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Detection of sea floor structures off the Gunnerus ridge

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Abstract: We produced a new gravity anomaly image around Antarctica to derive detailed sea floor information from 10 Hz sampled satellite altimetry data. From the obtained gravity image, we extracted linear features, by applying a combination of binarization, clustering and thinning techniques. In the South Indian Ocean, we recognized several lineaments located off the Gunnerus ridge. We also extracted a feature running in the middle of these lineaments and assume it to be a fossil ridge. These features suggest that the direction of spreading changed during the early stage of sea floor spreading between Antarctica and India. We applied the same image processing techniques to the gravity images processed by high-cut filtering, but the ridge-like feature can not be detected from these images. Differences between processed results indicate that the gravity images obtained in our work preserve more detailed information at short wavelength.

key words: gravity, satellite, altimetry

1. Introduction

The Antarctic plate, which is almost surrounded by divergent plate boundaries, is a splitting center of the Gondwana break-up, and is one of the key regions to reveal the mechanism of plate evolution. The driving force of continental break-up is assumed to be either uplifting by plume (Hill, 1991) or horizontal tension which brings thinning of the crust (Anderson, 1995). The different driving forces cause different forms and sequences of scar on the spreading sea floor. We thus assume that some clues to early stages of the splitting process are preserved as lineaments on the sea floor of the Antarctic Ocean.

However, the Antarctic Ocean is deficient in geophysical data, and many uncertainties remain there. Tectonics of the Atlantic mid ocean ridge system between the Africa plate and the South America plate are relatively well known, but the evolution of the Antarctic plate south of the Bouvet triple junction is hardly known. Similarly, magnetic anomaly lineation and fracture zone formations in the southern Indian Ocean are poorly identified. Reconstructions of Gondwana using marine geophysical data have been established in many studies (*e.g.* Norton and Sclater, 1979). However, the opening between India and Antarctica in these models has relied on the only constraints from a few identified magnetic anomaly lineation and fracture zone formations in the Indian Ocean (*e.g.* Fullerton *et al.*, 1989). The initial sea floor spreading history between India and Antarctica is still speculative (Nogi *et al.*, 1996).

To these data deficient areas, a remote sensing technique, especially satellite altimetry, can provide homogeneous data. Hence satellite altimeter data already have been applied for many fields (*e.g.* Sandwell and McAdoo, 1988), but we think the information contained in the enormous amount of raw data has not been used thoroughly yet. In the field of plate tectonic reconstructions, many studies (*e.g.* Tebbens and Cande, 1997; Marks and Stock, 1997) have referred to the satellite derived gravity images which were compiled and published by Sandwell and Smith (1997) or their latest result. Sandwell and Smith (ibid.) mainly aimed to obtain a global homogeneous data set and they succeeded in obtaining a high precision data set. However, it is also true that different data processing derives somewhat different gravity images (McAdoo and Marks, 1992; Sandwell, 1992). Moreover, the areas of interest are not always in similar conditions. For example, the quality of data obtained from areas with sea ice is inferior to that from open sea. Open sea oriented homogeneous processing is not necessarily appropriate to such areas. Specialized processing is needed to obtain more accurate or detailed information.

In our previous work (Terada and Fukuda, 1997), we examined the applicability of the GEOSAT 10 Hz sampled altimetry data to obtain fine structural information on the sea floor. We concluded that the GEOSAT data contain more detailed information than that derived from previous gravity images. Therefore, we first tried to obtain more detailed gravity images in the Antarctic Ocean from the GEOSAT data. We applied some techniques of image processing to the gravity images to derive more visible and clear figures showing sea floor structures. We detected a structure that suggests the direction changes of sea floor spreading between Antarctica and India near the continental margin.

2. Outline of the data processing

2.1. Processing of altimetry data

We basically follow the method given by Sandwell (1992) to obtain gravity anomaly images from satellite altimetry data. An outline of the method is as follows:

1) Apply sensor and geophysical corrections to each sample of altimeter data,
2) Group the original 1-dimensioned (1-D) profiles into ascending and descending order,
3) Subtract the long wavelength gravity field from each profile,
4) Convert these profiles into 2-D grids of ascending/descending order, and
5) Merge these two grids into the gravity anomaly grids using the FFT technique.

