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PRELIMINARY REPORT OF THREE COMPONENTS OF GEOMAGNETIC FIELD MEASURED ON BOARD THE ICEBREAKER SHIRASE DURING JARE-30, 1988-1989

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Abstract: Measurement of three components of geomagnetic field was carried out on board the icebreaker SHIRASE during the 30th Japanese Antarctic Research Expedition (JARE-30).

Vector anomalies of geomagnetic field were obtained and the directions of magnetic lineations were determined from the vector anomalies. They are in good agreement with the results previously reported along the ship's tracks (*e.g.* ROYER *et al.*: Tectonophysics, **155**, 235, 1988; ROYER and SANDWELL: J. Geophys. Res., **94**, 13755, 1989), except for the Antarctic continental margin and the Enderby Basin. In the Antarctic continental margin, N-S trending magnetic structure that coincides with the Australian-Antarctic depression is detected between Australia and Antarctica and the local magnetic anomaly that seems to be caused by the Napier Complex appears between 50°E and 60°E along 63°S. Further, in the Enderby Basin around 60°S, N-S and NNE-SSW trending magnetic lineations which have never been reported before are detected. These results may suggest new constraints on the evolution of the Indian Ocean.

1. Introduction

The history of sea floor spreading in the Indian Ocean is the key to understanding the dispersal of Gondwanna fragments. The spreading history is revealed by geomagnetic anomaly lineations as well as the other geophysical aspects, and they have been extensively studied (*e.g.* LAWVER *et al.*, 1985; POWELL *et al.*, 1988; ROYER *et al.*, 1988; ROYER and SANDWELL, 1989). But in the south of the Indian Ocean off Antarctica such a history has scarcely been studied because of the lack of geophysical data at sea. It is hard to make surveys at sea off Antarctica because of severe weather and hostile sea ices. A conventional proton magnetometer which is widely used is sometimes hard to be towed behind the ship under these circumstances. However, the STCM (Shipboard Three Components Magnetometer; ISEZAKI, 1986) is easy to operate in comparison with a conventional proton magnetometer even in these circumstances, because the sensors of this system are fixed on a deck. Further, vector geomagnetic anomalies

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are obtained by STCM and the directions of geomagnetic anomaly lineations are determined by the vector anomalies, because they have no components in the direction of geomagnetic anomaly lineations (ISEZAKI, 1986; SEAMA *et al.*, 1990; SEAMA *et al.*, in preparation).

