Development of the negative gravity anomaly of the 85°E Ridge, northeastern Indian Ocean – A process oriented modelling approach

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The 85°E Ridge extends from the Mahanadi Basin, off northeastern margin of India to the Afanasy Nikitin Seamount in the Central Indian Basin. The ridge is associated with two contrasting gravity anomalies: negative anomaly over the north part (up to 5°N latitude), where the ridge structure is buried under thick Bengal Fan sediments and positive anomaly over the south part, where the structure is intermittently exposed above the seafloor. Ship-borne gravity and seismic reflection data are modelled using process oriented method and this suggest that the 85°E Ridge was emplaced on approximately 10–15 km thick elastic plate (Te) and in an off-ridge tectonic setting. We simulated gravity anomalies for different crust-sediment structural configurations of the ridge that were existing at three geological ages, such as Late Cretaceous, Early Miocene and Present. The study shows that the gravity anomaly of the ridge in the north has changed through time from its inception to present. During the Late Cretaceous the ridge was associated with a significant positive anomaly with a compensation generated by a broad flexure of the Moho boundary. By Early Miocene the ridge was approximately covered by the post-collision sediments and led to alteration of the initial gravity anomaly to a small positive anomaly. At present, the ridge is buried by approximately 3 km thick Bengal Fan sediments on its crestal region and about 8 km thick pre- and post-collision sediments on the flanks. This geological setting had changed physical properties of the sediments and led to alter the minor positive gravity anomaly of Early Miocene to the distinct negative gravity anomaly.

1. Introduction

The 85°E Ridge extends from the Mahanadi Basin in the north to the Afanasy Nikitin Seamount in the south, is a prominent aseismic ridge in the northeastern Indian Ocean (figure 1). The northern part of the ridge (north of 5°N) is buried under thick Bengal Fan sediments, whereas in the south, its structure occasionally rises above the seafloor (Curray *et al* 1982; Liu *et al* 1982; Curray and Munasinghe 1991; Müller *et al* 1993; Gopala Rao *et al* 1997; Subrahmanyam *et al* 1999; Krishna 2003; Krishna *et al* 2011). At around 5°N, southeast of Sri Lanka, a westward shift of 250 km exists

Keywords. 85°E Ridge; elastic plate thickness; lithospheric flexure; process oriented modelling; Bengal Fan; northeastern Indian Ocean.

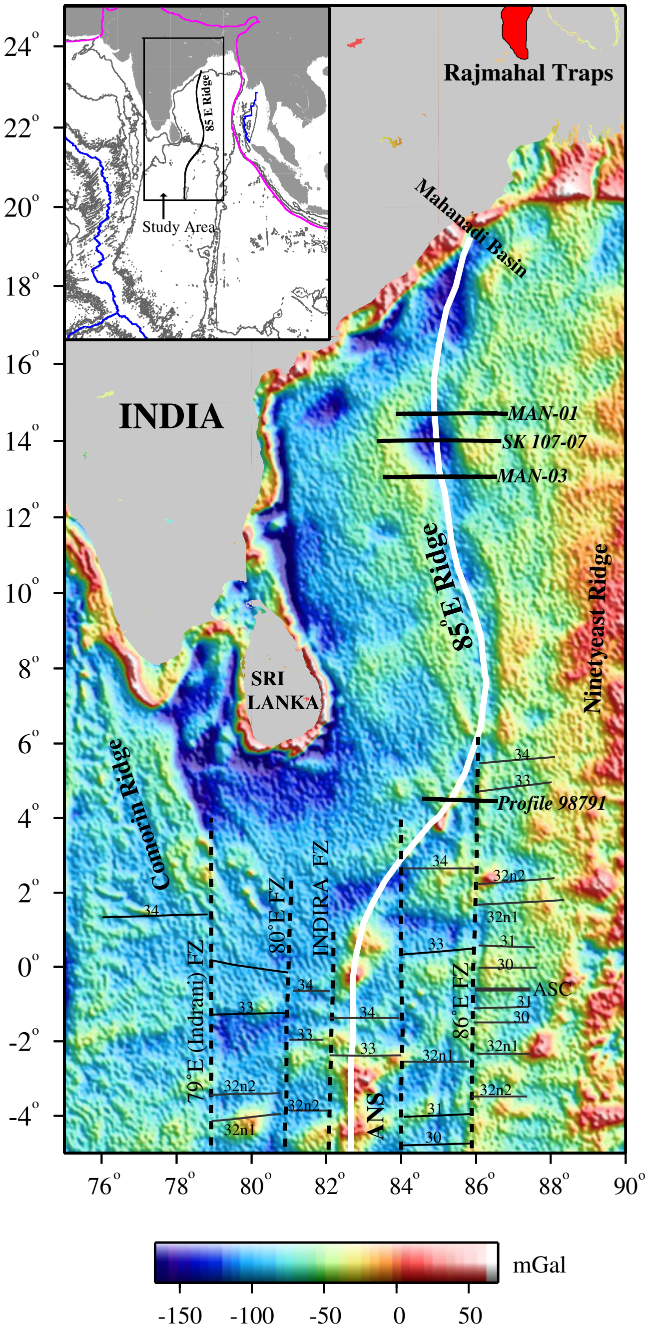

Figure 1. Satellite derived free-air gravity anomaly map (Sandwell and Smith 1997) of the northeastern Indian Ocean. The position of the 85°E Ridge is marked with white solid line. Thick solid lines indicate the location of seismic sections used in the analysis. Magnetic lineations (thin line) and fracture zones (dashed line) are superposed on the map (Krishna *et al* 2009). The general bathymetry (ETOPO2) of the Indian Ocean along with plate boundaries is shown in the insert map. ANS: Afanasy Nikitin Seamount.

which is not observed along other major N–S trending hotspot related tracks in the Indian Ocean such as the Ninetyeast and Chagos–Laccadive ridges.

