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Geological and Geophysical Exploration for Offshore Ilmenite Placers off the Konkan Coast, Maharashtra, India

by H. N. Siddiquie, G. V. Rajamanickam, A. R. Gujar, and M. V. Ramana, *National Institute of Oceanography*

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ABSTRACT

The occurrence of heavy mineral placers on the Indian coasts is known but no systematic attempt has so far been made to explore their offshore extension. The Institute carried out detailed offshore surveys (Sextants and microwave position fixing system) of a 130 km long strip along the Konkan Coast (1889 lkm echosounding, 895 lkm of shallow seismic and 1228 lkm of magnetics followed by 1117 grab and 66 piston-gravity core samples).

The coastal area is marked by 13 arcuate bays and tidal inlets. The onshore sediments of these bays contain heavy mineral placers which in most cases extend to offshore also. The seabed in most of the bays is marked by even topography and the nearshore sand covered areas are marked by steep gradient and the offshore clay covered areas by gentle gradients. The seabed in the bays down to a water depth of 9 to 12 m is largely covered by sand beyond which the sands are covered by clays. The surficial sands in these bays cover an area of 96 km² and contain upto 91 per cent heavy minerals and 64 per cent of ilmenite. The dual frequency echograms, seismic profiles and short cores confirm the extension of the heavy mineral rich sands

below the clays. The thickness of the heavy mineral rich sands ranges from 2 to 10 m and these cover total area of 436 km². The magnetic surveys in this area indicate that the magnetic picture is largely related to the basement configuration and structural trends over which are superimposed the anomalies due to heavy mineral placers. The high frequency and low amplitude and short wave length anomalies are perhaps due to heavy mineral placers. The offshore reserves and ilmenite are estimated to be about 12.5 million tons whereas estimates based on the 2 to 10 m thickness and spread of ilmenite bearing sands over an area of 436 km², total reserves appears to be very large. The extensive onshore and offshore deposits offer encouraging possibilities for future integrated development.

INTRODUCTION

The occurrences of heavy mineral placers usually called "black sands" are known from many localities along the Indian Coast. The onshore placers along the west coast largely comprise high grade beach and low grade dune sands. The placers along the SW coast i.e., Kerala contain ilmenite, zircon, rutile, monazite and sillimanite and extent from Cape Comorin to Quilon. Further north

on the west coast, onshore placers with varying proportions of ilmenite and magnetite and minor amounts of zircon and garnet have been reported from Konkan Coast, Maharashtra². On the east coast, heavy mineral placers contain ilmenite, magnetite, monazite and garnet are reported from Tinnavelli, Ramnad and Tanjore in Tamilnadu³, Visakhapatnam, Yada, Waltair and Bhimuniapatnam in Andhra Pradesh⁴, Ganjam, Cuttak and Wheeler island off the mouth of Brahmani river in Orissa⁵. The onshore reserves of ilmenite in India are estimated to be about 138 million tons⁷. The present production (1979) of heavy minerals from the beach sands of Kerala and Tamilnadu Coast is about 0.165 million tons⁷.

The occurrence of onshore placers of ilmenite along the Konkan Coast is known since 1945¹. The Directorate of Geology and Mining, Maharashtra surveyed the placers along a distance of 48 km from Undi to Purnagad and estimated the reserves of ilmenite to be 4 million tons⁶. However, no exploration of the offshore area was carried out and thus the extent of these deposits in the offshore was not known. The National Institute of Oceanography initiated detailed surveys in 1975 to (i) delineate the offshore extension of the promising onshore placers, (ii) understand the geology, structure, recent sedimentation and tectonic history of the area, (iii) environment of deposition of heavy minerals and formation of placers, (iv) evaluate the techniques for the exploration of the deposits and (v) examine the feasibility of their economic exploitation.

A detailed survey (Fig. 2 depicts the pattern of surveys in bay) of the 130 km long strip along the Konkan Coast (Fig. 1) was carried out during the years 1975-80. The equipment for the surveys was temporarily installed on fishing trawlers. These

surveys comprised echosounding, 1889 lkm, shallow seismic profiling, 895 lkm, magnetics 1228 lkm, followed by 1320 grab samples, 66 cores and 41 bulk samples.

