

# Institutt for Geologi Universitetet i Oslo



**Intern skriftserie nr.37**

MAGNETIC ANOMALIES AND THEIR POSSIBLE RELATION WITH HEAVY MINERAL  
PLACERS AND BASEMENT CONFIGURATION IN MIRYA BAY, KONKAN COAST,  
MAHARASHTRA, INDIA

by

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OSLO 1982

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Abstract

The offshore ilmenite placers off the Konkan coast have been explored in detail by echosounding, shallow seismic profiling and magnetic measurements followed by extensive sea bed sampling. The magnetic data show two different types of anomalies: (a) N-S trending high amplitude and long wavelength anomalies (250-350 nT, about 500-700 m) approximately on a line joining the Mirya Head with the Bhagvati Fort and extending 3 km offshore, and (b) low amplitude and medium to short wavelength anomalies (100-120 nT, about 100 m) distributed in a zone 3 km seaward of the shoreline. The high amplitude long wavelength anomalies may be due to structures (dykes) within the Deccan Traps. An attempt has been made to correlate the magnetic patterns with known offshore heavy mineral placers in Mirya Bay. The low amplitude and medium to short wavelength anomalies may be correlated with the known heavy magnetic mineral concentrations in the bay although other effects cannot be ruled out. From the quantitative studies of the anomalies, the depth to the top of dykes is 50 m and 100 m in nearshore and offshore areas respectively, while the width varies from 150-250 m. The average depth to the magnetic basement is about 50 m.

## INTRODUCTION

By a combination of extensive programs of bottom sampling and geophysical surveys it is possible to map and estimate offshore placer deposits as shown by Beiersdorf et al. (1980) who discovered a large sand deposit containing high heavy-mineral concentrations off the Zambezi Delta. In their investigation analysis of the magnetic field did not yield any significant information with respect to the placer deposits. On the other hand, such deposits is often associated with a high content of magnetic minerals and it is therefore of interest to evaluate the effect of these bodies on the observed magnetic field. A study of this kind can be carried out at the innermost continental shelf off the Deccan Trap region in western India (Fig. 1).

The occurrence of onshore ilmenites has been reported for about 200 km along the Konkan coast (Fig. 2). Siddiquie et al. (1979) described onshore placer ilmenites extending offshore to a waterdepth of 13 m in Kalbadevi, Mirya and Ratnagiri bays. They also estimated the quantity of the probable resources based on detailed sampling.

As a part of the NIO programme "Exploration for offshore ilmenite placers deposits off the Konkan coast, Maharashtra"; echosounding, sidescan sonar, shallow seismic (Huntec Boomer and EG&G Sparker) and magnetic surveys were carried out in conjunction with a detailed sampling programme during the field seasons of 1976-80. The field investigations during 1980 lead to the preparation of isogam maps for the different bays off the Konkan coast. The magnetic maps depicted various features including offshore extension of structural and

topographic trends observed in landsat imageries (Ramana, 1980; Das and Ray, 1976). Several magnetic closures were observed in many of the bays. A main question is if some of these closures can be attributed to the heavy mineral concentrations or if they reflect magnetic inhomogenities or relief in the underlying basement. To investigate the relationship between the anomalies and possible placer concentrations, the present study is focused on Mirya Bay. An accompanying study deals with the Jaigarh area to the north (Ramana, in prep.) (Figs. 2 and 3).

#### GEOLOGY AND TECTONIC FRAMEWORK

The Deccan Trap volcanic episode is one of the most important events in the geologic history of the Indian shield area after the fragmentation of Gondwanaland. On the basis of stratigraphic evidence, the Deccan Trap formation is considered to have started erupting some time near the end of the late Cretaceous continuing to the early Eocene (Wadia, 1961). The volcanic eruptions took place in two different main phases, at about 65-60 and 45-42 my. (Rama, 1964; Wellman and McElhinny, 1970; Wensink, 1973). About 600000 km<sup>2</sup> of the Indian shield is covered by the Deccan basaltic flows (Fig. 1) which also are presumed to extend offshore (Raju et al., 1971).

The bulk of the Deccan Traps shows a remarkable uniformity in both megascopic character and mineral composition. The basalts are host rocks for labrodorites, augites and iron ores. In the majority of the specimens irregular grains of magnetite are rather common. The presence

of leucoxene shows that the basalts are titaniferous and sometimes also contain plates of ilmenites (Pascoe, 1964).

Geophysical studies of the Deccan Traps have shown that volcanic flows are of both the fissure type and central type (Pascoe, 1964). The evidence for fissures comes from the dykes located in the central and western India. Dykes of large dimensions are observed at a number of places including the northern Konkan coast. The existing dykes (intrusions) indicate the location as well as the trend of the fissures (Wadia, 1961). The Deccan Trap region have been subjected to severe faulting along the west coast of India (Krishnan, 1968). Presently there is an alignment of hot springs and seismic epicenters along the west coast. In addition to the regional faults major structural lineaments and dykes have been mapped and reported along the Konkan coast (Fig. 2) (Wadia, 1961; Das and Ray, 1976).

#### DATA

Due to the failure of the electronic navigation system the positioning was carried out using a sextant and fixing flags over the higher altitude hillocks. The positions were computed by triangulation and plotted with a station pointer.

A dual frequency echosounder (Atlas Deso 10) was employed for bathymetry and calibrated every day by the bar-check method. Fig. 3 shows the bathymetry contoured at 1 m interval.

Marine magnetic data were collected with a proton precession Barringer magnetometer. The sensor was towed approximately 20-30m behind the ship to avoid the stern effect and minimize other magnetic effects. The total field has been recorded every 12 seconds, providing magnetic readings for approximately every 25m along the profiles. The data have been corrected to the IGRF 1980.1 epoch values and corrected for diurnal variation. The magnetic anomaly profiles were then plotted along the tracks (Fig. 3). Fig. 4 depicts an isogam map at a contour interval of 50 nT.

Seismic sparker measurements have been recorded along the tracks in Fig. 2. The data indicate that the basement rocks exposed onshore are buried by sediments of 40-50 m average thickness.

#### ONSHORE LINEAMENT ANALYSIS

Several investigators have mapped structural lineaments such as dykes, fractures and fault patterns in the Deccan Trap region. Structures of this kind are often associated with magnetic anomalies. Moreover, mineral deposits may be controlled by the fractures. Assuming a spatial relationship between fractures and placer deposits the lineaments may therefore be used to localize areas of such deposits.

As the study area is located close to the coastline and the sediment cover above the basaltic basement is quite thin (less than 50 m) it is reasonable to expect a relationship between onshore lineaments and offshore magnetic trends. To investigate this further, an analysis of the main onshore lineament trends has been carried out.

The analysis is based on:

- 1) Regional geological trends from aerial photos by Das and Ray (1977) (Fig. 6).
- 2) Gravity lineaments based on a Bouger gravity anomaly map of the Deccan Traps by Das and Ray (1977) (Fig. 6).
- 3) Landsat lineament map of the west coast of India between latitudes 16.5 and 19<sup>0</sup>N (Das and Ray, 1976) (Fig. 2).

Lineaments based on contour maps (magnetic, gravity and bathymetry) are defined as any kind of linear or sublinear feature or alignment of features in the contour pattern. These include (Frost, 1977):

- 1) Straight line contour patterns with a steep gradient
- 2) Alignment of maxima and/or minima
- 3) Alignment of "flattened" terminations of maxima and/or minima
- 4) Any combinations of the first three.

The geological lineaments mapped by Das and Ray (1976, 1977) and Bouger gravity trends defined by the above criteria (Fig. 6) have been digitized with an AGA Geotracer model 326 digitizing unit and stored on computer files at the Department of Geology, University of Oslo, Norway. The trends of the lineaments were then analysed statistically (Abdel-Rahman and Hay, 1978) and the result presented as rose diagrams and frequency polygons (Figs. 7 and 8).

The rose diagrams represent the cumulative length of the lineaments on the left side of the NS axis and the total number of lineaments on the right hand side. The circle refers to a distribution which is 20 % of



the total. The frequency polygons express the same information as the rose diagrams; however, they are more useful in the quantitative studies. The polygons give accurate orientation of the features, whereas the rose diagrams yield a qualitative expression of the lineament distribution.

Fig. 7 shows the data from the map of Das and Ray (1977). The lineaments of Das and Ray (1976) are presented in Fig. 8, in which the dykes and fractures have been analysed separately. The main results in terms of orientations are given in Table 1. Here, the concepts of "dominant" and "other" trends are introduced qualitatively.

The map of Das and Ray (1977) yields the three dominant trends N175E, N105E, N65E and less well-defined lineaments striking N135E and N160E. The major gravity trends strikes N25E, N145E and N165E whereas the trend N115E has a lower amplitude indicating a smaller number of lineaments (Fig. 7). The analysis reveals that the major trends of the geological and gravity lineaments are approximately similar.

