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A Strike-Slip Fault System Trending NE in and Around the Northwestern Corner of the West Philippine Basin

Chengsung Wang[1], Aleksandr S. Svarichevsky[2]
Chih-Feng Huang[1] and Shu-Lung Wang[1]

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ABSTRACT

The southwestern part of the Ryukyu arc-trench system to the west of 126°E is obviously bent northwards horizontally. The mechanism of this horizontal bending has been discussed in the literature, but it is still ambiguous. The West Philippine Basin (WPB) is generally believed to be produced by spreading along the Central Basin Ridge (CBR). However, the CBR does not extend to the northwestern corner of the WPB. Previous geomagnetic and geomorphological studies suggested that the CBR terminates or is displaced at its northwestern end. However, the detailed picture is still unclear. In this paper, we have examined bathymetry, gravity and seismicity in and around the northwestern corner of the WPB, and discovered a NE-trending right-handed strike-slip fault system which can be used to interpret the horizontal bending of the southwestern part of the Ryukyu arc-trench system. A plausible model showing how the right-handed fault system results in the bending of the Ryukyu arc-trench system is demonstrated. As the southeastern part of the right-handed strike-slip fault system, the Luzon-Okinawa Fault Zone, which is an obvious fault zone between the Luzon and Okinawa islands, is described in terms of bathymetric contours and profiles along some cruise lines. The Luzon-Okinawa Fault Zone is the main cause of the termination of the CBR.

(Key words: Right-handed strike-slip fault system, Western corner of West Philippine Basin, Ryukyu arc-trench system, Central Basin Ridge, Geophysical Data)

1. INTRODUCTION

The Philippine Sea plate (Figure 1) moves northwestwards in general. It subducts northwestwards along the Ryukyu trench in the north and along the Philippine trench in the west. However, this subduction system is interrupted and there is no active subduction of the same polarity in the Taiwan-Luzon region. Furthermore, the western component of the move-

[1] Institute of Applied Geophysics, National Taiwan Ocean University, Keelung, Taiwan, R.O.C.

[2] Division of Geology and Geophysics, Pacific Oceanological Institute, Russian Academy of Sciences, Vladivostok, Russia

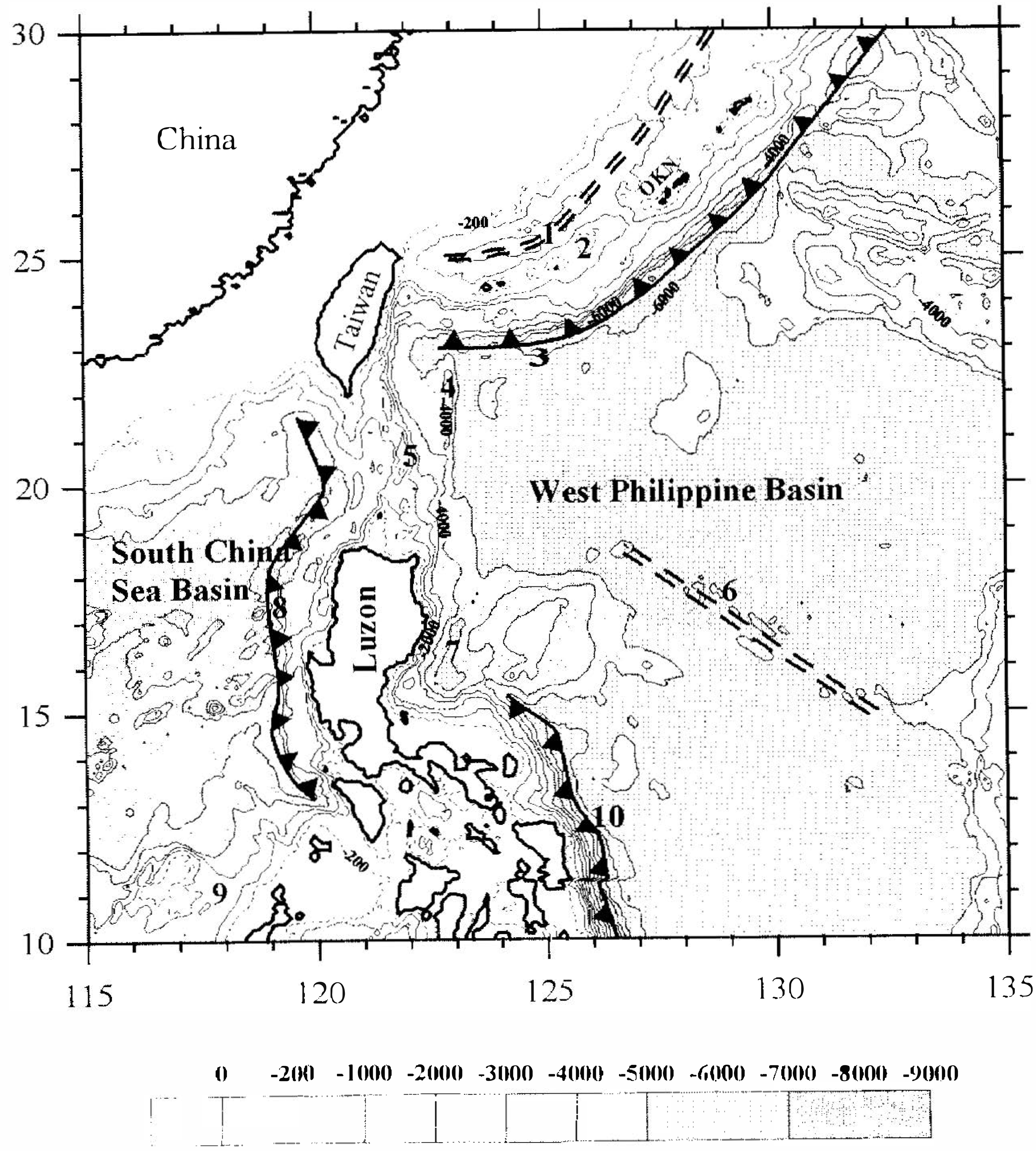

Fig. 1. Bathymetric map of the West Philippine Basin and its surrounding regions. Bathymetric data are ETOPO5 from National Geophysical Data Center (NGDC), with sampling spacing of 5 minutes (1/12 degree). The contour spacing is 1,000 meters. The numbered geological units are: 1. Okinawa trough; 2. Ryukyu arc; 3. Ryukyu trench; 4. Gagua ridge; 5. Luzon arc; 6. Central Basin Ridge of West Philippine Basin; 7. East Luzon Trough; 8. Manila trench; 9. Palawan trough; 10. Philippine trench; OKN: Okinawa island.

ment of the Philippine Sea plate is blocked in the Taiwan region, and on the west side of the West Philippine Basin (WPB) there exists the Manila trench, along which the South China Sea lithosphere subducts eastwards to produce the Luzon arc-trench system. Under such complicated circumstances, the northwestern corner of the WPB, bordered by the Ryukyu island arc, the Taiwan island and the Luzon island arc, is a region which presents interesting structural problems. Among these problems are the mechanism of northward horizontal bending of the southwestern part of the Ryukyu arc-trench system and the ambiguity of northwestern extension of the Central Basin Ridge of the WPB.

The Ryukyu arc-trench system is convex toward the Philippine Sea. It is clear from the bathymetric map (Figure 1) that the southwestern part of the Ryukyu arc-trench system has a noticeably greater curvature than the northeastern part. The change in curvature is evident from about the middle point of the Ryukyu arc-trench system at 126°E. Since the blockage of the westward component of the movement of the Philippine Sea plate near Taiwan changes the direction of this movement from the northwest to the north (Wang, 1982; Wang *et al.*, 1986), it may be considered to be a cause of the bending of the Ryukyu arc-trench system. However, it is likely to be the main cause for the bending, because the scale of the southern part of the Ryukyu arc trench is large, and whether the elasticity of the lithosphere could stand being bent is doubtful. Therefore, the mechanism of the bending still needs to be resolved.

