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Letter Section

New data which support the "laws of convergence rate of plates" proposed by Otsuki

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Abstract

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The VLBI geodetic networks have recently detected a shortening rate of about 6.2 cm/y in the baseline lengths between Kashima station on the Northeast Honshu Arc and the Pacific stations. In the northern part of the Mariana Trough, a change of the backarc spreading rate has been demonstrated through magnetic anomaly analysis. The backarc spreading commenced at about 3.5 Ma with a half spreading rate of 2.5 cm/y, and it has decreased to about 1 cm/y toward the present.

These new data are consistent with the first law of the convergence rate of plates proposed by Otsuki (1989), thus supporting its validity.

Introduction

Otsuki (1989) proposed two empirical laws on the fundamental relations of the plate kinematics at the zones of plate convergence, named jointly "laws of convergence rate of plates". The first law is expressed as:

$$V_a = V_{on} + V_{sn} - 7.2 \quad (\text{cm/y}) \qquad (1)$$

V_a denotes the backarc spreading rate (negative) or the contraction rate of arc crust (positive). V_{on} and V_{sn} are the components of absolute motions of overriding and subducting plates (positive when trenchward) parallel to the direction of V_a, respectively. This simple equation is valid for the recent subduction zones of plate all over the world when the maximum depth of the Wadati-Benioff zone is beyond 200 km.

Recently, new data supporting the validity of these laws have been reported. These data concern the changing rates of the baseline lengths in the global very long baseline interferometry (VLBI), and the changing rate of backarc spreading in the Mariana Trough, respectively.

Subduction rate of Pacific Plate at Japan Trench

The recent observations of VLBI, which provides one of the most powerful space geodetic tool for direct measurement of on-going plate motion, have offered some interesting data on the plate kinematics around the Northeast Honshu Arc. According to Heki (1989), the shortening rates of the baseline length between the Kashima station on the forearc of the Northeast Honshu Arc and the Kauai station on the Hawaiian Islands is

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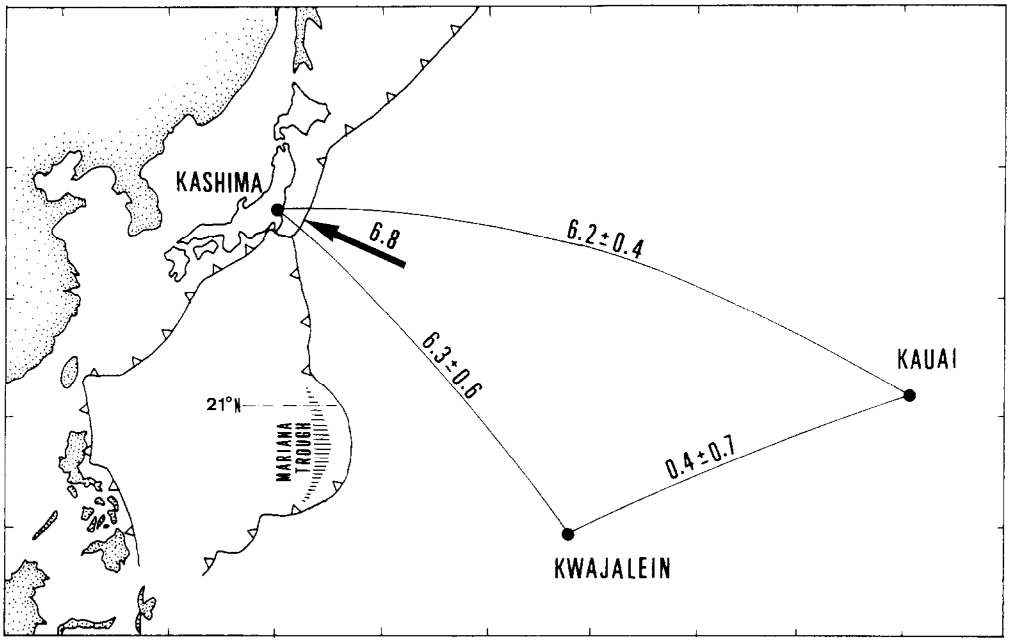

Fig. 1. Localities of the VLBI stations, shortening rate of the baseline lengths (cm/y) after Heki (1989) and locality of the magnetic anomaly profiles from the Mariana Trough shown in Fig. 2.

