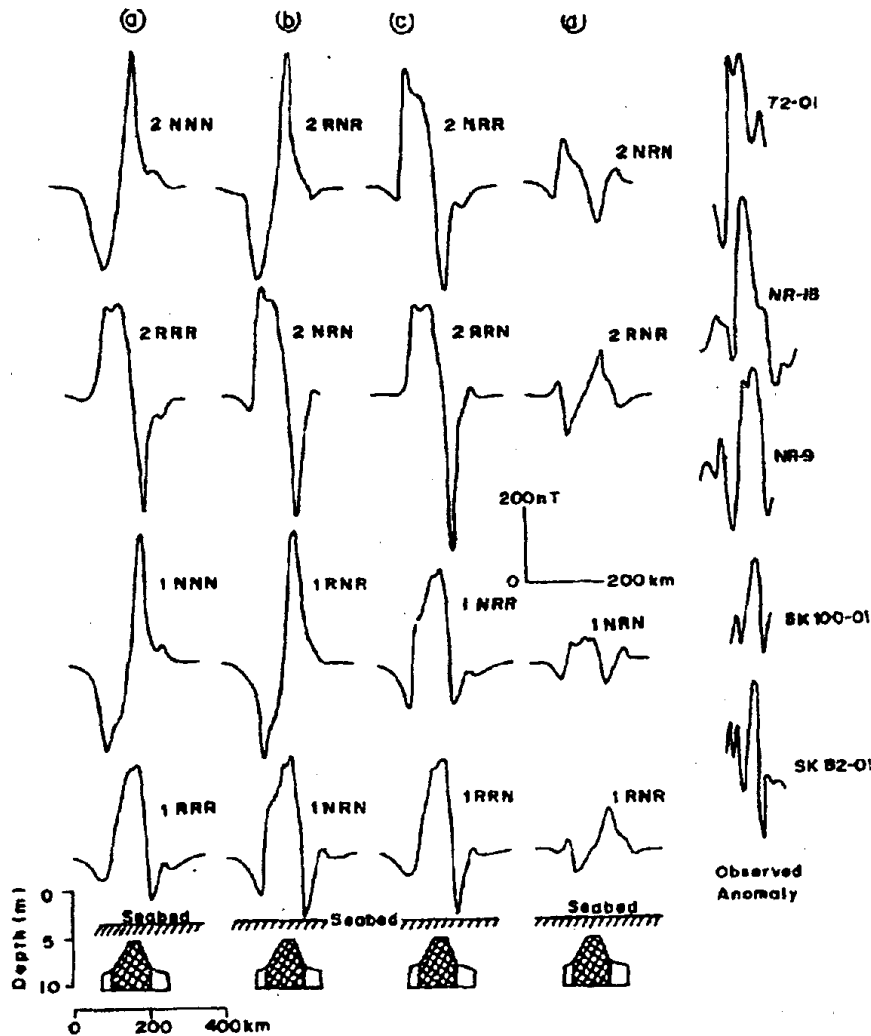


Fig. 6: Theoretical magnetic anomalies computed for various combinations of polarities and magnetizations. The prefix numbers 2 and 1 before polarities (N-normal; R-reverse) correspond to two different sets of the palaeoinclinations i.e. $I=+67^\circ$; $I=-67^\circ$ and $D=310^\circ$ and $I=+60^\circ$; $I=-10^\circ$ and $D=310^\circ$. The observed magnetic anomalies are shown for ready comparison. The modeled bodies represent the configuration of the ridge associated with the adjacent ocean floor (after Ramana et al., 1997b).

defined magnetic anomalies or ii) a negative magnetic anomaly as inferred from the model studies for normal magnetization (Cretaceous long-normal polarity). The observed magnetic anomalies from north to south across the ridge, though at places subdued, are associated with high amplitude positive magnetic anomalies over a large portion of the ridge (Fig.4). This observation supports the assumption that the ridge was evolved in one reversal within the K-T superchron. Tarduno et al., (1992) reported reversals within the Albian during the middle Cretaceous and during this period major plate reorganizations took place. The ridge might have evolved possibly in one reversal during the Middle Albian within the K-T superchron.

Detailed studies under the magnetic polarity constraint helped to propose two alternative processes for ridge emplacement. Evolution of the ridge may be either due to emplacement through the shearing of the lithosphere caused by stretching and compressional forces associated at the time of major plate reorganization immediately after the evolution of the early Cretaceous crust in the Bay of Bengal more precisely during one of the middle Albian (107-102 Ma) reversals within the K-T superchron coupled with the slow northward motion of Indian plate. The other explanation offered for the formation of the ridge is due to sagging of the lithosphere followed by deformation, caused by horizontal compressional forces on the passive continental margin as explained by Shemenda (1992).

Since the 85°E Ridge is seen associated with positive magnetic anomaly (one polarity), its evolution could be attributed to a short span event. The timing of the event is probably during polarity isochron MO (~118 Ma) or in one of the reversals within the middle Albian (107-102 Ma) in the K-T superchron when the Earth's magnetic field changed from normal to reversed polarity. This study also suggests that the 85°E Ridge was younger than the adjacent oceanic crust formed during the Mesozoic time.

It is further suggested that the 85°E Ridge could be extended to onshore into Bengal Basin. The 85°E Ridge, which trends N 10°W is associated with strong geophysical anomalies. The northward onshore extension of the ridge seems to coincide with the zone of strong magnetic and gravity anomalies as reported by Sengupta (1966) in the onshore western Bengal basin. As per this postulation, the 85°E Ridge extends on to the shore and joins with the zone of NNE-SSW trending strong gravity and magnetic anomalies, which correspond to the basement ridges along a line joining Midnapur Galse, Bolpur and Jangipur (cf. Figure 3, Sengupta, 1966) east of Rajmahal traps (Fig.4) The extended zone with strong geophysical anomalies seems to be independent of Rajmahal trap volcanism, which are normally magnetized whereas the extended basement ridge (Sengupta, 1966) is associated with positive magnetic anomaly and could be due to reverse polarity as in the offshore area.

Conclusions

The 85°E Ridge trends N10°W and is associated with positive magnetic and negative gravity anomalies between 5 and 16°N latitudes. Model studies strongly suggest a single polarity (reverse) to the ridge rocks.

A synthesis of all the available results favours the origin of the ridge through emplacement process rather than a trace of hotspot. The probable timing of its evolution within the middle Albian (~104 Ma) during the middle Cretaceous when major plate reorganization (India and Antarctica-Australia) took place. It is visualised that during the northward movement of Indian plate extensional stretching in the northern part and compression in the southern part resulted in the fissures into the lithosphere. The magma under the pre existing Kerguelen plume ejected out through these fissures. The ejected magma that cooled within a short span of 1 to 2 Ma is manifested in the form of the 85°E Ridge in the northeastern Indian Ocean.

Petrological and geochemical studies on the ridge rocks would only resolve unambiguously the proposed hypotheses of the origin and nature of the 85°E Ridge.

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Ramana et al.

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