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Delineation of Basement and Curie Isotherm of Bay of Bengal from Spectral Analysis of Magnetic Data

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ABSTRACT
Fifteen total intensity magnetic profiles in the Bay of Bengal were processed in frequency domain. The profiles were divided into small overlapping segments for determining average depths from spectrum. High frequency component was resolved from the frequency spectrum and average depth to the deeper levels of Curie Isotherm was determined from low frequency range of spectrum. Appropriate depths to the upper marker (Magnetic basement) and the lower surface (Curie Isotherm) along the length of the profile were tabulated. From these depths to the upper and lower markers of magnetic material, tentative models for crustal structure were prepared. Main geological features such as Continent Ocean Boundary, 85^{0}E ridge and 90^{0}E ridge have been delineated distinctly from the inferred models. It has been observed that the depth to the basement varies between 8km and 10km along southern profiles and between 10km and 12km along northern profiles. The Curie Isotherm depth varies between 15km and 17km along southern profiles and between 20km and 22km along northern profiles. The models also reveal the crustal dipping and thickening towards northern latitudes.

INTRODUCTION

The Bengal Fan/Geosycline forms the major part of the Northern East Indian Ocean and is bounded by the East Coast of India, Bengal Coast and South Western Coast of Burma plateau towards west, north and north-eastern sides respectively. Towards east, it is bounded by the Andaman group of Islands (Curray & Moore 1974). The Bengal deep sea fan is the largest fan in the world, a result of the intense continental collision of India and Asian plates, with a consequent uplift of the largest and most active mountain range in the world, the Himalayas. The Bengal Basin is fed by the confluent Ganges and Brahmaputra Rivers, which produce the greatest flow of sediment in the world today (Brune et al. 1992). Mahanandi, Godavari, Krishna, Palar and Cauvery Rivers also contribute a good chunk of sediments to Bengal fan. A superthick sedimentary strata of about 22km overlies the basement in the north (Brune et al. 1992). The Bengal sediment extents as far as approx. 7^{0}S in the Central Indian Ocean (Schlich 1982). The Bengal Basin or Bengal Geosycline is one of the thickest sedimentary basins of the world. The 90^{0}E ridge divides the entire Bay of Bengal into Bengal fan and Nicobar fan lobe. The water depth within the fan varies between less than 2000 and 4500meters. The fan has been divided into upper fan - off Ganges delta, which includes the southern extension of the ' swatch of no ground', middle fan and lower fan. It is widely known that most of the floor of the North Eastern Indian Ocean has evolved through the process of rifting of India from contiguous Antarctica-Australia and its subsequent northward drift. Bangal fan presents a complete record of the early history of evolution of the North Eastern Indian Ocean. The Bay of Bengal with its thick pile of sediments is important to understand the pattern of deformation experienced by the oceanic lithosphere, which was subjected to vertical loading or horizontal compressive forces.

Under favourable conditions, analysis of marine magnetic data is useful to construct the history of the Earth's magnetic field back to late Jurassic (175Ma) and to trace the relative motion of the rigid tectonic plates. Le Pichon & Heirtzler (1968) made the first attempt to interpret the linear magnetic anomalies in the Indian Ocean based on widely spaced profiles in terms of the seafloor-spreading hypothesis. Fisher, Sclater & McKenzie (1971) carried out a regional study of seafloor topography, linear magnetic anomalies and earthquake epicentres of the Central Indian Ridge. Mc Kenzie & Sclater (1971) utilising all available ship and aeromagnetic data across the Central Indian Ridge to identify seafloor spreading magnetic anomalies and transform faults and established the complex faulted and segmented nature of the Central Indian Ridge. Norton & Sclater (1979) prepared a model for the evolution of the break up of the Gondwanaland from seafloor spreading anomalies and fracture zones. Ramana et al. (1994; 2001)

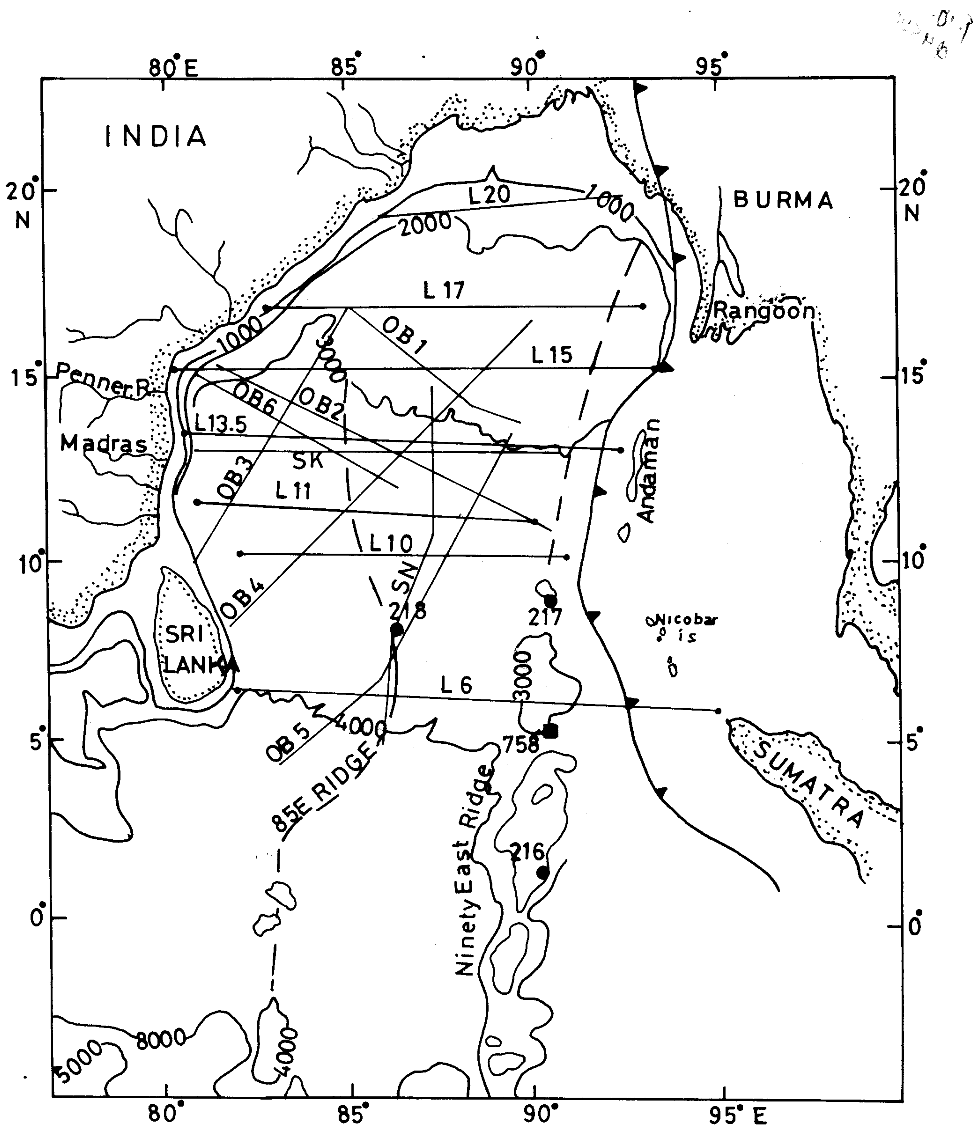

Figure 1. Layout Map of study area. Solid lines show total intensity magnetic profiles. Thick dashed lines show the continuous 85⁰E Ridge and the 90⁰E Ridge (Curray & Munasinghe 1991). Solid triangles along thick line represent the Sunda Subduction zone. Solid circles and squares are locations of DSDP and ODP sites respectively (Adopted from Gopala Rao et al. 1997).

presented the break up scenario of the eastern Gondwanaland through the identification of the Mesozoic magnetic anomalies in the Bay of Bengal and Enderby basin, east Antarctica. They have also demonstrated that the break up of India from Antarctica initiated before the formation of magnetic anomaly M11 i.e., 135 Ma. The spreading along the Central Indian Ridge, South East Indian Ridge and Indian Ocean triple junction play an important role in the tectonic history of the Bay of Bengal basin.

Sarma et al. (2002) determined the depth to the magnetic basement in the Central Bay of Bengal. The depth to the magnetic basement varies between 5km and 12km from the sea surface. Subrahmanyam, Vasudeva Rao & Prakasa Rao (2002) delineated the basement and Curie Isotherm/Moho in the Central Bay of Bengal from modelling of magnetic and gravity anomalies. In this paper an attempt has been made to delineate the structure of the magnetic basement and in particular Curie Isotherm depth from spectral analysis.