The lineaments mapped by Das and Ray (1976) show that the dykes are strongly oriented in the N175E and N25E directions (Fig. 8, Table 1) whereas less than 5% of the total number of the lineaments are aligned in the N55E and N85E directions respectively. The fractures trend dominantly in the N145E and N175E directions with less pronounced trends along N25E and N65E. The major direction of alignment of these lineaments coincide well with the orientation of the Deccan subsurface volcanic flexure described by Kaila (1981) in this area.

In summary the onshore lineament analysis using different sources of data reveal that the predominant trends are N-S, NNW-SSE and NW-SE. Trends striking ENE, NE and NNE are clearly identifiable, but less pronounced.

## RESULTS AND DISCUSSION

### Anomaly trends

The general characteristics of the magnetic anomaly distribution in the study area are:

- 1) A distinct linear trend in the anomaly field is observed in most of the area. This is particularly well developed in the nearshore region from Mirya Head to Bhagvati Fort and in an area further to the west at about  $73^{\circ}14'E$  (Figs. 4 and 5). The peak to peak amplitude of the anomalies are usually 250-350 nT and their wavelength varies in range from 500 to 700 m. The general trend of the anomalies is NS. In Table 1 the dominant trends are N000-010E, N176E and N156E. The latter trend is somewhat uncertain because it is based on the correlation between the westernmost parts of profiles C and D which is not entirely evident.
  
- 2) The amplitudes of the anomalies in the Mirya Bay proper and in the central region are smaller, generally of the order of 100-120 nT. However, the anomalies in the bay are more accentuated than those in the central region.

The most conspicuous feature of the anomaly maps (Figs. 4 and 5) are the two lineations, M1 and M2, separated by a distance of approximately 3 km (Fig. 5). The positive anomaly, M2, is interpreted as a curved feature, whereas the negative linear anomaly, M1, separates the smooth central region from the Mirya Bay anomalies. The main trends of the magnetic anomaly field correspond indeed with that of onshore geological lineaments and particularly with the dyke trends (Table 1). A similar relationship is also observed on the inner continental shelf off Jaigarh (Fig. 2). The presence of approximately NS trending dykes along the entire west coast region which parallel major features in the regional geology have been reported by Auden (1949) and Das and Ray (1976). The presence of these dykes indicates upwelling of basic to acidic magma along fault planes. It is therefore reasonable to attribute anomalies M1 and M2 to large massive dykes.

#### Determination of susceptibilities

Measurements of the susceptibility in the Deccan Trap rocks indicate a large variability (Verma and Pullaiah, 1971; Negi and Agrawal, 1978). For the modelling in this study a value of 0.00268 cgs units has been chosen to represent the volcanic basement. The value is the mean susceptibility computed from 33 samples measured by Negi and Agrawal (1978).

In the case of placer deposits, susceptibility determinations at different external fields in sediments collected from the Kalbadevi Bay have been carried out by Rao (pers. comm.) at the Tata Institute for Fundamental Research (Table 2). The Kalbadevi Bay is located just to the north of the study area.

In addition, three samples from bays further north, the Jaigarh area in Fig. 2, have been measured at the Department of Geophysics, University of Bergen. As expected, the sediment susceptibilities show little uniformity, hence the mean value calculated from the Kalbadevi Bay samples has been used in the modelling of the placer rich sands.

#### Dyke modelling and basement depths

Making the assumption that anomalies M1 and M2 are caused by dykes quantitative interpretation have been carried out by the method of Koulomzine (1970). The modelling includes anomaly  $M_1$  in lines A, B and C and anomaly M2 in lines A, B, C and D (Figs. 4 and 5). The body parameters and results are presented in Table 3. Analysis by the Peter (1949) half-slope method has given depths quite similar to those in Table 3.

The depth of the magnetic basement, that is the top of the dyke, is about 50 m below the sea surface in the case of the nearshore feature, M1; and about 100 m for the offshore dyke, M2. There is no appreciable change in the depths between the individual crossings of the same anomaly (Table 3).

Depth estimates are also made by using spectral analysis. The procedure is based on an algorithm developed by Green (1972). The regional is removed by fitting a second order polynomial to the data by the least-square method (Dahl, 1982). The spectral analysis method is a direct procedure to find average depths to ensembles of bodies

after transformation of the data to the wave number domain assuming two-dimensionality.

The main advantage of this method is that it allows determination of average depth to magnetic basement over a given profile length. Due to the short profile lengths, only average depths have been calculated for profiles A-D. Fig. 9 shows the computed regional and the corrected magnetic anomaly for profile B as well as the corresponding power spectrum. The results in terms of average depth to the basement are listed in Table 4.

#### Placer models

We now try to evaluate the possible relationship between placer deposits and magnetic anomalies. In the Mirya Bay, landward of M1, the magnetic field reveals medium to high frequency anomalies whereas the anomalies are quite subdued seaward of M1. Assuming that these high frequency anomalies are superimposed on the regional field we have treated them as reflections of the heavy mineral concentrations in the bay sediments. Fig. 10 shows a series of maps depicting the composition of the bottom sediments in the bay based on the sampling program by Siddique et al. (1979). This study indicates that the sands which contain placer deposits are mainly located in the bays along the coast.

The distribution of heavy magnetic minerals are also shown superimposed on the magnetic anomaly profile map in Figs. 11 and 12.

Fig. 12 shows a first-order correlation between high content of magnetic heavy minerals at the sea floor and the longer wavelength component of the magnetic anomalies. However, the individual short wavelength local anomalies are not reflected by changes in the magnetic heavy mineral distribution. As we may have strong lateral as well as vertical variations in the concentrations of magnetic minerals surface sampling may not reveal the integrated magnetic effect of the possible placer deposits. On the other hand the observed apparent correlation is found to be quite interesting and should be investigated in other bays along the coast.

To explore this relationship further, two-dimensional modelling of placer deposits have been carried out. The models are based volume considerations by Siddiquie et al. (1979) and the suggestion by Washington (1922) and that Pascoe (1964) that placers occur as thin local horizontal plates within the sands. The two-dimensional modelling is based on the method of Talwani and Heirtzler (1964) assuming induced magnetization only. The basic constraints are: 1) the sand lenses occur in the sediment overlying basement, 2) a horizontal homogeneously magnetized basement at a depth of 50 m below the sea floor.

A visual observation of the magnetic records in the study area indicates that the wavelength of the high frequency anomalies are generally about 200 m. Hence, keeping this width as an optimum body width and assuming a constant susceptibility the theoretical magnetic anomaly has been computed for different geometries of the placer body to generate the desired amplitude of the anomaly (100-150 nT). The computations have

been repeated for different geometries, susceptibilities and profile azimuths. Fig. 13 shows examples of such models. The upper models represent single bodies whereas the lower ones have been constructed by decreasing the susceptibility near the edges of the placer body. A main result is that it is not possible to obtain the observed anomalies from placer bodies trending north-south. These bodies yields only amplitudes of 20-50 nT. This is due to the direction of the induced magnetization vector which strikes about  $-20^{\circ}$ W with a shallow inclination ( $20^{\circ}$ ). However, placer bodies striking east-west may give rise to anomalies of amplitudes and wavelengths similar to those observed. Thus, this investigation has shown that a detailed grid pattern is required to perform an accurate evaluation of placers by modelling using both the amplitude and and wavelength information. Furthermore, placers of certain geometries, sufficient thickness and concentrations of magnetic minerals may yield amplitudes as those observed.

#### Basement relief models

It is be possible that some of the short wavelength anomalies are caused by relief in the basement surface. To explore such effects two-dimensional models (Talwani and Heirtzler, 1964) of simple geometric configurations that could be assumed to represent basement ridges have been constructed. The magnetic effect of the models (Fig. 14) have been calculated assuming that the basement is homogenously magnetized having the Deccan Trap susceptibility previously applied. Fig. 14 shows examples of the calculations. It is obvious that the amplitudes generated by features of this kind have maximum peak to peak values of about 50 nT. Thus, it appears that only a small part of the observed anomalies in the bay originate from undulations in the basement. Particularly, north-south trending ridges will not give any appreciable anomalies.

## SUMMARY AND CONCLUSIONS

The magnetic anomaly pattern in the Mirya Bay shows a predominantly north-south trend. Two well developed linear anomalies, M1 and M2, bounds a relatively smooth central region. Intermediate wavelength anomalies are mapped west of M2 and in the bay proper.

The magnetic trends correlate with onshore lineament trends, particularly with the dyke trends. Anomalies M1 and M2 are presumed to originate from dykes at depths of 50 m and 100 m respectively. Depth calculations by spectral analysis yield average basements depths of about 50 m.

Placer deposits containing considerable amounts of heavy magnetic minerals have been mapped in the Mirya Bay. An apparent correlation between the longer wavelengths of the anomaly field and the percentage of heavy magnetic minerals is observed. Moreover, magnetic modelling reveal that placer deposits may cause anomalies with amplitudes similar to those observed. However, one cannot rule out that major parts of the anomaly field in the bay originate from basement relief and/or intra-basement magnetization contrasts. To carry out a more detail evaluation of the relationship between placers and the magnetic field a detailed grid of survey lines is required.



