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THE INSTANTANEOUS ROTATION VECTOR OF THE PHILIPPINE SEA PLATE RELATIVE TO THE EURASIAN PLATE

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ABSTRACT

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Using all the available fault-plane solutions of the inter-plate earthquakes along the northwestern and eastern boundaries of the Philippine Sea plate, the instantaneous rotation vector of the Philippine Sea plate relative to the Eurasian plate is determined (pole: 45.5°N, 150.2°E, angular velocity: 1.20 deg/m.y.). The solutions along the Taiwan—Philippine region are not used because of the tectonic complexity in this region. To overcome the difficulty in determining the rotation vector only from the northwestern boundary of the Philippine Sea plate, the general property that the three instantaneous rotation vectors, Pacific to Eurasia, Philippine Sea to Eurasia, and Pacific to Philippine Sea, are contained in the same plane, is used. The rotation vector of Pacific to Eurasia is assumed as in the model RM1 of Minster et al. (1974). The rotation vector of Pacific to Philippine Sea is determined at the same time. Using these results, historical earthquakes in the Sagami and Nankai trough region are studied on the basis of plate motion and fault models deduced from the geodetic data. In this region, the co-seismic slip is comparable to the rate of plate motion. The recent start of plate convergence (several million years ago) may be one reason for this strong coupling of the oceanic lithosphere with the continental one. The slip vectors at the triple junction which connects the Japan trench, Sagami trough, and Izu—Bonin trench, show that this junction is not stable and migrates to the northwest along the Sagami trough at the rate of 3 cm/yr. However, if the crustal extension exists behind the Izu-Bonin trench, it may stay stable. The slip vectors of the shallow earthquakes along the eastern coast of Luzon and the Philippine trench deviate from those computed from the rotation vector of the Philippine Sea plate relative to the Eurasian plate. To explain this, a minor plate which includes the entire Philippines is introduced on the evidence of seismicity and topography. The tectonic complexity in the Taiwan—Luzon region may be reduced to the collision of this block with Taiwan.

INTRODUCTION

Instantaneous rotation vectors for various couples of plates have been estimated by the slip vectors of inter-plate earthquakes, strike of transform faults, and spreading rates at the crest of ridges (McKenzie and Parker, 1967; Morgan, 1968; Le Pichon, 1968). Recently, relative motions of the major plates have been determined as a whole by the least-squares method (Chase, 1972; Minster et al., 1974).

Instantaneous rotation vectors between plates bordering the consuming plate boundaries are important in discussing the seismicity along the subduction zones and the tectonics of island arcs. In fact, along many converging plate boundaries, relative motion deduced from instantaneous rotation vectors coincides, at least qualitatively, with the seismic or tectonic observations (Le Pichon, 1968; Isacks et al., 1968; Davies and Brune, 1971). However, with regard to the Philippine Sea plate, it is very difficult to determine the rotation vector for various reasons. The Philippine Sea is one of the largest marginal seas in the western Pacific and is surrounded by converging plate boundaries, i.e. the Nankai trough, Ryukyu trench, and Philippine trench to the west, and the Izu--Bonin, Mariana, Yap, and Palau trenches to the east (Fig. 1). It has no accreting boundary along which magnetic lineations and transform faults often provide useful information on the relative motions. The only available data for the determination of the pole of rotation is the slip directions of inter-plate earthquakes at the converging plate boundaries mentioned above. However, seismological studies show that the Taiwan—Philippine region is one of the most complex regions of any consuming plate boundary (Katsumata and Sykes, 1969; Fitch, 1970, 1972; Wu, 1970; Hsu, 1971; Sudo, 1972). Katsumata and Sykes (1969) pointed out that it is impossible to describe the slip vectors along the Ryukyu—Taiwan—Philippine region by a unique pole of rotation between one couple of plates and suggested the existence of a separate plate south of Luzon. Fitch (1970) also introduced a minor plate in the lesser Philippines. Thus it may not be appropriate to interpret the slip vectors in the Taiwan—Philippine region as the slip vectors of the Philippine Sea plate relative to the Eurasian plate. Fitch (1972) pointed out that the direction of the underthrusting along the east coast of Luzon differs by almost 19° from the one along the Philippine trench. He interpreted this change by the decoupling hypothesis which requires that the oblique convergence along the east coast of the Philippines is completely decoupled between the shear motion along the Philippine fault and normal thrusting to the trench axis. He obtained two solutions for the pole of rotation of the Philippine Sea plate relative to the Eurasian plate, using the strike of one part of the Philippine fault and the slip vectors along the Nankai trough and the Ryukyu trench. His solutions, depending on the decoupling hypothesis, are speculative because the amount of decoupling may not be determined uniquely. In the present attempt to determine the rotation vector of the Philippine Sea plate, we avoid using slip vectors in the Taiwan—Philippine region for the above reason. We also avoid using the strike of the Philippine fault. The decoupling hypothesis may well be right, but we feel that the pole position should first be estimated without such a hypothesis, and what is happening in the Philippine region, including possible "decoupling", should be investigated later. The slip vectors of shallow thrust-type earthquakes along the Nankai trough and the Ryukyu trench are

