

GEOPHYSICAL STUDIES OVER THE CONTINENTAL MARGINS OF THE EAST COAST OF INDIA

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(Received July 13, 1984; revised and accepted December 5, 1984)

ABSTRACT

Rao, T.C.S. and Bhaskara Rao, V., 1985. Geophysical studies over the continental margins of the east coast of India. *Mar. Geol.*, 67: 151–161.

Results of six profiles of continuous echosounding, magnetic and gravity data collected across the continental margin of the east coast of India between 10° and 20° N in the Bay of Bengal aboard R.V. "Chain" in 1973 are presented. Continuity of surface and sub-surface features from profile to profile is indicated. Two major structural elements — viz. the "Marginal High", situated at the foot of the continental slope and extending along the east coast of India, and the "Marginal Basin", wide in the south becoming narrower towards the north — have been delineated. Based on the topography and the gravity and the magnetic anomalies, the eastern margin of India may be divided into two parts, viz. the southern and northern margins. The southern margin is broader and more stable than the northern margin, over which lava flows occur.

INTRODUCTION

Many aspects of the continental margins remain unknown and controversial due to their complex nature. Some characteristic features of the continental margins were revealed by earlier geophysical investigations. Helmert (1909) identified a characteristic gravity "high" on the landward side of the continental slope and a "low" on its seaward side. From his gravity surveys, mostly on the passive margins, Vening Meinesz (1941) concluded that the sialic layer of the Earth's crust thins out abruptly towards the seaward side of the margins. Talwani and Eldholm (1972) have reported magnetic quiet zones over the continental margins of Norway.

The eastern and northeastern margins of India, including those of Bangladesh and Burma lie within the Bay of Bengal, where they are covered by one of the thickest deep-sea fans of the world, the Bengal Fan. It is nearly 3000 km long and 1000 km wide, extending between 20° N and 10° S (Fig.1). Heezen and Tharp (1964) constructed the bathymetric and physiographic map of the entire Indian ocean including the Bay of Bengal, using all