However, in contrast to the original method, we employed 10 Hz raw altimeter data and did not apply any high-cut filter opting instead to keep the short wavelength information (Terada and Fukuda, 1997).

2.2. Image processing

The distribution of gravity highs and lows reflects ocean floor structures more strongly than the gravity values themselves. Hence, regarding a gravity anomaly image from satellite altimetry as a remote sensing image, we apply a combination of binarization, clustering and thinning techniques (Duff, 1978) (Fig. 1). These processes enhance lineaments in the gravity image and extract the frames of sea floor structures from the gravity image.

In the binarization process of gravity anomaly grid data, we should determine a

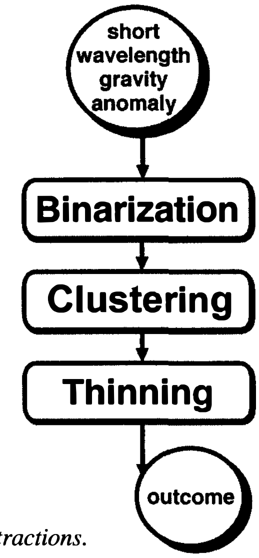

Fig. 1. Flowchart of feature extractions.

threshold value by searching for the median of gravity values in objective area. However, in the study area to be described later, the distribution of short wavelength gravity values is almost symmetrical about zero. Thus we adopted zero as the threshold to binarize the gravity grids.

In the next step, we cluster the binarized gravity at grid points. For this purpose we adopted an expand and contract method for 8 adjacent points and for 4 adjacent points to remove small pricks and fill in small cavities of a cluster.

We employed a parallel thinning algorithm to extract frames from the obtained clusters. This algorithm first checks the values (1 or 0) of 8 adjacent cells of a center cell, and then toggles the value of the center cell if it does not correspond to the edge. This sequence was repeated for all cells until no value changed.

3. Gravity images

Following the procedure described in section 2.1, we first obtained gravity anomaly images around Antarctica (0–360°E, 40–72°S). We employed GEOSAT JGM-3 geophysical data records (GDR) (*e.g.* Cheney *et al.*, 1991) and the EGM 96 global gravity model (Lemoine *et al.*, 1997) for long wavelength gravity data. GEOSAT JGM-3 GDR, renewed and released in 1997, is the latest version of GEOSAT. The accuracy of the GEOSAT JGM-3 is mainly improved in orbital corrections and ocean tidal corrections. In this paper, we call the gravity anomaly image that we obtained from the latest version of GEOSAT data a present gravity image (PGI).

Gravity anomalies without high-cut filtering were obtained on 1min by 1 min grids. A sample plot of the gravity image bounded by parallels 40–72°S and meridians 0–90°E is shown in Fig. 2. An index map of Fig. 2 is shown in Fig. 3. This area is expected to preserve early traces of sea floor spreading between Antarctica and India (Nogi *et al.*, 1996). We applied image processing to the gravity image in the box in Fig. 2 to extract the sea floor structures, as described in the next section. Figure 4 shows the enlarged gravity image. In Fig. 2 and Fig. 4, linear structures orthogonal to each other can be