6.2 ± 0.4 cm/y and the one between the Kashima station and the Kwajalein station on the Marshall Islands averages 6.3 ± 0.6 cm/y (Fig. 1).

These values must not be mistaken for the subduction rate ($V_{on} + V_{sn} - V_a$) of the Pacific Plate at the Japan Trench, because the directions of these baselines do not coincide with the direction of subduction. It is, in principle, possible to determine the kinematic parameters, including the subduction rate, of the motion of the Pacific Plate relative to the Kashima station by using the VLBI data. However, the present disposition of the VLBI stations does not allow determination of these parameters with high accuracy. According to Heki (1989) the Kashima station is moving WNW-ward at 3.1 ± 0.6 cm/y relative to the North America Plate and its direction is almost parallel to that of the Pacific Plate motion relative to the North America Plate calculated from the Model RM-2 by Minster and Jordan (1978). Therefore, we assume tentatively that the Euler pole of the Kashima station–Pacific Plate motion is located at the same position as that of the North America–Pacific Plate motion. Using the shortening rates of the Kashima–Pacific baselines, the rotation rate is calculated at about 0.614°/Ma, and hence the velocity of the Pacific Plate motion at the Japan Trench off Kashima relative to the Kashima station to be 6.8 cm/y. Its direction is almost at right angle with the axis of the Japan Trench. Heki (1989) attributed the 3.1 cm/y WNW-ward motion of the Kashima station to compressional deformation of the overriding plate. Therefore, the value of 6.8 cm/y can be regarded as that of $V_{on} + V_{sn} - V_a$.

The equation (1) suggests that the subduction rate ($V_{on} + V_{sn} - V_a$) at any subduction zone with the Wadati-Benioff zone deeper than 200 km is constantly 7.2 cm/y. The subduction rate of 6.8 cm/y estimated above on the basis of the VLBI data nearly coincides with 7.2 cm/y within the error limits of the VLBI data, supporting the validity of the first law of convergence rate of plates.

Change in backarc spreading rate in Mariana Trough

The Mariana Trough is a typical backarc spreading type basin. The backarc spreading is prevented at the northern and southern ends of the Mariana Arc by the buoyant subduction of the

Ogasawara Plateau and the Caroline Ridge. The mean spreading rate was estimated at 3 to 4.3 cm/y by Bibee et al. (1980), Fryer and Hussong (1981) and Hussong and Uyeda (1981). The velocity and direction of the Pacific Plate motion relative to the Philippine Sea Plate at the midst of the Mariana Trench are calculated at 4.7 cm/y and N62° W based on the kinematic model of the Philippine Sea Plate relative to the Eurasia Plate (Seno, 1977). If we assume that the direction of the backarc spreading is at right angle with the general trend of the Mariana Arc (N10° E), $V_{on} + V_{sn}$ is calculated to be 3.4 cm/y, and hence a backarc spreading rate of 3.8 cm/y is expected from eqn. (1). It is in good agreement with the observed data.

Recently, the Geological Survey of Japan (Yamazaki et al., 1988) have conducted intensive geophysical and geological studies for the northern part of the Mariana Trough. According to their studies, the area to the north of 22° N is now in a rifting stage, and the south is in a spreading stage, where magnetic lineations trending in N20° W are clearly observed, especially in the western half. The lineations in the western half show that the spreading at 21° N started at about 3.5 Ma with a half spreading rate of about 2.5 cm/y, and it decreased to about 1.5 cm/y at 2 Ma and thereafter to 1 cm/y (Fig. 2). Equation (1) suggests that a decreasing backarc spreading rate should accompany an increase of $V_{on} + V_{sn}$, namely a decrease in the westward motion of the Philippine Sea Plate, an increase in the westward motion of the Pacific Plate, or both.