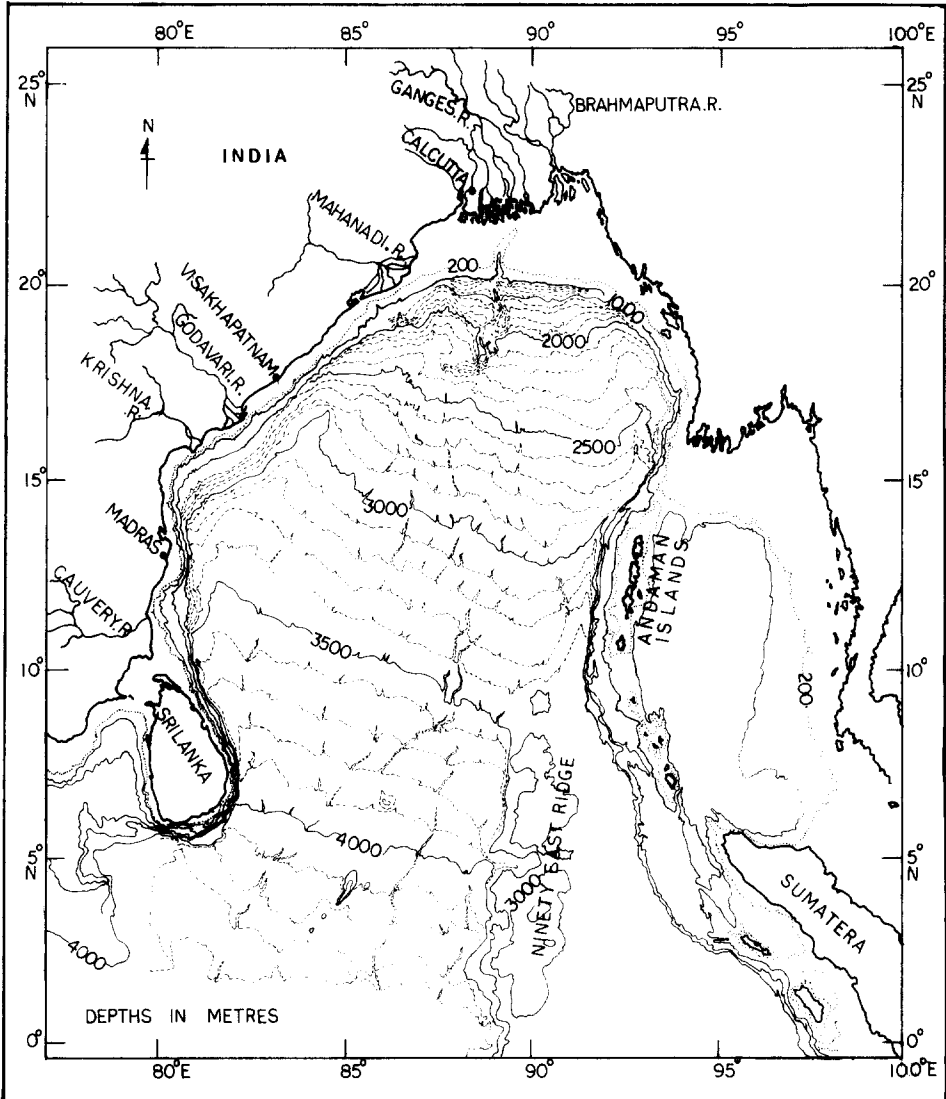


Fig.1. Bathymetry of Bengal Fan, after Curry and Moore (1971).

the echosounder data collected during the IIOE of 1960–1965. The bathymetric chart of the Bengal Fan, that has been subsequently updated by Curry and Moore (1971), is presented here as Fig.1. As earlier suggested by Dietz (1953), several seafloor channels originated by turbidity currents extend from the head of Bay of Bengal to the south of the Sri Lanka (Fig.1). LaFond (1957) has described a huge canyon called the “Swatch of No Ground” lying off the Ganges and the Brahmaputra River Deltas as the source of turbidity currents that are responsible for the transportation of the sediments into the Bengal Fan through the various channels.

Curry and Moore (1971) reported that the sediments are more than 12 km thick at the northern end of the Bay of Bengal. They were predominantly derived from the drainage of the two major rivers, the Ganges and the Brahmaputra. Some of the other perennial rivers, that discharge sediment into the Bay of Bengal are the "Mahanadi", the "Godavari", the "Krishna" and the "Cauvery". Based on their textural characteristics, Subba Rao (1964) reported the existence of relict sediments between 60 m water depth and the shelf edge and concluded that they were deposited when sea levels were lowered during the Pleistocene.

DATA COLLECTION

Continuous magnetic, gravity and topographic data were recorded in the Bay of Bengal on board R.V. "Chain" in 1973. The surveys consist of several profiles covering the area between 10° and 20° N and between the east coast of India and the western margins of the Andaman islands and Bangladesh. Parts of the profiles (numbered 10, 34, 31, 14, 28 and 25; Fig.2) that covered the continental margins of east coast of India are taken for the present studies. They run in an east-west direction.

Total intensity of the Earth's magnetic field was recorded by Varian Proton Precession Magnetometer. The sensor of the unit was towed about 150 m astern of the ship to avoid the ship's magnetic effect. Total magnetic

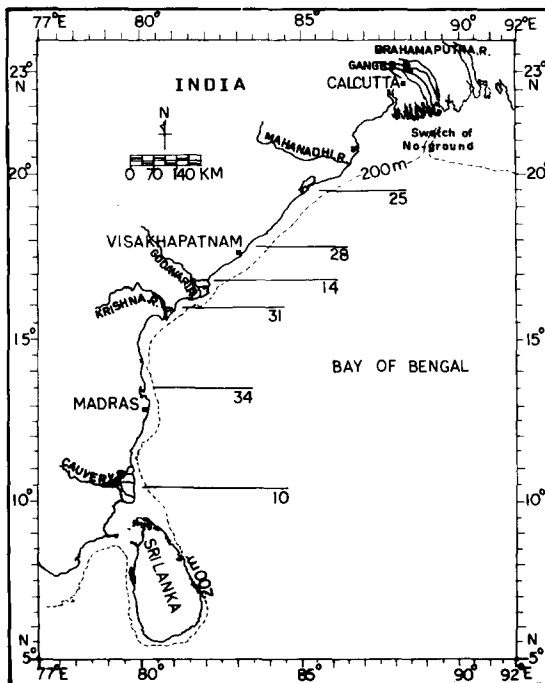


Fig. 2. Profiles location map.

