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Geophysical signatures over and around the northern segment of the 85°E Ridge, Mahanadi offshore, Eastern Continental Margin of India and their tectonic implications

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ABSTRACT

The nature and origin of the subsurface 85°E Ridge in the Bay of Bengal has remained enigmatic till date despite several theories proposed by earlier researchers. We reinterpreted the recently acquired high quality multichannel seismic reflection data over the northern segment of the ridge that traverses through the Mahanadi offshore, Eastern Continental Margin of India and mapped the ridge boundary and its northward continuity. The ridge is characterized by complex topography, multi layer composition, intrusive bodies and discrete nature of underlying crust. The ridge is associated with large amplitude negative magnetic and gravity anomalies. The negative gravity response across the ridge is probably due to emplacement of relatively low density material as well as ~2-3 km flexure of the Moho. The observed broad shelf margin basin gravity anomaly in the northern Mahanadi offshore is due to the amalgamation of the 85°E Ridge material with that of continental and oceanic crust. The negative magnetic anomaly signature over the ridge indicates its evolution in the southern hemisphere when the Earth's magnetic field was normally polarised. The presence of ~5 s TWT thick sediments over the acoustic basement west of the ridge indicates that the underlying crust is relatively old, Early Cretaceous age.

The present study indicates that the probable palaeo-location of Elan Bank is not between the Krishna-Godavari and Mahanadi offshores, but north of Mahanadi. Further, the study suggests that the northern segment of the 85°E Ridge may have emplaced along a pseudo fault due to Kerguelen mantle plume activity during the Mid Cretaceous. The shallow basement east of the ridge may have formed due to the later movement of the microcontinents Elan Bank and Southern Kerguelen Plateau along with the Antarctica plate.

Keywords: Bay of Bengal; 85°E Ridge; multichannel seismic data; potential field data; forward modeling

1. Introduction

Late Jurassic breakup of Eastern Gondwanaland and subsequent seafloor spreading between India and Antarctica resulted in the formation of the Bay of Bengal and Enderby Basin (Norton and Sclater, 1979; Powell et al., 1988). The Bay of Bengal encompasses the Eastern Continental Margin of India and the adjoining abyssal plains. It is carpeted by the sediments of the Bengal Fan which is the largest and thickest sedimentary fan in the world (Curry et al., 1982). Seismic reflection and refraction studies across the Bay of Bengal (Curry, 1994) reveal that the sediment thickness decreases gradually from 22 km in the proximal fan to <2 km in the distal Bengal Fan. The continental shelf is rather narrow and the topography is smooth throughout except over the Ninetyeast Ridge. The major tectonic features in the Bay of Bengal include the Ninetyeast and 85°E Ridges, oceanic fracture zones, etc.

Study of huge volume of multichannel seismic, sonobuoys and wide angle reflection data revealed the subsurface configuration of Enderby Basin, East Antarctica, the conjugate of the Bay of Bengal (Joshima et al., 2001; Stagg et al., 2004). The continental basement with Jurassic rift structures downfaults by about 6 km and the sediment thickness of 6-8 km at the shelf margin decreases rapidly to 1-2 km towards offshore. The sedimentary sequences identified in the Enderby Basin range from the syn-rift deposit of Early Cretaceous age to Recent deposits (Joshima et al., 2001).

1.1. *The 85°E Ridge*

The approximately N-S trending submerged 85°E Ridge in the Bay of Bengal (Fig. 1) was delineated from seismic reflection and refraction studies (Curry et al., 1982). In general, the ridge is about 100-180 km wide and is linear between 16° and 6°N latitudes. South of 6°N latitude, the ridge takes an arcuate shape off the southeastern coast of Sri Lanka and appears to abut the northern extension of the Afanasy Nikitin seamount (ANS) chain (Ramana et al., 1997). The 85°E Ridge is characterized by a steep negative free-air gravity anomaly which has been attributed to lithospheric flexure (Liu et al., 1982).

Several theories were proposed to explain the origin of the ridge. For example, Mishra (1991) opined that the ridge is an abandoned spreading center, while Chaubey et al. (1991) believed it is an outpouring of volcanic material through a weak zone within a short span of time. Mukhopadhyay and Krishna (1991) reported that the ridge comprised of thick oceanic crustal material with its underlying root in the lithosphere. Curry and Munasinghe (1991) suggested that the Rajmahal Traps, the 85°E Ridge and the Afanasy Nikitin Seamount chain have formed due to a hotspot that now lies beneath the Crozet Islands in the southern Indian Ocean. While Kent et al. (1992) were of the view that the ridge is

a northward continuation of the 86°E fracture zone, Muller et al. (1993) proposed that the ridge and ANS chain might have been formed by a hotspot now located underneath the eastern Conrad Rise on the Antarctica plate. Based on the diagnostic characteristics of potential field data over the ridge, and its deep burial nature (unlike other hotspots elsewhere), Ramana et al. (1997) suggested that the ridge may not be of hotspot origin but a manifestation of volcanic outpouring through a linear crack/fissure created during major reorganization of plates in Mid Cretaceous. Further, it was postulated that the gravity low is due to the upwelling of lesser density material and the ridge is devoid of an anti-root.

Recently, Subrahmanyam et al. (2001) have suggested that the associated gravity low of the ridge is due to a ~6 km deep depression in the Moho and not its low density composition. On the other hand, Krishna (2003) proposed that the formation of the ridge began at ~85 Ma in the northern Bay of Bengal and ended at ~60 Ma in the ANS region. Anand et al. (2009) suggested that the ridge is a geomorphological feature within the sediments north of 15°N latitude. From the above interpretations, it is evident that diversified opinions exist about the ridge and its origin, which are due to lack of ground truth data. However, a common view among majority of the researchers is that the ridge might have evolved during the Mid Cretaceous i.e., Cretaceous long normal polarity epoch (120-84 Ma).

Satellite derived free-air gravity mosaic (Sandwell and Smith, 2009) depicts a discontinuity in the characteristic gravity low attributed to the ridge from 15°N to 16°N latitudes in the Mahanadi offshore area (Fig. 1), therefore the northward continuity of the ridge remained speculative. Since high quality multichannel seismic (MCS) reflection data in this region were made available to us, we made an attempt to trace the northward continuity and structural configuration of the ridge. An integrated interpretation of the potential field data under seismic constraints aided in understanding the tectonics and crustal structure around the northern segment of the ridge.

2. Data and Methodology

The multichannel seismic reflection profiles used in the present study are provided by the Directorate General of Hydrocarbons (Ministry of Petroleum & Natural Gas, Government of India). We have interpreted these seismic profiles to understand the nature of the crust and overlying sedimentary pattern, and the crustal architecture and evolution mechanism of the 85°E Ridge. The gravity and magnetic data used in the present study were acquired by the National Institute of Oceanography, Goa under the research program 'Crustal studies of the Bengal Fan'. The reduced gravity and magnetic anomalies are plotted perpendicular to the MCS tracks (Fig. 2). The processed seismic sections along with the gravity and magnetic anomalies, and interpretation are shown in figures 3 to 6. We have

adopted some of the inferences from the published seismic sections in the Enderby Basin (Joshima et al., 2001; Stagg et al., 2004).

The potential field data has been subjected to forward modeling (Figs. 7a & b) under seismic constraints using the GM-SYS software designed for 2-dimensional forward/inverse modeling. The GM-SYS software is primarily based on the method/algorithms of Talwani et al. (1959) and Talwani and Heirtzler (1964). The gravity response has been computed using variable densities (Table 1) for the sediments and the underlying continental, transitional, oceanic crusts and the ridge. For modeling the magnetic anomaly data, the three-layer model of Kent et al. (1993) has been adopted to incorporate the seafloor spreading magnetic anomalies. The magnetic response was computed using remnant magnetization with inclination 67° and declination 310° (Ramana et al., 1997) since the oceanic crust in the Bay of Bengal was created at southern latitudes ($\sim 50^\circ\text{S}$) during the Early to Mid Cretaceous. Several iterations were performed by assigning appropriate density, susceptibility and magnetization values for the sedimentary column and crustal configuration, till the best fit between the observed and computed anomalies was achieved.

3. Results

The study area encompasses the Mahanadi delta and its offshore extension (Fig. 1). The seismic sections show the presence of thick (upto 5 s TWT) sediments overlying the acoustic basement on either side of the 85°E Ridge, a tectonic feature, traversing through the study area (Figs. 3 to 6). The ridge is buried under 2-3 s TWT thick sediments. The three dip lines (S1, S2 and S3) depict the presence of intrusive bodies below the shelf-slope which are probably related to rift phase volcanism. Another important observation along lines S1 and S2 is the presence of deformed basement at the base of the continental slope resulting in vertical faults cutting across the sedimentary column up to Quaternary. The Moho appears occasionally as a discrete reflector between 10 and 12 s TWT (Fig. 5).

Major seismic horizons/unconformities are identified based on the interpretation of Curray et al. (1982). These unconformities are: top of Paleocene (P), top of Miocene (M) and the base of Quaternary (Q). The sediment load above the P unconformity constitutes the post-fan deposits, while the sediments below P are the pre-fan sediments which are further subdivided into three sequences E, D and C. Since the characteristics of these pre-fan deposits E to C are similar to the oldest deposits in the conjugate Enderby Basin (Joshima et al., 2001), we have assigned similar ages to these deposits in our study area. Thus the oldest deposits E in the present study can be inferred as the syn-rift sediments of Early Cretaceous age. Likewise, the D and C sequences below the P unconformity constitute the Mid

Cretaceous and Late Cretaceous-Paleocene deposits respectively. The oldest sequences D and E (Early to Mid Cretaceous) depict upturning of the reflectors on both the ridge flanks (Figs. 3 and 4). The pre-fan deposits are relatively thicker (>2.4 s) west of the 85°E Ridge and significantly thin east of the ridge, while the post-fan deposits (overlying P unconformity) thicken towards north and offshore (Figs. 3 to 6). Immediately east of the ridge the entire oldest sediment pack is seen (Figs. 3 & 4), while further east, a shallow basement without the oldest sedimentary sequences D and E is conspicuous (Fig. 4). These oldest sequences are also absent along the profiles S3 and S4 towards east and northeast respectively (Figs. 5 & 6). Typical reflections akin to that of carbonate growth are seen beyond the ridge flanks along the profiles S1 and S4 (Figs. 3 & 6).

The 85°E Ridge is seen as a broad subsurface feature with a relief of ~2 s TWT from the adjacent basement (Figs. 3 & 4). The main characteristic features of the ridge are: i) complex topography, ii) multi layer composition, and iii) intrusive bodies, and, iv), discrete nature of the underlying crust. The seismic sections show a reflection free zone, with major reflections on either side terminating against it. This zone also depicts a piercing nature through the preexisting crust and represents the magmatic intrusion (Figs. 3 to 6). Prominent faults are seen above both the flanks of the ridge (profiles S1 and S2), and the sedimentary column is down faulted on either side of the ridge (Figs. 3 & 4). A thin acoustically transparent layer of sediment probably resembling carbonate buildup is seen over the ridge along profile S2 (Fig. 4). Along seismic section S3, a reflection free zone within the basement below 6.5 s TWT between shots 2250 and 3750 (Fig. 5) may correspond to a massive intrusion. The older sediments appear to downlap on the northwestern flanks of this intrusion. Below these sediments, strong dipping reflectors akin to seaward dipping reflectors (SDRs) are seen. This situation is analogous to the SDR-prism observed off Australia (Geoffroy, 2005). Further offshore, this intrusion continues into the gently dipping oceanic basement. Along the profile S4, the ridge appears as double humped feature (Fig. 6) with a median trough having the oldest sediment pack. Sagging of the pre-existing crust on either side of the ridge is seen on profile S2 (Fig. 4). In addition, excess volcanic outpouring in the form of a tongue is seen along profiles S2 and S4 (Figs. 4 & 6) but not seen in profile S1 (Fig. 3).

