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CHARACTERISTIC FEATURES OF FOCAL MECHANISM IN AND NEAR KYUSHU ISLAND (1)

By

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Abstract

The focal mechanisms of earthquakes which occurred in and near Kyushu Island were examined. As a result four seismic zones can be identified and each is characterized by the particularity of focal mechanisms. For the earthquakes which occurred in the western area of the Seto Inland Sea, that is, in the eastern sea region of Kyushu Island, the focal mechanisms could be analyzed in detail because they show a particular feature in comparison with the mechanisms of earthquakes in other seismic zones and are favoured by a good arrangement of observational stations. It may be suggested that the seismicity and the stress distribution do not necessarily enforce the recent hypothesis acknowledged as the plate tectonics.

1. Introduction

Kyushu Island, including its surrounding area, is one of the tectonically active regions in Japan. Earthquakes which occurred in this region were studied for the first time by Tani (1937), who pointed out some characteristic features on the basis of data from the Wiechert seismograms which were recorded at the Beppu Laboratory and the Aso Volcanological Laboratory of Kyoto University. For instance, he suggested that a fracture zone extending from northeast to southwest in the Bungo Channel could explain the features of the seismograms of earthquakes which occurred in the eastern sea off Kyushu Island, and moreover found several earthquakes of which the foci were fairly deep below Kyushu Island, that is, the so-called intermediate earthquakes. His interesting conclusion, however, were not developed until the geophysical ideas relating the characteristic features of stress distribution to the tectonical processes in focal regions were evolved. Since than a great deal of geophysical information has been accumulated and they help to enable us to study the characteristic features.

Recently the characteristic features of focal mechanisms in and near Kyushu Island have been studied by Ichikawa (1967, 1971) as a part of his research on focal mechanisms in Japan and its surrounding area. It still seems significant to reexamine the data, including additional data, to elucidate the tectonical processes in the region.

2. Determination of focal mechanisms

To determine focal mechanisms, generally speaking, the increase of accuracy in phase identification and the favourable arrangement of observational stations are indispensable. In this paper the determination of focal mechanisms was based on data reported in the Bulletins of the Japan Meteorological Agency (JMA), and data from the seismograms recorded at the Aso Volcanological Laboratory of Kyoto University

Table 1. List of earthquakes of which the mechanisms were determined

Seismic zone	No.	Date and origin time				Epicenter		H	M
			h	m	s	λ	φ	km	
	(1)	1968 Aug. 6	1	17	6.0	132°23′	33°18′	40	6.6
	(2)	1969 Nov. 30	1	43	16.1	132°24′	33°20′	40	5.1
	(3)	1968 Aug. 6	5	51	20.7	132°24′	33°22′	40	4.8
	(4)	1968 Aug. 6	11	34	39.0	132°24′	33°20′	40	
Western area of the Seto Inland Sea	(5)	1968 Aug. 6	13	21	3.4	132°27′	33°20′	40	5.3
	(6)	1969 Nov. 30	13	12	21.5	132°24′	33°15′	40	5.1
	(7)	1968 Jan. 12	11	58	35.1	132°30′	33°30′	50	4.8
	(8)	1964 Nov. 4	12	56	6.4	132° 7′	33°26′	60	5.8
	(9)	1969 Feb. 28	6	5	46.7	132° 5′	33°38′	70	
	(10)	1971 Oct. 19	0	23	22.5	132° 7′	33°28′	70	
	(11)	1971 Oct. 11	20	28	47.3	131°56′	33°44′	70	
	(12)	1969 Sept. 7	9	23	45.5	131°48′	33°37′	100	
	(1)	1970 July 26	7	41	8.3	132° 2′	32° 4′	10	6.7
	(2)	1970 July 26	16	10	33.4	132° 6′	32° 7′	10	6.1
	(3)	1969 Apr. 21	16	19	24.5	132° 7′	32° 9′	10	6.5
Hyuga Sea	(4)	1963 Oct. 4	8	24	31.0	132° 9′	31°53′	20	6.3
	(5)	1968 Apr. 1	9	42	1.5	132°32′	32°17′	30	7.5
	(6)	1961 Feb. 27	3	10	48.1	131°51′	31°56′	40	7.0
	(7)	1971 Feb. 3	3	14	52.8	131°57′	31°39′	50	4.9
	(1)	1965 Dec. 8	14	25	12.2	130°36′	32°33′	20	4.8
	(2)	1967 Oct. 1	19	10	16.4	130°26′	33° 6′	20	3.3
	(3)	1968 May 4	7	44	46.2	130°51′	32°48′	0	3.6
	(4)	1968 Aug. 13	21	39	18.9	130° 4′	32°42′	0	4.6
	(5)	1969 Jan. 8	18	36	19.2	130°18′	32°58′	20	3.8
	(6)	1969 Feb. 5	15	9	15.8	130°14′	33° 0′	10	4.2
Western area of the Kyushu Island	(7)	1970 Jan. 18	12	21	22.2	130°15′	32°57′	20	4.1
	(8)	1970 July 10	9	13	27.6	130°11′	32°44′	10	4.4
	(9)	1970 Aug. 9	6	55	46.3	130°49′	32°43′	10	4.5
	(10)	1970 Aug. 9	15	12	40.1	130°52′	32°45′	10	4.1
	(11)	1970 Aug. 9	15	25	2.4	130°50′	32°44′	10	4.1
	(12)	1970 Aug. 9	19	1	5.5	130°52′	32°47′	10	3.8
	(13)	1971 Mar. 7	7	14	49.0	130°26′	33°27′	20	4.1
	(14)	1971 Nov. 7	3	15	24.8	129°44′	32°27′	10	4.3
	(15)	1972 Jan. 12	23	22	10.1	131°11′	33° 3′	10	4.1
	(1)*	1969 Sept. 7	9	23	45.5	131°48′	33°37′	100	
	(2)	1967 July 7	8	15	58.0	131°10′	32°35′	150	
Intermediate earthquakes	(3)	1962 Apr. 23	4	15	32.0	130°54′	32°10′	160	
	(4)	1967 Nov. 28	11	36	54.7	130°57′	32° 5′	130	
	(5)	1963 Jan. 9	0	46	44.2	130°32′	31°11′	160	
	(6)	1964 Aug. 6	11	33	35.7	130°16′	30°53′	160	

