Geomagnetic Vector Anomaly in the Southern Lau Basin and Havre Trough

Toshitsugu YAMAZAKI*[1] Toshiya FUJIWARA*[2] Masato JOSHIMA*[1]

Geomagnetic vector anomaly measurements were conducted in the southernmost Lau Basin and Havre Trough during the R/V "Yokosuka" LAUHAVRE cruise in order to understand better their evolutional processes. This arc–backarc system was poorly surveyed previously except for the southernmost segment near New Zealand. The southernmost tip of a propagating rift, the southern extension of the Valu Fa spreading ridge, occurs at 24° 00′S, 177° 10′W in the southernmost Lau Basin, where a prominent graben occupies. Strong negative down–component magnetic anomalies (positive magnetization) probably associated with the oceanic crust of a Brunhes age can be traced down to 23° 50′S. The entire Havre Trough including the junction to the Lau Basin is in a rifting stage at present. No magnetic anomalies indicative of true seafloor–spreading was identified, although lineated magnetic anomalies probably caused by dikes and other intrusions emplaced in arc crust along the rift zone were observed. In the central Havre Trough, the occurrence of NE–SW trending magnetic structure was estimated, which is a little oblique to the trend of the active Kermadec Ridge and the remnant Colville Ridge.

Key words : Lau Basin, Havre Trough, backarc basin, rifting, magnetic vector anomaly, swath bathymetry

* 1　Geological Survey of Japan
* 2　Japan Marine Science and Technology Center

1. Introduction

The Lau Basin and Havre Trough are an active, 2,000 km long, back-arc basin associated with the Pacific-Australian plate convergence (Karig, 1970). The Havre Trough has relatively constant width of 100 to 120 km along the entire length of the Trough, whereas the Lau Basin widens northward. The Lau Basin north of 23° S has been relatively well surveyed (e.g. Taylor et al., 1996), and is the best example of a fast-spreading (6 to 10 cm/yr half-rate) back-arc basin. The southernmost part of the Lau Basin has, however, been much less surveyed, and details of the rifting-spreading transition has not been documented well. Furthermore, large part of the Havre Trough was little surveyed previ-

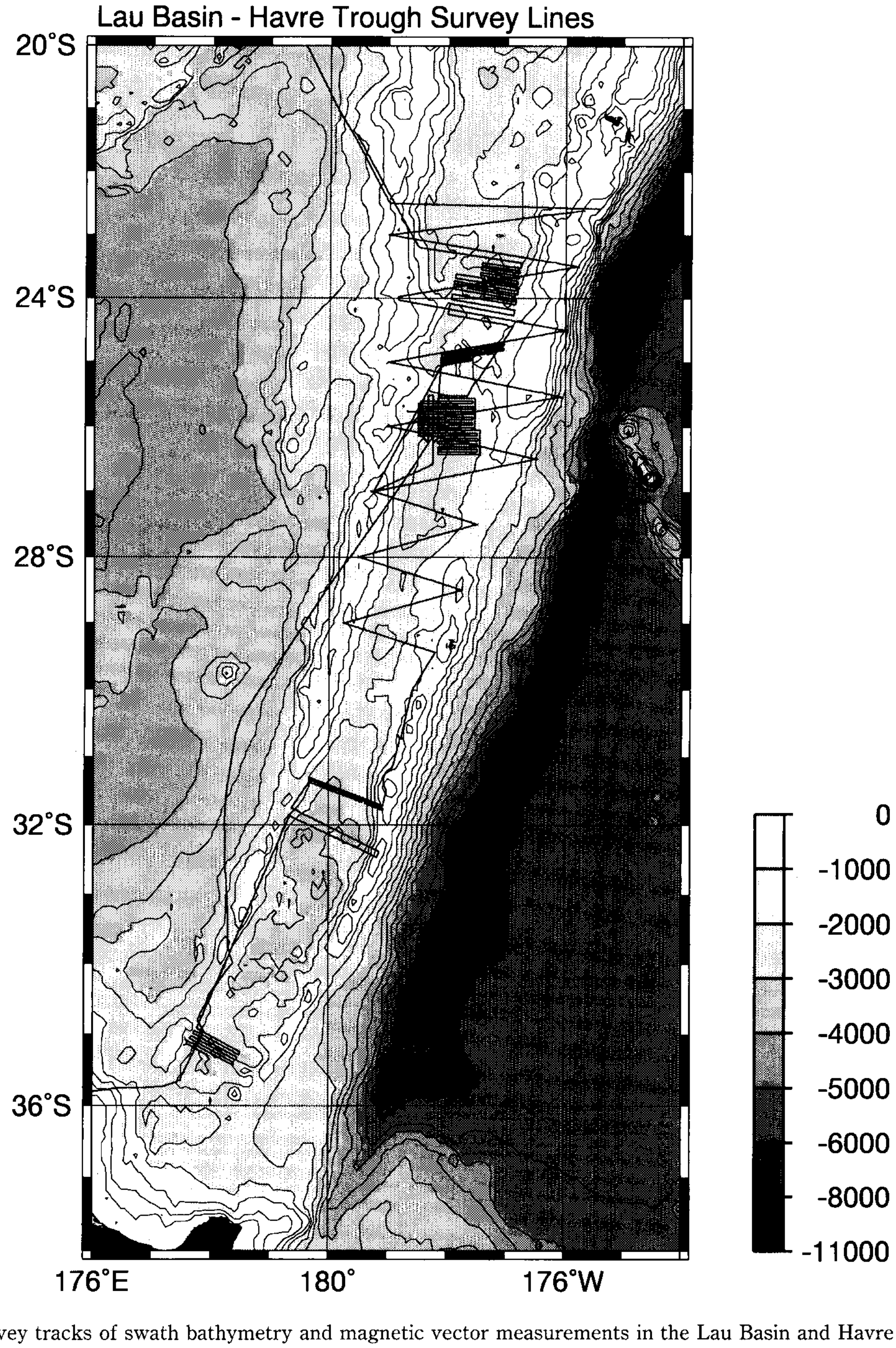


Fig. 1 Survey tracks of swath bathymetry and magnetic vector measurements in the Lau Basin and Havre Trough during the LAUHAVRE cruise of R/V "Yokosuka".

ously except for the southernmost segment close to New Zealand. The Havre Trough is considered to be in a rifting stage (Parson and Wright, 1996), but it is not known well whether or not oceanic crust occurs in some part of the Havre Trough.