Table 1a : Table below shows depths to the magnetic basement, Curie Isotherm and Geographic co-ordinates of the profiles in the E-W direction (Refer Fig. 1)

Profile	Seg-ment	Distance (km)	1	2	Inference
L6	I	0-300	6.21	21.7(0.04Hz)	
(82.083^{0}E, 6.4^{0}N-	II	250-600	5.69	16.9(0.04Hz)	85^{0}E Ridge
94.9^{0}E, 5.7^{0}N)	III	550-1100	4.40	30.70(0.02Hz)	90^{0}E Ridge
	IV	1000-1420	4.8	22.37(0.04Hz)	Subduction Zone
L10	I	0-300	9.00	15.6(0.04Hz)	
(82.07^{0}E, 10.2^{0}N-	II	250-450	15.0	17.81(0.04Hz)	
94.9^{0}E, 10^{0}N)	III	400-800	7.2	20.5(0.04Hz)	NNW-SSE High/Ridge
	IV	700-1015	6.2	18.75(0.04Hz)	90^{0}E Ridge
L11	I	0-250	7.5	22.0(0.04Hz)	COB
(81.008^{0}E, 11.6^{0}N-	II	200-440	5.5	29.6(0.04Hz)	85^{0}E Ridge
90.084^{0}E, 11.10^{0}N)	III	400-600	5.32	16.7(0.04Hz)	
	IV	580-1000	6.0	21.50(0.04Hz)	
SK	I	0-150	6.02	24.9(0.04Hz)	COB
(80.83^{0}E, 13.0^{0}N-	II	100-350	10.7	16.43(0.04Hz)	
91.659^{0}E, 13^{0}N)	III	300-600	8.4	22.6(0.04Hz)	85^{0}E Ridge
	IV	500-850	11.6	19.0(0.04Hz)	
	V	800-1000	14	22.5(0.04Hz)	
	VI	950-1170	7.38	17.08(0.04Hz)	90^{0}E Ridge
L13.5	I	0-400	6.1	15.8(0.04Hz)	COB
(80.46^{0}E, 13.647^{0}N-	II	350-600	5.9	20.5(0.04Hz)	85^{0}E Ridge
92.6^{0}E, 13.4^{0}N)	III	550-900	7.7	14.6(0.04Hz)	
	IV	850-1330	7.6	17.0(0.04Hz)	90^{0}E Ridge
L15	I	0-300	5.1	26.5(0.04Hz)	COB/Volcanic neck
(80.25^{0}E, 15^{0}N-	II	250-750	11.40	20.0(0.04Hz)	
93.26^{0}E, 15.2^{0}N)	III	700-1000	7.9	24.8(0.04Hz)	Sub Ridge
	IV	950-1300	7.1	22.0(0.04Hz)	90^{0}E Ridge
L17	I	0-300	12.62	19.0(0.04Hz)	COB
(82.886^{0}E, 17^{0}N-	II	250-450	11.6	19.0(0.04Hz)	85^{0}E Ridge
92.987^{0}E, 17.05^{0}N)	III	400-850	12.0	21.0(0.04Hz)	
	IV	800-1110	12.0	18.30(0.04Hz)	
L20	I	0-100	8.4	26.5(0.06Hz)	COB
(86.607^{0}E, 19^{0}N-	II	50-300	13.5	21.0(0.06Hz)	
92.5^{0}E, 19.5^{0}N)	III	250-500	12.5	16.0(0.04Hz)	
	IV	400-750	9.0	19.0(0.04Hz)	

COB: Continental Ocean Boundary

1. Depth to the Magnetic basement in km (without filtering)
2. Depth to the Curie isotherm in km (with filtering frequency in parenthesis)

Table 1b : Table below shows depths to the magnetic basement, Curie Isotherm and Geographic co-ordinates of the profiles in the NW-SE direction (OB1, OB2 and OB6), NE-SW direction (OB3, OB4 and OB6) and in SN direction (Refer Fig. 1)

Profile	Seg-ment	Distance (km)	1	2	Inference
OB1	I	0-250	5.5	16.58(0.04Hz)	
(85.046^{0}E,17.092^{0}N-	II	150-400	6.87	17.25(0.04Hz)	Sub Ridge
89.779^{0}E, 13.71^{0}N)	III	350-650	3.48	13.56(0.04Hz)	90^{0}E Ridge
OB2	I	0-150	7.6	20.0(0.04Hz)	COB
(81.4^{0}E, 15.4^{0}N-	II	100-400	13.70	20.96(0.04Hz)	
90.5^{0}E, 10.9^{0}N)	III	350-600	10.0	18.90(0.04Hz)	85^{0}E Ridge
	IV	550-1100	13.56	22.0(0.04Hz)	
OB6	I	0-150	7.45	20.37(0.04Hz)	COB
(80.87^{0}E, 15.2164^{0}N-	II	100-380	5.88	16.72(0.04Hz)	Volcanic neck
86.33^{0}E, 12.036^{0}N)	III	300-500	6.08	17.0(0.04Hz)	
	IV	450-733	11.0	22.45(0.04Hz)	Eastern flank of 85^{0}E Ridge
OB3	I	0-400	5.8	17.5(0.04Hz)	
(80.87^{0}E, 9.83^{0}N-	II	300-640	6.5	14.37(0.04Hz)	
84.98^{0}E, 16.99^{0}N)	III	600-883	8.10	16.54(0.04Hz)	Effect of 85^{0}E Ridge
OB4	I	0-250	8.35	17.8(0.04Hz)	COB
(81.820^{0}E, 8.0061^{0}N-	II	200-450	12.5	23.0(0.04Hz)	
89.998^{0}E, 16.631^{0}N)	III	400-750	9.8	17.58(0.04Hz)	85^{0}E Ridge
	IV	750-1050	11.0	23.5(0.04Hz)	
	V	1000-1300	11.35	19.8(0.04Hz)	
OB5	I	0-250	5.14	16.88(0.04Hz)	
(83.524^{0}E, 4.4519^{0}N-	II	200-550	9.8	17.64(0.04Hz)	
89.59^{0}E, 13.36^{0}N)	III	450-900	6.83	23.63(0.03Hz)	85^{0}E Ridge
	IV	850-1190	4.58	24.53(0.02Hz)	
SN	I	100-300	4.9	16.44(0.04Hz)	85^{0}E Ridge
(86.726^{0}E, 5.0771^{0}N-	II	250-600	10.0	16.0(0.04Hz)	
86.986^{0}E, 14.247^{0}N)	III	550-800	4.28	17.0(0.03Hz)	85^{0}E Ridge
	IV	750-1028	12.0	23.0(0.02Hz)	

COB: Continental Ocean Boundary

1. Depth to the Magnetic basement in km (without filtering)
2. Depth to the Curie isotherm in km (with filtering frequency in parenthesis)

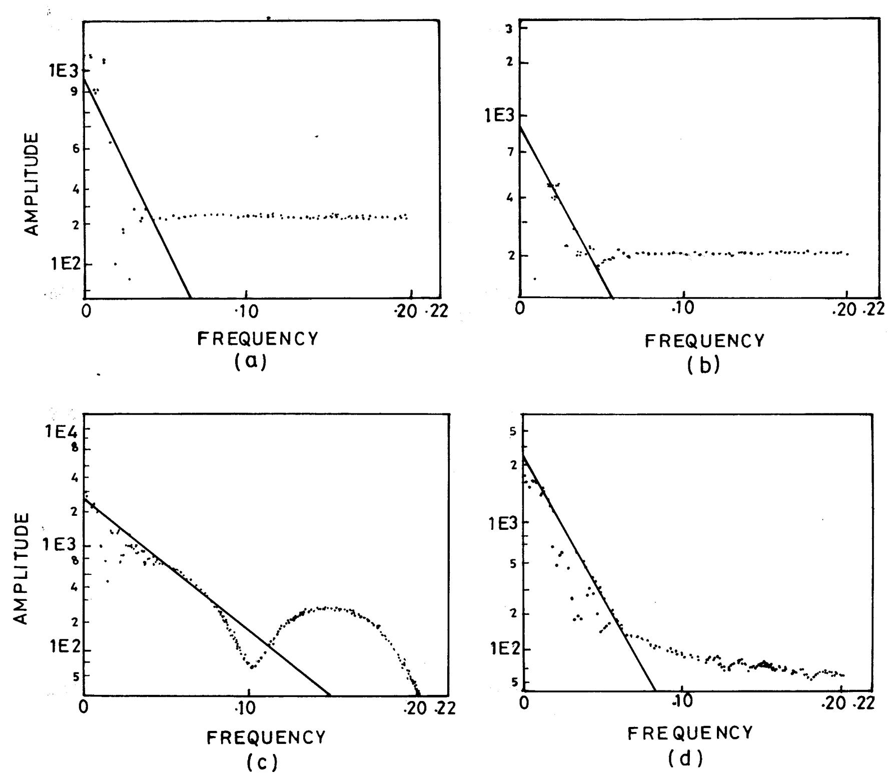

Figure 2a. Frequency spectrum of the magnetic anomaly L6 (Location shown in Fig.1) for shallow interface (a) Segment-I (b) Segment-II (c) Segment-III (d) Segment-IV (Refer Table 1a)

DATA SOURCE

Most of the data is obtained from the National Geophysical Data Centre (NGDC), Boulder, U.S.A. in CD ROM set version 3.2 except profiles SK, OB2 and OB6 (Fig.1). The data for profiles SK (Gopala Rao et al. 1994); OB2 and OB6 (Ramana et al. 1994) are digitised from the published work. The total area covered under this study is within the geographical limits of 6^0N to 20^0N latitude and 80^0E to 96^0E longitude across the Bay of Bengal.

