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Structural interpretation of the Konkan basin, southwestern continental margin of India, based on magnetic and bathymetric data

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Abstract Magnetic and bathymetric studies on the Konkan basin of the southwestern continental margin of India reveal prominent NNW-SSE, NW-SE, ENE-WSW, and WNW-ESE structural trends. The crystalline basement occurs at about 5–6 km below the mean sea level. A mid-shelf basement ridge, a shelf margin basin, and the northern extension of the Prathap Ridge complex are also inferred. The forces created by the sea-floor spreading at Carlsberg Ridge since late Cretaceous appears to shape the present-day southwestern continental margin of India and caused the offsets in the structural features along the preexisting faults.

Introduction

Rifting between the Indian Plate and the Mascarene Plateau at about 66–68 Ma (anomaly 28), followed by sea-floor spreading across the Carlsberg Ridge, as reported by McKenzie and Sclater (1971), is responsible for the present-day structure and configuration of the Arabian Sea (Fig. 1). Structure and tectonics of the western continental margin of India have been studied by several workers (Eremenko and Datta 1968; Naini and Talwani 1982; Ramana 1986; Bhattacharya and Subrahmanyam 1986; Subrahmanyam 1987; Biswas 1987; Subrahmanyam et al. 1989, 1991, 1993a,b; Gopala Rao 1990) who reported the existence of major NW-SE NNW-SSE, ENE-WSW, WNW-ESE, and N-S trends. The regional crustal features that have been identified include ridges, for example, the Chagos-Laccadive Ridge, the Laxmi Ridge, the basement

high, the Prathap Ridge of the slope, the mid-shelf basement ridge, and the sediment-filled basins of the shelf (Fig. 2). Naini and Talwani (1982) recognized two basins, a western and an eastern basin based on the structure and tectonics of Arabian Sea.

The area of investigation is located off the coast of India between Marmagao and Coondapoor, in 30–2000 m water depths. In this paper we delineate the structure and tectonics of the area from the interpretations of the total magnetic intensity and bathymetric data (Fig. 3).

Geologic setting

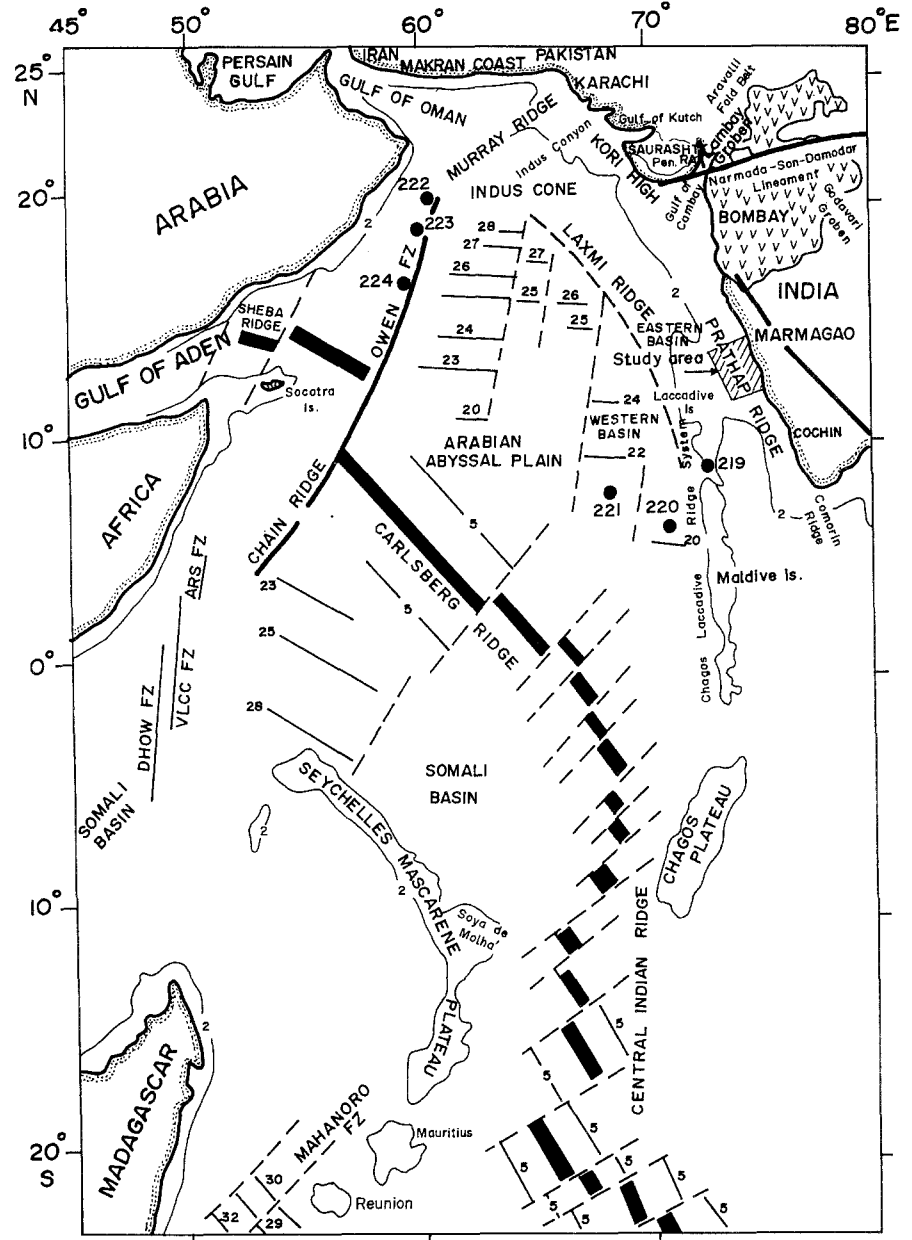
The western continental shelf of India consists of four major sedimentary basins (Fig. 2): the Kutch, Bombay, Konkan, and Kerala basins (Ramaswamy and Rao 1980). Well logs from the Oil and Natural Gas Commission of India show beneath the western shelf basaltic basement rocks overlain by Tertiary sedimentary rocks of variable thickness (Ramaswamy and Rao 1980) (Fig. 2). They are underlain by Mesozoic and/or Precambrian granitic gneiss. We report upon the results of a study that covers the northern part of the Konkan basin (Fig. 2). Eremenko and Dutta (1968) and Subrahmanyam et al. (1993b) reported four sets of major lineaments that trend NNW-SSE, ENE-WSW, WNW-ESE, and N-S (Fig. 4) in that area. Siddiquie et al. (1987) dredged orthoamphibolites (Precambrian age) in 30-m depth of water off the Bhatkal Coast and inferred seaward extension of this rock type into 60-m water depth.

