

Marine Geophysical Studies off Karwar, West Coast of India

V. SUBRAHMANYAM, M. V. RAMANA AND L. V. SUBBA RAJU
National Institute of Oceanography, Dona Paula, Goa 403 004

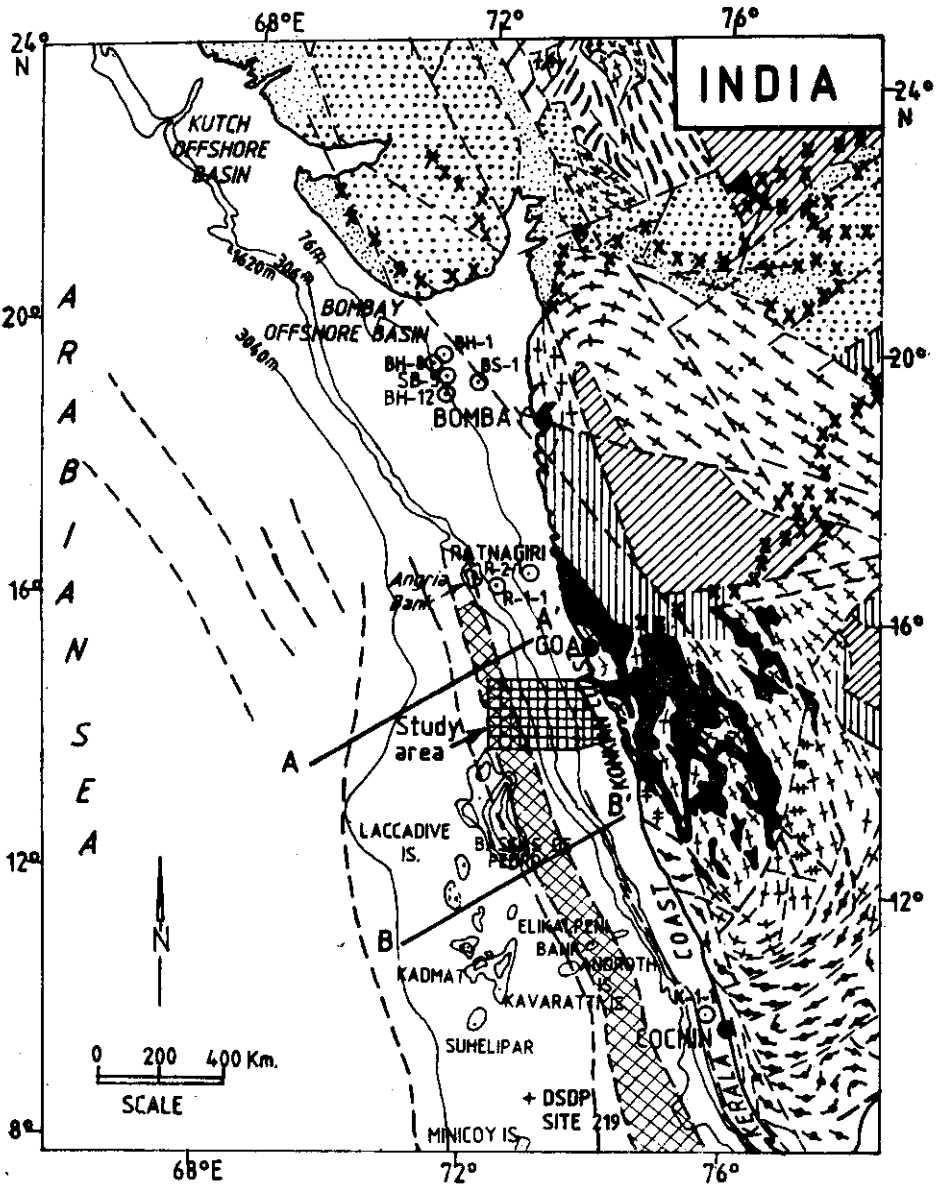
Abstract

Geophysical studies of the southwestern continental margin revealed significant surface and subsurface topographic highs (ridges) trending NNW-SSE to NW-SE beyond the shelf break. Residual magnetic anomaly map depicts prominent NNW-SSE, NW-SE and E-W trends. The magnetic anomaly map also reveals three different provinces, A, B and C, based on magnetic signatures, confined to inner shelf, outer shelf and lower shelf. A prominent E-W trending structural lineament with a NW-SE trending offset is observed cutting across the inner shelf and the lower shelf. Model studies of the geopotential data over the topographic rise indicate about 18 km thick mafic basement of continental origin at a shallow depth (~800 m). The gravity model studies indicate a thick consolidated sediment layer deposited over the horst and graben-like features within the granitic layer. The occurrence of ridges parallel to the shelf edge shows the similarity of the western Indian continental margin with the other typical and extensively studied passive margins.

INTRODUCTION

Geological and geophysical investigations carried out by Closs *et al.* (1969); Harbison and Bassinger (1970 and 1973); Babenko *et al.* (1981); Naini (1980); Rao (1967); Gopala Rao (1984a and 1984b) and Ramaswamy and Rao (1980) have contributed to our understanding of the subsurface geology and major structural features of the western continental margin of India (Fig. 1). Investigations have been intensified after the discovery of hydrocarbons on the continental shelf off Bombay. The data from wells on the western continental shelf (Fig. 1) published by the Oil and Natural Gas Commission of India indicate that Paleocene to Eocene sediments overlie either late Cretaceous/early Tertiary basalts or Archaean/Precambrian granitic gneisses (Sahay, 1978; Basu *et al.* 1980). Rhyolitic tuffs of Paleocene age were recovered at DSDP Drill Site 219 (Siddiquie *et al.* 1976; Fig. 1).