A geophysical and geological study including swath bathymetry, seismic reflection and refraction, gravity, magnetics, and bottom sampling by dredge was carried out in the southern part of the Lau Basin and the Havre Trough during the LAUHAVRE cruise of R/V "Yokosuka" (cruise ID: Y96-14 and Y97-01) in January and February 1997 (Fig. 1). This report presents preliminary results of the magnetic vector anomaly measurements. The purpose of the measurements was to clarify magnetic structure in this region; for example, to detect oceanic crust of seafloor-spreading origin and estimate its age, and to know strikes of magnetic boundaries such as faulted crustal blocks. Such information will be useful for understanding better the extensional tectonics of this region.

The advantage of magnetic vector measurements compared with ordinary total-force measurements using a proton magnetometer includes;

(1) The amplitude of total-force anomalies is affected not only by the magnetization of crust but also by the direction of the present geomagnetic field and the strike of a magnetized body, which is known as the skewness of magnetic anomalies. The vector anomalies are not affected by such geometrical parameters, and thus directly reflect the magnetization of crust.

(2) From vector anomaly data along single ship-track, we can deduce whether a magnetized body is two-dimensional (magnetic lineation caused by a magnetic polarity reversal or displacement by a fault) or three-dimensional (a seamount or a circular intrusive body). If it is two-dimensional, the position of the magnetic boundary and its strike can be determined.

2. Instruments and measurement procedure

A three-component magnetometer system (Tierra Technica SFG1212) equipped on-board R/V "Yokosuka" was used for the measurements (Oshida and Furuta, 1995). Three-axes flux-gate sensors with ring-cored coils are fixed on the roof of the bridge (about 2 m from the roof). Outputs of the sensors were digitized by a 20-bit A/D converter (1 nT/LSB). These data were sampled at 8 times per second. Ship's heading was measured using a gyro-compass (TOKIMEC ES-110) in the geophysics laboratory. Roll and pitch data were provided by a VRU (vertical reference unit) of a HS-10 multi-narrow-beam echo-sounding system. These data were also sampled at 8 times per second. Ship's position (GPS) and speed were taken from LAN every four seconds. Logging of these data was carried out using a personal computer (NEC PC9801BX). The data were stored on a hard disk unit and a magneto-optical disk (ICM MO-4120) by an ASCII format, and also transmitted to a geophysics data logging workstation.

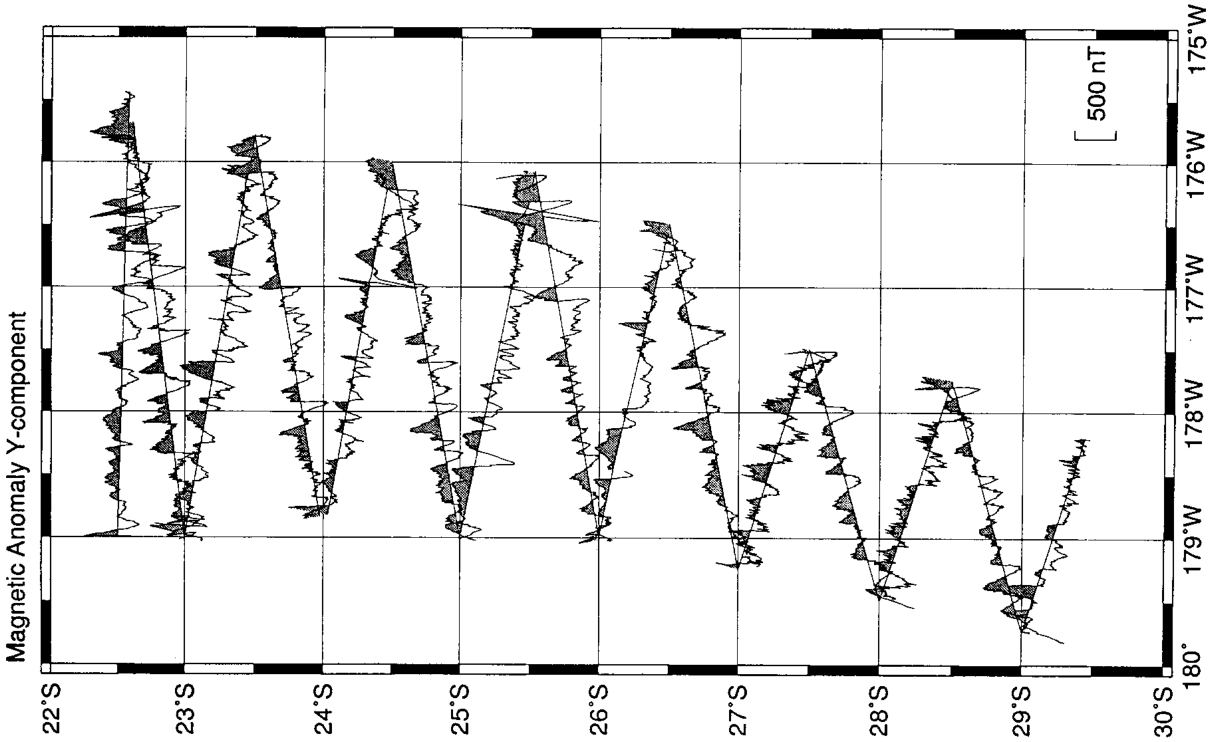
To obtain geomagnetic field vector from on-board measurements, the contribution of the magnetic field produced by a ship must be removed from the observed magnetic field (Isezaki, 1986; Seama, 1992). For this purpose, we conducted a calibration called "Figure-8 turn" (running along an 8-shaped track consisting of two circles, left and right turns; radius ~500 m). The calibration was performed four times during the R/V "Yokosuka" Y96-14 cruise, and a 3×3 matrix $\tilde{\mathbf{B}}$ representing the ship's induced magnetization and a vector $\mathbf{Hp}$, ship's permanent magnetization, were determined as:

$$\tilde{\mathbf{B}} = \begin{pmatrix} 1.0800 & 0.0389 & -0.0167 \\ -0.0324 & 1.2033 & 0.0218 \\ 0.0105 & 0.1195 & 0.8277 \end{pmatrix}$$