*The same event as (12) in the western area of the Seto Inland Sea.

were added to them. All these data were plotted on the upper hemisphere of Schmidt's net and a pair of nodal lines were drawn on it. It seems, however, that the mechanisms determined are not so accurate as to tolerate rigorous discussion, because some of the initial phases could not be identified very decisively and the number of data points is not great enough to calculate exact fault plane solutions. Thus the number of earthquakes of which the focal mechanisms were determined amounts to 39 and they are listed in Table 1.

Fig. 1 shows the epicentral distribution of earthquakes which occurred during the period from 1961 to 1972. It can be said, as shown in the figure, that an aseismic zone in the western area of Shikoku Inland allows us to distinguish Kyushu Island with its surrounding area from the adjacent regions. Moreover the following four seismic zones can be identified in the region, as found from the distributional pattern of epicenters: (1) the western area of the Seto Inland Sea, (2) the Hyuga Sea and (3) the western area of Kyushu Island. In addition the intermediate earthquakes (H≥ 100 km), occurring along a line which underlies Kyushu Island nearly in a NS direction, should be considered to form another seismic zone. These seismic zones are illustrated in Fig. 1. Of course the definition of the seismic zones is tentative and might be altered with the progress of the study. The mechanisms determined in each seismic zone will be shown in the following figures.

