

Analysis of Magnetic Anomalies in Relation to Placer Deposits and Basement Configuration off Mirya Bay, Central West Coast of India

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Abstract The offshore ilmenite placers off Konkan, central west coast of India, have been surveyed by echosounding, shallow seismic profiling, magnetics, and seabed sampling. The magnetic data show two different types of anomalies: (1) N-S trending high amplitude long wavelength anomalies (250–350 nT, 240–420 m) extending 3 km west of a line joining Mirya head with the Bhagavati Port and (2) low amplitude short wavelength anomalies (100–120 nT, 200–300 m) located to the east in Mirya bay. Magnetic modelling has been carried out for placer deposits, basement configuration, and basement relief. A first-order correlation between the short wavelength anomalies and the known heavy mineral concentrations is discernible; however, basement relief and/or intrabasement magnetization contrasts may also affect this. The high amplitude long wavelength anomalies may be due to dykes within the traps. The quantitative interpretation of the dyke anomalies indicates the magnetization contrast at depths of 50 and 100 m, respectively. The width varies from 150 to 200 m. The subbottom topography of the magnetic basement is shallow toward the coast and dips toward the inner shelf.

Keywords Offshore placer deposits, low amplitude short wavelength anomalies, modelling, basement relief.

Introduction

As a part of the program of the National Institute of Oceanography for "Exploration for offshore ilmenite placers of the Konkan, Central west coast of India," detailed surveys were carried out during 1976–80 along the inner shelf. These included echosounding (Atlas Deso 10), side scan sonar (EG&G), shallow seismics (Huntec boomer and EG & G sparker), and magnetics (Barringer oceanographic magnetometer) followed by seabed sampling at a close spacing.

The occurrence of onshore placers (ilmenite and magnetite) has been reported for about 200 km along the Konkan, central west coast of India (Figure 1). However, the extension of these placers offshore has not been studied in detail. Beiersdorf et al. (1980) showed that by a combination of extensive geophysical surveys and seabed sampling, it is possible to map and estimate the resources of offshore placer deposits. Using this approach, they discovered a large heavy mineral placer deposit off the Zambezi delta. However, in their investigations, analysis of the magnetic field did not provide significant clues to the exploration of placer deposits. Lericolais et al. (1987) discovered tin deposits in Bangka, Indonesia using

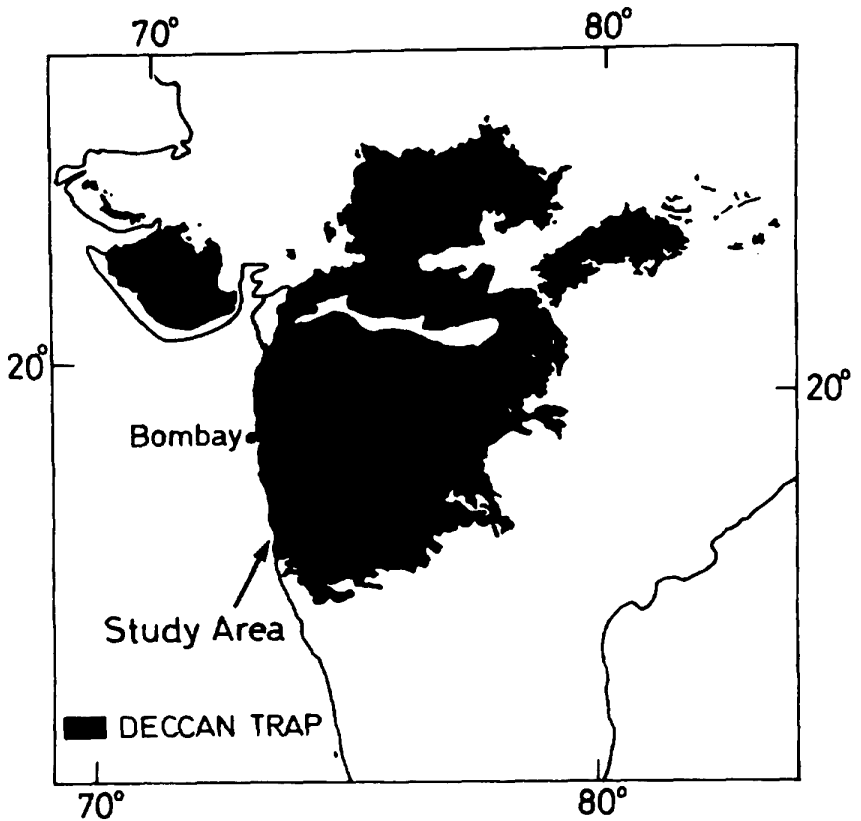


Figure 1. Extent of Deccan traps in India.

high resolution seismic and magnetic exploration. They presented a general model of the rock formations where magnetic anomalies with 20 to 100 nT were related to the tin concentrations.

The preliminary results of the studies by Siddiquie et al. (1979) indicate that the ilmenite placers off Konkan extend offshore to a water depth of about 10 to 13 m in Kalbadevi, Mirya, and Ratnagiri bays (Figure 2). They estimated the probable reserves to 1 m thickness at about 2 million tons. The field investigations during 1980 led to the preparation of isonanotesla maps for different bays of the Konkan coast (Ramana 1980). These maps depict various significant anomalies, including the offshore extension of topographic and structural trends observed in landsat images (Das and Ray 1977). Several short wavelength magnetic closures were observed in many bays. Because the placers usually contain a high concentration of magnetic minerals, it would be of considerable interest to evaluate the effects of these placers on the magnetic field. This in turn would also lead to an evaluation of the techniques for exploration. The problem is whether some of the observed short wavelength anomalies can be attributed to heavy mineral con-