Naini and Talwani (1982) reported isolated topographic highs on the continental slope rising between 8°N and 16°N, which they named the Prathap Ridge complex. Topographic highs on the slope between 12°N and 15°N were interpreted as also being part of the northern extension of the Prathap Ridge complex (Subrahmanyam et al. 1989, 1991, 1993b; Krishna et al. 1992). A basement ridge under the mid-shelf, a shelf margin basin, and the northward extension of Prathap Ridge from free-air gravity anomalies

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Fig. 1 Generalized map of the Arabian Sea showing various physiographic features (after Naini and Talwani 1982). The black bars offset by dashed lines represent segments of mid-ocean ridge crests and fracture zones (FZ), respectively. Thin lines with numbers correspond to magnetic lineations. Solid circles represent DSDP site locations. The hatched portion on the west coast of India indicates the area of study. The patterned portion indicates the extent of Deccan flood basalts on the Indian continent



(Subrahmanyam et al. 1991) and a sediment-filled graben beneath the inner shelf (between 30- and 60-m water depths) from magnetic anomalies (Subrahmanyam et al. 1993a) were also identified. Onshore from Marmagao to Coondapoor, exposures of Precambrian rocks are comprised of belts of younger schist (2900–2600 Ma), gneissic complex, and belts of older schist (3400–3000 Ma) (Radhakrishna and Vasudev 1977; Radhakrishna 1989). Amphibolite is the most common rock type within the gneissic complex.

Data

Total magnetic intensity and bathymetric data (Fig. 3) were collected during 1983–1988 onboard the vessels *RV*

Gaveshani, *MV Farnella*, and *MV Skandi Surveyor*. Bathymetric data were obtained with a Simrad EQ single-channel echo-sounder system. Total magnetic intensity data were collected with a OM 101 Barringer oceanographic proton precession magnetometer. A sampling rate of 12 s was used through out the surveys. Positioning was done with an Omega MX 1105 satellite/Omega navigator and MX 1107 dual-channel satellite navigator systems.

A bathymetric contour map was constructed at varied (20, 50 and 100 m) contour intervals (Fig. 4). The data from Naval Hydrographic chart No. 22 were also used (shown as dotted contour lines) to prepare the bathymetric contour map. The total intensity magnetic data were reduced using the International Geomagnetic Reference Field (DGRF) for the 1985 epoch and using the diurnal variations recorded at the Alibagh magnetic observatory (18°38'N; 72°52'E). Stacked total magnetic intensity