Towards the inner southwestern continental shelf of India, a group of tiny rocky islands and submarine banks made up of basalt and outcrops of ortho-amphibolite are reported (Narain *et al.* 1968; Valsangkar *et al.* 1981; Siddiquie *et al.* 1987). Along the western continental margin of India, parallel to the shelf edge, isolated topographic features rising from 2500 m water depth to approximately 300-400 m are seen beyond the shelf break (Udinstsev, 1975), which are associated with subbottom highs and form a continuous structural trend observed between Cochin to Goa (Fig. 1). Naini (1980) observed a complex of subsurface ridges between the shelf break and Laccadive islands from the widely-spaced geophysical tracks and



LEGEND

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| | AREAS OF EASTERN GHATS FOLDING (ca. 2600 my). | | TERTIARY-QUATERNARY GRABENS/FAULT BASINS |
| | AREAS OF DHARWAR - IRON ORE - ARAVALLI FOLDING (ca. 2600 my) | | MESO - CENOZOIC PLATEAU BASALTS (LIMITS) |
| | AREAS OF SEMRI-CUDDAPH-FOLDING (ca. 1200 my). | | TECTONIC STRUCTURES : MAJOR & MINOR FAULTS |
| | AREAS OF VINHYAN PLATFORM DEVELOPMENT (900 - 600 my) | | LOCATION OF ONGC AND DSDP DRILL SITES |
| | LATE PALAEOZOIC - MESOZOIC GRABENS/FAULT BASINS | | PRATAP RIDGE COMPLEX |

Figure 1. Generalized geological and tectonic setting of Indian peninsula and the main structural elements, physiographic features of adjoining Arabian sea, (after Ray, 1972; Naini, 1980)

included under the name Pratap Ridge. The seismic reflection studies of Harbison and Bassinger (1973); Ramaswamy and Rao (1980); Raju *et al.* (1981) and Naini (1980) indicated a prominent basement rise beyond the continental shelf.

As a part of the National Institute of Oceanography's project 'Geological and Geophysical surveys to decipher the regional geological structure and the tectonics of the continental margins and to understand their evaluation', over 4000 1km of echosounding and magnetics, 150 1km of gravity and 60 1km of high resolution shallow seismic surveys were carried out in a grid pattern in several cruises (Fig. 2) between 20 to 2500 m water depths. The main objectives of the present study are to analyse the magnetic and gravity data in the light of other geophysical data (bathymetry, high resolution shallow seismics, multichannel seismic reflection) for understanding the nature of basement configuration. The positions were obtained with a Tracor Satellite Navigator and Automatic Omega Navigation systems with an accuracy of ± 50 m. In order to facilitate interpretation of bathymetric, magnetic and gravity data, earlier and recent seismic records have also been consulted (Fig. 3a and 3b).

RESULTS AND DISCUSSION

Bathymetry

The width of the shelf is variable, being the widest north of the study area, off Bombay (~350 km) and narrower to the south, off Cochin (~60 km). A detailed bathymetric map was prepared with 10 m, 25 m, 100 m contour interval in the inner shelf, outer shelf and lower shelf respectively (Fig. 2). The average shelf break occurs at a depth of about 200 m. The bathymetry shows even topography, gently dipping with an average gradient of 1 : 870 towards offshore up to a water depth of 100 m. A steep gradient (1 : 20) is noticed between 200-1500 m beyond the shelf

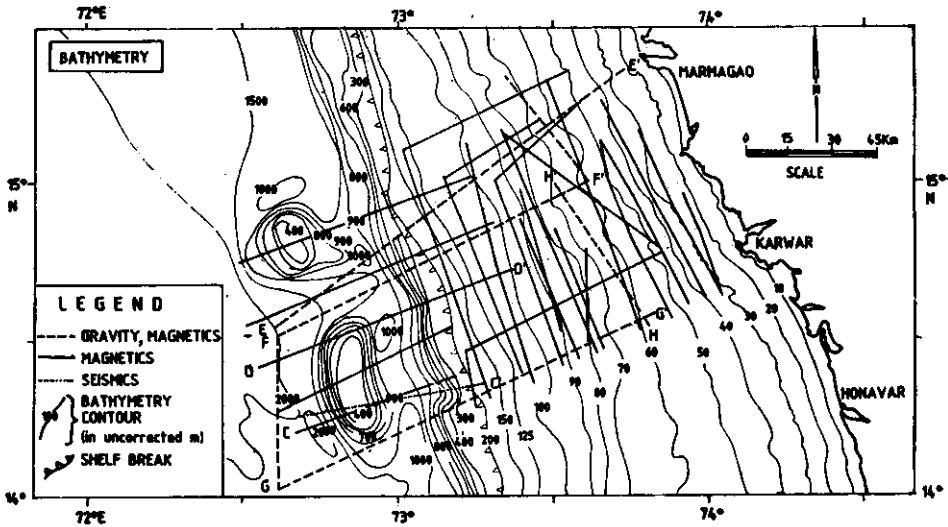


Figure 2. Detailed bathymetric map along with the survey tracks. Additional bathymetric data incorporated from Indian Naval Hydrographic Charts.

break. On the outer shelf between 1000-2000 m water depth, isolated prominent positive bathymetric highs are observed. These have an average gradient of 1:19 towards the coast and 1:3 towards offshore and trend in a NW-SE direction. These topographic highs rise to about less than 400 m from a mean bathymetric contour of 900 m with an average width of 13 km (Figs. 2 and 3a).