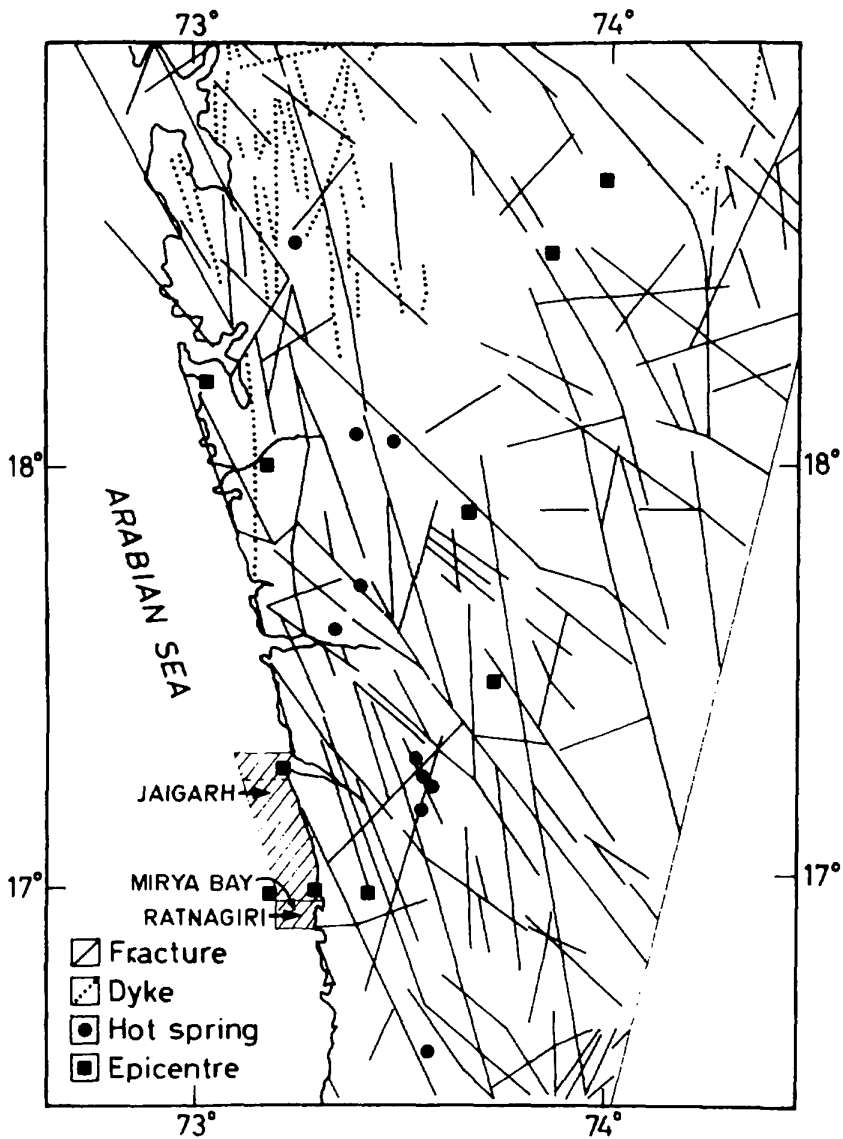


Figure 2. Map of the Konkan coast with dykes and fractures from landsat images mapped by Das and Ray (1977). The study area is shown by hatching and also the area to the north, i.e., Jaigarh. Results from Jaigarh inner shelf will be presented as a separate study (Ramana, in preparation).

centrations, or whether they reflect magnetic inhomogeneities or relief in the underlying basement. This paper analyzes the results of the surveys carried out in the Mirya bay. An accompanying study deals with the Jaigarh, Varvada, and Ambwah bays to the north (Ramana, in preparation) (Figure 2).

Geology

The coastal region to the east of the study area is largely covered by Deccan flood basalts and to the south by igneous and metamorphic rocks of Precambrian age (500–3500 my). The major structural trend of the Precambrian (Dharwar formation) is NNW-SSE to N-S (Radhakrishna 1983). The Deccan volcanic episode is one of the most important events in the geological history of the Indian shield after the fragmentation of Gondwanaland. The eruption of the Deccan traps started some time in the late Cretaceous and continued up to the early Eocene (Wadia 1961). The eruption took place in two phases, at about 65–60 and 45–42 my (Rama 1964; Wellman and McElhinny 1970; Wensink 1973). About 600,000 sq km of the Indian shield is at present covered by the traps (Figure 1), and the traps are reported to extend offshore (Raju et al. 1971; Sahay 1978). The Deccan traps show a remarkable uniformity in both megascopic character and mineral composition. In the majority of the specimens, irregular grains of magnetite are common. The presence of leucoxene shows that the Deccan traps are titaniferous and also contain ilmenite (Pascoe 1964). The evidence for fissure eruption comes from the dykes located in central and western India. Dykes of larger dimensions (100–150 m) are reported from a number of locations, including the northern Konkan (Auden 1949). The offshore placer deposits, which are extensions of onshore deposits, indicate the general assemblage of olivine, pyroxene, chlorite, composite grains of zoisite, spidote, apatite, rutile, and brown hornblende whose genetic link is established with Deccan traps.

The Deccan trap region has also been subjected to severe faulting along the west coast of India (Krishnan 1968). The occurrence of faults and structural lineaments has been interpreted from the linear alignment of hot springs and earthquake epicenters along the west coast (Wadia 1961; Das and Ray 1977).