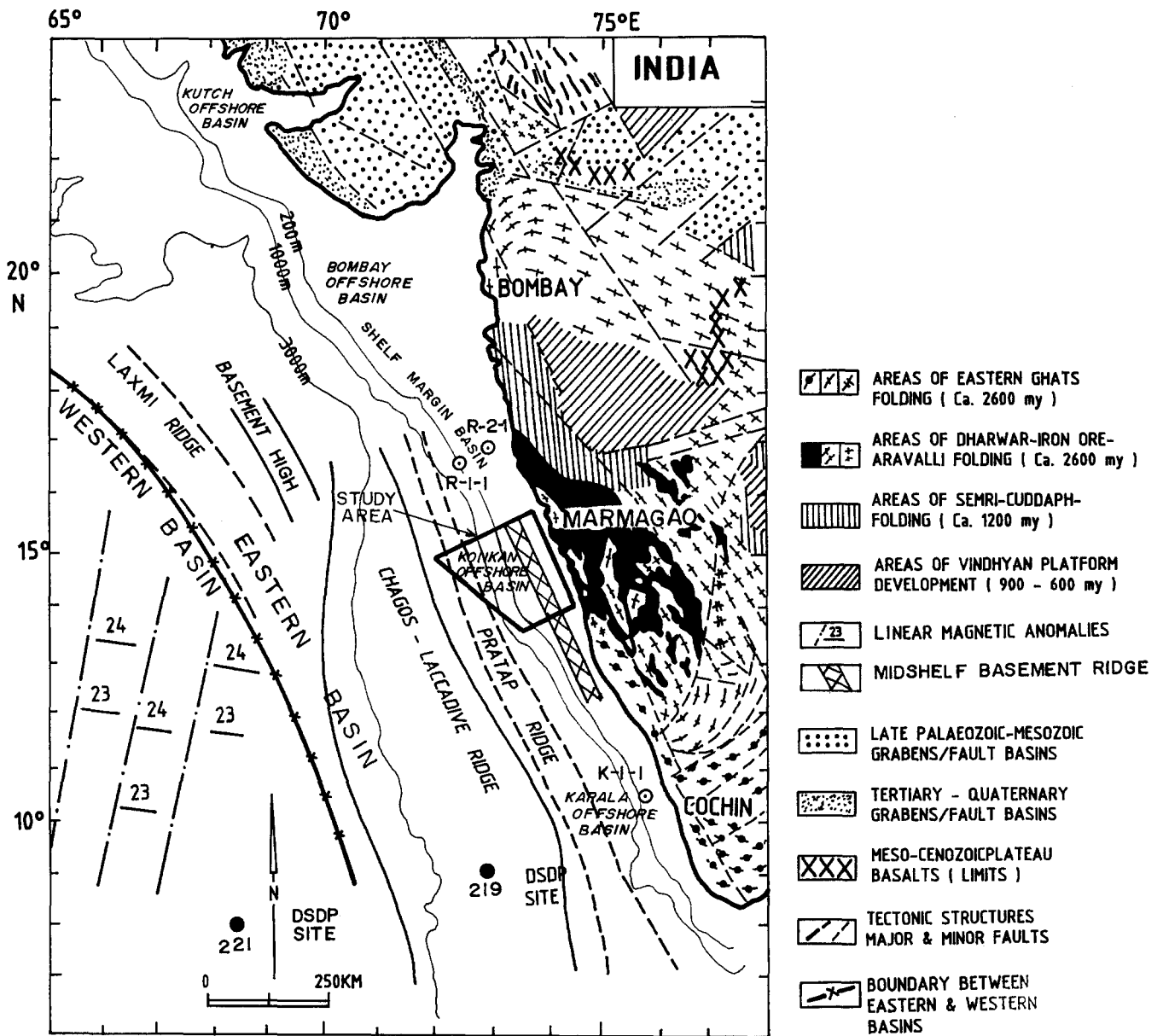


Fig. 2 Regional structure (after Naini and Talwani 1982, Subrahmanyam et al. 1993b), major sedimentary basins, well locations (after Ramaswamy and Rao 1980), land geology, and structure (after Ray 1977) along the western continental margin of India. Solid circles represent the DSDP site locations (after Whitmarsh et al. 1974)

anomaly profiles and the anomaly contour maps were then constructed after the data were corrected (Figs. 5 and 6).

Results and discussion

Bathymetry

The bathymetry of the study area ranges from 30 to 200 m (Fig. 4) and shows smooth topography that gently slopes from 20 to 200 m and steepens to a 2.6° slope from 200 to

800 m. Between 800- and 2000-m depths, two isolated bathymetric highs trending NNW-SSE are observed, which rise to 400 m below the mean sea level. Between these highs, the bathymetry deviates from the regional NNW-SSE trend and shows a NE trending bathymetric reentrant. Deeper than 2000 m, two additional and smaller bathymetric highs are shown in the isobaths. The reliefs of these highs are 200 and 1200 m, respectively, from the adjacent 2000-m deep sea-floor (Fig. 4).

Magnetics

The anomaly profiles and contour maps (Figs. 5 and 6) reveal four prominent trends: NNW-SSE, NW-SE, ENE-WSW, and WNW-ESE. The shelf between 30- and 50-m and between 50- and 200-m water depth is characterized by short-wavelength, high-amplitude (from approx. -800 nT to 1100 nT) anomalies and broad-wavelength, and high-

