

Geophysical mapping of Mariana Trough and West Philippine Basin : a preliminary report of Kairei KR9812 cruise

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Bathymetric and geophysical (magnetics and gravity) mapping were conducted in the Mariana Trough between 19°15'N and 22°20'N and the West Philippine Basin around the Central Basin Fault (CBF) during R/V Kairei KR9812 cruise. Spreading ridges in the mapped area of the Mariana Trough consist of five segments. The segment boundaries show typical structure of slow-spreading ridges, those are nodal deeps and inside-corner highs, except for the northernmost boundary. It is estimated from magnetic anomalies that seafloor spreading between 19° and 20°N started at 5Ma or a little older, and the average spreading half-rate during the last 3.6 m.y. is about 1 cm/year. The central part of the CBF between 127°50'E and 131°E can be divided into four segments bounded by N-S trending fracture zones. Extinct spreading centers of E-W trend with parallel minor ridges, nodal deeps and inside-corner highs were cut by lineaments and depression of NW-SE trend. These features can be interpreted as the combination of the earlier N-S spreading and the later NE-SW extension, although the age and cause of the latter remain unclear.

Key words : Mariana Trough, West Philippine Basin, Central Basin Fault, Bathymetry, Magnetic Anomaly, Backarc Basin

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1. Outline of KR9812 cruise

The KR9812 cruise of R/V *Kairei* left JAMSTEC pier, Yokosuka, on 5th December 1998, and arrived at Naha port on 24th December 1998; total 19 days. The cruise consists of two survey areas: Area A in the Mariana Trough between 19° and 22°N, and Area B in the West Philippine Basin including the Central Basin Fault (Fig. 1). All ship time in the survey areas were devoted to bathymetrical and geophysical (magnetics and gravity) mapping to investigate tectonic history of the backarc basins. Bathymetry, side scan images, magnetic (total force and vector) and gravity anomaly data were collected simultaneously along all survey lines in general. Sea conditions were generally good for winter season, in particular in Area B, although we had sometimes relatively high waves and swells due to the trade wind. Objectives and preliminary results of the survey in each area are presented in this report.

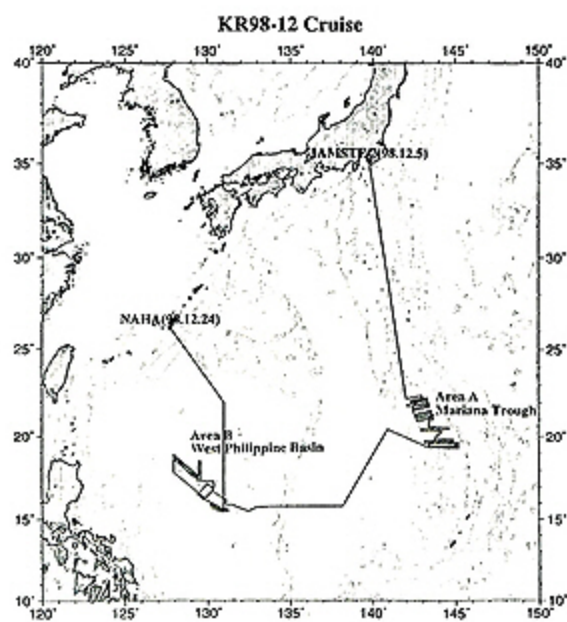


Fig. 1 Ship track of the KR9812 cruise.

2. Instruments and Data Processing

2.1 Bathymetry and side scan image

Bathymetric data were collected by the Sea Beam 2112 (Sea Beam Instruments). This is a multibeam survey system that generates data for producing wide-swath contour maps and side scan images. The system consists of 12 kHz projector array along the ship's keel and hydrophone array across the projector. The swath width varies from 120° at intermediate water depths to 90° at deeper seas. The accuracy of the depth measurement is reported as 0.5% of the depth. Swath width for side scan image is about 160° and 2000 pixel image for 1 ping is obtained. The system includes 4 kHz sub-bottom profiler subsystem, but we did not use it

during this cruise. The obtained raw data include data records (bathymetry, intensity, beam position), side scan records (binary side scan image), nautical information, and correction parameters such as water velocity structure. One of the important parameters controlling the accuracy of depths and positions is sound velocity profile. XBT measurements down to about 1,830m were carried out in each survey area during this cruise to obtain the sound velocity profiles.

We edited bathymetry data (deletion of bad data) and made grid files for making various maps. Software used for post processing are Sea View, GMT and MB system. During the survey in the Mariana Trough, wind direction was from east in general, and the survey lines were E-W or ENE-WSW directions. Thus the signal-to-noise ratio was lower in the lines towards east, and the raw side scan image showed the stripe pattern, where the eastward lines were weaker in intensity. To correct this, we tentatively dealt the eastward and westward lines separately, and made gazing angle correction table for each group. Other procedures (low-pass filtering for destripe, on-track pixels cut, inverse filtering for smoothing) are common for all lines.

2.2 Magnetometry

Magnetic total force was measured using PRT01 (Kawasaki Geological Engineering) proton precession magnetometer. The sensor was towed about 300m behind the ship. The data were acquired every 30 seconds. High quality data with a noise level of a few nT were obtained.

