

Marine magnetic anomalies in the northeastern Arabian Sea

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Abstract—Based on the analysis of some additional magnetic profiles, an updated correlation and identification of the sea-floor spreading type magnetic lineations in the northeastern Arabian Sea is presented. The anomaly 24A-B sequence, characterised by double troughed shape, is the most conspicuous anomaly identifiable across the entire area. Identification and correlation is suggested for; (i) well developed anomaly 23, and (ii) some of the hitherto unidentified isolated prominent anomalies, which were considered to be of sea-floor spreading origin by earlier workers. A new fracture zone is proposed west of 64° E longitude and minor alteration in the locations of the previously postulated fracture zones is suggested. Estimated half spreading rates between anomalies 23 and 28 vary from 4.5 to 9.1 cm y⁻¹.

INTRODUCTION

The northeastern Arabian Sea is considered to have a two-phase evolutionary history. The Chagos-Laccadive-Laxmi (C-L-L) Ridge complex approximately represents a boundary (Fig. 1) between areas of two different types of crust. The areas between C-L-L ridge complex and the western continental slope of India (Eastern basin) is underlain by transitional crust formed by rifting and related processes. Whereas, in the areas south and west of C-L-L ridge complex (Western basin), the crust is oceanic, formed by the process of sea-floor spreading (NAINI and TALWANI, 1982).

Sea-floor spreading history of the Arabian Sea was studied by several workers (McKENZIE and SCLATER, 1971; WHITMARSH, 1974; NORTON and SCLATER, 1979; NAINI and TALWANI, 1982; SCHLICH, 1982). These studies suggest that the Arabian Sea was created by rifting apart of the Indian and Seychelles continental blocks and symmetric sea-floor spreading along the Carlsberg Ridge. The opening of the Arabian Sea was initiated in early Tertiary time, when the spreading centre in the Mascarene basin jumped northwards to a position between India and Seychelles (SCHLICH, 1982). According to SCHLICH (1982), anomaly 28 is the youngest identifiable magnetic anomaly in the Mascarene basin and the spreading in Arabian Sea started since anomaly 27. On the otherhand, in this area, anomaly 28 is the oldest anomaly identified by other workers (McKENZIE and SCLATER, 1971; NAINI and TALWANI, 1982), indicating initiation of the opening of the Arabian Sea just prior to the anomaly 28 time. The earlier studies (McKENZIE and SCLATER, 1971; WHITMARSH, 1974; NORTON and SCLATER, 1979; NAINI and TALWANI, 1982) have indicated; (i) the entire magnetic anomaly sequence 20-28 is present only between 10°N to 20°N and 60°E to 65°E, (ii) anomalies older than 24 were not recognized east of 65°E so far, and (iii) the sequence of anomalies are offset by four NNE-SSW trending fracture zones (Fig. 1).

In this paper, we present identification of magnetic lineations along some recently acquired magnetic profiles in the northeastern Arabian Sea, and suggest modifications to some of the earlier interpretations.

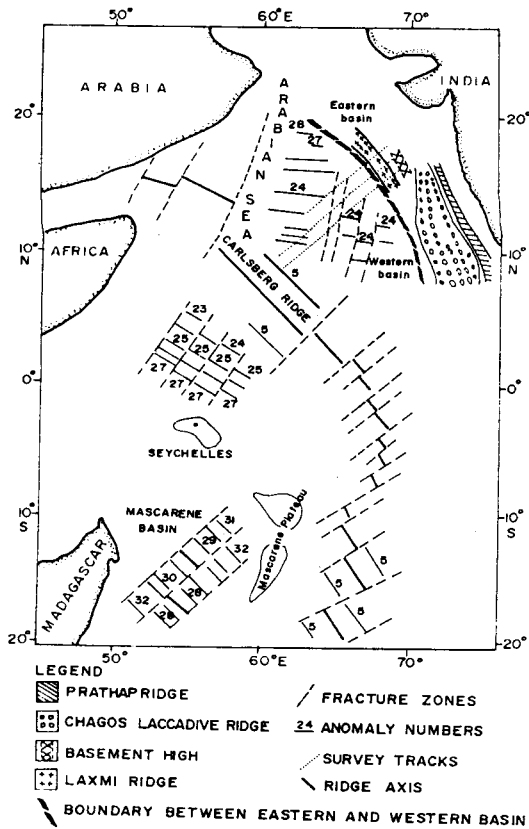


Fig. 1. Generalised map showing main structural elements, magnetic lineations and fracture zones in the Arabian Sea (compiled from NAINI and TALWANI, 1982; SCHLICH, 1982).