MAGNETIC PROFILE LAYOUT

Fifteen magnetic profiles have been considered for the present study. Out of them eight are in E-W direction, three are in NW-SE direction, three are in NE-SW direction and one profile is in N-S direction (Fig.1). The tracks of all these profiles are shown in Fig.1 and geographic co-ordinates of the limits of these transacts are given in Tables 1a and 1b.

PROCESSING

To begin with each magnetic profile was divided into smaller overlapping segments depending on the number of significant anomalous magnetic signatures observed. The magnetic data of each segment bas been transformed into the frequency domain. The depth is computed from the best-fit line of the spectrum as shown in Fig.2a. This gives the average depth to magnetic basement along the segment. The high frequency component (representing magnetic basement) has been removed from the spectrum by applying low pass filter in order to interpret the resulting long wavelength anomalies in terms of deeper sources. From the qualitative study of the unfiltered spectrum, the high frequency component to be removed has been chosen and the values of cut-off frequency are given in Tables 1a & 1b. The depth is determined from the slope of the best-fit line of this filtered spectrum (Fig.2b). This gives the average depth to deeper source along this segment. Considering the length of each segment and the high data density, the average depth to the deepest layer (depth obtained from filtered spectrum) may be taken to represent the average Curie Isotherm depth (Benerjee, Sengupta & Banerjee 1995). Beneath Curie Isotherm, the temperature is such that the Earth's crust loses its ferromagnetic property. A tentative magnetic crustal model has been computed along each transact based on the average depths of shallow and deep magnetic

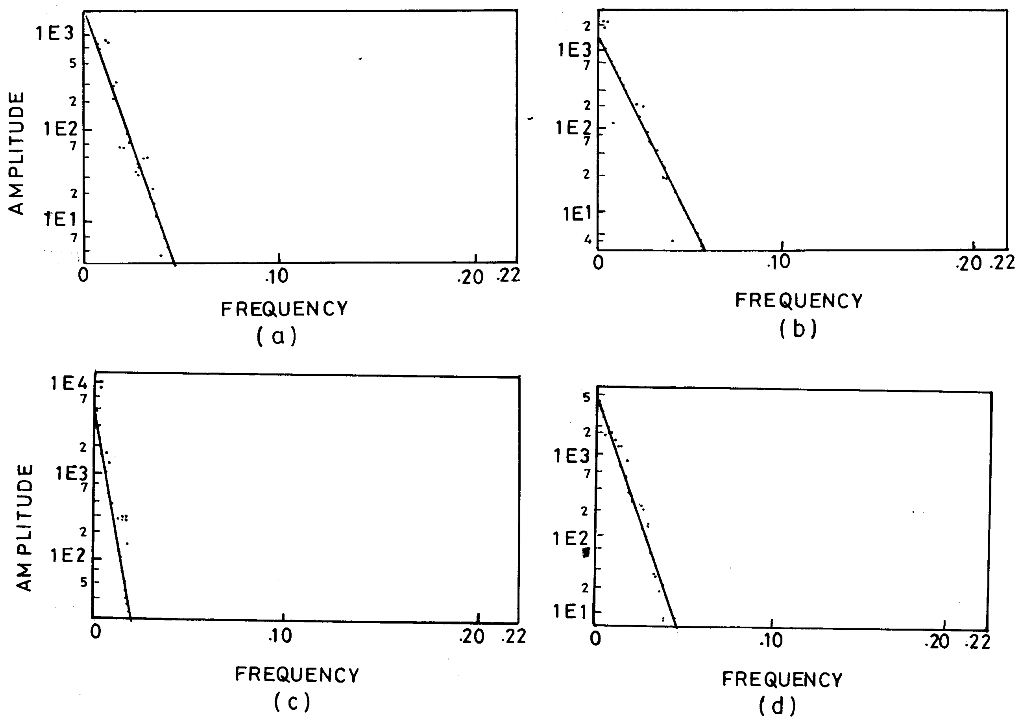

Figure 2b. Frequency spectrum of the magnetic anomaly L6 (Location shown in Fig. 1) for deeper interface (a) Segment-I (b) Segment-II (c) Segment-III (d) Segment-IV (Refer Table 1a)

horizons thus determined for all the segments of each profile. The entire magnetic parameters along each transact were tabulated in Tables 1a and 1b. The layout for all the profiles is shown in Fig.1. The co-ordinates for the limits of each profile are given in Tables 1a and 1b.

RESULTS

Profile L6: There is one major anomalous signature with amplitude of 250nT between 600 and 1000km. Another three anomalous signatures are also present with an amplitude ranging between 100 and 150nT. Thus the profile is divided into four overlapping segments. The depth to the basement and Curie Isotherm have been obtained along these four segments from the corresponding unfiltered (Fig.2a) and filtered (Fig.2b) frequencies spectrums respectively. The detailed depth values to basement and Curie Isotherm for each segment are shown in Table 1a. Along segment (IV) (1000-1420km), a continuous rise in seabed is observed. Thrust faulting followed by a subduction is inferred in this area. Other prominent tectonic features passing through this profile area are given in Table 1a.

The tentative crustal model is shown in Fig.3

Profile L10: Four distinct anomalous magnetic signatures could be observed from the qualitative study of this profile. Three signatures pass through the COB, 85^{0}E and 90^{0}E Ridges. The anomalous zone between 450 and 700km is significant. Ramana et al. (1992; 1994) interpreted this zone as a basement high/ ridge. Gopala Rao et al. (1997) expected a probable extension of Anomaly 34 in this area. The spectral depths obtained to basement and Curie Isotherm along the four segments are given Table 1A. Ninety east ridge passes through the zone between 800km and 1000km (Curray et al. 1982; Mukhopadhyay & Krishna 1995). The tentative crustal model prepared from these spectral depths is shown in Fig.4.

Profile L11: This profile has been divided into four segments, each due to a significant magnetic source. The spectral depth to the basement and Curie Isotherm along the four sections were determined and the values are given in Table 1A. Continental Ocean Boundary passes through the zone between 0 and 50km (Mukhopadhyay & Krishna 1995). Between 200km and 400km zone of the profile, the depth to the basement and Curie Isotherm are 5.5km and 29.6km respectively. Eighty five degree ridge passes

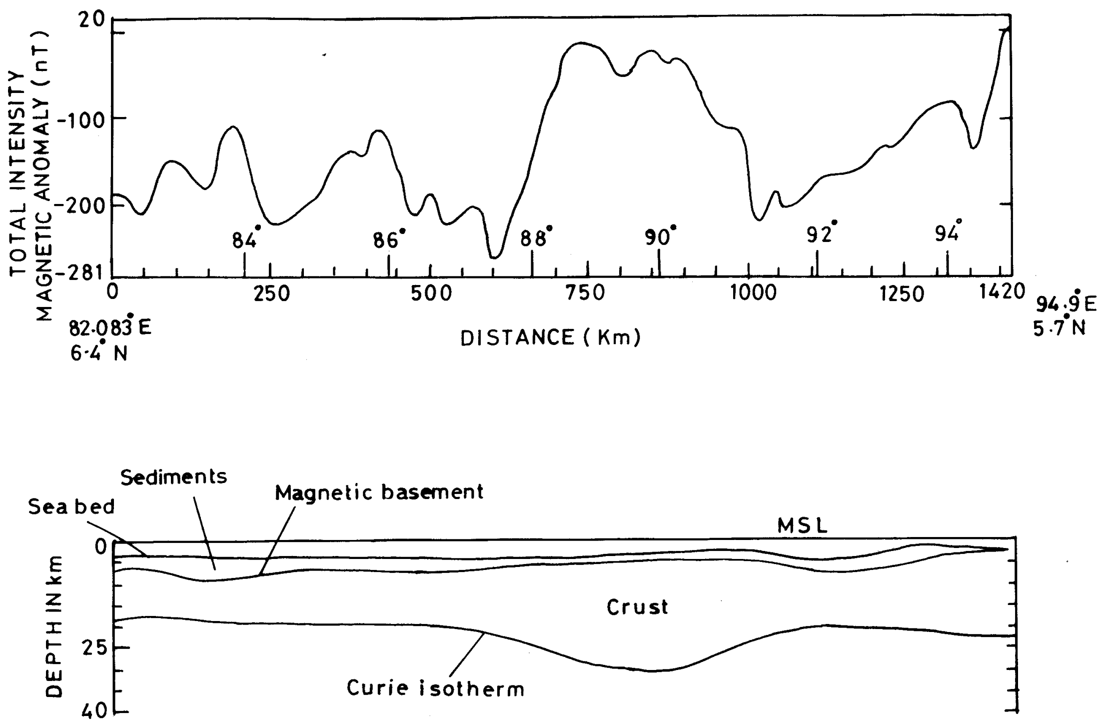

Figure 3. Total Intensity Magnetic profile L6 (Location shown in Fig. 1) and its tentative crustal model derived from spectral analysis (Refer Table 1a)