To establish the tectonics and structure of the ridge and the adjacent crust, it is necessary to understand the associated geophysical signatures (seismic image, gravity and magnetic response). The shipborne gravity anomaly along profiles S1 and S2 (Figs. 3b and 4b) depicts a typical low (~60 km wavelength) across the shelf margin basin created by the juxtaposition of continent and transitional/oceanic crust. Conversely, the shelf margin basin gravity anomaly is broad (~120 km) along the profile S3 in the north (Fig. 5b). Further, the gravity signature along seismic section S1

depicts a gentle gradient low over the ridge which is shifted towards offshore, i.e., eastward (Fig. 3b). The ridge along the profile S2 is characterised with a low amplitude broad gravity anomaly with a central high (Fig. 4b). Gravity anomaly along the profile S4 (Fig. 6b) extracted from the satellite derived free-air gravity mosaic of Sandwell and Smith (2009) depicts a broad low over the left hump of the ridge complex. The magnetic data across the ridge along the profile S1 depicts a prominent low (>300 nT) with an intermittent high (Fig. 3b). Similarly, along profile S2, the ridge is associated with a large amplitude negative magnetic anomaly (Fig. 4b). It is interesting to note that the ridge complex and magnetic anomaly show good mirror image correspondence along both these profiles unlike the gravity field. Along the profile S3, a similar prominent negative magnetic anomaly is seen within the broad shelf margin basin gravity low (Fig. 5b). The magnetic field depicts a broad low over the left hump of the ridge complex along profile S4 (Fig. 6b).

3.1. Model studies

Forward modeling of the potential field data has been carried out under seismic constraints to derive a realistic crustal configuration. Model study reveals the extension of the continental crust offshore by 40 - 70 km from the shelf break. The continental Moho depth decreases from ~40 km below the shelf to <20 km below the mid slope (Figs. 7a & b). A 40 - 80 km wide transition zone consisting of intrusive bodies with densities 2.9 - 3.1 gm/cc exists between the continental and oceanic crusts (TZ, Table 1). This transition zone is analogous to the proto-oceanic crust inferred between the continent and oceanic crusts (Nemcok et al., 2012). West of the ridge, normal oceanic crust can be inferred along the profile S1, but not along profile S2. The oceanic crust is relatively thicker east of the ridge, (Figs. 7a & b).

The models suggest that the ridge consists of several relatively low density, (2.7 gm/cc) normally magnetized intrusive bodies (RC, Table 1) over and on either side of the magmatic intrusion (MI) resting on discrete oceanic crust. The underlying oceanic crust and the Moho depict a flexure of about 2-3 km.

4. Discussion

The present study area covers the Mahanadi offshore and lies north of 15°N latitude. The satellite gravity mosaic does not reflect the continuity of the 85°E Ridge between 15°N and 16°N latitudes (Fig. 1). Further north, the influence of the shelf margin basin dominates the gravity signature. Interpretation of the MCS data (Figs. 3 to 6) shows unambiguously the topography as well as the internal pattern of the buried ridge. More than 2-3 s TWT (3-5 km) thick sediments rest over the top of the ridge. The gravity and magnetic data interpretation indicates its magmatic nature (Fig. 7). Therefore

it is difficult to believe that this ridge is a geomorphological feature within the sediments as suggested by Anand et al. (2009).

The occurrence of deep basement beneath a thick (upto 5 s TWT) sedimentary column suggests that the basement is relatively old. Presence of Early Cretaceous crust characterised by the younger sequence of Mesozoic magnetic anomalies M11 through M0 has been inferred in the Bay of Bengal (Ramana et al., 1994; 2001). Therefore the inferred basement west of the ridge dates back to Early Cretaceous, more specifically, the crust belongs to 133-126 Ma. The significant thinning of the pre-fan deposits east of the ridge over a shallow basement suggests that it may be of younger age (Figs. 4 to 6). The thickening nature of the post-fan deposits towards north and offshore unambiguously suggests the influence of Mahanadi and Ganga-Brahmaputra rivers sediment flux besides the detrital input. The faulting and subsidence of the entire sedimentary column at the base of the continental slope due to deformed basement (Figs. 3b & 4b) probably indicates neotectonic activity. The downfaulting of the sediment horizons on either side of the ridge (Figs. 3b, 4b & 6b) is a manifestation of differential compaction.

4.1. Ridge characteristics

The multi layer pattern, with variable internal reflections seen on the seismic sections (Figs. 3 to 6) indicates the multiple episodic evolution of the ridge. Based on seismic reflection data interpretation, Ramana et al. (2009) suggested that the 85°E Ridge is not a simple tectonic feature but a multi layered suit. A similar view that the ridge is comprised of multiple heads forming eruptive foci from a plume and evolved due to episodic eruptions over time has been expressed by Bastia et al. (2010).

The presence of upturned reflectors on both the ridge flanks within the oldest sequences D and E (Early to Mid Cretaceous) suggest its initial emplacement in the Mid Cretaceous (Figs. 3, 4 and 6). Thus, these sections suggest the emplacement of the subsurface ridge on the pre-existing (5-15 m.y. old) oceanic crust as noted by Liu et al. (1982). Several episodic eruptions may have occurred up to Late Cretaceous/Early Paleocene. The Paleocene and younger deposits truncate against the flanks of the ridge indicating that the ridge attained its present day topography prior to their deposition. In accordance with the age-depth relationship of Parson and Sclater (1977), the observed relief of >2 s TWT suggests that the ridge may have been exposed subaerially up to Late Cretaceous. The presence of carbonate buildup like features (Figs. 3 & 6) beyond the ridge flanks as well as on the ridge top (Fig. 4) indicates a shallow water environment around Mid - Late Cretaceous. Similar carbonate reef formation was also proposed over the ridge further south (Gopala Rao et al., 1997).

The ridge is well developed towards south in the study area (profiles S1 and S2), while its image is obscured along the section S3 in the north. Here, the basement associated with a significant reflection free zone (Fig. 5b) and typical geophysical signatures akin to those of the ridge elsewhere has been attributed to the ridge. The absence of well developed ridge topography is probably due to its failure to penetrate through the SDRs/thick oldest sediments of the continental rise. Thus the ridge appears to have its northward continuation in the Mahanadi shelf margin basin. Towards east, the inferred ridge continues into the oceanic crust (Fig. 5) which belongs to the shallow basement inferred elsewhere lacking the oldest sediment sequences. Variable geophysical signatures on the two humps of the ridge complex along the profile S4 (Fig. 6) and lack of oldest sedimentary sequences east of the right hump prompt us to infer that only the left hump belongs to the ridge, while the right one belongs to the shallow basement. Pateria et al. (1992) postulated that the 85°E Ridge along 14.65°N latitude splits into two sub-ridges with a thick sedimentary sequence in the median trough and the oldest sequence thinning east of the ridge complex. This ridge structure is similar to the ridge scenario in the present study (Figs. 4 & 6). Bastia et al. (2010) suggested that the ridge consists of two N-S trending highs with a linear chain of large isolated volcanic highs on the west and broad continuous ridge on the east. Our interpretation based on geophysical signatures suggests that the western hump belongs to the ridge while the eastern hump constitutes the shallow basement (Figs. 4 & 6).

Model study suggests that ridge may be comprised of different bodies of relatively low density material (2.7 gm/cc, Fig. 7) and is in agreement with Nemcok et al. (2012). The magmatic intrusion as well as the blocks on either side are normally magnetized indicating that ridge emplacement took place during the Earth's normal polarity epoch (Mid Cretaceous). The models reveal that ~2-3 km flexure in the Moho along with the density contrasts are responsible for the low gravity over the ridge. Detailed geophysical studies under seismic constraints revealed the complex crustal configuration of the northern segment of the subsurface 85°E Ridge.

4.2. Seismic characteristics of conjugate margins

A detailed comparison of seismic profile S1 from the present study (Mahanadi Offshore, Eastern Continental Margin of India) and C1 from the Enderby Basin, East Antarctica (Stagg et al., 2004) has been made to understand the subsurface configuration and tectonics of these conjugate margins (Fig. 8). Along the profile C1, the basement downfaults to 8 s TWT and is characterized by irregular topography. The sequences within the sedimentary column range from the syn-rift deposit (E) of Early Cretaceous age, the Mid Cretaceous (D) and Paleocene-Late Cretaceous deposits (C) to the Oligocene-Eocene (B) and Miocene-Recent (A) deposits (Joshima et al., 2001). Due to the conjugate nature of these margins, the sedimentary column in the present study area has similar ages. Thus the

underlying oceanic crust in the study area is of Early Cretaceous age which corroborates with the interpretation of Ramana et al., (1994; 2001).

From the seismic sections, it is clear that the prominent 85°E Ridge like feature is absent in the Enderby Basin, thereby suggesting that this feature has evolved only on the Indian plate, after its separation from the contiguous Antarctica-Australian plate in an off-ridge tectonic setting (Liu et al., 1982; Sreejith et al., 2010). The acoustic basement along profile S1 is subsided by >1 s TWT when compared with the conjugate profile C1 due to continuous excess sediment input in the Bay of Bengal. Further, the significantly thicker sediment overburden of Miocene to Recent age (sequence A in figure 8) in the Bay of Bengal when compared to that in the Enderby Basin, is the resultant of the denudation of the Himalayas due to rigorous Indian monsoons (Curry et al., 2003). The overall basement characteristics are similar on both the conjugate margins while the sedimentary structure reflects the varying depositional environments with time.

4.3. Volcanism in Northeastern India

The Eastern Continental Margin of India is a non-volcanic passive continental margin (Powell et al., 1988; etc.). Geological investigations reveal the extent of the Precambrian shield, the Gondwana and Tertiary basins in northeastern India (Sengupta, 1966). Drilling in the Mahanadi nearshore has indicated that a predominantly volcanic sequence of Early Cretaceous age overlies unconformably the continental basement and is overlain by Late Cretaceous deposits of sandstones and shales in shallow marine conditions (Bharali et al., 1992; Fuloria et al., 1992). Paleomagnetic studies revealed that the Rajmahal Traps in northeastern India are normally magnetized without any reversals (MacDougall and McElhinny, 1970) and were emplaced at ~118 Ma during the Mid Cretaceous (Kent et al., 2002). High amplitude (2000 nT) magnetic anomalies associated with the 85°E Ridge volcanism have been inferred in the Mahanadi offshore (Nayak and Rama Rao, 2002). Volcanism has also been inferred in other regions of northeastern India (Mall et al., 1999; Behera et al., 2004). Bastia et al. (2010) also reported a region of prominent SDRs, which are characteristic features of volcanic margins (e.g. off Namibia, Brazil, Australia) in the Mahanadi offshore basin. In the present study, SDRs are seen along the northernmost profile S3 (Fig. 5b) indicating the volcanic nature of the margin towards north. Non occurrence of SDRs along the southern profiles S1 and S2 indicates the non-volcanic nature of the margin in the south. Thus, the boundary between the volcanic northeastern continental margin of India and the non-volcanic passive margin towards south can be traced around 18°N latitude.

Under the influence of mantle plume heat, the lithosphere is thinned and weakened, and large amount of magma is ejected and emplaced forming ridges, plateaus, etc. (McKenzie 1985; White et al.,

1987). Further, the crust beneath the aseismic ridges and intraplate seamount chains may be characterized by low velocities due to extrusive lavas and debris flows with high average porosities (Pierce and Barton, 1991). This scenario is analogous to the northern segment of the 85°E Ridge, which might have emplaced on a weak lithosphere under the influence of the Kerguelen mantle plume. Further, the normal magnetic polarity of this ridge segment endorses the fact that it may have formed along with other volcanic products (e.g. Rajmahal Traps) in the Mid Cretaceous.