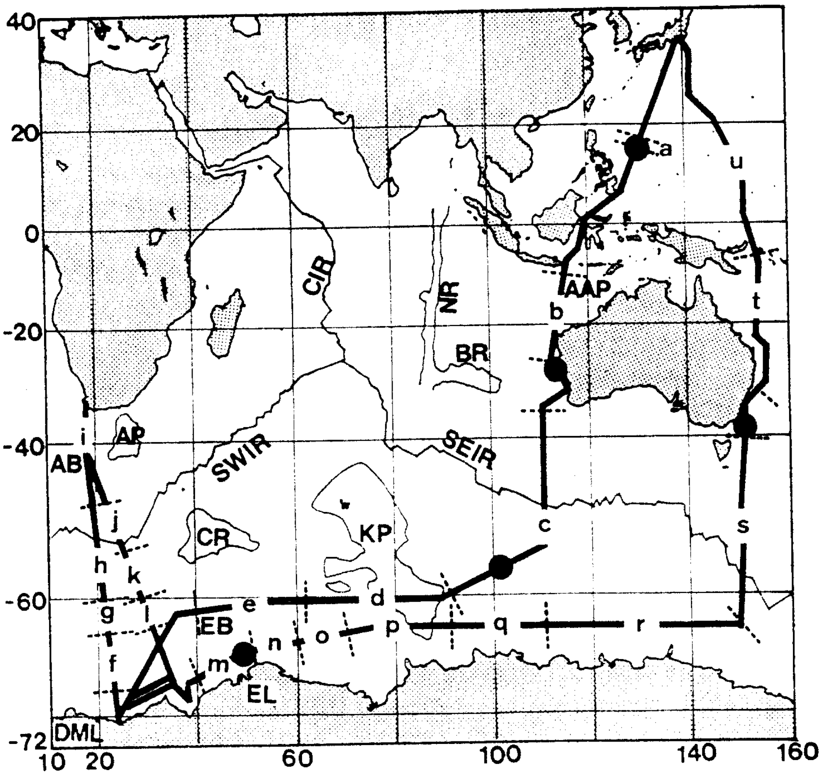

Fig. 1. Ship tracks during JARE-30. Solid circles show the positions of "8-shaped turn". Abbreviations: CIR, Central Indian Ridge; SEIR, Southeast Indian Ridge; SWIR, Southwest Indian Ridge; AAP, Argo Abyssal Plain; NR, Ninetyeast Ridge; BR, Broken Ridge; KP, Kerguelen Plateau; CR, Conrad Rise; AP, Agulhas Plateau; AB, Agulhas Basin; EB, Enderby Basin; EL, Enderby Land; DML, Dronning Maud land. Twenty-one observation lines (a–u) are listed in Table 1.

Table 1. List of twenty-one observation lines shown in Fig. 1.

Observation line	Location	Observation line	Location
a	17.0°N, 130.7°E - 15.0°N, 129.8°E	k	55.0°S, 27.0°E - 60.0°S, 29.5°E
b	10.0°S, 115.0°E - 27.0°S, 112.0°E	l	60.0°S, 29.5°E - 63.0°S, 32.0°E
c	36.0°S, 110.0°E - 60.0°S, 90.0°E	m	67.0°S, 40.0°E - 65.5°S, 50.0°E
d	60.0°S, 90.0°E - 60.0°S, 62.0°E	n	65.5°S, 50.0°E - 64.5°S, 60.0°E
e	60.0°S, 62.0°E - 61.0°S, 40.0°E	o	64.5°S, 60.0°E - 63.5°S, 70.0°E
f	68.0°S, 23.0°E - 63.0°S, 22.0°E	p	63.5°S, 70.0°E - 63.0°S, 90.0°E
g	63.0°S, 22.0°E - 60.0°S, 21.0°E	q	63.0°S, 90.0°E - 63.0°S, 110.0°E
h	66.0°S, 21.0°E - 46.0°S, 18.0°E	r	63.0°S, 110.0°E - 63.0°S, 150.0°E
i	46.0°S, 18.0°E - 34.0°S, 18.5°E	s	63.0°S, 150.0°E - 40.0°S, 151.0°E
	34.0°S, 18.5°E - 46.0°S, 22.0°E	t	32.0°S, 154.0°E - 5.0°S, 153.0°E
j	46.0°S, 22.0°E - 55.0°S, 27.0°E	u	5.0°S, 153.0°E - 34.0°N, 141.0°E

The first experiment of STCM on the icebreaker SHIRASE was carried out during JARE-30 (the 30th Japanese Antarctic Research Expedition) for the purpose of identifying geomagnetic anomaly lineations. Three components of the geomagnetic field were measured throughout this cruise of 84 days. Total intensity of the geomagnetic field was measured at the same time by a conventional proton magnetometer for about 4 days in order to confirm whether the three components of the geomagnetic field were correctly obtained or not. In this paper we will present preliminary results of this cruise. Ship's tracks during the cruise are shown in Fig. 1. For convenience, the ship's tracks are divided into twenty-one observation lines which are also shown in Fig. 1, and listed in Table 1.

2. Outline of STCM of the Icebreaker SHIRASE

STCM of the icebrekaer SHIRASE is outlined as follows. Three orthogonal flux-gate sensors were set on the deck. A controller installed in a laboratory controls STCM and sampling of all the other data. Signals from the sensors are obtained every 1 s. The ship's heading, rolling and pitching angles are also measured by a three-dimensional gyro installed on the ship at the same time. All of these data are stored once in the controller. The position data are stored in the controller every 1 min. Then all of the data in the controller are transmitted to the micro-computer every 1 min. Fifteen-second geomagnetic and gyro data are averaged in the micro-computer and stored in a mini-floppy disk. Depth data are obtained separately and later added to geomagnetic data.