DATA

Sea surface magnetic data were collected along three profiles (annotated with SK in Figs. 2 and 3), during the 50th cruise of RV *Sagar Kanya* in 1989. Primary position control along the track lines was maintained with an Integrated Navigation System. It uses a Magnavox (model 1107 RXT) dual-channel satellite navigation system as primary navigational aid. The navigational accuracy is of the order of 500 m. The total magnetic field was measured by a Geometrics Proton Precession Magnetometer towed 225 m aft of the vessel. The residual total magnetic intensity anomalies were calculated by removing the International Geomagnetic Reference Field of 1989 as regional field. Additional magnetic data were obtained from the National Geophysical Data Centre (Boulder, USA), and the magnetic profiles presented by NAINI and TALWANI (1982). The magnetic data are presented as profiles along the ship's tracks (Fig. 2) and as projected profiles (Fig. 3).

RESULTS AND DISCUSSION

After recompiling the available magnetic profiles of this area, we reviewed the anomaly identifications suggested by previous workers (McKENZIE and SCLATER,

1971; NAINI and TALWANI, 1982). We agree with most of their identifications, however with our new data we suggest alternate identifications to some anomalies particularly in the southern part of the study area. Wherever we have not added any new identifications or suggested any modification, the identifications by earlier workers are maintained (Figs. 2 and 3). We estimated the half spreading rates by considering the average distance between the mapped position of the identified anomalies and using the recent magnetic polarity reversal time scale (BERGGREN *et al.*, 1985). The synthetic magnetic anomaly profiles have been computed assuming a thickness of 2.0 km and a susceptibility of 0.01 cgs units, for the basalt layer responsible for the observed magnetic anomalies. The oceanic crust was assumed to lie at about 7.0 km below the sea-level. The synthetic anomalies were computed by the model generated from a ridge located at 10°S with a paleo strike of N75°W, and observed presently at 15°N striking approximately E-W direction.

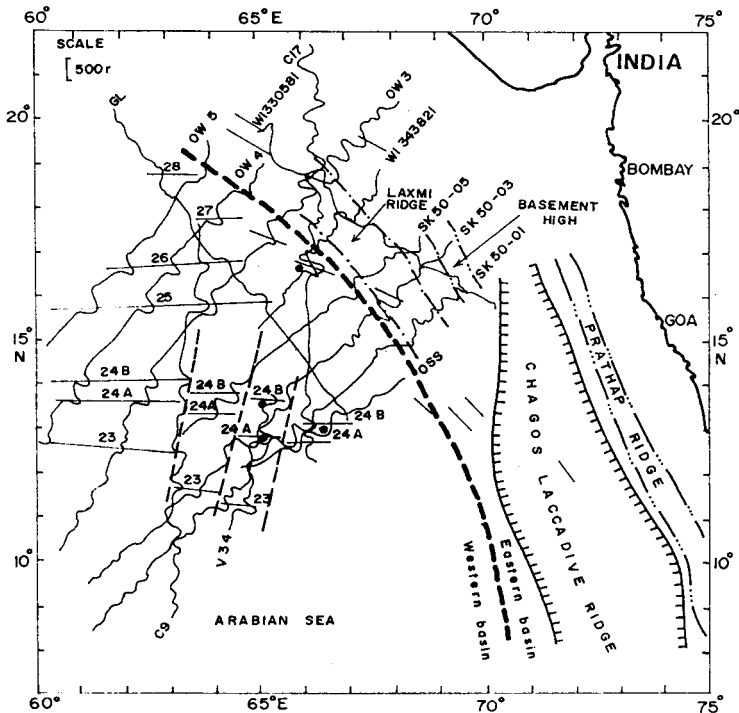


Fig. 2. Magnetic profiles plotted at right angles to the tracks, and identified sea-floor spreading anomalies. Solid dots represent isolated prominent anomalies identified by NAINI and TALWANI (1982). Thin lines with numbers are magnetic lineations and long dashed lines represent fracture zones. Thick dashed line corresponds to the boundary between eastern and western basins.