4.4. Sediment load characteristics

Isopach maps of the Paleocene-Cretaceous sediments (below the P unconformity on the seismic sections) and total sediment load were prepared to understand the sediment distribution and paleo topography. The progradation of the sediment pack parallel to the coast is seen interrupted by the ridge morphology (Fig. 9). The Paleocene-Cretaceous sediment isopach map (Fig. 9a) depicts a ~N-S trend on the northern segment of the 85°E Ridge. The extent of the ridge exposed up to Paleocene time is delineated by the zero contour. Sediment thickness is >2.5 s TWT in the western basin between the East Coast of India and the ridge. Immediately east of the ridge, there exists another elongated thick sediment pool (>2 s TWT). Towards northeast, shallow basement with <0.5 s TWT thick sediments is seen. Total sediment thickness map of the study area (Fig. 9b) depicts the continuation of the north-south trend in the study area and the presence of ~2.5 s TWT thick sediment load on the ridge. The sediment thickness on either side of the ridge is ~5 s TWT. Towards northeast, the shallow basement is overlain by ~3 s TWT sediments.

Thick sediment load can cause additional subsidence of the underlying crust. Corrected depths in the absence of sediment loading facilitate the estimation of crustal ages (Parsons and Sclater, 1977; Crough, 1983). The corrected depths in the study area have been derived using the sediment thickness and basement depths from the seismic sections (Figs. 3 to 6). The corrected depths of ~6 km and ~5.5 km resulted in crustal ages of ~130 Ma (Early Cretaceous) and 100-90 Ma (Mid Cretaceous) in the western basin (west of 85°E Ridge) and shallow basement (east of the ridge) respectively. The analysis of the sedimentary pattern obtained from the seismic sections and the crustal ages inferred above suggest that the western basin and the trough filled with thick oldest sediments are probably underlain by Early Cretaceous crust. The shallow basement towards east with minimum oldest sediments may be of younger age (Mid Cretaceous).

4.5. Tectonic Implications

The breakup of Eastern Gondwanaland and subsequent seafloor spreading between India and Antarctica resulted in the formation of the Bay of Bengal and Enderby Basin. The Elan Bank has been

inferred as a microcontinent (Weis et al., 2001; Frey et al., 2002; Ingle et al., 2002) belonging to the Indian plate. It was placed between the Krishna-Godavari and Mahanadi offshore basins (Gaina et al., 2003), and postulated to have separated due to a northward ridge jump around M2 time. The presence of fluvial conglomerate within the subaerial Albian lava flows (Pringle and Duncan, 2000) suggests that Elan Bank may have separated from the Indian plate after 108 Ma (Nicolaysen et al., 2001). Most recently, Gibbons et al., (2013) using global plate motion models suggested that it may have separated from the Indian plate at around 115 Ma.

The presence of Early Cretaceous crust west of the 85°E Ridge using magnetic data (Ramana et al., 1994; 2001; Gibbons et al., 2013) and the present study suggests that the probable palaeo-location of Elan Bank cannot be between the Krishna-Godavari and Mahanadi offshore. However, its juxtaposition would be appropriate north of Mahanadi due to its close fit against the Precambrian shield of India (Fig. 10). Similar location for the Elan Bank has been proposed by Chatterjee and Nicolaysen (2012) based on the interpretation of metamorphic, geochronologic and spatial datasets.

As the Indian plate moved northward in the absolute sense (Muller et al., 1998), it came under the influence of the Kerguelen hotspot resulting in widespread volcanic activity in northeastern India during the Early to Mid Cretaceous (Bharali et al., 1992; Fuloria et al., 1992; Mall et al., 1999; Nayak and Rama Rao, 2002; Behera et al., 2004). The hotspot activity left its imprints in the form of the Rajmahal and Sylhet Traps, lamprophyres, and the Albian lava flows on the microcontinents (SKP and Elan Bank) then attached to India (Coffin et al. 2002; Kent et al., 2002).

We opine that a northward ridge jump of a limited spreading ridge segment to the Kerguelen hotspot may have occurred due to hotspot-ridge interaction thereby transferring the microcontinents Elan Bank and SKP from the Indian to the Antarctica plate. This northward ridge jump may have occurred as a pseudo fault which corresponds to the ENE propagation of a ridge segment from the western Enderby Basin into the Indian continental margin, (Gibbons et al., 2013). The northern part of this pseudo fault is positioned along the western flank of the northern portion of the 85°E Ridge. The present study suggests that volcanism along this pseudo fault due to mantle plume activity may have resulted in the buildup of the northern segment of the 85°E Ridge. The movement of these microcontinents along with the Antarctica plate after 108 Ma might have resulted in the formation of the shallow basement east of the ridge (Fig. 10).

The northern segment of the 85°E Ridge appears to be the boundary between the two regions of different ages, i.e. Early Cretaceous crust to the west and Mid Cretaceous crust to the east. But the trough like feature just east of the ridge having the oldest sediment pack suggests that the ridge may

not be the western boundary of the later separation of the microcontinents. We suggest that the western edge of the shallow basement constitutes the boundary between the two regions of differing ages. The increasing width of the trough southward suggests an initial \sim N80°E direction of the motion of the microcontinents and Antarctica. Gopala Rao et al. (1997) noted an increase in the distance between the ridge and an eastern fracture zone, further south. This eastern fracture zone is probably the continuation of the western boundary of the shallow basement inferred in the present study. The tectonic fabric is in accordance to the continued seafloor spreading between India and Antarctica in \sim NNW-SSE direction up to \sim 99 Ma (Muller et al., 2000).

5. Conclusions

The integrated interpretation of potential field data under seismic constraints facilitated in delineation of the 85°E Ridge, its northward continuity and crustal configuration in the Mahanadi offshore. The deep acoustic basement, presence of \sim 5 s TWT sediments and estimation of crustal ages in the absence of sediment loading suggest that the underlying crust is of Early Cretaceous age west of the ridge. Further, the upturn of the oldest (Early to Mid Cretaceous) sediments on either side of the ridge flanks suggests that the ridge was emplaced after the deposition of these sediments. Truncation of the Paleocene and younger sediments on either flanks of the ridge indicate their deposition after ridge attained its present day configuration.

The ridge is associated with broad wavelength and large amplitude negative magnetic and gravity anomalies. Model studies reveal that the ridge may be comprised of relatively low density (2.7 gm/cc) magmatic material emplaced during Earth's normal magnetic polarity epoch and is associated with \sim 2-3 km flexure of the Moho. The study also reveals that the ridge is a multilayered suit developed due to episodic outpouring of magma through a feeder dyke on the pre-existing crust. The ridge is well developed towards south in the study area and its presence towards north in Mahanadi shelf margin basin can be inferred based on the typical double humped magnetic anomaly, and distinct broad gravity low due to a mixed response of the continental crust, the 85°E Ridge and the oceanic crust.

The presence of seaward dipping reflectors (SDRs) in the northernmost profile S3 and their total absence in the southern profiles S1 and S2 strongly suggests that the northern part of the Mahanadi offshore (north of 18°N latitude) shows its affinity towards volcanic margin, while the southern part devoid of SDRs is a normal passive margin. The fault/intrusion controlled subsidence at the base of the continental slope and downfaulting of the entire sedimentary column on either side of the ridge indicate the effects of neotectonic activity and differential compaction respectively.

The present study suggests that the microcontinents Elan Bank and Southern Kerguelen Plateau may have been juxtaposed north of Mahanadi rather than their placement between Krishna-Godavari and Mahanadi offshores. A northward ridge jump of a limited spreading ridge segment to the Kerguelen hotspot due to plume-ridge interaction may have occurred along a pseudo fault. Along this pseudo fault, the northern segment of the 85°E Ridge may have emplaced due to Kerguelen mantle plume activity in the Mid Cretaceous. The shallow basement east of the ridge may have formed due to the later movement of the microcontinents Elan Bank and Southern Kerguelen Plateau along with the Antarctica plate.

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REFERENCES

- Anand, S.P., Rajaram, M., Majumdar, T.J., Bhattacharya, R., 2009. Structure and tectonics of 85°E Ridge from analysis of geopotential data. *Tectonophysics* 478, 100-110.
- Bastia, R., Radhakrishna, M., Das, S., Kale, A.S., Catuneanu, O., 2010. Delineation of the 85°E ridge and its structure in the Mahanadi offshore basin, Eastern Continental Margin of India (ECMI), from seismic reflection imaging. *Marine and Petroleum Geology* 27, 1841-1848.
- Behera, L., Sain, K., Reddy, P.R., 2004. Evidence of underplating from seismic and gravity studies in the Mahanadi delta of eastern India and its tectonic significance. *Journal of Geophysical Research* 109, doi:10.1029/2003JB002764
- Bharali, B. R., Srivastava, S.K., Ravichandra, V. 1992. Seismostratigraphic analysis of Cretaceous-Tertiary sequence of the Mahanadi offshore Basin. *Geological Survey of India Special Publication* 29, 247–254.
- Chatterjee, N., Nicolaysen, K., 2012. An intercontinental correlation of the mid-Neoproterozoic Eastern Indian tectonic zone: Evidence from the gneissic clasts in Elan Bank conglomerate, Kerguelen Plateau. *Contributions of Mineral Petrology* 163, 789-806.
- Chaubey, A. K., Ramana, M. V., Sarma, K.V.L.N.S., Krishna, K.S., Murty, G.P.S., Subrahmanyam, V., Mittal, G.S., Drolia, R.K., 1991. Marine Geophysical studies over the 85°E Ridge, Bay of Bengal. In: *First International seminar and Exhibition on “Exploration Geophysics in Nineteen Nineties”* Hyderabad, India, Association of Exploration Geophysics Publication 2, 508-515.
- Coffin, M. F., Pringle, M. S., Duncan, R. A., Gladchenko, T. P., Storey, M., Muller, R. D., Gahagan, L. A., 2002. Kerguelen hotspot magma output since 130 Ma. *Journal of Petrology* 43, 1121-1139.

- Crough, S.T., 1983. The correction for sediment loading on the seafloor. *Journal of Geophysical Research* 88, 6449-6454.
- Curray, J. R., Munasinghe, T., 1991. Origin of the Rajmahal Traps and the 85°E Ridge: Preliminary reconstructions of the trace of the Crozet hotspot. *Geology* 19, 1237-1240.
- Curray, J. R., Emmel, F. J., Moore, D. G., Raitt, R. W., 1982. Structure, tectonics and geological history of the Northeastern Indian Ocean. In: Nairn, A. E., Stehli, F. G. (Eds.), *The Ocean Basins and Margins*, vol. 6, Plenum Press, New York, 399-450.
- Curray, J. R., 1994. Sediment volume and mass beneath the Bay of Bengal. *Earth and Planetary Science Letters* 125, 371-383.
- Curray, J. R., Emmel, F. J., Moore, D. G., 2003. The Bengal Fan: morphology, geometry, stratigraphy, history and processes. *Marine and Petroleum Geology*, 19, 1191-1223.
- Desa, M., Ramana, M. V., Ramprasad, T., 2006. Seafloor spreading magnetic anomalies south off Sri Lanka. *Marine Geology* 229, 227-240.
- Desa, M., Ramana, M. V., Ramprasad, T., 2009. Evolution of the Late Cretaceous crust in the equatorial region of the Northern Indian Ocean and its implication in understanding the plate kinematics. *Geophysical Journal International* 177, 1265-1278.
- Frey, F. A., Weis, D., Borisova, A. Yu., Xu, G. 2002. Involvement of continental crust in the formation of the Cretaceous Kerguelen Plateau: new perspectives from ODP Leg 120 sites. *Journal of Petrology* 43, 1207–1239.
- Fuloria, R.C., Pandey, R.N., Bharali, B.R., Mishra, S.K., 1992. Stratigraphy, structure and tectonics of Mahanadi offshore basin. *Geological Survey of India Special Publication* 29, 255-265.
- Gaina, C., Muller, R.D., Brown, B., Ishihara, T., 2003. Microcontinent formation around Australia. *Geological Society of Australia Special Publication* 22, 399-410.
- Geoffroy, L., 2005. Volcanic passive margins. *Comptes Rendus Geoscience* 337, 1395–1408.
- Gibbons, A. D., Whittaker, J. M., Muller, R. D., 2013. The breakup of East Gondwana: Assimilating constraints from Cretaceous ocean basins around India into a best-fit tectonic model. *J. Geophys. Res.* 118, doi:10.1002/jgrb.50079.
- Gopala Rao, D., Krishna, K., Sar, D., 1997. Crustal evolution and sedimentation history of the Bay of Bengal since the Cretaceous. *J. Geophys. Res.* 102, 17747-17768.
- Ingle, S., Weis, D., Frey, F. A., 2002. Indian Continental Crust Recovered from Elan Bank, Kerguelen Plateau (ODP Leg 183, Site 1137). *Journal of Petrology* 43, 1241-1257. doi: 10.1093/petrology/43.7.1241
- Joshima, M., Ishihara, T., Nakajima, T., Sugiyama, K., Tsuchida, K., Kato, A., Murakami, F., Brown, B., 2001. Preliminary results of the TH99 geological and geophysical survey in the Cooperation Sea and Prydz Bay area. *Polar Geosciences* 14, 244-262.

