

Geophysical studies for the evaluation of offshore placer deposits and basement configuration

M.V. RAMANA, T.K.S. PRAKASA RAO¹ and K. SRINIVAS

National Institute of Oceanography, Dona Paula, Goa - 403 004, India
¹Geophysics Department, Andhra University, Waltair, India.

Abstract – The marine geophysical studies carried out on the inner continental shelf of the central west coast of India suggested the offshore extension of onshore placer deposits upto 12 m water depths, and beyond these depths sands are overlain by recent soft clays in further offshore regions. The total magnetic anomaly map reveals smooth and broad wavelength anomalies. Over riding them are a) high frequency short wavelength and low amplitude anomalies, b) short wavelength and large amplitude anomalies and c) medium to long wavelength and large amplitude anomalies. Besides, the anomaly map is characterised by N-S, NW-SE and WNW-ESE trending magnetic lineaments. The presence of high frequency and short wavelength magnetic anomalies is due to the occurrence of different Fe-Ti oxide assemblages. A reasonably good correlation between magnetic anomalies and the percentage of magnetite was established. Model studies confirmed the considerable placer sediment thicknesses and helped in evaluation of placer deposits besides in deducing the geological basement configuration. The spatial distribution of structural features appears to control the placer deposits in the offshore region.

INTRODUCTION

CRONAN (1980), MACDONALD (1983) and others described the placer sands as detrital minerals deposited in subaqueous environment and undergo sorting and grading continuously through waves and currents. The placer minerals have higher specific gravity, because of this property they are not transported over long distances and always found in the river beds, beaches and nearshore areas and on preexisting coastline on the innershelf (EMERY and NOAKES, 1968). Previous works have reported the presence of Heavy mineral placers popularly known as black sands occurring at various places along the coasts of India (TIPPER, 1914; BROWN and DEY, 1955; JACOB, 1956; MAHADEVAN and SRIRAMADAS, 1954, OFFICERS OF GSI, 1949, KRISHNAN and ROY, 1945 and SIDDIQUIE *et al.*, 1979, 1982). The Konkan coast, comprising of about 13 bays, lies on the west coast of India between Vijaydurgh (in the south) to Jaigad (in the north) and the study area falls within this limits (bays including Varavada, Ambwah and Jaigad) which have been earlier surveyed (SIDDIQUIE *et al.* 1982) for offshore extension of placer deposits. Magnetite is the most abundant among the naturally occurring magnetic minerals in these bays. The prepared magnetic map provides an evidence on the spatial distribution of magnetically susceptible magnetic minerals and intensity of magnetization of the underlying rocks which in turn depends on the distribution of magnetic minerals either. The amount of magnetite present in the placer sands is mainly dependant on the source rocks, and the magnetite content in the source rocks is controlled by different geological processes under which the source rocks are formed. The magnetite content in turn impart a pattern to magnetic map. SCHWARZ and WRIGHT (1989) had shown that relatively small thin horizontally elongated volumes with a slight higher magnetite contents can be detected effectively with the help of magnetic investigations. The present paper deals with the mapping of geophysical anomalies and inferring their significance in evaluation of placer deposits and deciphering the nature and basement configuration.