In the magnetic polarity reversal time scales (HEIRTZLER *et al.*, 1968; LABRECQUE *et al.*, 1977; BERGGREN *et al.*, 1985) the normal polarity epochs of anomalies 25 and 26 are separated on both sides by very long (more than 2.0 my) period of reversed polarity epochs, thereby making this part of the sequence very distinctive. In previous studies (McKENZIE and SCLATER, 1971; NAINI and TALWANI, 1982) this sequence was traced upto about 65°E (Fig. 2). With new profiles we could not observe these anomalies further eastwards from 65°E. Southwards from anomaly 25, the magnetic

lineations characterised by its double troughed nature represent anomaly 24. These two troughs depict the signature of the two periods of normal polarity ordinarily denoted as anomaly 24. For further discussion, we define anomaly 24A as the first and 24B as the second of these two periods of normal polarity. We introduced this nomenclature to label anomaly 24 segments identified in present as well as previous studies (McKENZIE and SCLATER, 1971; NAINI and TALWANI, 1982). Based on our data we could trace the anomaly 24A-B (Fig. 2) across the entire study area and observe a slight different positions of these anomalies as compared to the positions given by NAINI and TALWANI (1982). It can be seen that anomaly 24A-B is the most conspicuous and easily recognizable anomaly sequence of this area (Fig. 3).

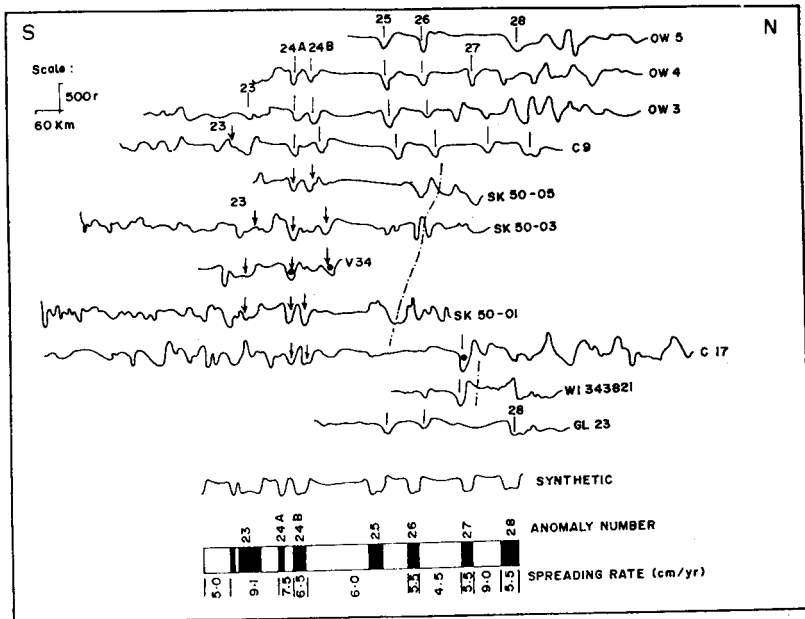


Fig. 3. Synthetic and observed magnetic anomalies in the northeastern Arabian Sea. The observed profiles are projected onto $N0^{\circ}E$. Synthetic profile was generated using magnetic polarity reversal time scale of BERGGREN *et al.* (1985), along with following parameters- (a) Paleo ridge striking $N75^{\circ}W$ and spreading at $10^{\circ}S$ with variable rates (given below model), (b) anomalies presently observed at $15^{\circ}N$ with an east-west strike, (c) ambient field: inclination = 15° , declination = -1.5° , (d) remanent field: inclination = -24° , declination = -15° . In synthetic model, black and white represent normally and reversely magnetized blocks respectively. Dash - dotted lines represent western boundary of the Laxmi Ridge. Solid dots represent isolated prominent anomalies mentioned in Figure 2. Anomaly identifications suggested in the present study are shown by vertical arrows, other identifications are after NAINI and TALWANI (1982).