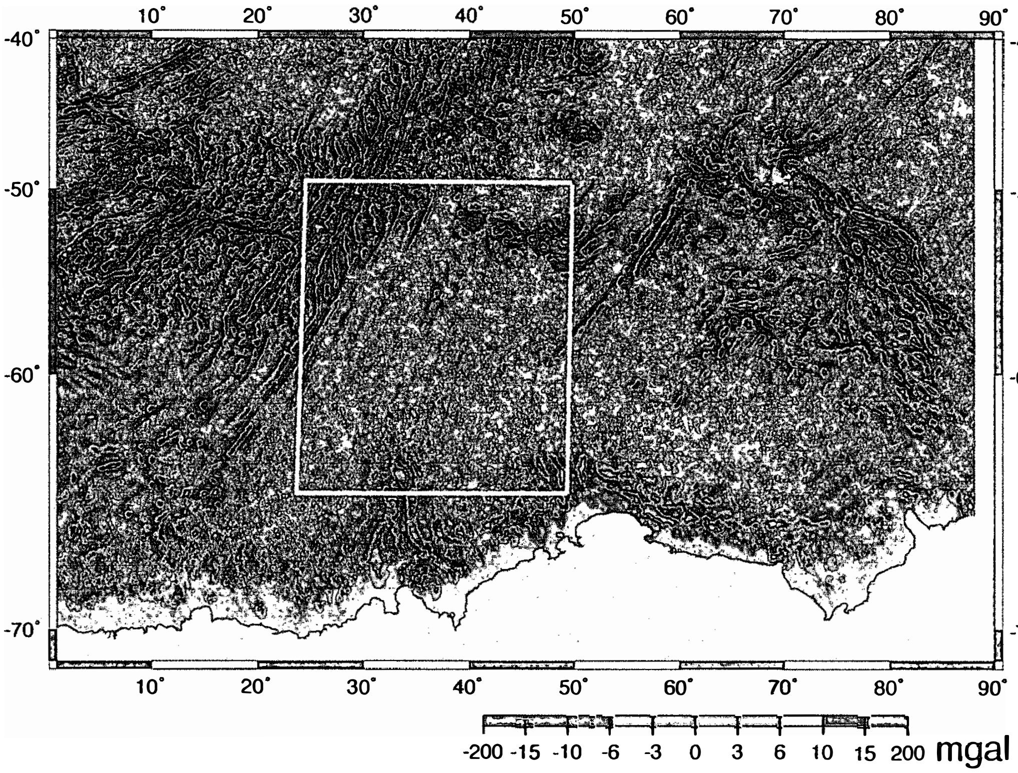

Fig. 2. A part of gravity anomaly images around the Antarctic margin. A box indicates the area applied feature extractions in Section 4.

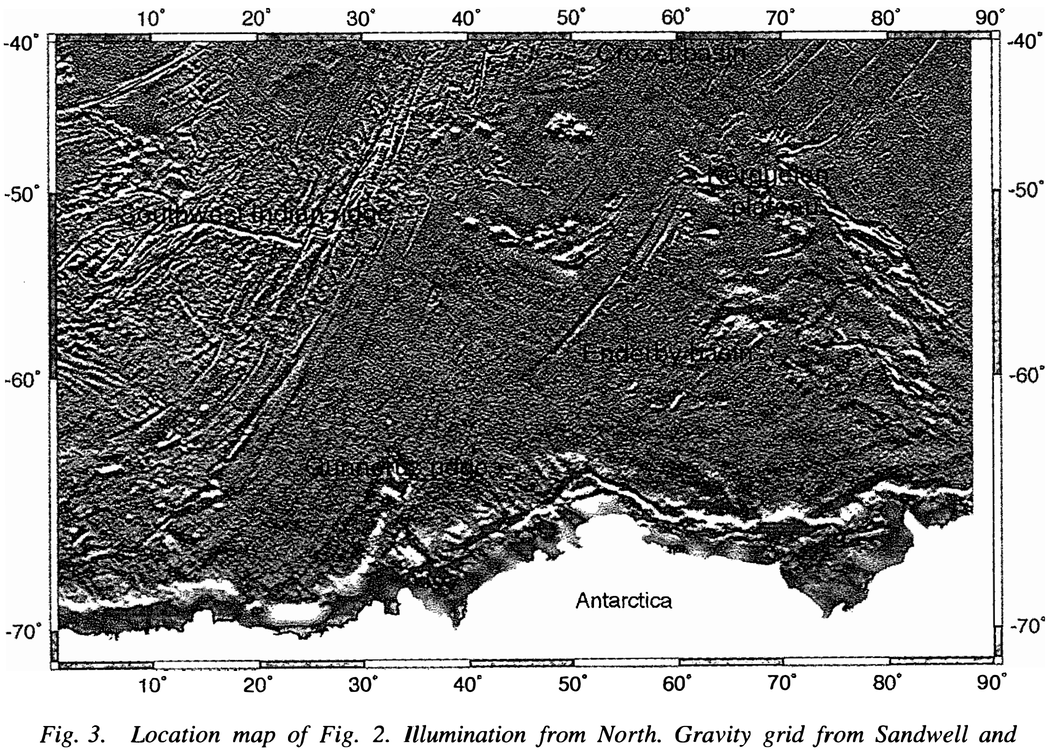

Fig. 3. Location map of Fig. 2. Illumination from North. Gravity grid from Sandwell and Smith (1997).