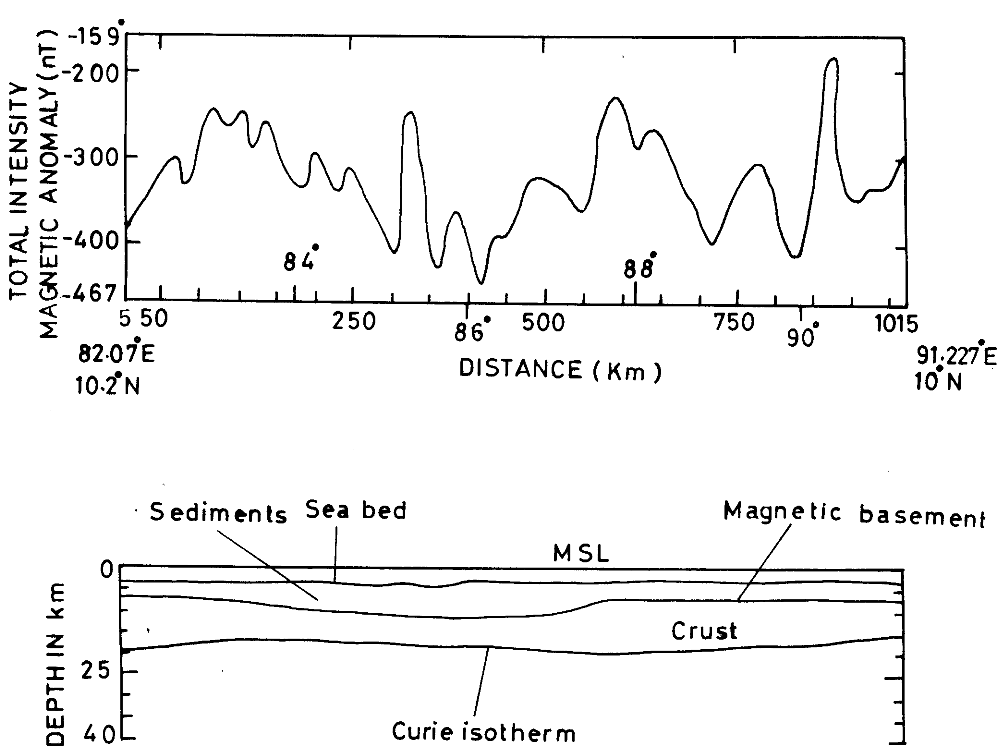

Figure 4. Total Intensity Magnetic profile L10(Location shown in Fig. 1) and its tentative crustal model derived from spectral analysis (Refer Table 1a)

through this area (Murthy et al. 1993). Tentative crustal model prepared from these spectral depths is shown in Fig. 5.

Profile SK: The profile has six distinct magnetic anomalous signatures and accordingly, the profile is divided into six segments. The length of each segment and the spectral depths to the basement and Curie isotherm are given in Table 1A. COB passes through the profile area between 0 and 100km (Curray et al. 1982; Curray & Munasinghe 1991; Pateria, Rangaraju & Raiverman 1992). The tentative crustal model is shown in Fig. 6.

Profile L13.5: The limits of the profile, length of each segment and the depths to the basement and Curie Isotherm are given in Table 1A. The major magnetic anomalous signature along this profile is between 400km and 600km. Through this area passes the 85^{0}E ridge (Curray et al. 1982; Mukhopadhyay & Krishna 1991; Ramana et al. 1997). Ninety east ridge passes through area of the profile between 900km and 1300km (Curray et al. 1982; Mukhopadhyay & Krishna, 1991, 1995). Tentative crustal model prepared from crustal depth is shown in Fig. 7.

Profile L15: Four distinct magnetic anomalous signatures could be identified along this profile. The depths to the basement and Curie Isotherm as obtained from spectral method along these four segments are given in Table 1A. Murthy et al. (1995); Murthy (1997) and Venkateswarulu, Raghava Rao & Bose (1992) interpreted the magnetic anomaly between 100km and 300km segment of the profile as due to hotspot trace/volcanic neck. The tentative crustal model prepared from spectral depths is shown in Fig. 8.

Profile L17: The profile is divided into four segments based on the magnetic anomalous signatures observed and spectral depths determined to basement and Curie Isotherm along these four segments are given in Table 1a. Curray et al. (1982), from the seismic profile along 17^{0}N latitude, interpreted the zone between 50km and 250km of the present magnetic profile as due to the combined effect of COB and 85^{0}E ridge. The tentative crustal model prepared from the spectral depths is shown in Fig. 9.

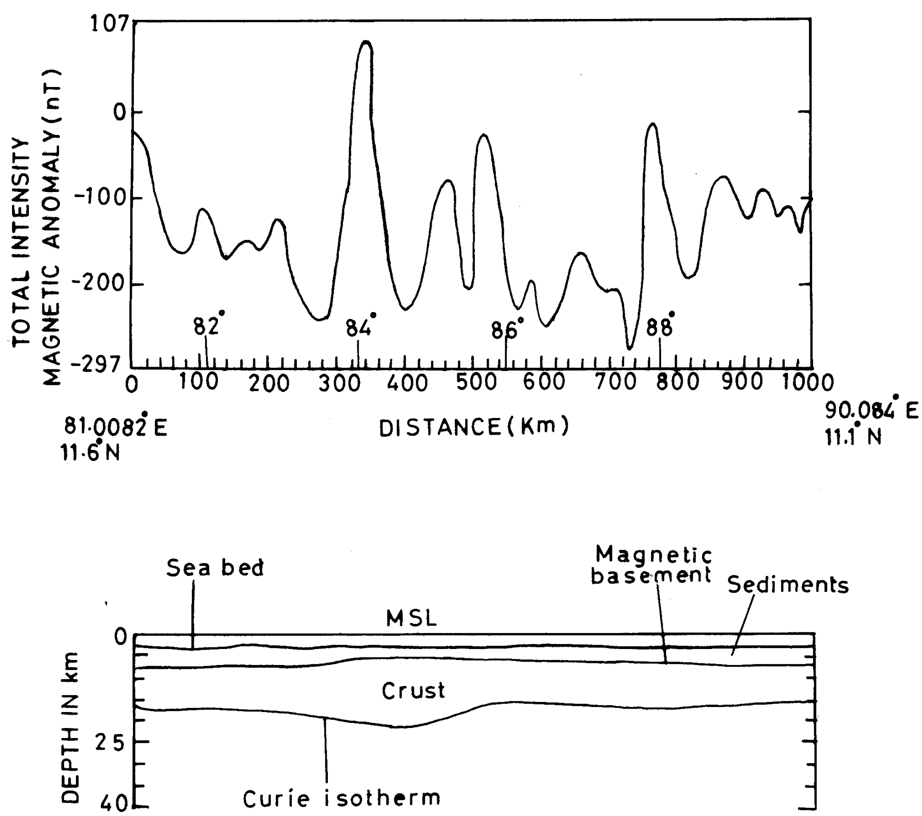

Figure 5. Total Intensity Magnetic profile L11(Location shown in Fig. 1) and its tentative crustal model derived from spectral analysis (Refer Table 1a)