We believe that the identification of anomaly 23 was not very convincing in the earlier studies. In the recent magnetic polarity reversal time scales (LaBREGUE *et al.*, 1977; BERGGREN *et al.*, 1985), the anomaly 23 is characterised by an older short span (approx. 0.15 my) of normal, a brief span (approx. 0.06 my) of reverse and a large span (approx. 0.61 my) of normal polarity epochs. Whereas in the magnetic time scale (HEIRTZLER *et al.*, 1968), the anomaly 23 is defined by a single large span (approx. 0.9 my) of normal epoch. Using the above mentioned time scales and the latest reported

half spreading rates (NAINI and TALWANI, 1982), synthetic profiles were generated for anomaly 23 (Fig. 4). It can be seen that except for the profile generated using HEIRTZLER *et al.* (1968) time scale, the other two scales result in a distinct shape of anomaly 23. The anomaly segments which very closely resemble with the distinct shape of anomaly 23 can be seen in the southern end of profile V34 and the neighbouring profiles SK50-01 and SK50-03. Therefore, we are inclined to identify these anomaly segments as anomaly 23 in this area. Further southwards from anomaly 23, we could not confidently trace distinct lineations of still younger anomalies. We feel the data is still inadequate to establish these lineations.

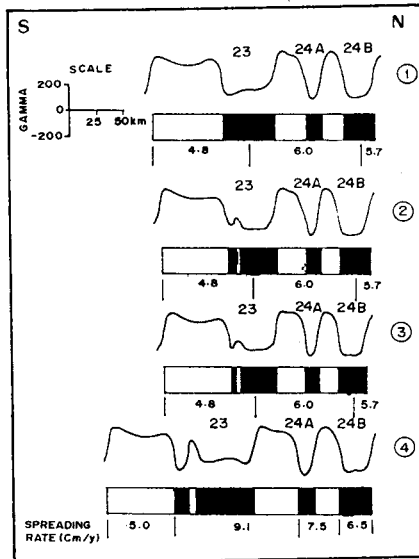


Fig. 4. Synthetic magnetic profiles to demonstrate the shape of anomaly 23. Different magnetic polarity reversal time scales used to generate synthetic anomalies are as follows; for profile 1, HEIRTZLER *et al.* (1968); for profile 2, LaBRECQUE *et al.* (1977); for profile 3 and 4, BERGGREN *et al.* (1985). Half spreading rates (given below models) used for profiles 1,2 and 3 are after NAINI and TALWANI (1982), and for profile 4 is from present study.

In the northeastern Arabian Sea, NAINI and TALWANI (1982, their Fig. 8) identified some isolated prominent anomalies, which could not be definitely correlated from one track to another, but were considered by them to be of sea-floor spreading origin. With the additional data, we attempted to identify some of those isolated anomalies (marked with dots in Fig. 2). One such sequence is observed on profile V34. The profile SK50-03 crosses the V34 profile obliquely. In profile SK50-03 we could observe the same sequence and correlate them with anomalies in profile V34, and establish that these dotted anomaly pair also represents an east-west trend. The anomaly segment in profile SK50-03, which corresponds to the northern dotted anomaly of V34, very closely matches with the segment of profile C9 between anomalies 24B and 25 (Fig. 3). We therefore conclude that northern dotted anomaly of V34 and corresponding anomaly in SK50-03 represent anomaly 24B. Similarly, the segment from the southernly dotted anomaly to anomaly 23 in profile V34, matches with anomaly segment in profile SK50-01 southwards from anomalies 24A to 23. Therefore, we infer that the southernly dotted anomaly of profile V34 is anomaly 24A. It can be seen (Figs. 2 and 3) that the zone between anomaly 24A and 24B in both the profiles SK50-03 and V34 is broader as compared to the other profiles, and this broad zone also trends east-west. If we

invoke the presence of a fracture zone to explain this broadening, then the trend of the fracture zone has to be oblique to the established general trend of the fracture zones of this area. Alternatively, if we consider the presence of a fracture zone parallel to the other fracture zones of this area, then there should be an offset in the anomaly sequence 24A and 24B in both profiles SK50-03 and V34. It is apparent that there is no such offset (Fig. 2). This broad zone perhaps represents imprint of a segment of short lived extinct spreading axis, or indication of some anomalous volcanism and crustal generation.