A shipboard three-component magnetometer system (Tierra Tecnica SFG1214) equipped on-board R/V *Kairei* was used for magnetic vector anomaly measurements. Three-axes flux-gate sensors with ring-cored coils were fixed on the roof of the bridge (about 2 m from the roof) and sampled at 8 Hz. Ship's heading data were also sampled at 8Hz, which were transmitted directly from a gyro compass for navigation in the bridge. Roll and pitch data of 8Hz were provided from an attitude sensor (TVM-4) installed on the floor of the gravitymeter room.

To correct for ship's induced and permanent magnetizations, variations of apparent magnetic field with orientation of the ship were measured by running along an figure-8 track (two circles, left and right turns) (Isezaki, 1985). Five "figure-8 turns" were performed during the KR9812 cruise. Geomagnetic field during each "figure-8 turn" was assumed to be constant and represented by the 1995 version of the International Geomagnetic Reference Field (IGRF1995). Three components of the magnetic field and ship's pitch, roll, and heading data sampled at 8 Hz were averaged for one second, then the three components of the geomagnetic field were calculated, and finally the data at one second intervals were averaged for one minute. Horizontal components, in

particular Y (east) component, may contain a large error till the gyro-compass is stabilized after a course change. Data of Y component at the beginning of each line were removed for 30 minutes. The mean anomaly of each component of each line was set to be zero by subtracting a linear bias from the observed anomalies. The bias is probably caused by some changes of ship's magnetization with time and temperature despite being assumed as a constant.

Another set of shipboard three-component magnetometer with a GPS (Global Positioning System) attitude determination system ("TANS Vector" of Trimble Navigation) was temporarily installed on R/V *Kairei*, and its performance was tested during the cruise. The purpose was to assess the possibility for utilizing the GPS attitude sensor for shipboard three-component magnetometer system instead of a gyro-compass and an attitude sensor for pitch and roll. The test was successful; the system behaved very well even right after a course change. The results will be reported elsewhere.

2.3 Gravimetry

Onboard gravity measurement was performed using a BODENSEWERK KSS31 marine gravity-meter system. An on-line data filter for "Sea State 4" was selected, which enabled us to obtain good gravity data with smooth variations. According to the documents provided by the manufacturer, the filter should have caused a delay of 123 seconds. The gravity data were logged every 1 minute throughout the cruise. Onboard gravity was tied to the absolute gravity at JAMSTEC pier and Naha port. The drift of the gravity meter for 19 days was -0.2 mgal/day.

3. Area A: Mariana Trough

3.1 Background and objectives

The Mariana Trough is an active backarc basin. It is crescent-shaped, with a maximum width of about 250 km at 18°N . The width of the trough decreases northward and southward. Please refer Fryer (1995; 1996) for thorough review of the Mariana trench-arc-backarc system.

The northern Mariana Trough evolves southward from an incipient rifting stage to a mature backarc-spreading stage. Thus the northern Mariana Trough gives us a rare opportunity to study rifting of an oceanic island arc. The Mariana Trough between 22° and 24°N is in a rifting stage, and structurally and thermally asymmetric (Yamazaki and Murakami, 1998). Yamazaki et al. (1993) inferred from magnetic total-force anomalies and seismic profiles that seafloor spreading occurs from about 22°N and southward in the trough. On the other hand, Martinez et al. (1995) and Baker et al. (1996) proposed that the Mariana Trough north of 21°N is composed of arc lithosphere intruded by arc and backarc basin magmas. A series of deep half-grabens, about 5700m at maximum water depth, occupies the trough

between 20° and 21°N , midway between the active and remnant arcs. They are considered to have been formed by amagmatic extension, and called the Central Grabens (Martinez et al., 1995; Stern et al., 1996; 1997). Martinez et al. (1995) inferred that the transition from rifting to seafloor spreading lies south of the Central Grabens at 20°N .

At 18°N , it is estimated that rifting of the Mariana Trough began in the latest Miocene, ca. 6 Ma, and that the extension has continued at a half spreading rate of 2.15 cm/year from the results of Deep Sea Drilling Project (DSDP) (Hussong and Uyeda, 1982). Recent magnetic vector measurements in limited areas around 18°N (Seama and Fujiwara, 1993; Yamazaki and Stern, 1997) revealed spreading history since 6 Ma with arcward ridge jumps (Seama and Yamazaki, 1998).

The KR9812 cruise was the second expedition of a systematic mapping project of the Mariana Trough. The first one was the KR9711 cruise of R/V *Kairei* in 1997, which covered between 22° and 24°N (Naka et al., 1998). The purpose of the mapping project is to clarify characteristics of the backarc basin evolution based on bathymetry and magnetic vector anomalies, and provide basic data for future detailed studies using submersible *Shinkai 6500* and ROV *Kaiko*. Previously only limited areas of the Mariana Trough were covered with multi-narrow-beam bathymetry. Magnetic anomaly is a basic tool for studying seafloor spreading, but in the Mariana Trough conventional magnetic total-force anomaly is not very useful due to the geometrical problem of the spreading system, the north-south strike of spreading axes in low magnetic latitudes. Magnetic vector measurements can overcome the problem. We carried out geophysical mapping of the trough between 19° and 22° during this cruise. The main objective of this area was to clarify where transition from rifting to seafloor spreading occurs.