Fig. 3 Map showing the survey tracks and adjoining land geology

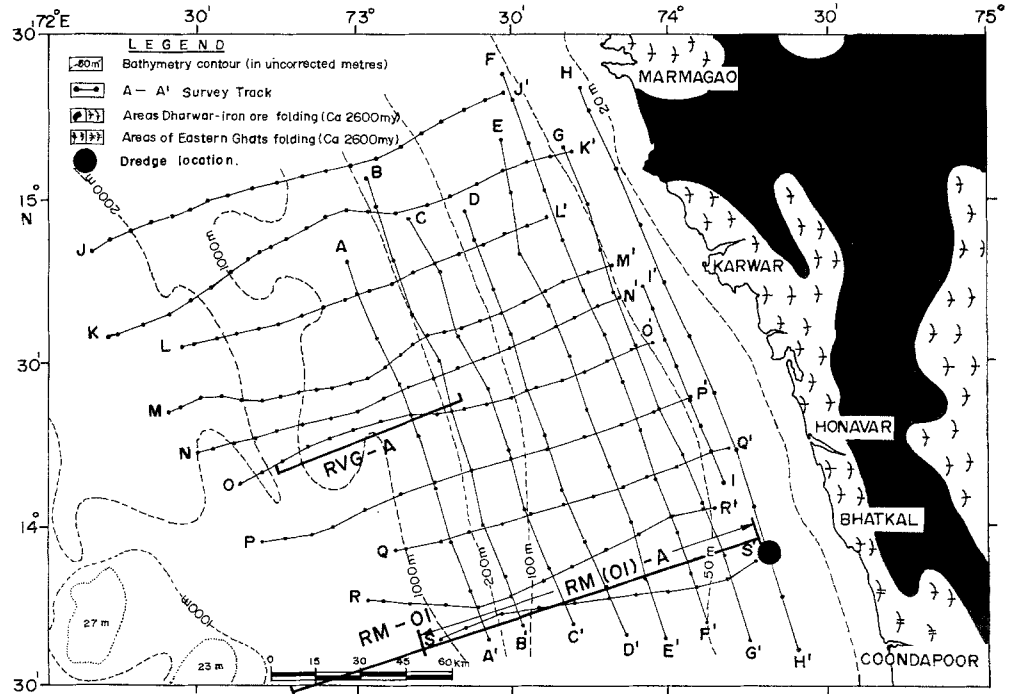
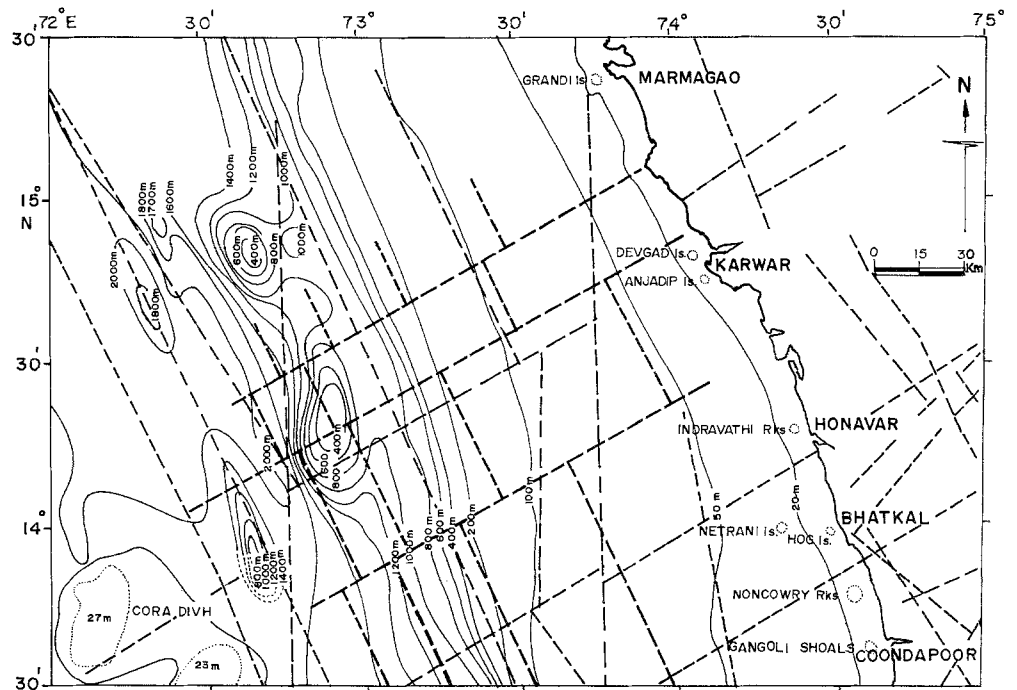


Fig. 4 Bathymetry of the study area along with tectonic trends. Solid dashed lines indicate the inferred structural and tectonic trends (after Eremenko and Datta 1968, Srinivasan and Sreenivas 1977, Naini and Talwani 1982, Subrahmanyam et al. 1993b)



amplitude (from approx. -1300 nT to 800 nT) anomalies, respectively. The margin from 200- to 1000-m water depths and beyond is characterized by broad-wavelength, low-amplitude (from approx. -200 nT to 100 nT) anomalies and medium-wavelength, medium-amplitude (from approx. -1500 nT to 350 nT) anomalies, respectively. The very high amplitude magnetic low (-1300 nT anomaly) of the inner mid-shelf between Honavar and Karwar is bounded by the NW-SE trending positive (approx. 1100 nT) anomaly in the north and the ENE-WSW trending

positive (approx. 800 nT) anomaly in the south. The NNW-SSE trending positive anomaly closures in the west, between 1000- and 2000-m water depth, are separated by low-amplitude (approx. -150 nT) E-W trending magnetic anomalies.