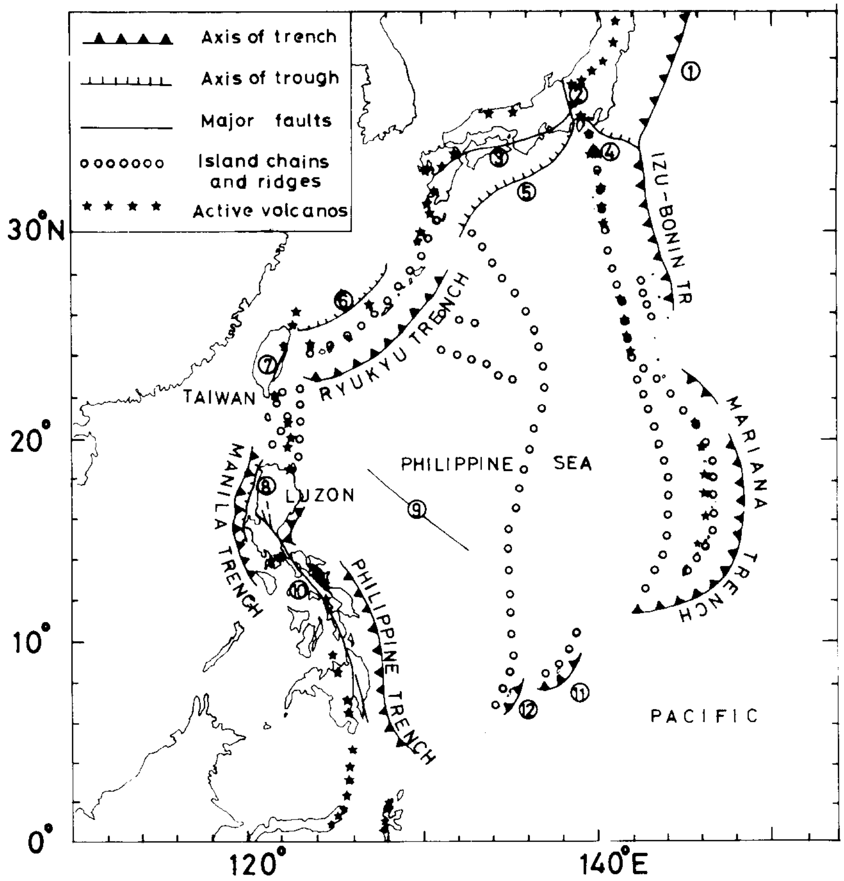


Fig. 1. Tectonic elements of the Philippine Sea and adjacent areas. Areas shown are: *1* Japan trench; *2* Fossa Magna; *3* Median Tectonic Line; *4* Sagami trough; *5* Nankai trough; *6* Okinawa trough; *7* Longitudinal Valley; *8* West Luzon trough; *9* Central Basin fault; *10* Philippine fault; *11* Yap trench; *12* Palau trench.

used as the indicator of the direction of underthrusting of the Philippine Sea plate to the Eurasian plate. It should be noted that the convergence of the Philippine Sea plate along the Nankai trough may be decoupled in part to the shear motion along the Median tectonic line, which is a major active fault in southwest Japan (Fig. 1, Kaneko, 1966; Okada, 1968), but it is probably only small because the rate of slip along this fault is lower than the rate of underthrusting of the Philippine Sea plate by one order of magnitude (Okada, 1971; Fitch, 1972). However, it is impossible to estimate the pole of rotation of the Philippine Sea plate relative to the Eurasian plate only from the slip vectors in the Nankai trough and the Ryukyu trench because they are almost parallel. They differ by only seven degrees from one another. Therefore only the azimuth of the great circle on which the pole exists can be estimated but not the pole position on the great circle. To overcome this difficulty, we make use of the general property of the instantaneous rotation vectors among three plates, namely that they are contained in the same plane.

Active extension in the inter-arc basins in the Philippine Sea (Karig, 1971a, b) may influence the rate and direction of the slip along the Izu–Mariana arc (Fitch, 1972). However, in the present study, this influence is not taken into account and the Philippine Sea is assumed to be a non-spreading rigid plate.

METHOD AND RESULTS

For brevity, we denote the Philippine Sea, Eurasian, and Pacific plates as PH, EU, and PA, respectively. We also denote the rotation vector of PH to EU as ${}_{PH}\vec{\omega}_{EU}$ with the usual sign convention. ${}_{PA}\vec{\omega}_{EU}$ and ${}_{PA}\vec{\omega}_{PH}$ are defined in the same manner. There is a general relation:

$$ {}_{PA}\vec{\omega}_{EU} + {}_{EU}\vec{\omega}_{PH} + {}_{PH}\vec{\omega}_{PA} = 0 $$

Therefore, the three vectors ${}_{PA}\vec{\omega}_{EU}$, ${}_{PH}\vec{\omega}_{EU}$, and ${}_{PA}\vec{\omega}_{PH}$ are contained in the same plane. The pole PH to EU is determined by the following two conditions:

(1) It exists on the great circle which contains both the pole PA to EU and the pole PA to PH.

(2) It exists on the great circle perpendicular to the slip vector of PH to EU. These relations are illustrated in Fig. 2A.

Once the pole PH to EU is obtained from this procedure at the intersection of two great circles, the ratio of the absolute values of the three vectors, $|{}_{PA}\vec{\omega}_{EU}| : |{}_{PH}\vec{\omega}_{EU}| : |{}_{PA}\vec{\omega}_{PH}|$ can be estimated by making a vector circuit (Fig. 2B). Then, if the absolute value of ${}_{PA}\vec{\omega}_{EU}$ is known, those of other vectors will also be determined.

The poles PA to EU and PA to PH, and the slip vectors of PH to EU are estimated as follows. First, the pole PA to EU is assumed to be 65.3°N, 69.8°W following the model RM1 of Minster et al. (1974). To estimate the error, two more points (66.0°N, 65.8°W and 64.6°N, 73.8°W) on the ellipse of 95% confidence in the model RM1 are selected for the pole PA to EU as indicated in the inset of Fig. 4. Second, to estimate the pole PA to PH, the fault-plane solutions of shallow thrust-type earthquakes along the Izu–Bonin–Mariana–Yap–Palau arc are used. Katsumata and Sykes (1969) estimated the pole PA to PH as 7°N, 142°E from the slip vectors of shallow earthquakes in this region and argued that the decrease in the depth of seismic activity and the reduced level of activity in the Yap–Palau region confine the pole position in the region between 0° and 10°N south or southwest of the Mariana arc. In this region the available solutions are scarce (Fig. 3, after Katsumata and Sykes, 1969; Fitch, 1972), so that we do not determine the pole PA to PH here, but six sample points for the pole are selected

