Linear Magnetic Anomalies in the Shikoku Basin, Northeastern Philippine Sea

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A linear magnetic pattern, offset along fracture zones was found in the Shikoku Basin, which lies between the Izu-Bonin and northern Kyushu-Palau Ridges. This lineation, nearly parallel to the trend of the Kyushu-Palau Ridge, seems to indicate that this basin originated from a type of seafloor spreading. A possible spreading center was suggested on the basis of symmetry of magnetic anomaly profiles and distribution of sediment cover in the basin. The anomaly profiles were tentatively correlated to the synthetic profile calculated from the reversal history of the earth's magnetic field during a period in Early to Middle Miocene, which gives a good fit of age to the result of the DSDP hole 297.

1. Introduction

Evolution of the marginal seas which lie between the continental margins and fringing island arcs may be one of the most important subjects in geophysics today. As the development of sea-floor spreading and plate tectonics has clearly indicated, one vital clue to elucidate the evolutionary history of the ocean basins is an appropriate set of magnetic anomaly information.

Among several marginal seas around Japan, linearity of magnetic anomalies has been found in the Sea of Japan (YASUI *et al.*, 1967; ISEZAKI and UYEDA, 1973) and the southern Okhotsk Sea (YASUI *et al.*, 1967). BEN-AVRAHAM *et al.* (1972) showed symmetric magnetic anomaly profiles across the Central Basin Fault in the western Philippine Sea and identified the fault as an extinct spreading ridge. UYEDA and BEN-AVRAHAM (1972) regarded this ridge as a relic of the ancient mid-oceanic ridge and proposed a model of tectonic history of the northwestern margin of the Pacific Ocean.

The Philippine Sea is divided into western and eastern basins by a north-south trending chain of submarine seamounts called the Kyushu-Palau Ridge

(Fig. 1). Physiographic features of the elongated eastern basin are distinctly different from those of the western basin called the Philippine Basin. The present article provides a compiled map of magnetic total force anomalies in the

Fig. 1. Area of study with sketch bathymetric chart of surrounding seas. Water depth in km. Rectangle shows area indicated in Fig. 2. Circles denote sites of the DSDP holes (double circles indicate holes penetrating basement).

northern part of the eastern basin which is called the Shikoku Basin (Fig. 1), and postulates a plausible interpretation of data. All the available results of geomagnetic total force measurement carried out by the authors using the Japanese research vessels: Hakuho-maru and Tansei-maru of the Ocean Research Institute, University of Tokyo, Umitaka-maru of the Tokyo University of Fishery and Bosei-maru of the Tokai University are included in the present analysis. Results of aeromagnetic survey conducted by the Hydrographic Department, Maritime Safety Agency of Japan are also used here by the courtesy of the staff. Although many other magnetic profiles have been collected in the same area by the USA and USSR ships, they are not included in the present work.

2. Magnetic Anomalies

Magnetic anomaly profiles plotted at right angles to the ship's and airplane's tracks are shown in Fig. 2. All of our data except only one track which overlaps with another are included in the figure. The attached letters are indices of cruises, *e.g.* KH 71-1 denotes the first cruise of the R.V. Hakuho-maru in 1971 and T 64 indicates a cruise of the R.V. Tansei-maru in 1964 (as for other indices, see Fig. 3). The broken lines represent tracks of aeromagnetic flight at a height of 4500 m. Slightly longer wavelengths and attenuated amplitudes of the aeromagnetic anomalies are attributable to the increased distance from source compared with the sea level anomalies. Amplitude of the sea anomalies range between 200 and 300 gammas (peak to peak). These values of anomalies are comparable to those in other marginal basins such as the Sea of Japan (ISEZAKI and UYEDA, 1973), the Philippine Basin (BEN-AVRAHAM *et al.*, 1972) and the Tasman Sea (HAYES and RINGIS, 1973), but are almost an order of magnitude smaller than those observed on the crests of the active mid-oceanic ridges at non-equatorial latitudes.