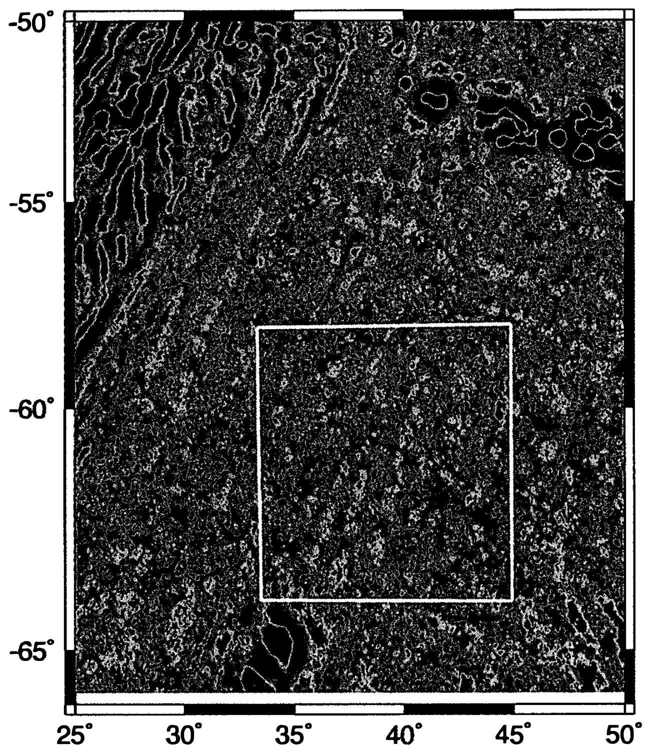

Fig. 4. Area of feature extractions (Section 4). A box indicates the area shown in Fig. 7 and Fig. 8.

observed. NNE-SSW parallel linear structures and WNW-ESE shorter linear structures attached to both ends of parallel structures (see boxed area on Fig. 2). WNW-ESE structures have not been seen clearly in gravity images published previously. These features are more obviously visible by applying image processing techniques.

4. Results

4.1. Detection of a fossil ridge

We applied image processing techniques to the gravity image shown in Fig. 4. The study area is located off the Gunnerus ridge of Antarctica, and is assumed to be the sea floor formed during early spreading between Antarctica and India (Nogi *et al.*, 1996). However, surface geophysical data are not enough to cover this area uniformly, and the sea floor features of this area are not seen clearly on the satellite gravity images previously derived (*e.g.* Sandwell and Smith, 1997).

Figure 5 shows a result after binarization and the clustering process. Figure 5 shows the following clearly. A rectangular region which consists of lineaments mentioned in section 3 exists between 55°S and 65°S. This rectangular region is divided into a northern part and southern part at the middle of the NNE-SSW lineaments. These two parts have partial symmetrical correspondence. Lineaments of the southern part keep their shape comparatively well. Lineaments of the northern part are torn along a line from 37°E–50°S to 50°E–66°S in Fig. 5. This scar breaks the symmetry of these two parts.

Figure 6 shows the results after the thinning process. The gray line indicates a linear

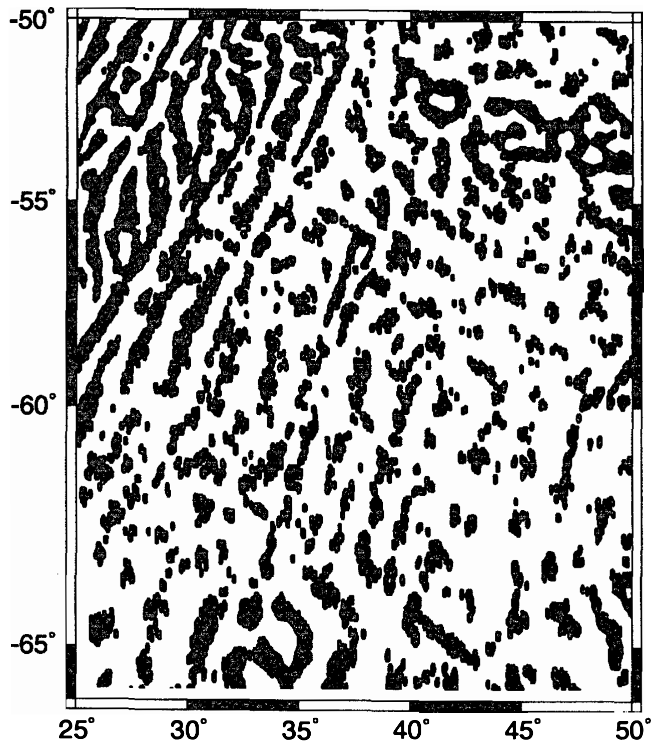

Fig. 5. Clustered images of Fig. 4. It can be recognized that a rectangular area is divided into two parts in the middle.