- Kent, G., Harding, A., Orcutt, J., 1993. Distribution of magma beneath the East Pacific Rise between the Clipperton Transform and the 9°17'N Deval from forward modeling of Common Depth Point data. *Journal of Geophysical Research* 98, 13945-13969.
- Kent, R. W., Storey, M., Saunders, A. D., Ghose, N. C., Kempton, P. D., 1992. Comments and reply on "Origin of the Rajmahal Traps and the 85°E Ridge: Preliminary reconstructions of the trace of the Crozet hotspot. *Geology* 20, 957-958.
- Kent, R. W., Pringle, M. S., Müller, R. D., Saunders, A. D., Ghose, N. C., 2002. $^{40}\text{Ar}/^{39}\text{Ar}$ Geochronology of the Rajmahal Basalts, India, and their relationship to the Kerguelen Plateau. *Journal of Petrology* 43, 1141-1153.
- Krishna, K.S., 2003. Structure and evolution of the Afanasy Nikitin seamount, buried hills and 85°E Ridge in the northeastern Indian Ocean. *Earth and Planetary Science Letters* 209, 379-394.
- Liu, C. S., Sandwell, D. T., Curray, J. R., 1982. The negative gravity field over the 85°E Ridge. *Journal of Geophysical Research* 87, 7673-7686.
- MacDougall, I., McElhinny, M.W., 1970. The Rajmahal Traps of India-K-Ar ages and paleomagnetism. *Earth and Planetary Science Letters* 9, 371-378.
- Mall, D.M., Rao, V.K., Reddy, P.R., 1999. Deep sub-crustal features in the Bengal Basin: Seismic signatures for plume activity. *Geophysical Research Letters* 26, 2545-2548.
- Mckenzie, D.P., 1985. The extraction of magma from the crust and mantle. *Earth and Planetary Science Letters* 74, 81-91.
- Mishra, D.C., 1991. Magnetic crust in the Bay of Bengal. *Marine Geology* 99, 257-261.
- Mukhopadhyay, M., Krishna, M. B. R., 1991. Gravity field and deep structure of the Bengal Fan and its surrounding continental margins, northeast Indian Ocean. *Tectonophysics* 186, 365-386.
- Muller, R. D., Royer, J-Y., Lawver, L. A., 1993. Revised plate motions relative to the hotspots from combined Atlantic and Indian Ocean tracks. *Geology* 21, 275-278.
- Muller, R.D., Roest, W.R., Royer, J-Y., 1998. Asymmetric seafloor spreading caused by ridge-plume interactions. *Nature* 396, 455-459.
- Muller, R.D., Gaina, C., Tikku, A., Mihut, D., Cande, S.C., Stock, J.M., 2000. Mesozoic/Cenozoic tectonic events around Australia. In: *The History and Dynamics of Global Plate Motions*, Geophysical Monograph 121, American Geophysical Union 161-188.
- Nayak, G.K., Rama Rao, Ch., 2002. Structural configuration of Mahanadi offshore basin, India: an aeromagnetic study. *Marine Geophysical Researches* 23, 471-479.
- Nemcok, M., Sinha, S. T., Stuart, C. J., Welker, C., Choudhuri, M., Sharma, S. P., Misra, A. A., Sinha N., Venkatraman, S., 2012. East Indian margin evolution and crustal architecture: integration of deep reflection seismic interpretation and gravity modelling. In: Mohriak, W.U., Danforth, A., Post, P. J., et al., (Eds.), *Conjugate Divergent Margins*. Geological Society of London, Special Publication 369, doi 10.1144/SP369.6.

- Nicolaysen, K., Bowring S., Frey F., Weis D., Ingle S., Pringle M. S., Coffin M. F. 2001. Provenance of Proterozoic garnet-biotite gneiss recovered from Elan Bank, Kerguelen Plateau, southern Indian Ocean. *Geology* 29, 235-238.
- Norton, I. O., Sclater, J. G. 1979. A model for the evolution of the Indian Ocean and the breakup of Gondwanaland. *Journal of Geophysical Research* 84, 6803-6830.
- Parsons, B., Sclater, J. G., 1977. An analysis of the variation of Ocean Floor Bathymetry and Heat Flow with Age. *Journal of Geophysical Research* 82, 803–827.
- Pateria, M.L., Rangaraju, M.K., Raiverman, V., 1992. A note on the structure and stratigraphy of Bay of Bengal sediments. *Geological Survey of India Special Publication* 29, 21-23.
- Peirce, C., Barton, P. J., 1991. Crustal structure of the Madeira-Tore Rise, eastern North Atlantic: Results of a DOBS wide-angle and normal incidence seismic experiment in the Josephine Seamount region. *Geophysical Journal International* 106, 357-378.
- Powell, C. M., Roots, S. R., Veevers, J. J., 1988. Pre-breakup continental extension in East Gondwanaland and the early opening of the eastern Indian Ocean. *Tectonophysics* 155, 261-283.
- Pringle, M.S., Duncan, R.A., 2000. Kerguelen Plateau: initial products of the Kerguelen Large Igneous Province. *EOS Transactions, American Geophysical Union* 81, 424.
- Ramana, M. V., Nair, R. R., Sarma, K. V. L. N. S., Ramprasad, T. Krishna, K. S., Subrahmanyam, V., D’Cruz, M., Subrahmanyam, C., Paul, J., Subrahmanyam, A. S., Chandrasekhar, D. V., 1994. Mesozoic anomalies in the Bay of Bengal. *Earth and Planetary Science Letters* 121, 469-475.
- Ramana, M. V., Subrahmanyam, V., Chaubey, A. K., Ramprasad, T., Sarma, K.V.L.N.S, Krishna, K. S., Desa, M., Murty, G.P.S., 1997. Structure and origin of the 85°E Ridge. *Journal of Geophysical Research* 102, 17995-18012.
- Ramana, M. V., Ramprasad, T., Desa, M., 2001. Seafloor spreading magnetic anomalies in the Enderby basin, East Antarctica. *Earth and Planetary Science Letters* 191, 241-255.
- Ramana, M.V., Desa, M., Ramprasad, T., Kumar, B.J.P., Lall., M., 2009. Crustal structure of the Eastern Continental Margin of India as deduced from multichannel seismic reflection data, 46th Annual Convention of Indian Geophysical Union, Wadia Institute of Himalayan Geology, Dehra Dun, India.
- Royer, J. Y., Sclater, J. G., Sandwell, D. T., 1989. A preliminary tectonic fabric chart of the Indian Ocean, In: Brune, J. N. (Ed.), *Proceedings of the Indian Academy of Sciences, Earth and Planetary Science* 98, 7-24.
- Sandwell, D. T., Smith, W. H. F., 2009. Global marine gravity from retracked Geosat and ERS-1 altimetry: Ridge segmentation versus spreading rate. *Journal of Geophysical Research* 114, doi: 10.1029/2008JB006008.

- Sengupta, S., 1966. Geological and Geophysical Studies in western part of Bengal Basin, India. American Association Petroleum Geology Bulletin 50, 1001-1017.
- Sreejith, K. M., Radhakrishna, M., Krishna, K.S., Majumdar, T. J., 2011. Development of the negative gravity anomaly of the 85°E Ridge, northeastern Indian Ocean – a process oriented modeling approach. J. Earth Syst. Sci. 120, 605-615.
- Stagg, H. M. J., Colwel, J. B., Direen, N. G., O'Brien, P. E., Bernadel, G., Borissova, I., Brown, B. J., Ishihara, T., 2004. Geology of the continental margin of Enderby and Mac Robertson Lands, East Antarctica: Insights from a regional data set. Marine Geophysical Researches 25, 183-219.
- Subrahmanyam, V., Krishna, K.S., Murthy, I.V.R., Sarma, K.V.L.N.S., Desa, M., Ramana, M.V., Kamesh Raju, K.A., 2001. Gravity anomalies and crustal structure of the Bay of Bengal. Earth and Planetary Science Letters 192, 447-456.
- Talwani, M., Heirtzler, J.R., 1964. Computation of magnetic anomalies caused by two-dimensional bodies of arbitrary shape. In: Parks, G.A., (Ed.), Computers in the Mineral Industries, Part 1. Geological Sciences, Stanford University Publication 9, 464-480.
- Talwani, M., Worzel, J.L., Landisman, M., 1959. Rapid gravity computations for two dimensional bodies with application to the Mendocino submarine fracture zone. Journal of Geophysical Research 64, 49-59.
- Weis, D., Ingle, S., Damasceno, D., Frey, F.A., Nicolaysen, K., Barling, J., 2001. Origin of continental components in Indian Ocean basalts: Evidence from Elan Bank (Kerguelen Plateau, ODP Leg 183, Site 1137). Geology 29, 147-150.
- Wessel, P., Smith, W. H. F., 1998. New improved version of Generic Mapping Tools released. EOS Transactions, American Geophysical Union 79, 579.
- White, R.S., Spence, G.D., Fowler, S.R., Mckenzie, D. P., Westbrook, G.K., Bowen, A.N., 1987. Magmatism at rifted continental margin. Nature 330, 439-444.

Figure captions

Figure 1: Satellite derived gravity mosaic (Sandwell and Smith, 2009) of the northeastern Indian Ocean. Study area is shown as a black box. Thin dashed black lines are fracture zones (Ramana et al., 2001; Desa et al., 2006; 2009; Royer et al., 1989). Thick dashed lines depict the extent of the subsurface 85°E Ridge inferred using the satellite gravity mosaic. Blue dashed lines indicate the likely hotspots tracks of the 85°E and Ninetyeast Ridges (Curry and Munasinghe, 1991). DSDP sites with maximum age are marked as black circles. Large igneous provinces are marked as thin blue outlines. NER: Ninetyeast Ridge; ANS: Afanasy Nikitin Seamount chain; ST: Sunda Trough; BOB: Bay of Bengal; 85ER: 85°E Ridge; AND: Andaman Islands; MH: Mahanadi

Figure 2: Maps showing the multichannel seismic profiles used in the present study superimposed on the general bathymetry. Contour interval is variable. (a) Shipborne gravity anomaly plotted perpendicular to the tracks (b) Residual magnetic anomaly plotted perpendicular to the tracks.

Figure 3: (a) Processed multichannel seismic section along the dip profile S1. Its intersection with the strike profile S4 is shown as dashed line. (Courtesy: DGH, India).