Seismics

A high resolution seismic record (Fig. 3a) across the western continental margin indicates a thick sedimentary basin between the shelf edge and the basement ridge. Sediment thickness of about 400 m is noticed over the summit of the basement ridge while on its flanks it is about 3 km. Sediments deposited on the lower shelf were uplifted by the basement ridge, and were subsequently eroded and remobilized forming slumps/slides. These slumps/slides give rise to contemporaneous faults along the slope (Fig. 3a).

A prominent shelf margin basin with a rapid increase in sediment thickness of up to 3 sec (TWT) is noticed across the southwestern continental margin along seismic reflection profiles AA' and BB' (Fig. 3b). Buried basement ridges are observed within the shelf margin basin. The bottommost reflector (acoustic basement) is undulatory in nature and gradually becomes shallower beneath the Laccadive ridge complex and continues further offshore. Gopala Rao *et al.* (1987) reported oceanic crust, west of Laccadive ridge complex, based on magnetic signatures typical of seafloor spreading and association with observed hyperbolic reflections on the seismic reflection record. Since neither such reflections nor magnetic signatures resembling seafloor spreading type were noticed within the shelf margin basin in the present study, the acoustic basement is believed to form part of the continental crust.

Magnetics

The earth's total magnetic field intensity data were corrected for diurnal variations and regional gradient (International Geomagnetic Reference Field for the epoch 1982). The residual magnetic anomaly map was prepared with contour intervals of 100 nT in areas of higher magnetisation and 50 nT in areas of lesser magnetisation (Fig. 4). The total magnetic intensity anomaly map (Fig. 4) depicts prominent NW-SE, NNW-SSE and E-W trending anomalies parallel to major structural trends (Fig. 5) shown by Eremenko and Datta (1968) and Naini (1980) in the offshore. The magnetic anomaly map (Fig. 4) reveals three different provinces A, B and C based on their anomaly signatures. They are the inner shelf, outer shelf and lower shelf. The inner shelf is characterised by a band of high frequency, short wavelength magnetic anomalies (100-600 nT, <3 km) between water depths of 20-50 m. Relatively medium frequency, short wavelength anomalies (50-250 nT, <3 km) are seen on the outer shelf between water depths of 50-200 m. Medium frequency, broad wavelength anomalies (300-350 nT, 32-34 km) are noticed on the lower shelf up to 2500 m water depth. A prominent NNW-SSE trending positive magnetic anomaly was observed on the lower shelf.

On the inner shelf, the observed high amplitude magnetic anomaly with sharp gradient suggests the occurrence of highly magnetised material at shallow depths. A prominent anomaly lineation trending E-W forms the southern boundary of the

C - C'

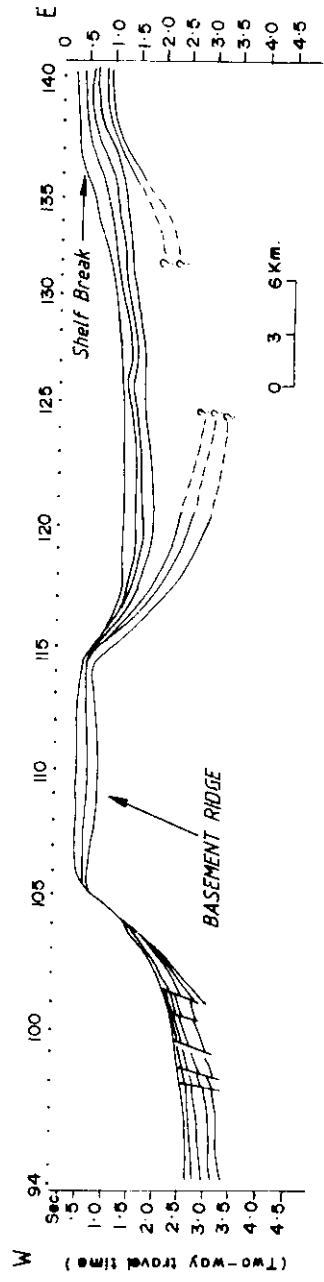


Figure 3a. 8 kJ - Sparker record along with interpreted section across the continental margin, off Karwar. Location is shown in Figure 2 as CC'.

