Significant Geophysical signatures in Bay of Bengal and geological model of emplacement of 85° E Ridge

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ABSTRACT

The paper discusses the results of the integrated analysis of geophysical data of Bay of Bengal. It is characterized with three distinct geophysical features viz. 85° E ridge, Ninety East ridge and latitudinal gravity high at 20°N. It evolves an evolutionary model of 85° E ridge within framework of Plate Tectonics. The study reaffirms that the 85° E ridge marks the track of plume (which resulted to Rajmahal volcanism on the land). It identifies few fracture zones in Bay of Bengal were the preferred locales for magmatic activity resulting to emplacement of the 85° E ridge. The low gravity character associated with the ridge is attributed to downward flexuring of MOHO due to subsequent isostatic adjustments. Another striking feature of northern Bay of Bengal, a latitudinal gravity high at 20°N, is inferred to be of younger in origin, evolved in response to continued Himalayan collision.

Key words: Bay of Bengal, Geophysical signatures, 85° E ridge, fracture zones, 20° latitudinal gravity high.
INTRODUCTION

Eastern continental Margin of is known to have been evolved consequent to rifting followed by drifting of Antarctica during Late Jurassic – Early Cretaceous epochs. Subsequent evolution of passive margin associated with northwardly drift of Indian Plate and development of Proto Bay of Bengal has been discussed by many earlier workers (Shastri, 1981; Prabhakar et al, 1994; Veevers et al, 1995; Lal et al, 2010). During this phase hot-spot related magmatic activity in the newly formed Bay of Bengal has resulted in the development of 85° E (Curray and Munasinghe, 1991) and Ninety East ridges (Sclater et al, 1974). Both the ridges are well identifiable on seismic as well as in gravity data. However, their contrasting behaviour over gravity map has been debated by various workers.

The nature and origin of Ninety East ridge, though, is not much debated. However, multiple opinions exist on the nature as well as origin of 85° E ridge. Based on analysis of geophysical data earlier workers have postulated various reasoning, viz;

1. Hot-spot model suggesting it to be plume track of the hot-spot (Curray and Munasinghe, 1991; Muller et al, 1993; Gopala Rao et al, 1997; Subramanyam et al 1999, Bastia et al, 2010; Radhakrishna et al, 2012) which has resulted to widespread Rajmahal volcanic activity;

2. Mishra (1991) suggested it to be aborted spreading ridge;


4. Bastia et al (2010) suggested volcanic plume related origin for the ridge that can be correlated with the activity of Kerguelen hot spot.

Considering the large area of the morphological high and associated low gravity character of the ridge (in proximity to the continent) the structure has been probed for hydrocarbon. However the deep well drilled over it, towards northern part, ended in basalt.
DISCUSSION ON GRAVITY ANOMALY MAP

The significant features observed on gravity anomaly map of Bay of Bengal (Gulati et al, 2012) are sequentially discussed below. From west to east they are:

1. A distinct gravity low considered to be associated with foot of the continent. However, this low appears to be discontinuous, especially in KG Basin. Further it diminishes towards north in Mahanadi Basin.

2. N-S gravity low, associated with $85^\circ$ E ridge, extending southward from around $18^\circ$ latitude. This low besides being breached at around $16^\circ$ latitude, gradually diminishes southward and takes a westward swing on the gravity map.

3. A prominent and wide tract of gravity high is associated with the Ninety East ridge. Though it trends almost N-S, its arcuate nature (concave westward) on the gravity map is significant in the area between $6^\circ$ to $15^\circ$ latitudes. Besides, the amplitude of gravity high reduces northward owing to the overwhelming increasing thickness of sediments.

4. An interesting E-W gravity high feature at about $20^\circ$ latitude is observed and the nature of this high is discussed in late part of this paper.