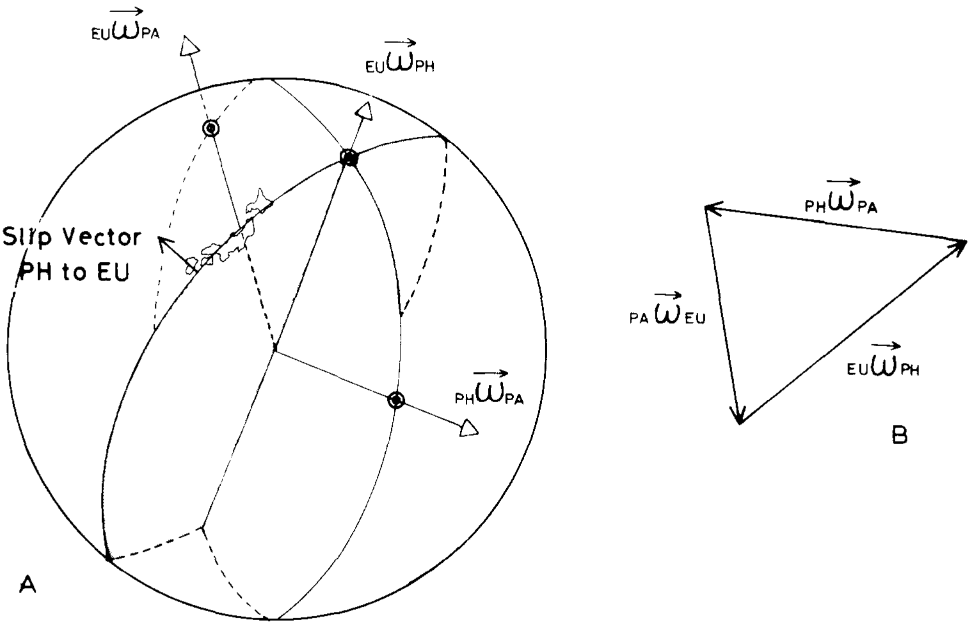


Fig. 2. A. Conditions for determination of the pole PH to EU. B. Vector circuit with the three instantaneous rotation vectors.

in the following manner. The earthquakes Nos. 11 and 12 have almost the same epicenters and directions of the slip vectors. *EA* and *E'A'* (Fig. 3) are two great circles perpendicular to the slip vectors of these earthquakes at their epicenters. Another three great circles perpendicular to the slip vectors of the remaining earthquakes, Nos. 10, 13, 14, intersect *EA* and *E'A'* at six points (Fig. 3, *A*, *A'*, *B*, *B'*, *C*, *C'*). These points are selected as the sample points for the pole PA to PH. Finally, to estimate the slip vectors of PH to EU, all the available fault-plane solutions of shallow thrust-type earthquakes along the Sagami trough, Nankai trough, and Ryukyu trench are examined. Those near Taiwan are excluded because of the tectonic complexity (Katsumata and Sykes, 1969; Wu, 1970; Sudo, 1972). The solution of the 1923 Great Kanto earthquake which took place at the northern end of the Sagami trough, is not used because of the ambiguity of its slip vector (Kanamori, 1971; Ando, 1971). One solution located at the northern end of the Ryukyu trench is excluded because its slip direction differs to some extent from those in the Nankai trough. Thus, nine solutions are selected for the present study (Fig. 5, Nos. 1—9, after Katsumata and Sykes, 1969; Kanamori, 1972; Fitch, 1972).

Thus we get three samples for the pole PA to EU, six for the pole PA to PH, and nine for the slip vector of PH to EU, providing 162 samples for the pole PH to EU (Fig. 4). Averaging over these points, the pole PH to EU is determined as 45.5 (3.7)°N, 150.2 (5.4)°E. The standard deviations are

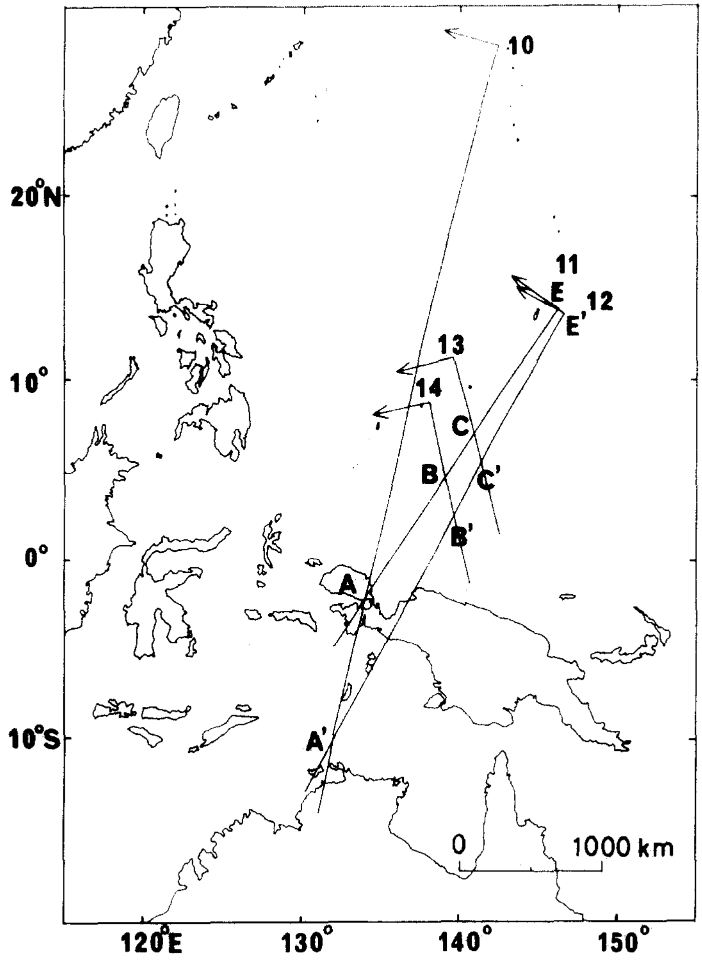


Fig. 3. Estimation of the pole PA to PH. Arrows numbered are slip vectors of shallow thrust type earthquakes (after Katsumata and Sykes, 1969; Fitch, 1972).

