

A two-stage evolution of Visakhapatnam-Paradip shelf, east coast of India, from magnetic studies

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Abstract. A detailed analysis of bathymetry and magnetic data of Visakhapatnam-Paradip shelf, east coast of India revealed three major structural lineaments over the shelf/slope of the area. Models derived from the anomalies associated with the trends indicate that trend A represents horst and graben type continental basement while trend B is due to a series of dyke intrusions. Trend C off Chilka lake forms the northward extension of 85°E lineation from deep sea Bengal Fan.

A two stage evolution of the eastern continental margin of India has been inferred from the study of this part of the margin, viz., the rift stage evidenced by dyke intrusions of reverse polarity located within the inner part of the shelf and post-rift stage characterized by vertical tectonics in the form of a horst and graben type continental basement. The hotspot related aseismic 85° E ridge further complicated the tectonics of this part of the area.

Keywords. Magnetic basement; dyke intrusions; 85° E lineation.

1. Introduction

The eastern passive continental margin of India (ECMI) was formed by the separation of Indian plate from combined Australia and Antarctica Plate. Its subsequent northward drift resulted in the formation of the Bay of Bengal and the largest sediment fan in the northern part, known as the Bengal Fan (Curry and Moore 1974). Accordingly, the ECMI also might have undergone the four stages of evolutionary history of passive margins viz., 1) An initial rift; 2) Opposed drift of the continental blocks; 3) Creation of oceanic crust; and 4) Deposition and accumulation of sediments on the newly formed oceanic crust (Heezen 1974). In recent years several aspects of stratigraphy, structure and sedimentation of the eastern continental margin of India from Visakhapatnam to Paradip have been reported by different workers (Banerjee *et al* 1988; Murthy 1989; Mukhopadhyay and Krishna 1991). In this paper magnetic and bathymetric data from Visakhapatnam to Paradip are analysed and possible evolutionary stages of ECMI are discussed.

1.1. Geology of the area

The study area lies seaward of Andhra-Orissa coast and the coastal geology mainly comprises of Precambrian rocks with predominant NE-SW trend (figure 1). It is divided into two major blocks based on coastal geology.

1.2 Visakhapatnam-Gopalpur block

This area is flanked by eastern ghats, largely comprised of khondalites and charnockites associated with metamorphosed manganiferous sediments. These rocks have undergone high grade metamorphism at greater depths and were later subjected to block upliftment (Krishnan 1982).

1.3 Gopalpur-Paradip block

This region forms the southern part of offshore Mahanadi basin, a pull apart type of basin formed by the break up of Gondwanaland during upper Palaeozoic to upper Jurassic period. Onshore basin is largely covered by Holocene deposits. The basement is composed of Archaean metamorphic complex covered by Precambrian metasediments, amphibolites and schists intruded by granite gneisses (Mishra et al 1984).

1.4 Offshore geology and stratigraphic sequence

Tectonically, offshore Mahanadi basin falls into four distinct zones viz., 1) Linear ridges and depressions; 2) Southerly dipping basement characterized by faults; 3) A hinge over Eocene shelf margin; and 4) A zone of growth faults and structures. The shelf is characterized by metamorphic basement overlain by Cretaceous volcanics of