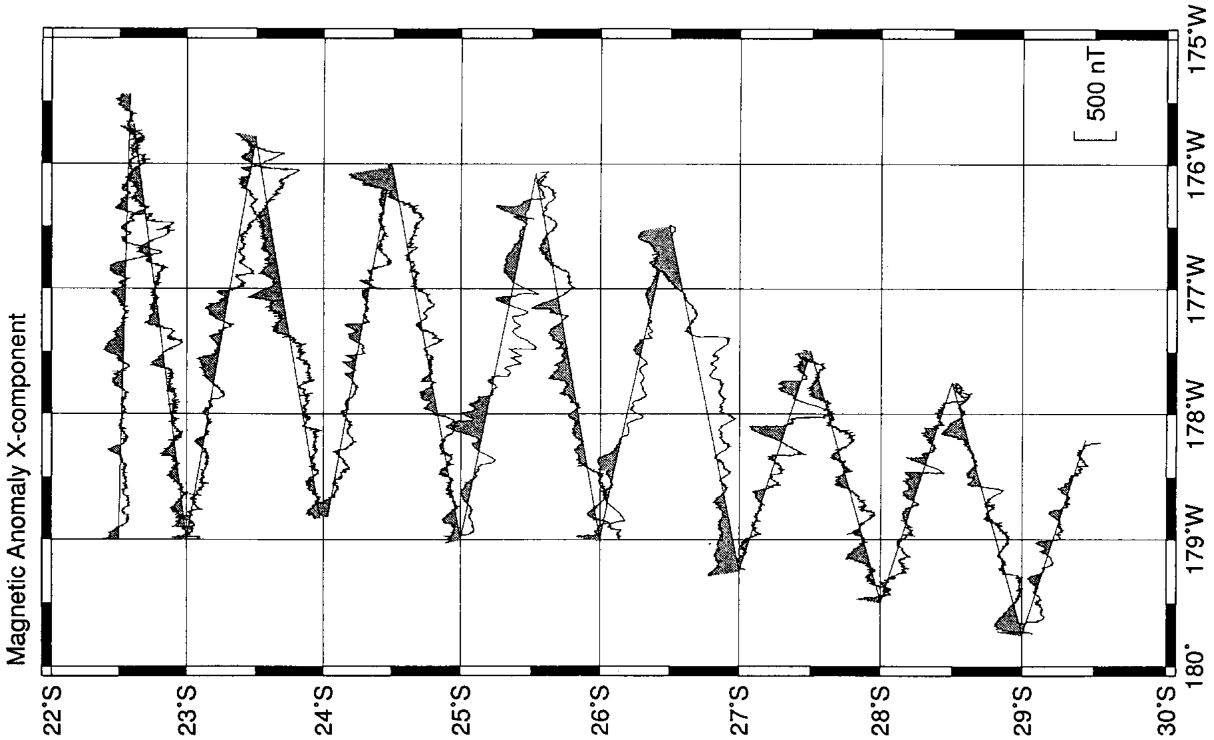
$$\mathbf{Hbp} = \begin{pmatrix} -2{,}603.8 \\ 2{,}583.6 \\ -7{,}767.6 \end{pmatrix}$$

Three components of the magnetic field and ship's pitch, roll, and heading data sampled at 8 Hz were averaged for one second, and then the three components of the geomagnetic field were derived using the values of $\tilde{\mathbf{B}}$ and $\mathbf{Hbp}$ presented above. Finally, the data at one second intervals were averaged for one minute. The vector measurements were conducted together with total-force measurements by a proton precession magnetometer (Kawasaki Chishitu STC010, towed about 300 m behind the ship).

The anomalies of each component was calculated using the 1995 version of the IGRF as the reference field.



Magnetic Anomaly Y-component
500 nT
22°S
23°S
24°S
25°S
26°S
27°S
28°S
29°S
30°S
180°
179°W
178°W
177°W
176°W
175°W



Magnetic Anomaly X-component
500 nT
22°S
23°S
24°S
25°S
26°S
27°S
28°S
29°S
30°S
180°
179°W
178°W
177°W
176°W
175°W