(b) Interpreted multichannel seismic section along the dip profile S1 plotted with the gravity and magnetic signatures. L1 indicates the shelf margin basin anomaly and L2 is the broad gravity low corresponding to the 85°E Ridge. Q, M and P represent base of Quaternary, Top of Miocene and Top of Paleocene respectively. E, D and C correspond to the Early, Mid and Late Cretaceous-Paleocene deposits respectively. ACB denotes the acoustic basement. Major faults/horizons within the acoustic basement are shown in gray, while those in the sedimentary column are shown as black lines. The typical reflection pattern within the rectangle may represent carbonate buildup. The magmatic intrusion is shown in red. 85ER: 85°E Ridge

Figure 4: (a) Processed multichannel seismic section along the dip profile S2. Its intersection with the strike profile S4 is shown as dashed line.

(b) Interpreted multichannel seismic section along the dip profile S2 plotted with the gravity and magnetic signatures. Blue dashed outline depicts the Moho reflection. The top of the carbonate buildup over the ridge is marked in yellow. Other information same as in figure 3b.

Figure 5: (a) Processed multichannel seismic section along the dip profile S3. Its intersection with the strike profile S4 is shown as dashed line.

(b) Interpreted multichannel seismic section along the dip profile S3 plotted with the gravity and magnetic signatures. SDRs: Seaward dipping reflectors. Gravity lows L1 and L2 are merged into L. Blue dashed outline depicts the Moho reflection. RFZ denotes the reflection free zone depicting geophysical anomalies akin to the ridge elsewhere. Other information same as in figure 3b.

Figure 6: (a) Processed multichannel seismic section along the strike profile S4. Dashed lines denote its intersection with the dip profiles.

(b) Interpreted multichannel seismic section along the strike profile S4 plotted with the gravity and magnetic signatures. Blue dashed outline depicts the Moho reflection. Other information same as in figure 3b.

Figure 7: Forward modeling of the geophysical data using the subsurface constraints derived from seismic data. 85ER represents the subsurface 85°E Ridge. Sedimentary column divided into 6 sequences (q, pl, m, oe, pal and cret) representing Quaternary, Pliocene, Miocene, Oligocene-eocene, Paleocene and Cretaceous sediments. Crust classified into continental, transitional and oceanic types. Densities and magnetic parameters of all bodies are given in Table 1. Black and white zones in the upper oceanic crust (UC) denote normally and reversely magnetized crusts respectively. TZ: Transition Zone; RC: Ridge Crust; MI: Magmatic Intrusion; CC: Continental crust; MC: Middle Oceanic crust; LC: Lower Oceanic Crust (a) Profile S1, (b) Profile S2.

Figure 8: Line drawings of the seismic sections along the profiles S1 (Eastern Continental Margin of India) and C1 (Enderby Basin, East Antarctica) plotted facing each other for comparison purpose. Profile C1 adopted from Joshima et al., (2001) and Stagg et al., (2004). A to E represent the sedimentary sequences as described in the text. ACB: Acoustic Basement; 85ER: 85°E Ridge. The plate reconstruction model for chron M0 time depicts the conjugate nature of the profiles (Euler pole: 0.75, 13.9, 85.85; Powell et al., 1988).

Figure 9(a): Paleocene-Cretaceous sediment isopach map of the study area in s TWT derived using the seismic data. Contour interval 0.5 s TWT.

Figure 9(b): Total sediment thickness map of the study area in s TWT derived using the seismic data. Contour interval 0.5 s TWT.

Figure 10: Figure depicting the geology and tectonics of the Northeastern Indian Ocean (Sengupta, 1966). The northern segment of the 85°E Ridge (85ER) is shown as thick pink zone. Dashed black line marks the western extent of the shallow basement inferred in the present study. The probable palaeo-location of Elan Bank (EB) and Southern Kerguelen Plateau (SKP) represented by their 2000 m isobaths is depicted as blue outline and their direction of motion is shown by an arrow mark. The eastern extent of the Precambrian Shield of India (PCI) is shown in green outline. The seismic tracks are shown as thin red lines. The Indian plate boundary is shown as fine black outline. Dashed blue line represents the likely boundary between the volcanic and non-volcanic margins of eastern India. RT: Rajmahal Traps; MH: Mahanadi; EC: Early Cretaceous crust; MC: Mid Cretaceous crust; ST: Sunda Trough; SP: Shillong Plateau; BOB: Bay of Bengal.

Table captions

Table 1: Physical properties of the various bodies inferred using forward modeling of the geophysical data under seismic constraints.

Table 1: Physical properties of the various bodies inferred by forward modeling of the geophysical data under seismic constraints

Profile S1			
Body	Density gm/cc	Polarity	Susceptibility μcgs units
water	1.03		
q	1.8	-	-
pl	2.0	-	-
m	2.2	-	-
oe	2.3	-	-
Pc	2.4	-	-
cret	2.5	-	-
UCC	2.68	-	1160-3087
MCC	2.8	-	618-1960
LCC	3.0	-	0
UC	2.7	R/N	6230-11860
MC	2.8	-	0
LC	2.9	-	0
Mantle	3.3	-	0
TZ	2.9-3.1	R/N	1490-16750
MI	2.7	N	1586-9826
RC	2.7	N	1705-8135