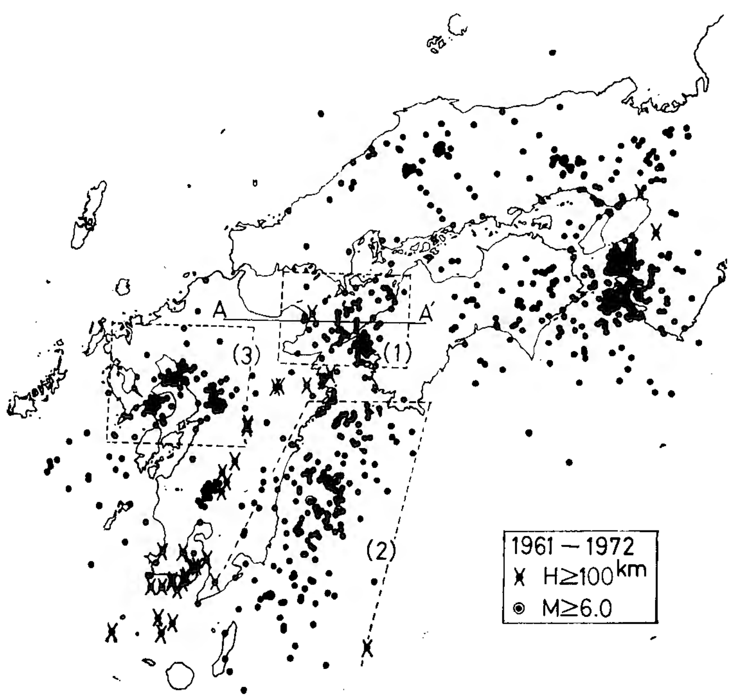

Fig. 1. Epicentral distribution of earthquakes.

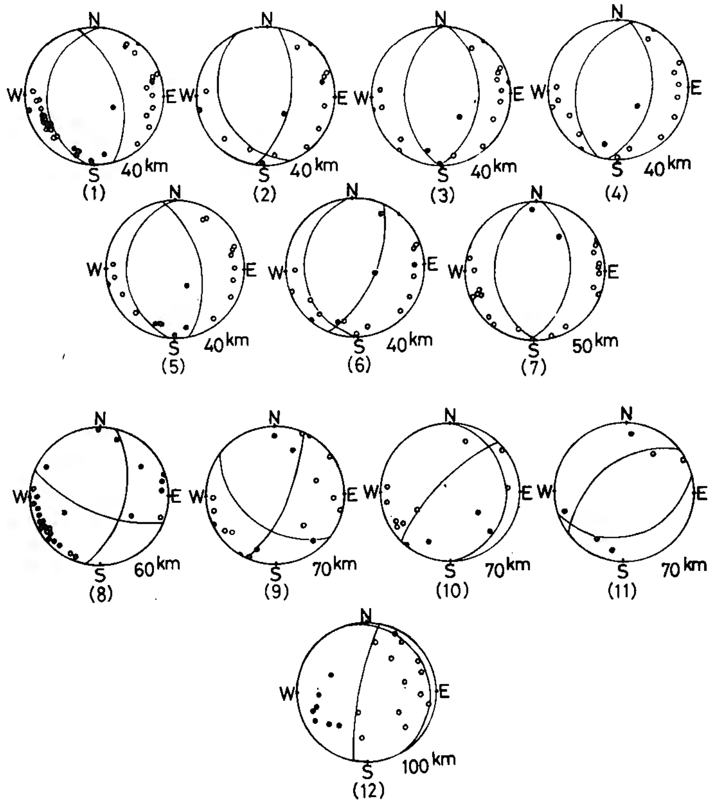

Fig. 2. Focal mechanism in the western area of the Seto Inland Sea. Compression and dilatation of P wave are represented by solid and open circles, respectively.

In Fig. 2 are shown the focal mechanisms in the western area of the Seto Inland Sea. As shown in this figure, it is indicated that for the focal mechanisms of events within the depth of 50 km, almost all their tension axes are directed nearly horizontally EW, in other words, the normal fault type of mechanism predominates. In the case of the focal depths beyond 50 km, however, the similarity among the focal mechanisms is not clear, though any common mechanism cannot always be found. When the focal mechanisms of events located beyond the depth of 50 km were examined one by one, it was found that the focal mechanism of the deepest event (H=100 km), which is represented by (12) of Fig. 2, is similar to the mechanisms of intermediate earthquakes which occurred below Kyushu Island. The relation between the focal mechanisms and the depth is schematically illustrated in Fig. 3, which also shows the spatial distribution of foci in the western area of the Seto Inland Sea. As shown in the figure, it should be noted that the focal depths are increased systematically from east to west. The trend of the spatial distribution of foci will be examined in relation to the plate tectonics hypothesis.