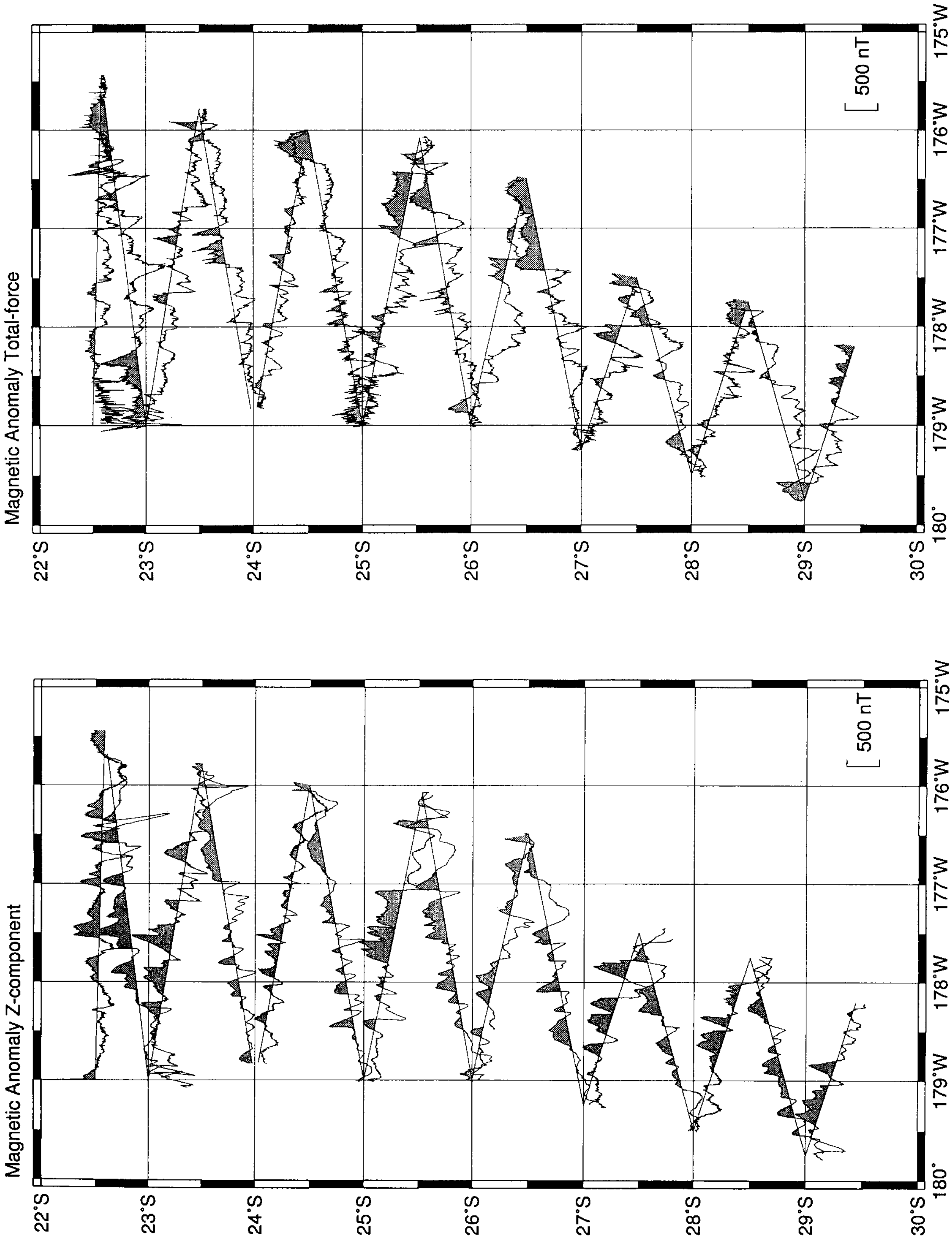


Fig. 2 Magnetic anomaly profiles of north (X), east (Y), down (Z) components, and total-force along reconnaissance zig-zag survey lines in the southern Lau Basin and northern Havre Trough.

The mean anomaly of each component of each survey line was set to be zero by subtracting a linear bias from the observed anomalies, because anomalies of each component showed a linear trend, and the values of the bias changed among survey lines. Thus interpretations should be based on relative changes but not absolute anomaly values. The linear bias was probably caused by an error of the gyro-compass and slight changes of ship's permanent magmetization, **Hp**, with time (Viscous Remanent Magnetization) despite being assumed as a constant. The existence of the latter effect was estimated from the fact that the difference between total force measured by the proton magnetometer and that calculated from the three components gradually and almost linearly changed with time. Note that the horizontal component (X: north and Y: east) may contain a large error before the gyro-compass is stabilized (~30 minutes) after a course change (beginning of each line).

As the study area is in the southern hemisphere negative Z (down) component means positive inclination of magnetization (remanent magnetization plus induced magnetization). A two-dimensional magnetic structure such as displacement by a fault or magnetic lineation of seafloor-spreading origin produces no magnetic anomalies in the strike direction. For qualitative interpretation of the horizontal component, therefore, magnetic structure of N-S (E-W) strike shows strong (weak) anomalies in Y-component but weak (strong) in X-component.

3. Results and discussion

Fig. 2 displays preliminary results of the three components of magnetic anomalies, and total force anomalies by a proton magnetometer along zig-zag reconnaissance survey lines across the southern Lau Basin and northern Havre Trough. Fig. 3 shows the results in the central Havre Trough. A bathymetric map and magnetic vector anomalies in a detailed survey boxes in the southernmost Lau Basin are shown in Figs. 4 and 5, and those in a box at the junction between the Lau Basin and Harve Trough in Figs. 6 and 7.

(1) Southernmost Lau Basin

A prominent graben of NNE-SSW strike occurs in the detailed survey box (Fig. 4) The southern end of the graben occurs at 24° S, 177° 10′W. The width of the graben between 23° 45′S and 24° S is about 15 km, and the maximum depth about 3,300 m. The relative height of the fault scarp bounding the graben is about 1,000 m. The graben widens northward from 23° 45′S, and the deepest part steps west at about 23° 30′S. The graben is considered to be the southernmost tip of a propagating rift, which locates on the southern extension of the Valu Fa Ridge of the Eastern Lau Spreading Center (ELSC). The southernmost tip of the Valu Fa Ridge was previously known to extend to at least 22° 45′S, 176° 45′W (Wiedicke and Collier, 1993; Person and Wright, 1996). The garben accompanies strong negative Z-component magnetic anomalies (positive magnetization) (Fig. 5), which suggests that recent volcanic intrusives and extrusives of a Brunhes age occupy the floor of the graben. The negative anomalies are terminated at 23° 50′S, whereas the graben continues further south to 24° S. This suggests that amagmatic extension has occurred between 23° 50′S and 24° 00′S. The tectonic setting that a deep graben at the tip of a spreading axis propagating into an arc crust is similar to that observed at 22° N in the Mariana Trough (Yamazaki and Murakami, 1997).