Origin of the 85°E Ridge is enigmatic due to its characteristic negative gravity anomaly and complex magnetic signatures. Curray and Munasinghe (1991) postulated that the Rajmahal Traps in the Bengal Basin, 85°E Ridge and ANS form the trace of the Crozet hotspot. However, geochemical results of lava samples of ANS do not show affinity to the Crozet hotspot volcanism (Mahoney *et al* 1996). Though many subsequent researchers favoured the hotspot activity for the emplacement of the ridge (Müller *et al* 1993; Gopala Rao *et al* 1997; Subrahmanyam *et al* 1999; Krishna 2003; Bastia *et al* 2010; Radhakrishna *et al* 2010; Michael and Krishna 2011), the source of the hotspot volcanism remains speculative. Alternatively, formation of the ridge due to shearing or sagging of crust by horizontal stretching/compressional forces has been proposed by others (Ramana *et al* 1997; Anand *et al* 2009). Following the analogy of the negative gravity signature of the Laxmi Ridge in the Arabian Sea and its continental sliver interpretation (Naini and Talwani 1983; Talwani and Reif 1998; Krishna *et al* 2006), one can also think in the direction of continental origin to the 85°E Ridge. This possibility has numerous difficulties for explaining the other aspects.

- The trend of the 85°E Ridge is not parallel to the configuration of the Eastern Continental Margin of India (ECMI) and to the identified continent–ocean boundary along the ECMI.
- The oceanic crust in the Western Basin does not provide any evidence for the presence of conjugate parts of the ocean floor evolved by the spreading process after so-called breakup of the 85°E Ridge from ECMI.
- The NW–SE trending oceanic fracture zones identified in the Western Basin obliquely cross the 85°E Ridge, and these fracture zones were earlier have interpreted as conjugate parts of the fracture zones evolved in the Enderby Basin (Krishna *et al* 2009).
- The breakup history of the Elan Bank from the north ECMI becomes more complex in case of consideration of the 85°E Ridge as a continental sliver.

Liu *et al* (1982) have modelled the negative gravity anomaly of the 85°E Ridge with consideration of two stage loading; initially emplacement of the ridge on a weak lithosphere (5–15 m.y) leading to excess thickening of the crust and subsequently loading of sediments on a stronger lithosphere of 40–80 m.y old. This model infers approximately 180 times increase in the flexural rigidity between emplacement and burial. Later, Krishna (2003) proposed an alternative forward gravity model, in which he explained the negative gravity anomaly as a result of the density contrast between the metasediments and less dense ridge material and a broader Moho depression beneath the ridge.

However, the above proposed models lack a clear understanding on the timing of emplacement of the ridge as well as flexural characteristics during the emplacement. The sources/mass anomalies that gave rise to the negative gravity anomaly, which otherwise expected to have been positive, also needs to be understood and quantified. Considering these complexities and keeping the earlier models in view, we have investigated the 85°E Ridge emplacement mechanism and its development through geological ages using the process oriented gravity modelling approach making use of deep seismic reflection data across the ridge.

The admittance analysis, in general, is used for estimation of flexural rigidity and isostatic response of the geological structures, but in the case of 85°E Ridge, the technique is unsuccessful because of absence of its topographic expression on the seafloor. Therefore we have carried out the process-oriented gravity modelling, in which the present-day gravity field of the ridge can be divided into different gravity anomaly components. The main objectives of this study are:

- to determine the effective elastic plate thickness of the ridge at the time of emplacement,
- to determine the crustal structure and isostatic compensation mechanism of the ridge,
- to investigate the changes in ridge gravity anomaly through time since its formation.

Thereupon we discuss the geological processes involved in development of the ridge negative gravity anomaly.

2. Tectonic setting

It is widely accepted that the Greater India separated from East Antarctica during the Early Cretaceous period and subsequently formed the conjugate oceanic regions, Bay of Bengal and Enderby Basin. The Indian landmass had witnessed two continental breakups in early stages of eastern Gondwana splitting. The first breakup occurred with separation of Greater India from Australia and East Antarctica during the Early Cretaceous (Curray *et al* 1982; Royer and Coffin 1992; Gopala Rao *et al* 1997; Müller *et al* 2000). In the second stage the Elan Bank, a submerged microcontinent lies presently on the western margin of the Kerguelen Plateau in the southern Indian Ocean, broke up from the present-day eastern margin of India at about 120 Ma (Gaina *et al* 2003, 2007; Borissova *et al* 2003; Krishna *et al* 2009). The breakup sequences and their timings suggest that most part of the oceanic crust in the Bay of Bengal was evolved during the Cretaceous Magnetic Quiet Period (120–83 Ma).

During the mid-Cretaceous period, a major change in the spreading direction occurred from NNW–SSE to N–S, resulted in northward drift of Indian plate followed by collision with Asian plate during the Early Eocene. The Indian plate, in the course of its northward movement resulted in formation of several major aseismic ridges in the Indian Ocean. The 85°E Ridge is one of the major aseismic ridges formed in this phase in the northeastern Indian Ocean and subsequently buried under the post-collision Bengal Fan sediments.

3. The 85°E Ridge – associated geophysical characters

In this study, we have investigated the ship-borne gravity and seismic reflection data of the 85°E Ridge that extracted from the geophysical database of the northeastern Indian Ocean created for understanding the evolution of the eastern continental margin of India and its conjugate Enderby Basin, East Antarctica (Gopala Rao *et al* 1997; Krishna 2003; Krishna *et al* 2009; Michael and Krishna 2011). The regional seismic profiles used in this study for modelling were acquired onboard MV *Sagar Sandhani* (MAN-01 and MAN-03), ORV *Sagar Kanya* (SK107-7) and RV *Issledovatel* (Profile 98791). Velocity structure of the basement and overlying sedimentary strata derived from seismic refraction results (Naini and Leyden 1973; Curray *et al* 1982; Curray 1994; Curray *et al* 2003) are considered in order to constrain the densities for various sedimentary layers.