## ACKNOWLEDGEMENTS

This work has partly been carried out during a NORAD sponsored fellowship program in "Marine magnetic dataprocessing and interpretation" at the Department of geology, University of Oslo. (NORAD project IND-015).

I extend my sincere thanks to Morten Sand, and Dagfin Arstad for their assistance in using the computer facilities at the Department of geology.

I am particularly indebted to Professor Olav Eldholm for his ready and constant support at all times and encouragement throughout the course of this work. I thank Dr. Yngve Kristoffersen for his help and suggestions and Odd Erik Faråsengen for his assistance during my stay in Oslo.

I am grateful to Dr. V.V.R. Varadachary, Director, National Institute of Oceanography, and Shri H.N. Siddiquie, for sponsoring me and encouragement given in carrying out these investigations.

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Lineament type	Aerial	Gravity	Fractures	Dykes	Magnetics	Magnetics
Dominant trends	N175E	N165E	N175E	N175E	N176E	N165-175E
	N130E	N145E	N145E			
	N65E	N25E		N25E	N000-010E	N15E
Other trends						
						N35E
			N25E			
			N65E	N55E		N75E
		N115E		N85E	N156-160E	N100-130E N160-165E
Source of data	Das and Ray (1977)	Das and Ray (1976)			Present study	Jaigarh shelf (Ramana, in prep.).

Table 1. Results of onshore lineament analysis.

Source	Sample	K-10 <sup>-3</sup> value measured at 1.0 Oe	Average
Rao (Personal comm.)	K 155	1.896	1.44
	K 89	2.041	
	K 133	0.776	
	K 42	2.148	
	K 40	1.811	
	K 14	0.283	
	K 138	0.075	
	K 11	1.291	
	K 60	2.534	
	K 37	1.794	
	K 149	1.146	
This study	J 119	3.366	1.84
	A 80	0.677	
	V 31	1.488	

Table 2. Susceptibility of the sediments.

Anomaly/ track	$\theta$	Depth to top of dyke	Width	Anomaly/ track	$\theta$	Depth to top of dyke	Width		
M1	A	60 <sup>o</sup>	50 m	160 m	M2	A	54 <sup>o</sup>	108 m	230 m
M1	B	50 <sup>o</sup>	52 m	130 m	M2	B	45 <sup>o</sup>	102 m	170 m
M1	C	60 <sup>o</sup>	47 m	170 m	M2	C	60 <sup>o</sup>	98 m	160 m
					M2	D	45 <sup>o</sup>	100 m	210 m

Table 3. Result of depth estimates by the Koulomzine (1970) method.

Profile	Average depth to basement
A	45 m
B	51 m
C	48 m
D	49 m

Table 4. Average basement depths from spectral analysis.

## FIGURE CAPTIONS

- Fig. 1. Extent of the onshore Deccan Traps in India (Subbarao, 1969).
- Fig. 2. Map of the Konkan coast with dykes and fractures from Landsat imageries mapped by Das and Ray (1976). The study area, Ratnagiri, shown by hatching, as is the area to the north, Jaigarh. Results from the Jaigarh shelf will be presented as a separate study (Ramana, in prep.).
- Fig. 3. Bathymetric map contoured at 1 m interval. Magnetic profile lines A-D are shown.
- Fig. 4. Magnetic residual anomalies plotted perpendicular to survey tracks.
- Fig. 5. Magnetic residual anomaly field contoured at 50 nT interval.
- Fig. 6. Aerial photo lineaments from Das and Ray (1977) and gravity lineaments identified by applying the technique of Frost (1977) on the Bouger anomaly map of Das and Ray (1977).
- Fig. 7. Rose diagrams and frequency polygons based on data from Das and Ray (1977).
- Fig. 8. Rose diagrams and frequency polygons based on data from Das and Ray (1976). The dominant magnetic trends in the survey area are superimposed (black bars) on the frequency polygons.
- Fig. 9. Observed, computed regional and corrected magnetic anomaly along profile B (top), and its computed power spectrum (bottom).
- Fig. 10. Results from the sampling of bottom sediments in the Mirya Bay. From Siddiquie et al. (1979).
- Fig. 11. Magnetic anomalies plotted perpendicular to the survey tracks and contours showing the percentage of heavy magnetic mineral content in the Mirya Bay bottom sediments.



Fig. 12. Percentage of heavy magnetic minerals plotted along profiles B and C in the Mirya Bay.

Fig. 13. Models of simple placer configurations. The thick curve represents the second observed positive anomaly east of M1 in profile B. The thinner curve is the calculated anomaly.

Model parameters:

a and b: suscept. .00144, body azimuth  $90^{\circ}$

c : suscept. .00144, " "  $0^{\circ}$

d and e: suscept. .00144 for central body with a 50% and 75% reduction for the outer bodies.

Body azimuth:  $90^{\circ}$  (d) and  $0^{\circ}$  (c).

Fig. 14. Models showing the magnetic effects of basement relief for various models striking east-west (right hand-side) and profiles striking north-south (left hand-side). A Deccan Trap susceptibility of .00268 is used in all models. The observed anomaly in Fig. 13. is included for reference (thick line). These models were computed for an inclination of  $20^{\circ}$ . If the declination is about  $60^{\circ}$ , as reported for the Traps in the literature, the resulting amplitudes will increase by a factor of 2 or more.