Two-dimensional modeling of the anomalies based on the method of Talwani and Heirtzler (1964) was carried out under depth constraints from seismic reflection (Raju et al. 1981) (Fig. 7), seismic refraction (Rao 1970, 1976), well log (Ramaswamy and Rao 1980), and palaeomagnetic

Fig. 5 Stacked total magnetic intensity anomaly profile map

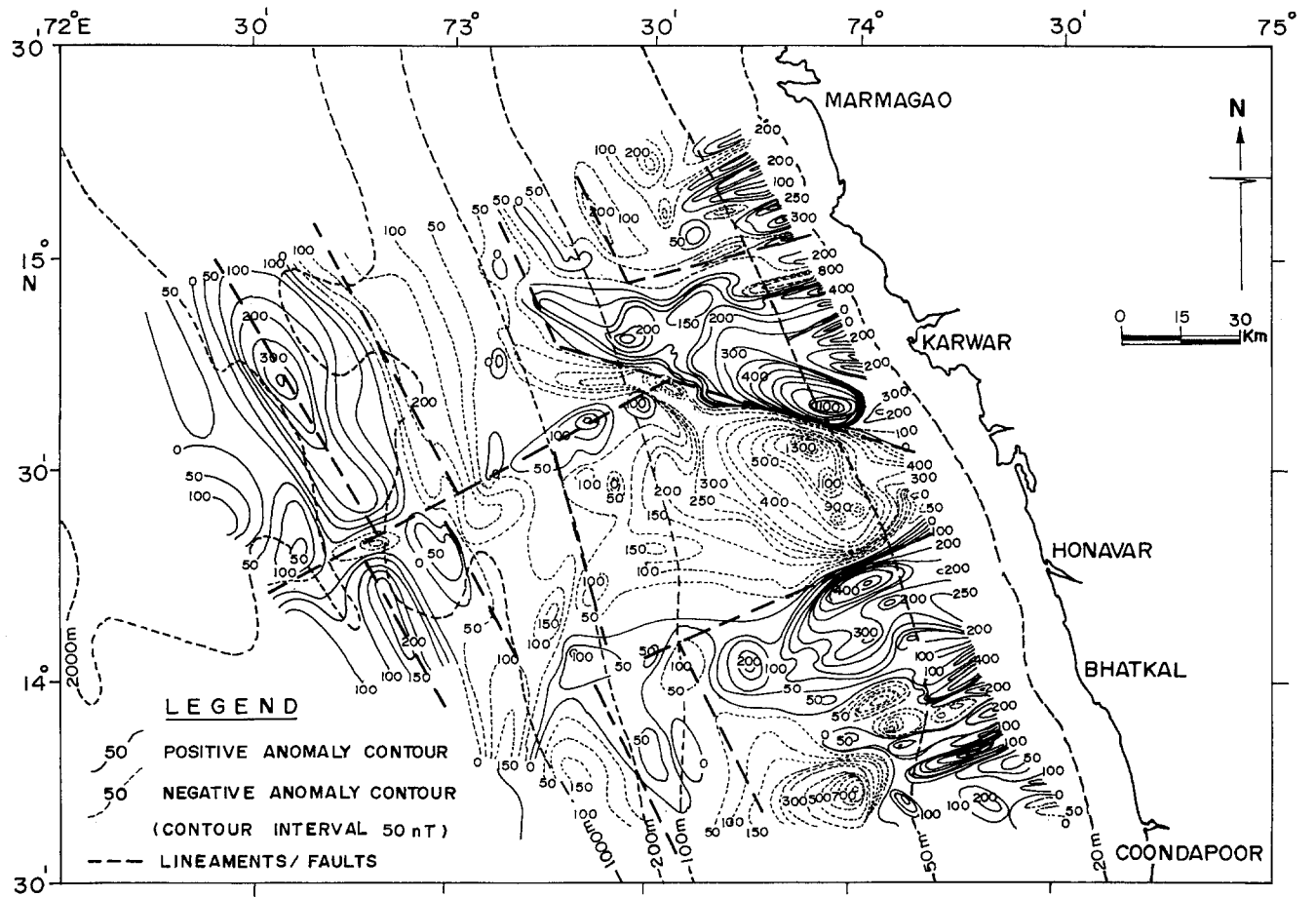
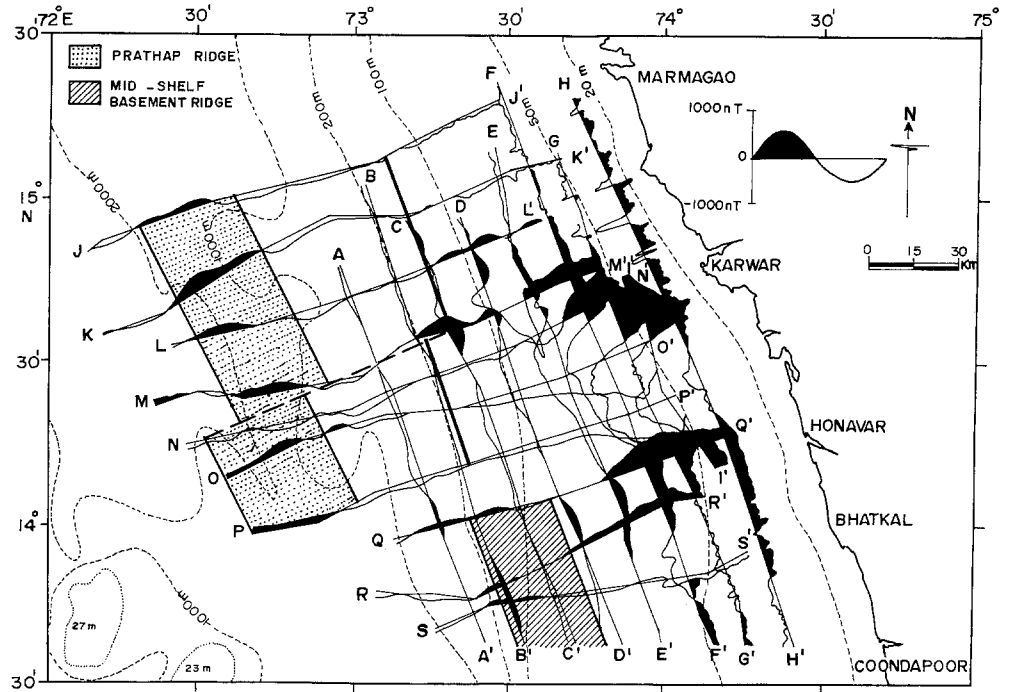
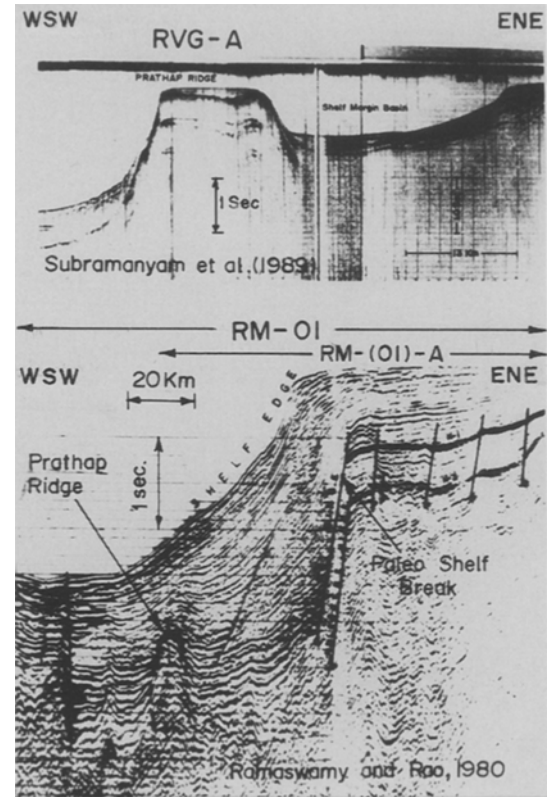
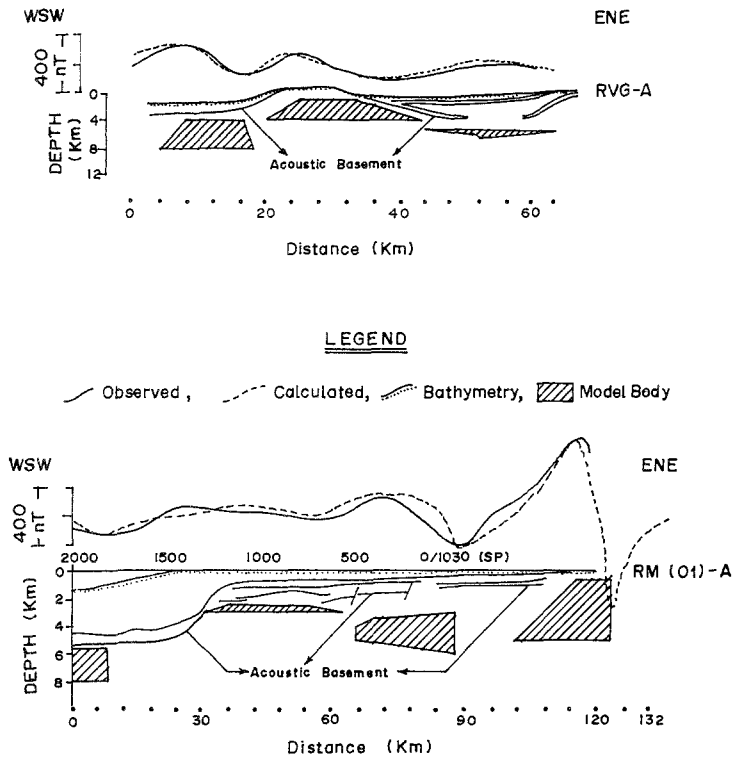