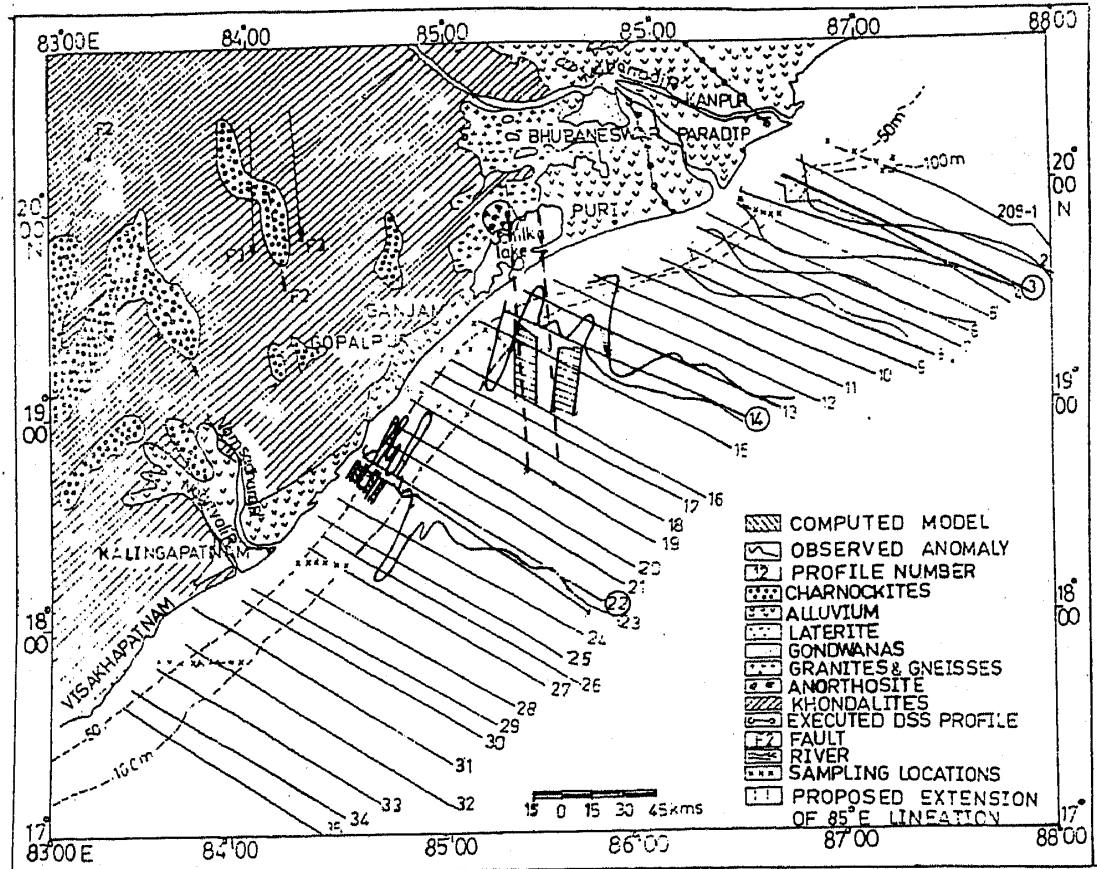


Figure 1. Location map of the study area showing coastal geology, tracks covered, interpreted models along with corresponding anomalies.

varying thickness which in turn are unconformably overlain by Tertiary sediments, both clastics and carbonates of predominantly shallow marine origin with thickness varying from 2000m near coast to 4000m near the shelf edge (Jagannatham *et al* 1983).

2. Data acquisition

Marine geophysical surveys comprising of magnetic and bathymetric data were carried out over the continental shelf between Visakhapatnam in the southwest and Paradip in the northeast (17°N to 20°N and 83°E to 88°E). Totally 34 traverses each of about 140km in length taken perpendicular to the coast (NW-SE) at a spacing of about 10km have been used in the present study. Location of profiles is shown in figure 1. All profiles are confined to continental shelf-slope margin region from about 30m to about 3000m water depth. Magnetic and bathymetric data were acquired during cruises of Regional Centre of NIO, Visakhapatnam on board the Research Vessel R. V. Gaveshani during 1989. The positions of the tracks were obtained by satellite navigation (NAVSAT) system with an accuracy of ± 20 m (Eaton *et al* 1976). Bathymetry data were collected using a narrow beam echosounder (frequency 30khz). Bathymetry contour map with an interval of 50m is shown in figure 2. Magnetic data were collected using Barringer proton precession magnetometer at one minute interval corresponding to a distance of about 230m at ship's speed of 8knots/hr. Magnetic data has been corrected for IGRF 1985 (Barraclough 1988). Isoneanoteslamap of the study area compiled at variable contour interval of 20nT and 100nT is shown in figure 3.