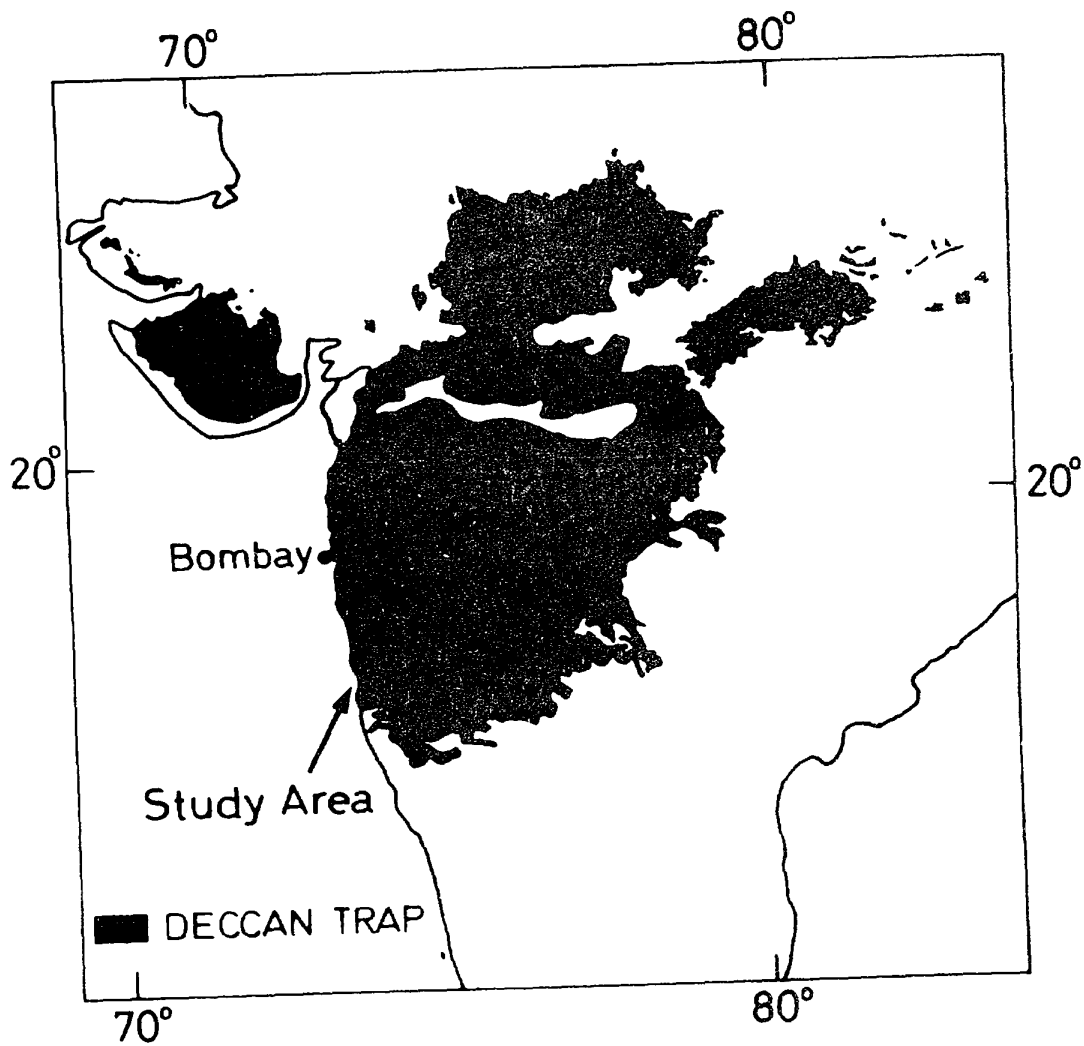


Fig. 1

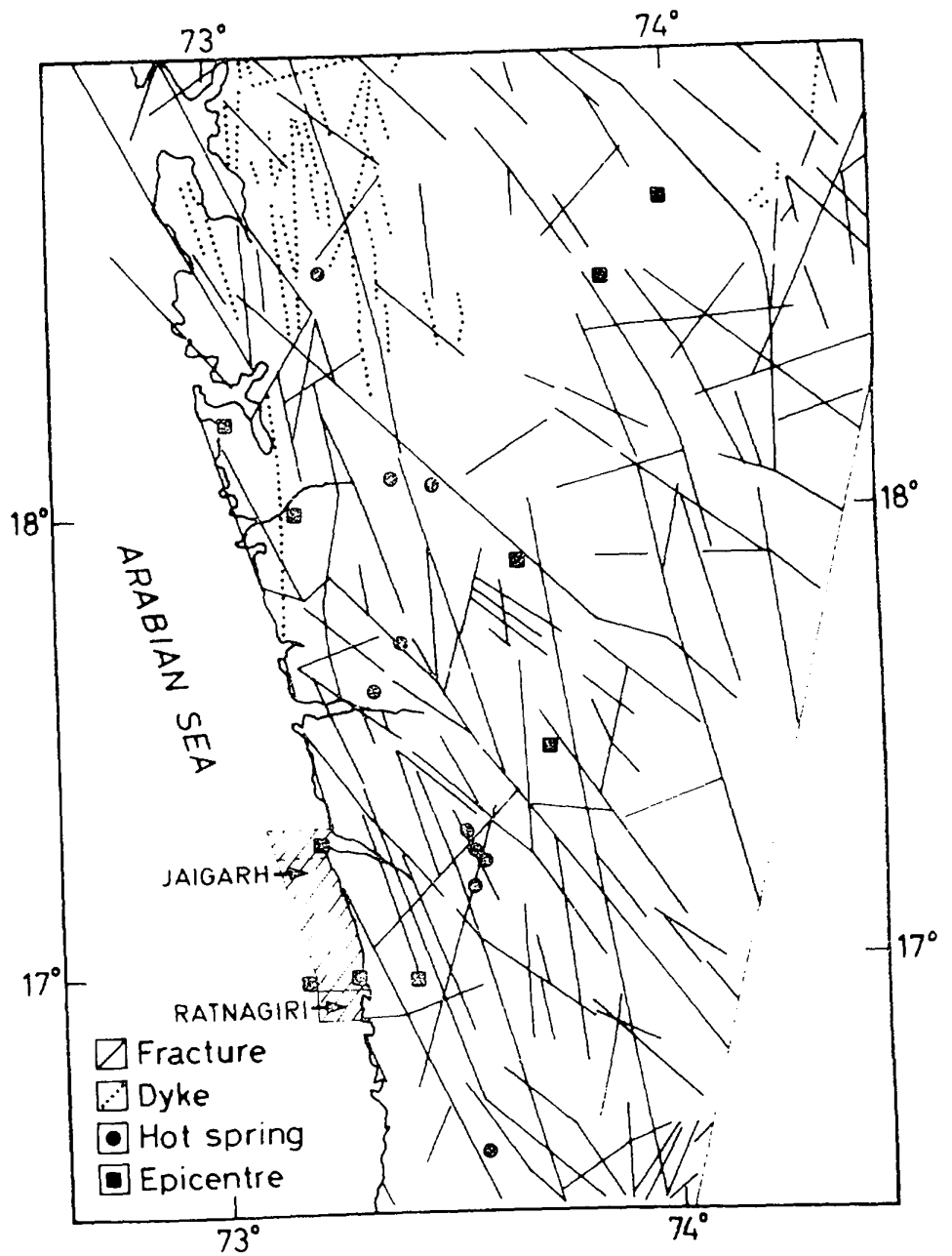


Fig. 2

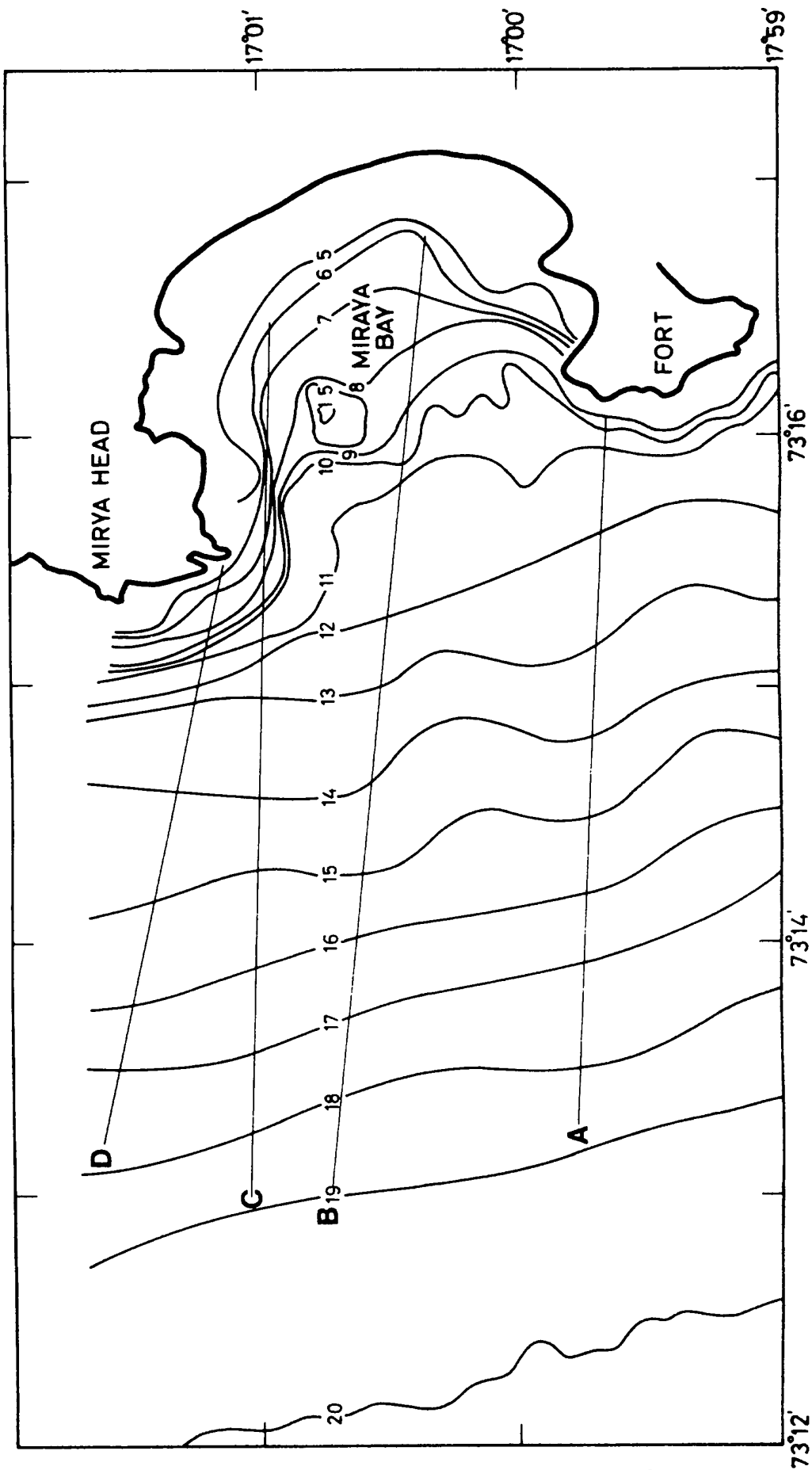


Fig. 3

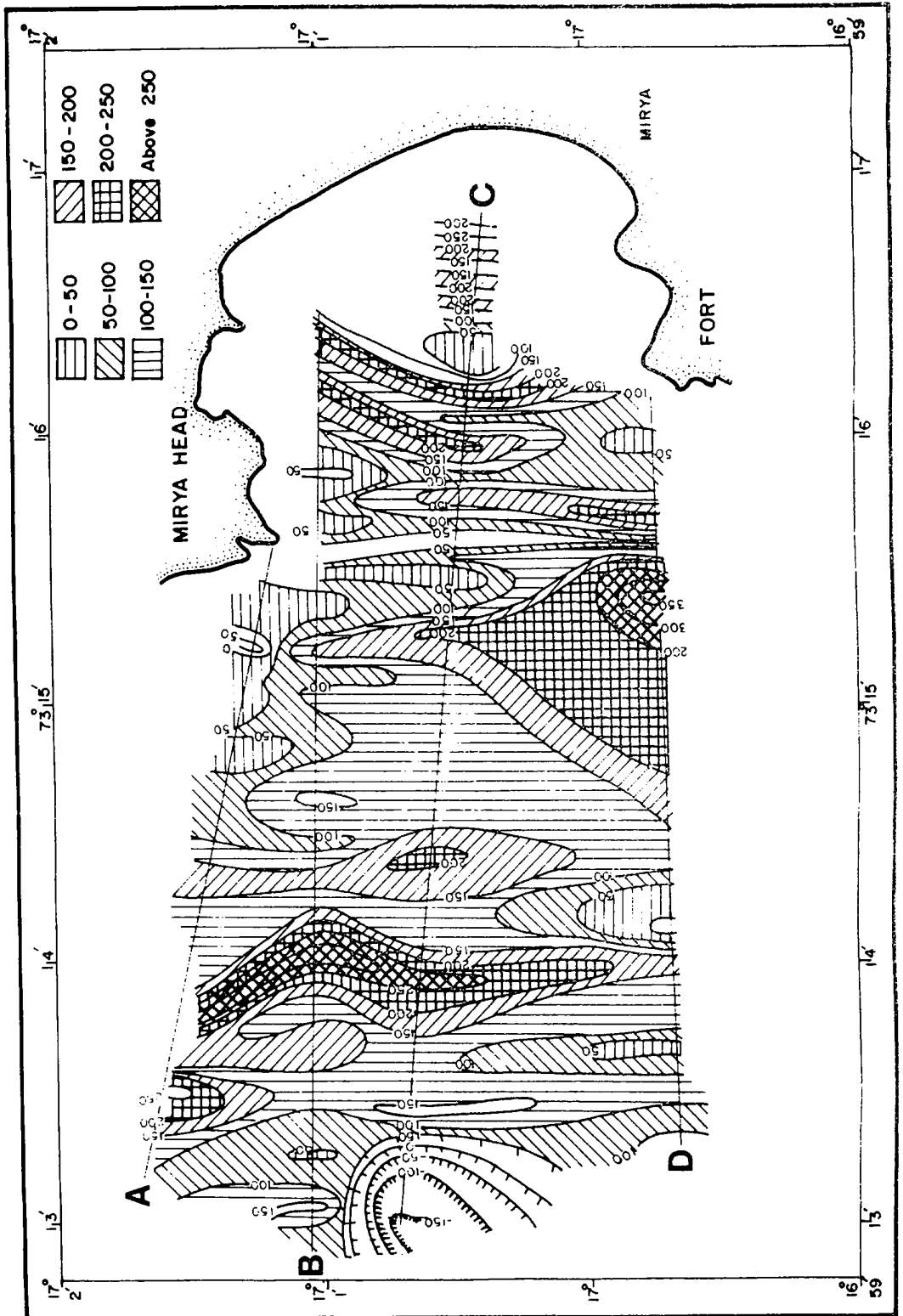