The historical changes in the absolute motion of the Pacific Plate are demonstrated by the orientation and age–distance relation of seamount chains in the Pacific Ocean. The possibility of the accelerated motion of the Pacific Plate since several million years was pointed out from the age–distance relation of the Hawaiian Islands (Jackson et al., 1972). Cox and Engebretson (1985) estimated the absolute motion of the Pacific Plate from the Pacific hotspot tracks and the Antarctica–Pacific motion, and found a change in the Pacific Plate motion at around 5 Ma. According to their result, V_{sn} of the Pacific Plate at the Mariana Trench increased from 8.1 cm/y or 8.7 cm/y before 5 Ma to 10.6 cm/y after 5 Ma. Pollitz (1986) reexamined the age–distance relation and the changes in the direction of the Pacific and Nazca hotspot traces. According to him, the Euler pole position and the rotation rate of the absolute motion of the Pacific Plate changed gradually from 65° N40° W and 0.84°/Ma before 5.2 Ma to 61° N95° W and 0.99°/Ma after 3.2 Ma. This change makes V_{sn} at the Mariana Trench increase from 9.2 cm/y to 10.6 cm/y. These results are quite consistent with the decrease in the half spreading rate of the western part of the Mariana

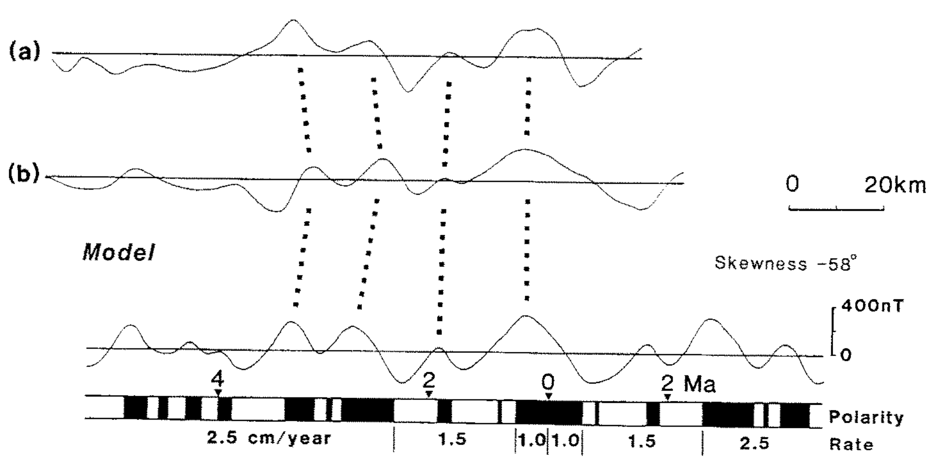

Fig. 2. Magnetic anomaly profiles from the northern part of the Mariana Trough (Fig. 1) and a synthetic profile calculated from a standard magnetic block model, after Yamazaki et al. (1988).

Trough from 2.5 cm/y at 3.5 Ma to 1.5 cm/y at 2 Ma.

The late Neogene history of the Philippine Sea Plate motion remains as yet unknown. The correlation between backarc spreading rate of the Mariana Trough as expected from eqn. (1) and the one based on observation, will become apparent and complete when the missing data available. Essentially more precise knowledge is needed on the spreading rate of the eastern part of the Mariana Trough and the changes of the absolute motion of the Pacific Plate during the last few million years in addition to the changes in the westward motion of the Philippine Sea Plate.

Conclusions

New data on the changing rates of the VLBI baseline lengths between the Kashima and Pacific stations and on the decreasing rate of the backarc spreading in the northern part of the Mariana Trough related to the change in the Pacific Plate motion support the validity of the first law of the convergence rate of plates as proposed by Otsuki (1989).

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