"8-shaped turns", that the ship runs on an 8 shape track, are conducted while cruising. By this turn two data sets of 360° rotation are obtained. These data are used to remove induced and permanent magnetic field of the ship. Five positions of "8-shaped turn" are shown by solid circles in Fig. 1.

3. Data Processing

The three components of the geomagnetic field were obtained from observed data according to the method by ISEZAKI (1986). Twelve constants relating to the induced and permanent magnetic field of the ship were determined using the data sets of "8-shaped turns". The residuals of each component were obtained by subtracting IGRF-85 field (IAGA DIVISION I WORKING GROUP 1, 1987) from observed geomagnetic data. Measurement by STCM became unstable by abrupt course change of the ship, probably caused by distortion of the ship. Unstable data during the course change of the ship were eliminated. The trend of the residuals of each component was removed. Anomalies whose wavelengths are approximately shorter than 5 km, which seemed to be noises, were removed by a moving average method. The moving average interval was 21 min that roughly correspond to the wavelength of 9 km, because the ship's velocity was usually about 15 kt.

Directions of magnetic lineations were calculated from the anomaly vectors based on the fact that the anomaly vectors have no component parallel to the direction of magnetic anomaly lineations. This direction was determined using the least squares method. A data set with an interval of a distance from peak to peak of anomalies was applied for each calculation.

4. Comparing Three Components with Total Intensity

We compared the total intensity of the geomagnetic field measured by a proton magnetometer with the three components of the geomagnetic field in order to confirm whether the three components of the geomagnetic field were correctly obtained or not. The data set along the observation line *a* in the Philippine Sea including both total intensity and three components was used for comparison. Figure 2 shows *X* (northward component), *Y* (eastward component), *Z* (downward component), *Tc* (total intensity calculated from three components, STCM) and *Tp* (total intensity measured by the proton magnetometer) magnetic anomaly profiles along the observation line *a*. The *Tc* profile is in good agreement with the *Tp*. This result suggests that the three components of the geomagnetic field were correctly obtained by STCM on the icebreaker SHIRASE.

Moreover, the amplitudes of *X* and *Z* components are large and the amplitude of *Y* component is small. The phase between *X* and *Z* is shifted by almost 90°. These features indicate the almost E-W direction of magnetic lineations. Because the magnetic anomaly produced by a two-dimensional source has no component parallel to the trend of a two-dimensional source and the phase between the other two orthogonal components is shifted by 90°. Since the almost E-W directions of magnetic anomaly lineations have been reported in this area (HILDE and LEE, 1984), this result also suggests that the three components of the geomagnetic field were correctly obtained by STCM on the icebreaker SHIRASE.

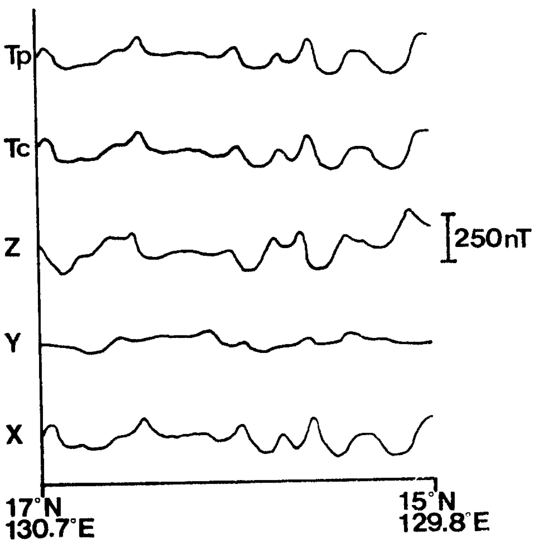

Fig. 2. Magnetic anomaly profiles from 17°N, 130.7°E to 15°N, 129.8°E (observation line a) in the Philippine Sea. X, Y, Z, Tc and Tp are northward component, eastward component, downward component, total intensity calculated from three components and total intensity measured by a proton magnetometer, respectively.