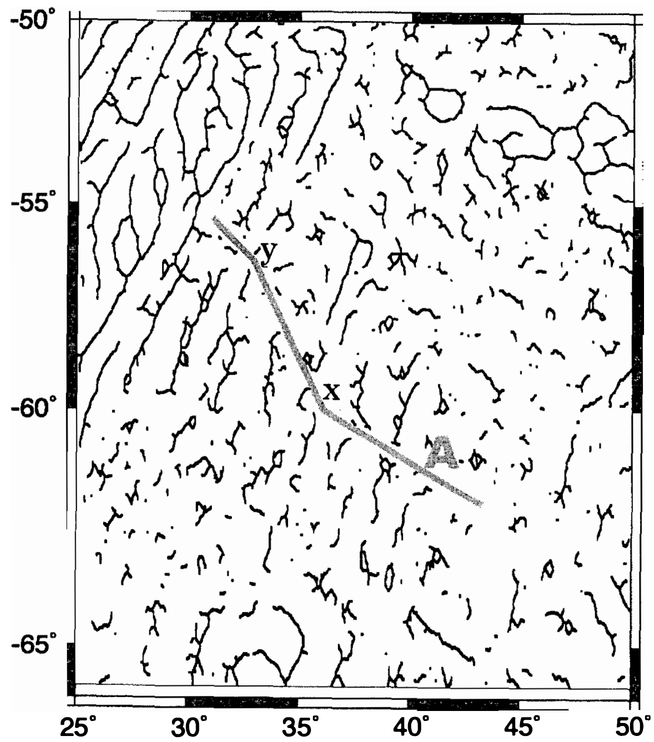

Fig. 6. Thinned images of Fig. 5. The gray line shows that the ridge-like feature changes direction at points x and y.

structure through the middle of the NE-SW lineaments. In this paper, we call this linear structure feature "A". Figure 6 shows that feature "A" changes direction at point x and point y.

From the symmetrical correspondence of the lineaments divided by feature "A", the lineaments are supposed to be the counterparts of spreading, and feature "A" is supposed to be a fossil ridge. The formation of the lineaments and feature "A" suggests that the direction of spreading changed in this area during the early stage of sea floor spreading between Antarctica and India.

4.2. Comparison with previous gravity images

We applied image processing techniques to the world gravity images (called WGI in this paper) compiled by Sandwell and Smith (1997). We compared the image processed results of WGI with those of PGI.

Results of the binarization processing applied to WGI and PGI are shown in Figs. 7a and 7b, respectively. Areas of Figs. 7a and b are boxed in Fig. 4. Figures 7a and b show enlarged images of the middle of the lineaments mentioned in Section 4.1. A WNW-ESE trending linear feature is considered to be a fossil ridge like feature. In Fig. 7b, this linear feature is preserved after the binarization processing applied to PGI. In Fig. 7a, this feature is eliminated by the processing on WGI. To detect such features by the processing of gravity images, usage of PGI is more appropriate than that of WGI.

Results of the thinning process applied to WGI and PGI are shown in Figs. 8a and 8b, respectively. Similar to results of the binarization processing, feature "A" (Fig. 8b) eliminated from the WGI results (Fig. 8a). The WGI were filtered to cut off components shorter than wavelength of 12 km; this length corresponds to the width of the linear feature in Fig. 7b.

