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The Philippine Sea: New survey results reveal the structure and the history of the marginal basins

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Abstract. The Hydrographic Department of Japan initiated a long-term geological and geophysical survey of the Philippine Sea in 1983. We here summarize the bathymetry and magnetic anomalies of this area, focusing on the structure and the evolutionary process of the marginal basins. The Shikoku and Parece Vela Basins developed as one backarc system in the later phase of their formation; the significant difference between the two basins, however, is clearest near the extinct spreading centers. The steep Oki-Daito Escarpment, located in the northern West Philippine Basin, was mapped for the first time during this survey. The N-S trending spreading fabric north of the escarpment is in striking contrast to the NW-SE to E-W lineament in the south. Our data reveal a more complicated history of the western Philippine Sea than has been proposed in previous studies.

Introduction

The Philippine Sea is one of the major marginal seas complexes of the western Pacific (Fig. 1). It is divided into three parts by the N-S trending Kyushu-Palau Ridge (KPR) and Nishi-Shichito/West Mariana Ridges (NSR/WMR) both of which are now inactive. The western part consists of the West Philippine Basin (WPB, Philippine Basin) and the Daito Ridge province. East of the KPR, the Shikoku Basin (SB) and the Parece Vela Basin (PVB, Oki-no-Tori-Sima Basin) are inactive backarc basins. A modern volcanic front is located further east and current backarc spreading occurs east of the WMR.

The basins in the eastern part of the Philippine Sea have been formed by successive episodes of west to east opening [Karig, 1971; Seno and Maruyama, 1984]. Many evolutionary models have been based on the identification of magnetic lineation in the SB [e.g., Kobayashi and Nakada, 1978; Shih, 1980a]. In contrast to the SB, very few profiles have been reported for the PVB prior to our survey. Mrozowski and Hayes [1979] compiled geophysical survey results and proposed E-W backarc spreading from 30 to 15 Ma in the PVB. Magnetic anomalies in the WPB have been studied by many researchers [e.g., Hilde and Lee, 1984]. All previous studies supported the idea that the basin opened in a generally NE-SW/N-S direction from the Central Basin Fault.

We have long surveyed the geophysical features of the Philippine Sea and the adjacent areas [Ohara et al., 1997]. Hereafter we focuses on the evolutionary processes of the marginal basins in the Philippine Sea derived from our data.

Data

The Continental Shelf Survey Project collected multibeam bathymetric data, geomagnetic total intensity data, gravity data, and seismic profiles between 1983 and 1997 using the survey vessel TAKUYO. During this period the TAKUYO tracked across the basin at 5 to 10 nautical mile spacings, the total length of the survey lines exceeding 200,000 nautical miles. Bathymetric data were collected using a Sea Beam family multibeam echo sounding system. The swath coverage in the surveyed area ranged from 30% to 100%. The total magnetic field was measured using a proton precession magnetometer. We compiled all data and made grid files (0.02° x 0.02°) with appropriate interpolation. GMT ver. 3.0 [Wessel and Smith, 1995] was utilized in gridding and creating shaded relief maps.

Results and Discussions

Shikoku/Parece Vela Basins and Modern Backarc

Our survey covered the whole Shikoku Basin (SB) and the northern half of the Parece Vela Basin (PVB). Both bathymetry and magnetic anomalies show a clear N-S trending lineation pattern in the western part and NW-SE lineations in the central

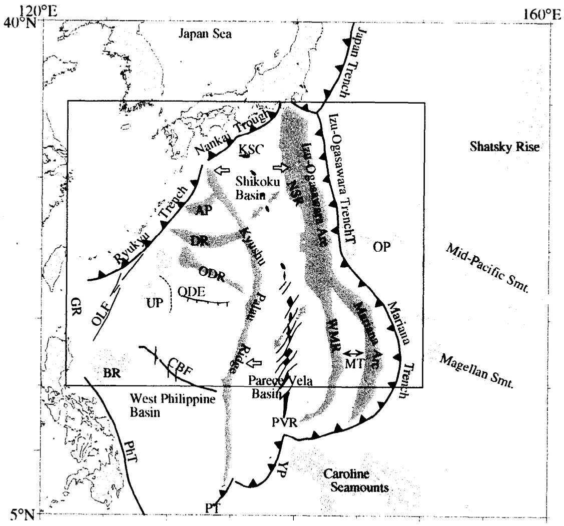

Fig.1 Major geomorphologic elements of the Philippine Sea and the adjacent areas. Box indicates the mapped area. Arrows indicate the former (white and gray) and present (black arrow) spreading directions. AP: Amami Plateau. BR: Benham Rise, CBF: Central Basin Fault, DR: Daito Ridge, GR: Gagua Ridge, KSC: Kinan Seamount Chain, MT: Mariana Trough, NSR: Nishi-Shichito Ridge, ODE: Oki-Daito Escarpment, ODR: Oki-Daito Ridge, OLF: Okinawa-Luzon Fracture Zone, PT: Palau Trench, PhT: Philippine Trench, PVR: Parece Vela Rift, UP: Urdaneta Plateau, WMR: West Mariana Ridge, YP: Yap Trench.