METHODS

Position Fixing : The positions during the initial surveys were fixed by horizontal angles of three stations (centre one being common) by Kelvin Hughes hydrographic sextants and plotted by micrometer station pointer on a scale of 1:10,000. Subsequently, a Motorola Mini Ranger MRS III system was used. The Range Console, Data Processor (MRDP-500), Receiver Transmitter, Track Plotter, Tape Recorder and Omni directional antenna were installed on the vessel. The accuracy of fixes obtained is of the order of about ± 3 metres within the range of system.

Echosounding : The echosounding during the surveys was carried out initially by a Sea Farer Echosounder (basic scale 10 m with a phasing down to 60 m) and subsequently, a dual frequency Atlas Deso 10 Echosounder (30 and 210 KHz basic scale of 0-20 m and a maximum range of 280 m) the latter provided a good resolution and also the desired subbottom penetration in clay covered areas. A bar check was usually carried out before the commencement of surveys daily and the necessary corrections made on the record.

Shallow Seismic Profiling : For shallow seismic profiling initially a Hunttec Hydrosonde 2A system was used. The system consisted of a sparker or a boomer source, the transmitter (energy storage unit) the hydrophone array and the receiver, a combination of signal processor, graphic recorder (19 cm wide wet paper) and a keying programmer. In the surveys in 1979 a boomer (ED-5 predominant beam, 5 KHz) was used as a energy source and this was fired in a

water at a energy level of 100 joules, once in every two seconds. Subsequently, a more powerful source i.e., an EG & G sparkarray (200 - 300 joules) was used. The system consisted of a sparker source, Power supply (Model 232-A), Control bank (Model 231), Hydrophone and receiver. The latter being combination of EPC 3200 recorder (49 cm wide dry paper) and a key programmer.

Magnetometer : Initially an Elsec proton precision magnetometer and subsequently a Barringer Proton Precision Oceanographic Research Magnetometer was used. The magnetometer was operated from a 24 volt DC supply. The sensor was towed approximately at a distance of about 1.5 times the length of the boat to avoid the noise due to the hull. The data were recorded at 4-12 seconds and later corrected to the IGRF 1980, 0.1 epoch and diurnal variations. The magnetic profiles were plotted along the track and isogonal maps at a contour interval of 100 nT were prepared.

Seabed Samples : The surface sediment samples were collected with a Van Veen Grab (area 0.04 m²), on a grid of approximately 200 - 300 m. The cores were collected with a Piston Gravity Corer (weight 160 kg, effective length 2.5 m, free fall 2 m, diam of core barrel 50 mm and acrylic tube 45 mm) fabricated in the NIO workshop. The locations for cores were carefully selected after an examination of the underway records and sediment samples. The sites for coring were mainly selected to confirm the extension of heavy mineral rich sands below the seabed and the overlying clays.

CONFIGURATION AND BATHYMETRY

The Konkan coast from Jaigad to Vijaydurg is marked by a number (13) of arcuate bays (Fig. 1), with promontories of Deccan plateau basalts. There are five major rivers (Shastri, Kajvi,

Machkandi, Rajapur and Vaghotan) and a number of tidal creeks indent the coast (Varvada, Malgund, Are, Kalbadevi, Pawas and Vadavetye). The present surveys extended to a depth of 18 - 22 m. The gradients in these bays in the nearshore sand covered areas vary from 1:700 to 1:14 whereas in the clay covered offshore regions it varies from 1:6300 to 1:300. The bays which are situated away from river sources, show steep gradients but the bays which have river sources show smooth gradients. The extent of these bays and their sediments have not significantly influenced the bathymetry and sediment distribution on the innershelf. The Purnagad and Vijaydurg bays do not seem to influence the shelf topography and sediment pattern but the Jaigad, Ratnagiri and Rajapur bays shows a projection on the innershelf. The offshore extension of the 15 m contour off Ratnagiri may be due to the large accumulation of sediments brought by Kajvi river. The inner shelf off the bay shows mostly even topography and rarely uneven or rugged topography (Fig. 3). The echograms clearly indicate the continuation of the surficial sandy layer below the clays to the inner shelf (Fig. 4).