3. Results and discussion

Bathymetry map (figure 2) indicates that the shelf width is narrow (50km) between Visakhapatnam and Chilka lake compared to north between Chilka lake and Paradip

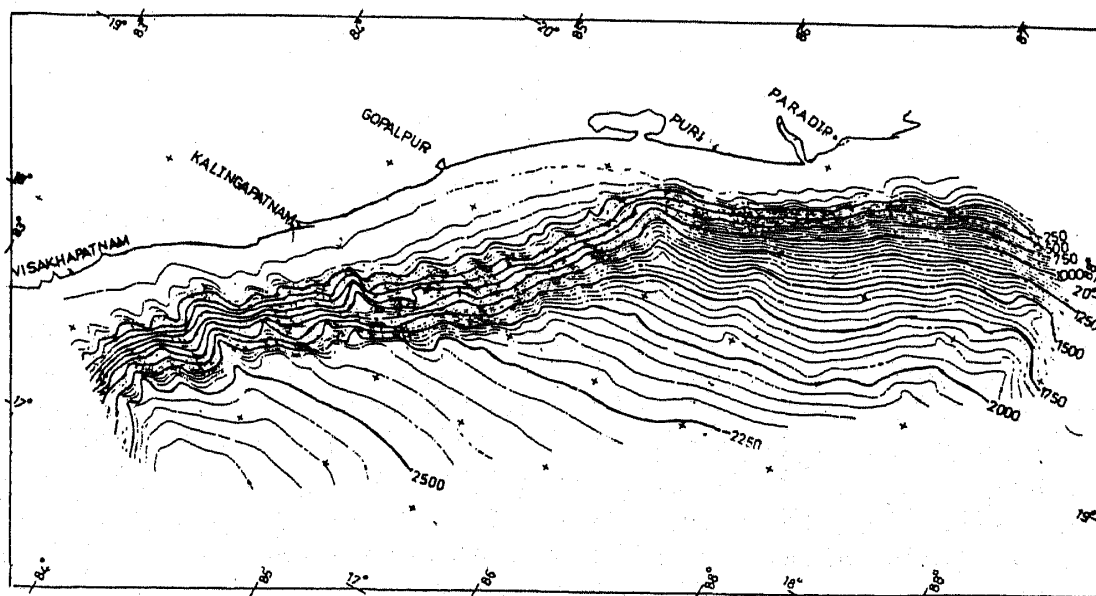


Figure 2. Bathymetry contour map of the study area (interval 50m) showing narrow shelf between Visakhapatnam and Gopalpur and a wider one between Gopalpur and Paradip.