5. The study infers a few NW-SE running fracture zones in Bay of Bengal, based on gravity variations. They seem to be originating from the areas of discontinuities in the gravity lows associated with ‘foot of the continent’ and are nearly orthogonal to the rift axis.
The 85° E ridge is a major structural feature in the Bay of Bengal, situated to the east of zone of continent-ocean boundary and disposed in the form of a buried ridge and the ridge is associated with negative gravity signatures. The ridge possesses a suite of high-amplitude negative anomalies, which are different from the volcanic constructs associated with composite signatures of oceanic crust. This broad negative free-air anomaly is severe in the northern part and gradually disappears at about 05° N latitude (Liu et al, 1982). Seismic studies indicate the ridge to a severely faulted buried feature. A deep well (AA) drilled for hydrocarbon exploration over the ridge was terminated in Basalt and is suggestive of volcanic origin of the ridge. While earliest sedimentary sequence overlying basalt, encountered in a well drilled (AA) for hydrocarbon exploration, has yielded Late Eocene - Oligocene age. The ridge appears to have divided the (proto) Bay of Bengal in two parts on either side of it. The sediments within these sectors possibly have two different sources at least until Late Eocene (i.e. till submergence of the ridge). The ridge is considered to be
marking trail of Crozet hotspot, which has also resulted into a widespread Rajmahal volcanics (Curry & Munasinghe, 1991; Bakshi et al, 1987) over the land and adjacent shelfal areas (Siawal et al, 2005). However its gravity manifestation in the two areas is markedly different. In view of this observation it is understood that the two areas comprising of different crust (i.e. Continental Crust of land and shelfal areas and oceanic crust of proto Bay of Bengal), have behaved differently while the Indian Plate travelled over Crozet Hotspot. Further recent studies (NIO & ONGC joint studies, 2014) have indicated presence of volcanic vents, within the ridge, through which the volcanic material is said to have extruded. This has resulted to emplacement of volcanic ridge. However authors rule out volcanic vents over the ridge in view of absence of any high gravity feature which support the existence of volcanic vents.

The seismic mapping has shown that the ridge is segmented and faulted. The vertical extent of the ridge is variable and appears to be reducing southward. Based on gravity map it appears that the ridge takes a westerly swing also. Author’s view is that the emplacement of the ridge happened through magmatism along the fracture zones (leaking of the transforms).

20° Latitudinal Gravity High

This is a very conspicuous feature in northern part of Bay of Bengal. On the gravity map, to the north of Mahanadi Basin, the east coast shelf, is taking an easterly swing. Seismic profile running across this feature (line-1) present day shelf break coincides with a basement high (Fig. 3A). Flattening at Basement level (Fig. 3B) shows that all the reflectors extend beyond the shelf break. In view of this, authors conclude that this feature is unrelated with shelf break, whilst, the NE-SW gravity high though suppressed represents the northeastwardly extension of east coast shelf.

Further, a critical observation reveal that the coast line of Bangladesh, which is contiguous to this gravity high, is highly ruptured suggesting reactivation of this feature. In the regional frame work, it bears parallelism with Dauki Fault (Fig. 1), which is known to have reactivated in response to Himalayan collision. The morphological similarity of this feature with southern flank of Shillong Plateau and Sylhet Trough complex with this high and associated south-eastern low is also striking. In view of this we attribute this feature to be unrelated
with shelfal phenomenon and have developed (developing) in response to continued Himalayan collision in a south-westerly closing ocean basin environment.

Figure 2: Index map showing location of seismic profiles studied.

Figure 3A: N-S Seismic section (line-1) across latitudinal high. Location of the line is shown in fig. 2.

Figure 3B: N-S Seismic section (line-1) across latitudinal high flattened at basement level. Location of the line is shown in fig. 2.
SEISMIC SIGNATURES OF THE 85° E RIDGE

Total sedimentary isopach map of Bay of Bengal prepared based on seismic mapping clearly brings out the definition of 85° E Ridge. The map also shows that the ridge is breached in the north, as is also apparent on the gravity map. The ridge is inferred to be a buried morphological feature. Seismic mapping has brought out that the area was under sedimentation realm during latest Oligocene period. In view of this it is inferred that until Late Oligocene the two lows (i.e. western and eastern) remained distinct entities with their distinct sediment supply areas. The eastern low was visualized to have fed from north while western low was fed from west. The morphology of the ridge along with its seismic facies is shown in figures 4a, 4b and 4c. The downward flexuring of the MOHO is observed on seismic profile and is shown in figure 5. Post magmatism isostatic adjustments might have resulted in downward flexuring of the MOHO.