DISTRIBUTION OF SEDIMENTS AND MINERALOGY

The seabed in the area surveyed is largely covered by sand, silty sand, sandy silt and clay. Sand covers the seabed in the bays to a water depth of 9 - 12 m. Beyond this depth, and off promontories, clays overlies sand or rock. The 66 cores collected in the area (maximum penetration 1.98 m) show clearly the clay sand contact. The top 40 cm comprises redish brown clay which overlies olive grey clay which in turn overlies heavy mineral rich sand. Rajamanickam and Gujar⁸ have reported from their studies of grain size distribution that the sediments are mostly well sorted and unimodal, but sediments

at river mouth are poorly sorted and polymodal. The sediments represent a mixed depositional environment i.e., dune/beach/river to barrier/lagoon and palimpsest type. The heavy mineral concentration ranges upto 90 per cent. The heavy mineral assemblage comprises mainly magnetite and ilmenite (Table 1) with minor quantities of augite, epidote, zoisite, apatite, tourmaline, topaz, hornblende, rutile, zircon, limonite and kyanite. The magnetites in the sands are titanomagnetite or finally intergrown with ilmenite. Due to weathering oxidization some magnetite has been altered to hematite and minor quantities of anatase and leuc-xene are also noticed. The shell fragments, quartz and felspar dominate the relatively coarser size (from 80 to 200 microns) whereas magnetite and ilmenite dominate the fraction below 100 microns, but mostly between 40 - 80 microns. Siddiquie et al⁹ have reported 42 to 57 per cent TiO_2 in the ilmenite and trace element analyses of these heavy mineral concentrates indicate appreciable concentration of vanadium (upto 0.5%) and chromium (Sahoo et al personal communication).

RESULTS AND DISCUSSIONS OF SEISMICS AND MAGNETICS

The initial Huntec Hydrosonde records provided a good resolution and a clear contact between the first and second reflector if it was within 10 to 15 m but the energy was insufficient to penetrate the second reflector i.e., sand and define the basement. Thereafter an EG & G Spark array with a higher energy 200 - 300 joules was used.

A representative seismic profile (Fig. 5) shows four reflectors. The first reflector in the nearshore is confined to be heavy mineral bearing sands by sampling and in water depths beyond 10 - 12 m this is overlain by clays. The seismic profiles indicate the continuation of heavy mineral

bearing sands below the clays to water depths of down to 20 m. The thickness of heavy mineral bearing sands varies from 2 to 10 m (Fig. 7) and thicker sands (more than 10 m) are associated with river mouths and buried ancient river channels and local sand lenses (Fig. 8). This is also confirmed from shallow cores and boreholes drilled in Mirya bay. The third reflector is interpreted to be murum (weathered basalt) and the fourth to be altered traps. This is confirmed by the bore holes drilled for harbour development in Mirya bay which show murum and altered traps to be present just below heavy mineral rich sands. The bore holes in the bays as well as along the coast indicate traps below altered traps even at a depth of 50 m. The third reflector is not present in all places and in such cases the basement is shallower (Fig. 6). The fourth reflector is highly irregular and always with multiples and with no clear deeper reflectors and therefore, interpreted to be basement (Deccan Traps : Late Mesozoic to Early Tertiary).

The irregular nature is probably due to erosion and structural disturbances such as faulting and intrusions. The basement depths plotted at 15 m water depth from north to south (Fig. 7) show that the offshore area is marked by two depressions one in Jaigad in the north and the other at Vijaydurg in the south. The bays associated with river mouths (Jaigad, Rajapur and Bijaydurg) are characterised by deeper basement (about 20 m). This may be due to the burial of older river channels formed during the lowered sea levels which incidently also follow faults (Das & Ray¹⁰, Desai and Peshwa¹¹). This also explains the thick sand deposits associated with river mouths and buried river channels. The shallower basement (about 10 m) north of

Ratnagiri especially in Varvada differs from other regions and this may be attributed to the upheaval of a block during the final phase of Deccan Trap eruption (Hora¹²). The presence of beach rock along the coast in this area also supports the recent uplift which may lead to shallow basement. Such beach rock is conspicuously absent north of Varvada and south of Ratnagiri.