3.1 *Seismic structure and gravity anomalies of the 85°E Ridge*

The overall trend of the ridge can be seen in satellite gravity anomaly map (figure 1). The ridge extends from 19°N to 5°S with variable widths range from 100 to 180 km. The width of the ridge is maximum near 14°N latitude and associated with a deep gravity low of ∼80 mGal. Further north, the gravity anomaly of the ridge is not very clear between 15°N and 16.5°N latitudes, but shows its presence again near 17°N latitude and appears to continue up to 19°N in the offshore Mahanadi Basin. The presence of the 85°E Ridge in the offshore Mahanadi Basin is confirmed from recently acquired high-quality seismic reflection data (Bastia *et al* 2010). Towards south between 11°N and 2°N, the ridge track bends in clockwise direction, then continues straight-down to join the Afanasy Nikitin Seamount (ANS). The prominent negative gravity anomaly associated with the 85°E Ridge in the Bay of Bengal region changes to positive south of 5°N and in further south, the

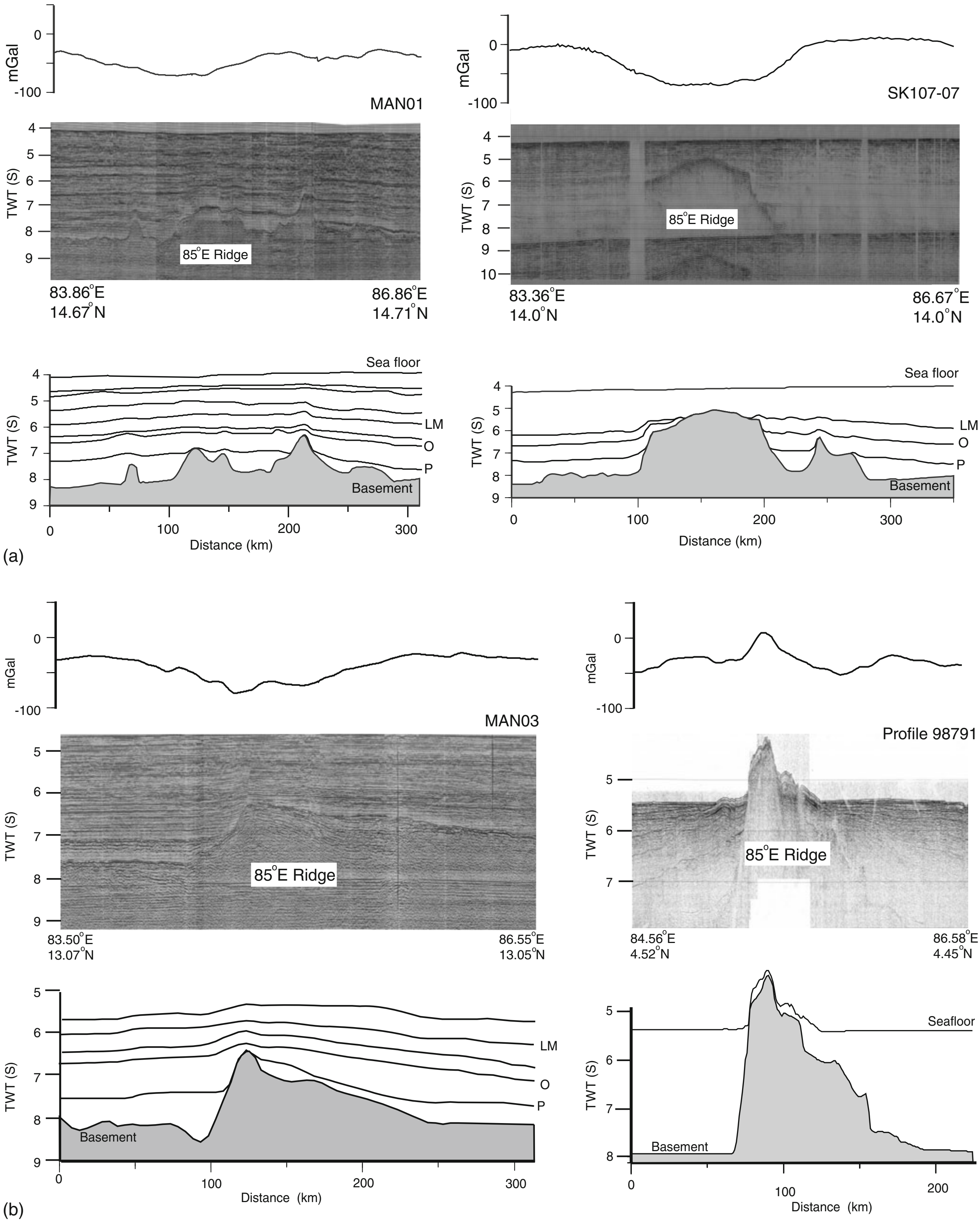

Figure 2. (**a**) MAN-01 and SK107-07 seismic reflection sections (Gopala Rao *et al* 1997; Krishna *et al* 2009) and its interpreted line diagrams across 85°E Ridge stacked with gravity anomaly data. The buried 85°E Ridge and associated negative gravity anomaly is clearly depicted. Paleocene (P), Oligocene (O) and Lower Miocene (LM) boundaries are marked. (**b**) Same as in (**a**) for seismic sections MAN-03 and 98791 (Gopala Rao *et al* 1997; Krishna 2003). The gravity anomaly along profile 98791 was extracted from satellite derived free-air gravity anomaly data (Sandwell and Smith 1997).

ANS is associated with significant positive gravity anomaly.