between parentheses. Now the ratio $|_{PA}\vec{\omega}_{EU}| : |_{PH}\vec{\omega}_{EU}| : |_{PA}\vec{\omega}_{PH}|$ is determined by making a vector circuit for each sample. Averaging these ratios gives 1 : 1.32 (0.13) : 1.27 (0.10). Assuming the absolute value of $_{PA}\vec{\omega}_{EU}$ as in the model RM1 (Minster et al., 1974) gives those of the other two vectors. Finally, using these results, the pole PA to PH is estimated as 2.0 (5.8)°N, 138.3 (3.6)°E (Fig. 4). These solutions are tabulated in Table I.

Based on the results described above, the rates and directions of the motion of the Philippine Sea plate relative to the Eurasian plate are calculated along the Sagami trough, Nankai trough, Ryukyu trench, and Philippine trench. Also those of the Pacific plate to the Philippine Sea plate are calculated along the Izu—Bonin—Mariana—Yap—Palau arc. These are shown in Fig. 5.

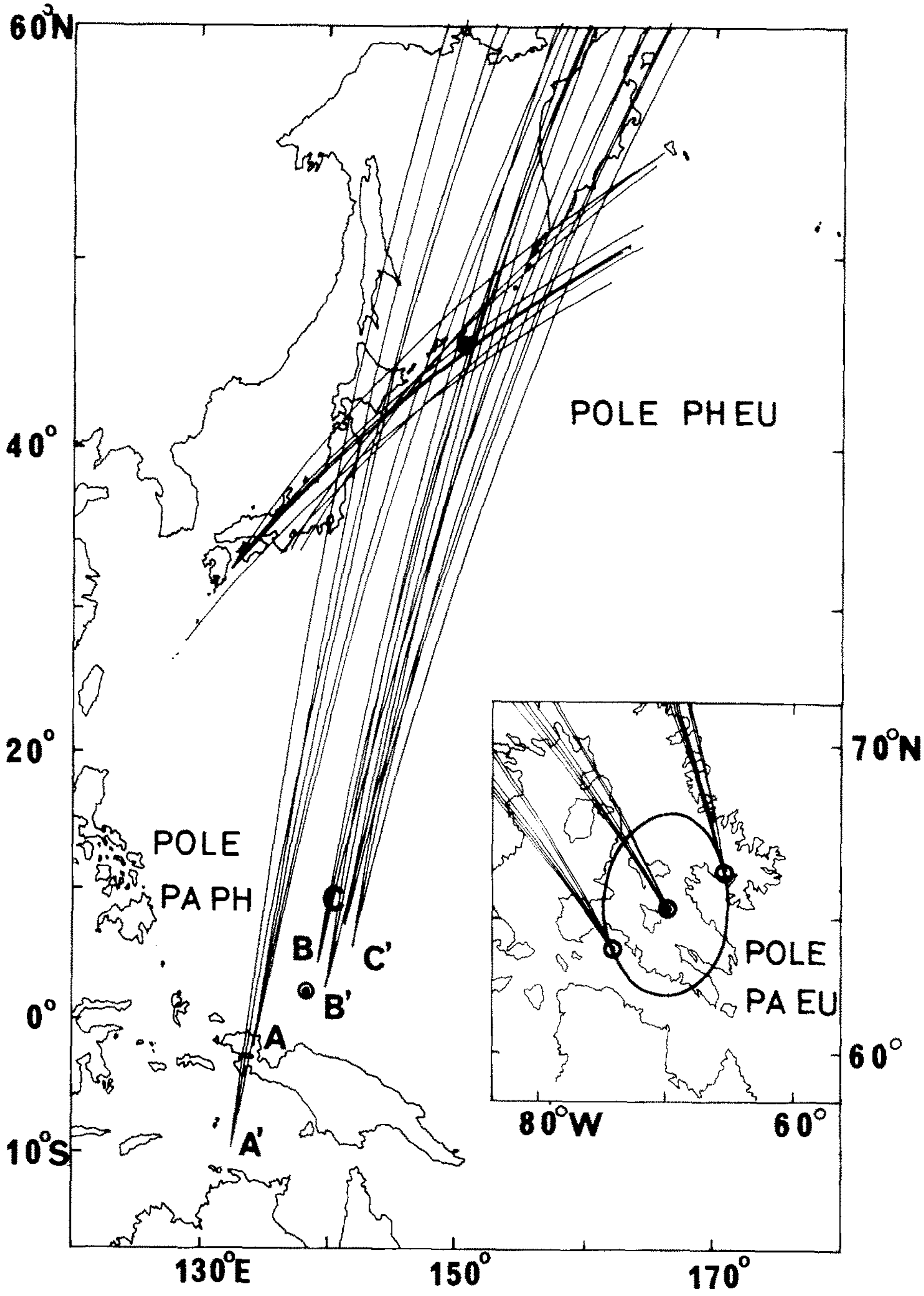


Fig. 4. Determination of the pole PH to EU.

TABLE I

Instantaneous rotation vectors of relative motions among the Philippine Sea, Eurasian, and Pacific plates

Plates	Pole				Angular velocity	
	Lat. (°N)	St.Dv. (deg)	Long. (°E)	St.Dv. (deg)	Omega (deg/m.y.)	St.Dv. (deg/m.y.)
PH EU	45.5	3.7	150.2	5.4	1.20	0.12
PA PH	2.0	5.8	138.3	3.6	1.16	0.09
PA EU *	65.3	3.2	−69.8	5.1	0.91	0.04

St.Dv. is standard deviation.
* Minster et al. (1974).