Water depth of the Shikoku Basin is approximately 4500 m, and its eastern margin is shallower than the western. Large topographic highs exceeding 1000 m in relative height are rare except for a chain of seamounts called the Kinan Seamount Chain which lie in the central part of the basin. The highest is the second Kinan Seamount with relative height of about 3000 m and crestal depth of 800 m, which was measured during the GDP-8 cruise. Magnetic anomalies related to the seamount body are smaller than 400 gammas according to this cruise and a previous survey reported by VACQUIER and UYEDA (1967, their Zetes 4-7 seamount). Relatively small apparent intensity of magnetization of the seamount body computed by their method of analysis may possibly be either due to small natural remanent magnetization of rocks of the seamount

body or owing to cancellation of normally and reversely magnetized rocks constituting the seamount. Other seamounts have their crestal depths deeper than 2000 m and magnetic anomalies observed on the sea surface are usually

Fig. 2. Magnetic anomaly profiles along ship's and aeroplane's tracks in the Shikoku Basin. Solid and dotted curves denote positive and negative anomalies. As to the indices of cruises, see text and Fig. 3.

Fig. 3. Selected profiles of total intensity magnetic anomalies. Small letters above profiles are indices of anomalies tentatively used in this paper only. The ship's names are given on the right-hand side of profiles. Triangles indicate location of the crests of seamounts in the Kyushu-Palau Ridge and Kinan Seamount Chain. See text for further explanation.

smaller than 200 gammas. Therefore, profiles of magnetic anomalies are not appreciably distorted by these bodies. In particular the effect of seamount anomalies is negligibly small in the aeromagnetic profiles obtained at a height of 4500 m above the sea surface. In contrast magnetic anomalies originating

Fig. 4. Magnetic lineations (—) and fracture zones (---) in the Shikoku Basin. Double circle denotes the site of the DSDP hole 297. Contours of 1000 m (---), 4000 m (.....), 7000 m (—) and 9000 m deep (deeper areas shaded) are shown after the bathymetric chart No. 6302, Hydrographic Department, Maritime Safety Agency of Japan. Dotted lines indicate possible spreading centers.

from topographies of the Kyushu-Palau Ridge are predominating, as shown by triangles in Fig. 3.

In Fig. 3 ten selected profiles projected onto a line normal to the Kyushu-Palau Ridge are arranged roughly from northwest to southeast, showing the correlation of anomalies. The correlations are not entirely convincing and may be subject to modifications with further data. But with the present data, they seem to be fairly reasonable, if we consider the small amplitudes of anomalies causing small signal-to-noise ratios of information. The horizontal arrows in four profiles (KH 72-2, U 64-1, GDP-12(N), GDP-12(S)) indicate amounts of offset of the profile below relative to the above to attain the best mutual correlations. The vertical arrows shown above profiles KH 72-2, GDP-8 and GDP-7 mark the positions of discontinuities in sediment thickness discussed in the next section. Again, the correlations of boundaries with different profiles are much better after the offsets are taken into account.

These offsets shown by the four broken lines in Fig. 3 seem to imply existence of the fracture zones. The broken lines attached to the three profiles U 64-1, GDP-12(N), and GDP-12(S) indicate possible positions of fracture zones crossed by these profiles. For instance, the left half of the GDP-12(N) magnetic profile is best correlated with others, if it is offset by the amount shown by the arrow. It was observed along the same track that the sea bottom and acoustic basement are vertically faulted by approximately 300 m at the position of the proposed fracture zone. It is clearly seen in Fig. 3 that wavelengths of the magnetic anomalies south of this fracture zone are remarkably smaller than those in the northern area.

The idealized pattern of the magnetic lineations and fracture zones in this basin is represented in Fig. 4. The real pattern is expected to be much more complicated. With the data available, it may be stated that the lineations are roughly parallel to the trend of the Kyushu-Palau Ridge.

3. Interpretation of Anomaly Pattern

The magnetic profiles were carefully examined for a center of symmetry, but it was difficult to achieve a unique solution from magnetic data alone. Seismic reflection profiler data obtained by MURAUCHI and ASANUMA (1974) seem help solving this problem. These data along the GDP-7, 8 and a few other tracks reveal that the acoustic basement across the basin along a line trending roughly EW has a relief similar to that of a spreading ridge (Fig. 5). Sediment cover is thinner on the central zone of the basin and thicker in both margins, although the sediment thickness generally increases toward north. There seem to exist discontinuities in sediment thickness about half way be-