field anomalies were computed using the IGRF subroutine. The gravity measurements were made with a La Costa-Romberg sea-surface gravity meter. Signals from this meter were sampled at fixed intervals of time and free-air gravity anomalies were calculated and recorded by the on-board oceanographic data processing and control system (Bowin et al., 1967). Continuous records of the ocean-bottom topography were obtained by the Precision Graphic Recorder with a bow- and hull-mounted 12 kHz transducer. Sonic depths thus recorded were corrected according to the sound velocities computed, using the Matthew's Tables (1939). Listings of the topographic, magnetic and gravity data along with the navigational data digitized at five minute intervals were made available to one of the authors (TCSR) during his visit to WHOI, in 1975-76. The stacked profiles of the bottom topography, magnetic field anomalies and the free-air anomalies are presented in Figs. 3, 4 and 5, respectively.

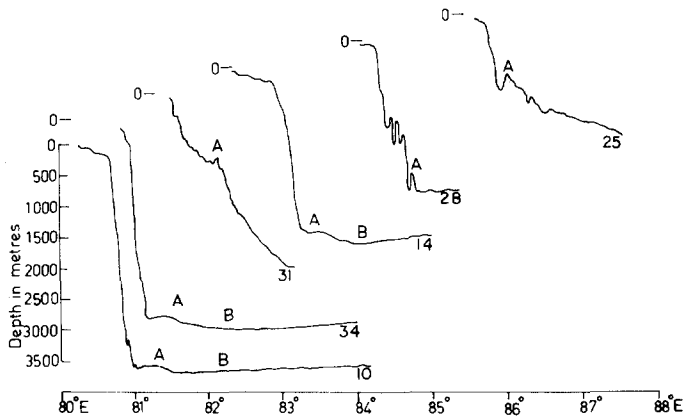


Fig. 3. Bottom topography recorded on profiles 10, 34, 31, 14, 28 and 25.

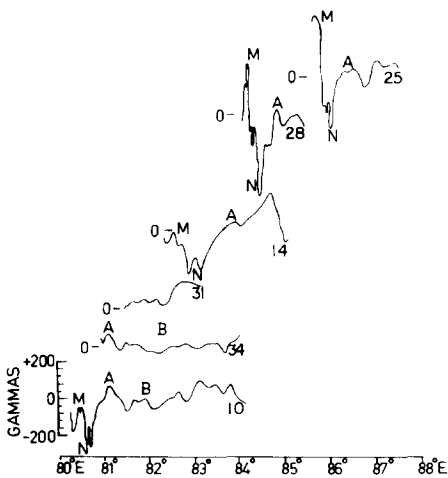


Fig. 4. Total magnetic field anomalies on profiles 10, 34, 31, 14, 28 and 25.

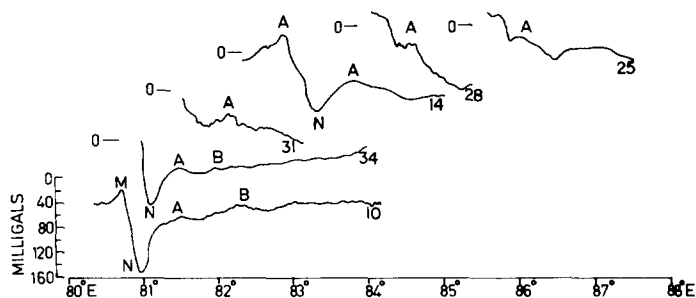


Fig.5. Free-air gravity anomalies on profiles 10, 34, 31, 14, 28 and 25.

RESULTS

Bottom topography, magnetic and free-air gravity anomalies recorded over the eastern margins of India reveal three specific physiographic provinces: (1) the continental shelf and slope; (2) the marginal high; and (3) the marginal basin.