Magnetic vector anomalies in the detailed survey box show a NNE-SSW trend in general (Fig. 5), which is consistent with the structural trend observed on the swath bathymetry (Fig. 4). A particular anomaly pattern, however, cannot be traced beyond a few profiles. The crust in this region is probably of island-arc origin except for the graben, and the magnetic anomalies would be caused by structurally controlled volcanic intrusions and/or fault displacement. The amplitude of the Y-component anomalies is generally larger than that of the X-component, but the amplitude of the X-component is not very small (Figs. 2 and 5). This also suggests the strike of magnetic boundaries being somewhat deflected from N-S.

The pattern of magnetic anomaly variations is similar among the northernmost three zig-zag lines (north of 23° 30′S) (Fig. 2), suggesting the occurrence of organized rifting and seafloor spreading in this region. A zone of the negative Z-component anomalies between 23° 30′S, 176° 45′W and 23° 30′S, 177° 00′W would be associated with the oceanic crust of Brunhes age produced by the Valu Fa spreading ridge. The anomaly pattern,

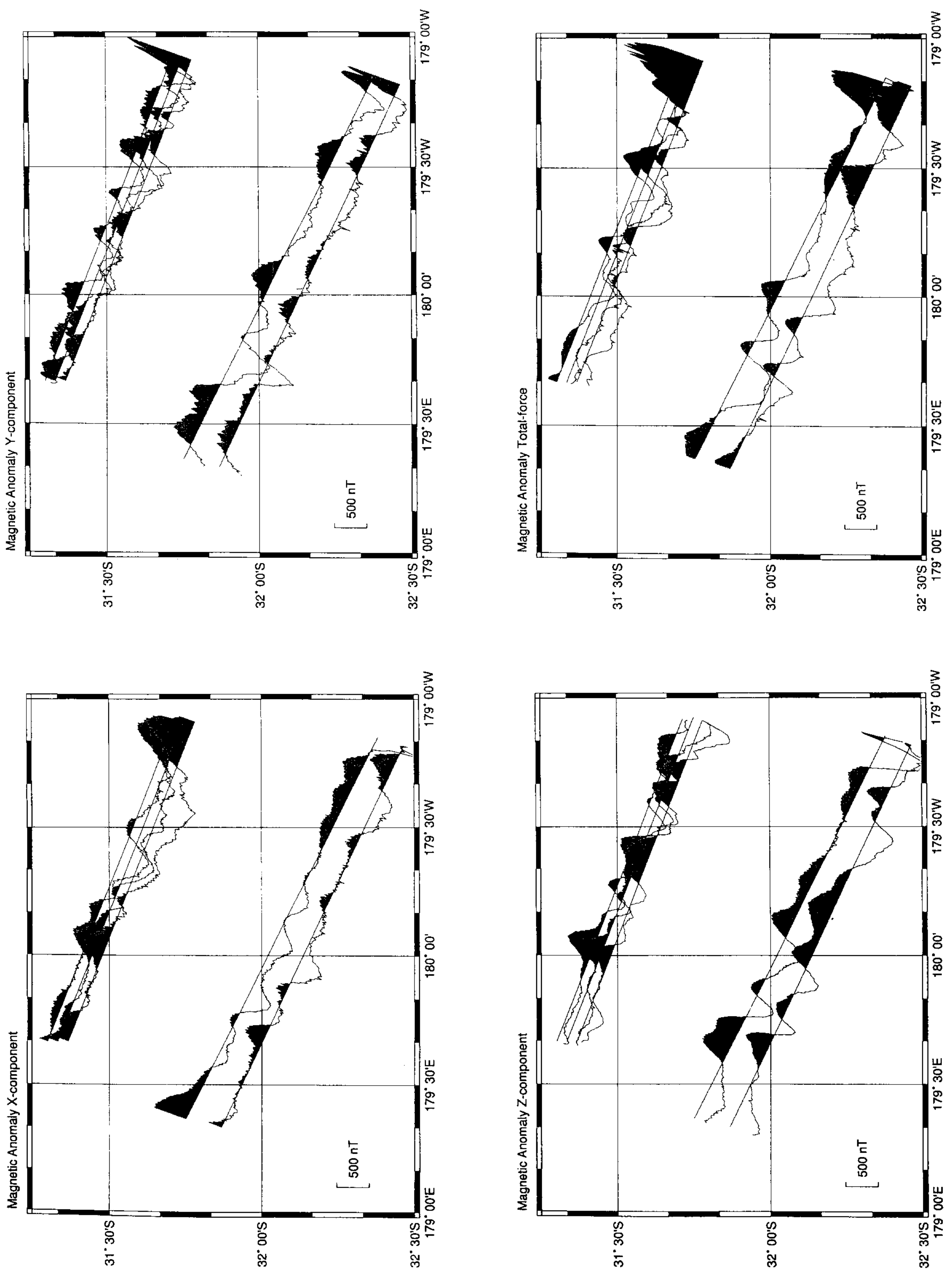


Fig. 3 Magnetic anomaly profiles of north (X), east (Y), down (Z) components, and total-force along survey lines in the central Havre Trough.