3.2 Bathymetry

Figure 2 displays simplified bathymetry of the whole survey area. Survey lines are in ENE-WSW or E-W directions and 6 to 7 mile intervals. Part of this area was already mapped by a multi-narrow-beam echo sounder (HS10) of R/V *Yokosuka* in 1992 and 1996 (Y9613), and we skipped these boxes (a gap of ENE lines around $21^{\circ}30'\text{N}$, boxes of $20^{\circ}32'-21^{\circ}00'\text{N}$, east of $143^{\circ}25'\text{E}$, and $19^{\circ}50'-20^{\circ}20'\text{N}$, $143^{\circ}45'-144^{\circ}15'\text{E}$). For the bathymetry of these boxes, please refer Yamazaki and Stern (1997).

We could identify the location of spreading center from rift valley topography and zones of high back-scatter on the side-scan images. Spreading ridges in the mapped area consist of following five segments from north to south; (1) from $22^{\circ}10'\text{N}$, $142^{\circ}55'\text{E}$ to $21^{\circ}20'\text{N}$, $143^{\circ}23'\text{E}$, (2) from $21^{\circ}10'\text{N}$, $143^{\circ}20'\text{E}$ to $20^{\circ}35'\text{N}$, $143^{\circ}30'\text{E}$, (3) from $20^{\circ}35'\text{N}$, $143^{\circ}52'\text{E}$ to $19^{\circ}55'\text{N}$, $144^{\circ}00'\text{E}$, (4) from $19^{\circ}50'\text{N}$, $144^{\circ}20'\text{E}$ to $19^{\circ}25'\text{N}$, $144^{\circ}29'\text{E}$, and (5) south of $19^{\circ}25'\text{N}$, $144^{\circ}31'\text{E}$.