The configuration of the Goa - Maharashtra coastline has apparently been controlled by a system of sinistral en-chelon faults. Babu¹⁴ based on geomorphological analyses has suggested that sedimentation around Ratnagiri has taken place in a basin bound by N-S faulted blocks which presumably extend to the offshore and obviously also affect the sedimentary basins and sedimentation in the adjacent offshore areas. The shallow seismic profiling carried out during the present survey has indicated the extension of N-S faults from the coast to the offshore areas. In addition growth faults have also been recognised off Jaigad and which may be related to recent seismo-tectonic activity (Rajamanickam *et al*)¹³. In some cases, the faults are difficult to recognise from seismic profiles but these can be confirmed from magnetic anomalies (Figs. 9, and 10).

The magnetic surveys were primarily carried out to explore the possibility of correlating the magnetic anomalies with heavy mineral concentrations, basement configuration and the structural trends. The magnetic distribution shows two different types of anomalies i.e., (a) NS trending high amplitude and long wave length anomalies (300 to 350 nT, about 800 m) (b) low amplitude and medium to high frequency (100 - 150 nT about 100 m). The high frequency and low amplitude and short

wave length anomalies (about 200 nT, 200 m) may represent magnetic response of heavy minerals for which modelling has been attempted. The high frequency and medium to high amplitude anomalies observed along the coast indicate the occurrence of heavy mineral placers below the seabed. A number of intrusions in the basement in some cases down to the second layers have been recognised (Fig. 11) and these are characterised by high amplitude and low wave length anomalies. The general N-S trend of the magnetic anomalies perhaps represents Dharwarian (Pre-cambrian) trend or dykes and fractures along these trends. The N-S trending anomalies in Mirya bay (Fig. 12) may be due to dykes at depths of 50 and 100 m and a width of about 200 m. A large number of features observed in the total intensity maps of the area may be related to fractures, faults and lineaments. The steep gradients observed in the total intensity maps north of Jaigad may be due to NNW-SSE trending dykes and fractures. The NNW-SSE lineations observed in Jaigad and NW-SE lineations in Varvada may represent the offshore extension of lineaments observed in Satellite imageries on land (Desai and Peshwa¹¹). The sudden change in magnetic anomaly pattern in Ratnagiri bay from the northern bays possibly represents a regional E-W fault.

The surveys so far carried out indicate the presence of ilmenite sand on the seabed over an area of 96 km². The bulk samples analysed at the Regional Research Laboratory, Bhubaneswar indicate that the sands contain 11 to 57 per cent of ilmenite, titanomagnetite and hematite. The TiO₂ content of the heavy mineral sands ranges from 42 to 57 percent^{6 & 9}. The leaching test indicate ilmenite is suitable for recovering titanium as synthetic

rutile. Assuming an average ilmenite concentrations of 10 per cent and a minimum thickness of 1 m for ilmenite bearing sands the reserves inferred to be about 12.5 million tons. The seismic data indicate that the thickness of ilmenite bearing sands ranges from 2 - 10 m and these extend to water depths of about 20 m over an area of 436 km². Thus the probable reserves in the area will be many times more than the onshore reserves of 4 million tons estimated by Mane & Gawade⁶. A comparison of the onshore and offshore deposits shows a higher concentration of ilmenite in the offshore than the onshore sands. The onshore deposits chiefly beach sand are restricted to a narrow coastal tract whereas the offshore deposits are fairly wide spread. The extensive onshore and offshore deposits offer possibilities for an integrated development.

Similar type of work is proposed along the western as well as eastern coasts of India. The target areas has been selected on the basis of the present knowledge of the beach placers. Five major areas (Fig. 13) have been selected for carrying out the detailed survey in the forthcoming years.

CONCLUSIONS

1. The extensive surveys indicate that while the onshore ilmenite placers are confined to a narrow coastal tract (about a km wide), the surficial offshore placers extend over a distance of 2 to 5 km and cover an area of about 96 km². The surficial offshore placers have been confirmed to extend further below the overlying clays to water depths of 13 to 20 m and totally over an area of about 436 km².