Marine Data

A fishing trawler was fitted with the scientific equipment for surveys, and the vessel navigated at 3 to 4 knots. The locations of survey tracks were fixed by sextant angles from onshore objects (± 15 m accuracy). A dual frequency Atlas Deso 10 echosounder was used for bathymetry; the echosounder was calibrated daily, and a bathymetric map at a contour interval of 1 m has been drawn (Figure 3). The marine magnetic data were collected with a Barringer Oceanographic Proton Precession magnetometer. The sensor was towed approximately 20 to 30 m behind the vessel to avoid the magnetic effect of the vessel. Total magnetic intensity values were recorded every 12 seconds, or at approximately every 25 m along the profiles. The raw data have been corrected to the IGRF 1980.1 epoch and for diurnal variations. The magnetic profiles were then plotted along the tracks (Figure 4), and a residual magnetic anomaly map was prepared at a variable contour interval (Figure 5). High resolution shallow seismic sparker profiling has been

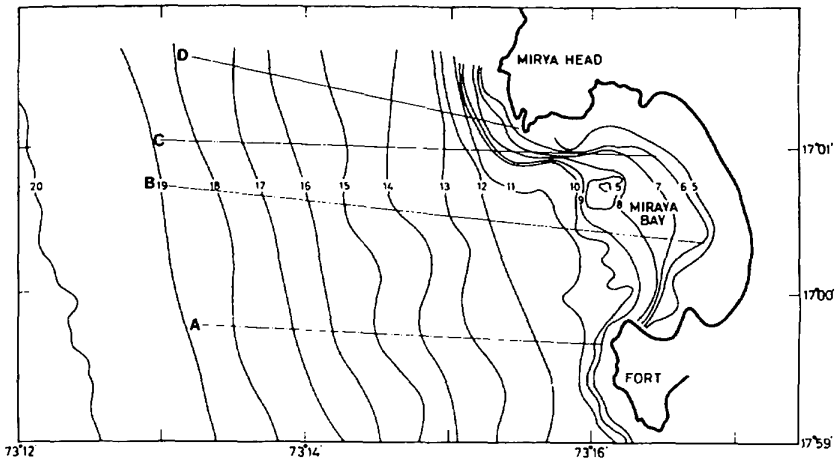


Figure 3. Bathymetry of the study area, contoured at 1m interval. A, B, C, and D are the cruise tracks.

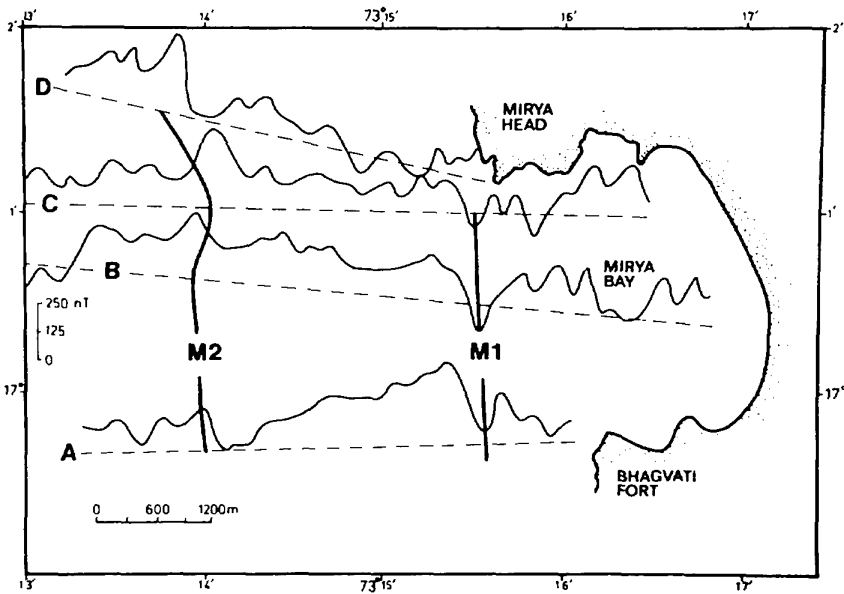


Figure 4. Total magnetic residual anomalies plotted perpendicular to the survey tracks. Thick lines M1 and M2 represent the subsurface dykes.

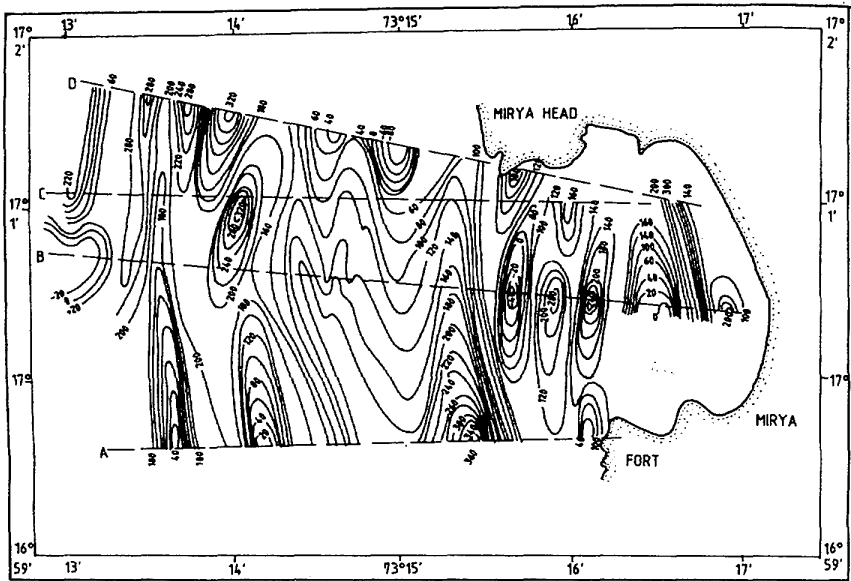


Figure 5. Residual magnetic intensity map prepared at variable contour interval.

carried out (200 joules energy) along two tracks. One of the interpreted seismic section along profile B is shown in Figure 6.