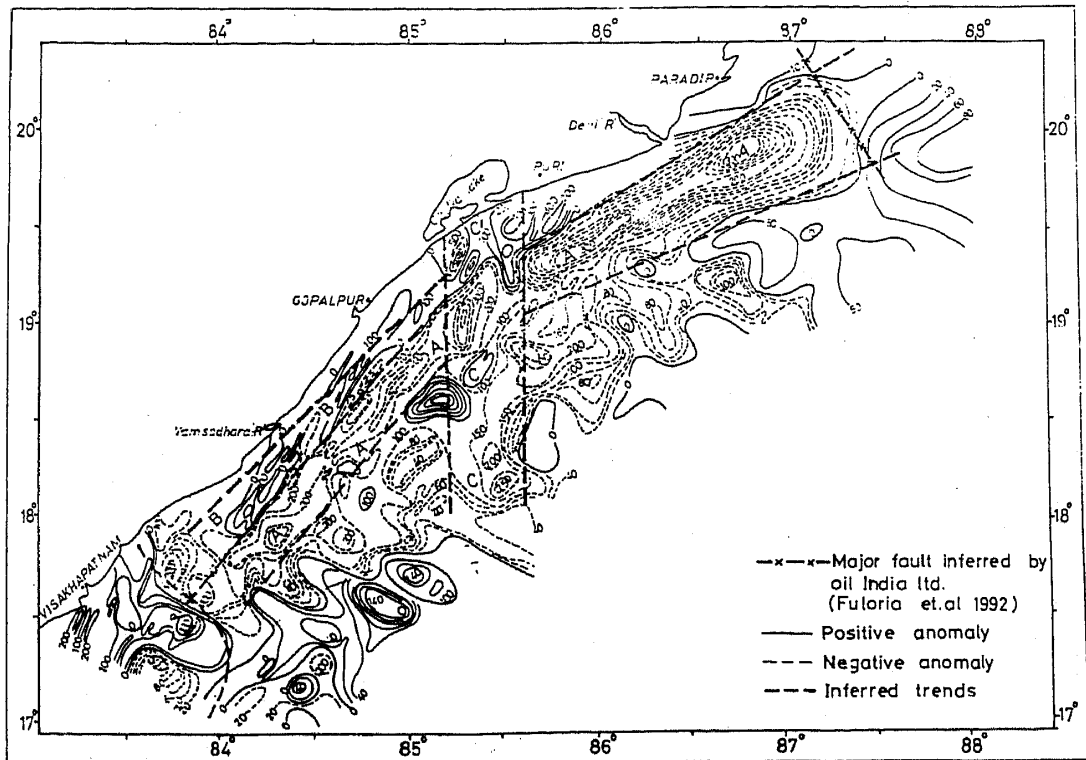


Figure 3. Total field magnetic anomaly contour map of the study area (interval 20nT and 100nT) showing trends A, B and C caused by horst and graben type basement configuration, basic intrusives and probable northward extension of 85°E lineation respectively.

(70km). The shelf gradient varies from 1:200 to 1:300 between Visakhapatnam and Paradip. The outer shelf off Visakhapatnam is associated with reefs and terraces forming as lineations running parallel to the coast (Murthy 1989). The characteristics of echograms suggest that the outershelf between Visakhapatnam and Gopalpur is rugged and to the north of Gopalpur upto Paradip the echograms indicate smooth topography comprising of recent sediments (Rao *et al* 1988).

3.1 Analysis of magnetic data

Total intensity magnetic anomaly map (figure 3) is characterized by three distinct magnetic anomaly patterns: 1) A prominent broad negative anomaly belt trending NE-SW parallel to the coast with amplitudes of -300 nT to -500 nT from Paradip to north of Visakhapatnam (marked A in figure 3) with a strike length of about 450km suggesting a major tectonic feature. This is flanked seaward by positive anomaly closures of about 80nT off Paradip and 120nT off Visakhapatnam; 2) A linear short wavelength but relatively low amplitude anomaly trend between Gopalpur and Visakhapatnam (marked B) recorded landward of the NE-SW trend A. These anomalies are conspicuously absent over the northern part between Gopalpur and Paradip (figure 4), probably masked by thick deltaic sediments (of about 2000mts near shore) from Mahanadi river. The anomalies recorded east of Chilka lake and Puri are gentle gradient and long wave length unlike the anomalies represented by trend B; 3) A prominent high amplitude asymmetric magnetic anomaly lineation of