Fig. 5. Schematic drawing from the seismic reflection profile along the GDP-7 track after the profiler record obtained by MURAUCHI and ASANUMA (1974). Shaded is the acoustic basement. See text for further explanation.

tween the center and margins. Positions of the discontinuous boundaries are indicated by X and Y in Fig. 5 and by the vertical arrows in Fig. 3. Coincidence of these boundaries in sediment cover with magnetic anomalies is fairly good and mutual correlation of boundaries among different tracks provides reasonable evidence of offsets in this basin. The position of a magnetic trough between the anomalies *k* and *j* in Fig. 3 is thus chosen as a possible spreading center, taking the fact that it is located roughly at the center of the zone of thin sediment cover. The observed asymmetry in morphology of basement may be caused by uplifting of the eastern part of the basin associated with the later volcanic activity of the Izu-Bonin Ridge as an active island arc.

Identification of magnetic anomalies in Fig. 2 with the chronological standard of magnetic polarity history has not been completely successful. More than one identification is possible. However, the result of the DSDP hole 297 (INGLE *et al.*, 1973) which is located between anomaly *c* and anomaly *d* in Fig. 3 indicates that age of the basement at the site is older than 15 m.y. BP. As the hole did not penetrate the basement rock which, according to the seismic reflection data, appears to be roughly 100 m from the bottom of the DSDP hole, the basement age at the site is extrapolated to be approximately 20 m.y. BP. Seismicity study by KATSUMATA and SYKES (1969) showed that no shallow earthquakes are observed around the central axis of the Shikoku Basin. Therefore, the spreading is now extinct. With the aid of this age control the overall magnetic anomaly profiles may be identified to the reversal history in Early to Middle Miocene (BLAKELY, 1974), as shown in Fig. 6. The synthetic profile was calculated for a ridge striking N30°W and spreading in a symmetric manner at a rate of 1.7 cm/y before 15.6 m.y. BP and at 2.8 cm/y afterwards. If the spreading was more discontinuous, asymmetric or one-sided, other identifi-

Fig. 6. Magnetic anomaly profile from KH 72-2 cruise and its reversed one in respect to a magnetic trough between anomalies *k* and *j* in Fig. 3. A synthetic profile generated for a ridge striking N30°W (magnetic dip 45°) and spreading at a rate of 1.7 cm/y before 15.6 m.y.BP and at 2.8 cm/y afterwards.

cation may be possible, although the subbottom topography and thickness of sediment seem to exclude possibility of one-sided spreading.

4. Some Tectonic Implication

As a possible spreading center is situated nearly at the center of the Shikoku Basin, it may be plausible that the basin evolved by a process of sea-floor spreading. Offsets of magnetic lineations due to fracture zones originated from the transform faults. Trend of the fracture zones given in Fig. 5 is tentative and may be changed to a great extent with further evidences from magnetic and seismic measurements. However, it seems worth pointing out that the extensions of the fracture zones proposed here, if this interpretation is valid, are nearly parallel to the trend of en échelon alignment of the Izu Ridge. It is also worth noting that the Kinan Seamount Chain does not lie exactly on the suggested center of spreading but appears to be more closely related to the proposed fracture zones.

In the further south of this area we have very few data available and can not test whether or not the same pattern of lineations continue to the West Mariana (Parece Vela) Basin. If a similar pattern of magnetic lineations and subbottom structure is found and identified to the same age, it would be concluded that the deep Shikoku and Parece Vela basins evolved by sea-floor

spreading for a period in Early to Middle Miocene. Paleontological ages of the sediment just above the basements at the DSDP holes 53 and 54 are Early Oligocene to Early Miocene and early Middle Miocene respectively (FISCHER *et al.*, 1971). These ages seem to be fairly consistent with the present conclusion. Age-to-distance relationship of these two holes is also agreeable with our hypothesis of symmetric spreading. If such was really the case, two ridges were joined together before the evolution of the inter-arc basin. The view seems to be generally consistent with the hypothesis postulated by KARIG (1971). Configuration of the island arc-trench system in the earlier times and its relevance to the geological history of the Japanese Islands will be discussed elsewhere. Further evidences from the geophysical measurement at sea as well as from the deep sea drilling will provide clues for the sound understanding of the tectonic history of the concerned areas.

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