Results and Discussion

Anomaly Trends

The magnetic anomalies in the study area generally trend N-S (Figure 4) and are grouped into (1) high amplitude long wavelength anomalies (250–350 nT, 240–420

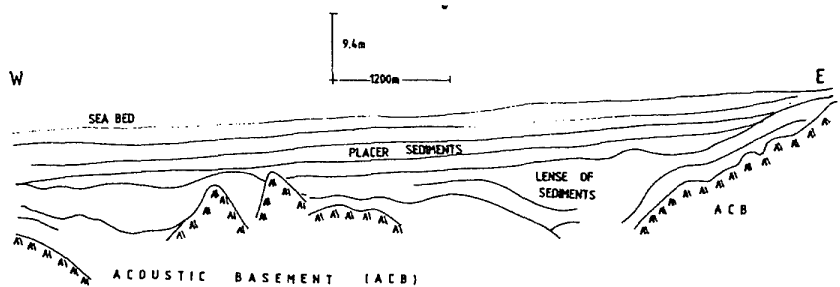


Figure 6. Interpreted seismic section of 200 joules sparker record showing different sediment layers above acoustic basement (Deccan traps).

Table 1
Results of Onshore Lineament Analysis

Lineament Types	Aerial	Gravity	Fractures	Dykes	Magnetics (offshore)
Dominant trends	N175E	N165E	N175E	N175E	N165-175E
	N130E	N146E N25E	N145E	N25E	N15E
Other trends			N26E	N55E	N35E
			N65E	N55E	
	N85E			N85E	N75E
	N105E N155E	N115E			N100-130E N160-165E

Source of data: Das and Ray (1977), Ramana (1986)

m) M1, M2 and (2) low amplitude short wavelength anomalies (100–120 nT, 200–300 m). The trend of the magnetic anomalies over the Deccan trap terrain are N-S, NE-SW, NNW-SSE and NW-SE and E-W (Negi and Agrawal 1983; Rao 1984). Based on the landsat images, Das and Ray (1977) presented a lineament map of the West Coast of India. It is clear from Figure 4 that the observed offshore trends of the magnetic anomalies are similar to the onshore structural trends of the Dharwar and Deccan traps. The high amplitude and long wavelength anomalies M1 and M2 off Mirya bay trend north to south and are separated by about 3 km (Figure 4). The anomalies are conspicuous in all the profiles and strike approximately N-S; it is therefore assumed that these anomalies are generated by buried dykes, as Ramana (1986) indicated from the trend analysis (Table 1) a general N-S orientation for the dykes.

Two-dimensional model studies were carried out using Talwani and Heirtzler's (1964) method. Figure 7 depicts a close fit between the computed and the observed anomalies. The body parameters were also computed (Table 2) using Koulomzine et al.'s (1970) method for comparison. The four profiles A, B, C, and D were subjected for harmonic analyses for obtaining the average depth (Table 4, Figure 8) to the top surface of the magnetic basement using the algorithms given by Green (1972) and Dahl (1982). In all cases, the depth to the top of the basement varies from 50 m to 100 m indicating the dip toward offshore.

Table 2
Causative Body Parameters Determined by Using Koulomzine's (1970) Method

Anomaly/ Tract	Q Deg	Depth To		Anomaly/ Tract	Q Deg	Depth To	
		Top Of Dyke	Width			Top Of Dyke	Width
M1 A	60	50 m	160 m	M2 A	54	108 m	230 m
M1 B	50	52 m	130 m	M2 B	45	102 m	170 m
M1 C	60	47 m	170 m	M2 C	60	98 m	160 m
				M2 D	45	100 m	210 m

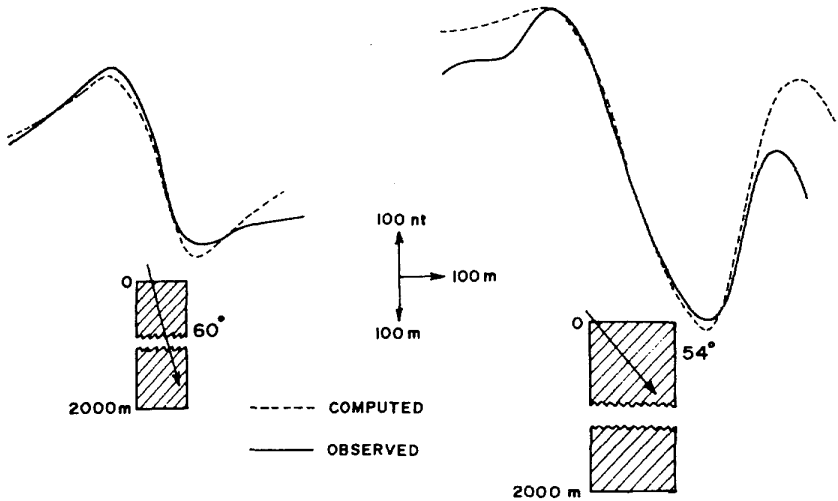


Figure 7. Observed and computed magnetic anomaly over dyke in the study area.

Susceptibility

The susceptibility measurements of Deccan basalts (Verma and Pullaiah 1971; Negi and Agrawal 1978) indicate a large variability. In the present studies, an average magnetic intensity of 2.68 Am^{-1} and remanent declination of 130° and inclination of 50° were used for generating the magnetic models from their studies.