KR9812_A Mariana Trough

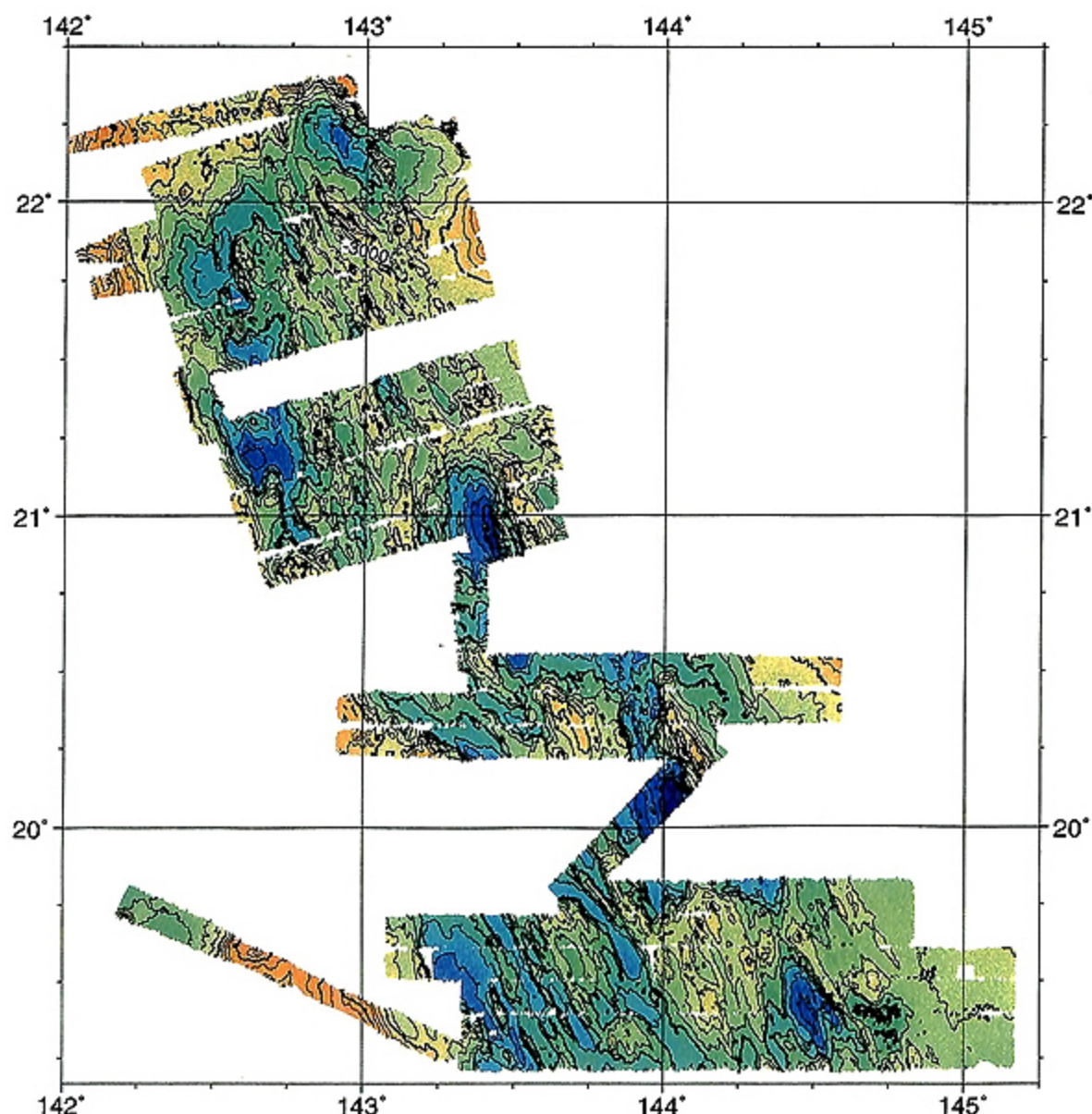


Fig. 2 Simplified bathymetric map of the Mariana Trough between 19° and 22° 30'N based on the data obtained during the KR9812 cruise.

Boundaries of the Segments 2/3 and 3/4 show typical structures at segment boundaries in slow spreading ridges like the Mid-Atlantic Ridge; those are nodal deeps and inside-corner highs. Figures 3 and 4 display a bathymetric map and a side scan image of the Segment 3. Highs at about 20°22'N, 143°40'E and 20°10'N, 144°08'E could be the inside-corner highs at both ends of Segment 3. This segment has well-developed rift valley. A deep between 20°00' and 20°10'N (the Central Grabens of Martinez et al., 1995) was previously thought to be enigmatic, but now can be interpreted as a structural component at a segment boundary.

The rift valley of Segment 1 is shallow, although we can still recognize possible spreading axis in it. A line of other evidence supports the idea that seafloor spreading occurs in this segment; (1) a well-developed zone of strong back-scatter on the side-scan image, (2) prominent ridge-and-trough structures of NNW-SSE strike, and (3) occurrence of magnetic anomalies similar to those of Segment 4 and south, as will be shown later. The boundary between Segments 1 and 2 is recognized as a discontinuity in topographic fabric, but no structure typical of segment boundaries occurs. This would be probably due to that the seafloor spreading of

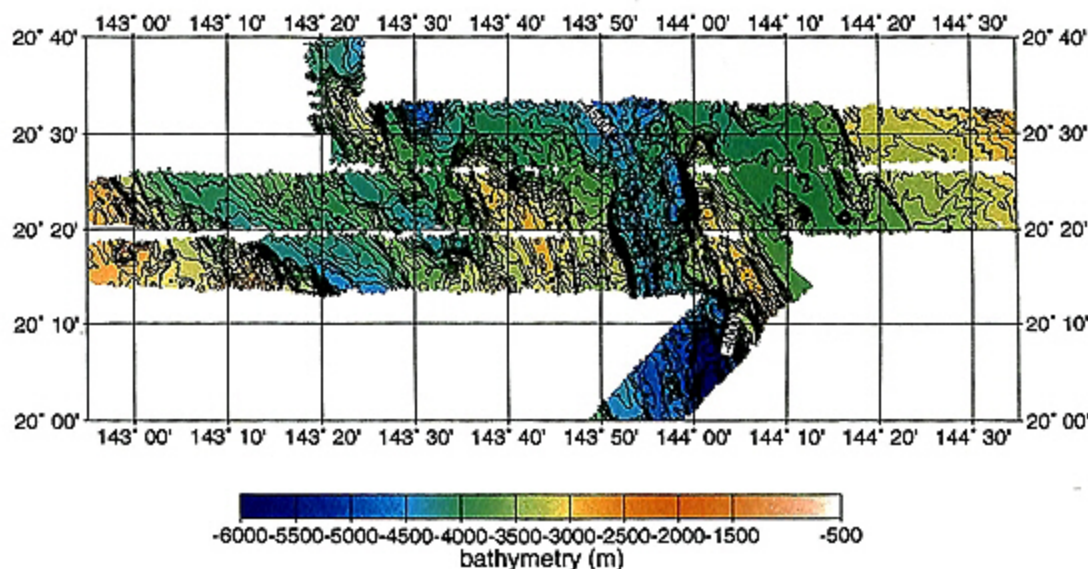


Fig. 3 Bathymetric map of the Mariana Trough between 20° and 20°40'N (Segment 3)