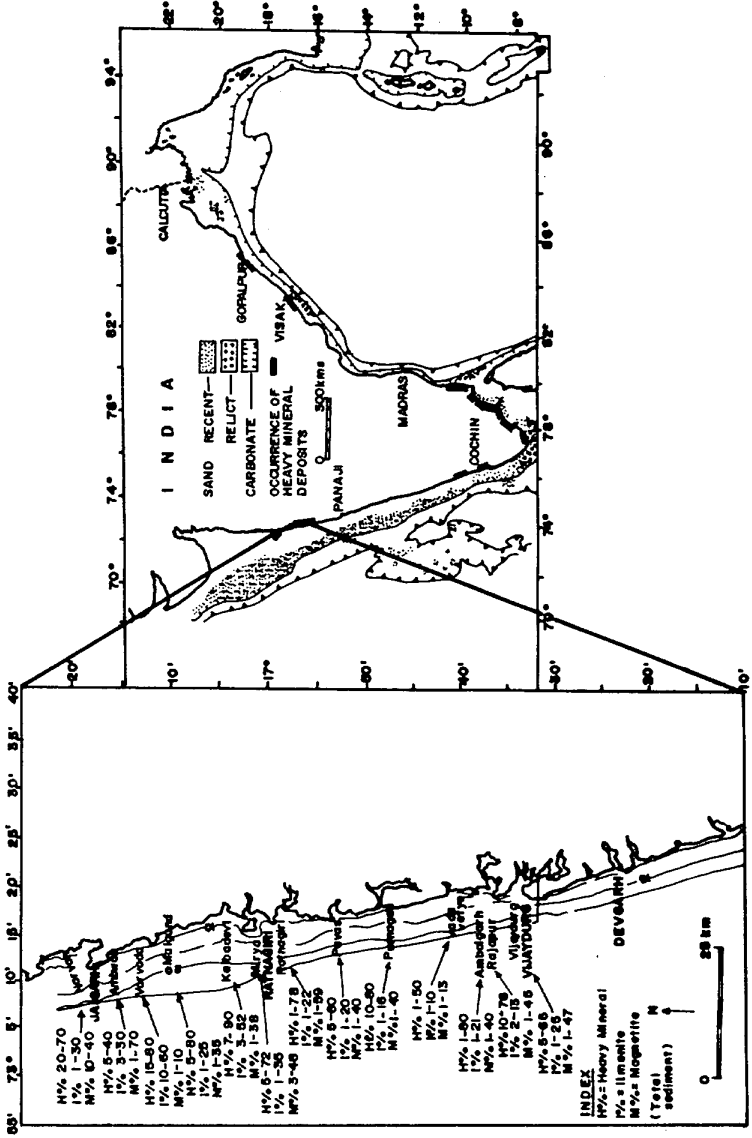


Fig. 1. Map showing the distribution of heavy mineral placer sands along the coast of India (Study area shown in the box).