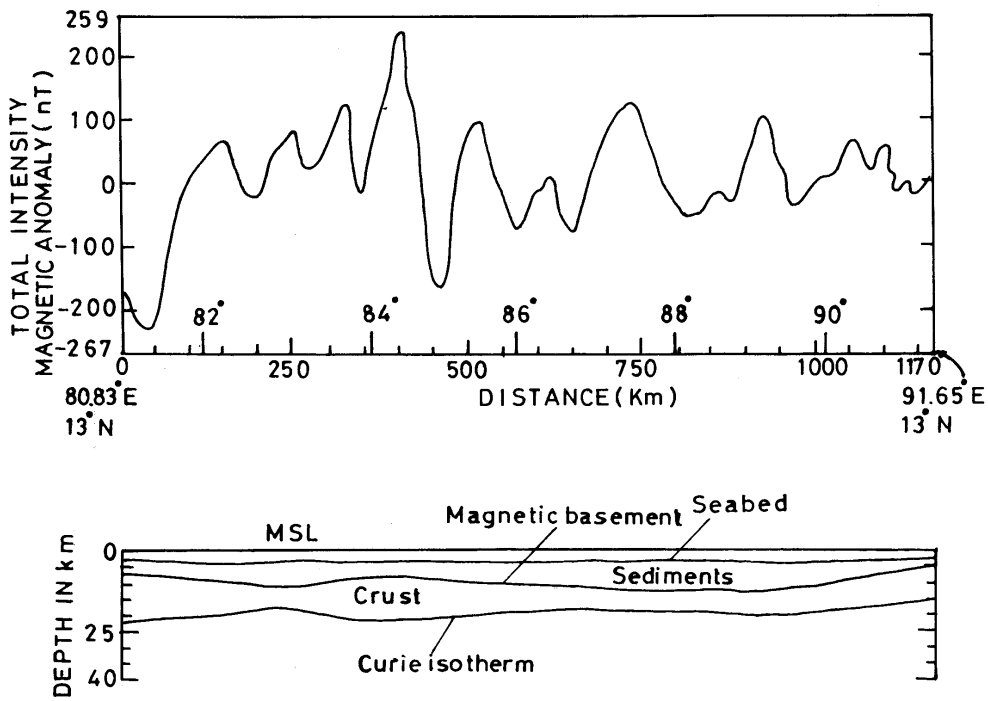

Figure 6. Total Intensity Magnetic profile SK (Location shown in Fig. 1) and its tentative crustal model derived from spectral analysis (Refer Table 1a)

Profile L20: Only one distinct significant magnetic anomaly could be identified on this profile. Another three magnetic signatures could also identified, but the amplitude is small. The spectral depths to basement and Curie isotherm along these four magnetic signatures are given in Table 1A. Between 0 and 150km area of the profile, lies the COB (Mukhopadhyay and Krishna, 1992). This COB could be distinctly identified from tentative crustal model prepared from spectral depths as shown in Fig.10. Between 700km and 770km zone, the depth to the seafloor is 200m. Bruma coast passes through this area (Mukhopadhyay & Krishna 1991).

Profile OB1: Three magnetic anomalous signatures could be identified on the profile and accordingly, the spectral depths to the basement and Curie Isotherm were determined for these three segments. The depth values are given in Table 1b. The tentative crustal model prepared is shown in Fig.11.

Profile OB2: Two significant magnetic anomalous signatures could be observed along this profile, one due to COB and the other over 85^{0}E ridge. The profile is divided into four segments for determining the spectral depths to the basement and Curie Isotherm. The derived depths are shown in Table 1B and the crustal model is shown in Fig.12.

Profile OB6: This profile is divided into four segments and the spectral depths obtained to the basement and Curie isotherm are tabulated in Table 1B. Between 100km and 380km zone, a buried volcanic neck/hotspot trace was inferred (Murthy et al. 1993; Murthy 1997; Venkateswarulu, Raghava Rao & Bose 1992). The crustal model prepared from these spectral depths is shown in Fig.13.

Profile OB3: This profile is divided into three segments and the spectral depths are given in Table 1b. The crustal model is shown in Fig.14.

Profile OB4: This profile is divided into five segments. The depths to the basement and Curie Isotherm were determined from the spectrum of each segment. The depth values are tabulated in table 1B. The crustal mode is shown in Fig.15.

Profile OB5: The profile is divided into four segments and the depth values to the basement and Curie Isotherm determined from spectral method are tabulated in Table 1B. The tentative crustal model is shown in Fig.16.

Profile SN: This profile is divided into four segments. The initial points of the profile grazes through the eastern flank of 85^{0}E ridge as can be seen from the seismic section of Curray et al. (1982). The spectral depths to the basement and Curie Isotherm

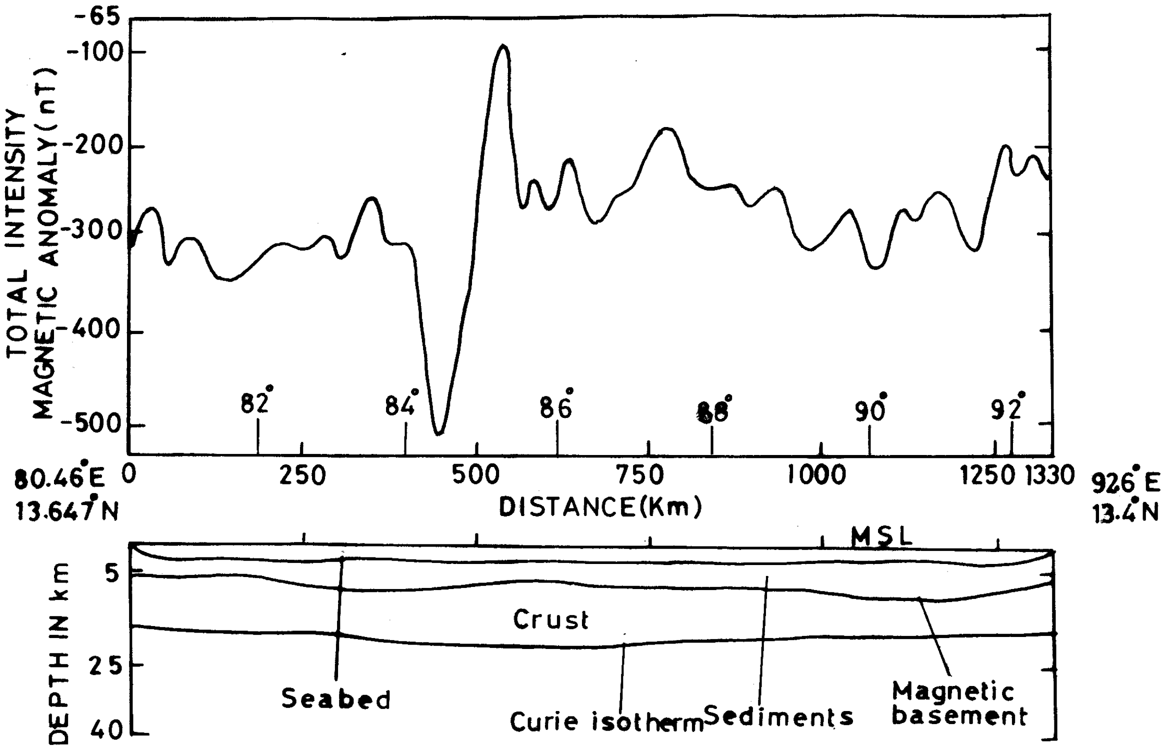

Figure 7. Total Intensity Magnetic profile L13.5 (Location shown in Fig. 1) and its tentative crustal model derived from spectral Analysis (Refer Table 1a)