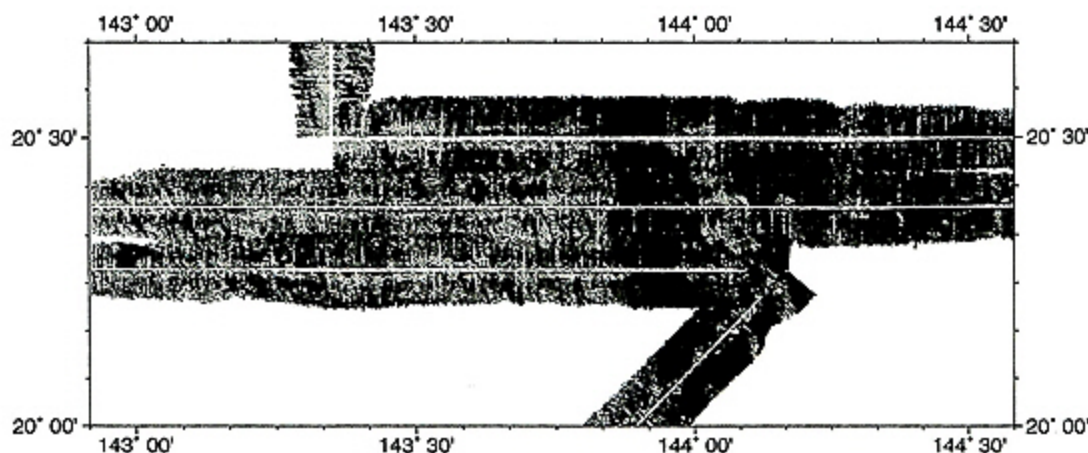


Fig. 4 Side scan image of the Mariana Trough between 20° and 20°40'N (Segment 3).

Segments 1 and 2 is in an incipient stage, and not matured yet.

3.3 Magnetic and gravity anomalies

Figure 5 shows Z (down) component magnetic anomalies after application of a low-pass filter, and their tentative interpretation. Magnetic anomaly profiles in the south of 22°N show similar variation patterns, and they are correlative with each other. This shows the occurrence of magnetic lineation of NNW-SSE strike, which is indicative of ENE-WSW seafloor spreading. The variation pattern is also similar to that around 18°N in the Mariana Trough (Yamazaki and Stern, 1997), where typical backarc spreading is known

to have occurred. We estimate that seafloor spreading between 19° and 20°N started at 5 Ma or a little older in the earlier part of the Gilbert Chron. The age of the initiation of the seafloor spreading seems to become younger northward in the trough. The average spreading half-rate during the last 3.6 m.y. (since the Gauss-Gilbert polarity boundary) is about 1 cm/year on the western wing of the spreading center in Segments 4 and 5 between 19° and 20°N. The spreading seems to have been asymmetric in these segments; the rate of the eastern wing is about 60% of the western counterpart. Magnetic anomalies of the eastern wing in the northern segments are disturbed by arc volcanism.

Free-air gravity anomalies (FGA) are close to zero at the

rift valleys south of 21°N (Segments 2 through 5). This suggests that they are mostly in an isostatic state, which is consistent with the occurrence of seafloor spreading. Positive FGA were observed around the possible spreading axis between 21° and 22°N (Segment 1), suggesting a little thicker crust than normal oceanic crust of 6 km. We plan to calculate the Mantle Bouguer anomaly to study segmentation of the spreading system.

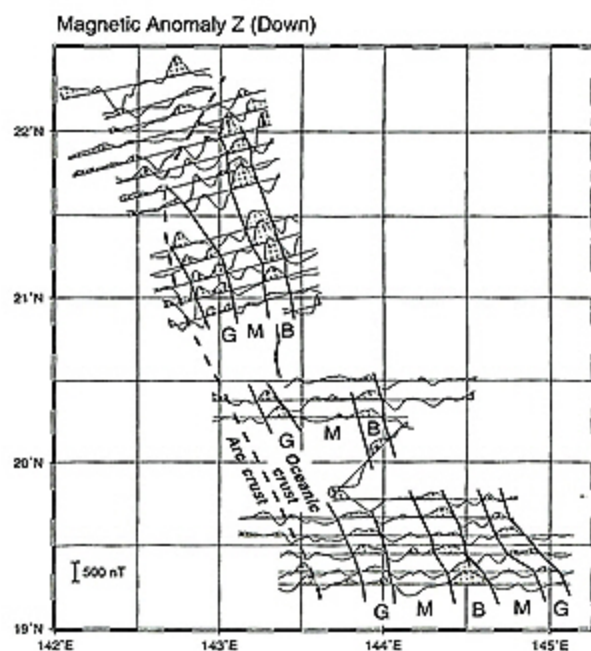


Fig. 5 Vertical component magnetic anomalies in the Mariana Trough, KR9812 cruise, and their tentative interpretation. B: Brunhes Chron (0 - 0.78 Ma), M: Matuyama Chron (0.78 - 2.6 Ma), G: Gauss Chron (2.6 - 3.6 Ma).

4. Area B: West Philippine Basin

4.1 Background and objectives

The West Philippine Basin (WPB) occupies the western half of the Philippine Sea plate from 5°N to 23°N. A NW-SE trending long linear structure is located at the center of the basin, which is called the Central Basin Fault (CBF).

The genesis of the WPB has long been debated. Karig (1971) proposed backarc spreading origin. Some studies, on the other hand, supported the idea of trapped normal ocean (Uyeda and Ben-Avraham, 1972; Shih, 1980; Hilde and Lee, 1984). Most previous studies concluded that the WPB was spread symmetrically from the CBF, although their interpretation of magnetic anomalies disagreed. Shih (1980) first mapped offsets in the lineation pattern in the basin, and Lewis and Hayes (1980) pointed out the CBF was offset by several fracture zones. Hilde and Lee (1984) mapped more than ten fracture zones in the middle of the basin and concluded that N-S spreading followed the earlier NE-SW

spreading, whereas the former studies proposed simple NNE-SSW spreading.