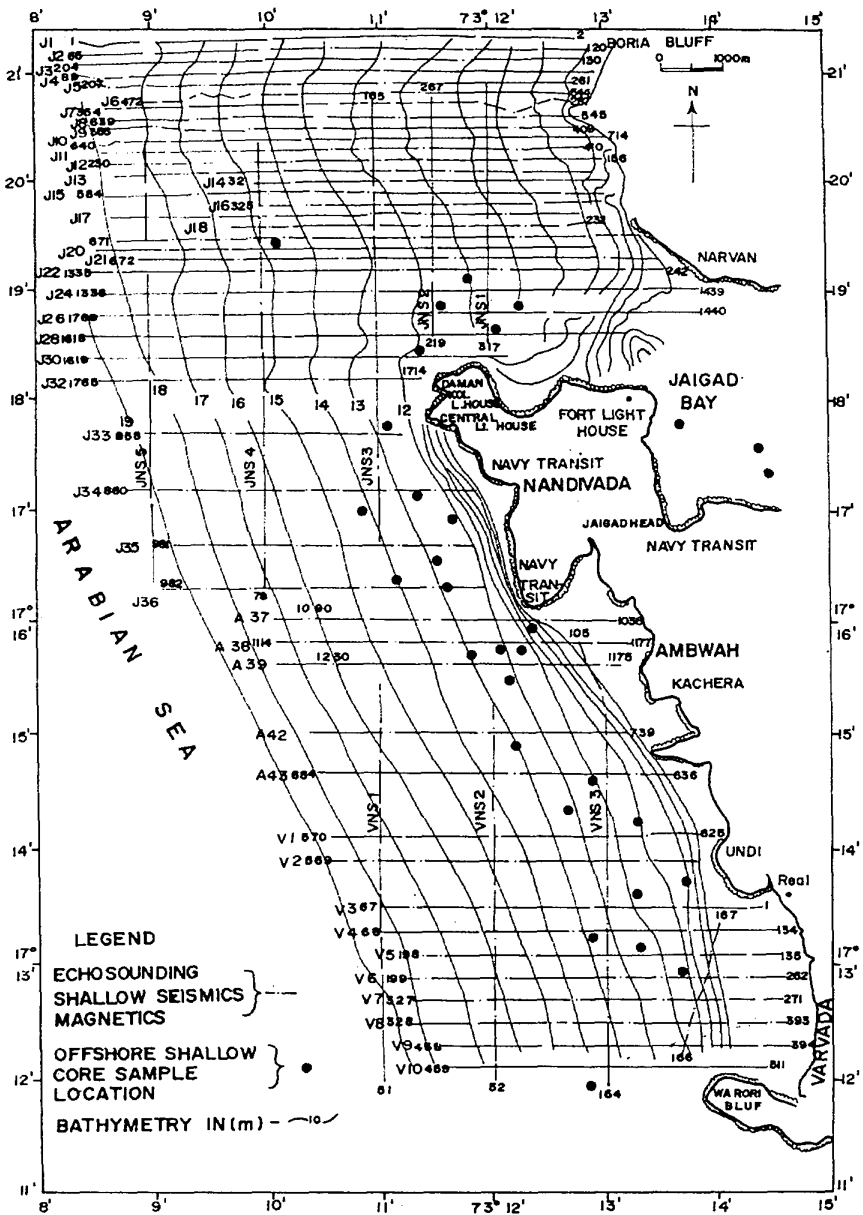


Fig.2. Track chart showing the layout and corrected bathymetry (contour interval 1 m).

GEOLOGICAL FRAMEWORK

The hinterland (adjacent to study area) geology comprises of thickly piled Deccan flood basalt flows or Deccan Traps (Upper Cretaceous to lower Eocene). The coast in this area marked by arcuate bays with rock promontories and cliffs of Deccan Traps (SIDDIQUE *et al.*, 1979). The most conspicuous structural deformations documented over the Deccan Trap covered areas are fractures, dykes, alignment of hot springs and earthquake epicentres (DAS and RAY, 1976, 1977; RAY, 1977). Majority of dykes mapped in the western India trend NNW-SSE, N-S, NE-SW and NNE-SSW directions (AUDEN, 1949). RAMANA (1986) reported several offshore lineaments from magnetic studies off Jaigad, Ambwah, Varavada and Mirya bays whose trends and their genetic links are similar to those of onshore lineaments. GLENNIE (1932) on the basis of geophysical studies, postulated the upwarping of crust along the West Coast of India assisted largely by the existence of faults.

DATA ACQUISITION

The geophysical surveys were carried out using a 44 feet long fishing trawler fitted with various marine geophysical instruments. Motorola Miniranger MRS III has been deployed for obtaining the positions and the system has an accuracy of ± 3 m. A dual frequency Atlas Deso 10 echosounder was used for obtaining the continuous depth to seabed. The bathymetric map at 1 m contour interval was prepared (Fig.2) for the study purpose. An EG & G Spark array (200-300 joules) was used for collecting shallow seismic reflection data. Total magnetic intensity measurements were carried out using Proton Precession type Barringer Oceanographic Magnetometer (BOM 101), whose accuracy is ± 1 nanotesla. The magnetic data was collected on an analog chart during 1980 field season and was digitised at 50 m interval. The data was corrected to International Geomagnetic Reference Field (IGRF) 1980.1 epoch and diurnal corrections were applied using the hourly values published by Colaba Geomagnetic Observatory, (18° 38'N and 72°52'E latitude and longitude). After reduction, the data are presented as stacked anomaly and total magnetic anomaly contour maps.

RESULTS

The seabed topography is even except near the promontories and varies between 2 to 18 m. The echogram (Fig.6) clearly depicts a distinct tonal difference corresponding to sand and clay and the analysis of seabed samples confirmed the occurrence of heavy minerals containing sands upto 9-12 m and clays in further offshore regions. Based on this type of distinct demarkation of sand/clay contact and other geological evidences, RAMANA *et al.*(1990) proposed the paleoshore line around 9-12 m water depths.

The shallow seismic sections were interpreted using the available bore hole data and the stratigraphic sequences of Holocene, Pleistocene and older sequences were established. The innershelf is uniformly covered by a minimum 5 m thick Recent to Holocene sediments whose thickness increases gradually towards offshore. Three to four well defined parallel to sub parallel reflectors were identified on the seismic sections (Fig.3) and are corroborated with sand/clay, coarse grained sand and pebbles, altered traps and weathered derivatives of Deccan Traps. ¹⁴C dating results indicated that the surface sediment (1-9m) were deposited during the period 4000-5000 years before present (GUPTA, Personal communication) and NAIR *et al.* (1979) reported the fine grained clastic clays occurring around 15 m waterdepth corresponding to modern/Recent sediments. These in turn were underlined by Holocene /Pleistocene sediments, altered trap basalts and Deccan traps of Eocene age (BHATTACHARYA *et al.*, 1987).