5. Results and Discussion

All results on the geomagnetic anomaly field are shown in Fig. 3. The directions of magnetic anomaly lineations are shown in Fig. 4. The direction of a solid line shows

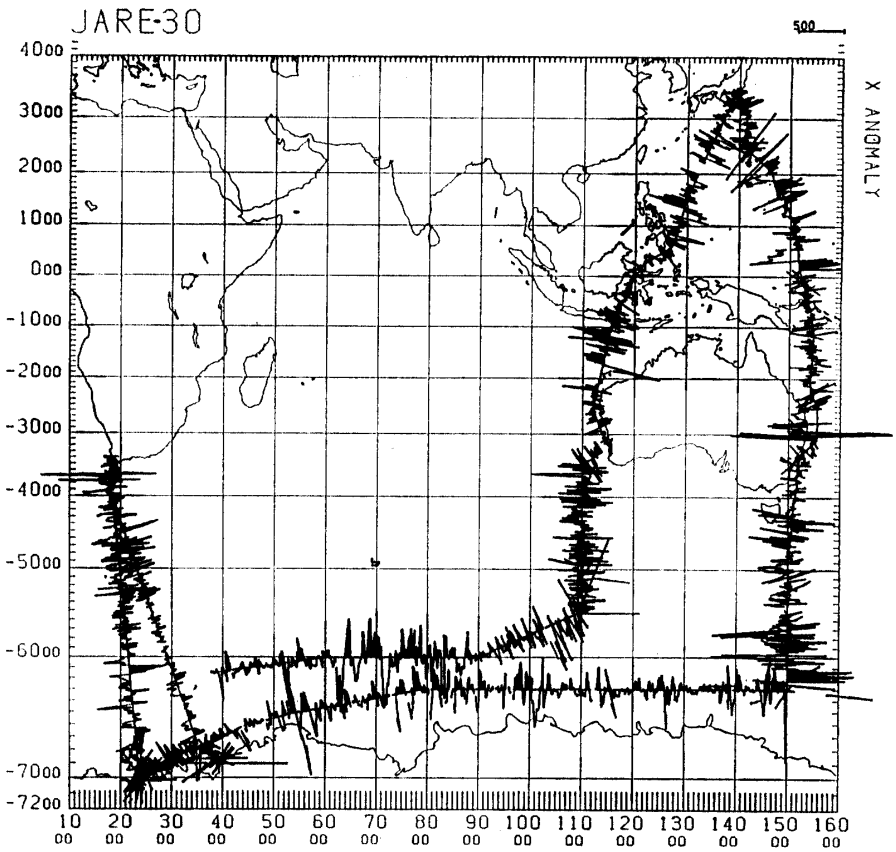

Fig. 3a. *Geomagnetic anomaly profiles, the northward.*

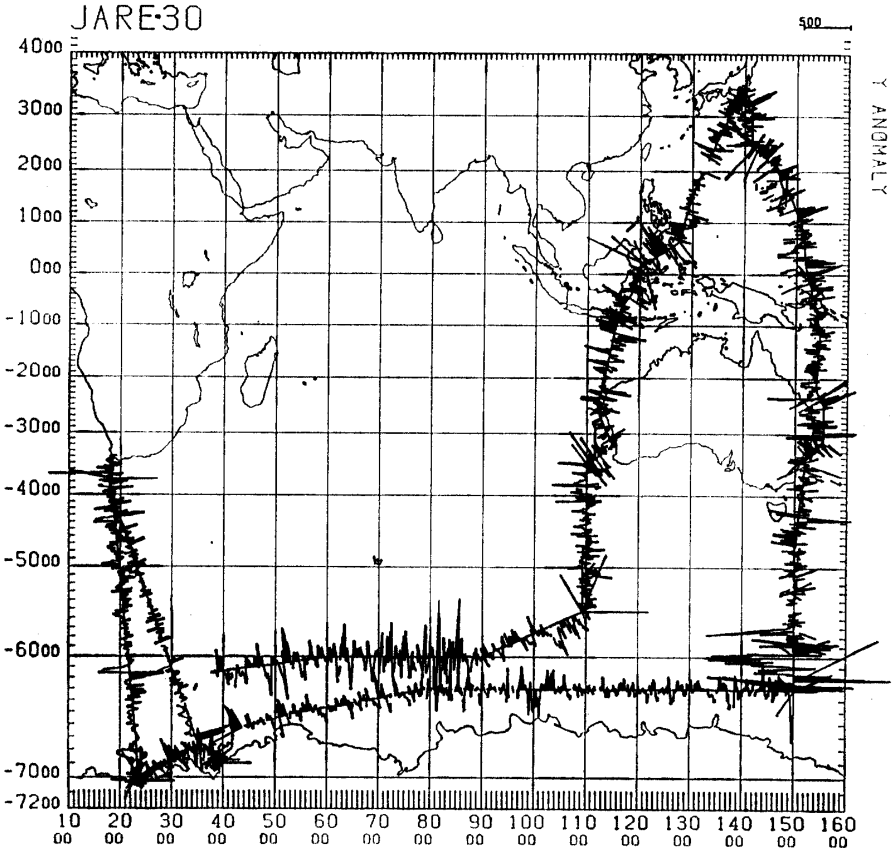

Fig. 3b. *Geomagnetic anomaly profiles, the eastward*

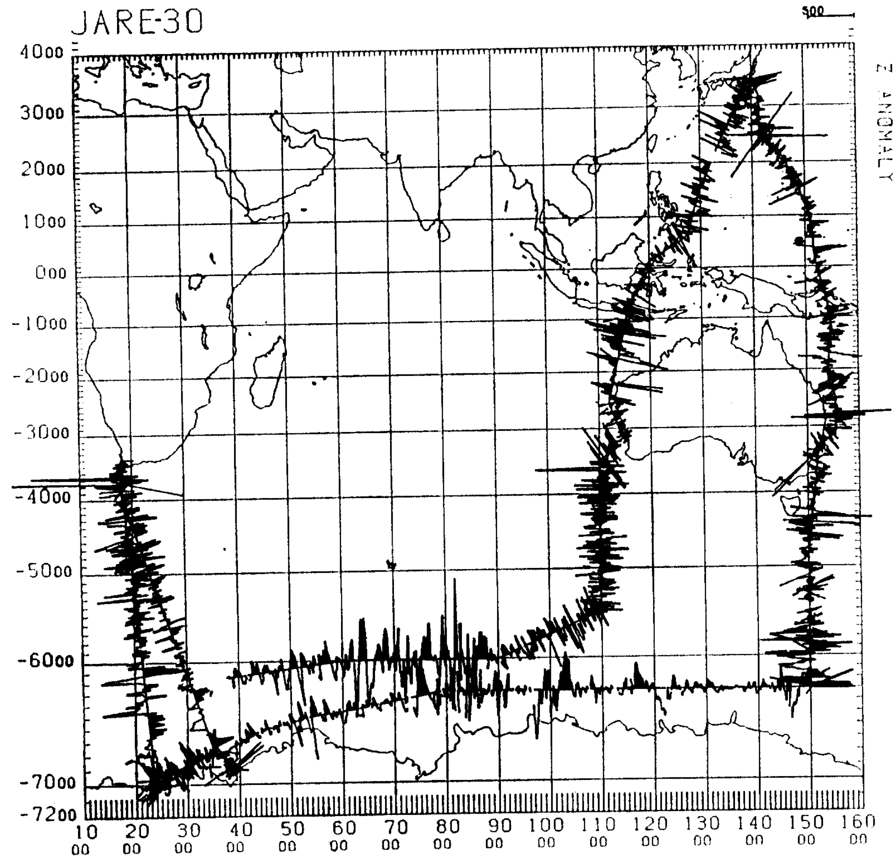

Fig. 3c. Geomagnetic anomaly profiles, downward components along ship's tracks during JARE-30. Positive anomalies are black. Scale at upper right is 500 nT.

the direction of lineation. The length of each line shows the reliability of the direction.

The wavelength that we discuss below is between 15 km and 150 km. The wavelength of 15 km corresponds to about 35 min data interval; that is longer than the moving average interval (21 min). The wavelength of 150 km corresponds to about 6 h data interval; that is fairly shorter than one day data interval. Therefore, we believed that there is little influence of geomagnetic daily variation. We discuss here the wavelength between 15 km and 150 km.