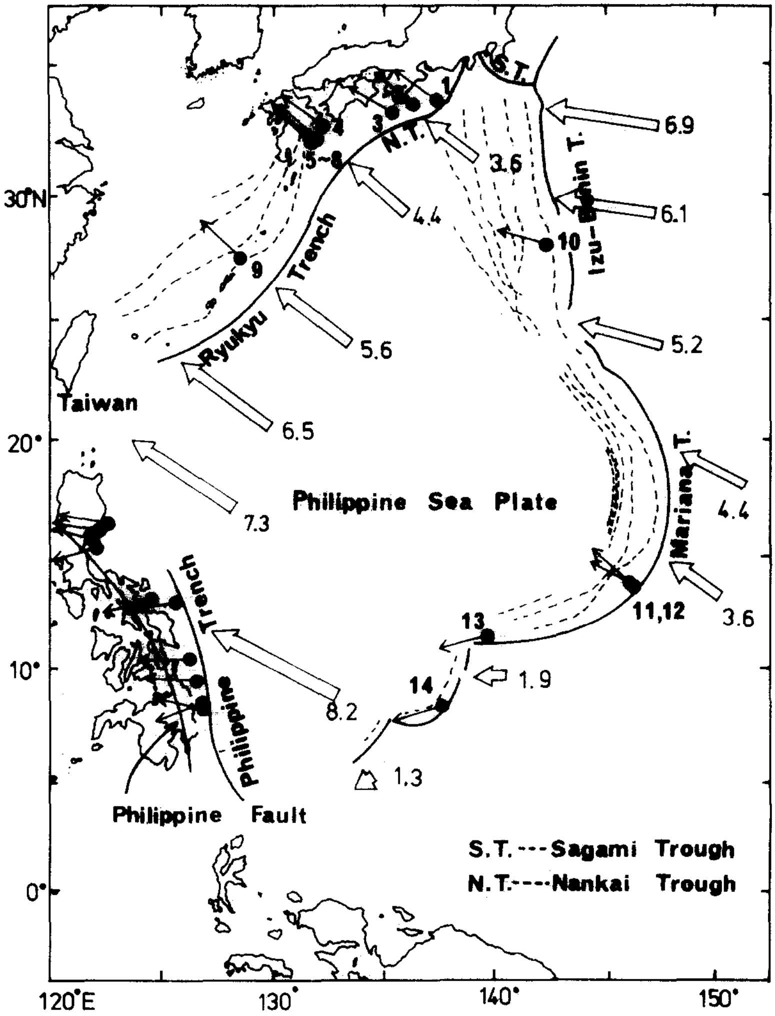


Fig. 5. Convergence along the margin of the Philippine Sea plate. White arrows are slip vectors computed from the present model. Numerals attached are slip rates (Unit: cm/yr). Solid circles with arrows are earthquakes and their slip vectors. Broken lines are contours of the Benioff zones after Katsumata and Sykes (1969).

DISCUSSION

Earthquakes in the Sagami trough region

The epicenters and magnitudes of the historical earthquakes in the Sagami trough region are shown in Fig. 6. The source areas of tsunamis of the 1605, 1703, 1923, and 1953 earthquakes are also shown (after Hatori, 1975a,b). These earthquakes associated with tsunamis and the 818 earthquake are unlocal great shocks and probably indicate the differential motion between the Philippine Sea and Eurasian plates. The 1923 Kanto earthquake is the only one of which the source mechanism was studied by the seismological and geodetic data (Kanamori, 1971; Ando, 1971). We can discuss quantitatively its source mechanism on the basis of plate motion.

The slip direction determined by the P-wave first-motion diagram (Kanamori, 1971) agrees well with the slip direction deduced from the rotation vector in the present study. However, the slip direction determined by the fault model deduced from geodetic data (Ando, 1971) deviates almost 30° from the seismological one. This discrepancy is larger than the uncertainty in the determination of the slip vectors and some irregularity may have happened about the direction of plate motion because the Philippine Sea plate is colliding with the continental one at the northern end of the Sagami trough. As for the fault displacement, it is well known that the geodetic model usually gives a larger amount of slip than the seismological

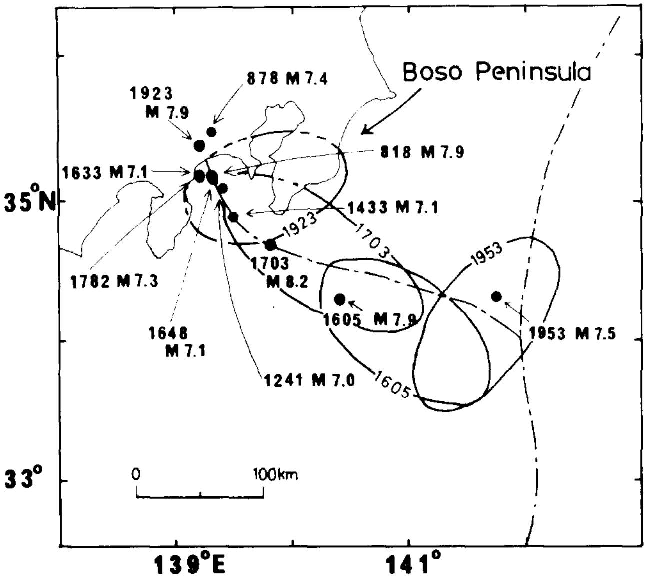


Fig. 6. Historical earthquakes in the Sagami trough region. The epicenter and magnitude data are from Tokyo Astronomical Observatory (1976). Heavy lines show the source areas of tsunamis of the 1605, 1703, 1923, and 1953 earthquakes after Hatori (1975a,b).

model (e.g. Ando, 1971). This is explained by introducing different time constants for the displacements associated with the seismic wave radiation and with the geodetic deformation (Kanamori, 1971; Ando, 1971). We take here the fault displacement determined by the geodetic model as the total slip at the time of the earthquake and define it as the co-seismic slip. Dividing 6.7 m of the co-seismic slip at the Kanto earthquake by the slip rate of 3.02 cm/yr in the present study gives a repeat time of 221 (±30) years. It should be noted that the 1703 Genroku earthquake shared the fault plane with the Kanto earthquake (see source areas of tsunamis in Fig. 6) and it occurred 220 years before the Kanto earthquake.

