42. Ocean-bottom Seismographic Observation at the offside of Japan Trench near the Erimo Seamount—Seismic Activity of the Oceanic Lithosphere and Velocity Structure around the Geophysical "Ocean-Continent Boundary".

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1. Introduction

The present day tectonic activity of the oceanic trench will be one of the most essential factors which cause the genesis of large earthquakes.

Since the presence of micro-earthquakes is the indication of the progress of the crustal deformation, the investigation of the activity of micro-earthquakes in and around the oceanic trench will reveal the present day tectonics of the oceanic trench.

Hitherto, the presence of aftershocks off the oceanic trench and in the adjacent oceanic basin has been reported in the Rat Island earthquake of Aleutian in 1965[1], and in the earthquake off the Urup Island in the South Kuril in 1963[2].

However, the presence of micro-earthquakes in and around the trench during the normal seismic activity has not been observed because most seismographic observation stations are located on land and are too far from the oceanic trench.

In order to investigate further such activity of micro-earthquakes in and around the oceanic trench, an ocean-bottom seismographic observation

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1) J. N. Jordan and J. F. Lander, *Science*, 148 (1965), 1323-1325.
2) T. Santō, *Bull. International Inst. of Seis. and Earthq. Engineering*, 1 (1964), 33-54.

was planned and performed at the offside of the Japan trench near the Erimo Seamount on the true oceanic crust. This paper will present the method of the field operation of deep ocean-bottom seismographic observation and some results of the observation. The field operation was performed by the M/S "Hakuhō-Maru" of the Ocean Research Institute, the University of Tokyo, on her cruise KH-69-2 in 1969.

2. Field Operation

The location of the ocean-bottom seismographic observation station is at 145°18.'3 E and 40°37.'0 N, 5610 m water depth and is to the southeast of the Erimo Seamount, as shown in Fig. 1.

The Erimo Seamount is located at about 144°57' E and 40°54' N at the junction of two trenches, the Kuril trench and the Japan trench[3].

The mooring period of the ocean-bottom seismograph was 2 days during May 7~9 in 1969. The recording period was from about 01 PM May 7 till 01 PM May 9, 1969.

The instrument is capable of recording continuously for about 133 hrs. However, the observation period was limited by the ship schedule of the M/S "Hakuhō-Maru", which was to be used for a comprehensive geophysical and geological study of the Japan trench.
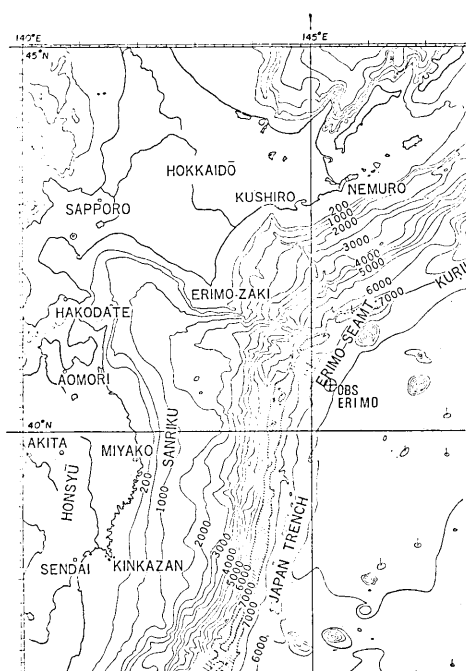

Fig. 1. The ocean-bottom seismographic stations around the Japan trench in May~ June of 1969 occupied by M/S "Hakuhō-Maru".

Instrumentation

In order to perform such deep sea operation, a new pressure vessel was designed and constructed for containing the recording instruments[4]. The pressure vessel is a steel tube type and made of SNC 2, with an

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3) Y. Iwabuchi, Topography and Trenches East of the Japanese Islands, *Jour. Geology*, **74** (1968), 37-46.

4) S. Nagumo et al., *Bull. Earthq. Res. Inst.*, **48** (1970), 955-966.

inside diameter of 240 mm, an outside diameter of 270 mm, and an inside length of 1100 mm.

The recording instruments are the same as described in the previous paper[5], except for the recording time which is extended to 133 hrs by using thin 1800 ft tape of 12 micron polyester type (Sony 2S-7).

The view of the pressure vessel is shown in Fig. 2. The layout of the recording instruments in the pressure vessel is schematically shown in Fig. 3. The tube of the pressure vessel is placed horizontally upon the guard ring for preventing it from the disturbances due to bottom currents.

Mooring and recovery system

The mooring and recovery rope system is shown in Fig. 4. The original design of this system is due to Captain M. Sato of the M/S "Tokai-Daigaku-Maru II".

The strength of the rope system is about 6 t. Wire rope with 8ϕ, 500 m length is used near the sea surface in order to reduce the water current resistance and also to prevent it from damage due to fishes. The combination of a tetoron rope, and a nylon rope is used for adjusting to the density variation from wire rope to polypropylene rope, and for obtaining the proper buoyancy of the long mooring ropes.
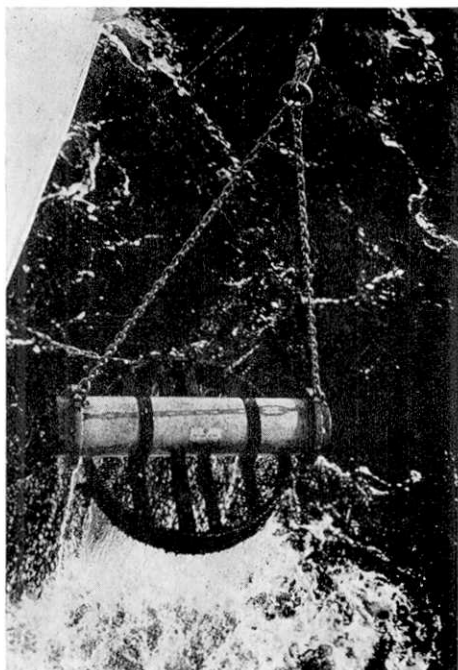

Fig. 2. The pressure vessel for operation at great water depth.
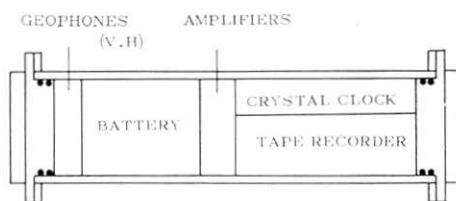
Fig. 3. Schematic diagram of the instrumentation layout inside the pressure vessel.

The total weight of the pressure vessel of the ocean-bottom seismograph is about 250 kg in the water. The complex rope systems near the sea surface are for the recovering operation. As described in the cruise report[6] of the Hakuhō-Maru KH-69-2, the deployment and re-

5) S. NAGUMO et al., *Bull. Earthq. Res. Inst.*, **46** (1968), 861–875.

6) Preliminary Cruise Results of R/V "Hakuhō-Maru" Cruise No. KH-69-2 (May-June, 1969), Japan Trench and Japan Sea, Ocean Research Institute, University of Tokyo, 1969.

Fig. 4. The mooring-recovery rope system used at the station Erimo, 6000 m water depth.

covery operation was very smooth. In spite of the first experience for us it took about 4.5 hours for deployment and 6.5 hours for recovery at the depth of 5.6 km.