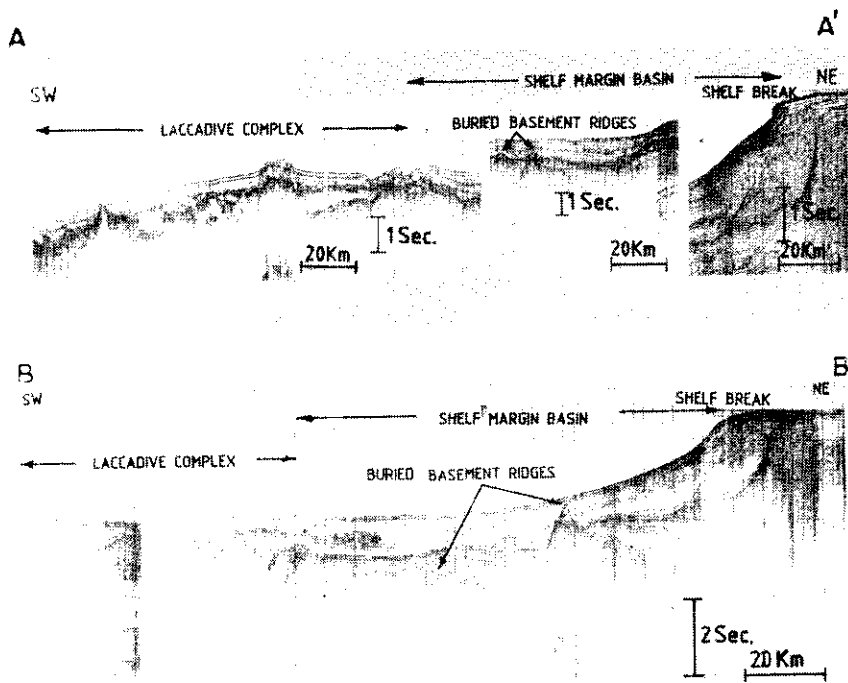


Figure 3b. Multichannel Seismic Reflection profiles across the western continental margin
Locations shown in Figure 1.

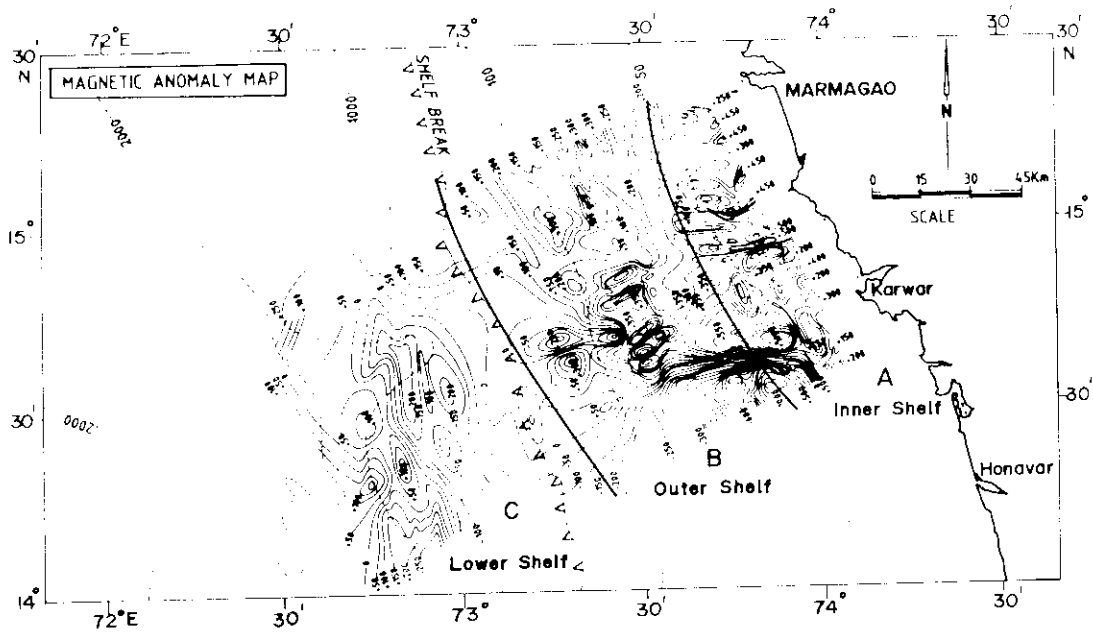


Figure 4. Residual magnetic anomalies contour map off Karwar, west coast of India.

study area (Fig. 4). This E-W trending anomaly is attributed to a major structural lineament F1, shown in Figure 5. This feature is having an offset of about 18–20 km in NW-SE direction on the outer shelf (Fig. 4). The shearing of this structural lineament and the associated mafic material is probably responsible for the sharp gradient magnetic closures at the offset. The medium frequency and short wavelength anomalies observed on the outer shelf between water depths of 50–200 m are bound by NW-SE trending lineaments on either side (Fig. 4). On the lower shelf, the anomalies are more conspicuous and trend NNW-SSE to NW-SE. The magnetic anomalies further north trend N-S to NW-SE (Gopala Rao, 1984a), and