Continental shelf and slope

The stacked profiles of the bottom topography (Fig.3) show that the continental shelf extends up to about 220 m on profiles 10 and 14. On other profiles the continental shelf is relatively narrow and the continental slope starts at about 120 m. On profile 31 the topography over the slope is uneven and several small-scale step-like features were recorded. The continental slope on this profile is not as steep as on the other profiles. Since it is located off the river mouths of the Godavari and the Krishna, rapid accumulation of sediments brought down by these rivers might have contributed to the smaller gradient in topography over the continental slope. Periodic slumping of the sediments may be responsible for uneven topography. On profile 28, three prominent topographic highs each with more than 200 m relief were recorded over the continental slope.

The magnetic anomalies (Fig.4) present a characteristic rise in anomaly "M" over the continental shelf on profiles 10, 14, 28 and 25. It is of negative value on profile 10 with its peak value of -42 gammas and becomes almost zero on profile 14 to attain large positive value of about 260 gammas on profile 28 and about 330 gammas on profile 25. On profiles 31 and 34, no such magnetic anomalies were recorded as the profiles start over the slope and the shelf is very narrow. Over the continental slope, the magnetic anomalies decrease rapidly and form a deep magnetic low "N" at its base. On profile 31 no significant anomalies were recorded except the one that was recorded towards the eastward end of the profile. On profiles 10 and 14, the magnetic low is of the order of -200 gammas and a small peak was recorded within the low. On profiles 28 and 25, the lows are very deep and attain values of the order of -260 and -280 gammas, respectively.

Free-air gravity anomalies (Fig.5) exhibit a gravity high "M" over the outer shelf on profiles 10, 14 and 25. It is of negative value on profile 10 and becomes progressively positive on profiles 14 and 25. On profiles 31 and 28, it trends to positive values but the peak is not recorded. Over the continental slope the gravity anomalies decrease rapidly and form a gravity low "N" at the seaward end of the slope. On profile 31, several small-scale gravity highs and lows were recorded over the topographic features. On profile 28, the gravity highs and lows occur over the topographic highs and lows.

Marginal high

Echosounder data recorded a prominent topographic high marked "A" (Fig.3) on all the six profiles over the continental margin of east coast of India. It is broader and of less relief on profiles 10, 34 and 14, whereas on profiles 28 and 25 it forms a sharp peak with a relief of more than 200 m. Unlike on other profiles, the high on profile 31 is recorded over the continental slope. On all other profiles except the profile 28, the western limb of the high is steeper than the eastern limb which gradually slopes down to join the topographic low. The magnetic anomaly "A" (Fig.4) is recorded in all the profiles except in profile 31. On profiles 10 and 34, the anomaly is positive and fairly predominant with a peak to peak value of about 60 gammas. The free-air gravity anomalies also recorded the gravity high "A" (Fig.5) on all the profiles that correlate with the corresponding highs recorded in the bottom topography and the magnetic anomalies.

Depths to the causative sources have been computed from the magnetic anomalies and the magnetic basement profiles have been constructed (Fig.6). The magnetic anomalies "A" (Fig.4) have indicated the corresponding high "A" in basement layers (Fig.6). The crustal structure deduced from the free-air gravity anomalies (Figs.7a-d) also show the high "A" in all the layers including the crystalline basement. The "high" located at the foot of the