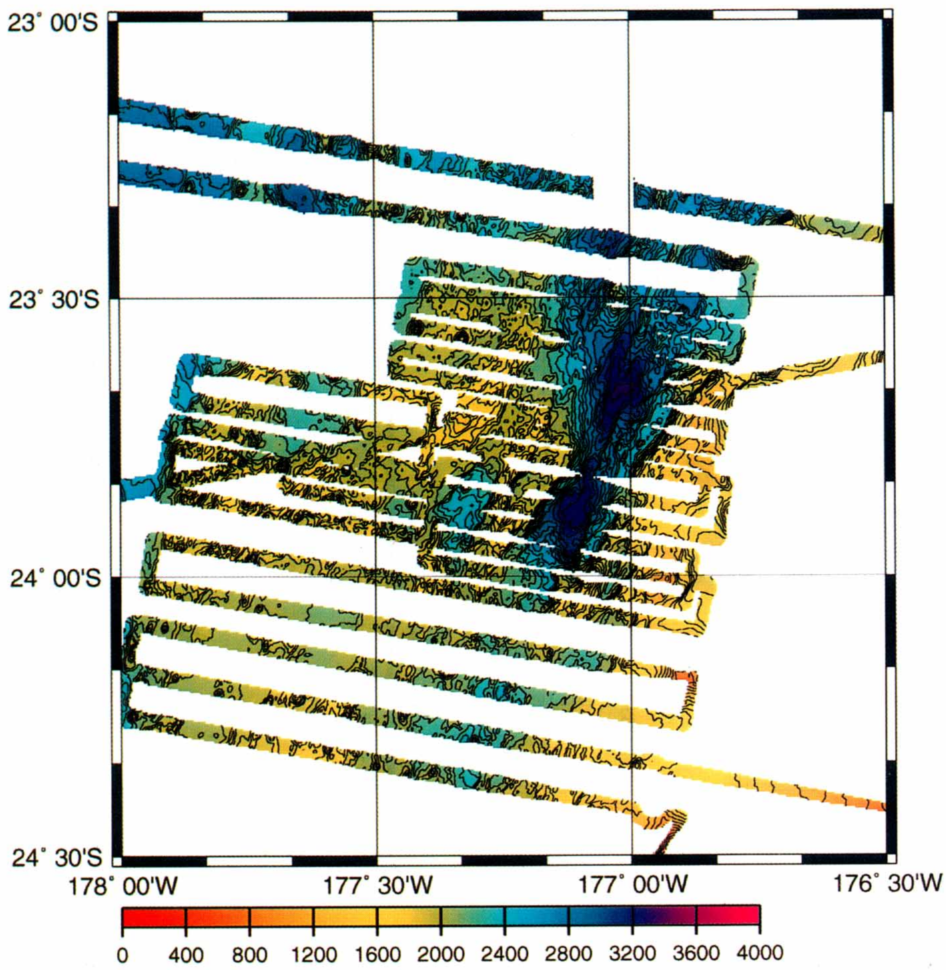


Fig. 4 Bathymetric map of a detailed survey box in the southernmost Lau Basin. Bathymetric contours are at 100 m intervals.

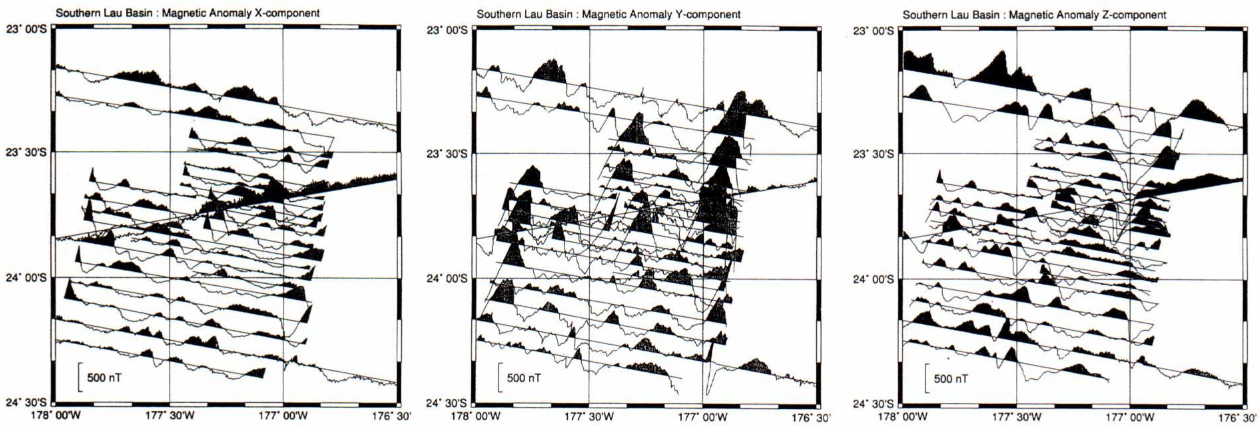


Fig. 5 Magnetic anomaly profiles of north (X), east (Y), and down (Z) components in a detailed survey box in the southernmost Lau Basin.

however, does not fit that expected from the magnetic polarity reversal sequence back from the Brunhes Chron. This suggests that the production of oceanic crust in this region has started during the Brunhes Chron. The anomaly pattern along the line next south to the three lines is quite different (Fig. 2). This fact suggests that the region south of about 23° 30′S belongs to a different tectonic regime.