Fig. 4

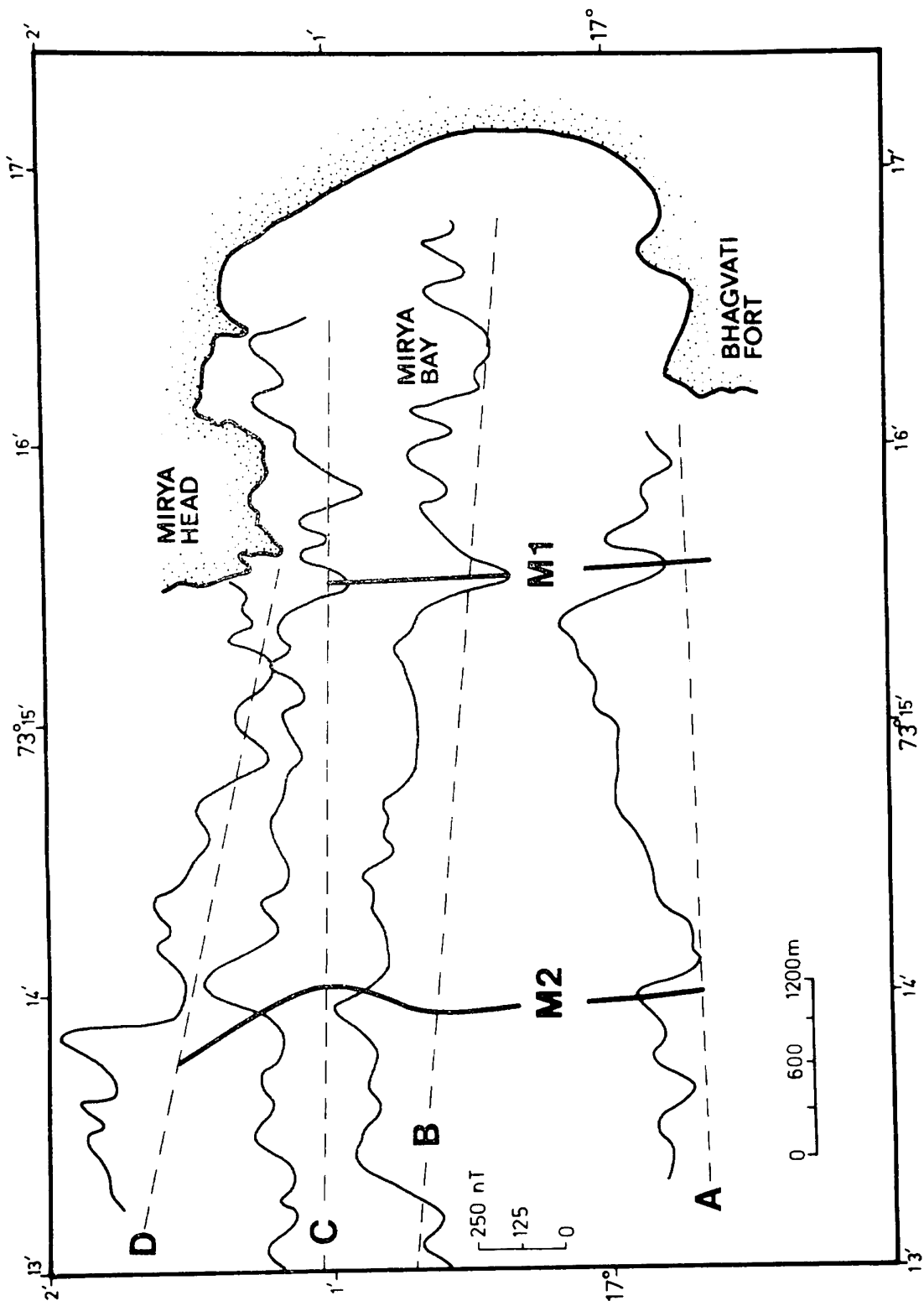


Fig. 5

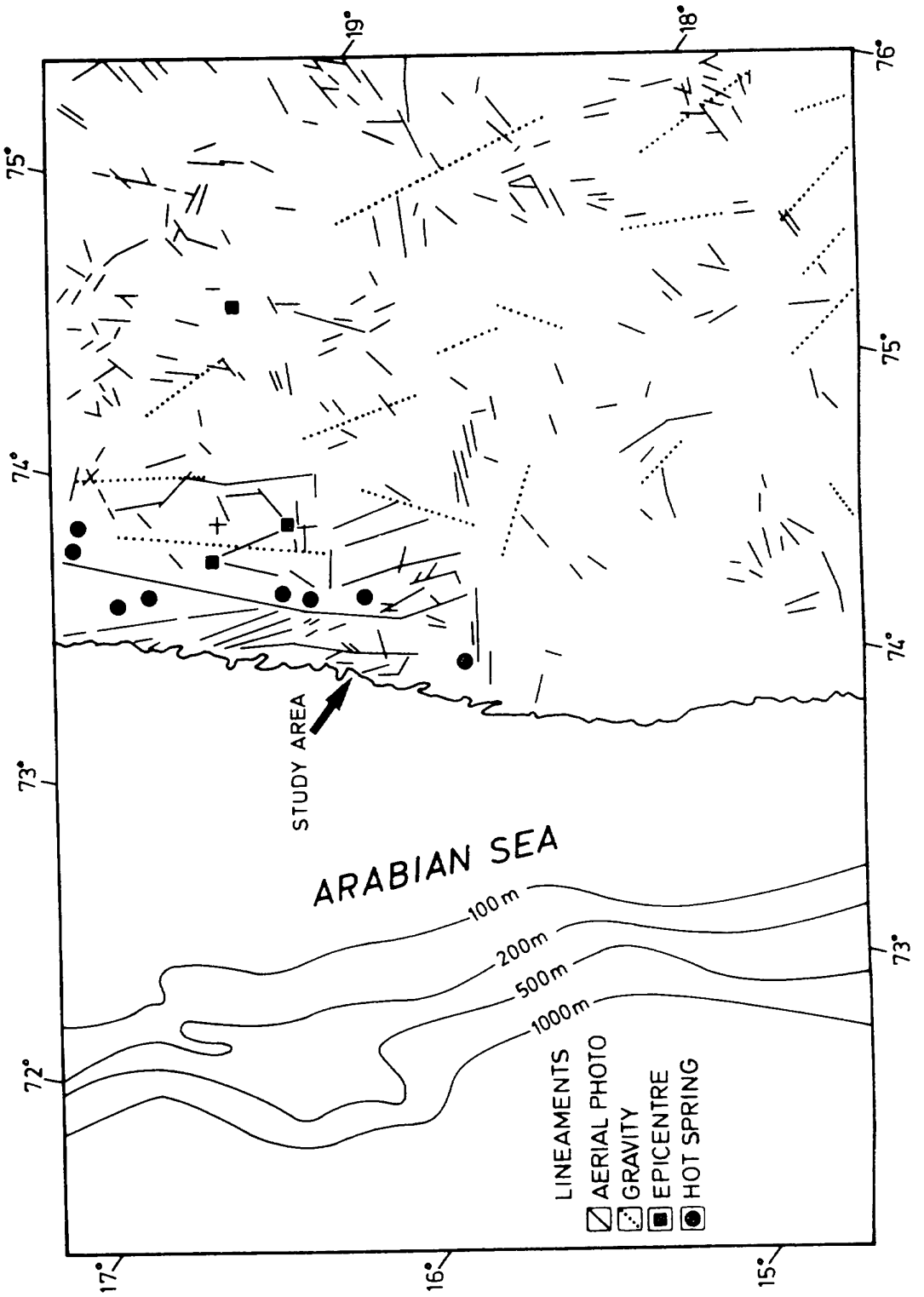
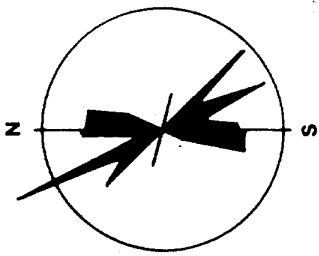
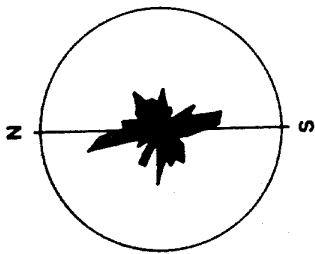