The Central Basin Ridge plays an important role in the evolution of the WPB. It was recognized as a transcurrent fault (Hess, 1948) and / or a seafloor spreading center (e.g., Hilde and Lee, 1984; Shih, 1980). However, how it extends in the northwestern corner of the WPB from 128°E to the Taiwan region is still far from clear. In the literature, different authors have different ideas (e.g., Karig, 1973; Agapova *et al.*, 1980; Lewis and Hayes, 1980; Scheka *et al.*, 1986; Shih, 1980; Hilde and Lee, 1984; Svarichevsky, 1989; Svarichevsky and Wang, 1992). Among them, Hilde and Lee (1984) and Shih (1980) suggested , on the basis of the magnetic lineations, that the northwestern part of the CBR has been displaced along some fractural zones to the Ryukyu trench, and Svarichevsky (1989) and Svarichevsky and Wang (1992) suggested, from geomorphological analysis, that a fractural zone or fault zone trending NE-SW put an end to the CBR at about 126°E.

In order to explain the northward horizontal bending of the southwestern part of the Ryukyu arc-trench system and to understand the behavior of the CBR in the WPB, this paper examines the bathymetry, gravity anomaly and seismicity for related tectonic structures in the northwestern corner of the WPB.

2. LUZON-OKINAWA FAULT ZONE

Figure 2 shows the topography of the northwestern corner of the West Philippine Basin (WPB) and the cruise lines for bathymetric data collection conducted by the Pacific Oceanological Institute of the Far-Eastern Branch of the Russian Academy of Sciences. From the bathymetric data together with seismic profiles, the existence of a thin undeformed sediment layer, with a thickness seldom exceeding 0.1 second in the WPB (Mrozowski and Hayes, 1986), is proved. Although the thickness of the sediment layer increases within the fan of underwater channels near the Luzon island (Karig and Wageman, 1975), the sediment layer is still too thin to significantly change the original topographic shape. Therefore, the sea bottom topography in the WPB can be regarded as having the original tectonic features.

Figures 2 through 4 show several very long narrow ridges and troughs trending NE-SW between 123°E and 127°E, which form a striking fractural zone. This fractural zone coincides in location with a displacement line in the Philippine Sea plate suggested by Hilde and Lee (1984) and Shih (1980) based on the magnetic lineation patterns. From the patterns of the magnetic lineations and the age they represent, and from the relation between the fractural zone and the shape of the Luzon island, the fractural zone is obviously a right-handed strike-slip fault zone. Because it extends from the eastern offshore region of the Luzon island to the

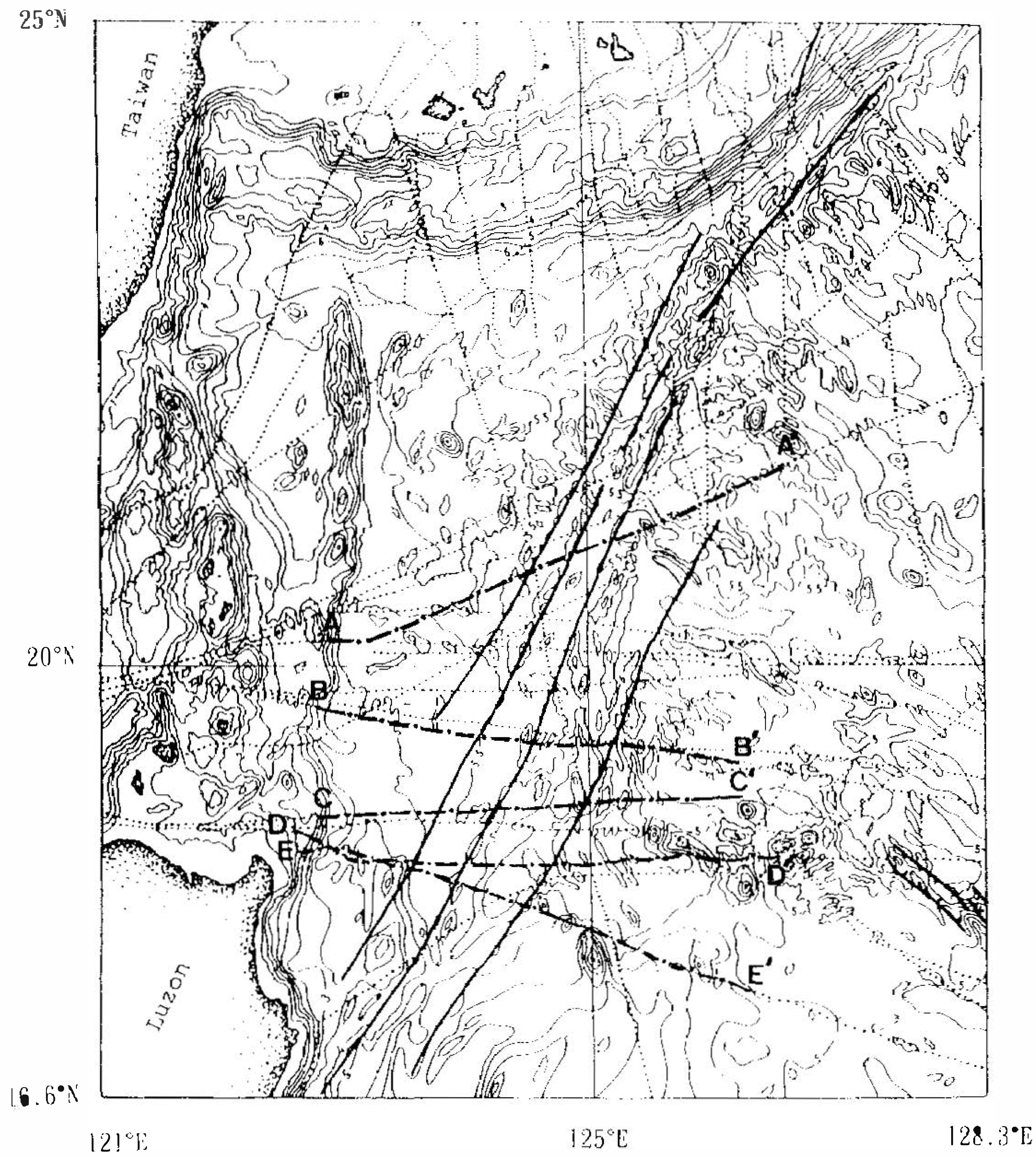

Fig. 2. The topography of the West Philippine Basin. Dotted lines: the cruise lines for bathymetric data collection conducted by Pacific Oceanological Institute, Russian Academy of Sciences; line segments: the rift-like valleys; solid lines: the edges of elongated troughs in the Luzon- Okinawa Fault Zone shown in Figure 3; dashed and dotted lines AA'-EE': cruise lines for bathymetric profiles shown in Figure 3.

western offshore region of the Okinawa island (Figure 4), this fault zone is named the Luzon-Okinawa Fault Zone.

The bottom of the troughs in the Luzon-Okinawa Fault Zone are situated at depths of 5500-6000 m, and the accompanied ridges are mostly less than 1000 m in height above the troughs (Figure 3). In the fault zone, there are separated mountains which rise 2500-4000 m above the sea floor. In general, the width of this fault zone reaches 100 km. This fault zone includes the East Luzon Trough as well as the arcs in the Sierra Madre Basin on the Luzon island (Karig, 1975; Lewis and Hayes, 1983), and extends northeastwards at least up to the axis of the Ryukyu trench. However, this fault zone may extend further at both ends. For example, on the Luzon island and in the South China Sea, the large Palawan-Macolod lineament (Alkaras, 1968; Wolfe and Self, 1983; Kulinich *et al.*, 1989) which is situated to the southwest of the East Luzon Trough, may be the southwestern extension of the Luzon-Okinawa Fault Zone.