The physical properties of the sediment samples determined by Ramana (1985)

Table 3
Magnetic Susceptibility of Placer Sediments

Source	Sample	Values Measured At 1.0 Oe, $\text{K} \times 10^{-3}$	Average
Ramana (1985)	K155	1.896	1.44
	K89	2.041	
	K133	0.776	
	K42	2.148	
	K40	1.811	
	K14	0.283	
	K138	0.075	
	K11	1.291	
	K60	2.534	
	K37	1.794	
	K149	1.146	
	J119	3.366	
	A80	0.677	
V31	1.488		

Table 4
Average Magnetic Basement Depths from Spectral Analysis

Profile	Average Depth To Basement
A	45 m
B	51 m
C	48 m
D	49 m

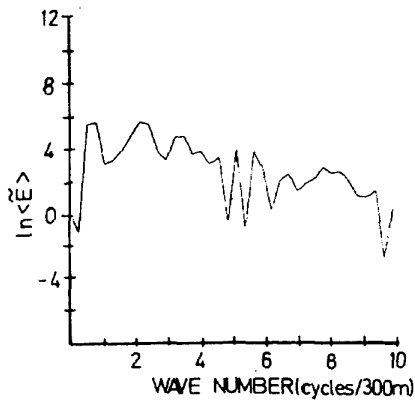
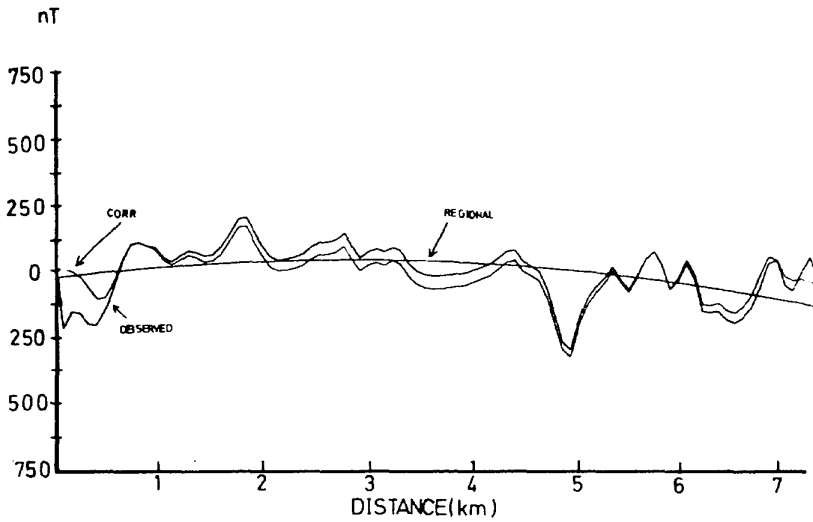


Figure 8. Observed, computed regional and corrected magnetic anomaly along profile B (top) and its computed power spectrum (bottom).

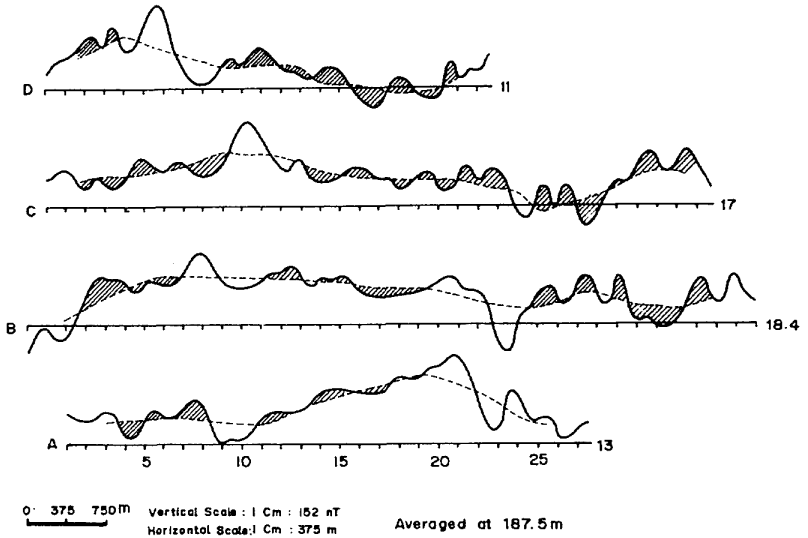


Figure 9. Magnetic anomaly profiles A, B, C, and D subjected to short wavelength filtering. Dashed line perhaps indicates the magnetic signature over the Deccan trap terrain.

from the Jaigarh and Kalbadevi bays situated north of the study area (Figure 2) indicate that the susceptibilities range from 0.75 to 3 Am^{-1} (Table 3). This wide range indicates the heterogeneity of the sediments, particularly of ferrimagnetic minerals such as magnetite. Hence, an average magnetization contrast of 1.44 Am^{-1} (Table 3) was used for computing the anomalies due to the placer bodies.

Modelling

Magnetite is the principal constituent of the minerals in the placers, and Mirya bay represents up to 48 percent (magnetite, augite, diopside, and hornblende) with other heavy minerals. The placer bodies are modelled as thin plates, which are uniformly magnetized by induction. Based on this assumption, an attempt has been made to understand the relationship between the magnetic signatures and the known magnetic heavy mineral concentrations.

In Mirya bay (Figure 4), landward anomaly M1, the magnetic field revealed

Figure 10. Models of simple placer configurations. The thick curve represents the second observed positive anomaly east of M1 in profile. The thinner curve is the computed anomaly.