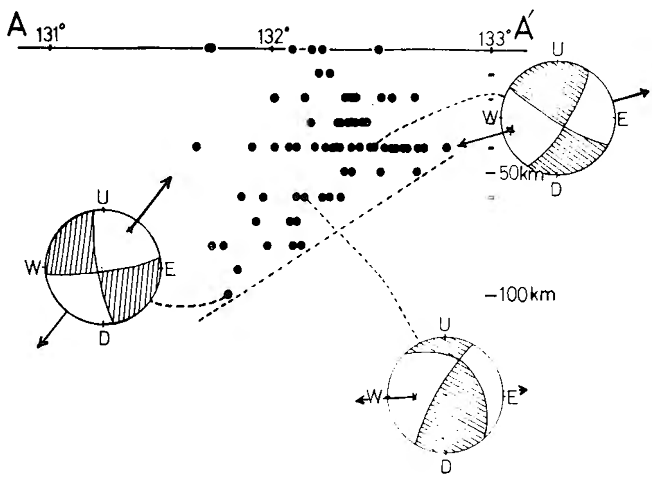

Fig. 3. Relation between the mechanism and the depth and the spatial distribution of foci, projected on the vertical plane indicated by AA′ in Fig. 1.

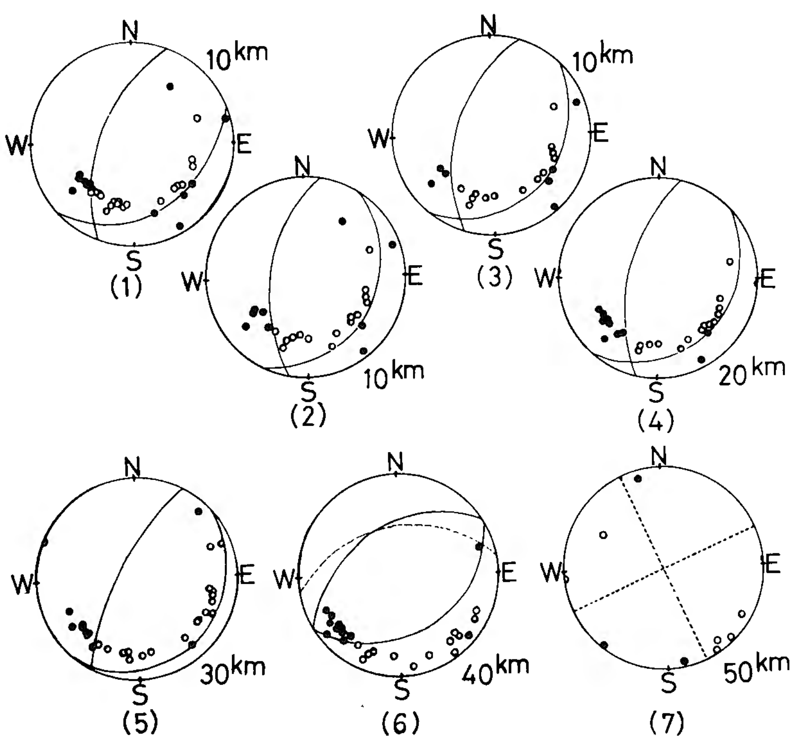

Fig. 4. Focal mechanism in the Hyuga Sea.