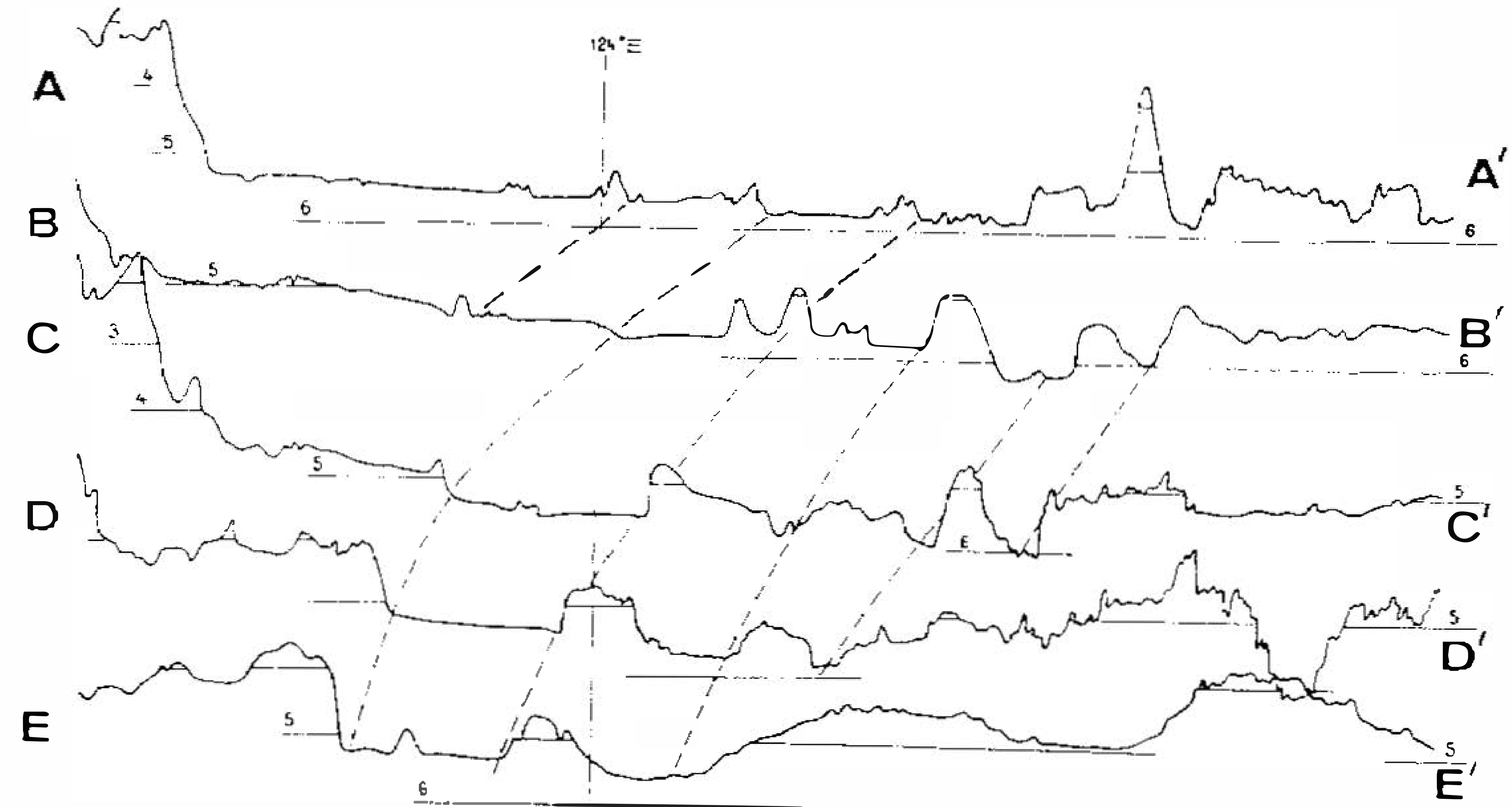

Fig. 3. The topographic profiles AA'-EE' crossing the Luzon-Okinawa Fault Zone along the cruise lines AA'-EE' in Figure 2. Dash lines indicating the edges of the elongated troughs; the numbers represent the depths of sea-floor in unit of 1000 meters.

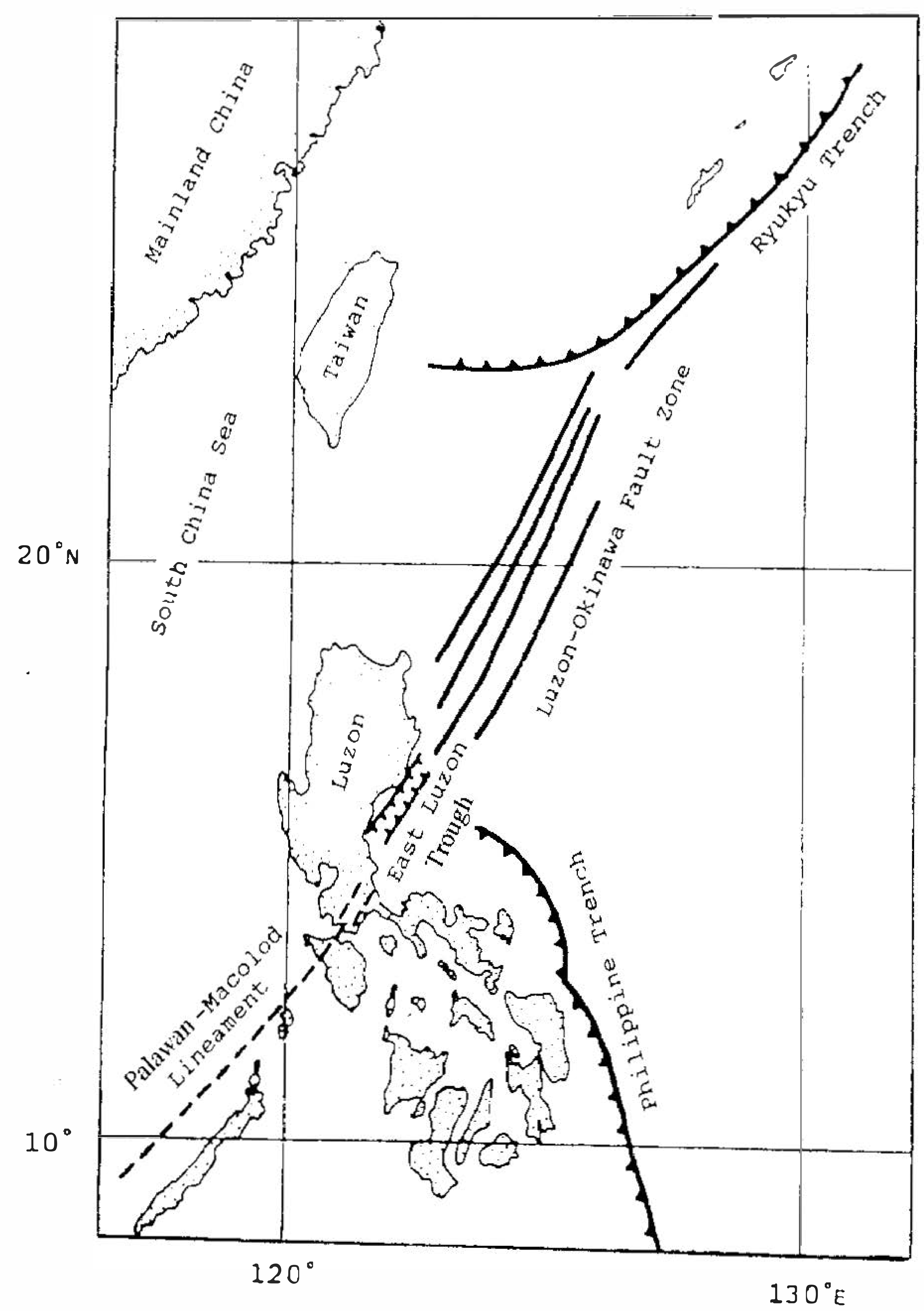

Fig. 4. Possible extensions of the Luzon-Okinawa Fault Zone. The solid lines indicate the edges of the elongated troughs shown in Figure 3.