2. The concentration of heavy minerals ranges upto 92 per cent and ilmenite upto 64 per cent. The seismic profiles

indicate that the thickness of the heavy mineral bearing sands ranges from 2 to 10 m and therefore, with a spread of ilmenite bearing sands over an area of 436 km², the total reserves would be very large. The extensive onshore and offshore deposits offer encouraging possibilities for future integrated development.

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Table 1 : The range (in per cent) of sand, silt, heavy minerals, magnetic and non-magnetic fractions and ilmenite in the offshore placers of Konkan Coast, Maharashtra, India

Bay	Sand	Silt	Heavy Minerals	Magnetite	Non-Magnetic	Ilmenite
Jaigad	20-98	1-24	20-70	10-40	1-10	1-30
Ambwah	20-98	1-20	5-40	1-71	3-15	3-30
Varvada	33-99	1-27	15-82	1-10	1-8	10-64
Kalbadevi	48-99	1-42	7-91	1-38	5-60	3-52
Mirya	12-99	1-37	5-72	3-48	1-51	1-35
Ratnagiri	8-99	2-69	1-78	1-59	1-50	1-22
Pawas	3-73	1-27	1-25	1-03	7-0	1-20
Furnagad	1-90	1-20	1-91	1-23	1-10	1- 55 ^{16.3}
Vijaydurg	1-85	1-15	1-40	1-07	1-9	1-21