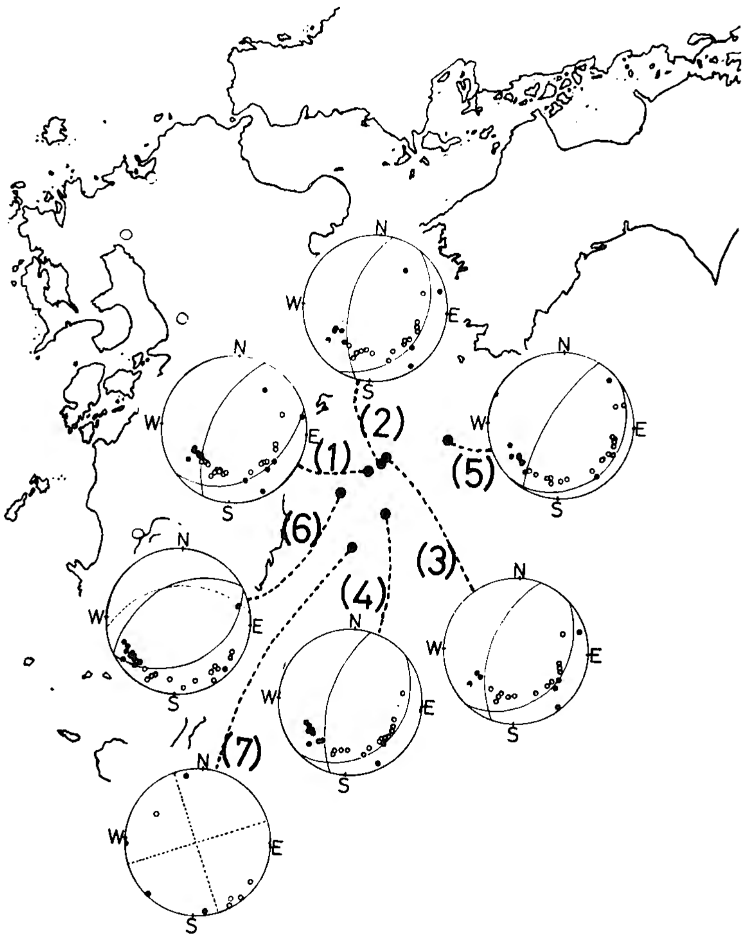

Fig. 5. Epicentral distribution of the events shown in Fig. 4.

The focal mechanisms of earthquakes in the Hyuga Sea are shown in Fig. 4 and on a topographical map in Fig. 5. This region is considered as a highly seismic zone, as seen from Fig. 1, but the focal mechanisms cannot be analyzed in detail because the arrangement of observational stations is unfavourable. And then the large events ($M \geq 6$) were picked up, for which the data from a number of distant stations are available. As shown in Fig. 4, it is indicated that the focal mechanisms of relatively shallow events are mutually similar and exhibit the reverse fault type. On the other hand, it seems that the focal mechanisms of deeper events are not necessarily the same as those of relatively shallow events, though the number of mechanisms determined is not enough to draw a decisive conclusion.

For the earthquakes in the western area of Kyushu Island, the number of data points was so small that we could not determine the focal mechanisms with the aid of

Fig. 6. Direction of the compression axes in the western area of Kyushu Island.

Schmidt's net. The data were plotted on a topographical map and, on the assumption that both the 'ension and the compression axes are directed horizontally, a pair of nodal lines were drawn and thus the compression axes were derived. Fig. 6 shows the distribution of compression axes derived as above mentioned. This figure indicates that the compression axes are directed either EW or NE-SW. The stress state might be referred to the tectonical structure in the western area of Kyushu Island, that is, the so-called triangular area.

The intermediate earthquakes which occurred below Kyushu Island were considered to form another seismic zone and the focal mechanisms are shown in Fig. 7. As seen from the figure, it is indicated that almost all the mechanisms of intermediate earthquakes are characterized by a nearly vertical nodal plane. And it should be noted, as mentioned before, that the deepest event in the western area of the Seto Inland Sea, which is represented by (12) of Fig. 2 and by (10) of Fig. 7, bears the similarity in focal mechanism to the intermediate earthquakes.

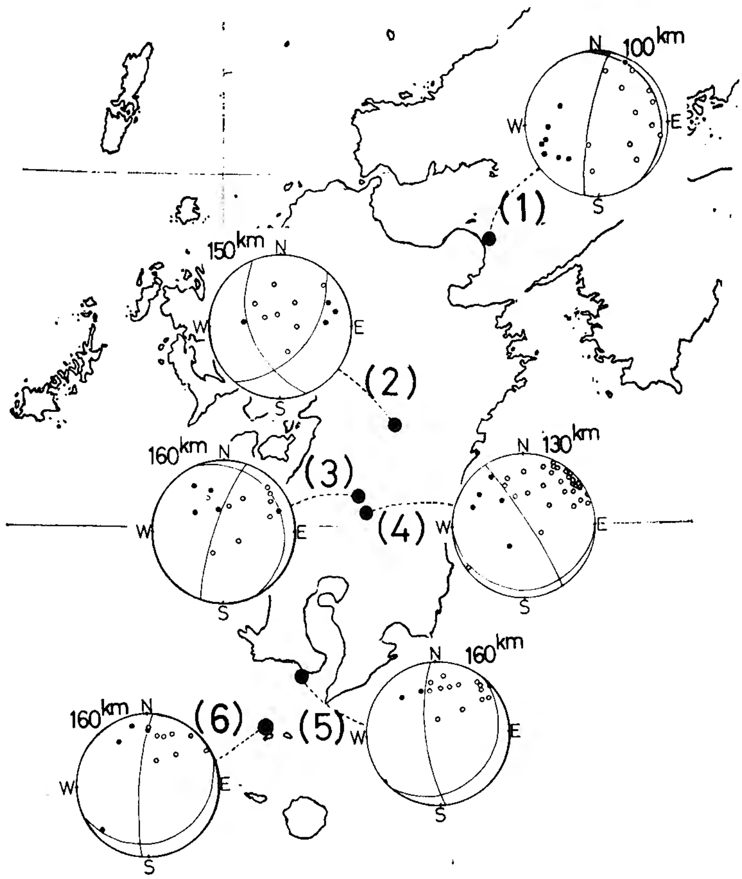

Fig. 7. Focal mechanism of the intermediate events.