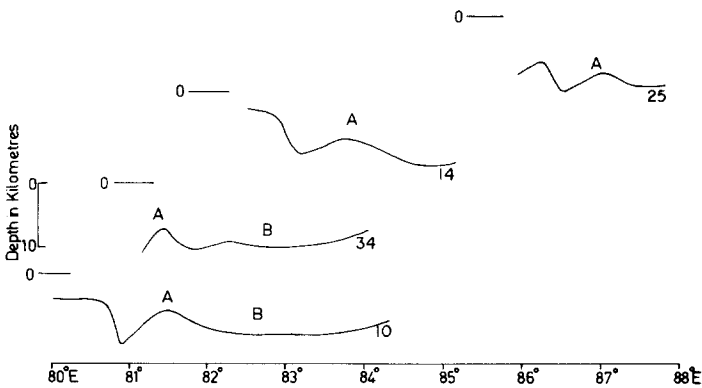


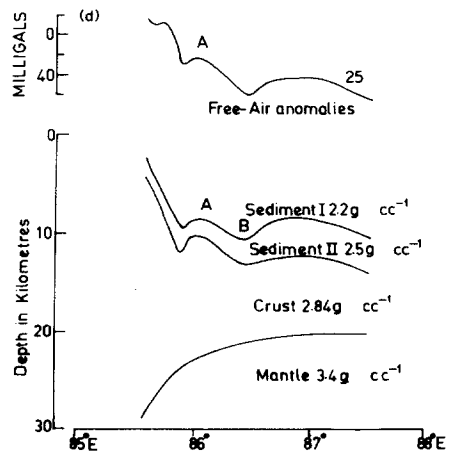
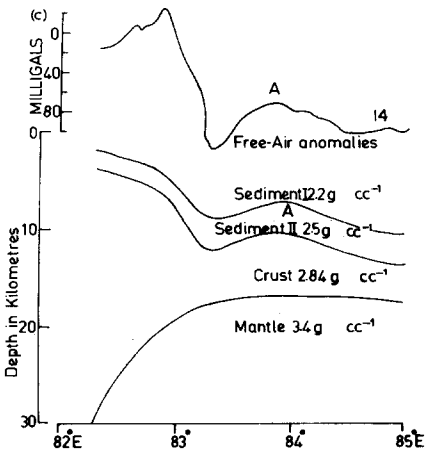
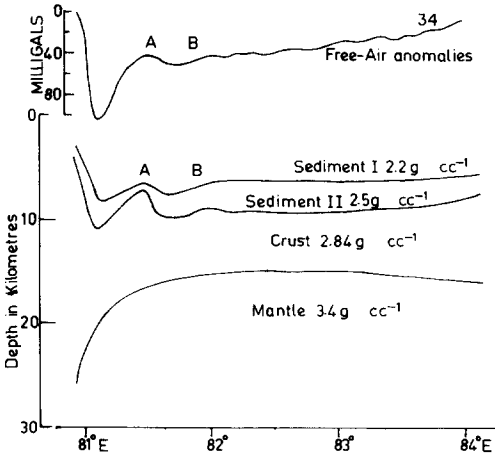
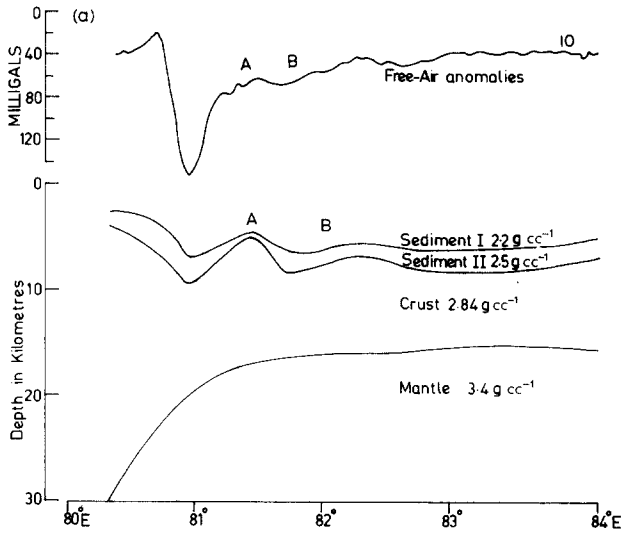
Fig.6. Magnetic basement computed from magnetic anomalies on profiles 10, 34, 14 and 25.

continental slope and extending all along the east coast of India is designated as the "marginal high". A topographic high of this nature may normally be viewed as arising due to the accumulation of sediments drained from the rivers in large quantities. However, from the nature of the magnetic anomalies recorded over the high (Fig.4) and the corresponding highs in the basement layers delineated from the magnetic and gravity anomalies (Figs.6 and 7), it appears that the high "A" might have originated in the basement layer and during its evolution have uplifted the overlying sedimentary layers. Thus the topographic high recorded in this region could be the surface manifestation of the high in the basement layer. Detailed seismic investigations would be needed to confirm its origin and development.

Marginal basin

Ocean-bottom topography shows a broad topographic low "B" (Fig.3) on profiles 10, 34, 14 and 25. It is not recorded on profiles 31 and 28 as these profiles do not extend to these depths. Depths to the magnetic basement computed from the magnetic anomalies (Fig.6) and the crustal structure deduced from the free-air gravity anomalies (Figs.7a-d) also indicate a broad low "B" in the crystalline basement layer. This low "B", recorded on the southern part of the eastern margins of India is called the "marginal basin". It is wide on profile 10 and becomes narrow on profile 34. While it is observed only on profiles 10 and 34 in the basement layer derived from the magnetic and gravity anomalies, the bottom topography recorded the "low" on profiles 10, 34, 14 and 25. A similar topographic low was earlier reported by Rao (1968) extending all along the east coast of India and Sri Lanka and was called a "trench".