5.1. Between Japan and Australia

There is a geomagnetic anomaly, whose amplitude is more than 500 nT, along the observation line *b* in the Argo Abyssal Plain. Clear WNW-ESE directions of lineations are present in this region. Their directions coincide with those of M series magnetic anomalies in this region (FULLERTON *et al.*, 1989). The amplitude of geomagnetic anomaly is almost the same as that previously observed by a proton magnetometer. A few N-S directions of lineations among WNW-ESE directions seem to correspond to fracture zones. Around 25°S of the observation line *b*, the directions of lineations turn to N-S. These directions of lineations were also previously suggested (FULLERTON *et al.*, 1989).

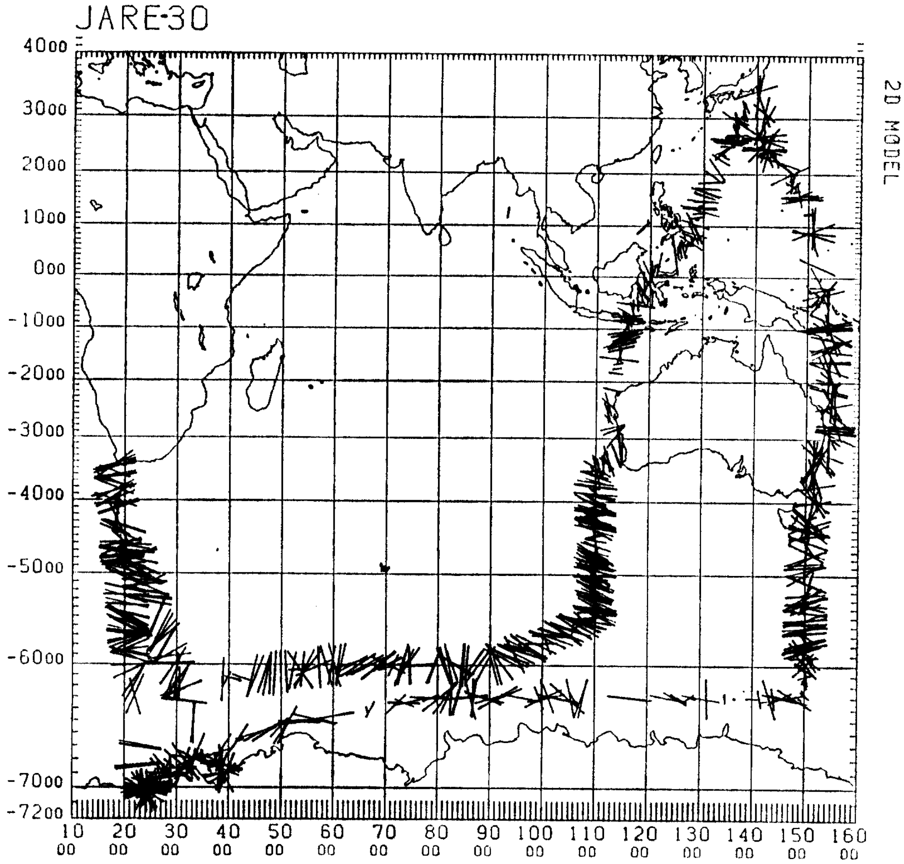

Fig. 4. Lineation direction diagram throughout JARE-30.

Along the observation line *u*, the directions of lineations are obscure, since they are affected by complicated sea bottom topography and seamounts.

Along the observation line *t*, directions of lineations are not clear and the amplitude of magnetic anomaly in this region is smaller than that in the Argo Abyssal Plain. However, the overall features of their directions are similar.

5.2. Between Australia and Antarctica

The amplitudes of *X* and *Z* components along the observation lines *c* and *s* between Australia and Antarctica are larger than that of *Y* component. The directions of lineations along both observation lines have a trend of the almost WNW-ESE. The directions of lineations along the observation line *c* are clear. This result suggests a typical two-dimentional magnetic structure along the observation line *c*. But the directions of lineations along the observation line *s* are obscure. These obscure directions seem to be caused by fracture zones accompanied with a long ridge offset.