How the Luzon-Okinawa Fault Zone extends northeastwards is still not clear. From the topography of the sea floor (Figure 2), it can be seen that part of the fault zone and the axis of the Ryukyu trench are on a straight line. Thus, part of the fault zone may extend northeastwards along the axis of the Ryukyu trench. However, from the bathymetric topography of the Ryukyu arc (Figures 1 and 2), we can see that there is a cusp in the shape of the Ryukyu trench at 126^{0}E, and the Ryukyu arc-trench system has a sharp turn there. This suggests that part of the Luzon-Okinawa Fault Zone may extend northeastwards and submerge beneath the Ryukyu subduction zone. In this way, the Ryukyu arc is divided into two parts, the northeastern Ryukyu arc and the southwestern Ryukyu arc. The northeastern Ryukyu arc is composed of a large volcanic chain as the inner arc and the highly-lifted folded frontal blocks as the outer arc , while the southwestern Ryukyu arc has an apparent non-volcanic outer arc, with the volcanic inner arc still being vigorously formed in the center of the southwestern part of the Okinawa trough (e.g., Wang and Hilde, 1973). Kao and Chen (1991) analyzed the focal mechanisms of the earthquakes and found that the stress pattern in the subducting lithosphere of the Philippine Sea plate beneath the northeastern Ryukyu arc is different from that beneath the southwestern Ryukyu arc.

From the location of the NE-trending Luzon-Okinawa Fault Zone and the NW-trending Central Basin Ridge, it is obvious that the Luzon-Okinawa Fault Zone is the main cause of the termination or displacement of the Central Basin Ridge at its northwestern end.

3. CENTRAL TAIWAN NE-SW FAULT ZONE

The frequent earthquakes in the Taiwan region (Figure 5) are generally believed to be the result of the complicated and intense interaction between the Eurasian and Philippine Sea plates. In Figure 5, it is known that the earthquakes in the northeastern Taiwan region are associated with the northward subduction of the Philippine Sea plate beneath the Ryukyu arc and northeastern Taiwan (e.g., Tsai *et al.*, 1977; Tsai *et al.*, 1981; Wang *et al.*, 1994) while the earthquakes to the south of 23^{0}N are associated with the eastward subduction of the South China Sea lithosphere along the Manila Trench (e.g., Tsai,1986). However, in southern Taiwan there exists a seismic zone (its boundaries are shown in Figure 5 by dashed lines) between these two subduction systems. This seismic zone runs in the NE-SW direction. It can be easily recognized by the contrast of the epicenter density in southwestern Taiwan, and its northern boundary is particularly clear. It has a width of about 50 km. Although the seismicity in the Taiwan region is very uneven due to the complicated tectonic structure and plate interaction, it can still be seen that the two boundaries of this seismic zone (the dashed lines in Figure 5) extend from the southwestern offshore area of Taiwan to the northeastern offshore area. These boundary lines go across the seismic belts along the northeastern coast line of Taiwan, the fore-arc basin in the Ryukyu arc-trench system near Taiwan, and the center of the Okinawa trough (the back-arc basin).

Figure 6 shows the NS-directional hypocentral profiles of the Taiwan region. The northern and southern boundaries of the NE-SW trending seismic zone in southern Taiwan and their extension to the northeastern area of Taiwan (indicated by dashed lines in Figure 5) are shown on the hypocentral profiles by the inverted triangles. To the west of 121.5^{0}E (profiles 1

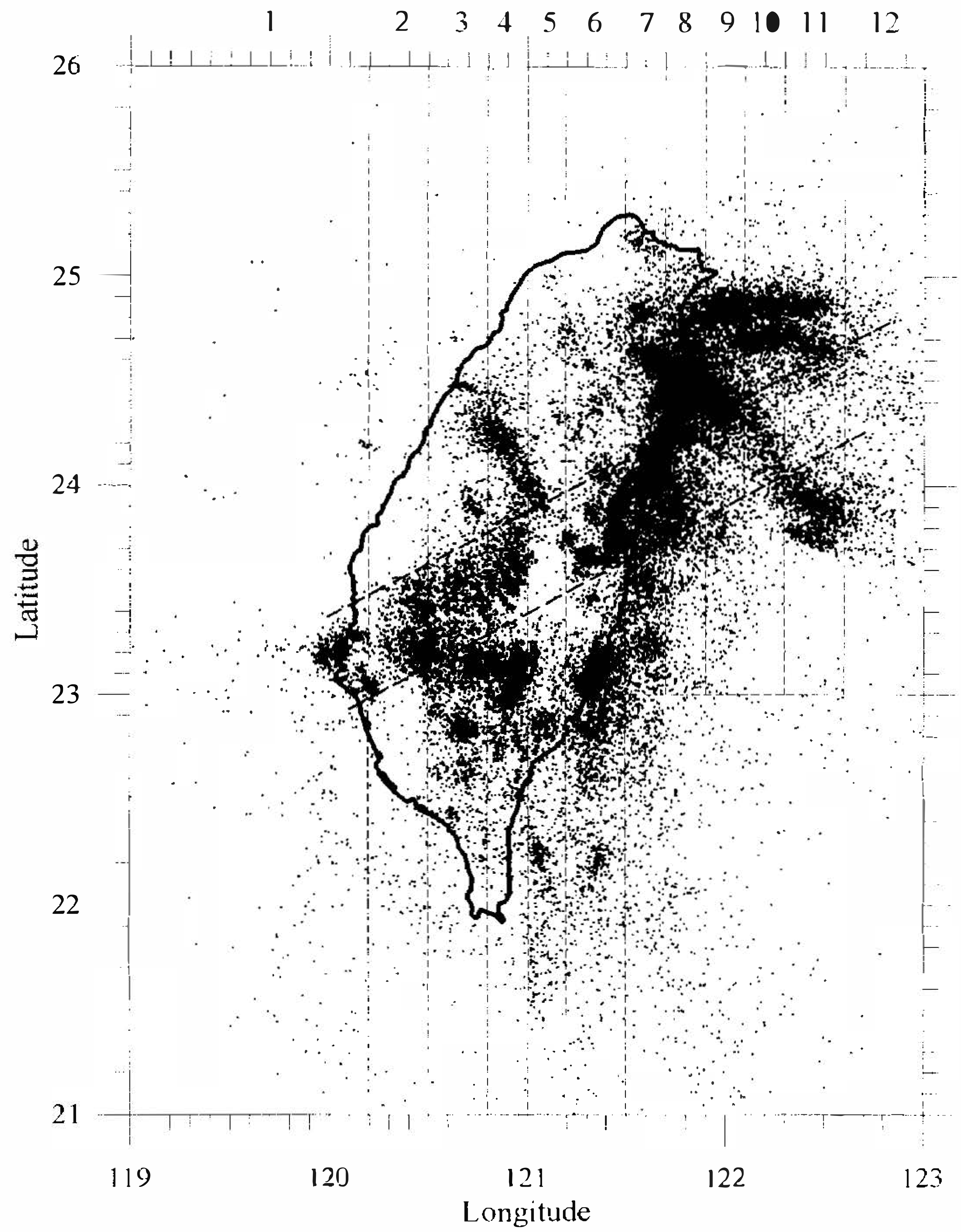

Fig. 5. Seismicity map of Taiwan. The earthquakes were recorded and determined during 1991-1995 by CWBSN (Central Weather Bureau of Seismographic Network) operated by Seismological Observation Center, Central Weather Bureau, Ministry of Transportation, ROC. The boundaries of the Central Taiwan NE-SW Fault Zone are indicated by the dashed lines.

through 6), most profiles show clear boundaries for the NE-trending seimic zone. To the east of 121.5^{0}E (profiles 7 through 12), although the hypocentral distribution is complicated by the existence of a Benioff zone dipping to the north, the extended boundaries can still be correlated to the pecularities of the hypocentral distribution.