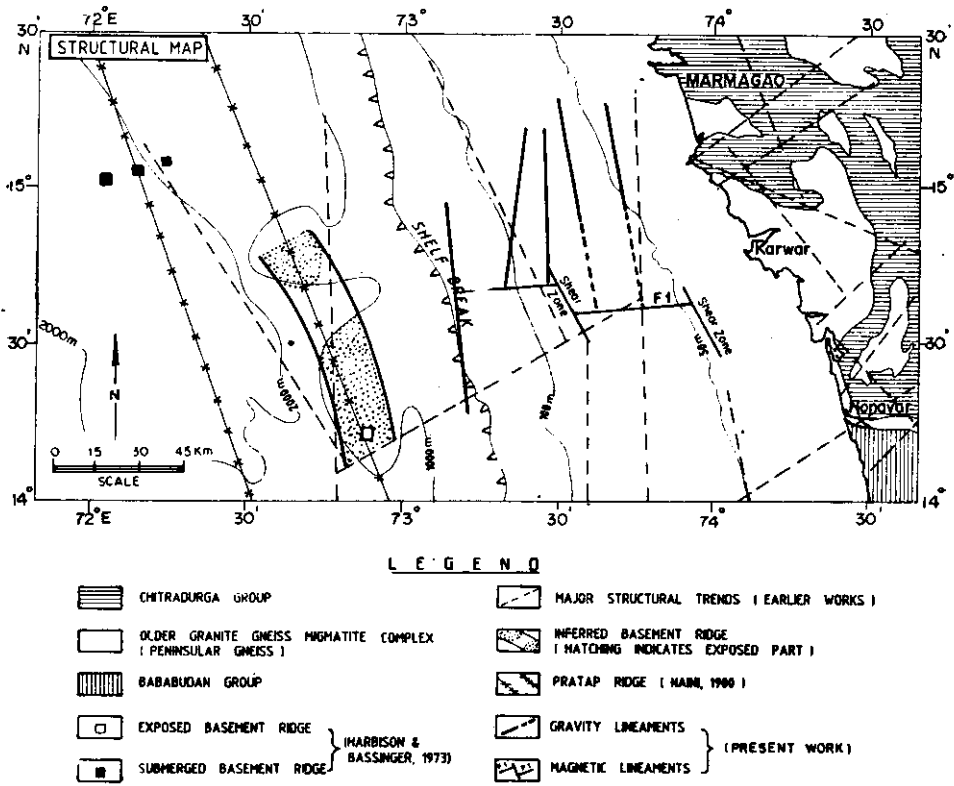


Figure 5. Generalized main structural features and geological sketch map of the continental margin off Karwar, west coast of India. Features and nomenclature (after Radhakrishna and Vasudev, 1977; Naini, 1980; Eremenko and Datta, 1968; Srinivasan and Sreenivas, 1977)

the regional tectonic trends on the inner shelf off central west coast of India are N-S, NW-SE to NNW-SSE (Ramana, 1986). The magnetic anomalies along the western continental margin between Coondapoor and Kasargod (between 12°20' and 13°40'N latitudes) also trend NW-SE, WNW-ESE and E-W (Subrahmanyam, 1987). This N-S, NW-SE, NNW-SSE and WNW-ESE trends along the western continental margin and the NW-SE to NNW-SSE and E-W trends in the present study are comparable, suggesting similar tectonic fabric controlling the basement grain along the western continental margin.

Figure 4 depicts the positive anomaly (300 nT peak to peak amplitude and 32 km wavelength) over the ridge and a magnetic low (150 nT amplitude 26 km wavelength) along the eastern flank of the ridge. This prominent exposed basement ridge is followed to the west by a number of parallel buried ridges (Fig. 3b).

Since subsurface geology of the study area is not well known, a comparative study of the magnetic anomalies over the different geological formations has been carried out before attempting any quantitative interpretation.

Two dimensional model studies by the method of Talwani and Heirtzler (1964) were carried out over the entire length of the profile C-C' (Fig. 2) for inferring the nature of the basement configuration using the available palaeomagnetic data on the western continental margin of India and on the adjacent land mass. Polygonal surfaces were presumed while computing the theoretical anomalies (Fig. 6). The top of the crystalline basement is fixed based on the seismic controls (Figs. 3a and 3b). It was found from the model studies that heterogeneity exists within the crystalline basement which is indicated by different magnetisation contrasts ranging from 0.0001 to 0.005. Further, two different magnetisations exist within the rock unit. The rocks with high magnetisation are interpreted as the mafic charnockite bodies/basalts, whereas negligible magnetisation is attributed to granitic terrain, since Archaean (granitic) basement rarely contributed any significant magnetic anomalies (Gopala Rao, 1984b).

Several synthetic magnetic anomalies were generated using the different permutations and combinations of magnetisation contrast and thickness of the block. However, the best fit models are presented in Figure 6. The model with depths to the top of the basement varying from 800 m to 2000 m revealed a maximum 18 km thick mafic rocks below the seabed.

It is interesting to observe that the computed magnetic anomalies are out of phase with the observed anomaly when the remanent component is introduced while carrying out model studies, suggesting the dominance of Induced Component since its formation. The computed and observed magnetic anomalies for three different trials over the subsurface lithological units are shown in Figure 6. Trial III has given the best fit with the observed anomaly. It is also observed from the model studies that the crystalline basement (granitic terrain) is associated with mafic rocks indicating that the basement between water depths 100-2500 m, is comprised of highly magnetised mafic rocks intruded into the Precambrian shield.

Gravity

The free air anomaly observed along profiles EE' and FF' shows about 25 mgal anomaly over the buried ridge and along profile GG' about 60 mgal anomaly above the exposed ridge system (Fig. 7). A gravity high of about 50-60 mgal in profiles EE' and FF' on the outer shelf is bordered by approximately NW-SE trending transverse faults within the basement. Gravity profile HH' along the inner shelf shows two prominent highs of around 30 and 20 mgal. These two highs are attributed to undulations within the basement.