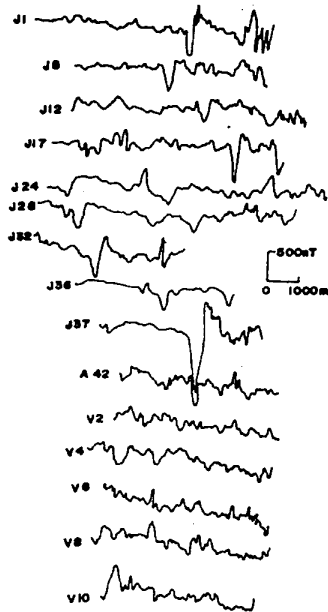


Fig.3a

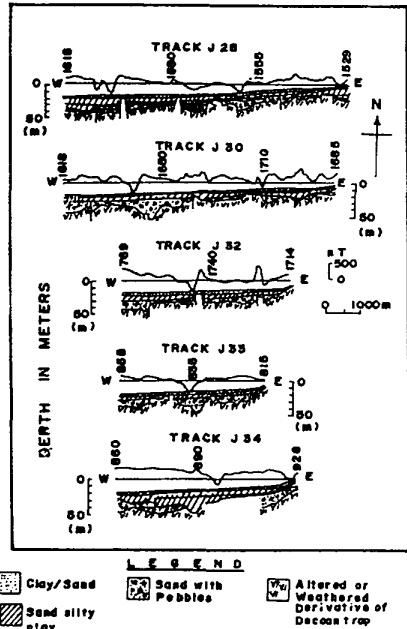


Fig. 3b

Fig.3. (a) Line drawings of interpreted shallow seismic sparker records (b) Total magnetic anomalies showing the high frequency component.

The stacked anomaly and the total intensity anomaly contour maps (Figs.4&5) revealed that the magnetic response vary over a wide range. The susceptibility measurements of 77 offshore placer sediment samples with low field susceptibility and hysteresis apparatus designed by LIKHITE and RADHAKRISHNA MURTY (1965) and were discussed extensively by RAMANA (1988). The susceptibility varies between 2.9×10^{-3} to 0.6258×10^{-3} . By and large samples from Jaigad bay show higher values of susceptibilities which are due to the appreciable volume fraction of paramagnetic minerals and their Fe content, besides the volume fraction of magnetite and its grain size. Available data on chemical analysis of samples from Jaigad bay (RAJAMANICKAM, 1983) indicate that the percentage of magnetite varies between 10-40 and that of ilmenite between 1-30. The higher percentage of magnetite may be one of the factors effecting the magnetic susceptibility of placer sands. Chemical analysis of onshore basalts (WASHINGTON, 1922) and placer sediments (RAJAMANICKAM, 1983) indicated the percentage variation of iron and titanium oxides are higher for placer sediments in general. The percentage variation of TiO_2 , Fe_2O_3 and FeO in the placer sands of the study area and the average composition of these oxides in the basalts amply justify the strong magnetic nature of the basement and the placer sediments.