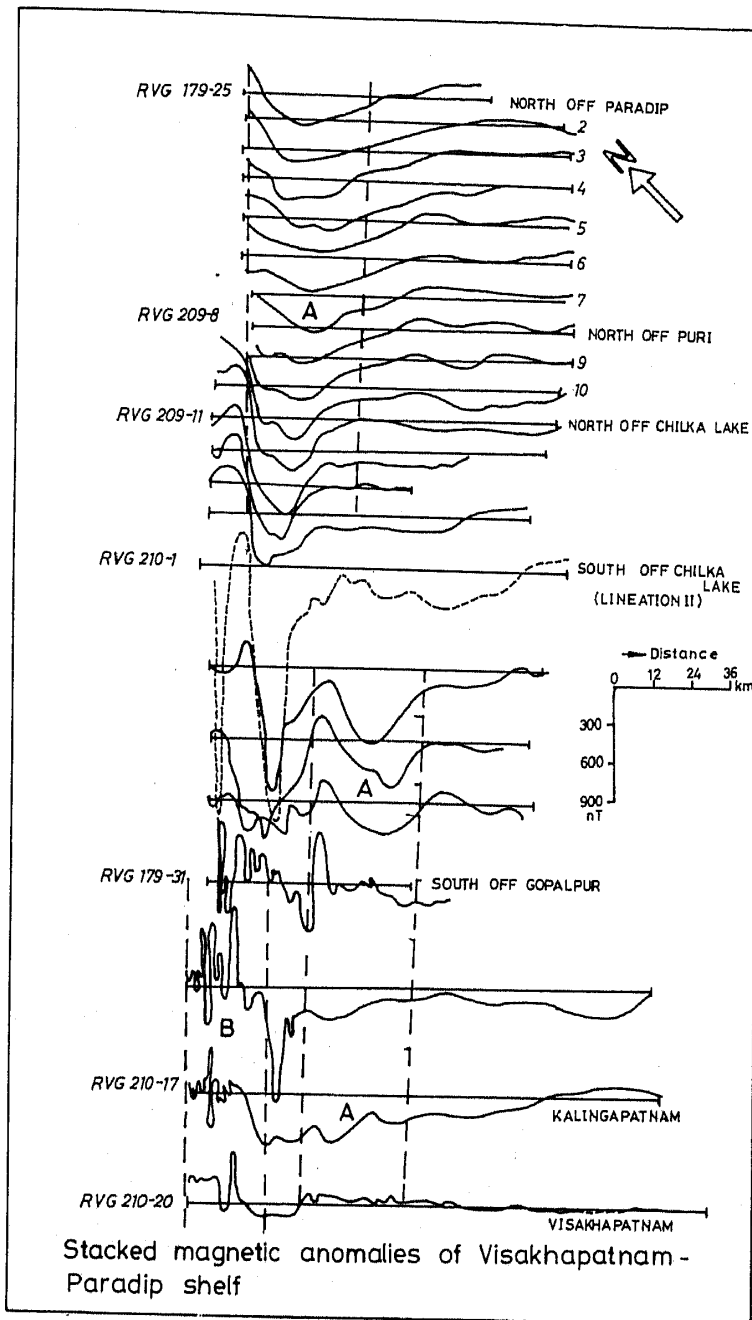


Figure 4. Stacked magnetic anomaly sections of Visakhapatnam to Paradip shelf showing trends A, B and C.

small areal extension, with amplitude of the order of 1800nT over the inner shelf south of Chilka lake, trending approximately N-S (marked as C in figure 3). There is a significant change in the width of the anomaly at the trend C. The width increases towards north east which may probably indicate the beginning of Mahanadi Offshore basin marked by wider and deeper basement structure. This trend intersects the major NE-SW trend A off Chilka lake. Babu Rao *et al* (1982) from aeromagnetic studies reported anomalies of similar nature over the offshore regions of Chilka lake.

A minor E-W trending negative anomaly with an amplitude of about - 100 nT to - 200nT is observed north of Visakhapatnam (figure 3) which appears to intersect

NE-SW trend A. This E-W trend correlates well with the major fold axis swerving into offshore region north of Visakhapatnam reported earlier by Sriramdas and Rao (1979) and Murthy *et al* (1987b).

Magnetic data along three representative sections viz., south of Paradip, off Chilka lake and south of Gopalpur (figure 4) characterized by anomalies of the three major trends described earlier are analysed to delineate the magnetic basement structure of the study area. The anomalies are interpreted using the method of Talwani and Heirtzler (1964). The observed and computed magnetic anomalies and the resulting basement structure are shown in figures 5a, 5b and 5c.

Models derived from the magnetic anomaly associated with trend A suggest an undulating basement resembling a horst and graben configuration (figure 5a). The maximum depth obtained to the base of the graben, off Paradip is of the order of 6 km, whereas the flanks on either side varied from 1.5 km (landward) to 3 km (seaward). The horst and graben basement model correlate well with the results obtained from Deep Seismic Sounding (DSS) on adjacent onshore Mahanadi Basin by Kaila *et al* (1987) in the absence of magnetic data between 30m water depth and the coast line. While the DSS results report the horst and graben configuration beneath the onshore Mahanadi Basin, the present study suggests its extension both offshore and further south west up to Visakhapatnam as reflected by the trend A in figure 3.