3. Results

Example of Records

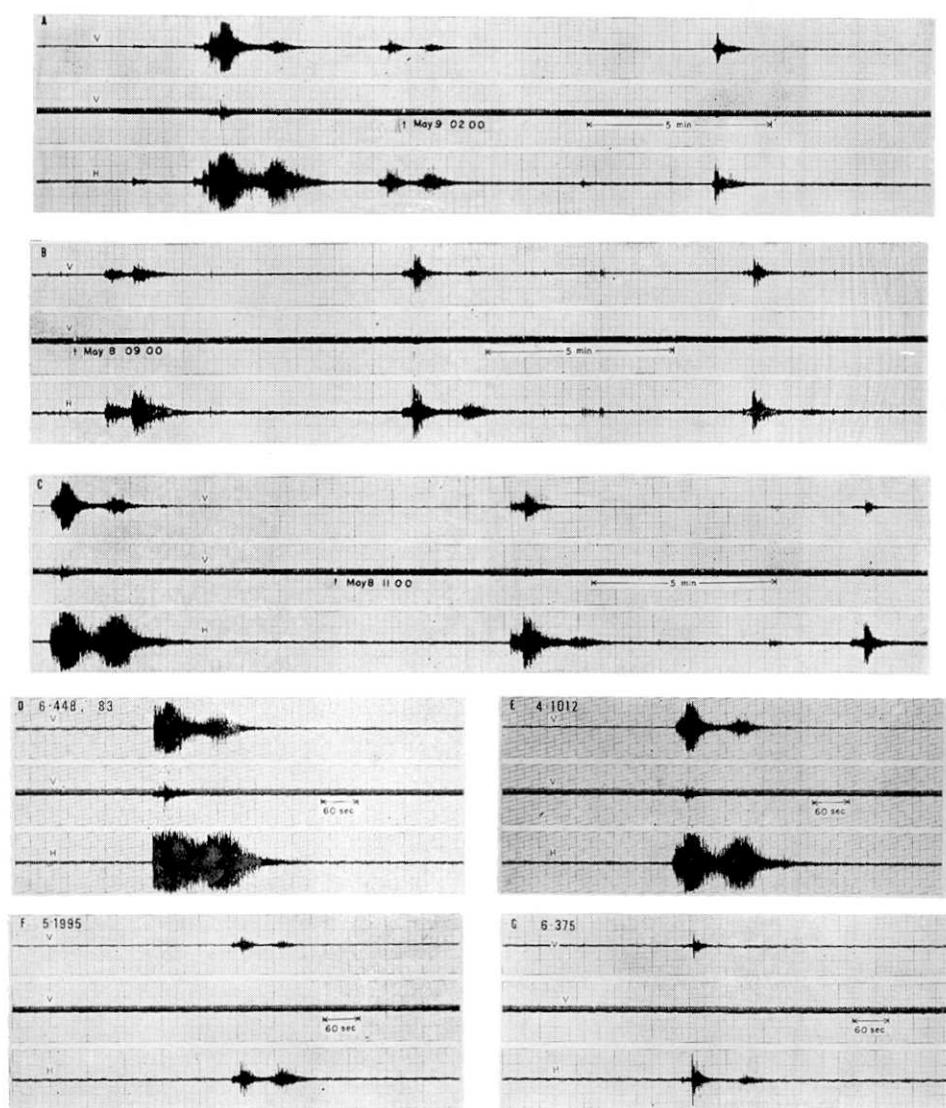Many earthquakes have been recorded during the 2-days mooring

Fig. 5A–G. Examples of seismograms. (to be continued)

period.   First let us see several example of such earthquake records.

Fig. 5. (A), (B), (C) shows a remarkable seismic activity around the Japan trench.   In Fig. 5-A, three earthquakes have occurred during 25 minutes.   Their S-P times are about 22 sec, 14 sec and 5 sec respectively.

This means that these earthquakes occur not at the same place but in wide area.   The first 2 earthquakes in this figure have a remarkable third phase, T-phase.

In Fig. 5-B, three earthquakes have been registered during 25 minutes. The first earthquake with a S-P time of about 40 sec does not have any
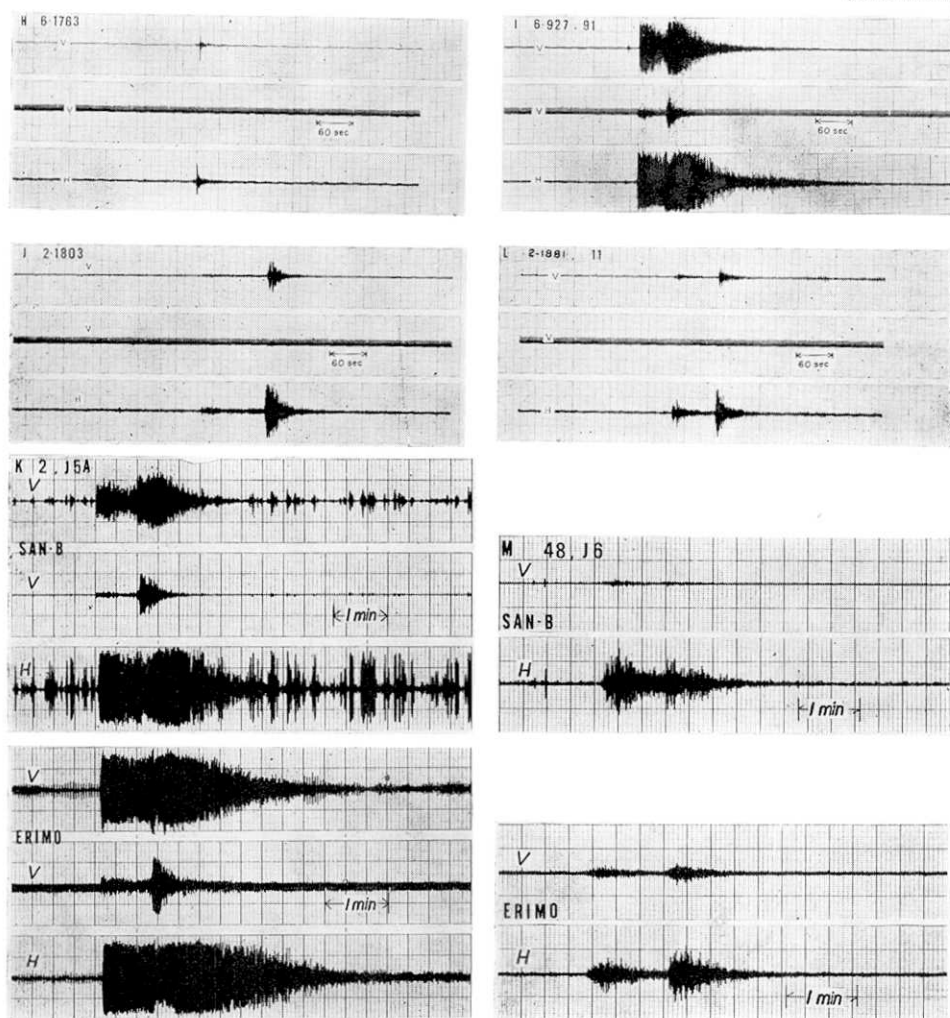
(continued)

Fig. 5H–M.   Examples of seismograms.

Table 1. List of earthquakes registered at the ocean-bottom seismographic station Erimo in May 7~9, 1969.