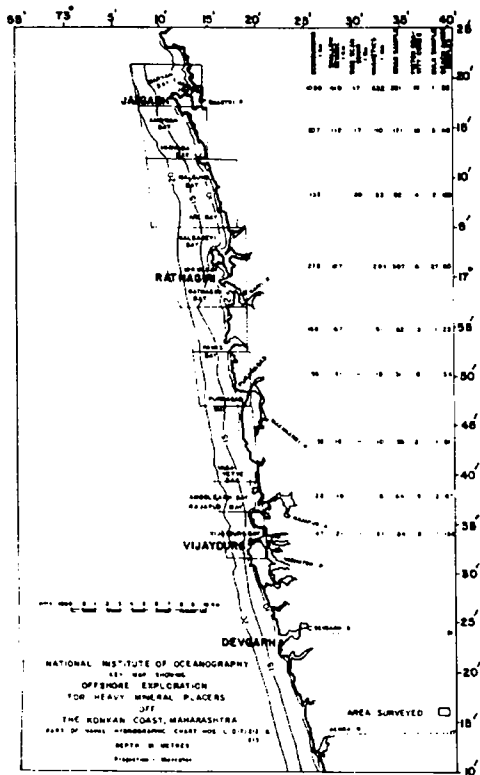


Fig. 1: KEY MAP OF THE AREA SURVEYED FOR OFFSHORE ILMENITE PLACERS

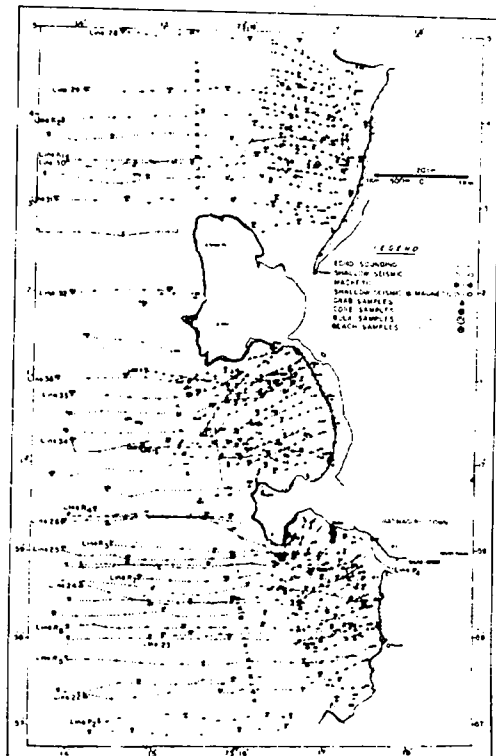


FIG 2 MAP SHOWING THE PATTERN OF DETAILED SURVEY OF KALBADEVI, MIRYA AND RATNAGIRI BAYS



Fig.3: ECHOGRAM SHOWING THE UNEVEN AND RUGGED TOPOGRAPHY OFF MALGUND

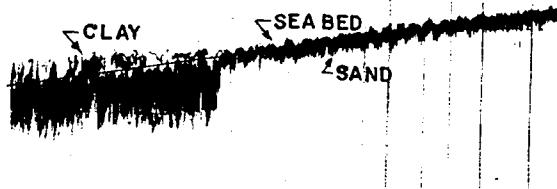


Fig. 4: ECHOGRAM SHOWING THE EXTENSION OF THE ILMENITE PLACERS BELOW THE CLAYS OFF JAIGAD

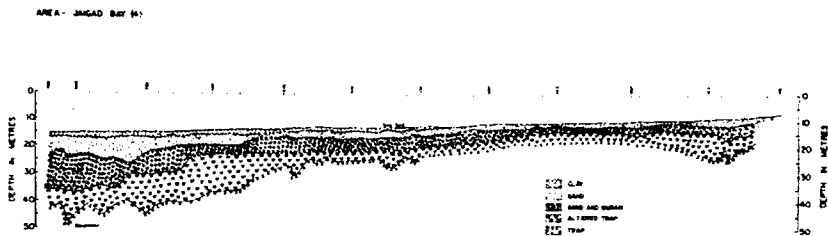


Fig.5 INTERPRETED SEISMIC PROFILE OF JAIGAD

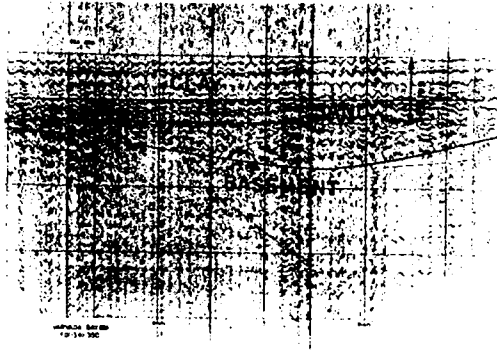


Fig. 6: SHALLOW SEISMIC (SPARKER) RECORD SHOWING ILMENITE PLACERS OVERLYING SHALLOW BASEMENT OFF VARVADA

Fig. 7: SCHEMATIC DIAGRAM SHOWING THE VARIATIONS IN THE BASEMENT AND THICKNESS OF ILMENITE PLACERS NORTH TO SOUTH

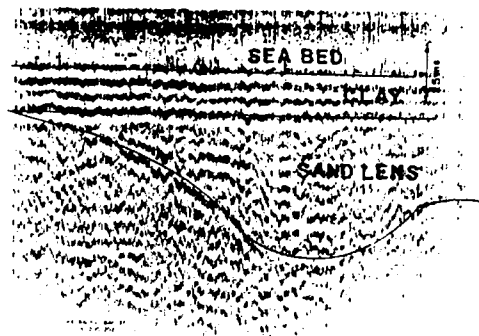


Fig. 8: SHALLOW SEISMIC (SPARKER) RECORD OF SAND LENS IN A CHANNEL OFF KALBADEVI

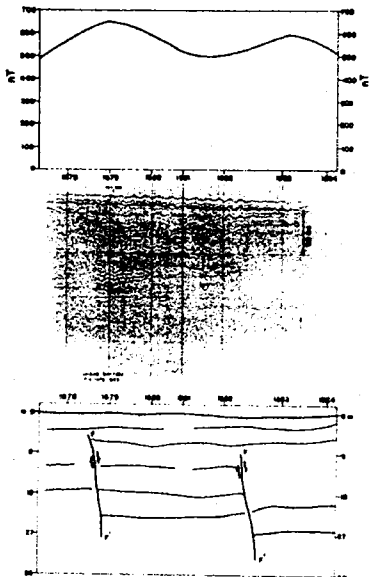


Fig 9 SHALLOW SEISMIC (SPARKER) RECORD SHOWING CLAYS OVERLYING ILMENITE PLACERS AND EN-ECHOLON FAULT WITH INTERPRETED LINE DRAWING AND MAGNETIC ANOMALY OFF JAIGAD