Magnetic anomalies recorded over the "marginal basin" are comparatively of low amplitude and short wavelength, whereas the anomalies recorded on the same profiles extended to the Central Bay of Bengal (Rao, 1980) are of large amplitude and long wavelength. Talwani and Eldholm (1972) reported low magnetic anomalies over the continental margins off Norway which were different from the large amplitude and long wavelength anomalies recorded in the deeper parts of the adjacent sea. The sea area covered by the low-amplitude anomalies was designated by them as the magnetic quiet zone. It may thus be seen that the "marginal basin" over which similar low-amplitude anomalies are recorded may correspond to the magnetic quiet zone and it is possibly underlain by a continental type of crust as inferred by Talwani and Eldholm (1972). Alternatively, magnetic quiet zones were also reported over the oceanic crust which was formed during the upper Cretaceous magnetic quiet zone. Emery et al. (1970) suggested that the properties of the oceanic crustal layers could be altered because of the overlying thick sediment and may contribute to the occurrence of low-amplitude magnetic anomalies. The crustal structure deduced on the profiles 10 and 34 yields a more than 8 km thickness of sediment. This overlying load of sediments might have transformed the underlying originally oceanic crust into continental crust by bringing about changes in the physical properties.



DISCUSSIONS AND CONCLUSIONS

The coastline of the east coast of India makes a bend at about 16°N . The coastline of peninsular India between 8° and 16°N trends nearly north-south. At 16°N , it bends towards the northeast and the coastline extends in a SW-NE direction. Accordingly, the eastern margins of India may be divided into two parts, the "southern margin" and the "northern margin". The "southern margin" extends from the southern tip of India up to 16°N , and the "northern margin" occupies the area between 16° and 20°N .

As described earlier, the topographic, the magnetic and the gravity anomaly features differ between the southern margin and the northern margin. Over the former, the continental shelf is wider and extends up to 220 m water depths. The topography over the continental slope is fairly smooth except for some minor undulations. The "marginal high" is of less relief and broader over the southern margins. The "marginal basin" which occurs only on the southern margin is wider at the southern end, gradually becoming narrower towards the north.

Over the northern margin the continental shelf is narrow. The shelf edge occurs at about 120 m water depth. However, on profile 14 which is situated near to the area where the coastline turns northeast, the shelf is anomalously wide and continues up to 220 m water depth. It may also be observed that the magnetic and gravity features exhibit an unusual shift towards the east. Similar eastward shifts are observed on the other profiles north of profile 14. This would explain the NE-SW shift in the trend of the features. The "marginal high" is recorded as a sharp and narrow peak. The "marginal basin" which was deduced over the southern margin from the magnetic and gravity anomalies is not present over the northern margin. In general, the patterns of the bottom topography and gravity anomalies suggest that the northern margins are more disturbed tectonically than the southern margins. Venkataraman and Rangaraju (1968), while postulating vertical movements over the coastline of the northern margins during the Paleozoic era, resulting in the formation of grabens and ridges, believe that similar movements had occurred over the southern margins in the early Cretaceous.

Sastri et al. (1973) found the Cretaceous-Tertiary unconformity only in the Cauvery Basin located over the coastline to the south of Madras but not in the Godavari Basin lying to the south of Visakhapatnam. They further concluded that the positive tectonic movements which occurred during Cretaceous times resulted in simple uplift and erosion in the Cauvery Basin, whereas these movements have resulted in widespread lava flows over the coastline around Visakhapatnam. Sastri et al. (1973) also predict that the volcanic vents through which the trap lavas have been erupted could be

Fig.7(a). Crustal structure deduced from the free-air gravity anomalies on profile 10; (b) crustal structure deduced from the free-air gravity anomalies on profile 34; (c) crustal structure deduced from the free-air gravity anomalies on profile 14; (d) crustal structure deduced from the free-air gravity anomalies on profile 25.