Crustal model studies by the method of Talwani *et al.* (1959) were carried out along profiles EE' and HH' assuming 5 layers (Fig. 8). For computing theoretical anomalies, densities of 2.3, 2.6, 2.9, and 3.27 gm/cc were chosen for sediments, granitic layer, mafics/basalt and mantle respectively, with 1.03 gm/cc density for

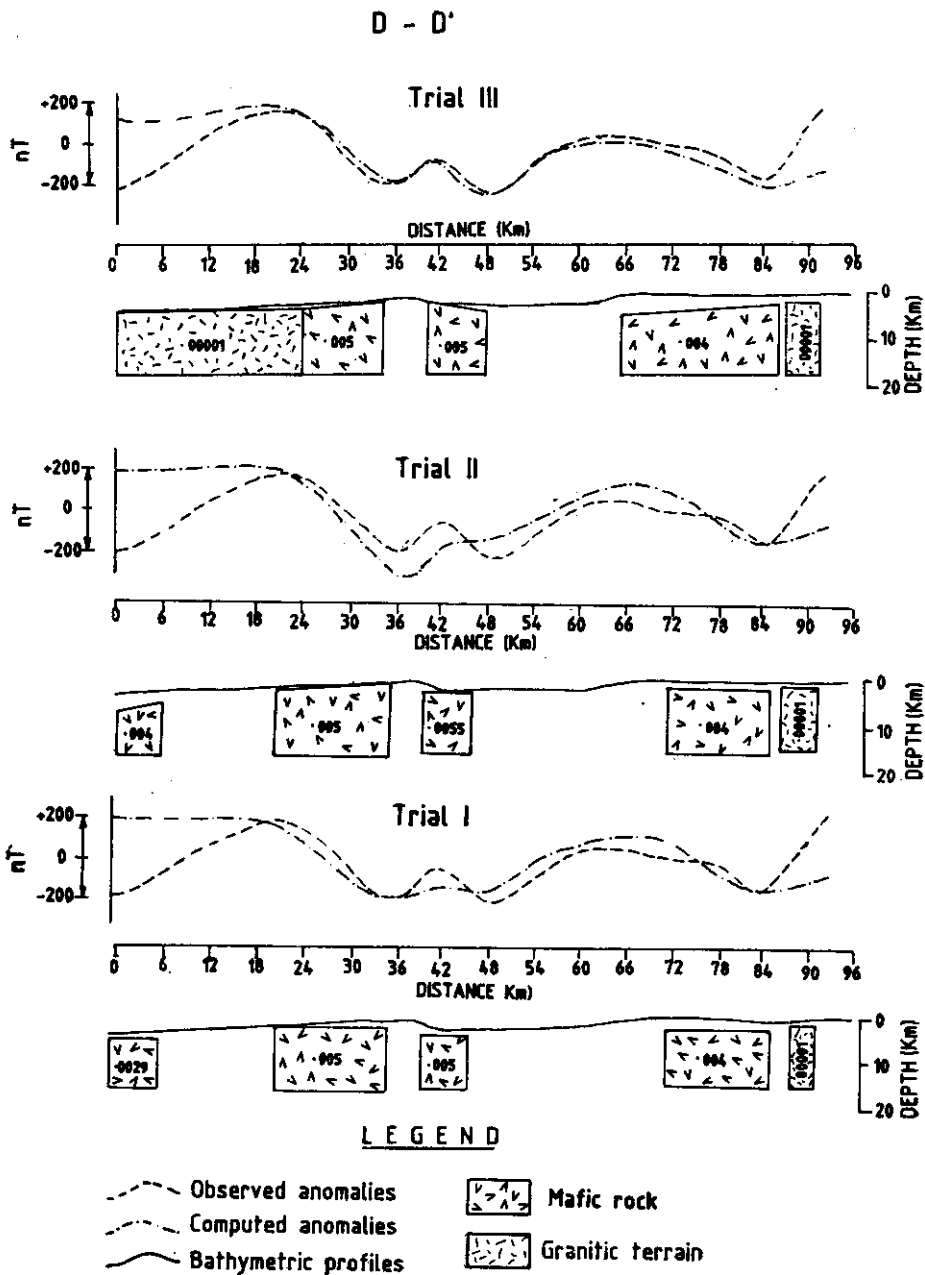


Figure 6. Total observed and computed magnetic intensity anomalies and bathymetry along representative profile (DD'). Computed anomaly profiles are generated by two dimensional magnetic block models at bottom. Following magnetisation parameters were used for computing anomaly profiles : a) Declination of the earth's field : -1.8° ; b) Inclination of the earth's field : 12° ; c) Magnetisation : parallel to the present earth's field and Induced component only. For granitic terrain : 0.001 Am^{-1} , and basalts/charnockites : $2.9 \text{ to } 5.0 \text{ Am}^{-1}$.

water layer. Naini (1980) computed the isostatic gravity anomaly with the depth of compensation $T = 30$ km for the Arabian sea. For generating the gravity model in the present study, the same depth of compensation has been adopted. From the