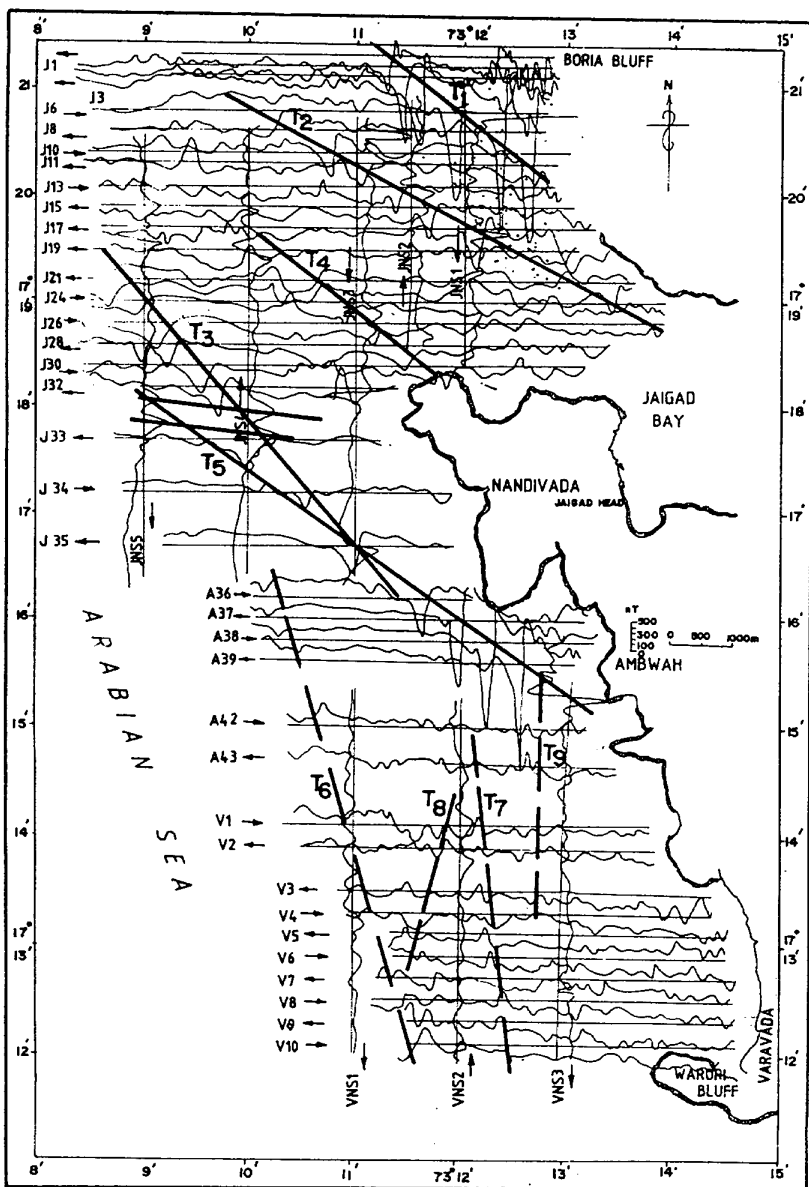


Fig.4. Stacked magnetic anomaly profiles along the tracks and inferred lineations (T1-T9).

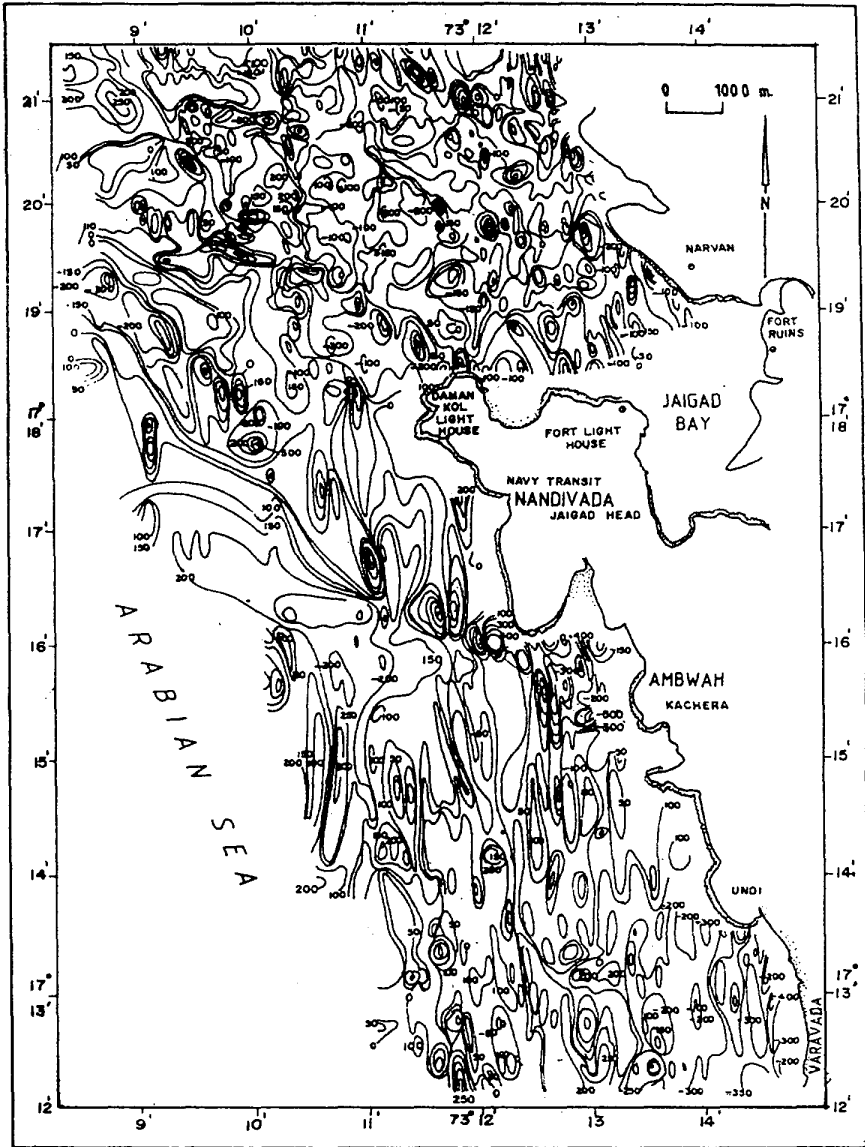


Fig.5. Total magnetic intensity anomaly map of Jaigad, Ambwah and Varavada bays (Variable contour interval).