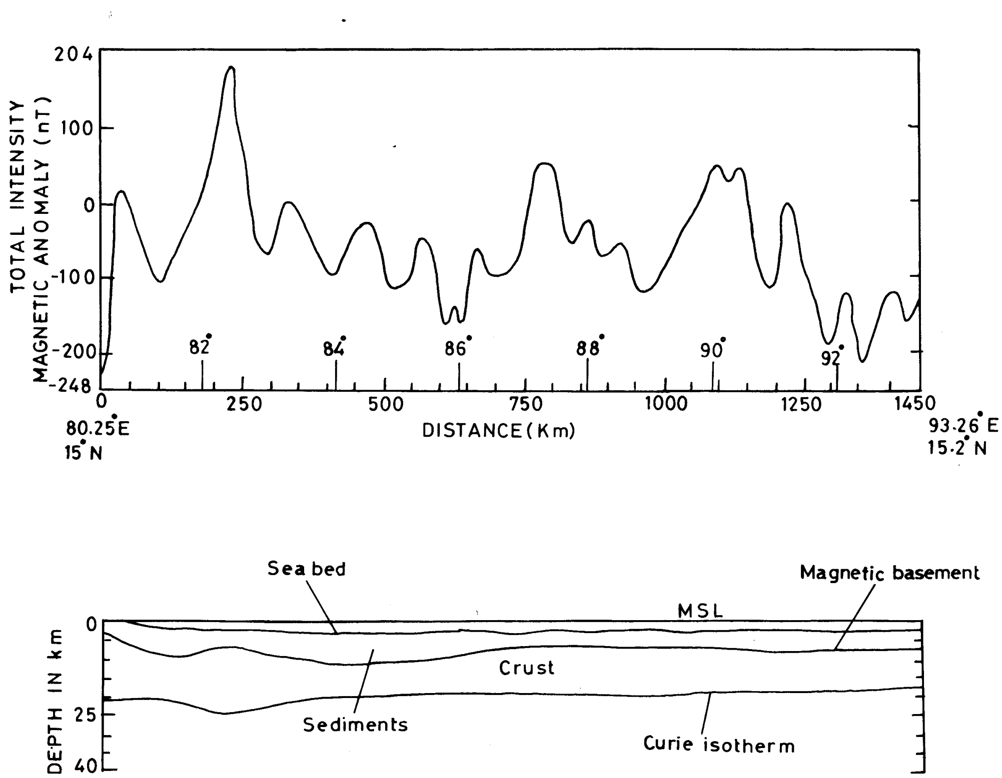

Figure 8. Total Intensity Magnetic profile L15 (Location shown in Fig. 1) and its tentative crustal model derived from spectral Analysis (Refer Table 1a)

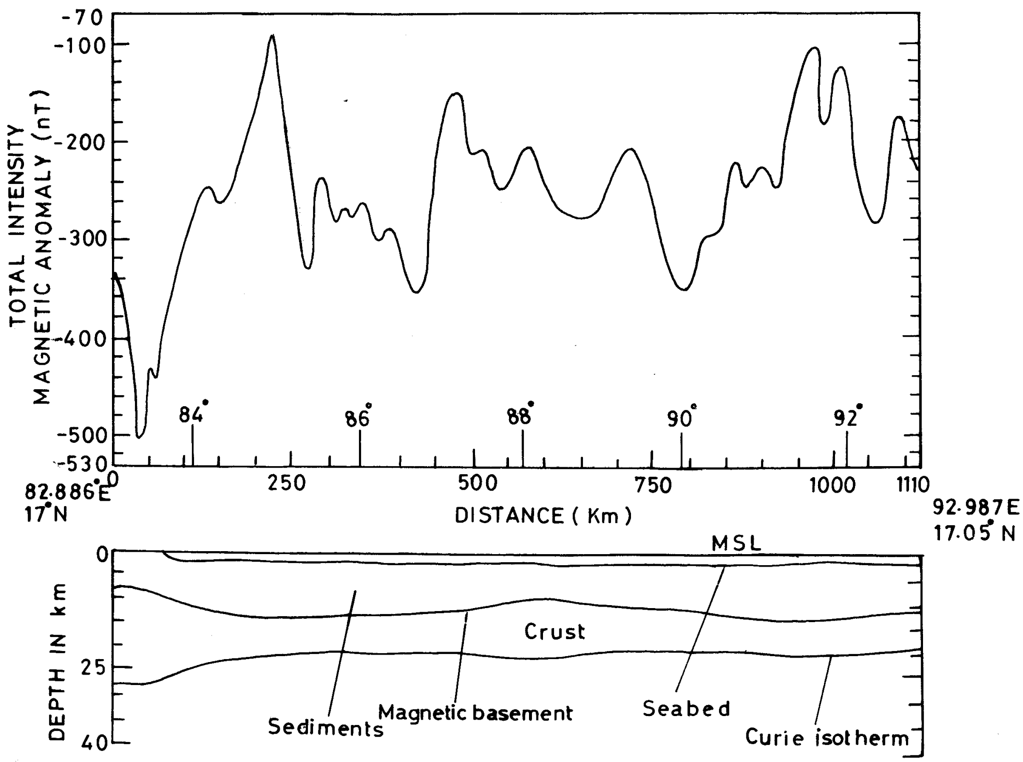

Figure 9. Total Intensity Magnetic profile L17 (Location shown in Fig. 1) and its tentative crustal model derived from spectral Analysis (Refer Table 1a)

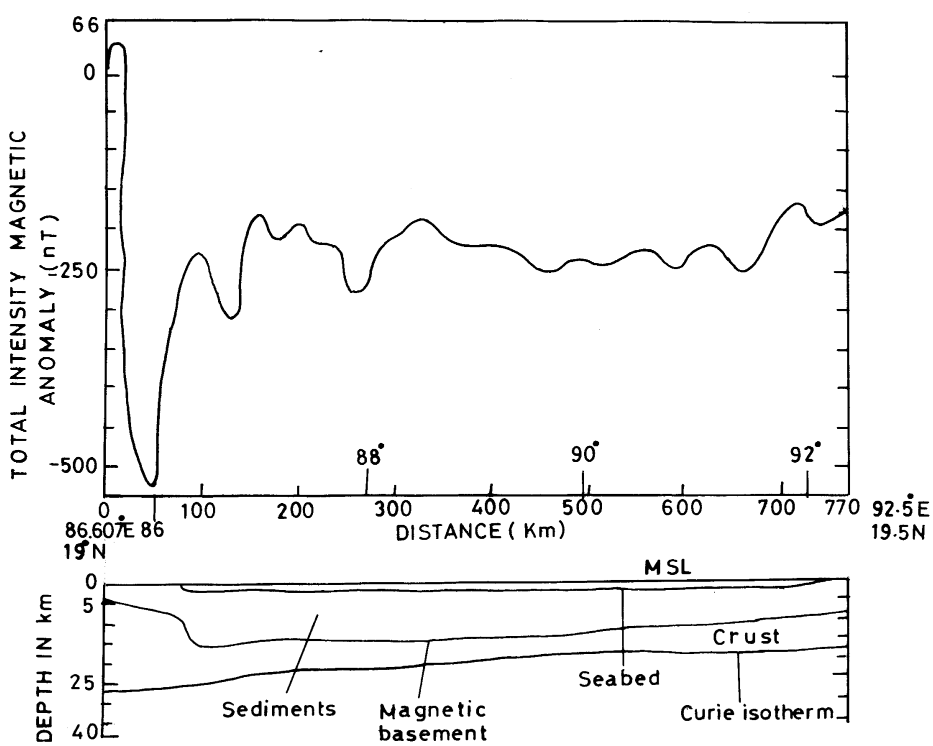

Figure 10. Total Intensity Magnetic profile L20 (Location shown in Fig. 1) and its tentative crustal model derived from spectral Analysis (Refer Table 1a)

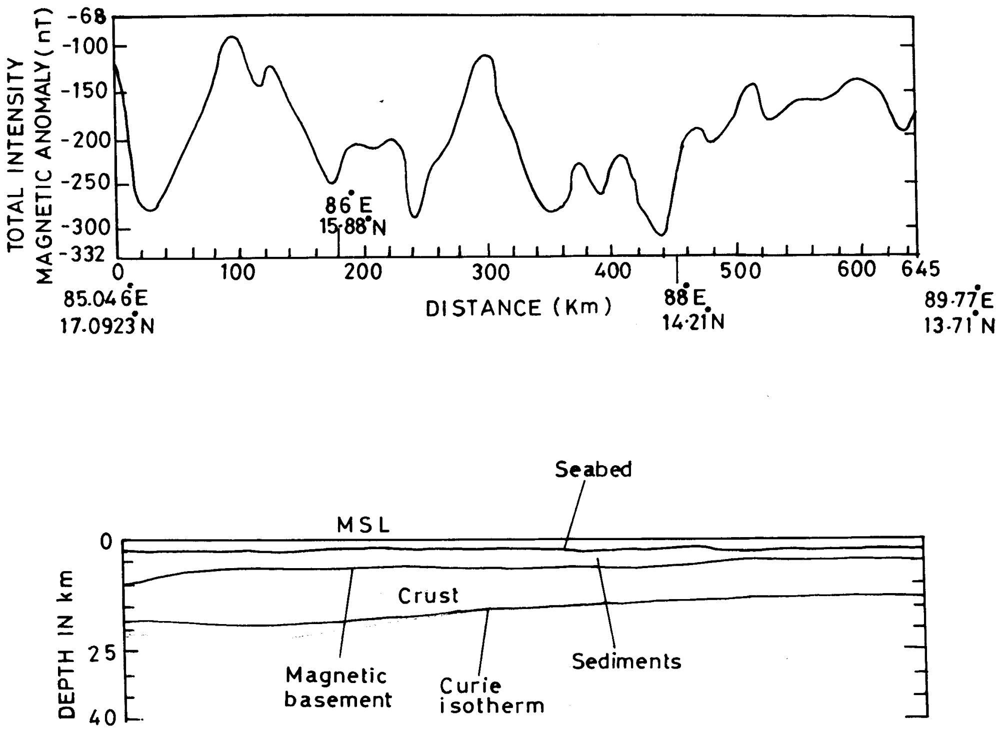

Figure 11. Total Intensity Magnetic profile OB1 (Location shown in Fig. 1) and its tentative crustal model derived from spectral Analysis (Refer Table 1b)