Recent surveys by the Hydrographic Department of Japan lead us better understanding of the northern part of the basin. A large escarpment facing south (the Oki-Daito Escarpment) was discovered, and spreading fabric trending almost N-S was found north of it (Okino et al., 1999). *R/V Yokosuka* Y9611 and *R/V Kairei* KR9801 cruises mapped the detailed structure of the CBF for the first time and obtained some rock samples (Fujioka et al., 1997; 1999). These cruises revealed very interesting and enigmatic features near the extinct spreading center, which includes 1) axial rift valleys segmented by N-S trending fracture zones, 2) NW-SE trend of the axial rift valley in each segment, oblique to spreading fabric of E-W trend in the surrounding basin, 3) no continuation of the axial valley west of 126°E, and 4) a small block characterized by NE-SW lineament at the western part of the CBF. The evolution process of the WPB is more complicated than previously thought.

The final goal of the study is to propose a new model of the WPB genesis. In this cruise, we focused on mapping of the seafloor just outside the CBF to understand the final stage of the basin opening and to discuss the possibility of volcanic/tectonic activity at the extinct spreading center after the cessation of the opening. A long N-S line along 131°E was planned to obtain the magnetic profile across the basin.

4.2 Bathymetry

Figure 6 shows a simplified bathymetric map around the CBF. The area of the extinct spreading center of the WPB east of 128°E has been covered almost completely by compiling the data of Y9611 (using HS10) (Fujioka et al., 1997), KR9801 (Fujioka et al., 1999) and this cruise. The morphology of the CBF and its environs is very rough and complicated. Although the basin floor displays E-W trending minor ridges and troughs segmented by N-S fracture zones, the prominent deep rift valley runs NW-SE. Hilde and Lee (1984) proposed N-S spreading at the CBF at the final stage of the WPB genesis. The E-W lineaments and the N-S fracture zones support this idea, but the deep rift valley seems to be oblique to these spreading fabric.

We tentatively divided the central part of the CBF into four segments from west to east; (1) from 127°50'E to 128°30'E, (2) from 128°30'E to 129°30'E, (3) from 129°30'E to 130°20'E, and (4) from 130°20'E to 131°00'E. Each segment is bordered by fracture zones.

The eastern boundary of Segment 1 is a fracture zone which slightly curves to NW. A nodal deep is observed near the intersection of the fracture zone and the rift valley. The rift valley trends WNW-ESE, oblique to the E-W spreading fabric on the basin floor.