The southwestern extension of the NE-trending seismic zone in southern Taiwan to the southwestern offshore area of Taiwan and the northern South China Sea basin is a linear gravity anomaly (Hsu and Sibuet, 1995; Hsu *et al.*, 1995). The Tsen-Wen Hsi (曾文溪), a major river in southwestern Taiwan, runs along the center of the seismic zone, and Coral Lake (珊瑚潭) and Tsen-Wen Water Reservoir (曾文水庫) also lie on this center. Besides, the rivers in southwestern Taiwan run in the NE-SW direction, which is parallel to the trend of the seismic

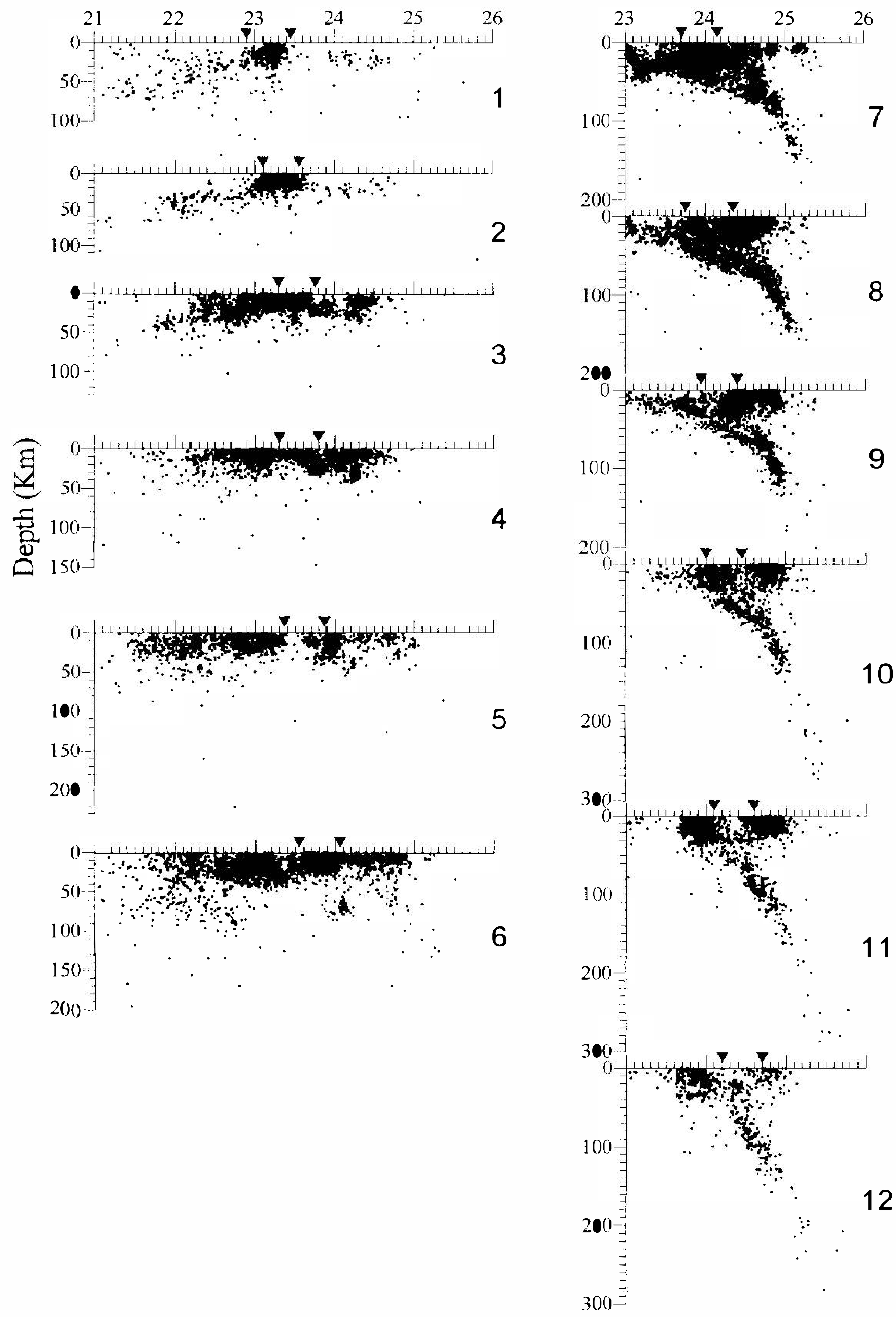

Fig. 6. Hypocentral profiles along the NS-directional zones indicated by the dashed lines in Figure 5. The numbers above the profiles are latitudes.

zone. Therefore, we recognize the NE-trending seismic zone as a fault zone. We refer to this seismic zone and its northeastern extension as the Central Taiwan NE-SW Fault Zone. According to the fault plane solutions in the literature (e.g., Chang and Shin, 1994; Jiang, 1994; Shin *et al.*, 1994), the faults in the Taiwan Fault zone are right-handed, like those in the Luzon-Okinawa Fault zone.

In Figure 5, we can see that along the fore-arc basin of the Ryukyu arc-trench system in the northeastern offshore region of Taiwan, there is an obvious earthquake belt. This belt bends northwards obviously when it intersects with the Central Taiwan NE-SW Fault Zone.

Figure 7 is a sketch showing how the bending of this seismic belt is made possibly by successive slips in the fault zone. We believe that successive slips in some fault zones are the main mechanism of the bending of the Ryukyu arc-trench system.

4. NE-TRENDING FAULT SYSTEM IN WPB

Here we consider a NE-trending right-handed strike-slip fault system in the northwestern corner of the West Philippine Basin (WPB) and the surrounding areas, such as the Ryukyu arc, the Taiwan island and the Luzon arc. Because the plate tectonics is very complicated in this region, the fault systems are also very complicated. To simplify the discussion, faults not striking NE are neglected. The Central Taiwan NE-SW Fault Zone is considered to be a northwestern part of the NE-trending fault system, and the Luzon-Okinawa Fault Zone a southeastern part. Figure 8 shows the shaded topography in the Taiwan region. From the shaded topography, we can see some clear NE-trending depressional structural lineaments. If we trace these NE-trending structural lineaments (the solid line segments in Figure 9), and then draw some straight lines following the tendency of these lineaments (dashed lines in Figure 9), then the straight lines show the approximate locations of some major faults. It is very interesting to see that the boundary lines of the NE-trending seismic zone in southern Taiwan, and their northeastern extensions mentioned in the last section, are among these straight lines. These major faults extend northeastwards across the Ryukyu arc-trench system, and southwestwards across the Taiwan island and the Luzon arc.

It can be seen in Figures 1, 2, 4 amd 5 that the bending of the Ryukyu arc-trench is most obvious between the Central Taiwan NE-SW Fault Zone and the Luzon-Okinawa Fault Zone.