In the northwestern part of the Sagami trough, there was a longer time interval (885 years) before the Genroku earthquake since the 818 earthquake. It is known in the historical documents that the upheaval of the southern end of the Boso peninsula (Fig. 6) was three to four times larger for the Genroku earthquake than the Kanto earthquake. Then the larger amount of slip at the Genroku earthquake may explain the longer time interval. It is difficult to discuss quantitatively those earthquakes in the southeastern part of the Sagami trough because their directions or amounts of co-seismic slip are not known.

Triple junction

With the slip vectors calculated in the present study, the stability of the triple junction which connects the Japan trench, Sagami trough, and Izu—Bonin trench, can be discussed. A velocity vector circuit of the relative motion of plates is constructed after McKenzie and Morgan (1969) (Fig. 7B).

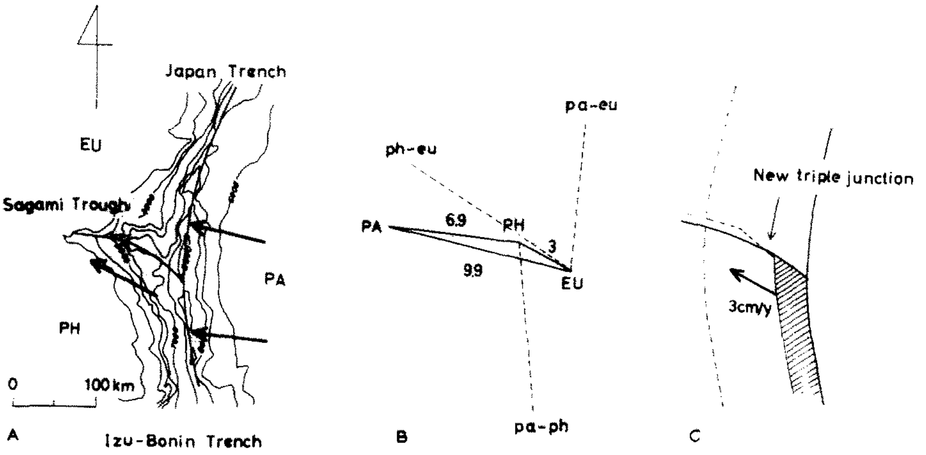
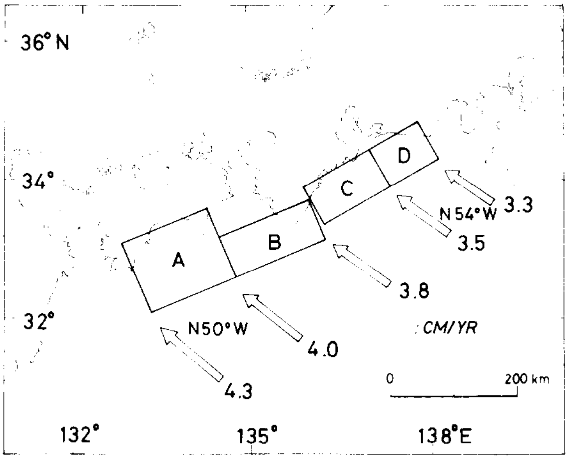


Fig. 7. A. Triple junction off the east coast of Japan. Arrows represent the directions of relative motions of plates. B. Vector circuit constructed by the relative motions of the plates (unit: cm/yr). Broken lines represent the strikes of plate boundaries. C. Migration of the triple point.

It shows that the triple junction is not stable and it moves to the west along the Sagami trough at the rate of 3 cm/yr as shown in Fig. 7C. The hatched area will be filled with the Pacific plate, but if crustal extension exists behind the Izu—Bonin trench (Karig, 1971b), some part or whole of the hatched area may be filled with the new crust and the triple junction may appear stable (Fitch, 1972).

Earthquakes in the Nankai trough region

Along the coast of southwestern Japan, destructive earthquakes have occurred repeatedly at 100—200 year time intervals. The studies of the source mechanisms of the 1944 Tonankai and 1946 Nankaido earthquakes (Fitch and Scholz, 1971; Kanamori, 1972; Ando, 1975) show that these earthquakes indicate the underthrusting of the Philippine Sea plate beneath the continental plate at the Nankai trough. Ando (1975) studied historical



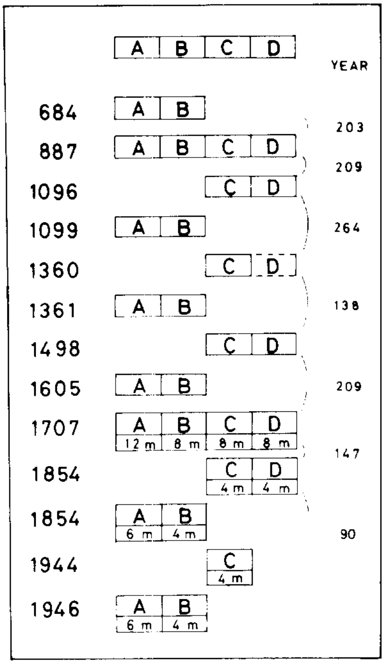


Fig. 8. Slip vectors of relative motion between the Philippine Sea and the Eurasian plates along the Nankai trough (unit: cm/yr). Rectangles are the horizontally projected fault planes for historical earthquakes obtained by Ando (1975).