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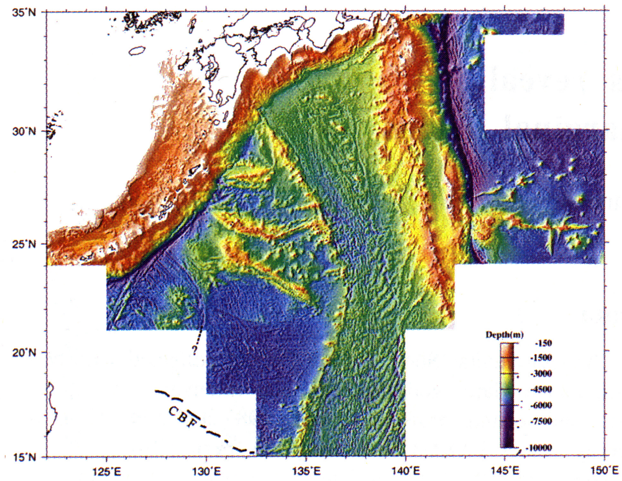

Fig.2 Shaded relief map of bathymetry sunlit from the northwest.

part of two basins (Figs. 2 and 3). The weak magnetic lineation pattern in the PVB is due to E-W spreading occurring when the basin was near the magnetic equator. Based on our survey data, we propose a detailed evolutionary process of each basin [Okino et al., 1994; 1998]. This process consists of the five stages summarized in Table 1. In the SB, spreading first occurred at the northern end and then propagated southward. The spreading direction was ENE-WSW ~ E-W during the first stage and later changed to NE-SW. On the other hand, spreading in the PVB propagated northward. The spreading direction changed from E-W to NE-SW, similar to the directional change of the SB. The axis was highly segmented during the final spreading stage, with conspicuous fracture zones developing (Fig. 2). The pseudofaults and propagating ridges tips indicating complex ridge propagation during the early stage have previously been noted in the western PVB [Okino et al., 1998], though we could not find these features in the SB.

Magnetic Anomalies 6A (21 Ma) and 6B (23 Ma) seem continuous over the two basins (Fig. 3). This indicates that the two basins opened as one backarc system subsequent to this period. At 19 Ma, the united Shikoku-Parece Vela Basin (SPVB) shifted spreading direction to NE-SW, with ridge segmentation. Kimura [1986] inferred that oblique subduction causes a strike-slip movement of the forearc sliver relative to the backarc side, based on Kuril Arc data. Kasuga and Ohara [1997] also proposed that spreading direction change in the SPVB was attributable to oblique subduction of the Pacific Plate. In the Izu-Bonin/Mariana arc, the forearc sliver was subjected to northward migration due to northwesterly subduction. At an earlier stage of spreading, extension was constrained by trench retreat, spreading perpendicular to the trench being dominant. As spreading continued, the coupling of the forearc and the subducting plate increased; the forearc and the arc-side of the backarc basin then started moving northward, causing the rotation of the spreading axis. The fracture zones in the central part of the SPVB appear to change direction and curvature gradually, suggesting the non-rigid behavior of platelets or the successive movement of Euler pole during this stage.

The difference between the extinct spreading axes of the two basins is a prominent feature of this area. The Kinan Seamount