Four seismic reflection sections crossing the 85°E Ridge along 14.7°, 14°, 13° and 4.5°N latitudes (figure 2a, b) provide details on ridge structure and morphology. These results are intended mainly for the analyses of gravity data and for determination of crust-sediment structural configurations using the process oriented modelling approach. The 85°E Ridge structure in the Bay of Bengal region is completely buried below the Bengal Fan sediments of variable thickness. For example, along 14.7°N and 13°N latitudes the ridge is carpeted by about 2.8 and 1.7 s TWT Bengal Fan sediments (figure 2a, b), respectively; whereas along the 14°N about 0.8 s TWT thick sediment strata overlie the ridge crest.

Based on seismic results of the Bay of Bengal, Curray *et al* (1982) and Gopala Rao *et al* (1997) have divided the entire sediment section into two sedimentary packages and interpreted that the lower package was deposited mainly from the rivers of east coast of India, whereas the upper package was deposited from the Ganges and Brahmaputra rivers after establishing the contact of the Indian subcontinent with the Asian continent. Further the packages are classified as pre- and post-collision sediments and are separated by an erosional Paleocene unconformity (figure 2b) (Moore *et al* 1974). The pre-collision sediment package consists of pelagic and terrigeneous sediments deposited prior to the India–Eurasia collision, whereas, the post-collision part mainly consists of Bengal Fan sediments. The 85°E Ridge acts as a structural partition for dividing the thick Bengal Fan into Western and Central basins (Curray *et al* 1982).

The subsurface disposition of the ridge is quite variable as can be seen from the seismic sections (figure 2a, b). The ridge topography has a steep westward throw and gentle eastward dip along MAN-03 and appear as a double peaked basement rise along SK107-7, whereas along MAN-01 the relief of the ridge is much less with eastern side of the ridge dominated by a prominent basement high probably associated with an oceanic fracture zone (Gopala Rao *et al* 1997). Gravity anomaly plots stacked along these sections show that the ridge is associated with a prominent negative gravity anomaly (∼50 mGal) flanked by regional gravity highs on either side (figure 2a, b). The wavelength of the negative anomaly is relatively greater than the width of the ridge.

The morphology and gravity signature of the southern part of the ridge structure along profile 98791 at 4.5°N are distinctly different in comparison to the sections of the Bay of Bengal. The ridge along the profile 98791 is characterized by shallower basement and exposed above the seafloor (figure 2b). The pre-collision sediments are nearly absent and the thickness of the fan sediments are lesser compared to the north. Along this profile the ridge is associated with a prominent positive gravity anomaly with amplitude of about 40 mGal. The wavelength of the gravity anomaly is comparable with the width of the ridge.

4. Gravity anomaly modelling – process oriented approach

Process oriented modelling utilizing gravity anomaly data is an extremely useful and widely accepted technique in order to investigate geologically complex regions, where the gravity anomalies have been changed through geological ages. Earlier Watts (1988) and Watts and Fairhead (1999) have used this technique to study the complex rifted continental margins in terms of crustal structure, subsidence history and long-term mechanical properties of the crust. In this analysis, the observed gravity anomaly is considered as a sum of several processes, those were involved during the evolution of continental margins such as rifting, underplating, sediment loading, flexure, erosion, etc. The technique essentially involves 2D flexural backstripping of each sedimentary layer identified in seismic section and computation of gravity anomalies corresponding to relevant processes at the margin. We followed this approach in the present study to model the gravity field and its temporal variation of the 85°E Ridge. We start our model with a concept that the 85°E Ridge was evolved in an oceanic setting by a volcanic activity and eventually this was buried under thick Bengal Fan sediments. The first step in the modelling is to reconstruct ridge topography by flexurally unloading each sedimentary layer by computing the flexure caused by distributed load on elastic plate using finite difference-numerical method (Allen and Allen 1990) and removing this effect from the basement. The oldest sedimentary sequence overlying the basement in the Bay of Bengal region was deposited from Early Cretaceous to Paleocene. This means that thin cover of sediments were present by the time of ridge emplacement at about ∼85 Ma (Krishna 2003) and from sediment depositional history, probable thickness of this layer could be estimated. All the sedimentary layers except the thin basal sediment layer have been backstripped for different elastic plate thickness (Te) values. The backstripped section represents the initial topography of the ridge covered with a thin layer of sediments overlain by water. The ridge emplacement is modelled; as a load on thin elastic plate, or as a load on a plate with no strength (Airy), which results in flexural and Airy

Table 1. *Model parameters used for the flexural calculations and gravity modelling.*

Parameter	Value
Density of seawater (ρ_w)	1.03 g cm^{-3}
Density of oceanic crust (ρ_c)	2.90 g cm^{-3}
Density of load (ρ_l)	2.65 g cm^{-3}
Density of mantle (ρ_m)	3.30 g cm^{-3}
Density of sedimentary layer 1 (ρ_1)	2.30 g cm^{-3}
Density of sedimentary layer 2 (ρ_2)	2.60 g cm^{-3}
Density of metasediments (ρ_3)	2.80 g cm^{-3}
Average crustal thickness (t)	6 km
Young's modulus (E)	100 Gpa
Poisson's ratio (σ)	0.25
Universal gravitational constant (G)	$6.67 \cdot 10^{-11}$ Nm^{2}kg^{-2}
Acceleration due to gravity (g)	9.8 ms^{-2}

type Moho configurations, respectively. The gravity anomalies associated with the restored section for both flexure and Airy Moho configurations are calculated, which give rise to 'ridge anomaly' for respective compensation mechanisms. In the second stage, we brought back the sedimentary layers on to the restored section and add these deflections to reconstruct the present-day basement and Moho. The positive contribution of the sediment load and negative effect of flexure at the Moho, when added will give rise to 'sedimentation anomaly'. The combined effect of ridge anomaly and the sedimentation anomaly can be compared with the observed gravity anomaly over the ridge for a specific *Te* value. Entire process is repeated for different *Te* values ranging from 0 to 25 km, until a good fit is obtained between the observed and calculated gravity anomalies considering RMS error as well as amplitude and wavelength of the anomalies as the goodness of fit. The model parameters used in the computations are given in table 1.