Fig. 9. Cyclic migration of the earthquakes along the Nankai trough since 684 A.D. The numerals on the right represent intervals between the successive seismic cycles. For the earthquakes of 1707, 1854 (twin), 1944, and 1946, the fault displacements obtained by Ando (1975) are also shown under the fault planes. (Modified from Ando's (1975) figure.)

earthquakes in this region also. He proposed four fault planes (Fig. 8) and attributed historical earthquakes to these fault planes (Fig. 9). He also obtained slip directions and fault displacements from geodetic and tsunami data for the 1707 Hoei, 1854 Ansei I, Ansei II, Tonankai and Nankaido earthquakes. The slip directions in his model coincide with those in the present study. The co-seismic slips in the geodetic model (shown in Fig. 9) are divided by the slip rates of plate motion at the corners of the fault planes (Fig. 8). The comparison with the time intervals of the earthquakes is shown in Table II. It is seen that they almost coincide with each other. This indicates that in the Nankai trough region, the differential movement of the plates is almost taken up by the co-seismic slip.

In southwestern Japan, a well-defined Benioff zone and volcanic front are lacking. This means the recent beginning of the underthrusting of the Philippine Sea plate beneath southwestern Japan. Studies of the travel-time anomalies of seismic waves and seismicity of the microearthquakes in this region (Kanamori, 1972; Shiono, 1974) showed that the length of the downgoing slab under southwestern Japan does not exceed 150—200 km. With the slip rate of the plate, the beginning of the convergence of the Philippine Sea plate in the present stage does not much precede 5 m.y. ago, provided that the instantaneous rotation vector did not change in several million years.

It should be noted that the differential movement of the plates along subduction zones does not necessarily take the form of the seismic slip. For example, large thrust-type earthquakes do not occur along the Ryukyu and Izu—Mariana trenches. In these regions, a considerable portion of the differential movement of the plates appears to be taken up by aseismic slip. The difference in the strength of coupling of the oceanic lithosphere with the continental one may be related to the stage of evolution of the subduction zone (Kanamori, in preparation). The younger stage of convergence of the Philippine Sea plate under southwestern Japan may be one reason for the strong coupling in the region.

TABLE II

Comparison between earthquake recurrence rate and rate of plate motion

Earthquake	Time interval (year)	*D*/slip rate (year)	Magnitude *
1707 Hoei	102, 209	174—346	8.4
1854 Ansei I	147	93—140	8.4
1854 Ansei II	147	87—173	8.4
1944 Tonankai	90	93—133	8.0
1946 Nankaido	92	87—173	8.1
1923 Kanto	220	193—257	7.9

Time interval is defined by the interval between an earthquake and the one previous to it.
D/slip rate is the fault displacement divided by the slip rate of plate motion.
* Magnitude data are after Tokyo Astronomical Observatory (1976).

Plate convergence in the Taiwan—Philippine region

The directions of the slip vectors of shallow thrust-type earthquakes along the east coast of the Philippines (Fig. 5, after Katsumata and Sykes, 1969. Fitch, 1972) deviate 13—47° in a counterclockwise sense from the computed ones in the present study (Fig. 5). To explain this, a minor crustal block which includes the entire Philippines is introduced based on the following reasons:

(1) The world-wide seismicity map of shallow earthquakes (Fig. 10, Barazangi and Dorman, 1969) shows a narrow zone of seismicity which encircles the Philippines. This suggests the existence of a minor plate including the entire Philippines.

(2) The vertical profiles of earthquake foci along the latitude lines from 10°N to 17°N in the Philippines region (Hsu, 1971) indicate two inclined seismic zones, the left one dipping to the east, and the right one dipping to the west.

(3) Ludwig et al. (1967) and Hayes and Ludwig (1967) described a deep-sea trench (Manila trench, Fig. 1) near the west coast of Luzon. This (with 2) indicates that the Philippines are not a part of the Eurasian plate at least along the Manila trench.

(4) The fault-plane solutions of the earthquake of March 12, 1966 and two nearby earthquakes off the northeastern coast of Taiwan, considered with the sinistral shear motion along the Longitudinal Valley, suggest the existence of a sliver of crust off the east coast of Taiwan other than the Philippine Sea plate (Wu, 1970; Sudo, 1972).

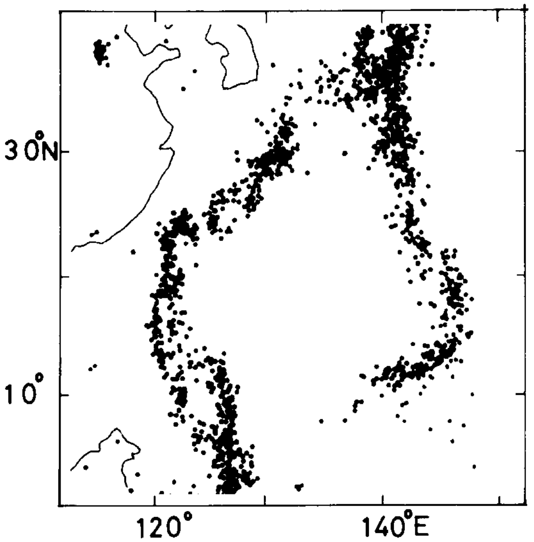


Fig. 10. Shallow seismicity in the Philippine Sea and adjacent areas (Barazangi and Dorman, 1969. Depth ⩽ 100 km, $M \geqslant 4$, 1961—1967).

(5) The Longitudinal Valley of Taiwan continues topographically to the West Luzon trough (Chai, 1972) and the Coastal Range of Taiwan might have originally belonged to the Luzon arc system (Karig, 1973).