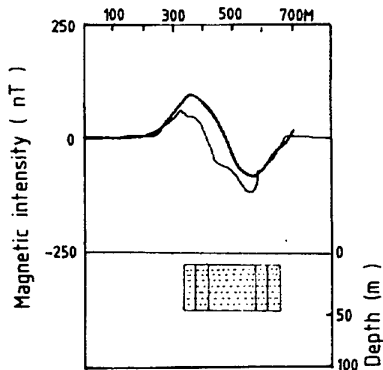
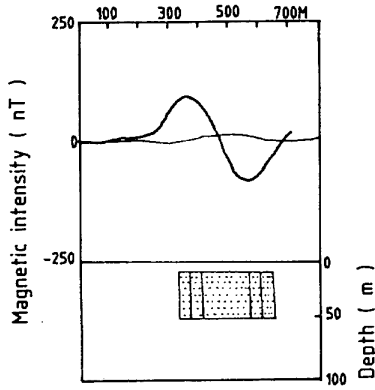
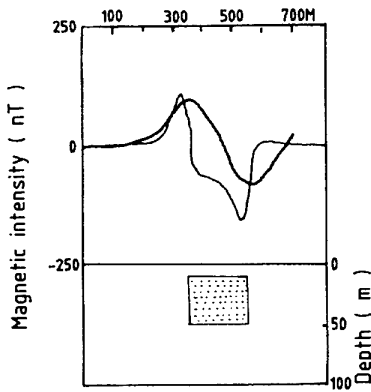
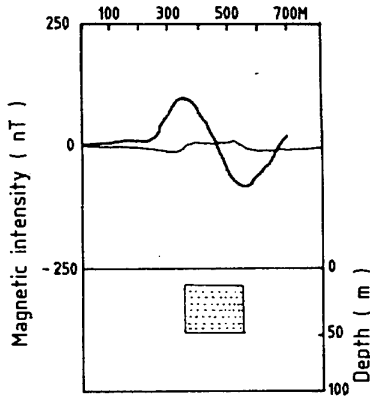
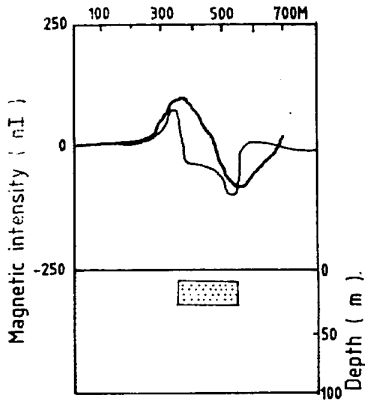
Model parameters:




a and b: Magnetization contrast 1.44 Am^{-1} , profile azimuth 90° . Strike of the body N-S.

c: Magnetization contrast 1.44 Am^{-1} , profile azimuth 0° strike E-W.

d and e: Magnetization contrast 1.44 Am^{-1} for the central body with a 50 percent reduction for outer bodies.

Profile azimuths: 90° (d) and 0° (e). Strike of the body N-S and E-W respectively.



-  Placer body of simple geometry
-  Observed anomaly
-  Computed anomaly

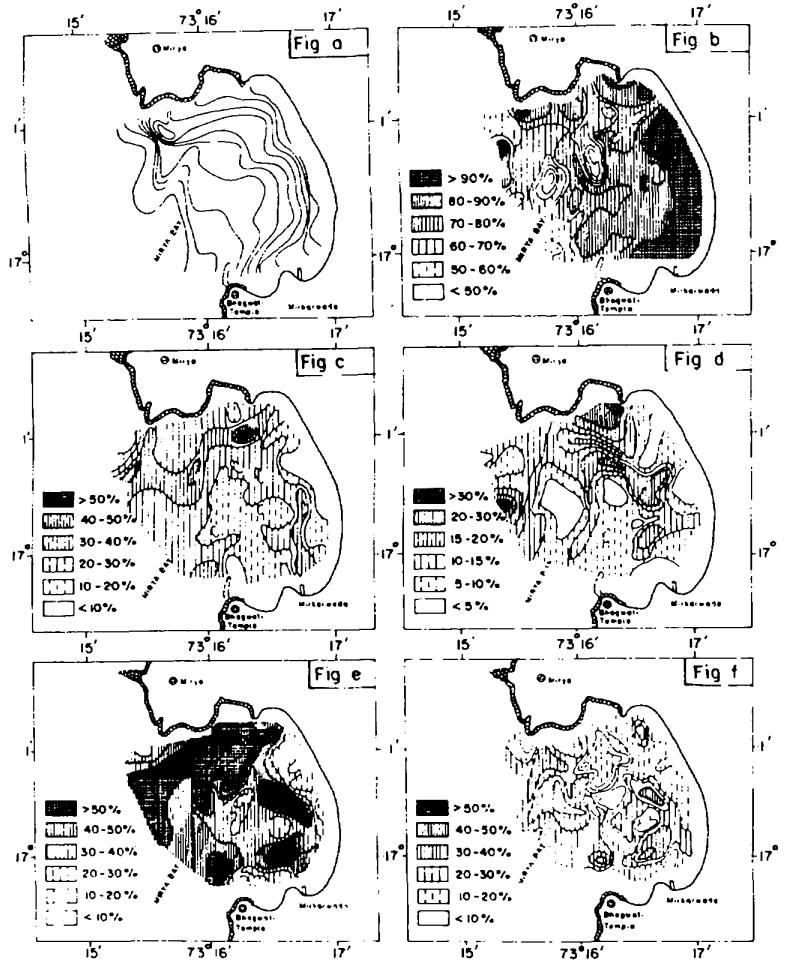


Figure 11. Results from the sampling of the bottom sediments in Mirya bay (after Siddiquie et al. 1979).

low amplitude short wavelength anomalies, whereas the amplitudes of the anomalies are relatively subdued seaward of M2. This may be due to the burial of the placer sediments. These short wavelength anomalies appear to reflect the heavy mineral concentrations within the sediments and are superposed over the regional magnetic field. To study the response of magnetic field over the Deccan trap terrain, the four magnetic profiles A, B, C, and D were subjected to filtering using the average width of the short wavelength anomalies which appear to superpose over the regional field. Figure 9 shows the effect of such filtering where the dashed line represents the regional field.