5. Crustal structure and elastic plate thickness (*Te*) beneath the ridge

Following the approach described above, we have computed individual gravity anomalies contributed by two different sources, ridge structure and overlying sediments for three profiles (MAN-01, SK107-07 and MAN-03) in the Bay of Bengal region and one profile (98971) in the distal Bengal Fan region and the results are shown in figure 3. The ridge anomalies of the Bay of Bengal profiles are, in general, positive with variable amplitudes and wavelengths for different *Te* values, while the sediment anomaly is negative due to less thickness of sediments on top of the ridge compared to its flanks. The sum anomaly is calculated by adding the ridge and sediment anomalies for different *Te* values and compared with the observed gravity anomalies (figure 3). It can be seen from profiles MAN-03 and MAN-01 results that $Te = 15$ km gives a better match both in terms of amplitude and wavelength, though the RMS errors correspond to $Te = 15$ and 25 km are almost same. For profile SK107-07, $Te =$ 10 km gives a better fit with the observed anomaly. However, anomalies computed for the Airy model ($Te = 0$ km) matches poorly with the observed anomaly and shows much shorter wavelength than the width of the ridge and more negative than the observed anomaly. The model results along the southern profile (98791) provide a best-fit for *Te* value 10 km (figure 3) by comparing the sum anomaly with the observed anomaly.

The sediment loaded crustal structure derived for the best-fit *Te* (10 km) along profiles SK107-07 and 98791 are presented in figure 4. The crustal model along the profile SK 107-07 suggests a broad flexure of Moho with a wavelength more than the width of the ridge. For gravity model studies, different densities are used for various lithological units following the published seismic refraction results. Naini and Leyden (1973) identified a total of nine reflecting layers with velocities ranging from 2.0 to 5.78 km/s with oceanic basement having velocity of 6.2 km/s. Subsequently using seismic reflection and refraction data, Curray *et al* (1982) have determined seismic velocities ranging from 1.7 to 4.85 km/s for different lithological units and 6–7.5 km/s for igneous basement. Later, Curray (1991) mapped high velocity (6.0–6.4 km/s) pre-collision sedimentary section (metasedimentary rocks) below the Bengal Fan sediments. The observed seismic velocities were converted to density values and broadly grouped into three density distributions for consideration of gravity model studies. Density values of 2.3 and 2.6 gm/cc are considered for the top and intermediate sedimentary layers (layer-1 and layer-2 in table 1), whereas a higher density of 2.8 gm/cc is considered for the metasedimentary rocks (layer-3 in table 1), which is slightly higher than the density considered for the volcanic ridge (2.65 gm/cc). We are of the opinion that the density 2.8 gm/cc considered for metasediments is not unusual as sediments undergo more compactness due to the overburden than the basalts.

The crustal model derived along profile 98791 (figure 4) is similar to that along the northern section with deflection of the Moho due to the loading of ridge and sediments. However, a single sediment layer with an average density of 2.3 gm/cc is used in the modelling, as the sediments in the distal Bengal Fan region are relatively less in thickness to consider the compaction effects.

Thus, the analysis supports flexural isostatic compensation model with *Te* ranging from 10