Segment 2 is a good example to understand the relationship

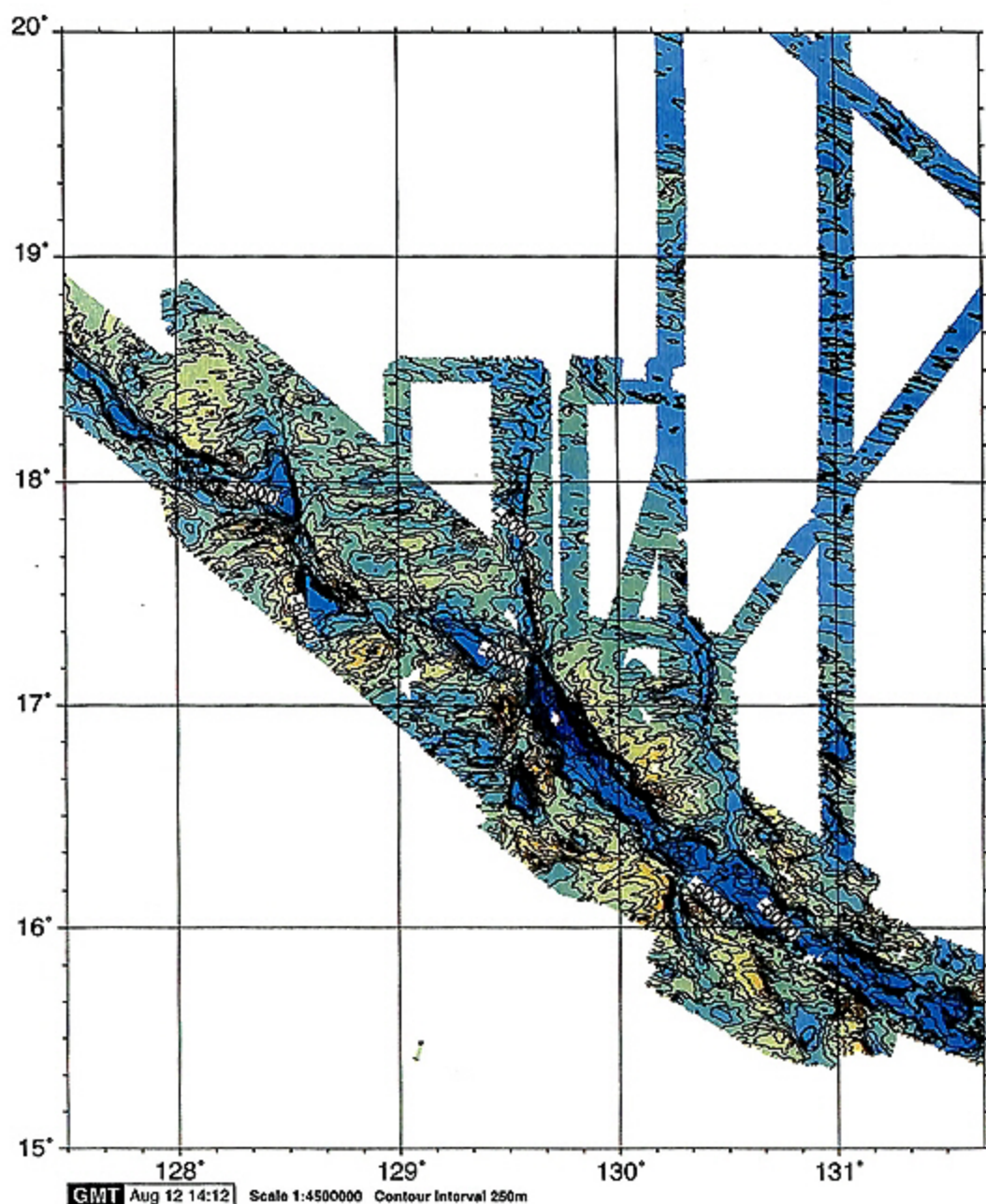


Fig. 6 Simplified bathymetric map around the Central Basin Fault in the West Philippine Basin. Data obtained during the Y9611, KR9801, and KR9812 cruise were used.

between the E-W fabric and NW-SE lineament (Fig. 7). The segment is bordered by well-developed fracture zones on both sides. A triangular depression at $17^{\circ}25'N$, $128^{\circ}35'E$ is considered to be a nodal deep. The extinct spreading center trends E-W direction, which is parallel to the minor ridges just outside the rift. The lineaments and depressions trending NW-SE cut the E-W structure. A topographic high at $17^{\circ}30'N$, $128^{\circ}45'E$ is interpreted as an inside corner high, which was cut by NW-SE trending escarpments. It indicates that the NE-SW extensional stress may have caused this NW-SE structure after cessation of the N-S spreading. Little

strike-slip displacement along NW-SE escarpment can be recognized.

Segment 3 includes the deepest point of the CBF, about 7,900 m, which is located in the NW-SE trending deep trough. Two triangular depressions at $16^{\circ}35'N$, $129^{\circ}35'E$ and $16^{\circ}20'N$, $130^{\circ}20'E$ look like nodal deeps, so the original center of N-S spreading may exist between them. The deep NW-SE rift may be a second stage structure like the NW-SE lineaments observed in segment 2.

North-south trending fracture zones at both sides of Segment 4 are not sharp. In this segment, the oblique