3. Conclusional discussions

In this paper the focal mechanisms of earthquakes, which occurred in and near Kyushu Island, were examined. As a result it was found that the four seismic zone can be identified, and the particular mechanisms in each zone were pointed out;

(1) in the western area of the Seto Inland Sea, the focal mechanisms of events within the depth of 50 km exhibit the normal fault type,

(2) in the Hyuga Sea, shallow events ($H \leq 30$ km) exhibit the reverse fault type,

(3) in the western area of Kyushu Island, the compression axes are directed either EW or NE-SW, and

(4) the focal mechanisms of intermediate earthquakes are characterized by a nearly vertical nodal plane.

It should be noted, however, that the mechanisms determined are considered to be not very accurate as to tolerate the further discussion because of uncertainty in phase identification.

Relating to the above result, some problems will be preliminarily examined. In the first, there is a question concerned with the following suggestion made by Ichikawa (1967, 1971), who discussed the characteristic features of focal mechanisms in Kyushu Island and its surrounding area in his paper concerning focal mechanisms in Japan; in the southwestern area of Japan, very shallow events ($H \leq 30$ km) have the general trend of compression axes parallel to the Honshu Arc, that is, to EW direction and the usually shallow events ($30 \text{ km} \leq H \leq 100$ km) have the compression axes perpendicular to the Ryukyu Arc. Moreover he noticed the particularity of the mechanisms in the western area of the Seto Inland Sea as an exceptional case. In this case, the tension axes were directed EW, in contrary to the general trend, and the compression axes were directed NS. The general feature of focal mechanisms given in this paper is compatible with that of Ichikawa's papers. But there is a discrepancy in the result obtained in the western area of the Seto Inland Sea. That is, Ichikawa suggested the predominancy of the strike-slip fault type, but the present result supports the normal fault type. Here it should be noticed that the former was based on the quadrant type model, but in the latter case the quadrant type is scarcely found and this means the question concerning the trend of compression axes parallel to NS.

The second is concerned with the result that the normal fault type predominates in the western area of the Seto Inland Sea, and on the other hand the reverse fault type in the Hyuga Sea. It was usually said that both areas are localized in the northern end of the seismic zone along the Ryukyu Arc. Thus, the change of the fault type in both cases may leave further discussion. Probably it may not be sufficiently explained by the fault structure directed NE, that is, from the western area of the Seto Inland Sea through the Bungo Channel to the Hyuga Sea, which was suggested by Tani (1937). In the opinion of Ichikawa (1967, 1971) for the particularity of focal mechanisms in the western area of the Seto Inland Sea, the particularity may be deduced from the fact that the area is located at the junction of the southwestern Honshu Arc and the Ryukyu Arc, as well as the Izu Peninsula at the junction of the Honshu Arc and the Izu-Mariana Arc. This idea is surely attractive, but the reason such stress distribution is originated at the junction is open to discussion.

Finally, the adaptability of the new hypothesis, the plate tectonics, to the western area of Japan should be considered. This hypothesis implies the sinking of the so-called Phillipine plate toward NNW, that is, normal to the Nankaido through near the south of Shikoku Island, as judged from the focal mechanism of the Nankaido earthquake (For example, see Fitch and Scholz (1971)). Thus it presumes the predominancy of compressional or tensional force directed NNW and the descending of focus deeper as the epicenter moves toward NNW. The present result does not necessarily enforce those presumptions, because the axes of compression and tension have the horizontal components directed nearly EW, especially for the intermediate events, and the focal depth increases as the epicenter moves westward (Fig. 3). Therefore, to reconcile the present result with the plate tectonics hypothesis, it must be thought that the plate descends toward NNW near the focus of the Nankaido earthquake and nearly westward below Kyushu Island, that is, the remarkable deformation of the Phillipine plate. Such a deformation must be thought to be incompatible with the presumption of a rigid plate from the movement of the plate under the ocean bottom without conspicuous deformation, as pointed out by Beloussov (1970).

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