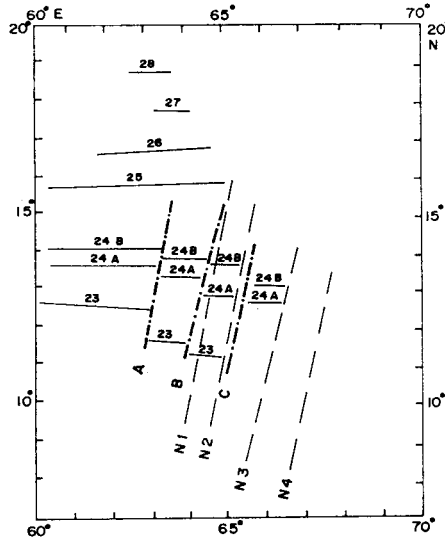


Fig. 5. Location of postulated fracture zones in the northeastern Arabian Sea. Thin dashed lines (N1,N2,N3 and N4) are after NAINI and TALWANI (1982), and dashed dotted lines (A,B and C) are proposed in the present study. Note fracture zone A is a new one, whereas B and C are suggested modifications in the positions of N1 and N2.

Towards the northern end of profile C17, NAINI and TALWANI (1982) reported one more such isolated anomaly. Here we got new USNS *Wilkes* profile (WI 343821), which intersects profile C17 obliquely. With these two profiles, we observed that the dotted anomaly of C17 profile represents nearly NW-SE lineation. Similar NW-SE trending lineations were reported by NAINI and TALWANI (1982) on profile OW3 approximately along 65°E longitude. The NW-SE trending lineations in the eastern part of the Arabian Sea was considered to be of non sea-floor spreading origin by NAINI and TALWANI (1982). Whereas, MASSON (1984) considered these NW-SE lineations as evidence of pre-anomaly 28 sea-floor spreading between India and Seychelles. Although the present data do not throw any light regarding the identification of these anomalies, but we infer, that a general pattern of approximately NW-SE trending large amplitude prominent anomalies are present in the immediate vicinity of the western boundary of the Laxmi Ridge. Additional closely spaced magnetic profiles are needed to understand the extent, correlation and origin of these anomalies.

The spreading rates between anomalies were estimated during repeated trials so as to obtain a good match between the synthetic profile and the undisturbed segments of the observed anomaly profiles. From the best fit model, we obtain half spreading rates varying from 4.5 to 9.1 cm y^{-1} between anomalies 23 and 28. The half spreading rates estimated by us are slightly higher in comparison to those reported by NAINI

and TALWANI (1982). Partly this may be attributed to the use of different magnetic polarity reversal time scales in these two studies. Half spreading rate upto 8.1 cm y^{-1} between anomalies 23 and 27 was reported in the central and eastern Indian Ocean (SCLATER and FISHER, 1974; LIU *et al.*, 1983). It indicates a very rapid northward drift of India in this period. The high spreading rates (maximum 9.1 cm y^{-1}) estimated in the present study (mainly between anomalies 23 and 24) are therefore compatible to these observations.

The anomaly pair 24A and 24B could be traced continuously from profiles OW4 to C9, but we observe a right lateral offset of these anomalies on profile SK50-05 (Fig.2). We therefore, suggest the presence of a new fracture zone west of 64°E (Fig. 5). This fracture zone also accomodates the offset in anomaly 23 observed southwards. Based on our study, we offer slight modifications of the position of two other fracture zones (N1 and N2), postulated by NAINI and TALWANI (1982), and the suggested fracture zone positions are shown in Figs. 2 and 5.

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