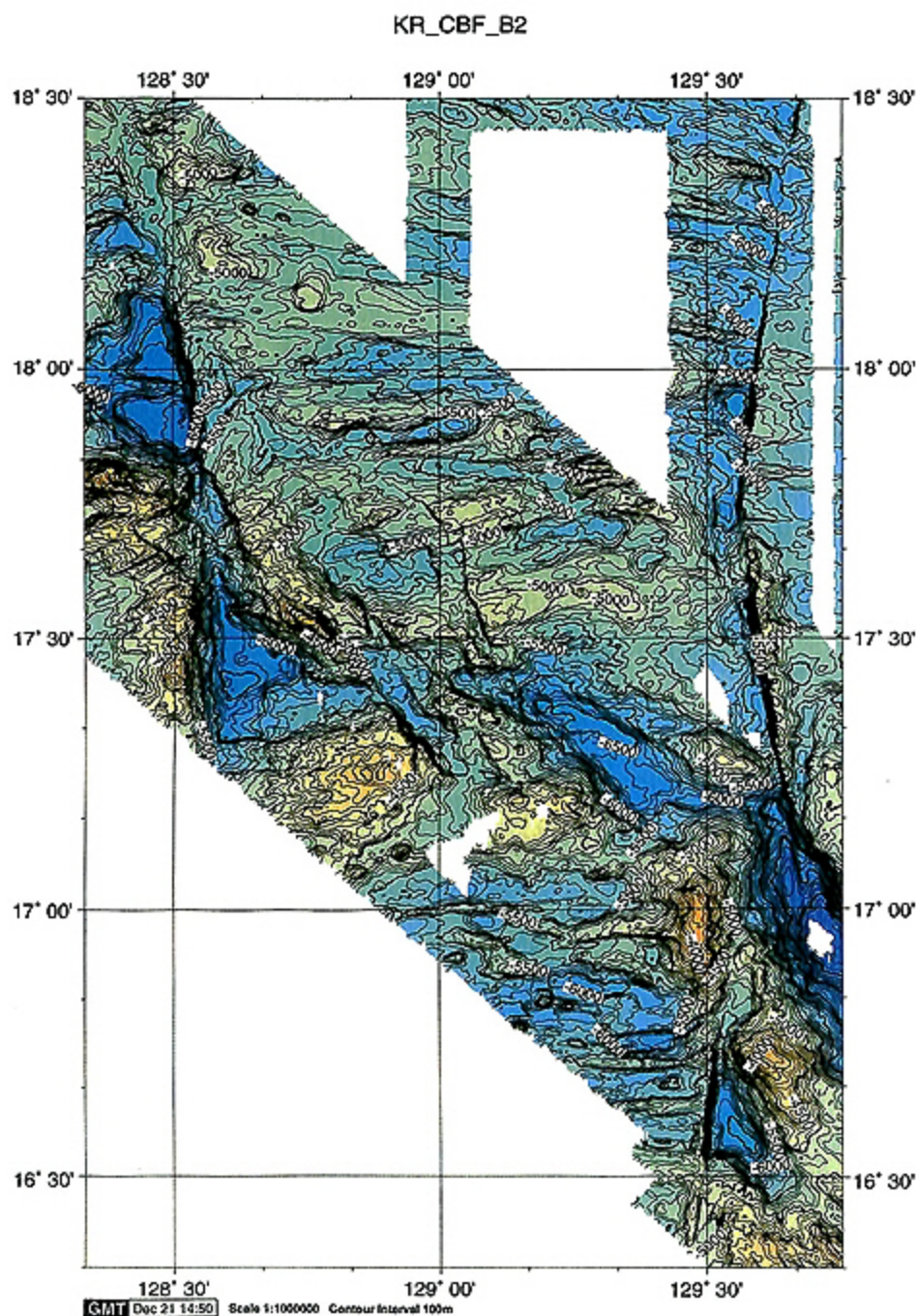


Fig. 7 Bathymetric map around the Central Basin Fault between 128°20'E and 129°45'E (Segment 2).

structure has two slightly different directions; the NW-SE lineament similar to Segments 2 and 3 and the WNW-ESE trending deep rift valley.

The features of the central part of the CBF can be interpreted as the combination of N-S spreading and the later NE-SW extension. The age and the origin of the NE-SW extension remain unsolved. Hilde and Lee (1984) estimated the cessation of the spreading at around 35 Ma. On the other

hand, much younger age (around 27 Ma, K/Ar method) has reported from the basalts obtained at the easternmost rift valley of the CBF (Okino et al., 1999). This may indicate the age of the second stage of the CBF formation.

4.3 Magnetic and gravity anomalies

The intensity of magnetic anomaly is relatively small, especially south of the CBF rift valley. In the northwestern part of the surveyed area, lineaments of E-W trend were

Line B24 (along 131°E)

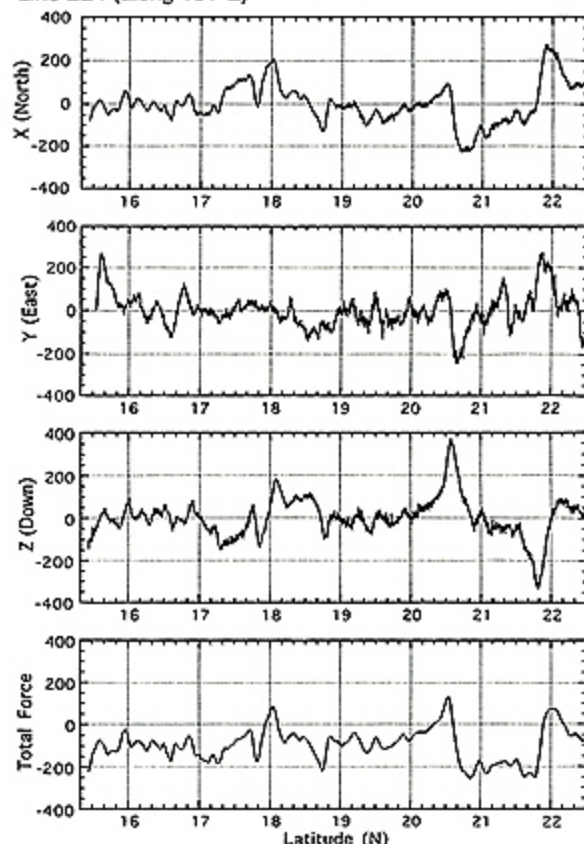


Fig. 8 Magnetic anomalies (north, east, vertical components, and total force from the top) along 131°E in the West Philippine Basin.

recognized. This area corresponds to the northern part of Segments 1 and 2, where the E-W minor ridges are developed. Near 128°E-128°30'E, the pattern is rather ambiguous, that may be due to the fracture zone.

Line B24 along 131°E shows variations along the general spreading direction of the basin (Fig. 8). Between 16°50'N and 18°20'N, Y (east) component is almost zero and X component contributes the anomaly variation. This indicates the magnetized body extends E-W direction. North of 18°20'N, the amplitude of Y component increases, suggesting the change of spreading direction. Prominent large positive anomalies are observed in the total force at 20°30'N and 21°50'N. Northern one corresponds to the location of the Oki-Daito Escarpment and its Z component shows large negative values.

Free-air gravity anomaly outside of the rift valley is almost zero, which indicates the basin is almost isostatically compensated. The rift valley and the inside corner highs are associated with rather large anomalies.

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