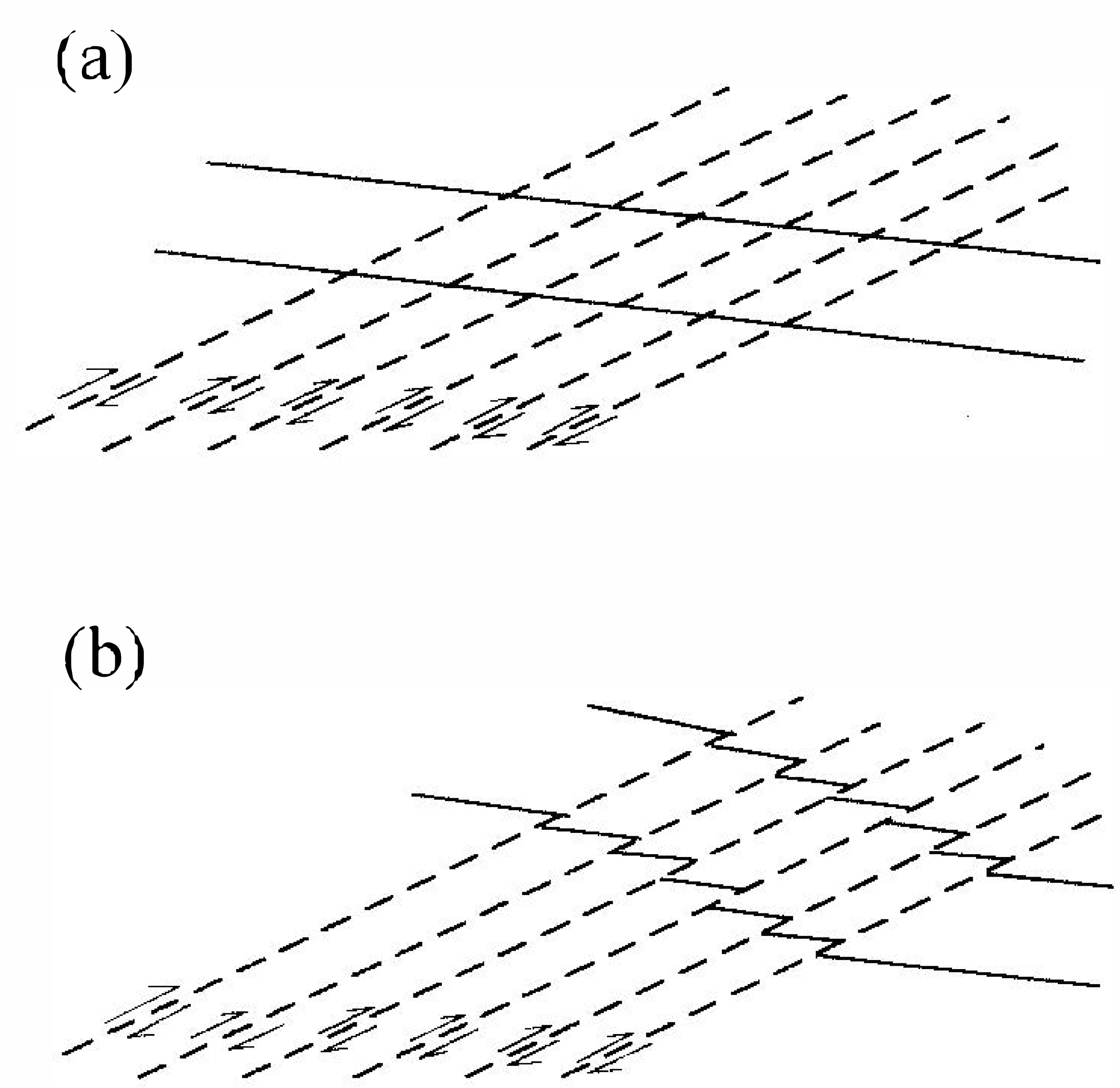

Fig. 7. A sketch showing how the bending of the seismic belt along the fore-arc basin of the Ryukyu arc-trench system is possibly bent by the Central Taiwan NE-SW Fault Zone. (a) seismic belt along the fore-arc basin in the Ryukyu arc-trench system before the bending; (b) the same seismic belt after the bending.

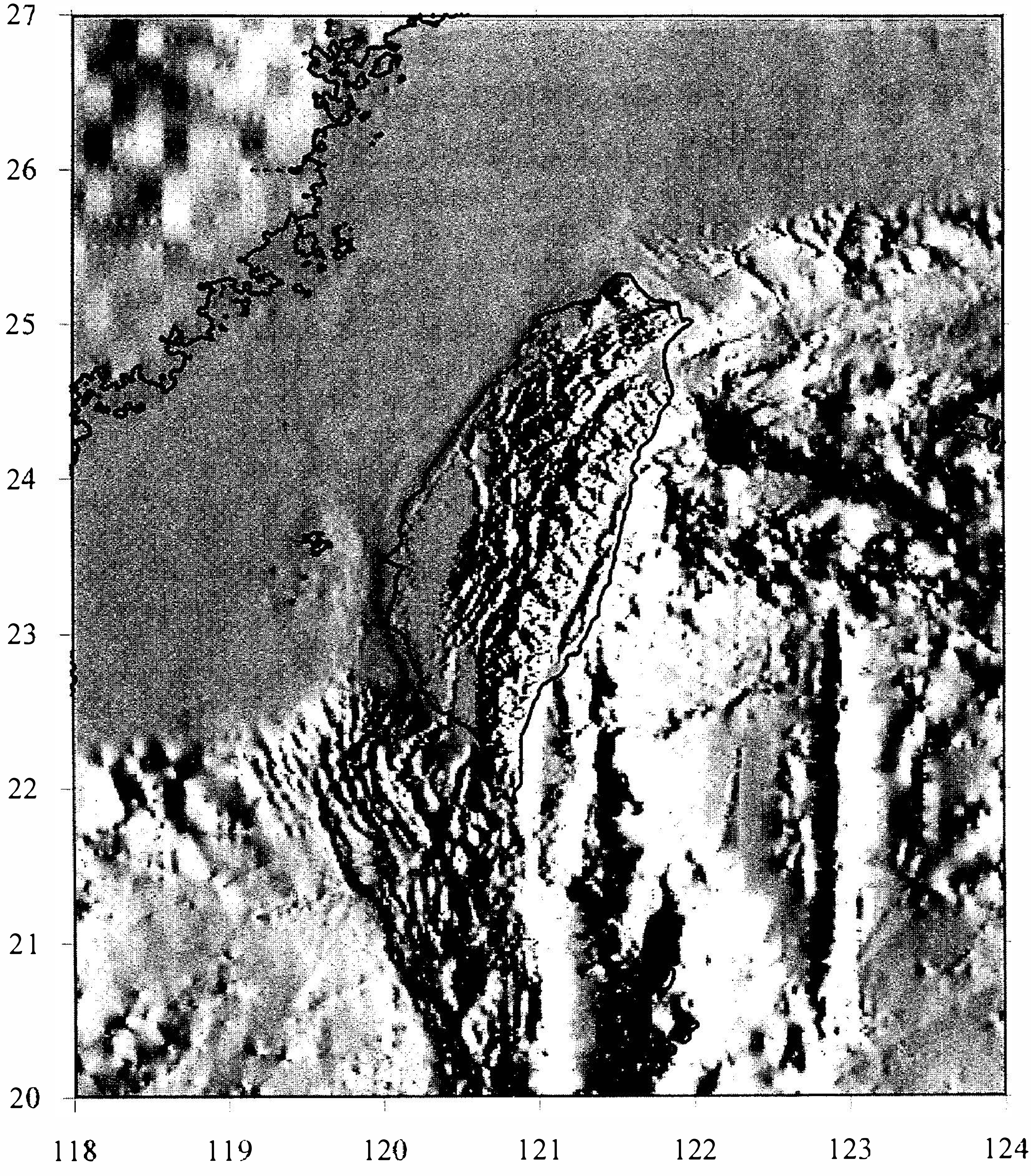

Fig. 8. Shaded topographic relief map of the Taiwan region, compiled by Institute of Oceanography, National Taiwan University from cruises of different research projects conducted mainly by *R/V Researcher I*. Data are provided by Professor C. S. Liu of National Taiwan University.