Fig. 6 Total magnetic intensity anomaly contour map. Thick dashed lines indicate structural lineaments/faults



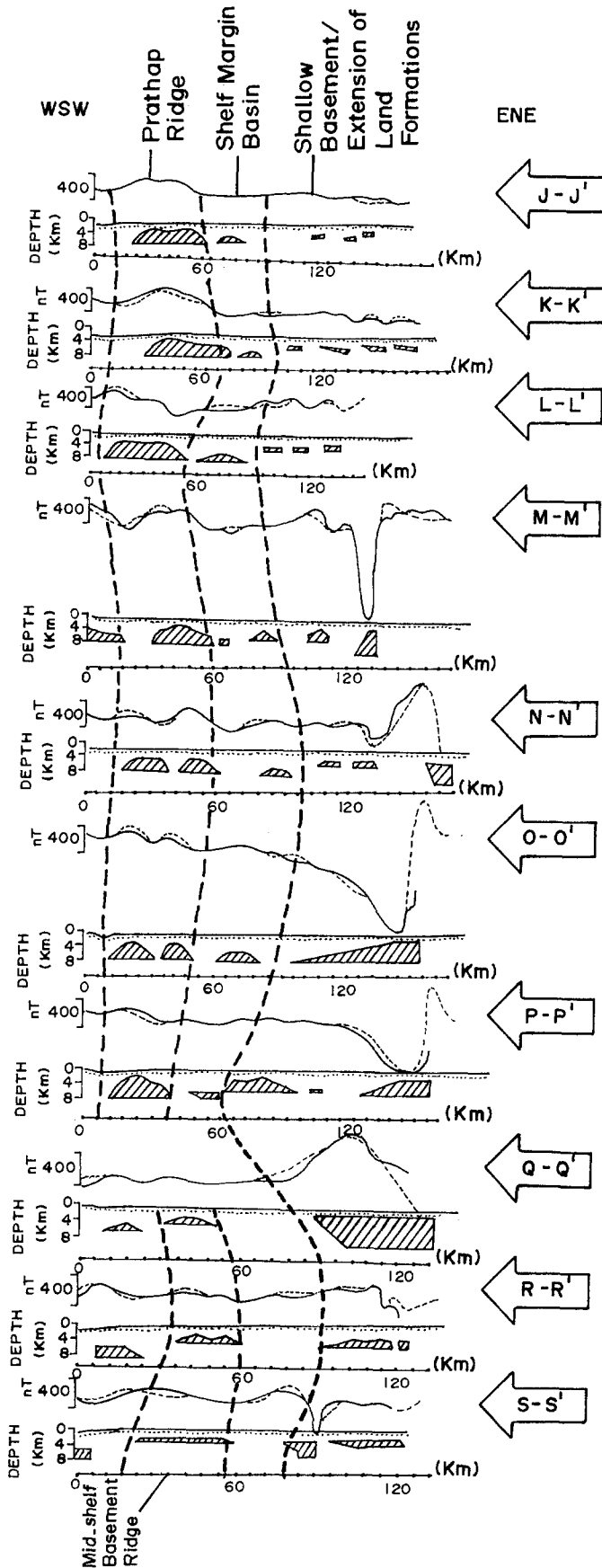
(Athavale 1970; Gopala Rao 1990) studies. Best-fit models were obtained with the remanent parameters $RI = \pm 60^\circ$, $RD = +100^\circ$, $+300^\circ$; and $RI = \pm 50^\circ$; $RD = +140^\circ$, $+320^\circ$ (Fig. 8). The studies indicate that the depth to the top of the magnetic basement from the mean sea level in the area of study varies between 0.5 and 6.0 km. Shallow sediment cover of about 0.5–1.5 km overlies the basement rocks near the coast, and a cover of 1.5–2.0 km is interpreted to overlie basement rocks on the shelf. Thick cover of about 4–5 km over the slope region (200- to 1000-m water depths) and shallow sediment cover of about 2.0 km beyond the slope (1000- to 2000-m water depths) are also interpreted to overlie basement rocks. The deep basement depth in the slope region confirms the existence of a sediment-filled shelf margin basin (about 4–5 km thick) trending parallel to the shelf edge. Shallow depths to the basement in the mid-shelf and beyond the slope regions confirm the presence of ridges parallel to the coast. The basement ridge inferred below the mid-shelf area may be the northward extension of the basement ridge reported by Subrahmanyam et al. (1993a).

The anomaly contour map (Fig. 6) also reveals the major structural lineament/fault trends in NNW-SSE, NW-SE, ENE-WSW, and WNW-ESE directions. The prominent high-amplitude anomalies of the inner mid-shelf show distinct trends indicating that the structures causing the anomalies are different (Fig. 6). The ENE-WSW trending anomalies of the inner mid-shelf off Bhatkal occur in an area where orthoamphibolites were dredged. Thus, these anomalies were interpreted as representing an orthoamphibolite body (Siddiquie et al. 1987). We suspect it likely that the positive anomaly closures adjoining the

Fig. 7 Seismic reflection records RVG-A (after Subrahmanyam et al. 1989) and RM-01 (after Ramaswamy and Rao 1980) showing the observed magnetic anomalies along these seismic traverses and the computed anomalies generated by the two-dimensional block models

prominent negative anomaly closure off the Honavar coast are also due to the presence of an orthoamphibolite body, and these positive anomalies were interpreted as being due to the basement rocks with the following remanent (reverse magnetization) parameters: RI ranging from $+60^\circ$ to $+50^\circ$ and RD ranging from $+100^\circ$ to $+140^\circ$. We interpret the high-amplitude negative anomalies off the Honavar coast as resulting from basement rocks with the following remanent (normal magnetization) parameters: RI ranging from -60° to -50° and RD from $+300^\circ$ to $+320^\circ$. The magnetic anomaly bodies constructed from modeling are located adjacent to each other, between 30- and 100-m water depths offshore Karwar and Honavar. These bodies probably formed at different magnetic polarity epochs. The deeper basement depth (2.0–2.5 km) observed to the normally magnetized material in these water depths between Karwar and Honavar, compared to the adjoining areas in the north and south, may suggest that the area is a paleograben, which was later filled with normally magnetized material.