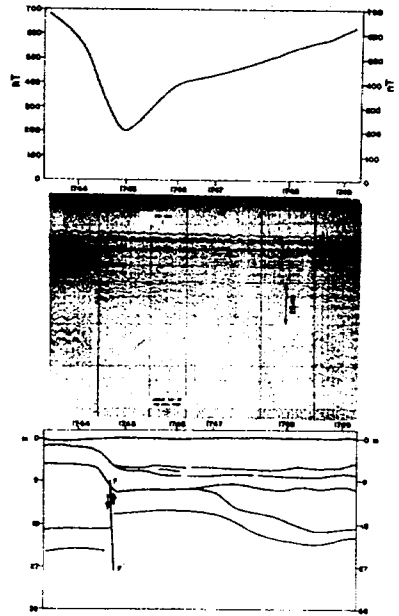


Fig 10 SHALLOW SEISMIC (SPARKER) RECORD OF A FAULT WITH INTERPRETED LINE DRAWING AND MAGNETIC ANOMALY OFF JAIGAD

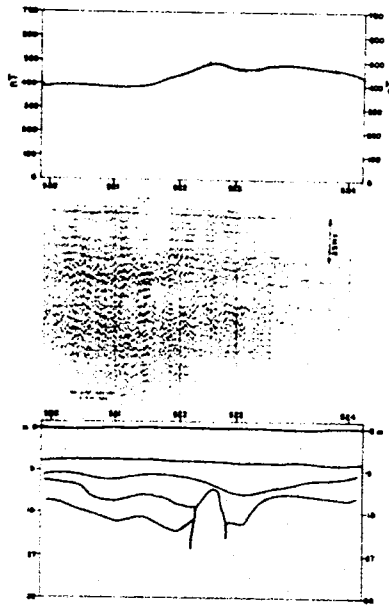


Fig 11 SHALLOW SEISMIC (SPARKER) RECORD OF AN INTRUSION WITH INTERPRETED LINE DRAWING AND MAGNETIC ANOMALY OFF MALGUND

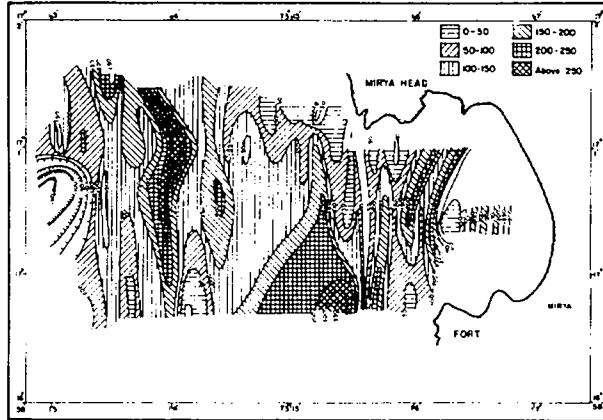


Fig. 12 : RESIDUAL MAGNETIC ANOMALY
MAP OFF MIRYA BAY

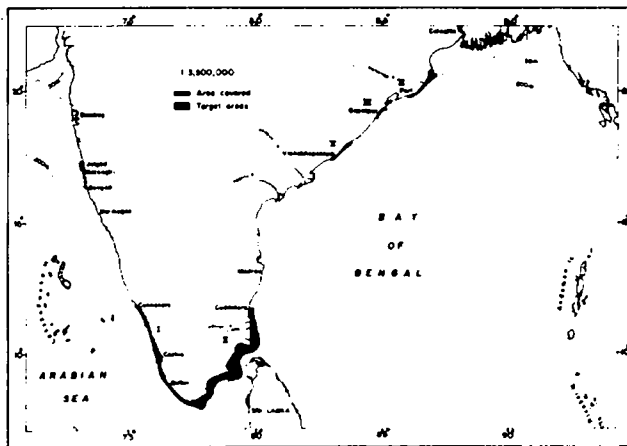


Fig 13. MAP SHOWING TARGET AREAS FOR FUTURE EXPLORATION FOR OFFSHORE PLACERS IN INDIA