A cursory glance at the total intensity anomaly profiles (Fig.3) and contour map of the study area (Fig.5) reveals i) smooth and broad anomalies with large wavelengths represent the regional background and overriding them are (a) high frequency and low amplitude anomalies (b) short wavelength and large amplitude anomalies and (c) medium to long wavelength and large amplitude anomalies and ii) anomaly map is characterised by N-S, NW-SE and WNW-ESE magnetic lineaments (RAMANA, 1986) of these NW- SE and N-S trends predominate and they persist over considerable length, representing the overall basement (PreCambrian-Dharwar) grain. The smoothing effect in preparation of a contour map can be seen from the diffuse anomaly trends like N-S in Ambwah and Varavada bays and the poorly defined NNW-SSE trend in Jaigad bay region. Further, the small anomaly closures are found to confine to just one or two traverses, very close to the shore. The wavelengths of NW-SE trending anomalies are small but their amplitudes are remarkably high. Off Narvan, Kachera, Undi and Varavada low amplitude anomaly closures are randomly distributed. The trend of the magnetic anomalies recognised in the northern part of the map area (Fig.4) are indicative of dislocations and block movements along NW-SE/WNW-ESE oriented weak planes. Periodic eruptions from upper Cretaceous to Tertiary or even Quaternary times might have acted as driving force for the block movements and the upheaval of coastline stage by stage. The observed N-S, NW-SE, WNW-ESE and NNW-SSE magnetic anomaly trends are probably fracture/fissure zones, faulting and dislocations through which magmatic material might have been emplaced and was subjected to erosion later by percolating waters and other processes.

Petrographic and other mineralogical studies indicate that the magnetite with varying percentage is the chief constituent of Deccan Traps. Presence of different Fe-Ti oxide assemblages within different parts of the same unit of rock due to highly variable oxidation may be attributed to the birds eye pattern (GRANT, 1984/85) of magnetic anomalies found associated with the Deccan Traps. A close study of NW-SE and WNW-ESE trending magnetic anomalies suggest that they are due to subsurface bodies of considerable depth and lateral extent and are partially controlling the spatial distribution of placer sands.

High amplitude anomalies observed off Ratnagiri (GOPALA RAO, 1984b) and Mirya Bay (RAMANA, 1988) have been interpreted in terms of dyke/intrusive bodies since the orientation of these offshore features and onshore dykes/intrusives (AUDEN, 1949) could be well correlated (RAMANA, 1986). In the study area, the observed high amplitude magnetic anomalies with their variable wavelengths are interpreted as the associated bodies with shear or fissured zones. These intrusive bodies exhibit magnetic susceptibilities varying from 1.44×10^{-3} to 8.0×10^{-3} and occurring at variable depths from 20-70 m below the seabed. The observed string of anomaly closures which are rather similar in the entire study area (high frequency, short wavelength) with variable amplitudes (30-200 nT) are superposed over the regional field (Fig.3).

A reasonably good correlation between magnetic anomalies and percentage of magnetite has been established (RAMANA, 1988) in Mirya bay. Similar type of high frequency anomalies (Fig.3) observed off Jaigad, Ambwah and Varavada bays and are attributed to the presence of considerable percentages of magnetite in the placer sands. The widely ranging magnetic response (Figs. 4&5) is related to the variations of volume percentage distribution of magnetite. Under the constraints viz. (i) the heavy mineral rich placers occur in the sedimentary formation as lenticular bodies above the basement and ii) if at all the placer sediments possess magnetisation, it is due to induction. The synthetic magnetic anomaly response of these placer sands were generated (Fig.7) using the method proposed by TALWANI and HEITZLER (1964) which closely represents the above mentioned induced anomalies. Results obtained in Mirya bay (RAMANA,