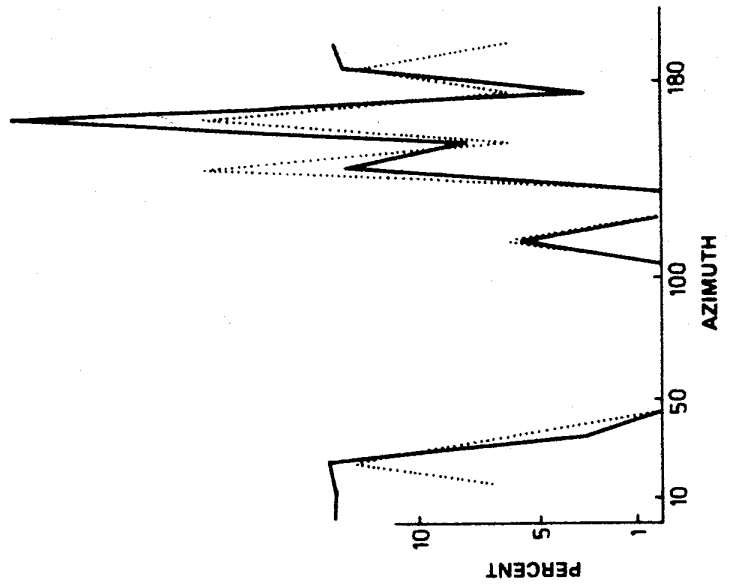
Fig. 6



GRAVITY LINEAMENTS



AERIAL PHOTOLINEAMENTS



..... FREQUENCY OF LINEAMENTS  
 — CUMULATIVE LENGTH OF LINEAMENTS

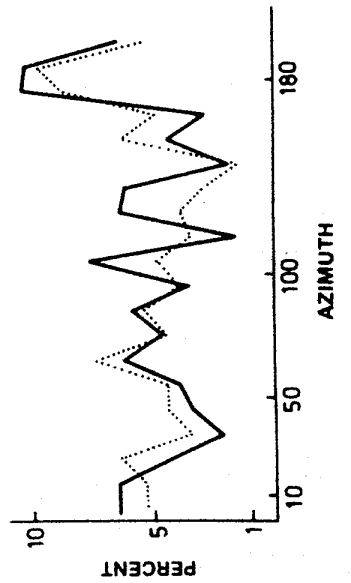
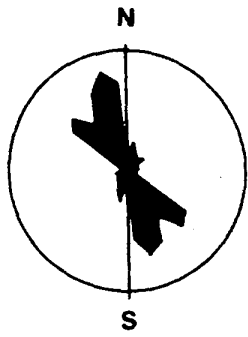
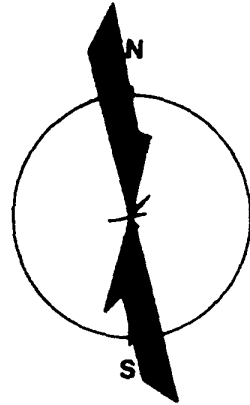


Fig. 7





**FRACTURES**



**DYKES**

■ TREND OF MAG ANOMALIES

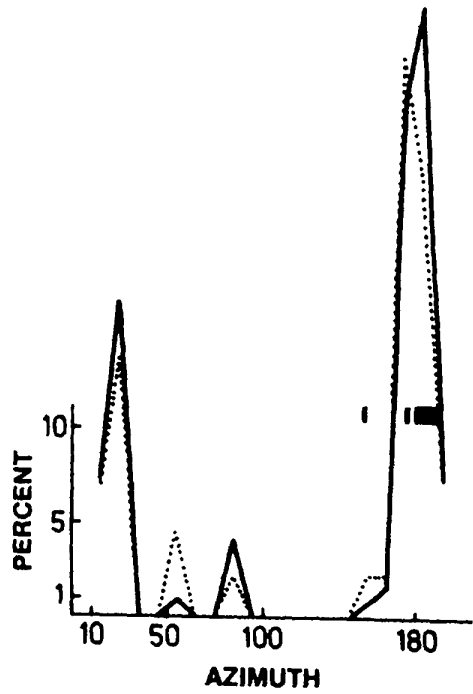
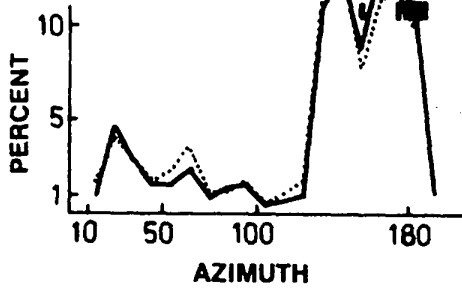


Fig. 8

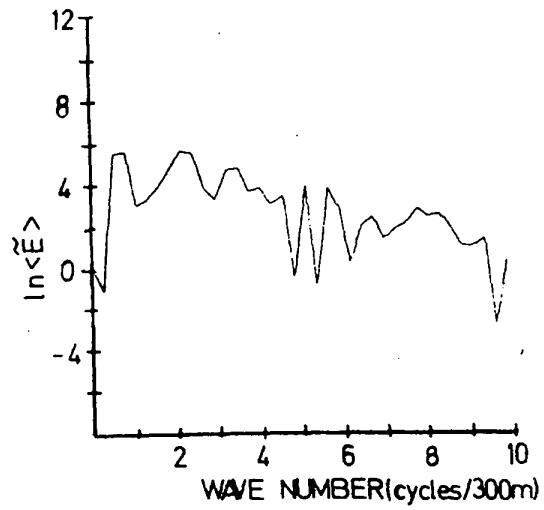
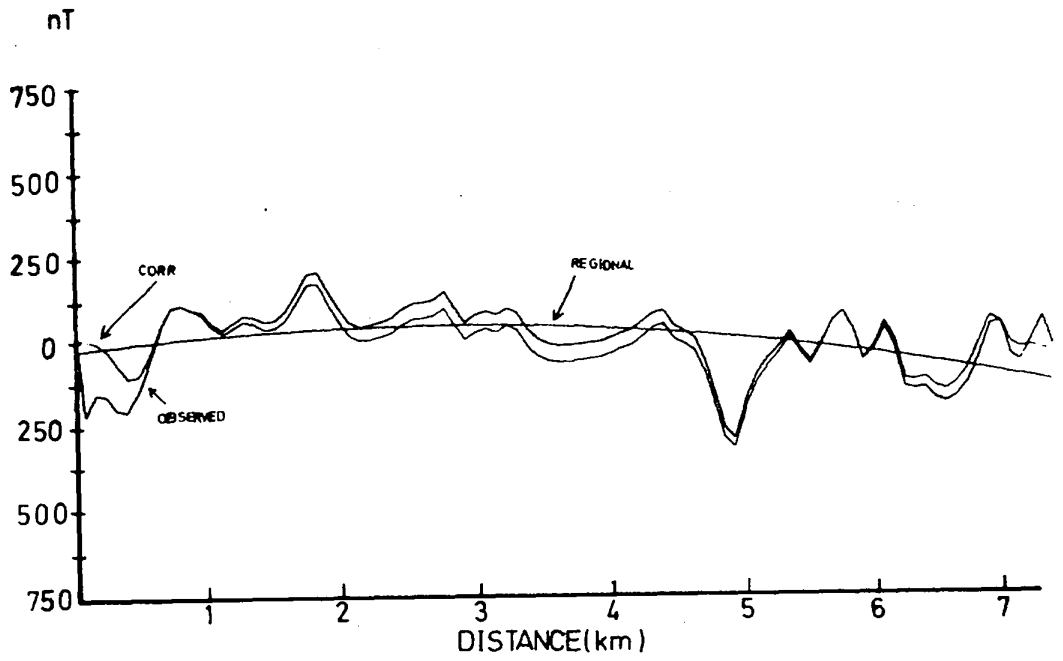