1969 May 7	Arrival of P		S-P	JMA
1969 May 7	12^h 55^m	22.3^s	12.3^s	
	13 10	30.0	48.2	Middle of Hokkaido, 220 km
	15 48	39.0	23.6	
	16 14	40.3	3.2	
	18 05	44	44	
	19 14	32	105	
	19 36	37.7	73.0	S. of Miura Pen., 120 km
	23 01	11.4	14.9	
	23 03	38.8	1.9	
	23 41	33.0	5.6	
May 8	00 07	58.5	3.8	
	00 10	18.2	4.6	
	00 20	39.9		
	00 33	25.0		
	00 42	09.8	50	
	01 30	14.3		
	02 06	14.4		
	02 49			
	04 12	55.5	6.0	
	09 00	48.4	48.1	
	09 08	45.6	19.0	
	09 17	52.2	16.0	
	10 52	16.6	17.0	
	11 04	45.5	28.0	
	11 19	02	23.7	
	11 49	33.5	68.4	E. of Chiba Pref. 40 km $M=4.4$
	12 48	15	14	
	14 06	50.7	83.3	
	13 11	02	22.5	
	13 38	24	28	
	14 24	43	10	
	15 03	39.6	39.1	
	16 14	30.1	3.9	
	20 33	07.3	23.9	
	21 18	00.6	8.9	
	22 48	38.4	2.7	
	23 20	14.6	1.9	
	23 58	15.1	24.7	

Table 1.   (continued)

	Arrival of P		S-P	JMA
May 9	$01^h\ 11^m$	$31^s.4$	$15^s.9$	
	01 54	19.3	15.7	
	01 59	20.7	15.3	
	02 08	23.8	5.5	
	02 25	18	12	
	03 16	20	17	
	03 37	25.8	19.3	Off Sanriku, 40 km, M=4.3
	05 07	32.6	14.6	
	05 53	12.4	46.9	S. of Kuril, 40 km, M=5.0
	07 13	02.8	24.6	
	09 35	50.4	4.3	
	09 38	55.3	1.5	
	09 39	28.8	5.2	
	10 54	13	27	
	11 09	07.4	11.5	

T-phase. The latter two earthquakes with S-P times of about 14 sec have T-phases with small amplitudes.

Fig. 5-C, shows another example of similar violent seismic activity. In Fig. 5-(D)~(M) are shown different patterns of earthquakes. In Fig. 5 (D), (E), (F), (G) earthquakes which have T-phases are shown. (D) is the shallow earthquake off Sanriku (cf. Table 2). The amplitude of the T-phase relative to the S-phase amplitude is different in each earthquake. Fig. 5(H) shows an example of micro-earthquakes with S-P times less than 6 seconds. In Fig. 5(I) shallow earthquakes to the south of Kuril (cf. Table 2) are shown. (J) is the earthquakes with an S-P time larger than two minutes; the epicenter is not known. (K) is an intermediate deep earthquake (H=220 km) in the middle of Hokkaido, (L) is an intermediate deep earthquake (H=120 km) off the Miura peninsula, (M) is a shallow earthquake east of Chiba Prefecture (cf. Table 2).

S-P time frequency distribution

As many as 52 earthqukes were registered during the two days recording period. The readings of each earthquake are tabulated in the Table 1.

The S-P time frequency distribution is shown in Fig. 6. The three groups will be seen in the figure. One group corresponds to earthquakes with S-P times less than 6 seconds, another group to earthquakes with S-P times peaking at around 15~18 seconds and ranging from 6 seconds to 30 seconds.

The third group contains earthquakes with an S-P time larger than 30 seconds. As will be shown in the following section, the first group consists of earthquakes which occur on the oceanic lithosphere, beyond the central part of the Japan trench. The second group consists of earthquakes which occur along the continental slope of the Japan trench, and in the aftershock area of the 1968 Tokachi-Oki earthquake. The third group consists of earthquakes which occur outside the focal region of the great earthquakes off Sanriku.
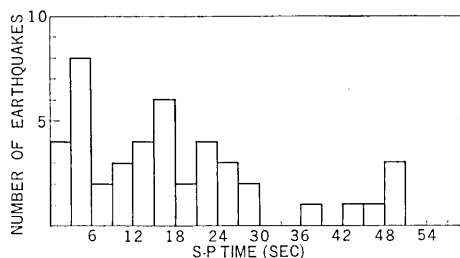

Fig. 6. The S-P time distribution of earthquakes registered at the Erimo OBS station ($\lambda=145°18.'3$ E, $\varphi=40°37.'0$ N water depth 5.6 km), at the offside of the Japan trench during the period of May 7∼9 1970. The half-wave amplitude is more than 100 μkines.

Seismic Activity

In order to represent the seismic activity in a certain area and in a certain period, we will use the number of earthquakes per day which will be observed at a certain station in the center of the area and of which the velocity amplitude of the seismic motion is larger than a certain specified value, and the S-P time is smaller than a certain specified value. The specified velocity amplitude is taken as 100 μkine.
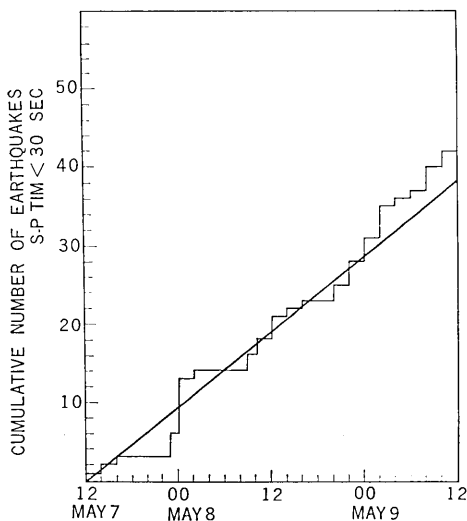
The cumulative number of earthquakes for which the S-P time is smaller than 30 seconds, as a function of time, is shown in Fig. 7. The period is about two days from May 7 to 9, 1969. The increase of the cumulative number of earthquakes is not straight. However, when one takes the average, as shown by the straight line in the Fig. 7, the average daily occurrence frequency will become about 19 earthquakes per day.
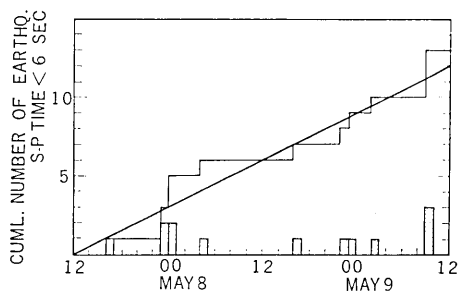

Fig. 7. Cumulative number of earthquakes as function of time registered at the Erimo OBS station. The half-wave amplitudes are more than 100 μkines, and the S-P time is less than 30 seconds. The average daily frequency is about 19 earthquakes per day.

Fig. 8. Cumulative number of earth-quakes as a function of time registered at the Erimo OBS station. S-P times are less than 6 seconds and the half-wave amplitudes are more than 100 μkine. Average daily frequency is about 6 earthquakes per day. Shaded bar shows the hourly number of earthquakes.

Similarly the cumulative number of earthquakes for which the S-P time is smaller than 6 seconds, as a function of time, is shown in Fig. 8. In the same figure, the number of earthquakes for each one hour interval during the observation period is shown by a shaded bar. The occurrence of earthquakes is not continuous. However, when one takes the average, the average daily frequency will be about 6 earthquakes per day.

4. Seismic Activity at the offside of the Japan Trench

As will be shown in the next section, the value of Ōmori's coefficient K is about K=10.6 km/sec for this ocean-bottom seismographic station. Therefore, the earthquakes with S-P times at the station less than 6 seconds will take place in the area which is shown by a circle in Fig. 9.