present over the continental margin just to the south of Visakhapatnam. They also suggested that the coastal basins over the east coast of India may extend under the sea. Depths to the magnetic basements obtained from the aeromagnetic anomalies recorded over the profiles that extend from the Indian continent into the Bay of Bengal (Rao and Bhattacharyya, 1976) revealed the presence of basin structures over the continental margins of the east coast of India and they were interpreted as the continuation of the coastal basins under the sea. From the above, it is suggested that the southern margin along the east coast of India is relatively stable and wider, whereas the northern margin appears to have undergone tectonic movements. The isolated topographic highs recorded over the continental slope of northern margin over which the magnetic anomalies are also recorded suggest that the Deccan trap volcanism may have extended into the offshore regions. More detailed magnetic and gravity data along with seismic data are required to delineate the structure and origin of the eastern margins of India.

ACKNOWLEDGEMENTS

The authors are grateful to Dr. Carl Bowin, Woods Hole Oceanographic Institution, for giving the data. They thank the Director, National Institute of Oceanography, Goa, for permitting them to continue the work. They also express their thanks to Andhra University for providing the computer facilities to analyse and interpret the data.

REFERENCES

- Bowin, C.O., Bernstein, R., Ungar, E.D. and Madigan, J.R., 1967. A shipboard oceanographic data processing and control system. *IEEE Trans. Geosci. Electronics*, GE 5: 41-50.
- Curry, J.R. and Moore, D.G., 1971. Growth of the Bengal Deep-sea Fan and denudation in the Himalayas. *Geol. Soc. Am. Bull.*, 82: 563-572.
- Dietz, R.S., 1953. Possible deep-sea turbidity current channels in the Indian ocean. *Geol. Soc. Am. Bull.*, 64: 375-378.
- Emery, K.O., Uchupi, E., Phillips, J.O., Bowin, C.O., Bunce, E.T. and Knott, S.R., 1970. Continental rise of eastern North America. *Bull. Am. Assoc. Pet. Geol.*, 54: 44-108.
- Heezen, B.C. and Tharp, M., 1964. Physiographic Diagram of Indian Ocean, the Red Sea, the South China Sea, the Sulu Sea and the Celebes Sea. *Geol. Soc. Am.*, Scale 1:11,000,000.
- Helmert, F.R., 1909. Die Tiefe der Ausgleichfläche bei des Prattischen Hypothese für das Gleichgewicht der Erdkruste und der Verlauf der Schwerestörung vom Innern der Kontinente und Ozeane nach den Küsten. *Sitzungsber. Dtsch. Kgl. Preusz. Akad. Wiss.*, 18: 1192-1198.
- LaFond, E.C., 1957. The Swatch of No Ground. *Natl. Inst. Sci. India, Bull.*, 11: 84-89.
- Rao, T.C.S., 1968. Bathymetric features of Bay of Bengal. *Natl. Inst. Sci. India, Bull.*, 38: 421-423.
- Rao, T.C.S., 1980. Some marine geophysical studies in the Bay of Bengal. Unpubl. Ph.D. Thesis, Andhra University, Waltair, 171 pp.
- Rao, T.C.S. and Bhattacharyya, G.C., 1976. Aeromagnetic anomalies in Bengal Fan. *Ind. J. Mar. Sci.*, 5: 117-119.

- Sastri, V.V., Sinha, R.N., Gurucharan Singh and Murthy, K.V.S., 1973. Stratigraphy and tectonics of sedimentary basins on the east coast of peninsular India. *Bull. Am. Assoc. Pet. Geol.*, 57: 655—678.
- Subba Rao, M., 1964. Some aspects of continental shelf sediments of the east coast of India. *Mar. Geol.*, 1: 59—87.
- Talwani, M. and Eldholm, O., 1972. Continental margins of Norway. A geophysical study. *Geol. Soc. Am. Bull.*, 83: 3575—3606.
- Vening-Mienezs, F.A., 1941. Gravity over the continental edges. *K. Ned. Akad. Wetensch., Proc.*, 44: 53—61.
- Venkataraman, S. and Ranga Raju, M.K., 1968. Oscillatory movements in Cretaceous—Tertiary basin of south India. *Geol. Soc. India, Mem.*, 2: 201 pp.