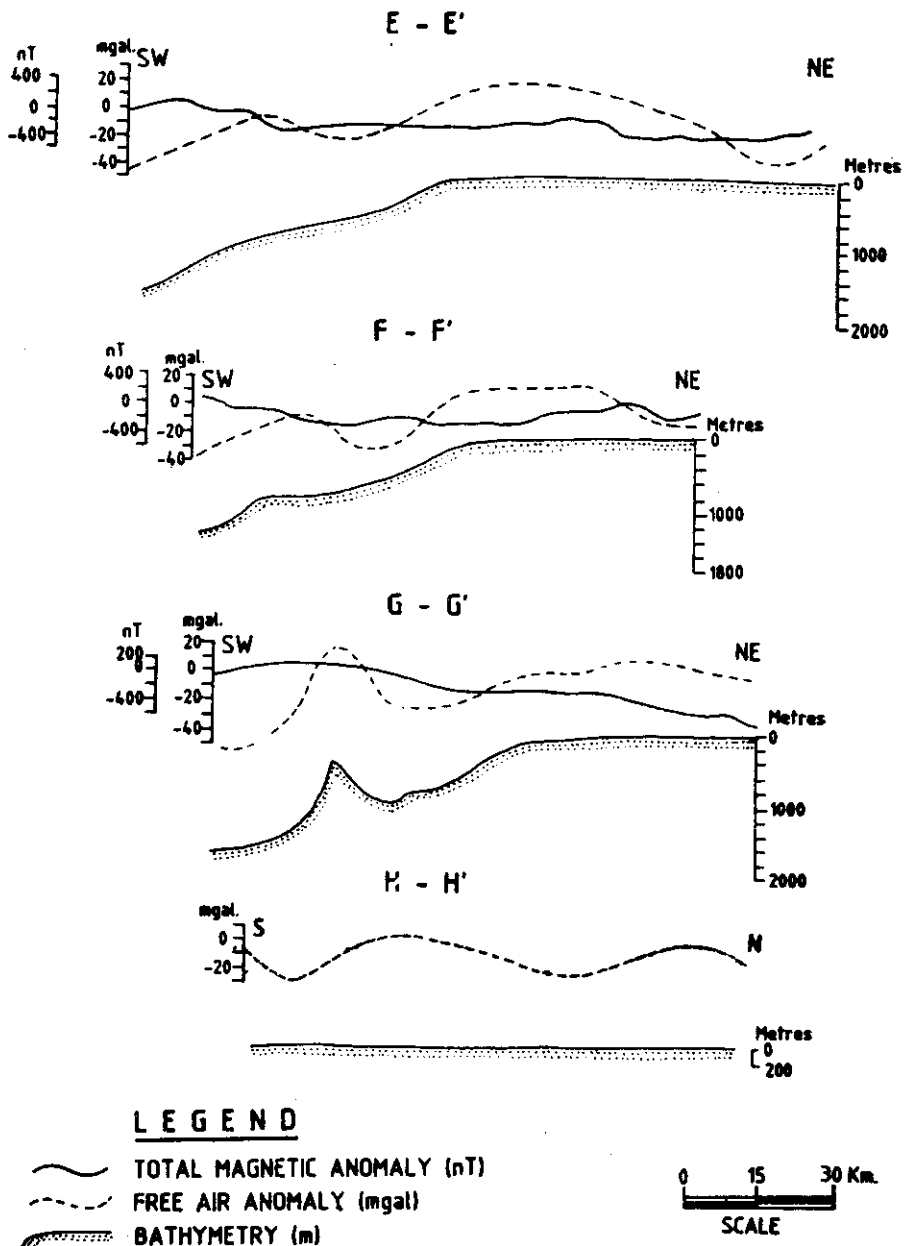


Figure 7. Map showing the composite geophysical anomalies along the tracks EE', FF', GG' and HH'

model studies (Fig. 8) it is seen that sediment thickness varies between 1-3 km on the shelf and beyond shelf break. It increases up to 5 km on either side of the ridge. The bottom surface of the crust is at a depth of 29 km below the shelf, and thins below the shelf break to about 18 km.

The 50-60 mgal gravity high on the shelf is due to the doming of mafic rock below the granitic layer, and is bounded by gentle faulting on either side (Fig. 8). The observed 30 mgal gravity high is attributed to a basement ridge, similar to buried