The boundary of the minor plate is outlined on the above evidence of seismicity and topography (Fig. 11), although it is more or less speculative. The region off the east coast of Taiwan to the northeastern end of Luzon has no seismic or topographic evidence to border the boundary. With this minor block and the slip directions along the east coast of the Philippines, the general picture of the tectonics in the Taiwan—Philippine region can be outlined. The difference between the directions of underthrusting along the east coast of Luzon and along the Philippine trench (Fig. 5) suggests that the pole of relative motion between the Philippine Sea plate and the minor plate is located off the northeastern coast of Taiwan. The low level of seismicity in this region and a drastic change of maximum depth of seismic activity from greater than 600 km to less than 200 km between 8°N and 12°N along the Philippine trench (Fitch, 1970) are consistent with this pole position. It also explains the reason why it was difficult to define the boundary in the region mentioned above. The discrepancy between the slip directions along the east coast of the Philippines and the ones deduced from the pole PH to EU (Fig. 5) indicates that the minor plate must move to the north or northwest relative to the Eurasian plate. The decoupling ratio of the motion of the Philippine Sea plate relative to the Eurasian plate between the motions relative to

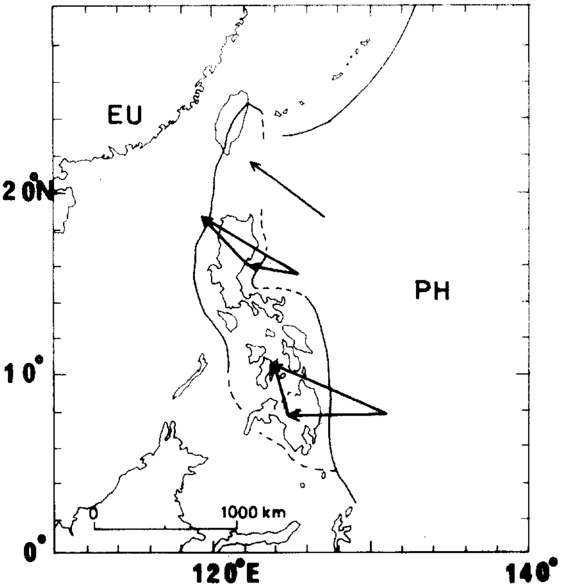


Fig. 11. Boundary of the minor plate introduced in the text. Broken lines represent the boundary which is poorly defined. Solid arrows show an example of decoupling of the motion of the Philippine Sea plate relative to the Eurasian plate between the motions relative to the intervening minor plate.

the intervening plate cannot be determined uniquely. One of the plausible solutions is illustrated in Fig. 11.

The region between Taiwan and Luzon appears to be most complicated. There is the Longitudinal Valley in Taiwan which has a sinistral shear motion with some compressional component (e.g. Allen, 1962). Off the east coast of Taiwan to the northern end of Luzon, most of the tectonic units are en-echelon lineaments of a broken set of ridges and troughs which have offsets suggesting sinistral shear motion (Karig, 1973). Along the east coast of Taiwan, earthquake foci do not clearly define a dipping zone and all the activity is confined within the upper 100 km (Katsumata and Sykes, 1969). These features are explained by the collision of the minor block with Taiwan and with the continental shelf south of Taiwan. The vertical profile of earthquake foci across the Manila trench (Hsu, 1971) shows clearly the seismic zone dipping to the east. A considerable portion of the differential motion between the plates may be taken up by the underthrusting along the Manila trench. But to acertain this, the data from large earthquakes is needed.

The view that the Philippine fault has a main role with the plate motion (Fitch, 1972) is not taken here for the following reasons:

(1) The world-wide seismicity map shows that the earthquake epicenters do not align along its fault trace (Gutenberg and Richter, 1954; Barazangi and Dorman, 1969) and only one historical earthquake along the Philippine fault is known to be unequivocally associated with the actual surficial fault displacement (1973 Ragay Gulf earthquake; Allen, 1975).

(2) A close study of the fault zone in southeastern Luzon (Rutland, 1968) showed that the faulting in the late Miocene and Plio-Pleistocene was essentially of dip-slip character and major strike-slip motion has not occurred since the late Miocene. In contrast, other studies cited by Karig (1973) indicate that the fault zone has at least several tens of kilometers of left-lateral slip since the late Miocene. Even in this case, the rate of slip along the fault is of the order of several mm/yr which is lower than that of underthrusting along the Philippine trench by one order of magnitude. Then the decoupling of the underthrusting to the shear motion along the Philippine fault may be very small. The rate of several mm/yr is comparable to that of the Median tectonic line (Okada, 1971) and it may be preferable to regard the Philippine fault as an intra-plate active fault such as the Median Tectonic Line.

CONCLUSIONS

The results in the present study show that the seismic and tectonic observations along the northwestern boundary of the Philippine Sea plate are consistent with the rates and directions of the motion of the Philippine Sea plate relative to the Eurasian plate deduced from the instantaneous rotation vector. The sequence of the great earthquakes in the Sagami and Nankai trough region examined on the basis of the plate motion shows that the co-seismic slip is comparable to the rate of plate motion in this region. This means that the occurrence of great earthquakes in this region can be predicted roughly if the fault displacements are assumed. Strength of the coupling of the oceanic lithosphere with the continental one may have some relation with the evolution of the subduction zone because underthrusting along the Nankai trough began more recently than in other regions such as the Izu—Mariana arc.

As for the southwestern boundary, the slip directions along the east coast of the Philippines and those deduced from the pole of relative motion between the Philippine Sea and Eurasian plates show a discrepancy which suggests that the Phillipines are not a part of the Eurasian plate but a different minor plate. Introducing this minor plate makes it easy to understand the tectonic complexity in the Taiwan—Philippine region. The geometry of the minor plate inferred from the seismicity and topography is more or less speculative at the present stage. More studies, especially focal mechanisms of recent earthquakes and heat flow, are required to refine and correct the present study of the tectonics in this region.

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