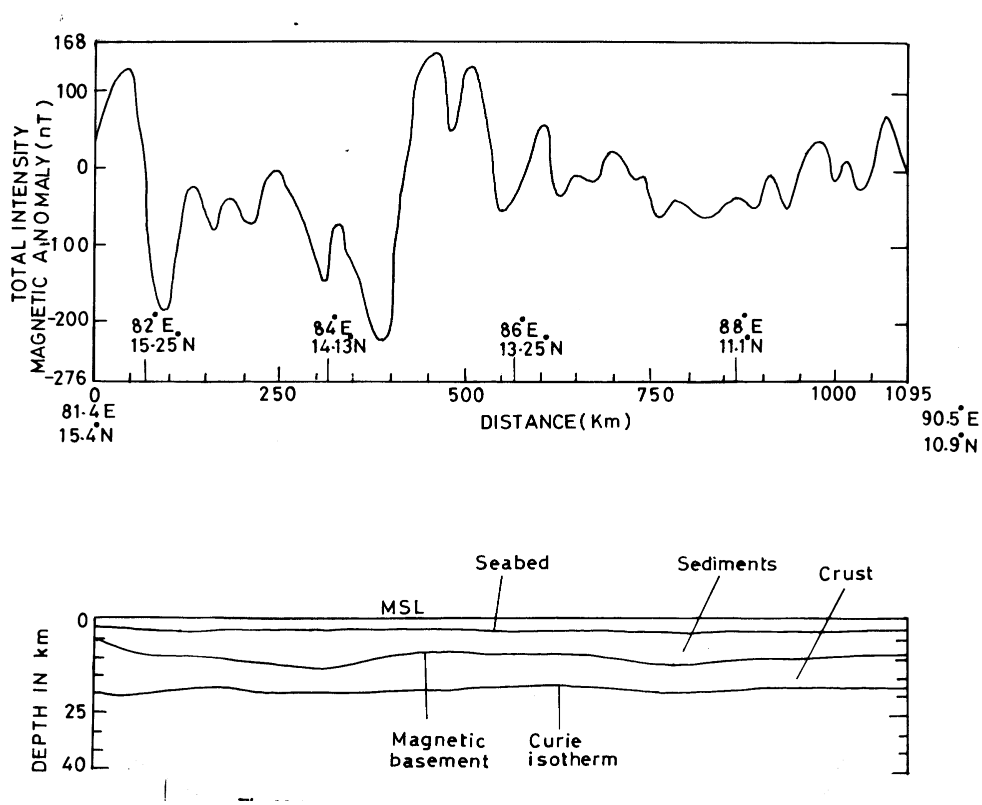

Figure 12. Total Intensity Magnetic profile OB2 (Location shown in Fig. 1) and its tentative crustal model derived from spectral Analysis (Refer Table 1b)

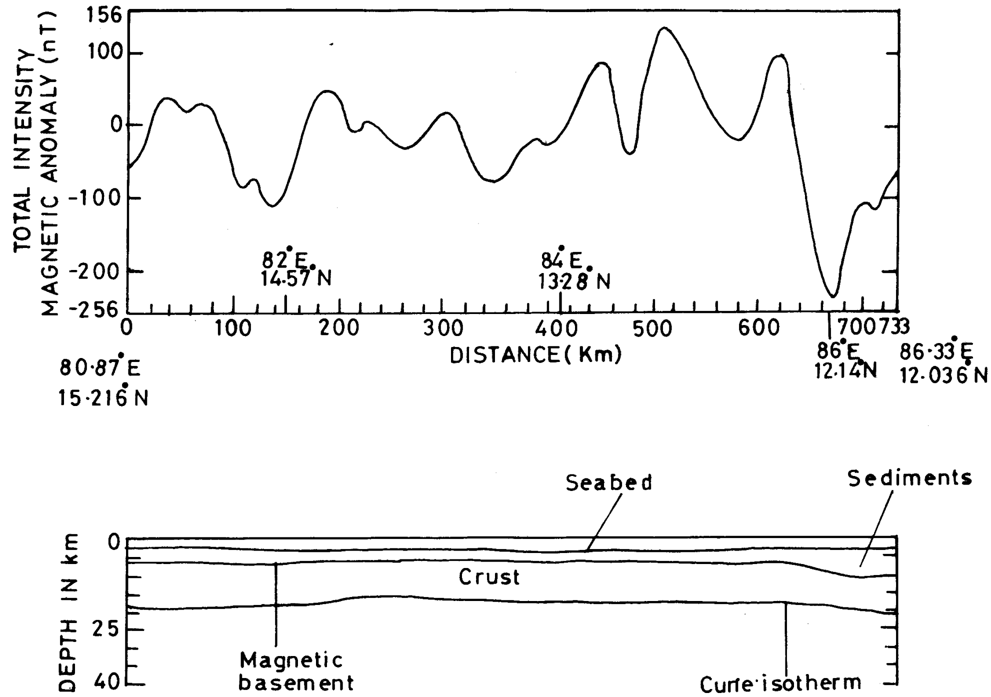

Figure 13. Total Intensity Magnetic profile OB6 (Location shown in Fig. 1) and its tentative crustal model derived from spectral Analysis (Refer Table 1b)

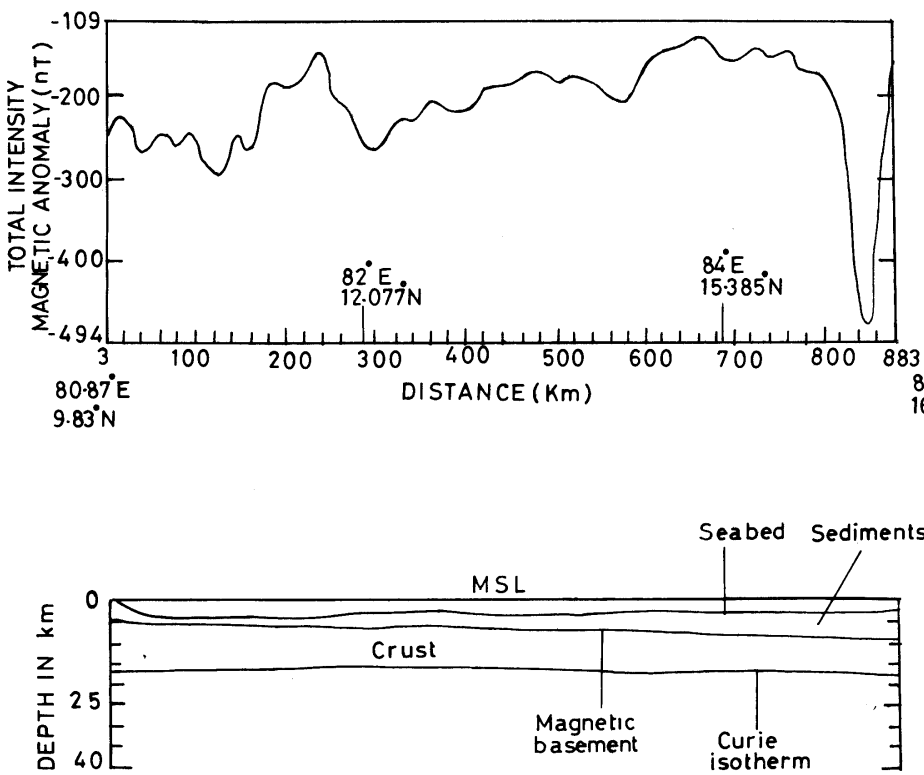

Figure 14. Total Intensity Magnetic profile OB3 (Location shown in Fig. 1) and its tentative crustal model derived from spectral Analysis (Refer Table 1b)