Model studies from the analysis of magnetic anomalies of trend B indicate that the normally magnetised continental crust is intruded by a series of shallow, highly magnetic and juxtaposed intrusive bodies of different magnetisation contrasts at depths varying from 600m to 3000m (figure 5b). Earlier studies by Murthy *et al* (1993) also indicate the presence of such intrusives within the continental crust off Madras, which are interpreted as due to rift related volcanism. Similar occurrences of rift related intrusives are reported over south western continental margin of Australia (Veevers *et al* 1985). The derived model and the remanent magnetisation parameters from the present study also indicate that these intrusive bodies might have originated during the initial stages of rifting of the ECMI. These are different

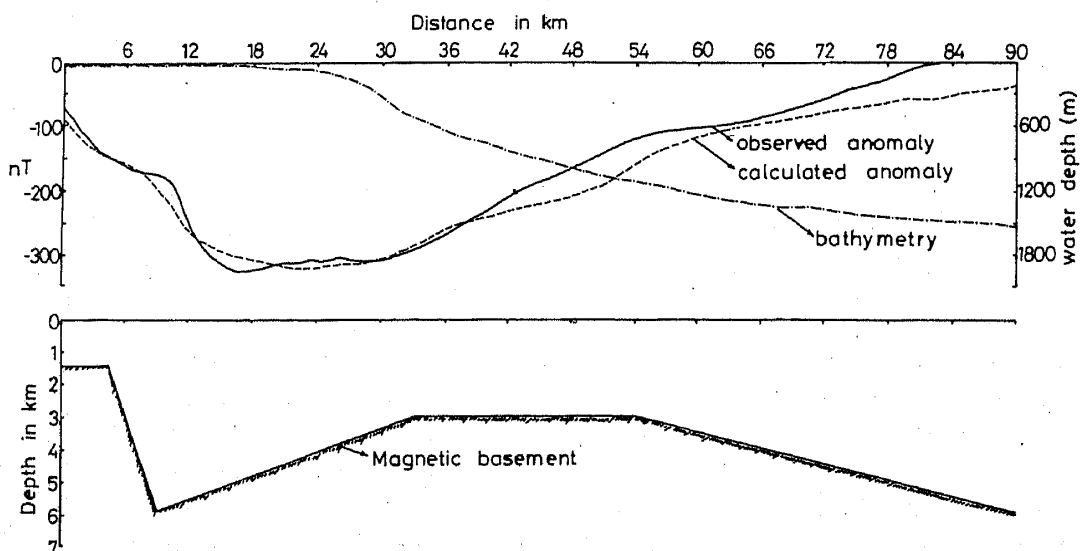


Figure 5a. Two dimensional modelling inferred from magnetic anomaly off Paradip showing horst and graben basement structure.