The model studies for simple geometry of the placers (Figure 10) indicated

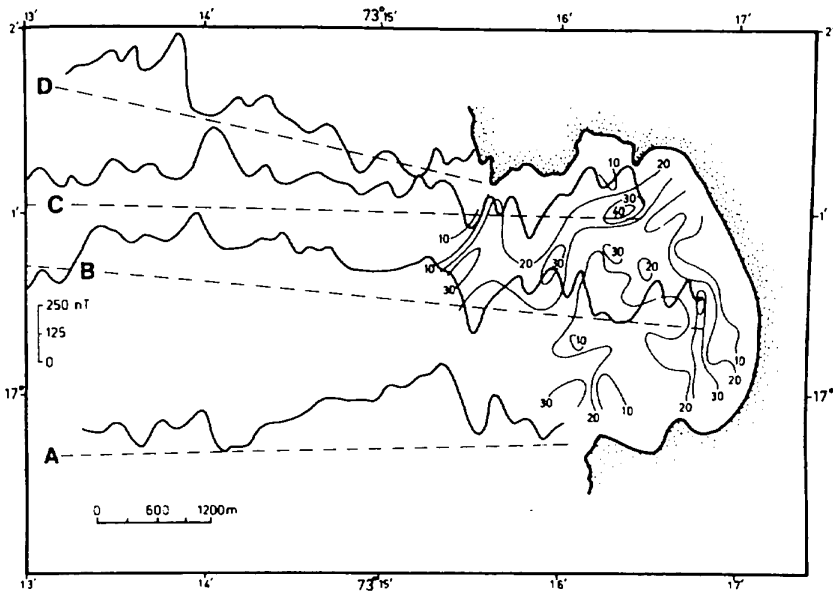


Figure 12. Magnetic anomalies plotted perpendicular to the survey tracks and the contours showing the percentage of magnetite heavy mineral content in the bay sediments.

that the short wavelength anomalies generated were similar in character to the observed anomalies on the four profiles. The imprint of the long wavelength anomalies indicates deeper origin, which is attributed to the subsurface dykes. Hence, it may be stated that if the study area is devoid of placer deposits or subsurface structural features (such as dykes in the present case), the magnetic field may be smoother, as shown in Figure 9, after filtering, suggesting that it may be possible to differentiate the anomalies that are generated by the placer deposits and the magnetized basement. A detail study of this approach is in preparation (Ramana).

The composition of the bottom sediment (Figure 11) based on Siddiquie et al. (1979) indicates that the heavy mineral-rich sands are concentrated in the bay. The distribution of heavy magnetic minerals was superposed on the magnetic anomaly map (Figures 12 and 13). A first-order correlation between the high content of magnetic heavy minerals and the longer wavelength component of the magnetic anomalies was observed (Figure 13). The changes in the individual short wavelength anomalies could be due to the different concentrations of heavy mineral assemblages in the sedimentary layers.

There may be lateral as well as vertical variations in the concentration of the magnetic minerals; hence, surface sampling may not reveal the composite magnetic effect of buried placers. However, the observed apparent correlation is quite interesting for exploration. In order to explore this relationship further, model studies were carried out using the method of Talwani and Heirtzler (1964), assuming induced magnetization for placers sediments. The basic assumptions of

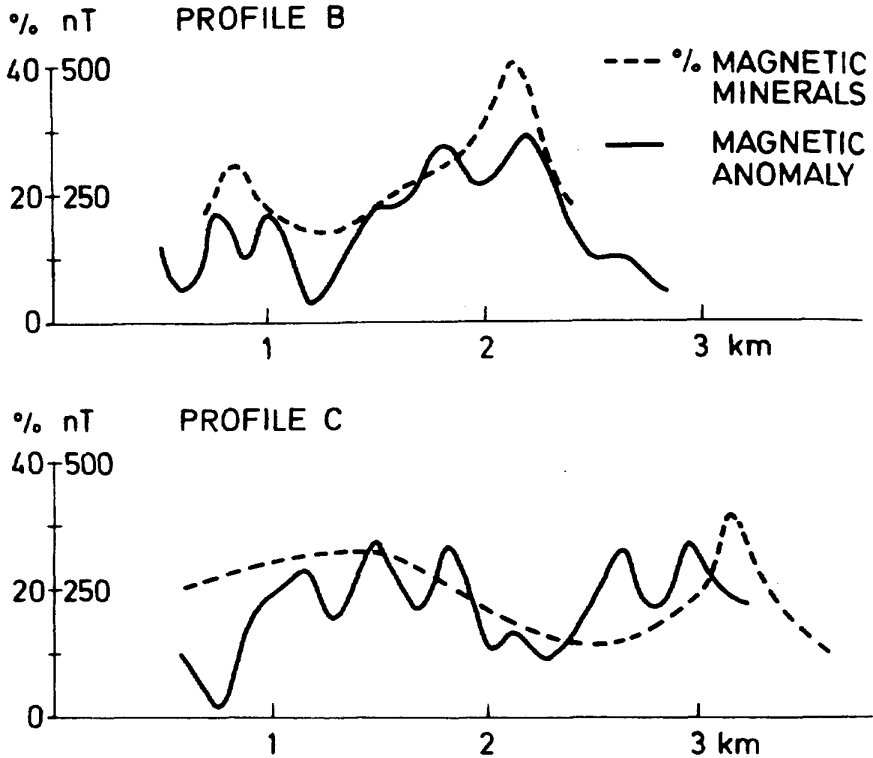


Figure 13. Percentage of magnetic heavy minerals plotted along profiles B and C in the Mirya bay.

present investigations are: (1) occurrence of heavy mineral sand lenses within the sediments; (2) an horizontal basement with uniform magnetization; and (3) magnetization contrast between the sediments and the basement. The models are based on volume concentration of the sediments (Siddiquie et al. 1979) and apparent thickness of the sediment column from the interpreted seismic section (Figure 6).