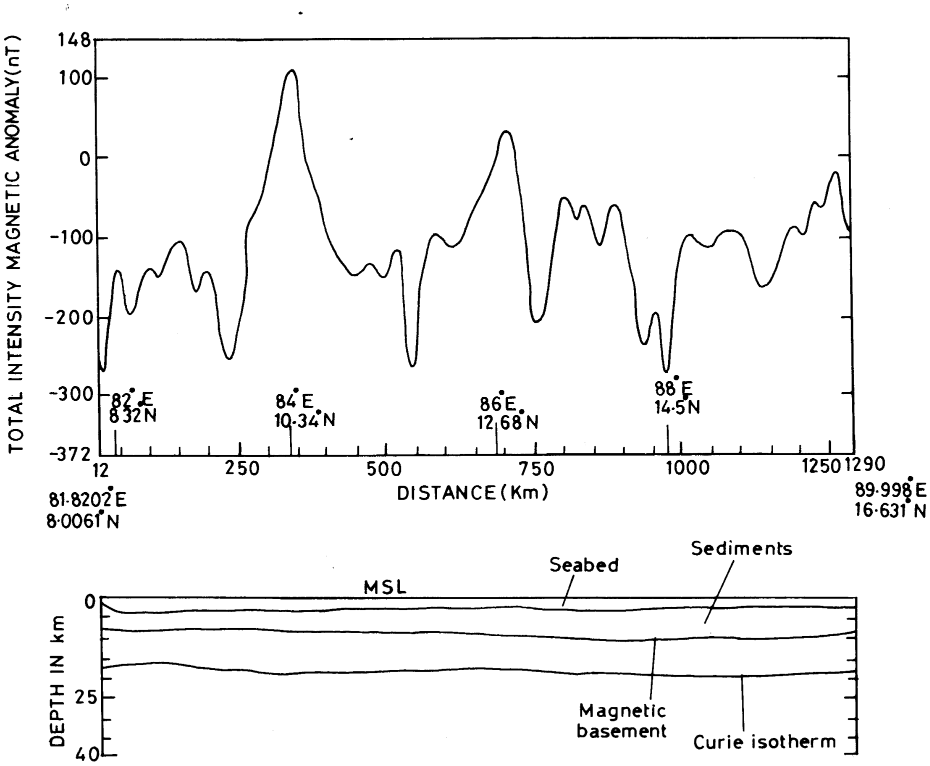

Figure 15. Total Intensity Magnetic profile OB4 (Location shown in Fig. 1) and its tentative crustal model derived from spectral Analysis (Refer Table 1b)

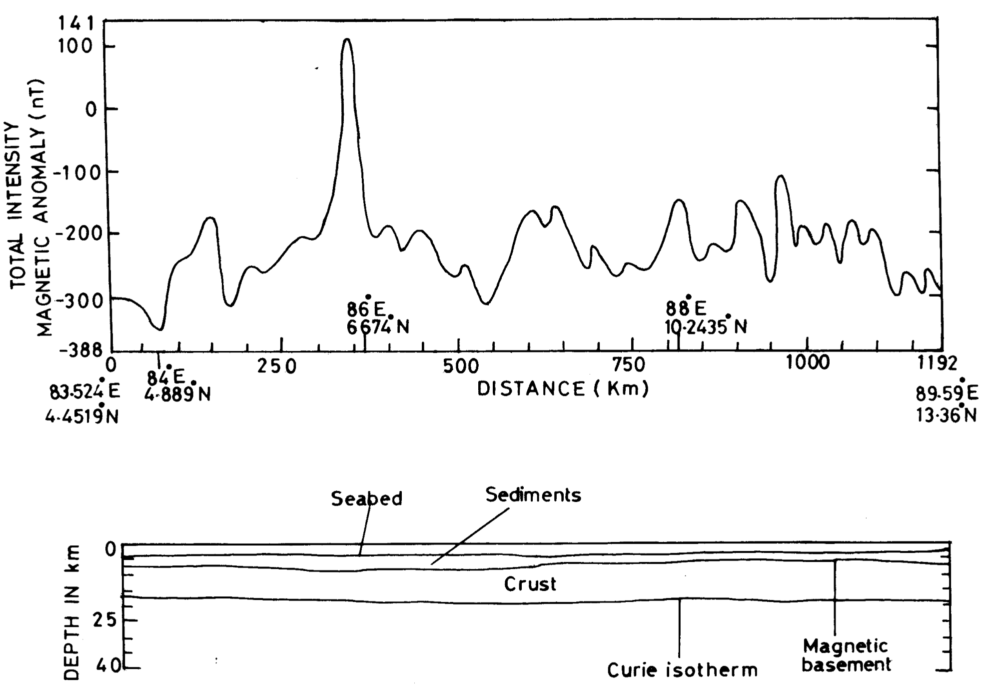

Figure 16. Total Intensity Magnetic profile OB5 (Location shown in Fig. 1) and its tentative crustal model derived from spectral Analysis (Refer Table 1b)

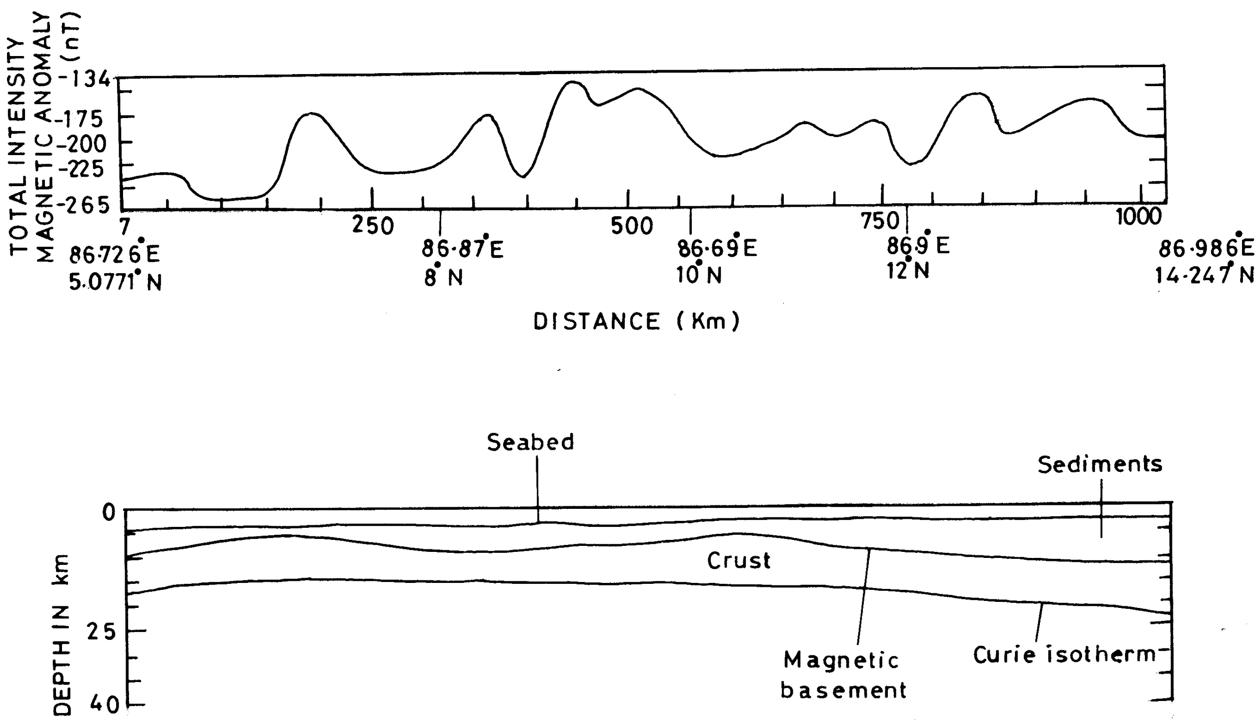

Figure 17. Total Intensity Magnetic profile SN (Location shown in Fig. 1) and its tentative crustal model derived from spectral Analysis (Refer Table 1b)

are given in Table 1B and the crustal model is shown in Fig.17.

CONCLUSIONS

The depth to the magnetic basement agrees well with the depth of the basement as observed from sediment Isopach map of Curray (1994), in the study area. Results of present investigation for deeper marker are in agreement with the inference drawn by other workers on the depth to the Mohorovicic discontinuity, the circumstances of the crust mantle boundary and the favourable conditions for effective transmission of S_n waves in Bay of Bengal (Curray et al. 1982; Curray 1994; Mukhopadhyay & Krishna 1991; 1992; Brune et al. 1992). From spectral depths and from the inferred models, the main tectonic elements like Continental Ocean Boundary, 85^{0}E ridge and 90^{0}E ridge have been identified distinctly. The crust mantle configuration present along the NW-SE sections reveals that the crustal thickness is different on either side of the 85^{0}E ridge. East of the ridge, the thickness relatively less when compared to the western side. The depth to the magnetic basement is in the range of 8-10km along the southern profiles and in the range of 10-12km along northern profiles. This clearly indicates the variation of sediment load from south to north. The Curie Isotherm is at an average depth of 15-17km along southern profiles and 20-22km along northern profiles. Since the depths determined from spectrum are only approximate, the depths may be used as tentative parameters while attempting for detailed modelling. The models also reveal the crustal dipping and thickening from south to north.

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