As is evident from the Fig. 9 the circle covers the area which ranges from the deepest part of the Japan trench to the true oceanic basin. Ludwig et al.[7] here discovered that the oceanic crust continues to exist beneath the deepest part of the Japan trench and extends further towards the continental side crossing the trench axis. This means that the small earthquakes which were observed at the ocean bottom seismographic station southeast of the Erimo Seamount at the offside of the Japan trench with a true oceanic crust, and for which the S-P times were less than 6 seconds, took place in the oceanic lithosphere.

The existence of such small earthquakes in the oceanic lithosphere beyond the deepest part of the trench will have great geophysical significance.

First of all, since the existence of the seimic activity is the direct evidence of the progresss of crustal deformation,[8] the existence of seismic activity in the oceanic basin will mean that the oceanic side of the Japan trench is also subjected to the active tectonic movement at present as well as the continental side of the Japan trench.

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7) W. J. LUDWIG et al., Jour. Geophys. Res., 71 (1966), 2121-2137.
8) S. NAGUMO and K. HOSHINO, Bull. Earthq. Res. Inst., 45 (1967), 1295-1311.

The grade of the seismic activity at the offside of the trench is, however, a little lower than that of the continental side. The daily frequency of earthquakes with S-P times less than 30 seconds, which are thought to occur along the continental side, is about 3 times the daily frequency of the earthquakes with S-P times less than 6 seconds. The value of the seismic activity of 6 per day above 100 μkine is larger than the common values in the Japan islands.

The occurrence of aftershock activity at the offside of oceanic trenches following great submarine earthquakes, has been reported by Jordan and Lander[9] for the 1965 Rat Island earthquake (M=7.5) in the Aleutian, and by Santo[10] for the 1963 Urup earthquake (M=8.1) in the Kuriles. It is well known that the 1933 Sanriku Earthquake (M=8.1) took place at the deepest part of the Japan trench.
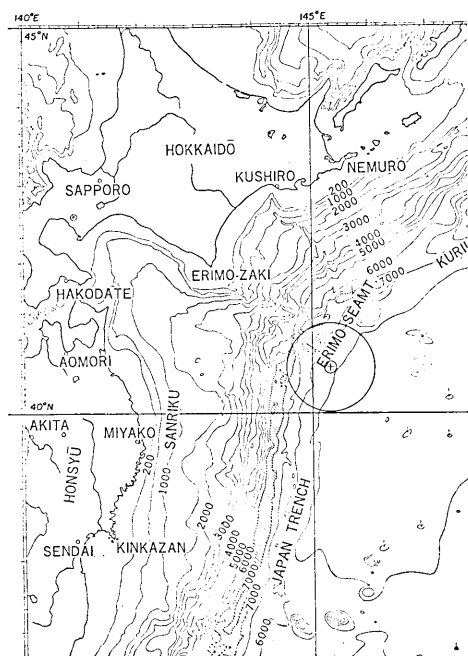

Fig. 9. The probable area where earthquakes take place with S-P times less than 6 seconds. It ranges from the deepest part of the Japan trench to the true oceanic basin.

The existence of such aftershock activities and the existence of small earthquakes in the normal period will be the definite evidence that the oceanic lithosphere is competent for generating earthquakes whenever the generating conditions are given.

The supposition of a rigid plate or an incompetent plate for the oceanic lithosphere is invalidated. It will be very strange that the competent oceanic lithosphere does not generate earthquakes during her trans-pacific journey.

5. Determination of Ōmori's Coefficient K

As is well known, Ōmori's coefficient K is defined by the formula

$$X=K(Ts-Tp) \tag{1}$$

9) J. N. Jordan, *loc. cit.*, 1).
10) T. Santō, *loc. cit.*, 2).

where X is the focal distanse, Tp and Ts are the arrival time of the P-phase and the S-phase respectively. In an isotropic homogeneous medium, Tp and Ts are $Tp = X/Vs$, where Vp and Vs are the velocity of the P-wave and S-wave respectively. Therefore the S-P time is given by the formula

$$Ts - Tp = Tp\{(Vp/Vs) - 1\} \tag{2}$$

and K is given by the formula

$$K = Vp/\{(Vp/Vs) - 1\}. \tag{3}$$

The K-value for the specific ocean-bottom seismographic station ERIMO will be determined from $\{(Vp/Vs) - 1\}$ and Vp. $\{Vp/Vs - 1\}$ will be determined by the plot of S-P time versus Tp. Since Vp is the mean velocity of the P-wave to the station ERIMO from the hypocenter, assuming a straight ray path, Vp is determined by the formula

$$Vp = \sqrt{H^2 + \mathit{\Delta}^2}/(Tp - To) \tag{4}$$

where H is the focal depth, $\mathit{\Delta}$ the surface, and To the origin time.

The K-value is determined by employing five earthquakes, which are registered both by the ocean-bottom seismographic station ERIMO and the stations of Japan Meteorological Agency. The epicenters of the five earthquakes are shown in the Table 2 and Fig. 10.

Table 2. List of earthquakes registered both by the Japan
Meteorological Agency and ERIMO OBS station
during the period of May 7~9, 1969.
(After the Seismological Bulletin of the Japan Meteorological Agency)

	Origin time		Long	Lat	H	M	Location
May 7	13 09 ʰ ᵐ	28.9 ˢ	142.°49′	44°03	220 km		middle of Hokkaido
7	19 35	01.8	139. 38	35 10	120		S. of Miura Pen.
8	11 47	58.5	140. 29	35 14	40	4.4	E of Chiba Pref.
9	03 36	57.3	143. 19	40 53	40	4.3	Off Sanriku
9	05 52	09.9	148. 43	44 04	40	5.0	S of Kuril Is.

The solid line contour in the Fig. 10 is the iso-depth line of the deep seismic surface of the earthquake which are constructed by Utsu and Okada.[11]

Fortunately, these earthquakes are located at the proper places for estimating the value of K for various directions and depths.