Fig. 9

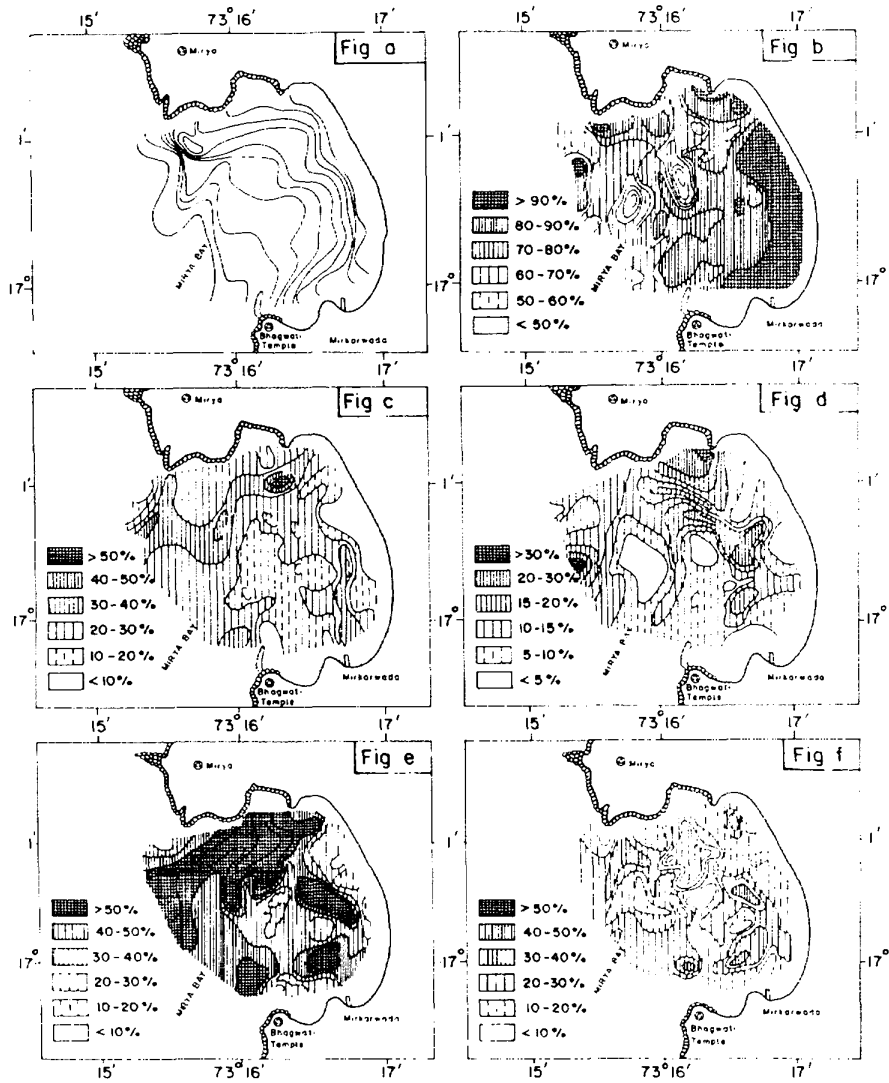


Fig a: MAP SHOWING BATHYMETRY Fig b: SAND DISTRIBUTION  
 Fig c: HEAVY MINERALS MAGNETIC TOTAL SEDIMENT Fig d: ILMENITE TOTAL SEDIMENT  
 Fig e: HEAVY MINERALS TOTAL SEDIMENTS Fig f: HEAVY MINERALS NON MAGNETICS TOTAL SEDIMENT