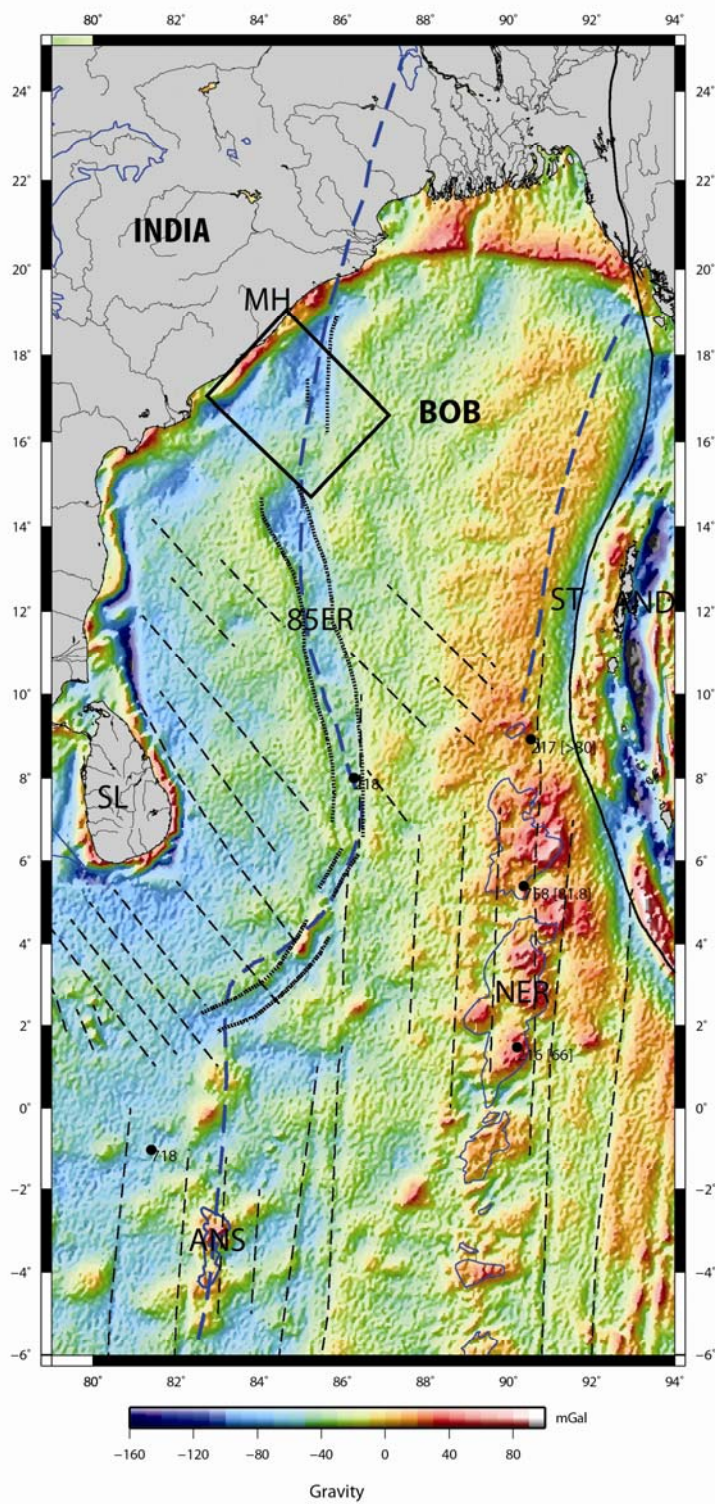


Fig. 1
Desa et al

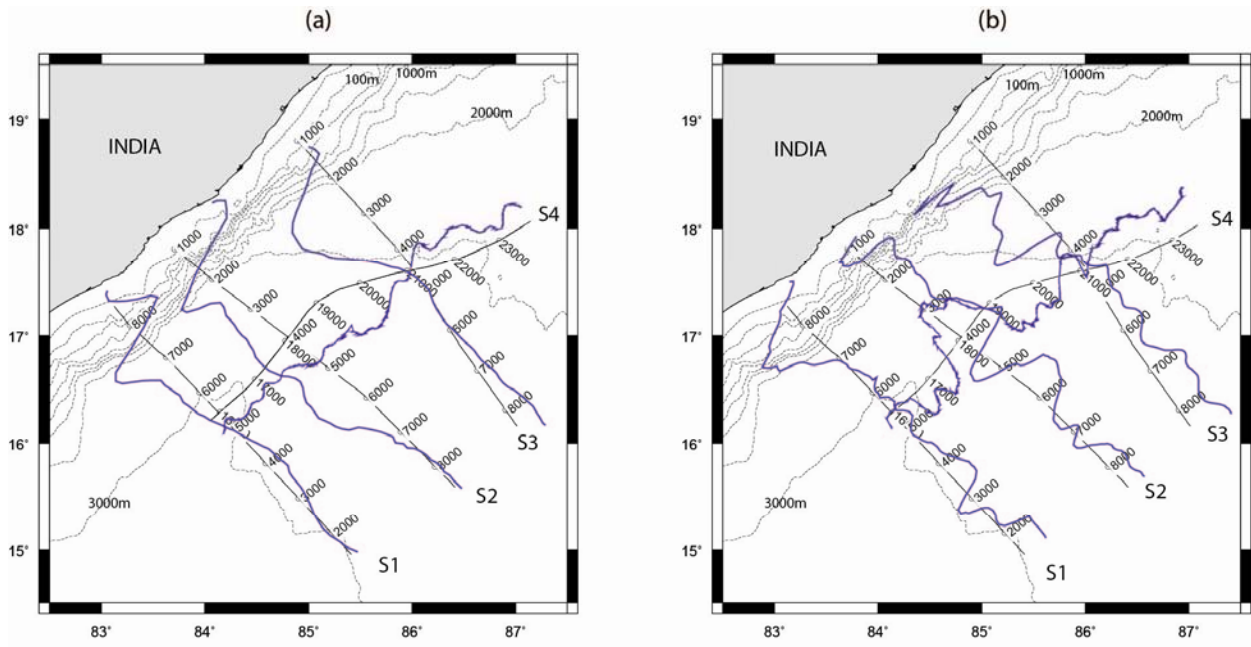


Fig. 2
Desa et al

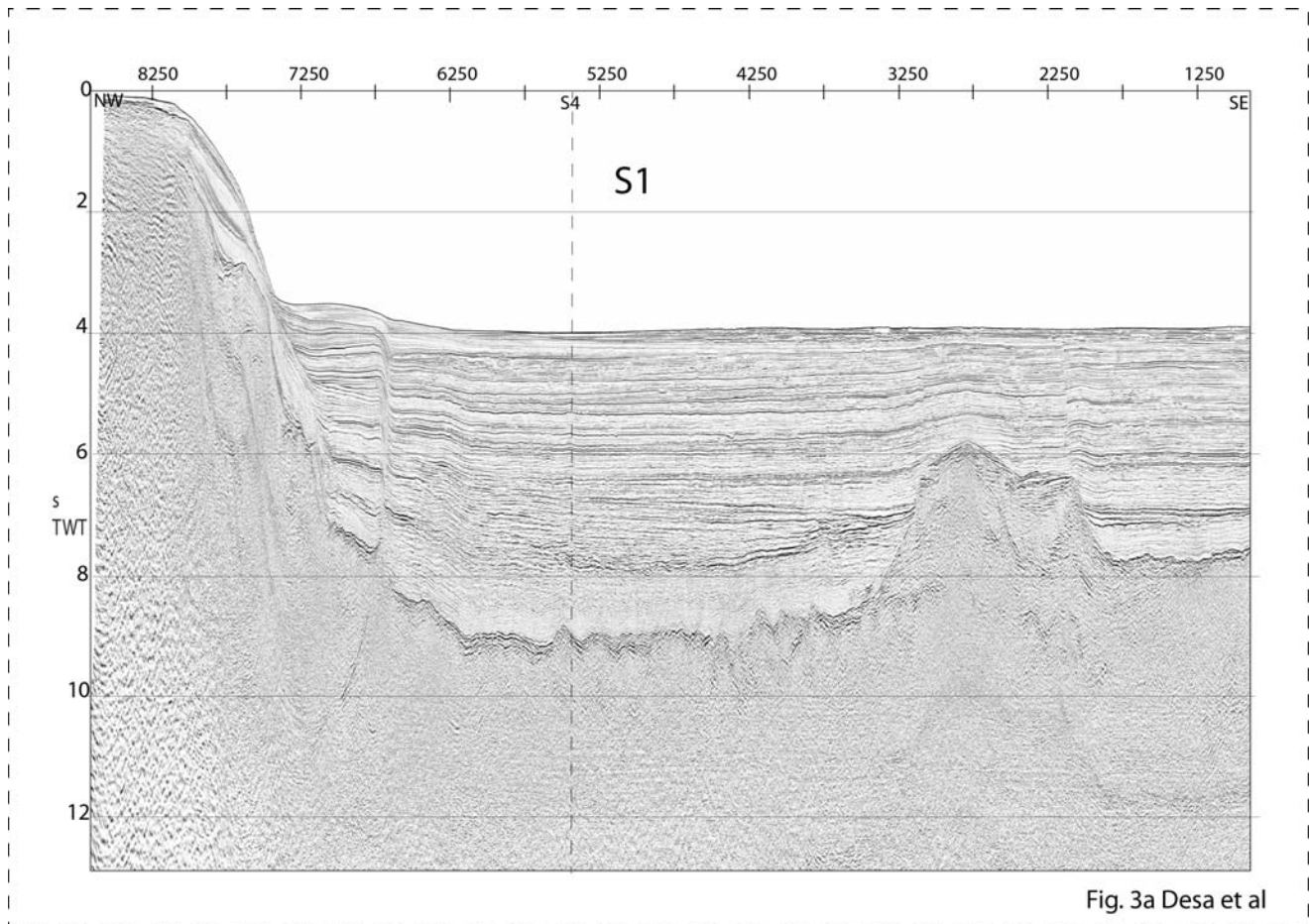


Fig. 3a
Desa et al

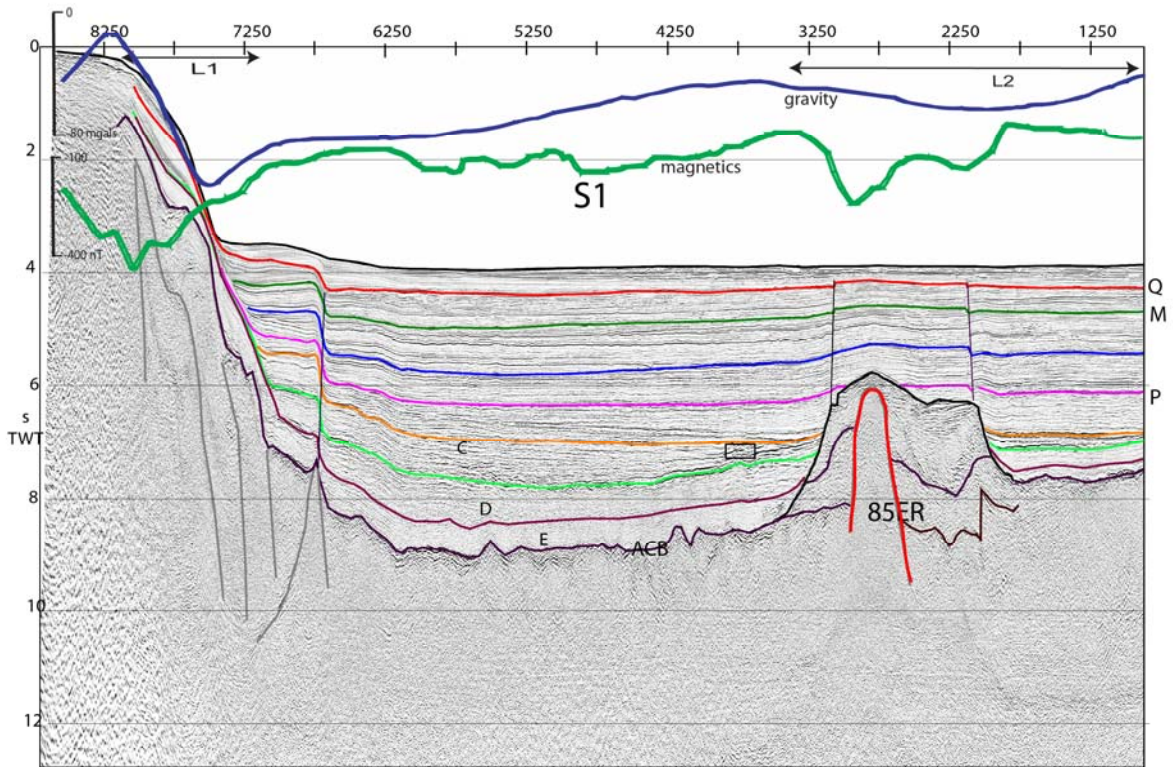


Fig. 3b Desa et al

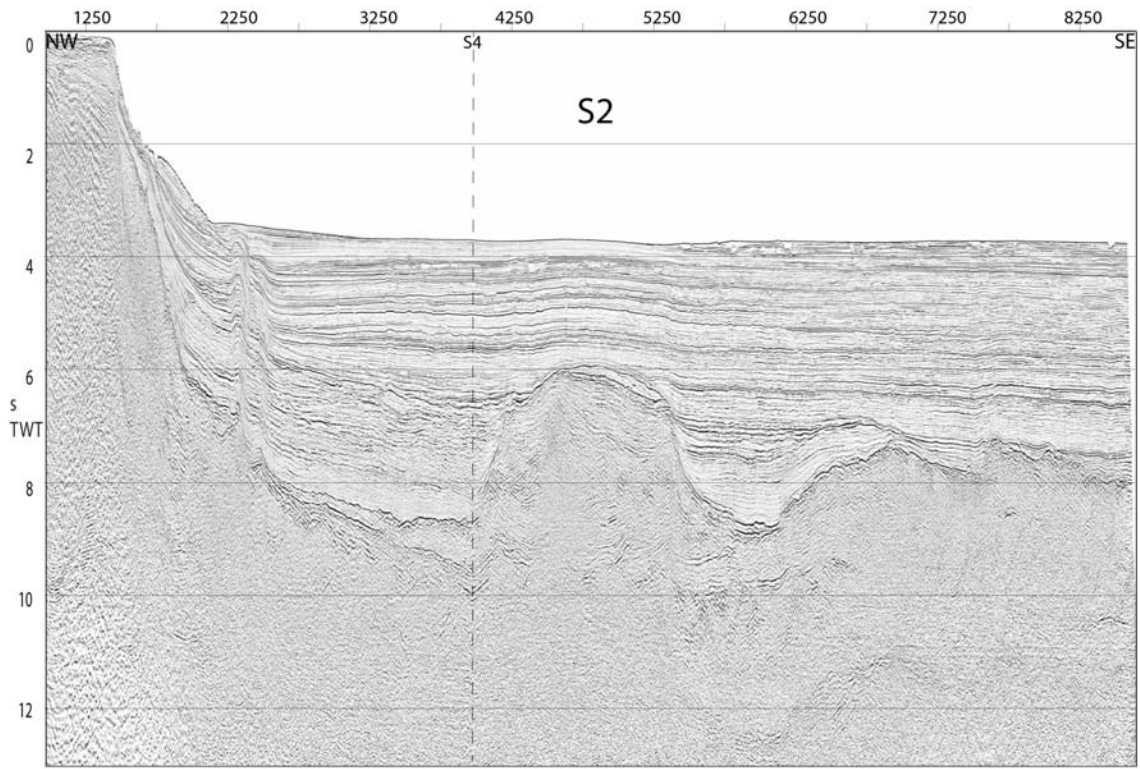


Fig. 4a Desa et al