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11) T. Utsu, and H. Okada, *Jour. Faculty of Science, Hokkaido Univ., Ser. VII.,*
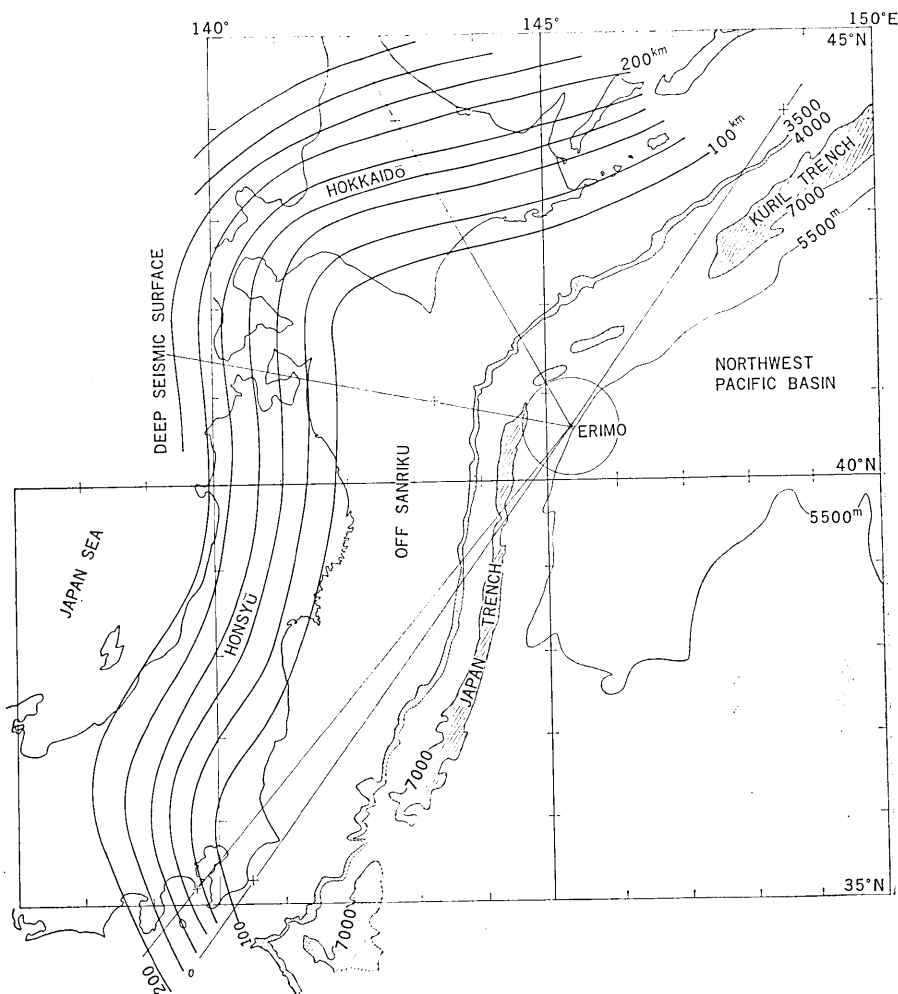3 (1968), 65-84.

Fig. 10. Epicenters of the five earthquakes registered by both the OBS station Erimo and stations of the Japan Meteorological Agency during the period of ·May 7-9, 1969.

Determination of $\{(Vp/Vs)-1\}$

The plots of the S-P time versus Tp for the five earthquakes are· shown in the Fig. 11. The data are taken from the Bulletin of the Japan Meteorological Agency. The data of the ocean-bottom seismo-- graphic station ERIMO are indicated by the arrow.

1) For the intermediate deep earthquake in the middle of Hokkaido,. $H=220$ km, the value of $\{(Vp/Vs)-1\}$ is 0.76. This value is in. agreement with those obtained by Yoshiyama[12] and Utsu[13] for the·

12) R. YOSHIYAMA, *Bull. Earthq. Res. Inst.*, **35** (1957), 627-640.
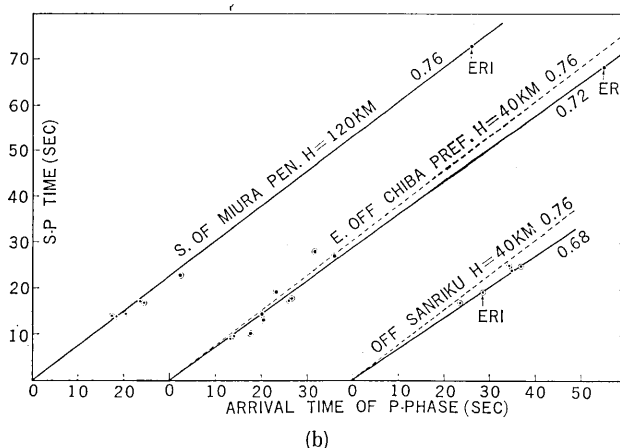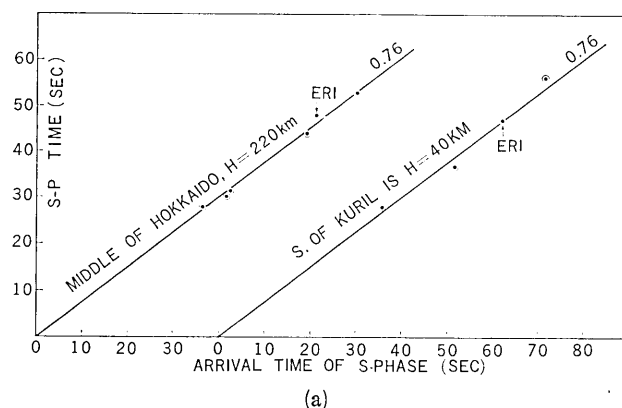
13) T. UTS, *Zisin* (**ii**), **22** (1969), 41-53.

Fig. 11.   S-P times as a function of the arrival time of the P-phase for the five earthquakes of Table 2. The gradient represents the value of $\{(Vp/Vs)-1\}$.

earthquakes for which the focal depths are greater than 100 km.

2)   For the shallow earthquake to the south of the Kuril Island, $H=40$ km, the value of $\{(Vp/Vs)-1\}$ is also 0.76. The focal depth of the earthquake is reported as $H=40$ km. It will be very significant that the value 0.76 is obtained for the shallow earthquake. This will be due to the fact that the ray path is in the oceanic lithosphere. This also supports Utsu model[14] for the ocean-continent boundary structure around the Japan trench, where the high velocity zone along the deep seismic surface extends towards the oceanic lithosphere and has a thick layer.

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14) T. UTSU, *Jour. Faculty of Science, Hokkaido University, Japan, Ser. VII*, **3** (1968), 1-25.

3) For the intermediate deep earthquake to the south of the Miura Peninsula, $H=120$ km, the value of $\{(Vp/Vs)-1\}$ is obtained as 0.76. This value is also in agreement with those of Yoshiyama and Utsu.

4) For the shallow earthquake to the east of Chiba Prefecture $H=40$ km, the value of $\{(Vp/Vs)-1\}$ for the station ERIMO is obtained as 0.72. This value is smaller than the value 0.76 for intermediate and deep earthquakes and larger than the value 0.68 for shallow earthquakes in and near Japan. The intermediate value 0.72 will be due to the fact that the ray path is composed of the continental lithosphere and the oceanic lithosphere.

5) For the shallow earthquake off Sanriku, $H=40$ km, the value of $\{(Vp/Vs)-1\}$ is obtained as 0.68. This value agree with the value obtained by Yoshiyama[15] for shallow earthquakes. These values of $\{(Vp/Vs)-1\}$ for five earthquakes are listed in the table 3.

Table 3. $\{(Vp/Vs)-1\}$, $\overline{Vp}$ and K for the ocean-bottom seismographic station Erimo.

Vp: Apparent mean velocity of the P-wave to the station ERIMO from the hypocenter assuming the straight ray path.

K: Omori's Coefficient, calculated from the formula $K=Vp/\{(Vp/Vs)-1\}$.

Epicenter	Focal depth H(km)	$(Vp/Vs)-1$	$\overline{Vp}$ km/s	K km/s
middle of Hokkaido	220	0.76	8.31	10.9
S of Miura Pen.	120	0.76	8.24	10.8
S of Kuril	40	0.76	8.02	10.5
E of Chiba Pre.	40	0.72	7.41	10.3
Off Sanriku	40	0.68	6.42	9.4

Detemination of $\overline{Vp}$

Next, the mean velocity $\overline{Vp}$ of the P-wave is determined by the formula (4). The values are shown in the same Table 3. For the intermediate deep earthquakes in the middle of Hokkaido ($H=220$ km) and to the south of Miura peninsula ($H=120$ km), the mean velocity to the ERIMO station is obtained as 8.31 km/sec and 8.24 km/sec respectively. These values are larger than the normal value for the Moho-discontinuity, and agree very well with the value of the velocity along the deep seismic surface of the Utsu Model.[16]

15) R. YOSHIYAMA, *loc. cit.*, 12).
16) T. Utsu, *loc. loc.*, 14)

For the shallow earthquake to the south of Kuril Island, ($H=40\,\text{km}$), $\bar{V}p$ is obtained as 8.02 km/sec. This value is a normal value for the Moho-discontinuity. For the shallow Sanriku earthquake ($H=40\,\text{km}$, $\varDelta=179\,\text{km}$), the value of $\bar{V}p$ is obtained as 6.41 km/sec. This value is equal to the velocity in the layer above the Moho-discontinuity in the oceanic crust, which is obtained by Ludwig et al[17].