There is a long wavelength (longer than 80 km) anomaly in each component along the observation line *r*. The directions of lineations trend almost E-W except for two regions, namely around 131°E and 142°E. The directions of lineations in these two regions trend N-S. These regions coincide with the morphological depression extending from southern Australia through the southeastern Indian Ocean to Wilkes Land, Antarctica (VEEVERS, 1982).

5.3. Between 110°E and 40°E in Southern Indian Ocean

Large amplitudes in each component of geomagnetic field excceed 500 nT along the observation lines *d*, *n* and *p*. Along the observation line *n*, there is a characteristically large amplitude of *X* component, which is over 1000 nT, and the wavelength of the magnetic anomaly is longer than that in the other two regions. The area along the observation line *n* corresponds to the continental shelf adjacent to Enderby Land where metamorphic rocks of the Archean Napier Complex lie. Strong magnetization of metamoprhic rocks of the Napier Complex was suggested by FUNAKI (1988). However, there is no feature of long wavelength and large amplitude magnetic anomalies along the observation line *e*. The long wavelentgh and large amplitude anomalies in this area are local magnetic anomalies and may be caused by the boundary of the Napier Complex and/or magnetic property of the Napier Complex.

In the other two observation lines *d* and *p* where there are large amplitude magnetic anomalies, the directions of lineations are not clear. The anomalies with similar amplitude and wavelength measured by a proton magnetometer were reported by MIZUKOSHI *et al.* (1986). These features are caused by the Kerguelen Plateau.

Along the observation line *e* in the Enderby Basin, the amplitudes of *Y* and *Z* components are larger than that of *X* component which implies that the directions of lineations are almot N-S. In contrast, along the observation lines *m*, *o* and *q*, amplitudes of *X* and *Z* components are larger than that of *Y* component and the directions of lineations are almost E-W. These results may suggest a structural difference between the deep basin and the continental shelf, which may be related to the breakup of Gondwanna.

5.4. Between Africa and Antarctica

Along the observation lines *h* and *j*, the short wavelength (shorter than 40 km) anomalies with the stable E-W directions of lineations are present. This result is almost the same as was previously suggested (ROYER *et al.*, 1988).

Along the observation line *k*, the long wavelength (longer than 80 km) anomalies with the NNE-SSW directions of lineations are present. These directions are parallel to the trend of fracture zones in this area.

Along the observation lines *g* and *l*, the long wavelength anomalies with both N-S and NNE-SSE directions are present. These directions of lineations in the Enderby Basin have never been suggested. Further, these directions seem to be linked to N-S trending magnetic lineations along the observation line *e* in the Enderby Basin mentioned above.

Along the observation line *f*, intermediate wavelength (approximately 60 km) anomalies with stable WNW-ESE directions are present. These directions are in good agreement with the directions of lineations of **M** series magnetic anomaly off Dronning Maud Land (BERGH, 1977).

Along the observation line *i*, the long wavelength anomalies with both N-S and E-W directions are present. These directions are affected by the Agulhas Basin magnetic bigtht (BERGH and BARRET, 1980) and fracture zones.

6. Conclusion

We have confirmed that vector anomalies of the geomagnetic field were correctly obtained by STCM on the icebreaker SHIRASE. The directions of magnetic lineations have been determined by these vector anomalies. Vector anomalies of the geomagnetic field and the directions of magnetic lineations along the ship's tracks are in good agreement with the results which have so far been suggested, except for the Antarctic continental margin and the Endreby Basin.

In the Antarctic continental margin, the N-S trending magnetic structure coinciding with the Australian-Antarctic depression is detected along 63°S between Australia and Antarctica (observation line *r*) and the local anomaly which seems to be caused by the Napier Complex appears along about 63°S between 50°E and 60°E (observation line *n*). In the rest of this area along about 63°S (observation lines *m*, *o*, *p* and *q*), the directions of lineations trend almost E-W. Around 60°S along the ship's tracks in the Enderby Basin (observation lines *e*, *g* and *l*), N-S and NNE-SSW trending magnetic lineations which were never reported have been detected.

These results may put forward new constraints on the evolution of the Indian Ocean, suggesting also that STCM is a useful equipment around the Antarctic area.

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