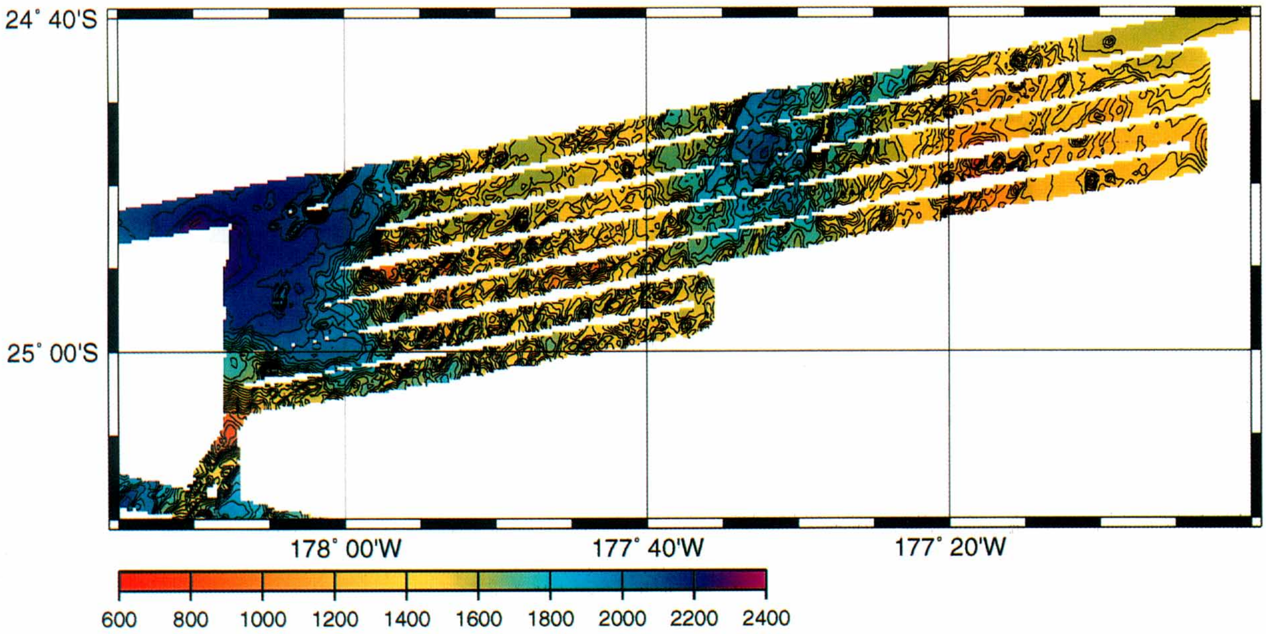


Fig. 6 Bathymetric map of a detailed survey box at the junction between the Lau Basin and Havre Trough. Bathymetric contours are at 50 m intervals.

(2) Junction between the Lau Basin and Havre Trough.

The backarc basin shallows at the junction between the Lau Basin and Havre Trough, near to where the Louisville seamount chain intersects the Tonga-Kermadec subduction system. Bathymetry in a detailed survey box shows that circular or elongated knolls and small ridges of several hundred meters in relative height lie along N25° E direction on the basement of 1,200 to 2,000 m deep (Fig. 6). They are considered to be formed by rift volcanism intruded into arc crust.

The amplitudes of the magnetic anomalies in this region are not larger than those in the southernmost Lau Basin (Fig. 2), whereas water depth is shallower. This implies that the magnetization of the crust is weaker in this region. No correlation in magnetic anomaly pattern can be recognized among the zig-zag tracks between 24° S and 26° S. On the other hand, a NNE-SSW trend was observed on magnetic anomalies in the detailed survey box (Fig. 5), in which the survey tracks are at 2-mile intervals. Larger amplitude in the Y-component anomaly than the X-component supports the NNE-SSW trend. However, a particular anomaly pattern cannot be traced beyond a few profiles. The trend of the magnetic anomalies coincides well with that of the lineaments on the bathymetry.

(3) Northern Havre Trough

No correlation can be recognized in magnetic anomaly pattern of each component among the zig-zag tracks south of 26° S (Fig. 2). Seismic profiles show a half-graben structure, deepening of an acoustic basement westward in general (Murakami, in this volume), but the amplitude of magnetic anomalies does not show regional differences. There is a tendency of negative Z-component anomalies (positive magnetization) over the Kermadec Ridge and Colville Ridge, and positive anomalies in the Havre Trough. The amplitude of the X-component anomalies are similar to that of the Y-component. This suggests that strikes of magnetic boundaries are more deflected from north (ca. ±45°) than those in the southernmost Lau Basin and the junction area.

(4) Central Havre Trough

The morphology of the arc-backarc system changes near 32° S. North of 32° S, the Trough is relatively shallow (less than 2,500), and both the active Kermadec Ridge and remnant Colville Ridge are wide and shallow, whereas south of 32° S the Trough is as deep as 3,000 to 3,750 m, and the two ridges are narrow and deep (Fig. 1). Three survey lines north of the boundary and two south of it were arranged for the purpose of detecting