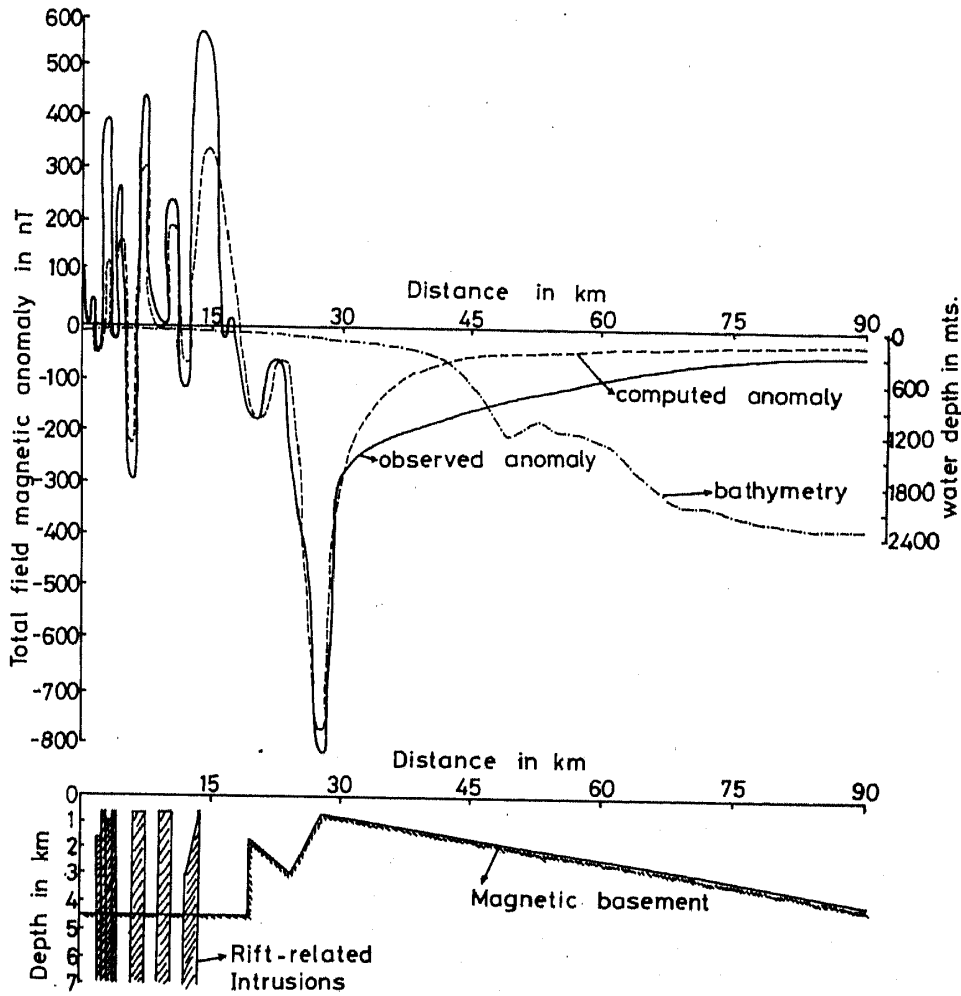
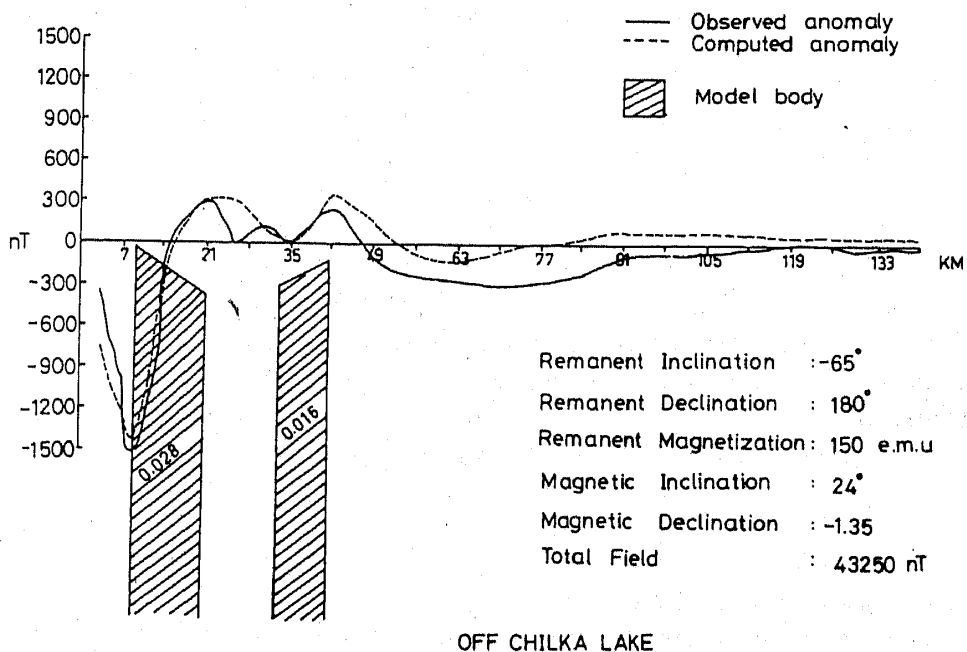


Figure 5b. Two dimensional modelling of magnetic anomaly off Gopalpur showing rift related intrusive bodies impregnated into horst and graben basement structure.