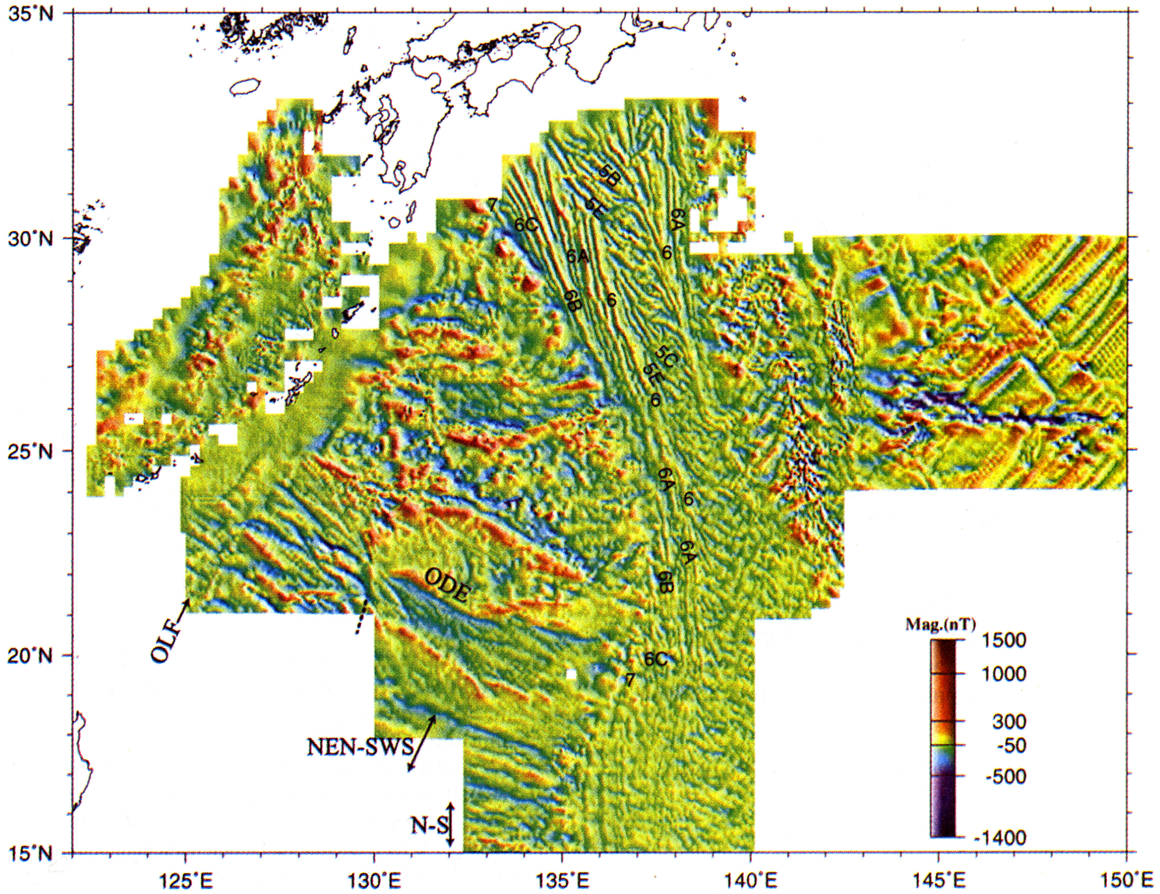

Fig.3 Shaded relief map of magnetic anomalies. Numbers indicate the results of identified magnetic anomalies.

Table 1. Five stages of the backarc spreading in the Shikoku and the Parece Vela Basins.

phase	pre-spreading	I	II	III	post-spreading
characteristics	rifting	propagation	whole arc opening	direction change	
SB*and PVB spreading direction*	30-27 Ma	27-23 Ma E-W(ENE-WSW) ridge jump (PVB)	23-20 Ma E-W stable spreading	20/19-15 Ma NE-SW ridge segmentation	volcanism (KSC) amagmatic extension (PVR)
spreading half-rate*	low	2.3-4.7 cm/yr.	4.5 cm/yr.	2-3 cm/yr.	

*Okino et al. [1994; 1998]

Chain (KSC) is located near the ridge-transform-ridge (RTR) intersection of the SB. After spreading cessation, the magma remaining beneath the axial zone caused post-spreading volcanism near the RTR intersection. On the other hand, the axial zone of the PVB is a row of depressions deeper than 6500 m. The axis, named the Parece Vela Rift (PVR), consists of right stepping diamond shaped depressions, which parallel the NW-SE spreading fabric found in the central part of the basin. Mantle peridotites and gabbros were dredged from a fracture zone escarpment next to a depression, the lower crust and upper mantle materials being exposed along the fracture zone [Ohara et al., 1996]. Peridotite exposure also can be placed at the RTR intersections, magma-poor parts of the mid-oceanic ridge [Cannat and Seyler, 1995]. Similarly, the PVB may have been magmatically starved during the evolutionary terminal phase. The distinct contrast between the KSC and PVR provide the information valuable in studying the fossil rift structure.

Modern backarc situations are different between the Izu-Ogasawara Arc and the Mariana Arc. Rift grabens have been reported for the backarc side of the Izu-Bonin Arc [Taylor et al., 1991], but the oceanic crust has not been formed. In the Mariana Arc, backarc spreading has already started and propagated northward. It is therefore likely that the rifting and spreading area will eventually extend throughout the whole Izu-Bonin/Mariana Arc.