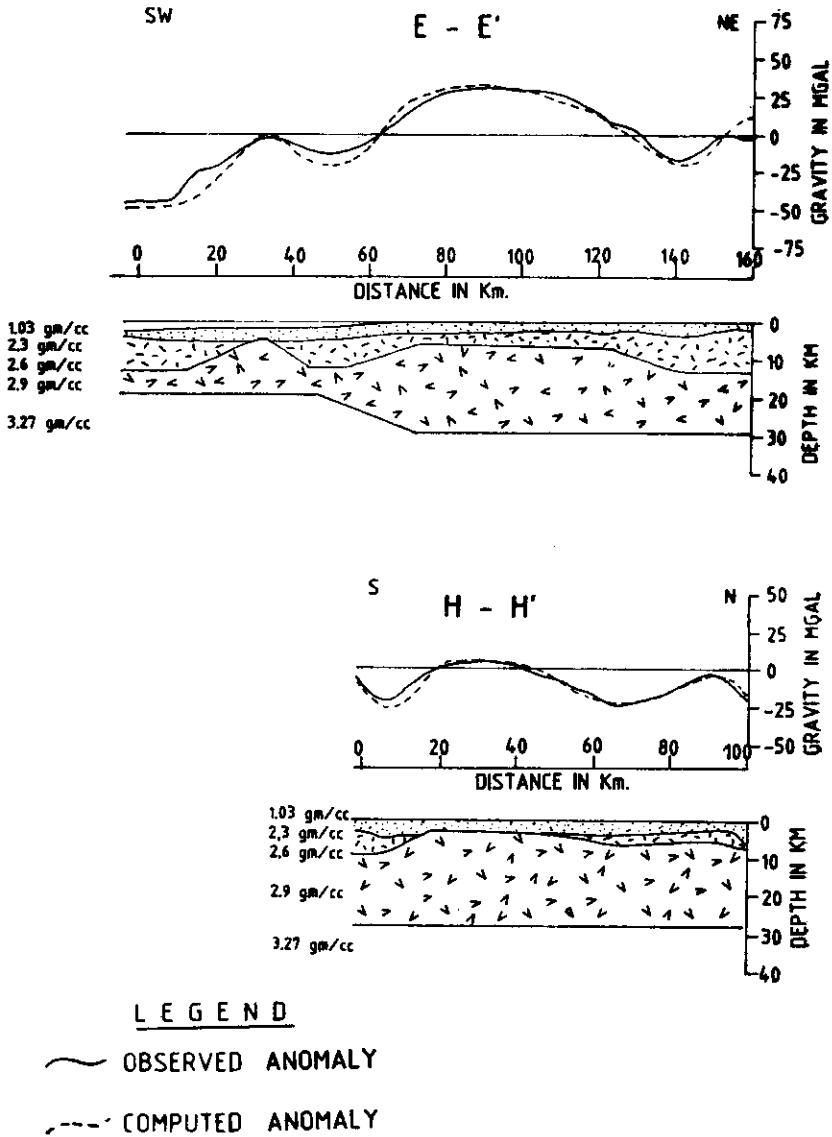


Figure 8. Crustal section along the profiles EE' (across the continental margin) and HH' (along the midshelf) of western continental margin of India.

basement ridges noticed in the shelf margin basin along profiles AA' and BB' (Fig. 3b). The gravity anomaly on the profile HH' is interpreted as due to the uplift of the crust bounded by gentle faults on either side (Fig. 8). The deformations within the crust were responsible for the occurrence of horst and graben-like features, reported by Kalinin (1964) along the western continental margin.

Further, the amplitude of gravity anomaly on the mid shelf (Fig. 7) diminishes towards south, suggesting the occurrence of crust at deeper level. From Figure 5, the continental margin is effected by NS, NW-SE and EW trending lineaments. The interpreted structural lineament F1, along EW direction might have originated at the time of crustal deformation, thus giving rise to variations in the crustal thickness. These crustal deformations were interpreted by Kalinin (1964) and Raju (1968) as thrusting and faulting within the Precambrian basement and controlled sediment processes along the western continental margin. Babenko *et al.* (1981) reported that the eastern margin of the Arabian sea is an area of conjugated structures formed by horizontal and vertical crustal movements. Burk (1968) suggested the existence of basement ridges on the rifted continental margins. Associated gravity high indicates common origin. The gravity measurements off the east coast of North America carried out by Rabinowitz (1974) show a prominent 50 mgal free air anomaly along with an isostatic anomaly which is computed for 30 km depth of compensation.

From the present studies (Fig. 8), we observe that ridge, graben and horst like features are similar to the reported features on the western continental margin of Africa and eastern continental margin of America (Karl Hinz *et al.* 1982; Rabinowitz, 1974). These features with considerable thickness are associated with prominent gravity anomalies suggesting their origin from the continental type of crust.

CONCLUSIONS

(1) The sea-bed topography is gentle and smooth up to the shelf break (up to 200 m). Beyond the shelf break, prominent 13 km wide NW-SE trending topographic highs extend over a length of 25 km in the north and 45 km in the south.

(2) The study area is divided into three provinces A, B and C confined to inner shelf, outer shelf and lower shelf, based on magnetic signatures. They are characterised by high frequency, short wavelength; medium frequency, medium wavelength and medium frequency, broad wavelength anomalies respectively.

(3) Beyond the shelf break the observed NNW-SSE, NW-SE trending magnetic anomalies closely follow the structural trends and the axis of the ridge.

(4) A prominent positive magnetic anomaly with an average wavelength of 32 km, and an amplitude of about 300 nT was observed over the ridge beyond the shelf break.

(5) Magnetic model studies suggest the basement configuration of southwestern continental margin to be comprised of heterogeneous mafic rocks.

(6) The observed high amplitude gravity anomalies are associated with the crustal doming within the continental shelf and ridge-like feature beyond the shelf edge.

(7) The continental crust thins down from 29 to 18 km below the shelf break and continues further offshore.

(8) The present study shows a number of parallel basement ridges beyond the shelf edge on the western continental margin of India, which are similar to ridges occurring in typical and extensively studied passive margins of western Africa and eastern America.

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