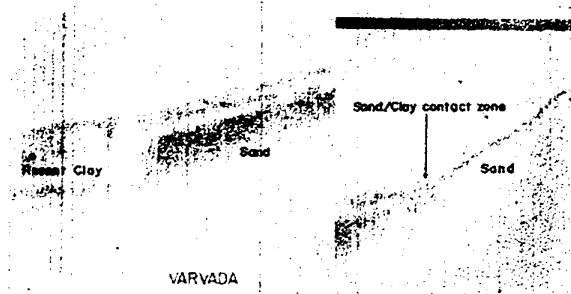
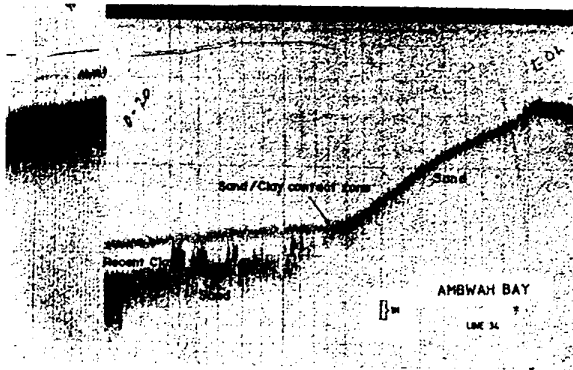
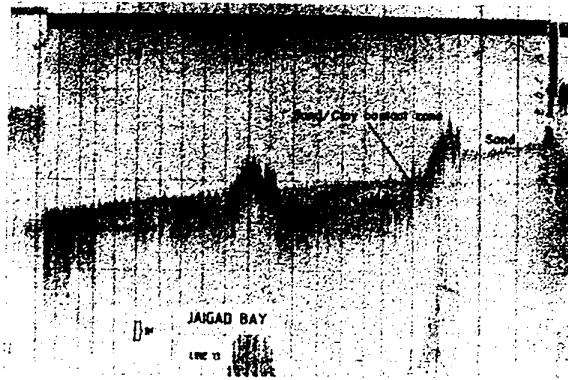


Fig.6. Representative echograms showing the seabed, sand/clay contact zone in Jagad, Ambwah and Varavada bays.

1988) based on the analysis of magnetic anomalies shows the magnetic intensity is directly related to the bulk of magnetite content and bulk susceptibility of the placer minerals in the sedimentary formations. These results have formed a base for the present study. The magnetic observations find support in seismic inferences where thickness of heavy mineral sediment layer has been identified as 20-30 m and corresponding magnetic profiles are characterised by high frequency anomalies with variable anomaly amplitudes superposed on the long wavelength regional magnetic field (Fig.3). Further, the two dimensional studies (Fig.7) indicated the presence of several intrusive bodies, basement dislocations, block movements and narrow shear zones. A structural and depth to the top of magnetic basement maps were prepared using the model interpreted results (Fig.8).

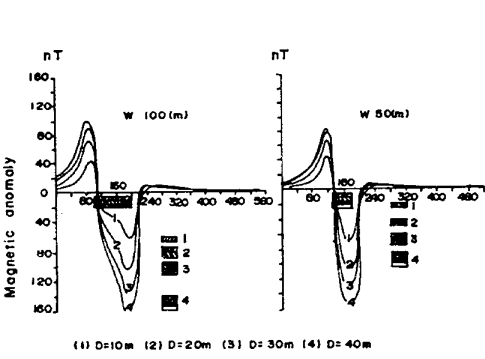


Fig. 7a

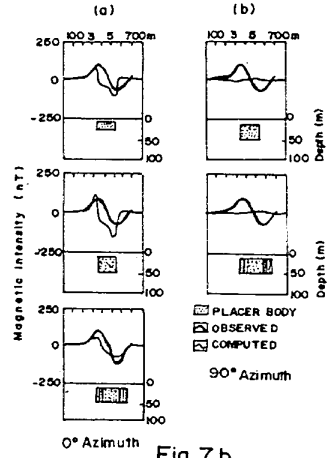


Fig. 7 b

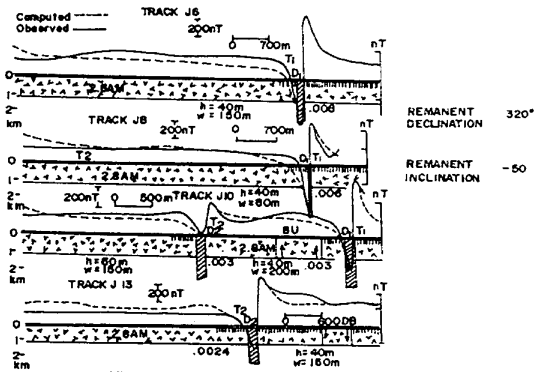


Fig. 7c

Fig.7. Observed and computed magnetic anomalies along the tracks over two dimensional prismatic blocks (a) and (b) magnetic response over a variable thickness of placer body (c) along selected tracks.