Each phase of backarc spreading shown in Table 1 is deduced from the features observed in the SPVB. We can see, however, a similar evolutionary process within other backarc basins. The initial spreading stage (Phase I) is characterized by ridge propagation and jump, observable in younger backarc basins such as the Mariana Trough [Fryer, 1995] and the Lau Basin [Parson and Wright, 1996]. During the mature spreading stage (Phase II), the formation of the oceanic crust occurs over the whole arc at high a spreading rate. The North Fiji Basin [Auzende et al., 1988] and East Scotia Sea [Barker, 1995] exemplify this phase. The last phase (Phase III) is recognized for the first time in the SPVB using our data. Spreading rate decrease and geological coupling increase between the subducting and the overriding plates are phenomena closely related to the cessation of cyclic backarc spreading. The segmentation of the spreading axis may be a common feature of the terminal phase.

West Philippine Basin

The West Philippine Basin (WPB) is the largest and deepest inactive basin in the Philippine Sea. The basin is thought to have spread from the NW-SE trending Central Basin Fault (CBF), though the origin of the basin is uncertain and various evolutionary models have been proposed [e.g. Shih, 1980b; Hilde and Lee, 1984]. Hilde and Lee [1984] mapped more than ten fracture zones in the middle of the basin and concluded that N-S spreading followed earlier NE-SW spreading, though former studies proposed simple NNE-SSW spreading.

We have found a large WNW-ESE trending escarpment, tentatively named the Oki Daito Escarpment (ODE), which roughly parallels the Oki-Daito Ridge in the northern WPB. The Oki Daito Escarpment seems identical to the Lapu-Lapu Ridge reported by Mrozowski et al. [1982]. It is a southerly facing escarpment, the maximum relief exceeding 1000 m. The spreading fabric of the basin floor changes abruptly against the ODE; the trend is nearly N-S in the north and NW-SE in the south (Fig. 2). This indicates that the northern part of the basin may have not spread from the CBF. The E-W curvilinear feature at 8-10°N revealed by altimetry data [Sandwell and Smith, 1997] may be one candidate for an ODE counterpart.

The central part of the WPB, born by breaking up the older northern part, is deeper than the older northern part. The production of the oceanic crust occurred under the NE-SW to N-S extension. Magnetic lineations trending WNW-ESE are very clear south of 19°N (Fig. 3). Between the ODE and the clear WNW-ESE lineations, a wide negative magnetic anomaly zone is apparent, the bathymetric fabric trending NW-SE. The stress field slightly changed from NNE-SSW to N-S in the later phase. North-south trending fracture zones, offsetting the magnetic lineations, are apparent near the CBF. The shorter wavelength of the magnetic lineations and the rough bathymetry support a slow spreading rate during the later phase of the evolution.

The northwestern part of the basin is characterized by NW-SE lineaments and the Urdaneta Plateau (Fig. 2). A long linear fracture zone extends southwesterly from the Ryukyu Trench, offsetting the bathymetric fabric and the magnetic lineations. These features indicate that NE-SW spreading formed this area. The northwestern area is bordered by a narrow curved trough within the central part of the basin. The northwest-southeast spreading fabric is dominant and no significant depth difference is apparent on either side of the boundary. The magnetic lineation pattern found in the northwestern part of the basin, however, does not correlate with that found in the central part. This boundary may be one of the fracture zones extending from the CBF, or may be a kind of propagator pseudofault.

The interpretation of magnetic anomalies in previous studies disagree. For example, the age for spreading cessation ranges from 26 Ma [Shih, 1980b] to 35 Ma [Hilde and Lee, 1984]. Our magnetic data supports Hilde and Lee [1984]'s main conclusion that N-S slow spreading followed earlier NE-SW spreading, though the definite age identification is still unclear. One of our dredged samples from the intersection of the CBF and KPR was determined to be 27.4±1.6 Ma using the K/Ar method, a sample obtained from a minor ridge trending E-W adjacent to the CBF. This sample is alkali rich and was possibly formed during post-spreading volcanism. If the basin ceased to open at around 35 Ma, post-spreading activity may have continued for a long period, or the second stage of the basin history may have taken place near the extinct spreading center at around 27 Ma, when the SB and PVB began to open.

Our data elucidate a more complicated history of the WPB than has been proposed in previous studies. The data suggest that the tectonic background of the basin genesis is different from the rather simple backarc spreading process found in the SPVB, providing valuable information about variation in the evolutionary process and in the origin of marginal seas. Our survey covers only the northern part of the WPB, so additional age dating and swath surveying of basin parts, including the CBF, are needed to reconstruct the evolutionary process of the Philippine Sea.

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