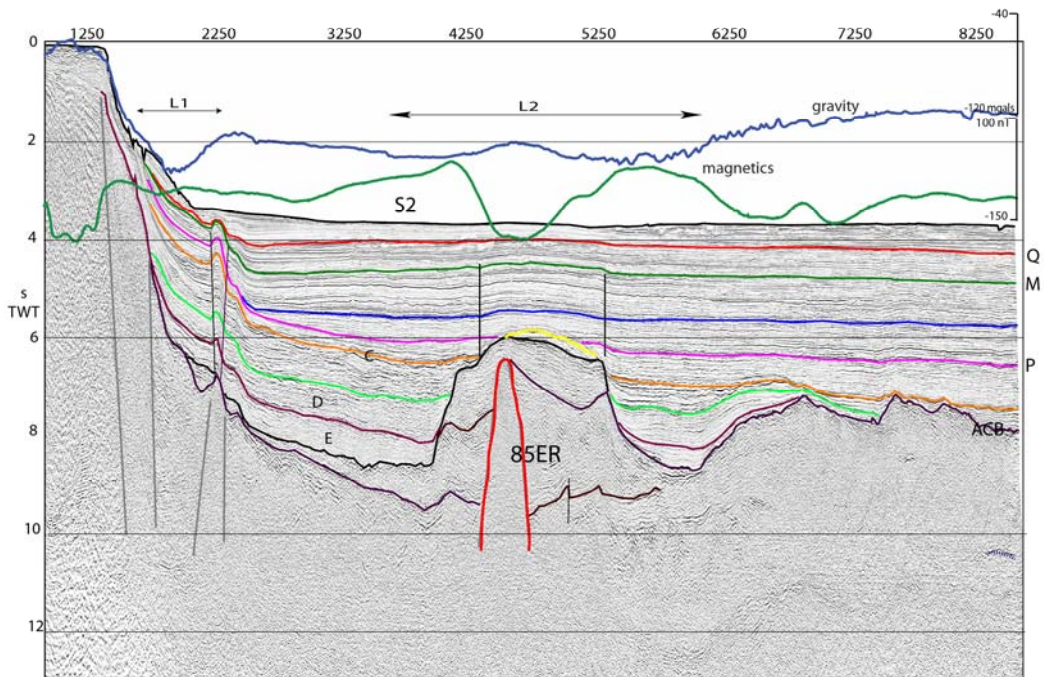


Fig. 4b Desa et al

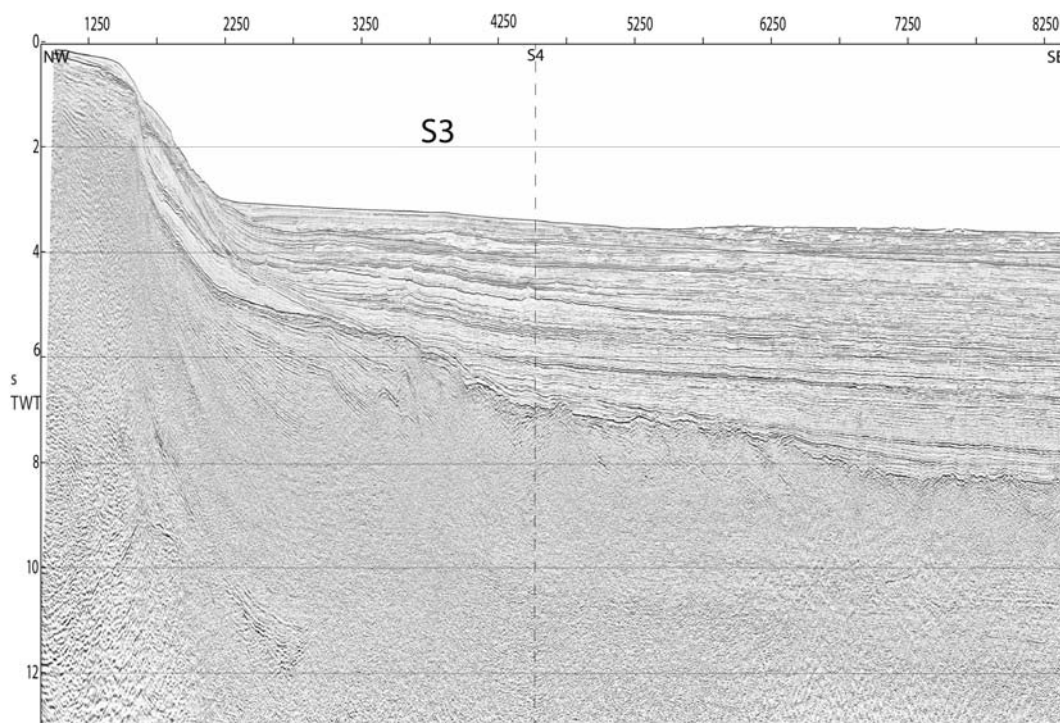


Fig. 5a Desa et al

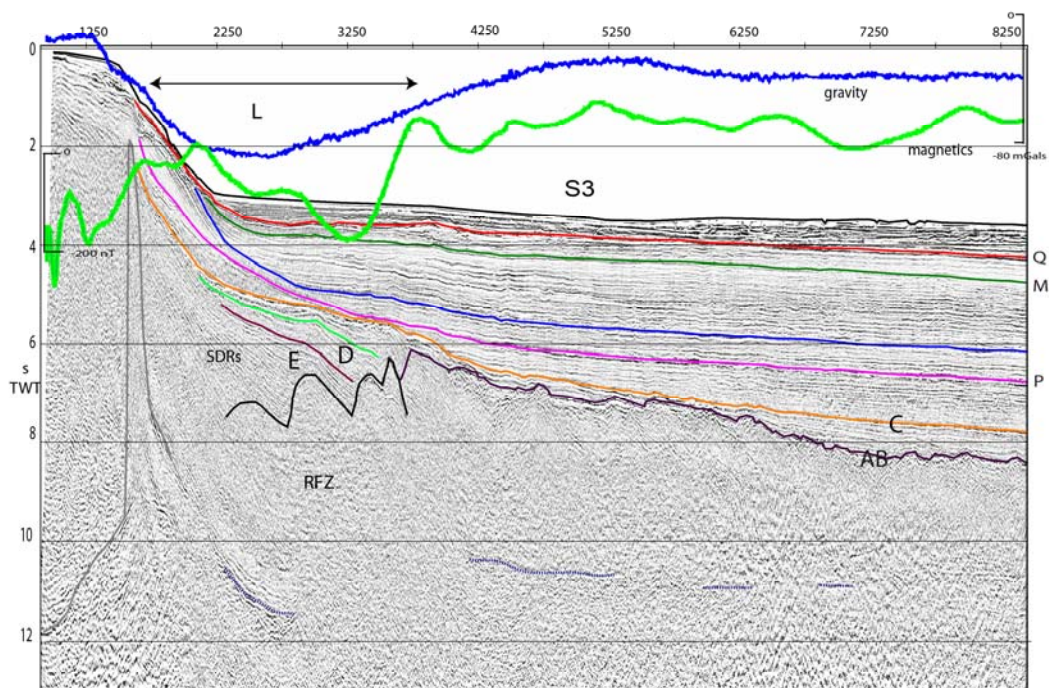


Fig. 5b Desa et al

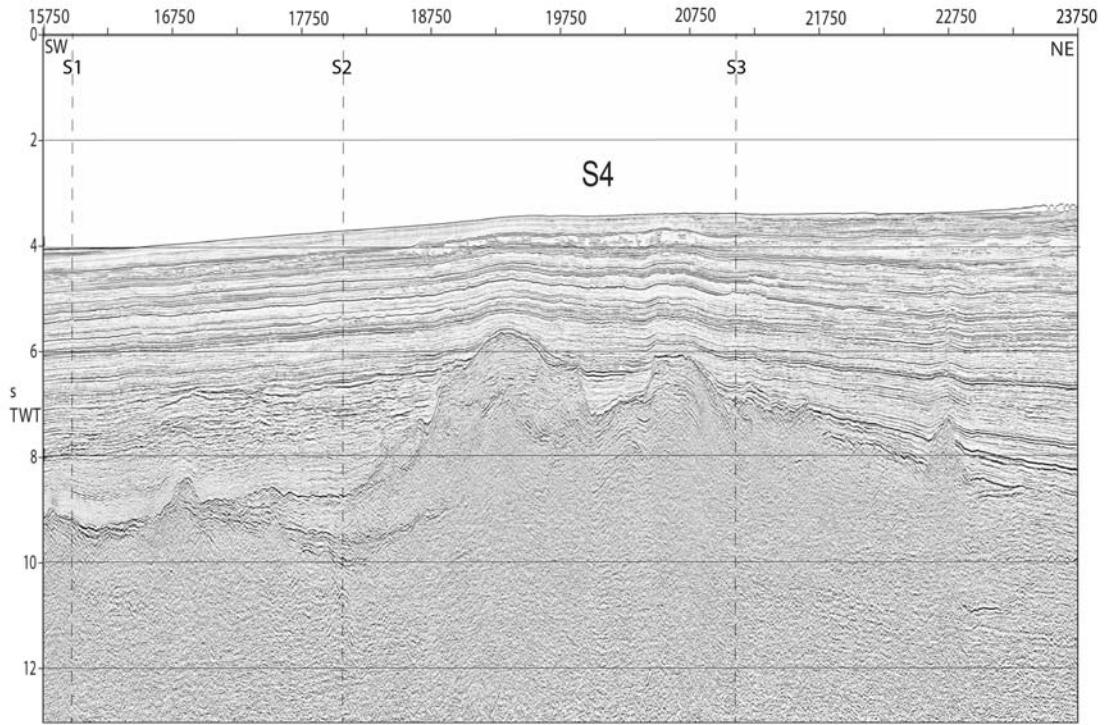


Fig.6a Desa et al

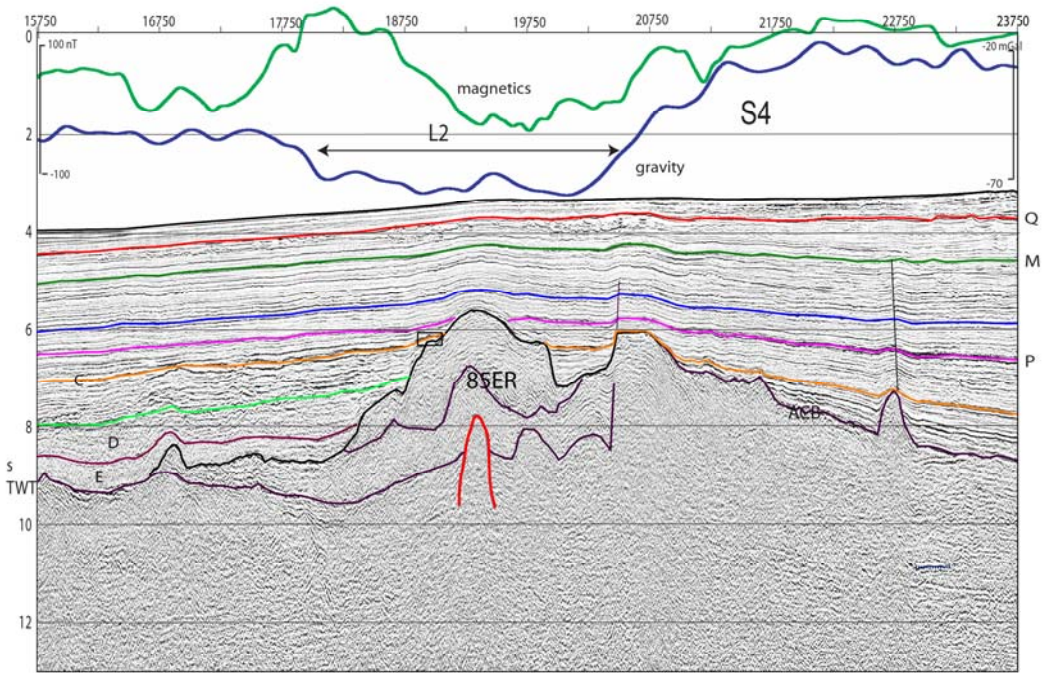


Fig.6b Desa et al

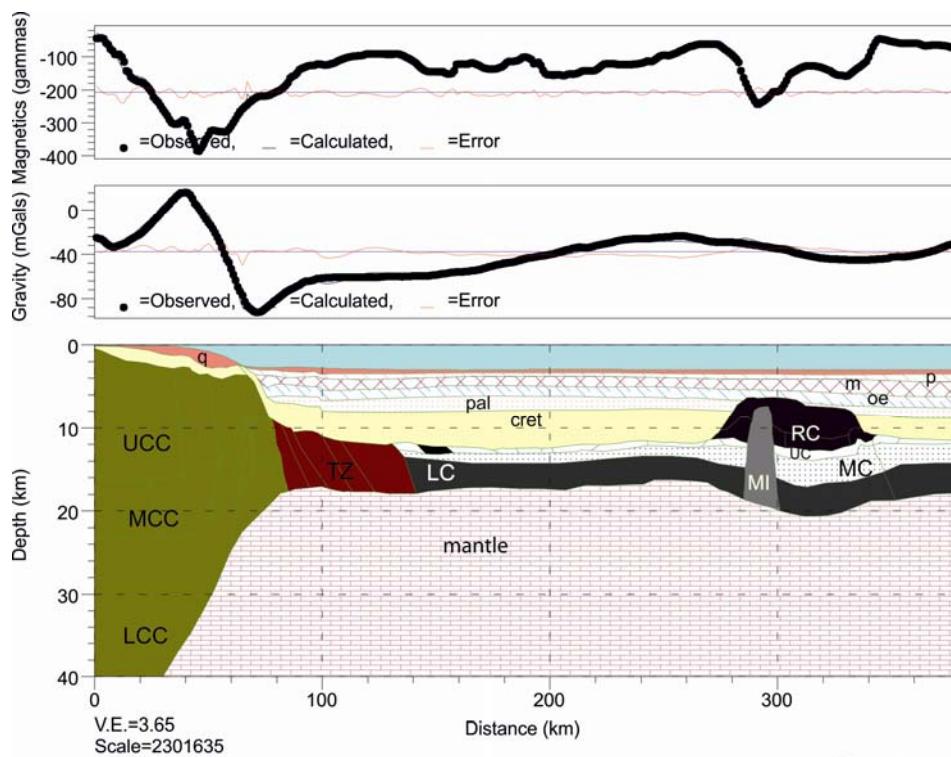