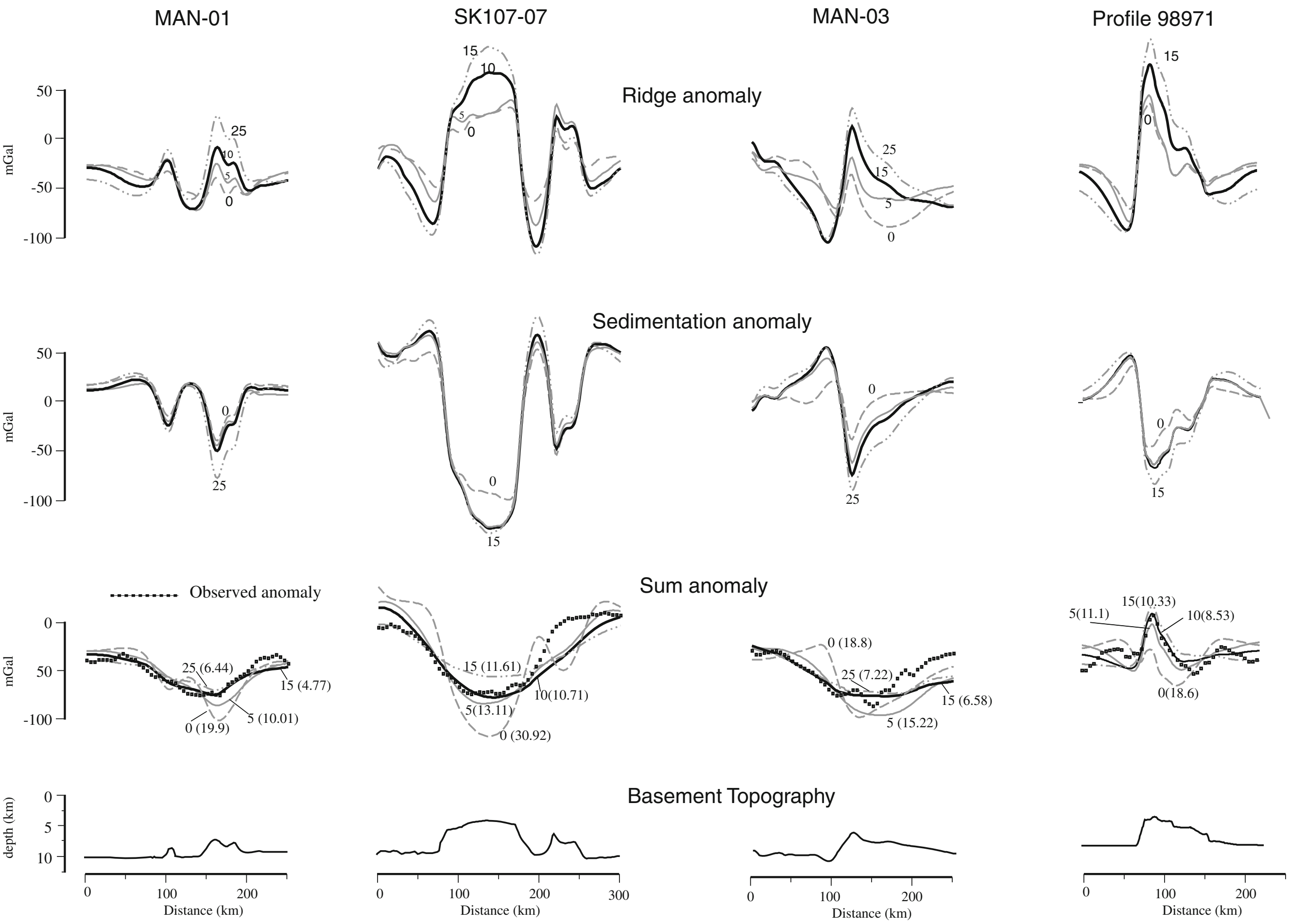

Figure 3. The ridge and sedimentation anomalies computed for different *Te* values through process oriented gravity modelling for profiles MAN-03, MAN-01, SK107-07 and 98791. The sum anomaly of these two is compared with observed gravity anomaly with degree of fitness shown as RMS error (value in bracket). The best fitting *Te* is 15 km for MAN-01, MAN-03 and 10 km for SK107-07 and 98971 based on the least RMS error criteria as well as wavelength of the anomalies. The basement topography is shown in bottom panels.

to 15 km for both northern and southern parts of the ridge. The negative gravity anomaly of the 85°E Ridge could be explained by a combination of sources: the flexure at Moho boundary, the presence of high density metasedimentary rocks on either side of the ridge and thick Bengal Fan sediments over the ridge. Whereas in south the gravity anomaly is positive due to the absence of high-density deeper sedimentary rocks and the exposition of the ridge structure above the seafloor.

6. Different stages of the 85°E Ridge – simulation of gravity anomalies

It can be noted from the above discussion that the initial flexural rigidity and the subsequent sedimentation effects explain well the present-day negative gravity anomaly over the 85°E Ridge. Curray *et al* (1982), Gopala Rao *et al* (1997) and Michael and Krishna (2011) have identified several seismic horizons and unconformities within the sediments of the Bay of Bengal and discussed the sedimentation history in detail since the Early Cretaceous. Keeping these results in view, we made an attempt to understand how the gravity field of the ridge had changed through time, particularly in response to sediments of the Bay of Bengal. In other words, we have simulated the gravity field at three different geologic ages: Late Cretaceous, Early Miocene and Present, since the formation of the ridge. We followed simple procedure of flexurally loading the sedimentary layers, phase by phase, to the restored section and computed the gravity anomalies for each phase, particularly during the Late Cretaceous, Early Miocene and Present. Also for anomaly computations we have used best fitting *Te* values derived for each profile discussed in the previous section. Here, we present the simulated gravity anomaly and corresponding crustal models along the profile SK107-07 for three different