Fig. 10

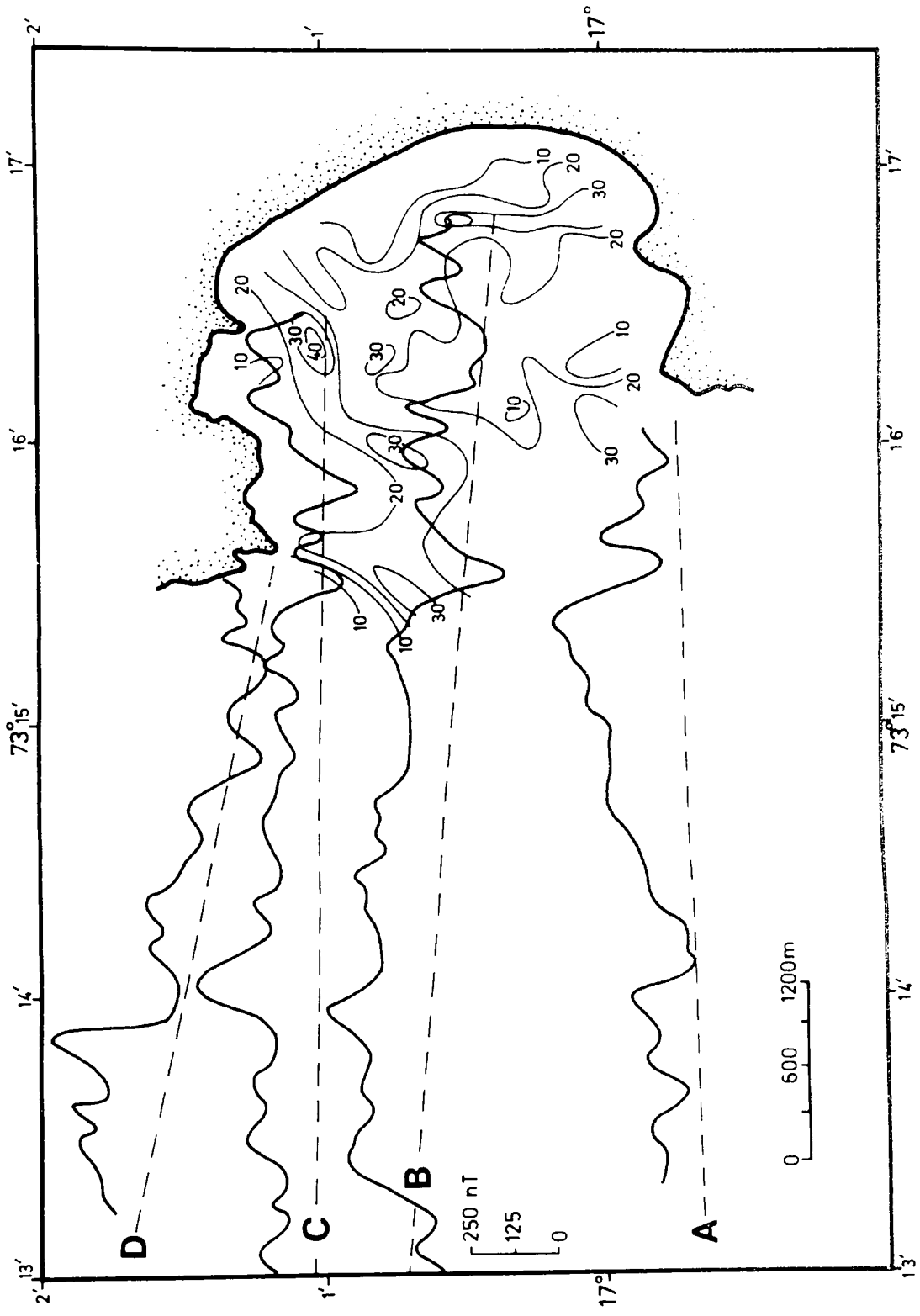


Fig. 11

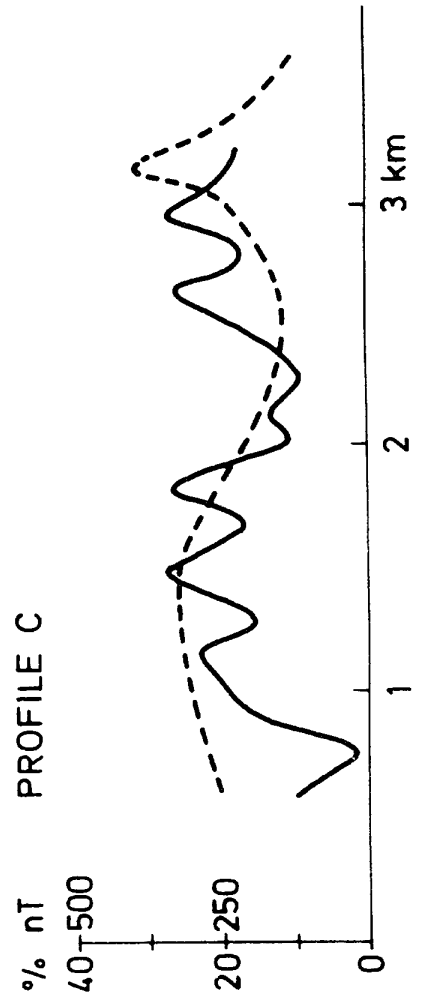
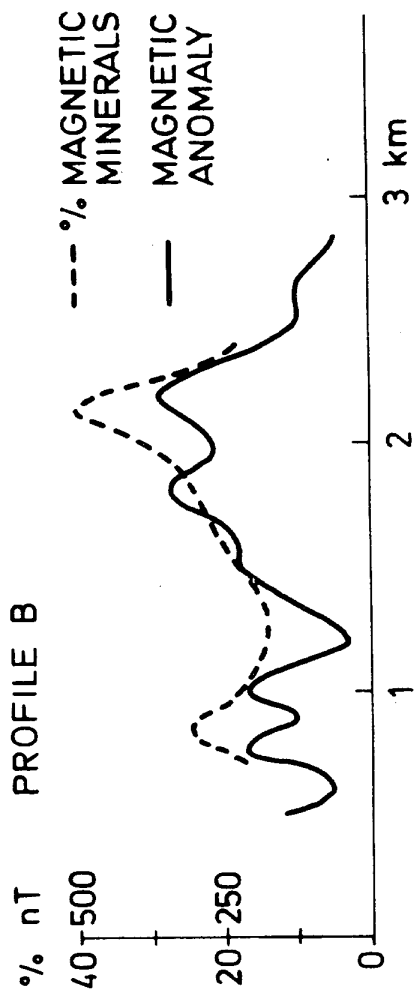
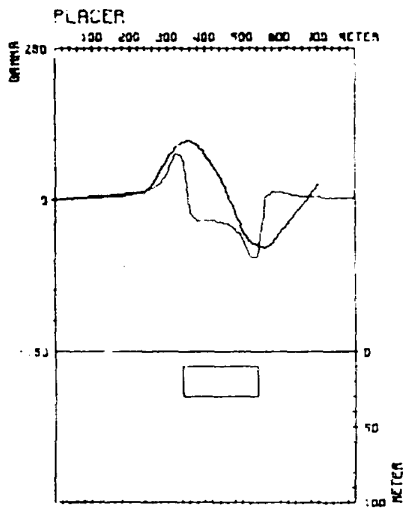
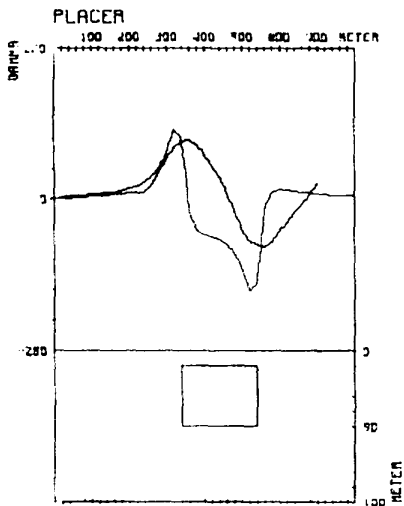


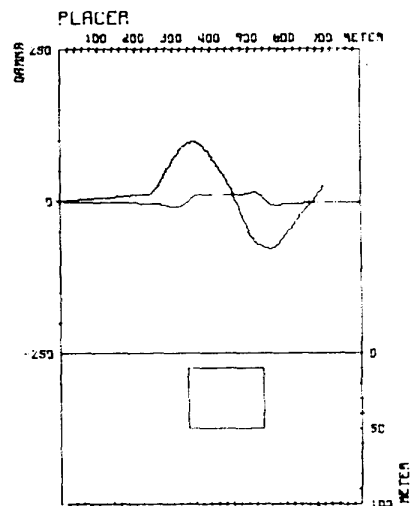
Fig. 12



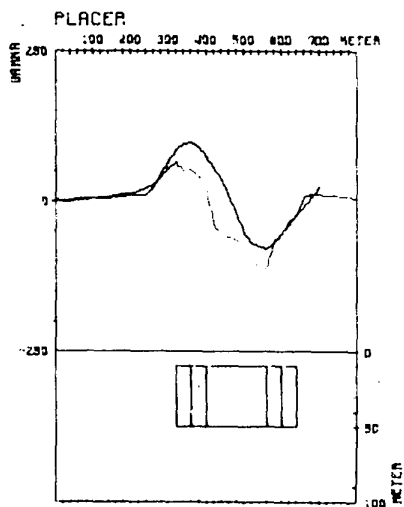
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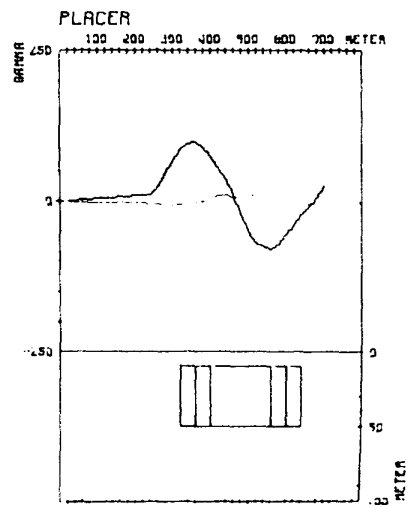
b



c



d



e

Fig. 13

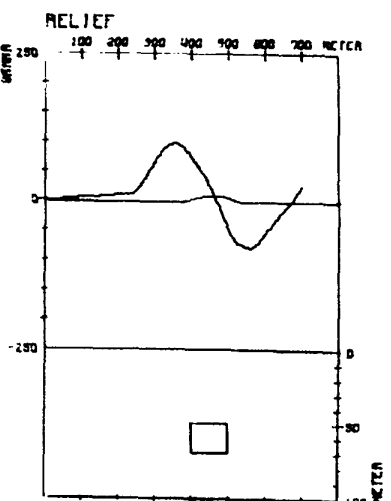
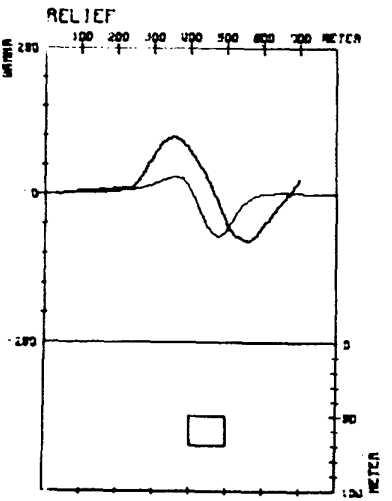
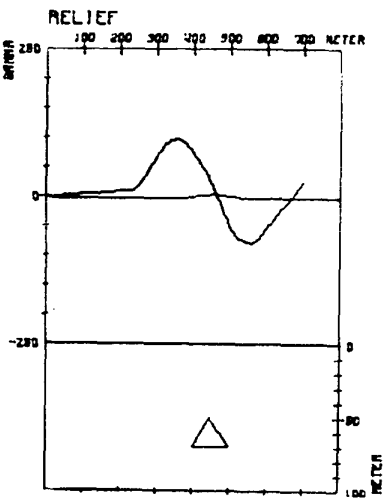
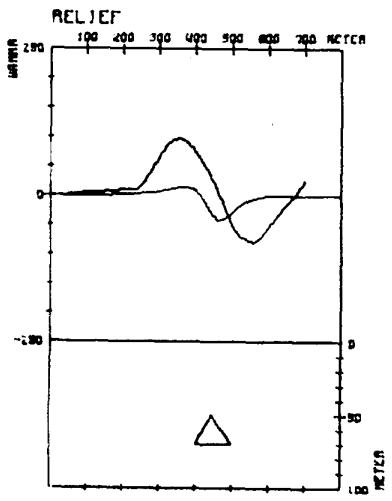
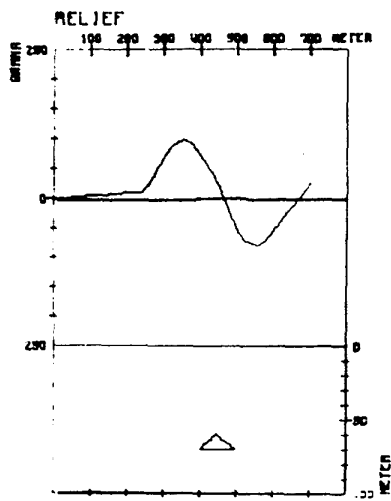
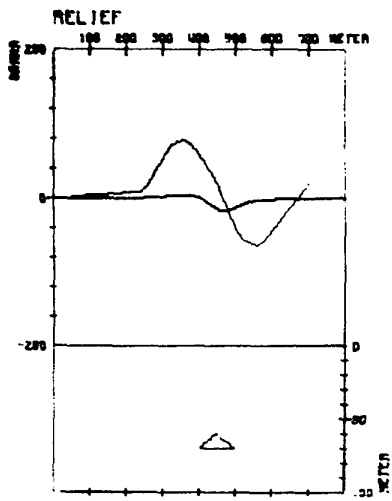


Fig. 14