These results indicate that the gravity images obtained in our work include more detailed information than high-cut filtered gravity images, and that a combination of basic

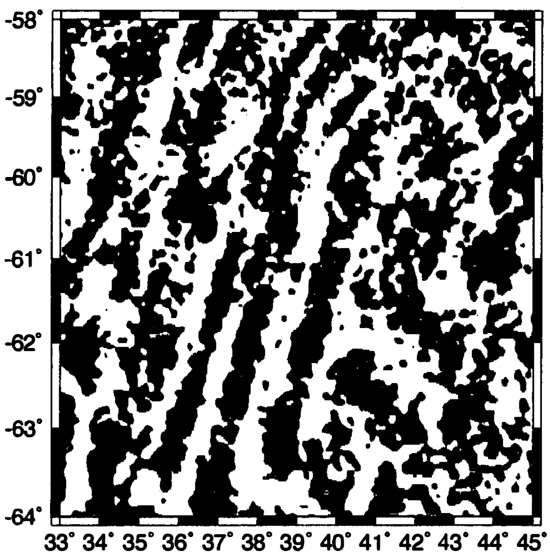

Fig. 7a. Binarized images of lineaments center from WGI (Sandwell and Smith, 1997).

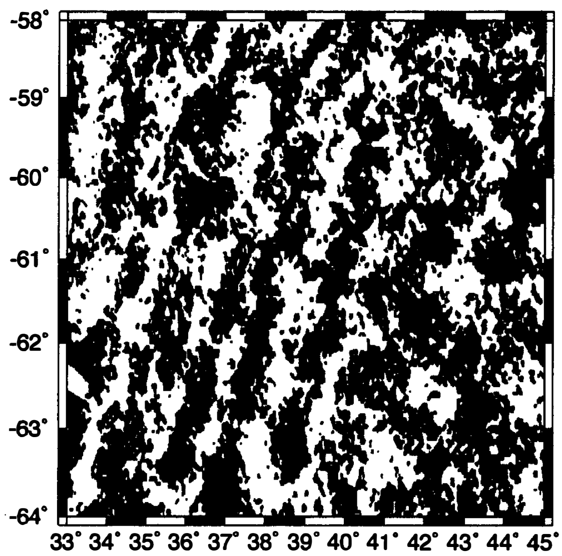

Fig. 7b. Binarized images of lineaments center from PGI.

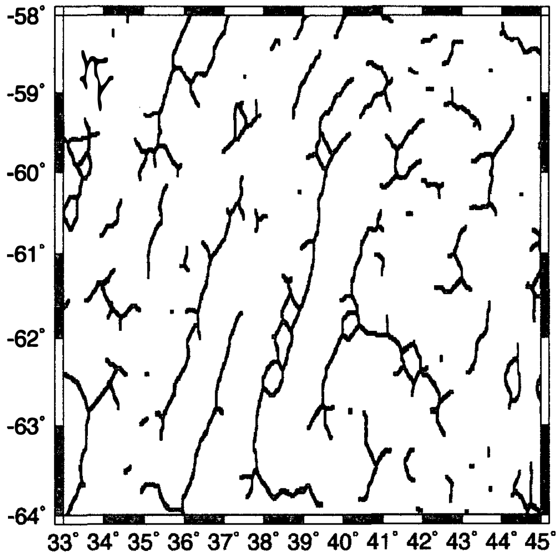

Fig. 8a. Thinned results of Fig. 7a.

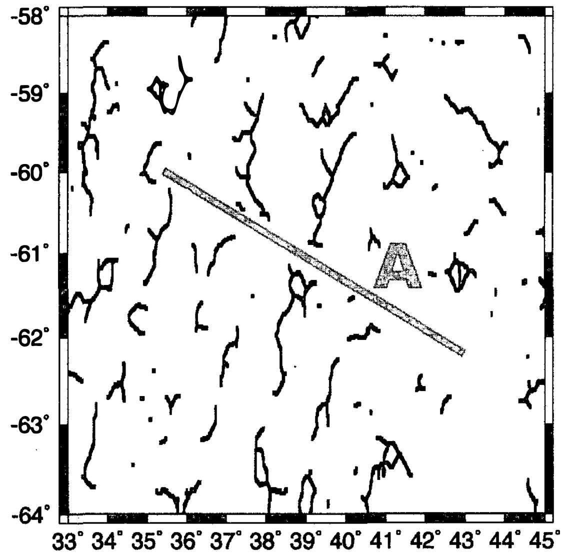

Fig. 8b. Thinned results of Fig. 7b.

image processing techniques efficiently condenses data mass, conserving essential features.