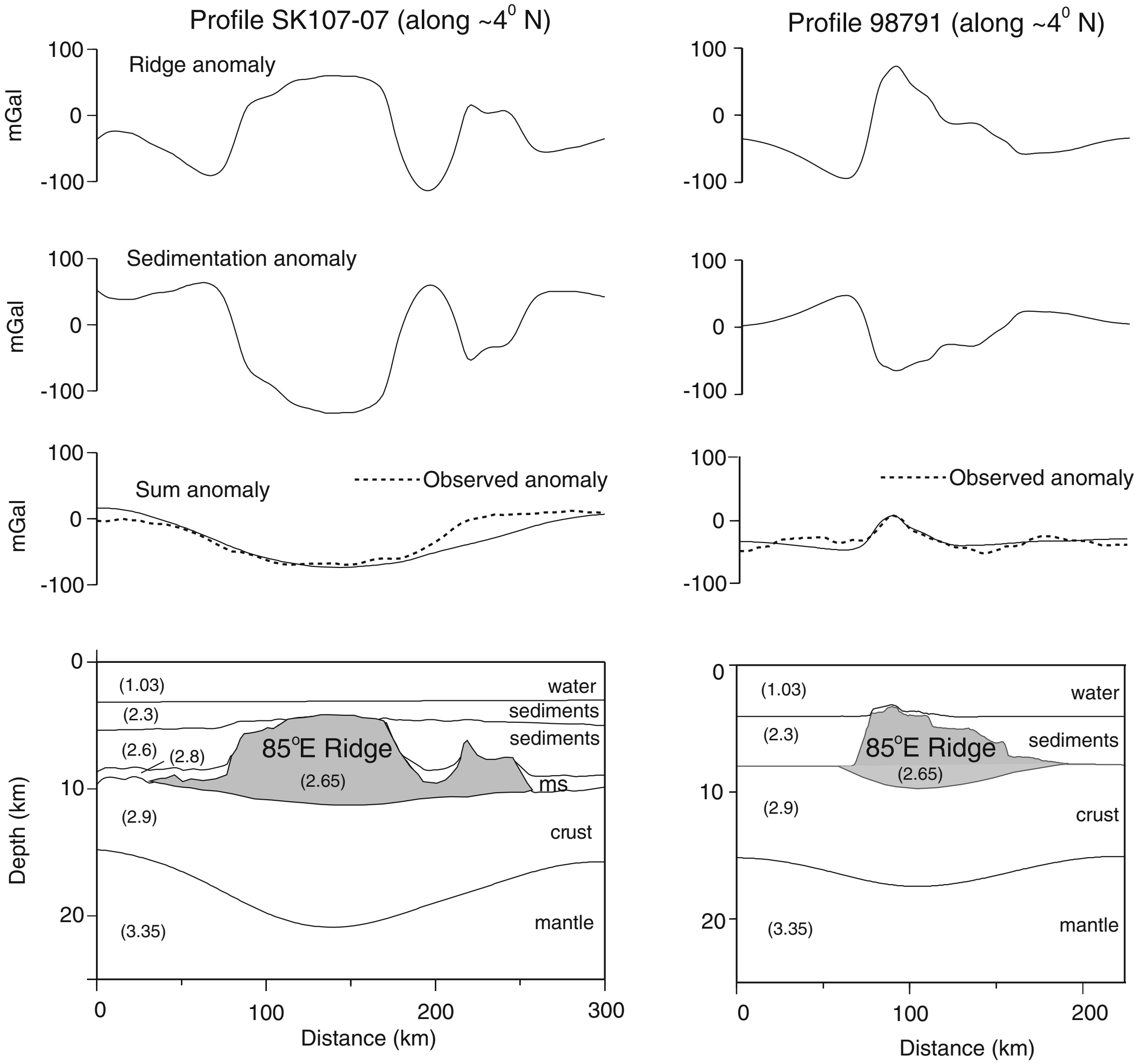

Figure 4. Crustal structure of 85°E Ridge along profile SK107-07 and 98971 along with different anomaly components (see details in text) obtained from process oriented gravity modelling. The values in bracket represent density for each layer in g cm^{-3}. The sum anomaly computed for best fitting *Te* (10 km) is shown along with the observed gravity anomaly for both the profiles. ms indicates metasediments.

ages (figure 5). As can be seen, during the Late Cretaceous the ridge structure was elevated above the seafloor and associated with positive gravity anomaly due to the density contrast created between the ridge material and water. The second panel shows the crustal structure of the ridge and corresponding gravity anomaly determined for the Early Miocene age when the ridge got buried completely under the sediments. The anomaly shows a substantial reduction in amplitude, but the anomaly was still positive and mimics the topography of the ridge. After loading thick Miocene and post-Miocene sediments, the lower sediments deposited before the continental collision have attained higher densities almost equivalent to the density of metasediments (2.8 gm/cc) (third panel in figure 5). It can be seen that the reduced gravity high over the ridge presents till the Early Miocene age, subsequently the anomaly switches to negative. Another interesting aspect is the response of the crust to the sedimentary loads since the ridge emplacement. The Moho deflection produced by the ridge load during the Late Cretaceous progressively broadens with the addition of sedimentary layers. As the thickness of sedimentary layer is less on the crest of the ridge and increases on either side, the sediment load flattens the flanks of the deflection caused by the ridge load. The wavelength of computed gravity anomaly matches with that of the sediment loaded Moho deflection. This suggests that the sedimentary layers mask the gravity effect of the ridge and the negative anomaly could be attributed to the deflection created by the load of the ridge and sediments on the crust.

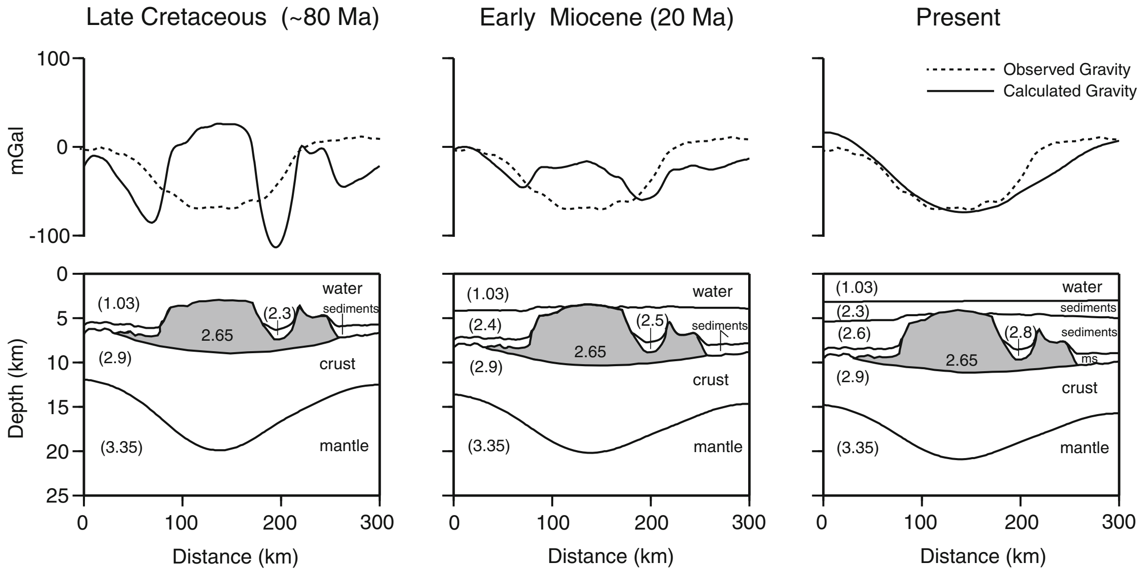

Figure 5. Reconstruction of the gravity anomalies over the 85°E Ridge through geological ages for the profile SK 107-07. The bottom panels represent the crustal structures for the respective periods. Note the change of gravity anomaly from positive to negative. ms indicates metasediments.