Figure 4: Seismic sections showing morphology of the 85° E ridge as seen on seismic profiles (line2, line3 and line4). The location of the seismic profiles is shown in figure 2.

Figure 5: Seismic section showing morphology of the 85° E ridge as seen on seismic profiles (line-3). Seismic signatures show downward flexure of MOHO. The location of the seismic profiles is given in figure 2.
GEOLOGICAL MODEL FOR EMPLACEMENT OF THE 85° E RIDGE

Acton (1999) estimated the northward movement of Indian Plate at the rate of 66km/my, during dominantly Late Cretaceous period (120 to 73 ma). The distance between Rajmahal Hills and the northern part of the ridge is about 850 kms. Rajmahal Traps are dated between 107 +/- 3 ma to 118 +/- 2 ma with mean age of 117 ma (Bakshi et al, 1987) though abrasions of 88 +/- 2 ma and 128 +/- 7 ma (Ramana et al, 1997) are also reported. In view of this the initiation of magmatic activity resulting to the formation of the ridge may have started about 12my after the Rajmahal volcanism (i.e. at about 105my). The identification of magnetic anomaly M-11 (Ramana et al, 1994) suggests opening of proto Bay of Bengal during 138ma. The morphology of the ridge appears to be controlled by the identified fracture zones. A three stage evolutionary model for 85° E ridge is visualized.

1. Rifting followed by northward drift of Indian Plate. It is associated with development of fracture zones in (proto) Bay of Bengal crust.
2. Outburst of Rajmahal volcanism during Early Cretaceous.
3. Magmatism along the fracture zones as the Indian Plate passed over the plume during its northward movement. The southward reducing amplitude of gravity low, as is observed on gravity map (Fig.1), may be representing the gradual depleting nature of the plume.
4. Presence of any vent type feature over the ridge is ruled out in view of absence of corresponding geophysical signatures.

IMPACT ON HYDROCARBON PROSPECTIVITY

The eastern continental margin of India is believed to have evolved consequent to separation of Indian landmass from Antarctica-Australia assembly during Late Jurassic – Early Cretaceous. However emplacement of 85° E ridge during late part of Early Cretaceous (105 ma) broadly subdivides the Bay of Bengal into two sedimentary domains. The western was fed by peninsular rivers while the eastern was provided input from (proto) Mahanadi and (proto) Damodar Rivers during early phase. The collision between India and Burmese land, towards northeast, provided overwhelming sedimentation in the form of Barail Delta. It was during this period the ridge got completely buried. In view of this the development of source and reservoir facies need to be visualized differently, at least for Pre Oligocene Period, for these two sectors. Moreover towards north in the eastern low, the late Jurassic –
Early Cretaceous source facies (if any) got completely buried below Rajmahal volcanics. This might also have resulted in over maturation of source facies, if any. In view of this, the area to the west of 85° E ridge is considered to be more prospective. However, a caution is suggested to be undertaken while carrying out exploration in the eastern low (barring biogenic component).

CONCLUSION
Based on integrated study of geophysical data of Bay of Bengal following conclusions are made:

1. The low gravity nature of 85° E ridge is associated with downward flexuring of the MOHO. The study suggests an evolutionary model for 85° E ridge within the framework of Plate Tectonics. Based on 117 ma age (Baksi et al, 1987) for Rajmahal volcanics and northward drift of Indian Plate at the rate of about 66 km/my (Acton, 1999) during Late Cretaceous, magmatic activity leading to emplacement of 85° E ridge is estimated to have initiated at around 105 ma in proto Bay of Bengal.

2. Few fracture zones have been identified, based on gravity variations, in Bay of Bengal. These are nearly orthogonal to the shelf.

3. The E-W latitudinal high in the northern part of Bay of Bengal is one of the most conspicuous feature. This latitudinal high is inferred to be a younger phenomenon developed in response to continued Himalayan collision. Further the rupturing of coastline of Indian Subcontinent adjacent to its eastern proximity is also suggestive of its recent reactivation.

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