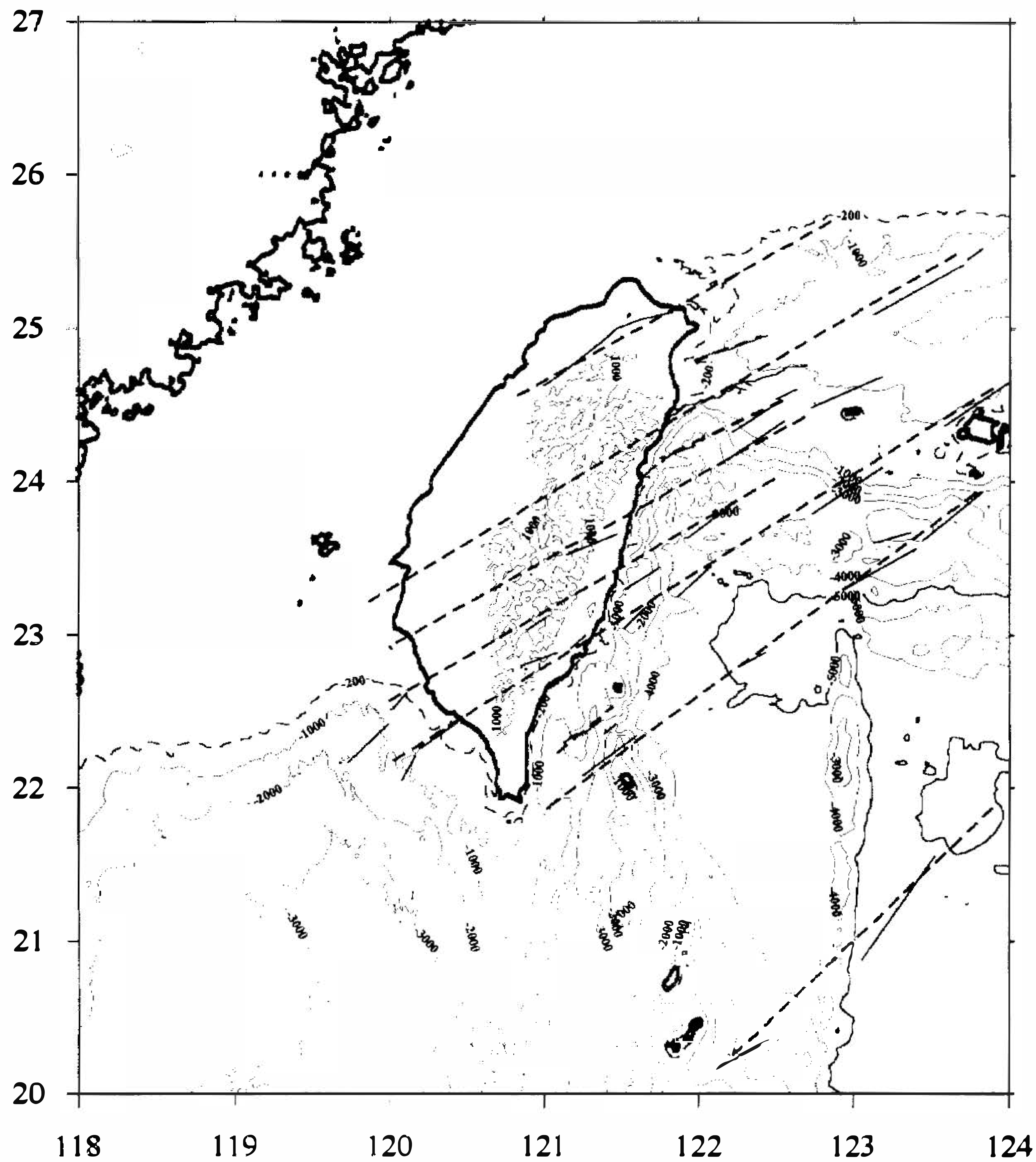

Fig. 9. The NE-trending depressional structural line segments (solid lines on or near the dashed lines, traced from the shaded topography in Figure 8) and the approximate location of some major faults (indicated by the dashed lines). See text for description.

If we put all the major NE-trending faults in the Taiwan region (shown in Figure 9) and those in the Luzon-Okinawa Fault Zone (shown in Figure 4)together, then a NE-trending right-handed strike-slip fault system is formed. Figure 10 shows the location of these major faults of the NE-trending fault system against the background of the shaded topography of the north-western corner of the WPB and its surrounding areas. It is interesting to note that these major faults match the shaded topography very well. From the shaded topography, we can see that the set of major faults in the NE-trending fault system, as indicated by dashed lines in Figure 10, is not complete. In other words, there exist further major faults which have yet to be picked out, especially in the Luzon-Gagua ridge area.

Figure 11 shows the locations of the major faults of the NE-trending fault system against the background of the free-air gravity anomaly in the northwestern corner of the WPB and its