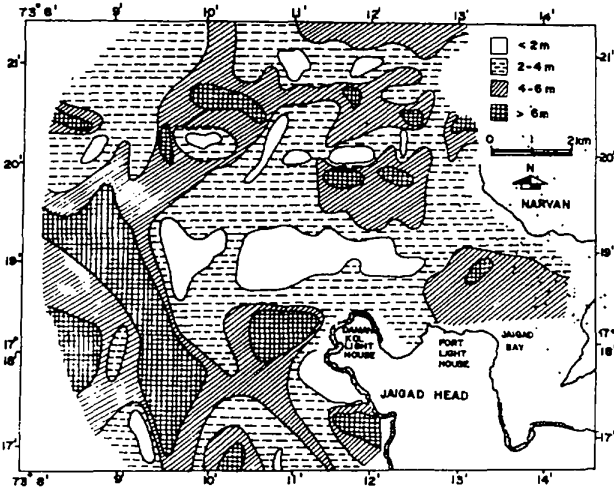


Fig.8. Isopach map of heavy mineral rich sands (After Rajamanickam *et al.* 1988)

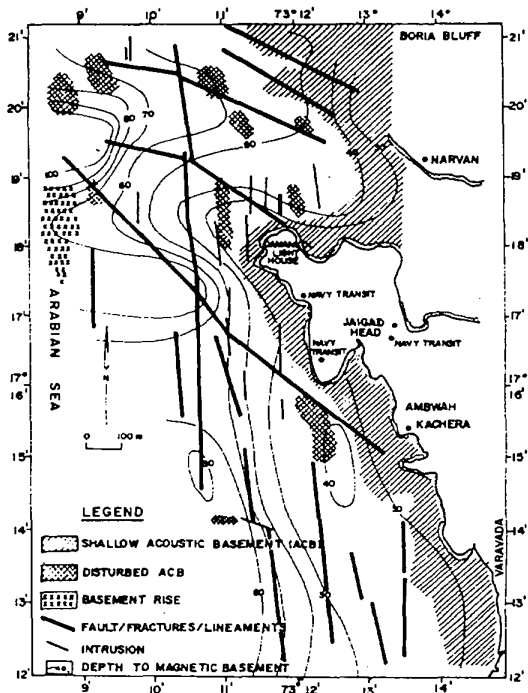


Fig.9. Structural map of Jaigad, Ambwah and Varavada bays and the depth to the magnetic basement.

The magnetic model studies discussed above facilitated to establish a reasonably good correlation between high content of heavy minerals (magnetite) and anomaly contour map. The isopach map (Fig.9) of sand depicts the observed string of closures and sparsely distributed low amplitude closures correspond to the spatial distribution of sand. Where the thickness is more, there the magnetic anomalies are rather pronounced in their amplitudes.

A conservative estimates of about 21 million tonnes of heavy mineral deposits (ilmenite and magnetite) have been done by SIDDIQUEE *et al.* (1982), RAJAMANICKAM *et al.* (1988) and GUJAR *et al.* (1989) along the Konkan Coast (Central West Coast of India) using the combined results of geophysical signatures and analysis of seabed samples by considering an average minimum thickness of 4 m sands spreading over an area of 36 sq.km. Similar estimates have been made for the other bays (Fig.1).

CONCLUSIONS

The marine geophysical methods help for delineating the horizontal as well as vertical distribution of heavy mineral placers in the offshore. The high frequency anomalies are no doubt an indication of magnetite distribution. The long wavelength and relatively large amplitude magnetic anomalies are due to the structural elements and their distribution in time and space. Two dimensional model studies of the area of investigation indicated the presence of several intrusive bodies, basement dislocations, block movements and narrow shear zones (Fig.7). Based on the analysis and interpretation of magnetic and shallow seismic reflection records, echograms and available borehole lithological data, structural pattern of the area and depth to the magnetic basement and its configuration was delineated. There exhibits a good correlation of the distribution of heavy mineral sands and the orientation of various structural elements. The depth to the basement for the study region varies from 30 to 100 m and the basement deepens towards west supporting the general westward dip of the Deccan Traps.

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