Fig. 7a
Desa et al

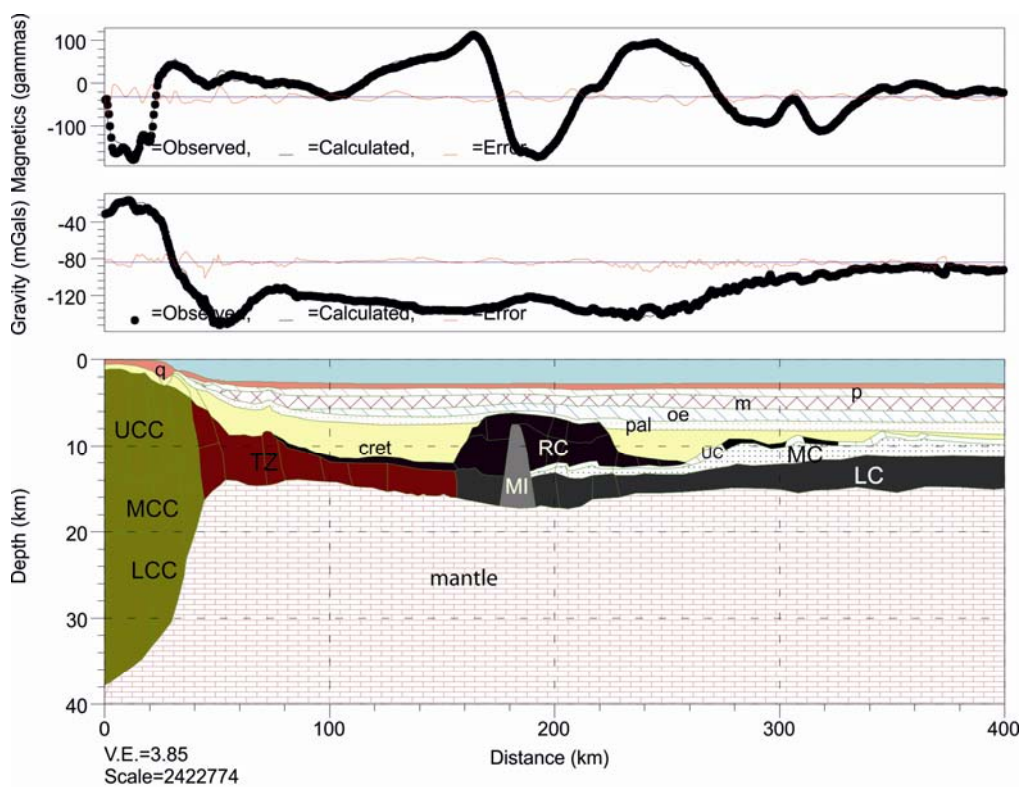


Fig. 7b
Desa et al

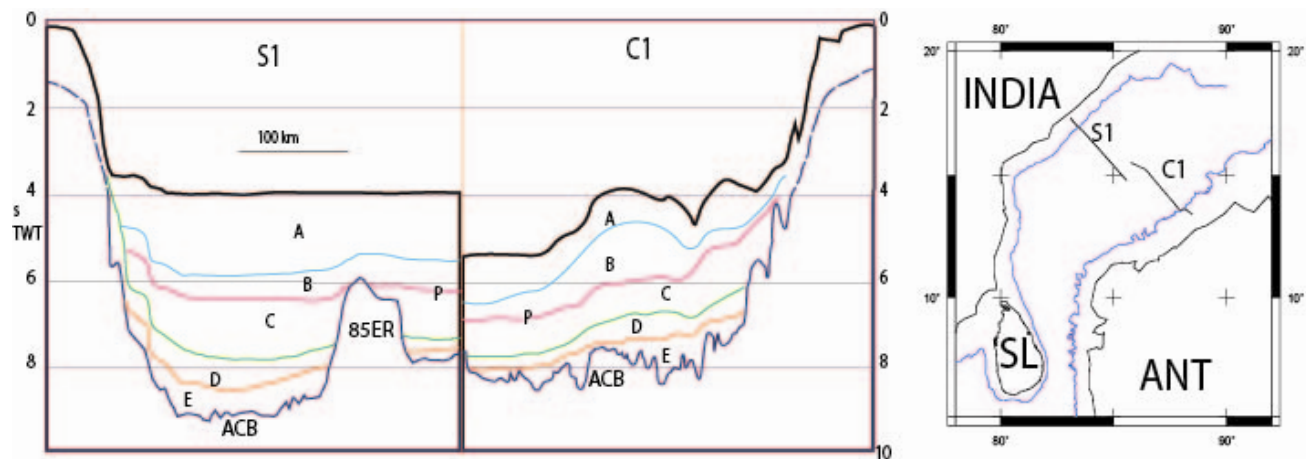


Fig. 8 Desa et al

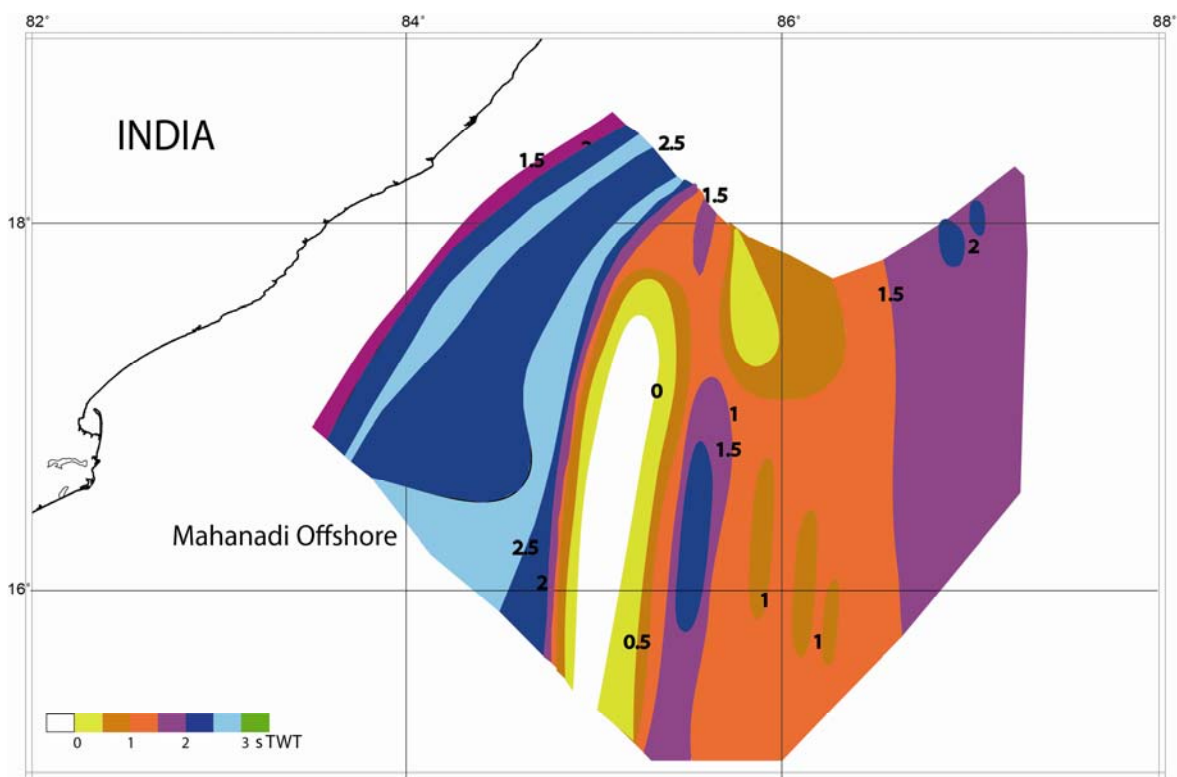


Fig. 9a Desa et al

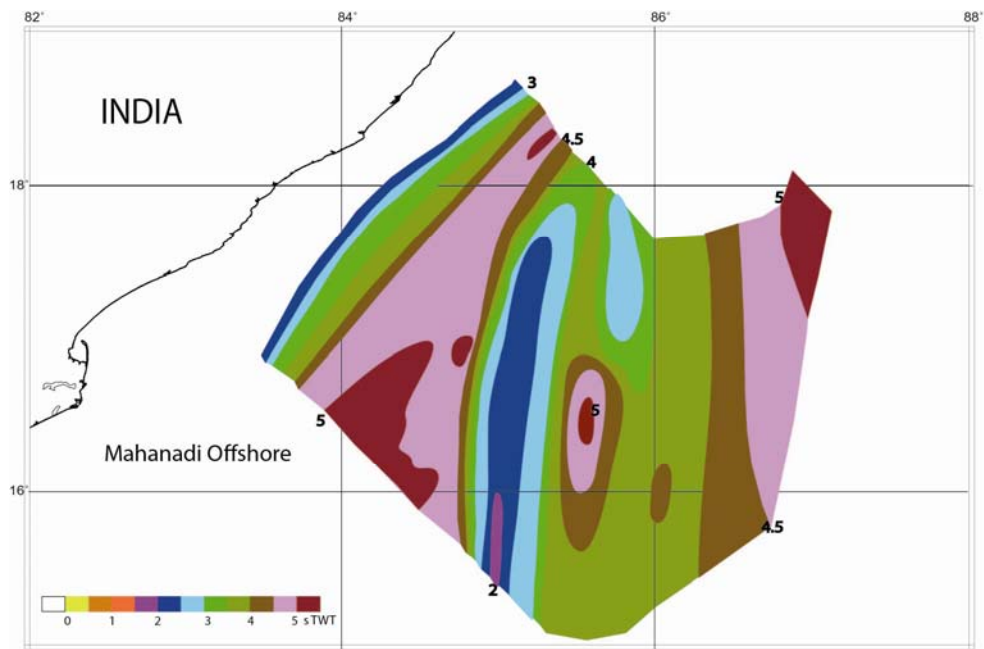


Fig. 9b Desa et al

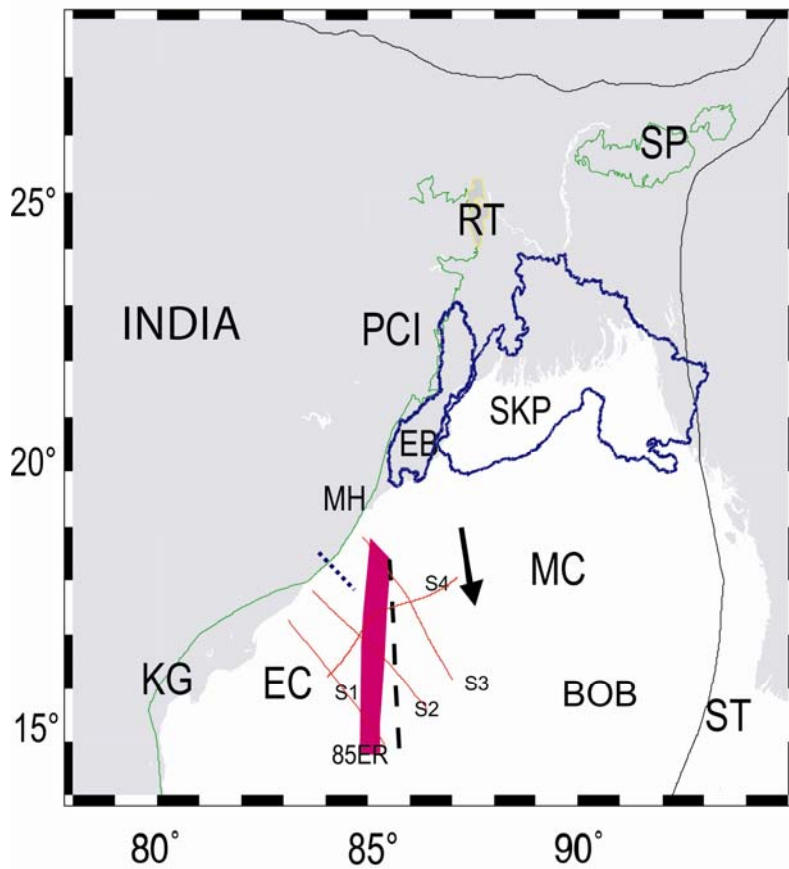


Fig. 10 Desa et al