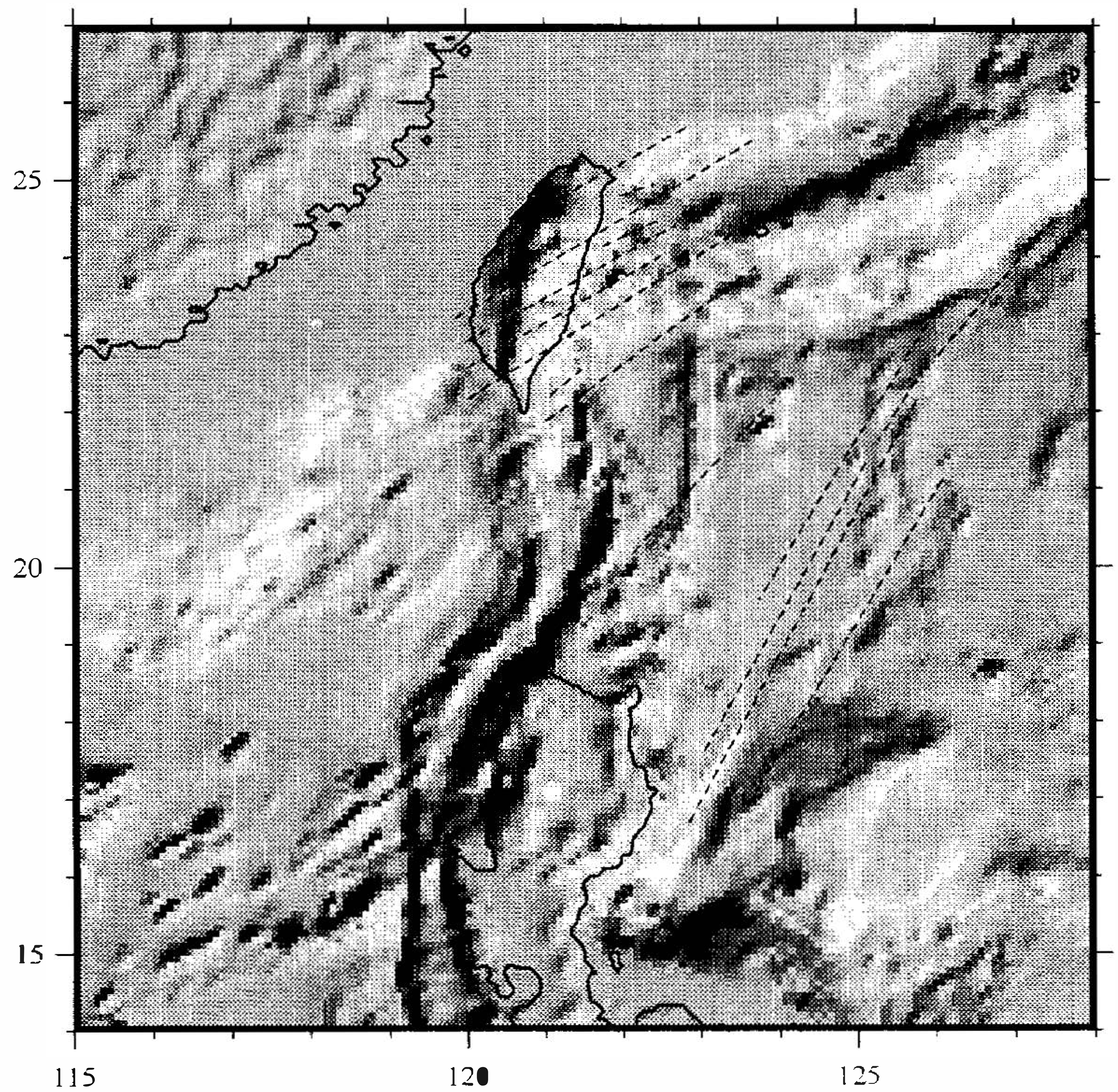

Fig. 10. The approximate location of some major faults in the NE-trending fault system against the bathymetric background of the northwestern corner of the West Philippine Basin and its surrounding regions. Bathymetric data are ETOPO5 from NGDC.

surrounding areas. Some major faults fit the pattern of the gravity anomaly well. In the Luzon-Okinawa Fault Zone, there is a linear negative anomaly. A major fault to the north of the Luzon island coincides with the deformation of the Manila trench. In the southwestern off-shore area of Taiwan, there are some linear gravity anomalies, which coincide with the trend of the NE-trending faults in the Taiwan area.

From the topography shown in Figure 10, it is clear that the northwestward extension of the Central Basin Ridge (CBR) is truncated by the Luzon-Okinawa Fault Zone. Therefore, the Luzon-Okinawa Fault Zone is the main cause of the termination or displacement of the CBR. From the Luzon-Okinawa Fault zone to the Taiwan area, the trends of the major faults gradually change from NE to NEE. It is clearly related to the northward horizontal bending of southwestern part of the Ryukyu arc-trench system (Figures 9, 10 and 11). Therefore, the NE-trending right-handed strike-slip fault system is the main cause of this horizontal bending.

5. CONCLUSIONS

Base on the bathymetric, gravity and seismicity data, we have discovered a NE-trending right-handed fault system in the northwestern corner of the West Philippine Basin and its

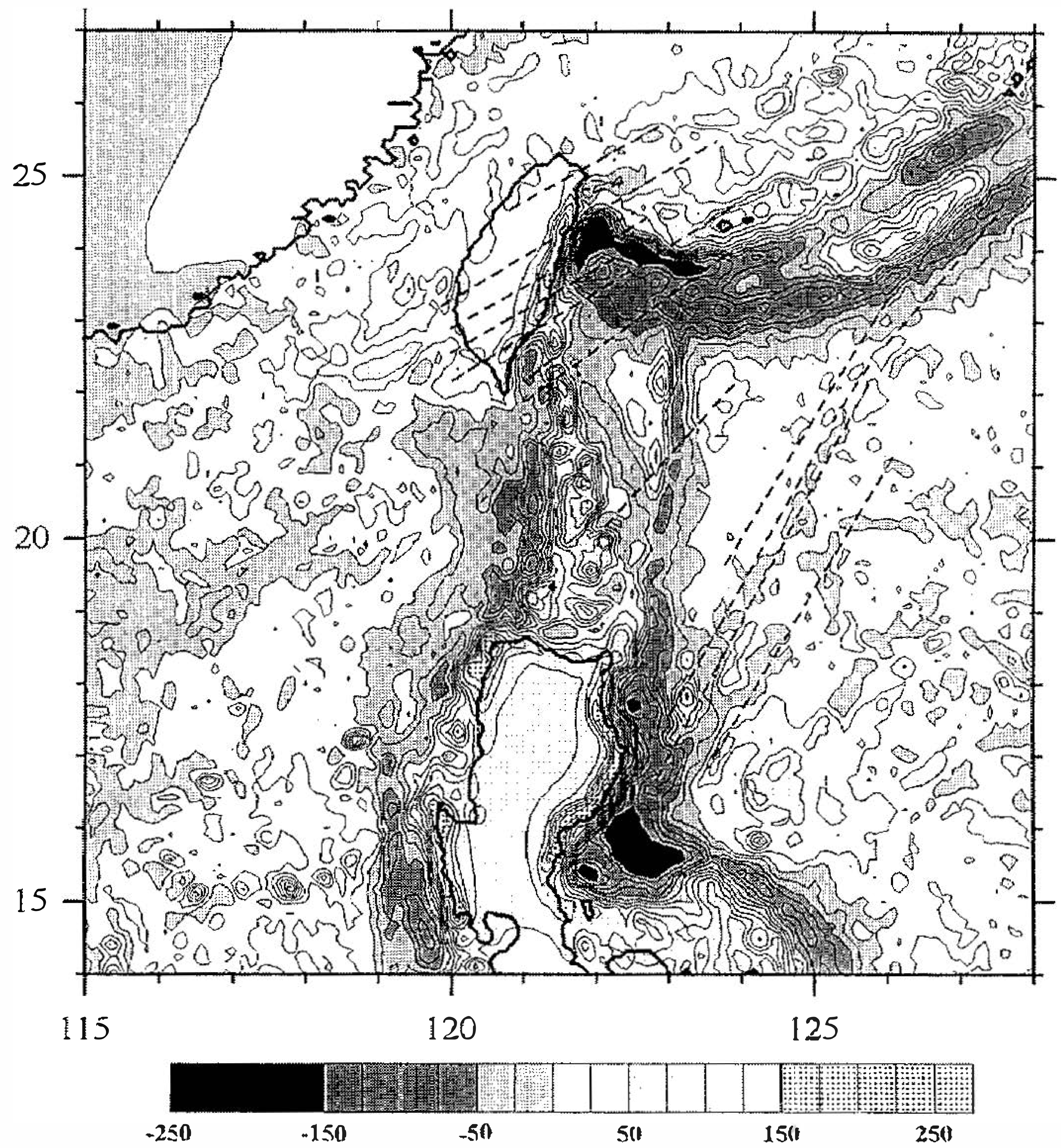

Fig. 11. The approximate location of some major faults in the NE-trending fault system against the background of free-air gravity anomalies in the northwestern corner of the West Philippine Basin and its surrounding regions. The gravity anomaly data are reduced from satellite altimetry. The data are released by Sandwell and Smith (1995), and have sampling spacing of 3 minutes (0.05 degree). The contour spacing of the figure is 50 mgal.

surrounding areas, including the Ryukyu arc-trench system, the Taiwan island and the Luzon arc-trench system. This fault system includes the Central Taiwan NE-SW Fault Zone, the Luzon-Okinawa Fault Zone, and a series of approximately parallel major faults in this region . This fault system is the main cause of the northward bending of the southwestern part of the Ryukyu arc-trench system. It is also the main cause of termination or displacement of the Central Basin Ridge of the West Philippine Basin at its northwestern end.

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