For the shallow earthquake to the east of Chiba Prefecture ($H=40\,\text{km}$, $\varDelta=703\,\text{km}$), the value of $\bar{V}p$ is obtained as 7.41 km/sec. This value will be due to the combination of the ray path in the continental lithosphere and oceanic lithosphere.
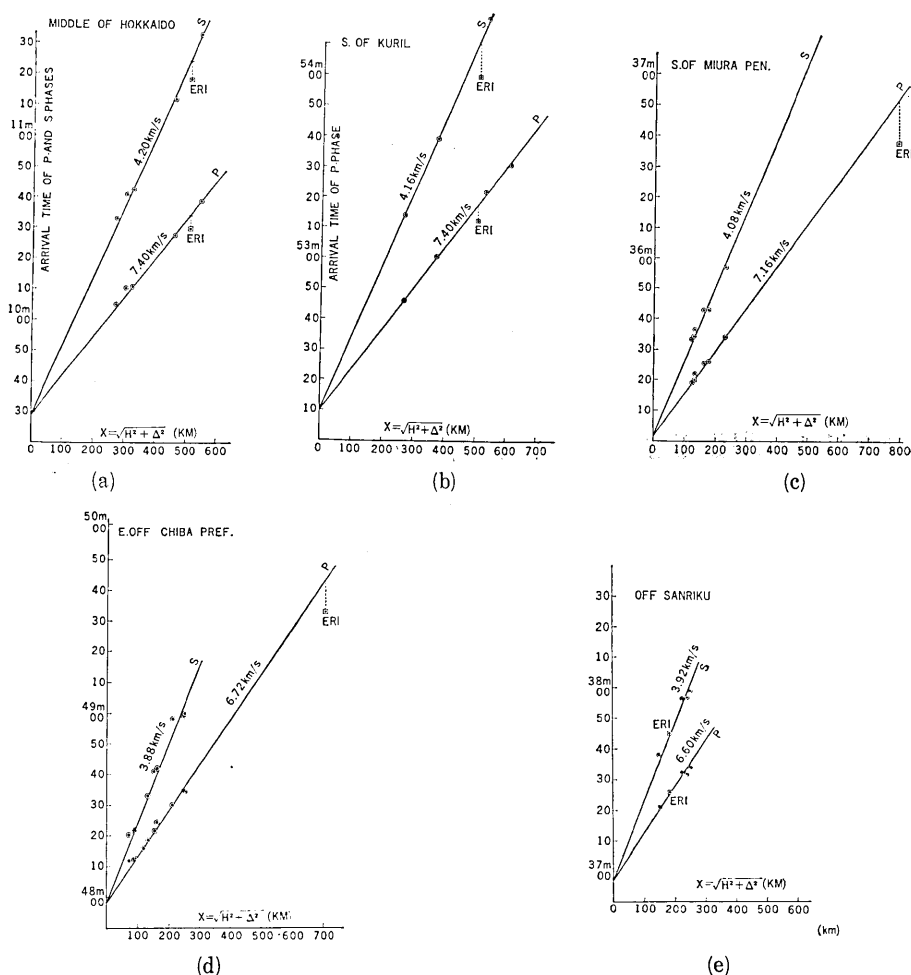

Fig. 12.   Travel time anomaly of the P-phase and the S-phase at the OBS station Erimo for the five earthquakes of the Table 2.

17)   W. J. Ludwig et al., loc. cit., 7).

Ōmori's coefficient K

The value of K, calculated from the formula (3), is shown for each earthquake in the Table 3. It ranges from 10.9 km/sec to 9.4 km/sec. These values are very large compared with the well known common value of 8 km/sec. The K values are different for different eathquakes, according to their azimuth, distance, and depth. For the earthquakes with S-P times larger than 20 seconds, the K value is larger than 10 km/sec. The K value for the shallow Sanriku earthquake is smaller than the 10 km/sec. It will be very interesting to notice that the K-value for the shallow earthquake to the south of Chiba Prefecture is $K=10.5$ km/sec despite of a P-wave velocity of $Vp=7.4$ km/sec.

6. Travel Time Anomaly

A large travel time anomaly for the P-phase and S-phase was observed at the ocean-bottom seismographic station ERIMO. The travel time distance curves of the P-phase and the S-phase are plotted in Fig. 12 for the five earthquakes which are listed in the Table 2. The data are taken from the Bulletin of the Japan Meteorological Agency. The data of our ocean-bottom seismographic station ERIMO are plotted there also as open squares. The straight line distance from the hypocenter to the station ERIMO is taken as the abssisa. As seen in these figures, the deviations of the arrival time at the ocean-bottom seismographic station ERIMO are evident and very great and earlier by more than several seconds. The straight lines in the figures are the average travel time distance curves fitted for the data of stations on land. Only for

Table 4. Travel time anomaly of the P-phase at the ocean-bottom seismographic station ERIMO. Anomaly is taken as the difference of the observed values and the Wadati-Sagisaka-Masuda's table for the P-wave and Sagisaka-Takehana's table for the S-wave. $\varDelta Tp = Tp(\text{obs}) - Tp(W\text{-}S\text{-}M)$, $\varDelta Ts = \varDelta Ts(\text{obs}) - Ts(S\text{-}T)$

	H	$\varDelta$	$\varDelta T_{p,s}$	
			W-S-T	S-T
middle of Hokkaido	220 km	458 km	-4.6 s	-5.9 s
S of Miura Pen	120	781	-6.7	-11.0
S of Kuril	40	500	-6.8	-14.7
E of Chiba Pre	40	703	0	-8.0
Off Sanriku	40	179	$+0.8$	$+0.9$

the earthquake off Sanriku, the deviation is very small.

In the Table 4 are shown the real time anomalies at the ocean-bottom seismographic station ERIMO refered to the Wadati-Sagisaka-Masuda's travel time curves for the P-wave[18] and the Sagisaka-Takehana's travel time curves for the S-wave[19]. As seen in the Table 4, the travel time anomalies are very great.

7. Velocity Structure Around the Ocean-Continent Boundary

From these travel time anomalies, let us derive the velocity structure around the boundary of the geophysical ocean and continent.

(1) *The intermediate deep earthquake in the middle of Hokkaido ($H=$ 220 km)*. The cross-section of the velocity structure along the ray path from the epicenter to the ocean-bottom seismographic station ERIMO is represented in Fig. 13. The seismic surface of deep-focus earthquake is quoted from Utsu's paper.[20] The earthquake focus is located at the seismic surface.
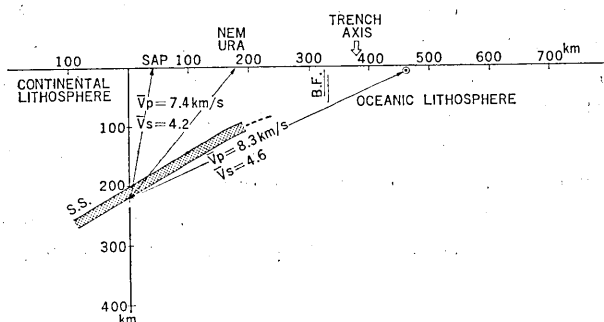

Fig. 13. The velocity profile for the intermediate deep earthquake in the middle of the Hokkaido, $H=220$ km. Mark S.S. represents deep seismic surface. The velocities in the high velocity zone in the deep seismic surface are $Vp=8.3$ km/sec and $Vs=4.6$ km/sec. The velocities in the continental lithosphere are $Vp=7.4$ km/sec and $Vs=4.2$ km/sec.