OFF CHILKA LAKE

Figure 5c. Two dimensional modelling of magnetic anomaly off Chilka lake showing the two intrusive models indicating the inferred northward extension of 85° E lineation.

from the charnockitic intrusions reported on some parts of the east coast of India cutting across the coast in NW–SE, as the present lineation runs parallel to the coast (trend B).

Magnetic models constructed on the basis of two dimensional source bodies from the N–S trending asymmetric anomaly (trend C) recorded south of Chilka lake indicate two shallow mafic intrusives at depths of 0.6 to 3.6 km (landward) and 0.6 to 4.5 km (seaward) separated laterally by a distance of about 10 km (figure 5c). Best possible fit between observed and computed models is obtained assuming high susceptibility contrasts of 0.028 and 0.016 emu for landward and seaward intrusives respectively and by assuming remanent magnetization parameters (remanent inclination = -65° and declination = 180°). Palaeolatitude (47° S) computed from the palaeomagnetic parameters used in the modelling of the anomaly indicates that these intrusives might have erupted within the Indian plate when the latter was located in the southern hemisphere. This N–S lineation is also recorded upto 12° N in the southern Bay of Bengal from long range profiles (Murthy *et al* 1993) though with reduced amplitude and it represents the extension of the buried 85° E ridge in the Bengal Fan reported for the first time by Curray *et al* (1982). If this trend is extended further on to the Indian subcontinent, it connects to the Rajmahal traps (of upper Jurassic age) indicating probable common source of origin for both these features. Curray and Munasinghe (1991) attributed to hotspot origin for the 85° E ridge as well as Rajmahal traps. It is therefore likely that the two intrusives might represent the trace of the hotspot over which the Indian plate migrated in a northward trend. The high natural remanent magnetisation and high susceptibility obtained for the 85° E ridge anomaly suggests that the formation is composed of highly magnetised rock like serpentinite (altered product of peridotite) generally emplaced in the form of vertical tectonic protrusions (Bonatti 1976). Occurrence of peridotites onland at Chilka lake (Babu Rao personal communication) also supports northward continuation of this feature upto 20° N. The asymmetric magnetic anomaly pattern recorded above 85° E ridge may be due to phase shift produced by the northward drift of the Indian plate as reported earlier (McKenzie and Sclater 1971; Schouten 1971). The two intrusive configuration deduced from the present study closely agrees with the occurrence of very prominent double humped feature corresponding to the 85° E ridge from the multichannel reflection data at 13° N (Gopal Rao *et al* 1991). Thus the present analysis shows the lineation of 85° E ridge and its possible extension, (figure 1) abutting the continental shelf of Chilka lake. However, it is not possible from the present model studies to distinguish the magnetisation properties between rift related dykes (trend B, between Gopalpur and Visakhapatnam) and those associated with hotspot activity of 85° E ridge (trend C, south off Chilka lake). The trend C approximately parallels a major fault zone identified by Fuloria *et al* (1992) at about 87° E longitude. According to them this fault marks the NE limit of the Mahanadi offshore basin whereas the trend C from the present study may be considered as the SW limit of the Mahanadi offshore basin.

4. Conclusions

In summary, the present study based on magnetic data (figure 1) gives evidence for at least two stages of evolution of the eastern continental margin of India: 1) Rift

phase represented by the two intrusive bodies (trend B); 2) Post rift stage represented by horst and graben configuration (trend A) over the shelf region. The study also suggests possible extension of 85° E ridge (trend C) into the land area adjacent to the eastern continental margin of India.

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