5. Conclusions

We processed satellite altimetry data to obtain a new gravity image which includes more detailed sea floor information than that derived from previous marine gravity images. In the next step, we applied image processing techniques to the new gravity images to obtain fine structures on the sea floor. We detected linear structures from the obtained gravity anomaly image. The feature extraction procedure makes it obvious that a fossil ridge-like linear feature exists in the middle of these structures. The features suggest that the direction of spreading changed during the early stage of sea floor spreading between Antarctica and India. We also applied the same techniques to the high-cut filtered gravity images, but the ridge-like feature can not be detected from these images. Differences between these two results indicate that the gravity images obtained in our works include more detailed information at short wavelength.

Besides the features mentioned in this issue, the present gravity images obtained in our work suggest the existence of several structures uncharted on previous maps. To fill in the blanks of the survey, some studies became to combine satellite derived and direct surveyed data (*e.g.* Nogi *et al.*, 1996). We think that processing of present gravity images can supply for these studies more detailed constrains about the evolution of the southern ocean floor.

References

Anderson, D.L. (1995): Archons, perisphere and non-plumes. EOS Trans., **76**, 41.
Cheney, R.E., Doyle, N.S., Douglas, B.C., Agreen, R.W., Miller, L., Timmerman, E.L. and McAdoo,

D.C. (1991): The complete Geosat altimeter GDR handbook. NOAA Manual NOS NGS 7, National Ocean Service, Rockvill, MD, 79 p.

Duff, M.J.B. (1978): CLIP 4: A large scale integrated circuit array parallel processor. Proc. 3rd IJCPR, Cororado, CA, 728–733.

Fullerton, L.G., Sager, W. and Handschumacher, D.W. (1989): Late Jurassic-Early Cretaceous evolution of the Eastern Indian Ocean adjacent to northwest Australia. J. Geophys. Res., **94**, 2937–2953.

Hill, R.I. (1991): Starting plumes and continental break-up. Earth Planet. Sci. Lett., **104**, 398–416.

Lemoine, F.G., Smith, D.E., Kunz, L., Smith, R., Pavlis, E.C. *et al.* (1997): The Development of the NASA GSFC and NIMA Joint Geopotential Model. Gravity, Geoid and Marine Geodesy, ed. by Segawa *et al.* Berlin, Springer-Verlag, 461–469 (International Association of Geodesy Symposia, 117).

Marks, K.M. and Stock, J.M. (1997): Early Tertiary gravity field reconstructions of the Southwest Pacific. Earth Planet. Sci. Lett., **152**, 267–274.

McAdoo, D.C. and Marks, K.M. (1992): Gravity fields of the Southern Ocean from Geosat data. J. Geophys. Res., **97**, 3247–3260.

Nogi, Y., Seama, N., Isezaki, N. and Fukuda, Y. (1996): Magnetic anomaly lineations and fracture zones deduced from vector magnetic anomalies in the West Enderby Basin. Weddell Sea Tectonics and Gondwana Break-up, ed. by B.C. Storey *et al.* London, Geological Society, 265–273 (Geol. Soc. Spec. Pub., 108).

Norton, I.O. and Sclater, J.G. (1979): A model for the evolution of the Indian Ocean and the break-up of Gondwanaland. J. Geophys. Res., **84**, 6803–6830.

Sandwell, D.T. (1992): Antarctic marine gravity field from high-density satellite altimetry. Geophys. J. Int., **109**, 437–448.

Sandwell, D.T. and McAdoo, D.C. (1988): Marine gravity of the Southern Ocean and Antarctic Margin from Geosat. J. Geophys. Res., **93**, 10389–10396.

Sandwell, D.T. and Smith, W.H.F. (1997): Marine gravity anomaly from Geosat and ERS-1 satellite altimetry. J. Geophys. Res., **102**, 10039–10054.

Tebbens, S.F. and Cande, S.C. (1997): Southeast Pacific tectonic evolution from early Oligocene. J. Geophys. Res., **102**, 12061–12084.

Terada, K. and Fukuda, Y. (1997): Applicability of 10 Hz satellite altimetry data to the Antarctic margin. Proc. NIPR Symp. Antarct. Geosci., **10**, 26–35.

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