The seismic ray path from the focus to the ocean-bottom seismographic station ERIMO crosses the contour of the deep seismic surface and lies within the narrow zone which exists along the deep seismic surface. The seismic ray paths to the land stations in Hokkaido lie

18) K. WADATI, K. SAGISAKA and K. MASUDA, *Jour. Met. Soc. Japan, Second Ser* **10** (1932), 460–474.

19) K. SAGISAKA and M. TAKEHANA, *Quart. J. Seis.*, **8** (1934), 149–161

20) T. UTSU, *loc. cit.*, 14).

within the continental lithosphere above the deep seismic surface. The P-wave and S-wave velocities to the ocean-bottom seismographic station ERIMO are $Vp=8.3$ km/sec and $Vs=4.65$ km/sec respectively. The velocities to the land stations are $Vp=7.4$ km/sec and $Vs=4.2$ km/sec respectively. These values confirm the existence of the high velocity zone along the deep seismic surface which was discovered by Utsu[21] and Oliver.[22]

These observed values of P- and S-wave velocities agree strikingly well with the values which were employed by Utsu for the structure around the boundary of the geophysical ocean and continent. The velocity anomaly of the high velocity zone is about 10% higher both for P-wave and S-wave.

(2) *The intermediate deep earthquake to the south of Miura peninsula* $(H=120\,km)$. The cross section of the velocity structure along the ray path from the epicenter to the ocean-bottom seismographic station ERIMO is represented in Fig. 14.
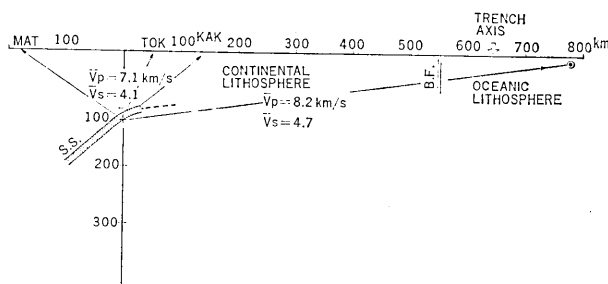

Fig. 14. The velocity profille for the intermediate deep earthquake, south of the Miura peninsula, $H=120$ km. The velocities of the high velocity zone in the upper part of the oceanic lithosphere is about $Vp=8.2$ km/sec and $Vs=4.7$ km/sec.

The seismic surface is not clear in the region shallower than about 100 km. The ray path runs along the ocean-continent boundary structure, as seen in Fig. 10. It seems to cross obliquely from the geophysical continent to the geophysical ocean.

The velocities of P-and S-waves to the ocean-bottom seismographic station ERIMO are $Vp=8.2$ km/sec and $Vs=4.7$ km/sec respectively. The values to the land stations are $Vp=7.1$ km/sec and $Vs=4.1$ km/sec respectively. These values confirm the existence of the high velocity zone

21) T. UTSU, *loc. cit.*, 14).

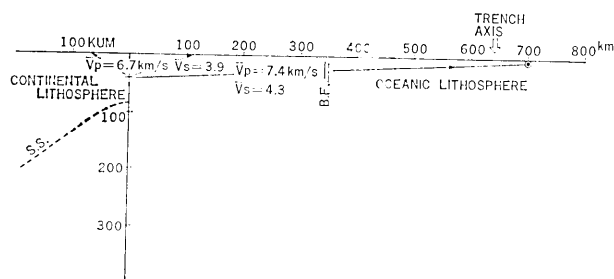22) J. OLIVER and B. L. ISACKS, *Jour. Geophys. Res.*, **72** (1967), 4259.

Fig. 15.   The velocity profile for the shallow earthquake
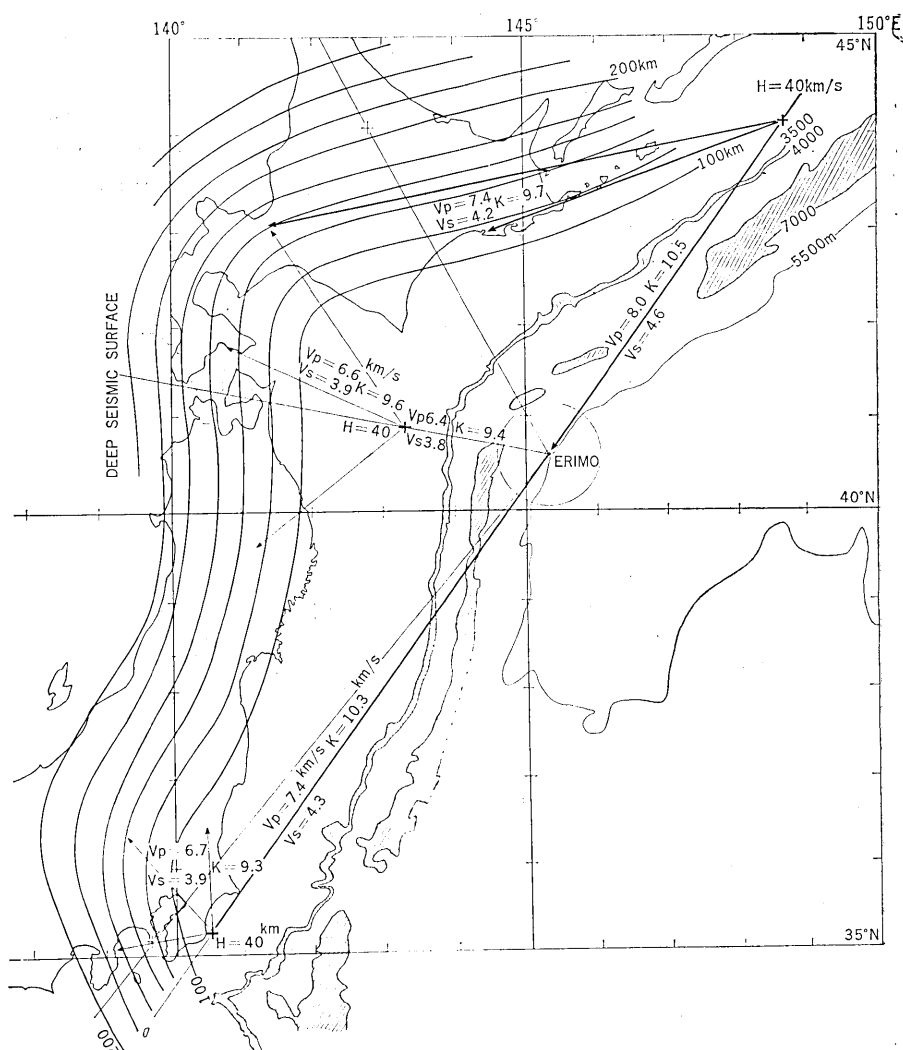east of Chiba prefecture, $H=40$ km.