The presence of basement ridge, as indicated by a positive magnetic anomaly, is located offshore north and south of Honavar but no ridge is seen off Honavar. However, the free-air gravity anomaly (Subrahmanyam et al. 1991) clearly indicates the presence of a ridge off Honavar. We specu-



late that the change in the magnetic signature of the ridge off Honavar may be due to the ridge being comprised of volcanic rocks extruded during a normal polarity period.

Krishna et al. (1992) advocate a hotspot origin for the Prathap Ridge to explain the observed variable magnetic signatures of the ridge. However, Subrahmanyam et al. (1989, 1991, 1993a,b) believe that the Prathap Ridge and the mid-shelf basement ridge were formed prior to the break-up of eastern Gondwanaland.

The anomaly profiles and the interpreted models reported in this paper are used to map the boundaries of the inferred major structural features: a mid-shelf basement ridge, a shelf margin basin, and the northward extension of the Prathap Ridge and their extent (Fig. 5). These features trend in a NNW-SSE direction parallel to the shelf edge (Fig. 9). Some of these structural features are seen sheared along the ENE-WSW direction. This sort of displacement along the preexisting faults appears to be influenced by the forces generated by the spreading axis of the Carlsberg Ridge. Detailed block movements of similar type on the western continental margin of India have been discussed by Subrahmanyam et al. (1993b).

Conclusions

1. The bathymetry is smooth to a water depth of 200 m and steeper to a depth of 1000 m. NNW-SSE trending isolated topographic features have been noted beyond 1000 m water depths.

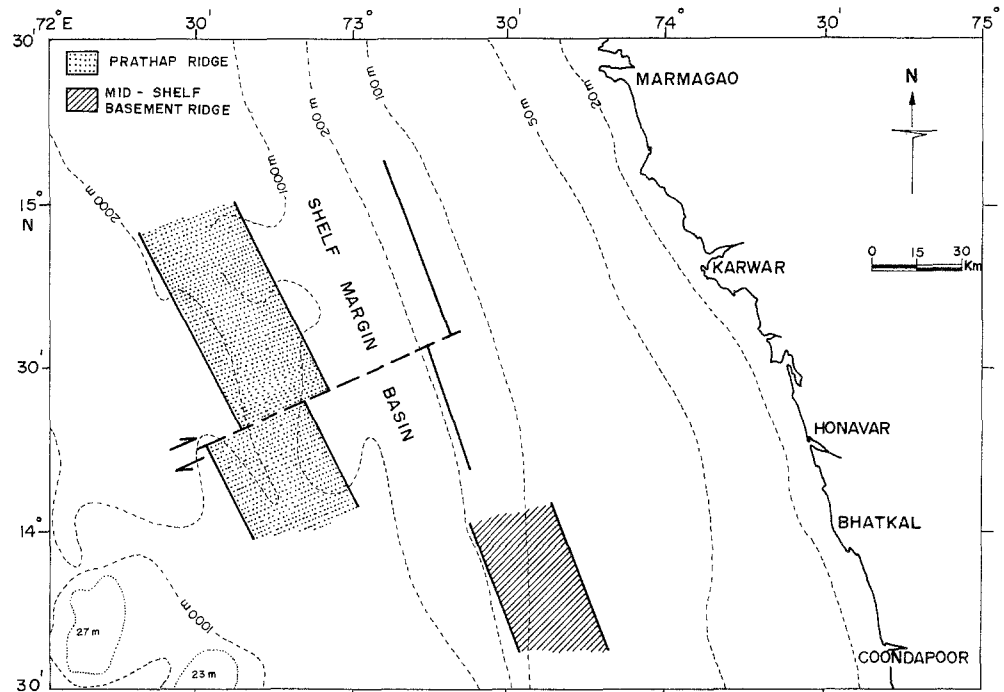
2. The magnetic anomalies in the study area trend NNW-SSE, NW-SE, ENE-WSW, and WNW-ESE.

3. From modeling of the magnetic anomalies, depth to the top of the basement from the mean sea level is interpreted to range from 0.5 to 6.0 km. Deeper depths to the top of the basement in the outer shelf area were interpreted from our modeling to represent a shelf margin basin trending parallel to the shelf edge. The shallow depths to the top of the basement in the mid-shelf and beyond the slope areas are interpreted to indicate the existence of the basement ridge and the northward extension of Prathap Ridge. Both of these features trend in a NNW-SSE direction, parallel to the shelf break.

4. The displacement of the major structural features along the preexisting ENE-WSW faults in the study area appears to be influenced by the forces generated by the spreading axis of the Carlsberg Ridge.

Fig. 8 Observed and calculated magnetic intensity anomalies (unstacked) across the southwestern continental margin of India. Computed anomaly profiles are generated by two-dimensional block models at the bottom of each transect. The following parameters were used for computing anomaly profiles: Induced: magnetization = 1.1 A/m, inclination = +12° to 15°, declination = -2.5°. Remanent: magnetization = 2.5 A/m, inclination = +50° to +60°, -50° to -60°; declination = +130° to +100°, +320° to +300°

Fig. 9 Inferred structural and tectonic features in the study area



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