The visual inspection of the magnetic anomalies in the study area indicates that the width of the short wavelength anomalies are about 200 m. Keeping this width as an optimum body width and considering the average susceptibility of the sediments from Table 1, the theoretical magnetic anomalies have been computed for different geometries of the placer body to generate the desired amplitude of the anomaly (100 to 120 nT). The computations have been repeated for different dimensions with varying susceptibilities and generated anomalies similar to those observed for different profile azimuths. Figure 10 depicts such an example. The upper models represent single bodies, whereas the lower ones have been constructed by decreasing the susceptibility near the edge of the placer body. These bodies yield amplitudes of only 20 to 50 nT for varying thicknesses. This is due

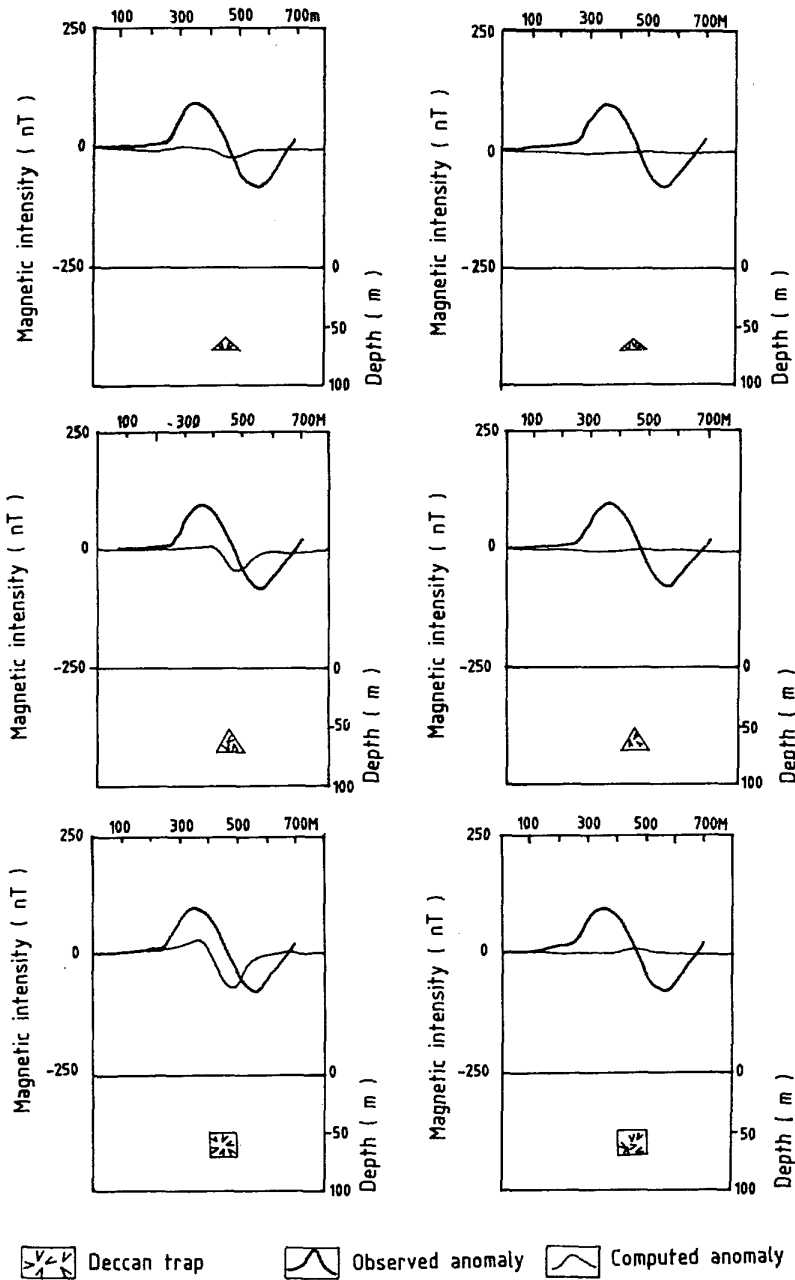


Figure 14. Models showing the magnetic effect of basement relief for various models striking E-W (right-hand side) and N-S (left-hand side). Magnetization contrast of 2.68 Am^{-1} has been used for model studies. The observed anomaly in Figure 11 is included for reference (thick line). These models were computed for an inclination of 20° and declination of -2°W .

to the direction of induced magnetization vector which strikes about -2°W with a shallow inclination of about 20° . However, the placer bodies striking north-south generated the anomalies similar to those observed (Figure 10).

It is also possible that some of the very low amplitude short wavelength anomalies are caused by relief within the basement. To explore such effects, relief models were constructed in the manner of Talwani and Heirtzler (1964) with simple geometric configurations which could be assumed to represent basement ridges (Figure 14). It is obvious from the models that amplitudes generated by features of this kind may have a maximum peak-to-peak value of about 50 nT. Thus it appears that the very low amplitude (less than 50 nT) anomalies observed in the study area may have originated from reliefs within the basement. Particularly, east-west trending ridge-like features may not produce any appreciable anomalies at all.

Conclusions

The magnetic anomalies in Mirya bay generally trend N-S and are similar to and apparently are a manifestation of the extension of the Dharwar (Precambrian) and Deccan trap (Cretaceous-Eocene) onshore trends. Two distinct types of anomalies are identified: (1) high amplitude long wavelength anomalies (250–350 nT, 240–420 m and (2) low amplitude short wavelength anomalies (100–1220 nT, 200–300 m).

Spectral analysis and quantitative interpretation indicated that the average depth to the magnetic basement occurs 50 m near shore and 100 m offshore and that the basement is the extension of onshore Deccan basalts. The high amplitude anomalies might have originated from the subsurface dykes within the traps. The short wavelength anomalies along the profiles are attributed to the heavy mineral placer bodies over the magnetic basement. Basement relief models responded with low amplitudes.

The studies further show a first order correlation between the magnetite concentrations and short wavelength magnetic anomalies.

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