Fig. 16.   The planar view of the velocity heterogeneity for the shallow earth-
quake east of Chiba prefecture, $H=40$ km; The shallow earthquake south of Kuril,
$H=40$ km; and the shallow earthquake off Sanriku, $H=40$ km.

along the extension of the deep seismic surface in the shallower part of the oceanic lithosphere. The velocity anomaly of the high velocity zone is about 15% higher both for P-and S-waves.

(3) *The shallow earthquake to the east of Chiba prefecture* $(H=40\,km)$. The cross section of the velocity structure along the ray path from the epicenter to the ocean-bottom seismographic station ERIMO is shown in Fig. 15, and a planar view of the velocity structure is shown in Fig. 16. The ray path runs through the shallower part of the continental and oceanic lithosphere crossing obliquely the boundary of the geophysical continent and ocean. The velocities of P- and S-waves to the ocean-bottom seismographic station ERIMO are $Vp=7.4\,$km/sec and $Vs=6.7\,$km/sec respectively. The amount of the velocity anomaly is about 10% for both for P- wave and S-waves.

(4) *The shallow earthquake to the south of Kuril* $(H=40\,km)$. The planar view of the velocity structure is shown in Fig. 16. As seen in the figure, the heterogeneity of the velocity distribution is remarkable.

(5) *The shallow Sanriku earthquake* $(H=40\,km)$. The planar view of the velocity structure is shown in Fig. 16. The velocities of P-wave and S-waves from the epicenter to the ocean-bottom seismographic station and to the land station are nearly the same. This will mean that there

Table 5. Anomaly of the P-wave and the S-wave velocity around the ocean-continent boundary structure. Apparent mean velocities of the P-wave and the S-wave to the station ERIMO are determined by assuming straight ray path, $\bar{V}p,s=(Tp,s-To)/X$, where Tp,s arrival time of the P and S waves at the station ERIMO, and T_0 origin time according to JMA Bulletin, $X=\sqrt{H^2+\varDelta^2}$ where H focal depth and $\varDelta$ surface distance. Apparent velocities to the land stations are determined from the time distance curve. The wave velocity anomaly is represented by the ratio of the velocity to ERIMO station and the velocity to land stations.

	H(km)	Apparent mean velocity to Erimo		Apparent velocity to Land stations		Velocity ratio	
		Vp(km/s)	Vs(km/s)	Vp(km/s)	Vs(km/s)	P	S
middle of Hokkaido	220	8.31	4.65	7.40	4.20	1.12	1.10
S of Miura Pen.	120	8.24	4.68	7.16	4.08	1.15	1.15
S of Kuril	40	8.02	4.58	7.40	4.16	1.08	1.10
E of Chiba Pref.	40	7.41	4.31	6.72	3.88	1.10	1.11
Off Sanriku	40	6.42	3.82	6.60	3.92	0.98	0.98

is not much difference of velocities in the crust of the oceanic and continental lithospheres. The values of *P*-wave and *S*-wave velocities and the values of the velocity anomalies are summarized in Table 5.

8. Summary and Conclusions

The ocean bottom seismographic observation was performed at the offside of the Japan trench, $\lambda=145°18.'3$, $\varphi=40°37.'0$, near the Erimo-Seamount in the time from May 7 to 9, 1969 by the Research Vessel M/S "Hakuhō-Maru" of the Ocean Research Institute, University of Tokyo.

1. The deep ocean-bottom seismographic observation, about 5.6 km deep, was succesfully performed. The observation is of the anchored buoy system. The instruments and the rope-buoy system for mooring were newly developed for this operation. The operations of deployment and recovery were very smooth and efficient.

2. As many as 52 earthquakes were registered by the ocean-bottom seismograph during the two days recording period. This shows that the seismic activity in this region is very high.

3. The presence of the small earthquakes and micro-earthquake activity was discovered on both sides of the deepest part of the Japan trench. The frequency of earthquakes with amplitudes larger than 100 μkine is six earthquakes per day.

4. The presence of such seismic activity evidences that the trench tectonics in this area is active at present.

5. The presence of small earthquakes and micro-earthquakes in the oceanic lithosphere evidences that the oceanic lithosphere is competent for generating earthquakes.

6. The value of Ōmori's coefficient *K* is determined at the offside of the Japan trench and is about $K=10.9\sim9.4$ km/sec, which is much larger than the common value in the continental lithosphere.

7. The value $\{(Vp/Vs)-1\}$ for shallow earthquakes in the oceanic lithosphere is obtained as about 0.76.

8. Large travel time anomalies are observed at the ocean-bottom seismographic station.

9. From these travel time anomalies the velocity structure around the ocean-continent boundary is obtained. The velocities *Vp* and *Vs* in the high velocity zone along the deep seismic surface are 8.4 km/sec and 4.65 km/sec respectively.

10. The amount of the velocity-anomaly in the high velocity zone is about 10% both for *P*-wave and *S*-wave.

11. The value of Ōmori's coefficient *K* and the velocity distributions agree very well with the Utsu-Oliver Model for the geophysical

ocean-continent boundary structure around the oceanic trench.

Acknowledgement

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42. えりも海山付近，日本海溝外側における海底地震観測—
海洋性岩石圏の地震活動と地球物理的
"海洋—大陸境界" 付近の速度構造

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東京大学大学院　長 谷 川 周 而*
地 震 研 究 所 　{是 沢 定 之
　　　　　　　　小 林 平 八 郎**

えりも海山の南東，日本海溝外側の海洋性地殻の上，東径 145°18′.3，北緯 40°37′.0，水深 5610 m の地点において海底地震観測を行った．この観測は東京大学海洋研究所研究船 "白鳳丸" によって (KH-6-2)，1969 年 5 月 7 日～9 日に行われた．

　5.6 km という深い海洋底における観測は初めての試みであったが，非常に順調に遂行された．観測方式は従来から使用している アンカードブイ 式である．耐圧容器などの観測計器や繋留，回収のロープシステムなどはこの観測のために新しく設計製作された．

　48 時間の繋留期間中に 52 コという多数の地震が記録された．このことは，この周辺における地震活動度が著しく高いことを示している．日本海溝最深部からその海洋側にわたって微小地震が発生していることが発見された．その活動度は 100 μkine 以上の速度振巾を持つ地震の発生頻度で表わすと 6 コ/日である．

　このような地震活動の存在は，この地域における海溝造構運動が現在生きていることの証拠であると思われる．また，微小地震が海洋性岩石圏に存在するということは，海洋性岩石圏が地震を発生する "能力" のあることを示すものであると考えられる．

　海底地震観測点 Erimo における大森係数 K の値は 10.9～9.4 km/sec となる．この値は大陸性岩石圏における普通の値よりはるかに大きい．

　海洋性岩石圏に発生した浅発地震に対して {(v_p/v_s)−1} の値が 0.76 と求められた．この値は深発地震に対して知られている値と等しい．

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　海底地震観測点において大きな走時異常が観測された．これらの走時異常から地球物理的 "海洋―大陸境界" 週辺の速度構造を求めた．深発地震面に沿って高速度層が存在しその速度は $v_p = 8.3$ km/sec, $v_s = 4.65$ km/sec, と求められた．大陸性岩石圏に対する速度異常は P 波，S 波共に約 10% 程度である．以上求められた大森係数 K の値や，速度分布等は，海溝周辺における地球物理的な "海洋大陸境界" の構造に対する宇津―オリバー モデルに非常によく一致する．