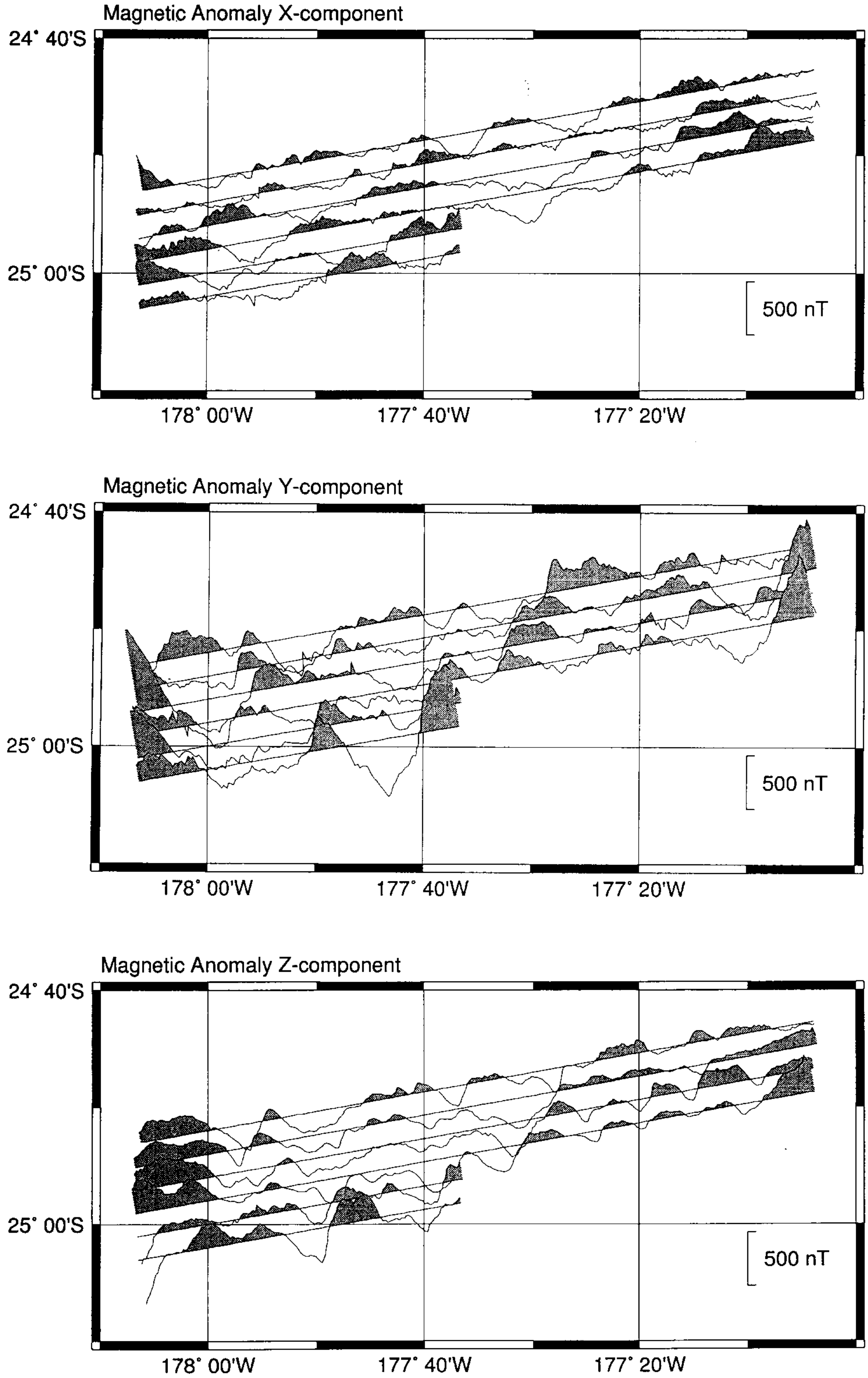


Fig. 7 Magnetic anomaly profiles of north (X), east (Y), and down (Z) components in a detailed survey box at the junction between the Lau Basin and Havre Trough.

differences in the tectonics and examining a possibility that seafloor spreading has started south of 32° S.

Magnetic anomalies of each component show similar variation pattern among the three northern lines, like magnetic lineations (Fig. 3). Those of two southern lines are also correlative with each other. The anomaly patterns of these two sets are, however, significantly different. These observation suggests that the basement of this region has a two-dimensional structure in general, but each block does not extend for a long distance. This feature resembles that of the detailed survey boxes in the southernmost Lau Basin and at the junction between the Lau Basin and Havre Trough. The anomaly patterns do not fit those expected from the magnetic polarity reversal sequence back from the Brunhes Chron. These results suggest that the central Havre Trough, both north and south of 32° S, is in a rifting stage at present, and an organized seafloor spreading has not started yet. The lineated magnetic anomalies are probably caused by dikes and other intrusions emplaced in arc crust along the rift zone ('pseudo-magnetic lineation') (Wright, 1993), although Malahoff et al. (1982) interpreted their airborn magnetic anomaly data as that seafloor spreading has occurred since about 2 Ma between 30° S and 32° S.

The amplitudes of the X-component anomalies are similar to those of the Y-component, as is in the northern Havre Trough. This suggests that the strike of magnetic boundary is about ±45°. This agrees with the structural trend observed on the swath bathymetry of this cruise, and also that on a few tracks of GLORIA side-scan sonar (Caress, 1991). This trend is slightly oblique to the NNE-SSW trending Kermadec and Colville Ridges.

Acknowledgments

We greatly thank Takeshi Matsumoto, Jean Deltail, Kazuo Kobayashi, E. Ruellan, and other on-board scientists and technician, Captain Fusao Saito, officers and crew of R/V "Yokosuka", and onshore JAMSTEC people related to this cruise. The figures were produced using the GMT software (Wessel and Smith, 1995). The LAUHAVRE cruise was conducted as a part of the French-Japan New STARMER Program. A part of this study was supported by the Ridge-Flux Project funded by the Science and Technology Agency.

References

Caress, D. W. (1991) : Structural trends and back-arc extension in the Havre Trough. Geophys. Res. Lett., **18**, 853-856.

Isezaki, N. (1986) : A new shipboard three-component magnetometer. Geophysics, **51**, 1992-1998.

Karig, D. E. (1970) : Ridges and basins of the Tonga-Kermadec island arc system. J. Geophys. Res., **75**, 239-254.

Malahoff, A., R. H. Feden, and H. S. Fleming (1982) : Magnetic anomalies and tectonic fabric of marginal basins north of New Zealand. J. Geophys. Res., **87**, 4109-4125.

Oshida, A., and T. Furuta (1995) : New geophysical data logging system of R/V "Yokosuka". JAMSTEC J. Deep Sea Res., **11**, 421-435.

Parson, L. M., and I. C. Wright (1996) : The Lau-Havre-Taupo back-arc basin: a southward-propagating, multi-stage evolution from rifting to spreading. Tectonophysics, **263**, 1-22.

Seama, N. (1992) : Magnetic vector measurements onboard vessel. Marine Surveys and Technology, **4**, 41-49 (in Japanese with English abstract).

Taylor, B., K. Zellmer. F. Martinez, and A. Goodlife (1996): Sea-floor spreading in the Lau back-arc basin. Earth Planet. Sci. Lett., **144**, 289-296.

Wessel, P., and W. H. F. Smith (1995) : New version of the Generic Mapping Tools released. EOS Trans., **76**, 329.

Wiedicke, M., and J. Collier (1993) : Morphology of the Valu Fa spreading ridge in the southern Lau Basin. J. Geophys. Res., **98**, 11769-11782.

Wright, I. C. (1993) : Pre-spread rifting and heterogeneous volcanism in the southern Havre Trough back-arc basin. Mar. Geol., **113**, 179-200.

Yamazaki, T., and F. Murakami (1997) : Asymmetric rifting of the northern Mariana Trough. The Island Arc, in press.

(Manuscript received 14, July 1997)