7. Structure and tectonics of the 85°E Ridge

Modelling of seismic and gravity data of the 85°E Ridge determines the elastic plate thickness ranging from 10 to 15 km for both northern and southern parts of the ridge, suggest that the ridge emplacement was in an intraplate (off-ridge) setting. When the hotspot volcanism takes place over relatively older lithosphere, the emplaced volcanic construct would be compensated regionally. Progressive sedimentation led to deeper burial of the ridge and alteration of pre-collision basal sediments into metasedimentary rocks. The crustal model also suggests that the 85°E Ridge and sedimentary load over the ridge are compensated by the regional flexure of the Moho boundary (figure 4). This observation is not in agreement with the earlier interpretations of the ridge structure (Liu *et al* 1982; Mukhopadhyay and Krishna 1991; Ramana *et al* 1997; Subrahmanyam *et al* 1999; Anand *et al* 2009), wherein they favoured the Airy model of isostatic compensation for the 85°E Ridge. Subrahmanyam *et al* (1999) have considered underplated magmatic material within the deep crust beneath the ridge in order to explain the negative gravity field satisfactorily; this led to believe that the 85°E Ridge was formed by a hotspot on young oceanic crust similar to the cases of emplacement of the Ninetyeast and Chagos–Laccadive ridges. Unfortunately, no deep seismic reflection or seismic refraction data are available to examine the presence of underplating or subsurface loading beneath the ridge. Hence, we considered a simple model, in which the ridge includes only a surface load emplaced on a thin elastic plate. However, in some cases of intraplate originated volcanic structures, *Te* values were estimated considering the underplated material as subsurface load. Therefore, an attempt has been made to understand the effect of crustal underplating in the present results. As a test case, we modelled profile SK107-07 with the consideration of about 3 km thick underplated material and density of 3.05 gm/cc below the flexed oceanic crust for different *Te* values. Now the best fitting *Te* is increased from 10 to 15 km. Even this model is consistent with the intraplate origin suggested for the 85°E Ridge.

The results obtained in this work are collated with the earlier geophysical results of the 85°E Ridge and Conrad Rise, and with the geochronology of the rocks recovered from the ANS (Sborshchikov *et al* 1995) in order to understand the evolution of ridge and ANS in a broader perspective. Recent understanding on the evolution of conjugate oceanic regions of Bay of Bengal and Enderby Basin (Gaina *et al* 2007; Krishna *et al* 2009) enlighten that most part of the oceanic crust in the Bay of Bengal was accreted during the Cretaceous super-long normal polarity phase. Hence it is obvious that no coherent magnetic anomalies related to the Earth's magnetic reversals are probable in the Bay of Bengal. In spite of this, the 85°E Ridge is associated with alternate stripes of strong positive and negative magnetization patterns distributed for asymmetrical extents (Michael and Krishna 2011). Following the magnetic model studies and correlations of the ridge magnetization pattern with Geomagnetic Polarity Timescale, Michael and Krishna (2011) found that the ridge was formed from 85 Ma onwards and recorded the changes of Earth's magnetic fields, earlier to that, the underlying Bay of Bengal crust was created during the Cretaceous super-long normal polarity phase. The intermediate elastic plate thickness (10–15 km) derived from the present study strongly support the emplacement of the ridge on already evolved oceanic crust. These results when combined with the age constraint (∼120 Ma) of the Bay of Bengal oceanic crust (Gopala Rao *et al* 1997; Krishna *et al* 2009) would conclusively suggest the emplacement of the ridge on an oceanic crust of about 35 m.y old.

It was suggested that the ANS includes two components of volcanism, the main plateau was constructed along with the formation of the oceanic crust during 79–73 Ma, and seamount highs were formed subsequently in an intraplate setting (Krishna *et al* 2011). The low elastic plate thickness up to 5 km determined beneath the ANS (Paul *et al* 1990), is much lower than the *Te* values calculated for the 85°E Ridge and is attributed to the initial on-ridge volcanism. Following the above geophysical results, we believe that the 85°E Ridge volcanism started approximately 85 Ma ago in Mahanadi Basin by a short-lived hotspot. Around this period, the Conrad Rise hotspot has emplaced the main plateau of the ANS and Marion Dufresene Seamount together close to the India–Antarctica Ridge (Diament and Goslin 1986), thereafter the hotspot has moved to the Antarctica plate leaving the plateau of the ANS as an isolated feature on the Indian plate. At other end in the Bay of Bengal the hotspot which emplaced the 85°E Ridge has continued the process towards south and probably ended at ∼55 Ma in the vicinity of the ANS.

8. Conclusions

Structure and isostatic compensation mechanism of the 85°E Ridge were studied using process oriented modelling of gravity and seismic reflection data. The important observations are as follows:

- Process oriented modelling of seismic and gravity data of the 85°E Ridge revealed that the ridge was emplaced on a lithosphere, whose elastic plate thickness (*Te*) was approximately 10–15 km and suggest the off-ridge emplacement. This result is consistent for both northern and southern parts of the ridge in spite of their contrasting gravity signatures.
- The isostatic model of the 85°E Ridge suggests that the ridge structure and the overlaying sediments are supported by a broad flexure of the Moho boundary. The negative gravity anomaly of the ridge in the Bay of Bengal region can best be explained by the combined effect of thick sedimentary column, presence of metasediments at the basal level and flexure of the Moho boundary.
- The gravity anomalies of the 85°E Ridge are reconstructed with possible crustal structures of different geological ages since the ridge formation. At the time of ridge emplacement, that is during the Late Cretaceous the ridge was associated with a significant positive anomaly with a compensation generated by a regional flexure of the Moho boundary. In Early Miocene, the ridge was approximately covered by the post-collision sediments and led to alteration of the initial gravity anomaly to a small positive anomaly. Presently the ridge structure is buried under 3 km thick Bengal Fan sediments and its flanks are underlined by about 8 km thick post-collision sediments; and this geological setting had probably changed the physical properties of the pre-collision sediments and contributed to the distinct negative gravity anomaly over the 85°E Ridge.
- Based on the present results and published plate reconstruction information, we interpret that the 85°E Ridge was emplaced by a short-lived hotspot from 85 to 55 Ma in an intraplate geological setting.

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