

*Report on DELP 1985 Cruises in the Japan Sea*  
*Part II: Seismic Refraction Experiment Conducted in*  
*the Yamato Basin, Southeast Japan Sea*

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**Abstract**

Refraction seismic study was designed to constrain the structure of the Yamato Basin, the southeastern part of the Japan Sea using 20 OBS's, five tons of explosives and airgun. The Yamato Basin has a steep velocity gradient in the upper part of the crust as commonly observed in the oceanic crust. The Moho depth is determined at around 18 km subsurface, which is nearly twice as deep as that of the normal oceanic crust. The apparent Pn velocity is 8.0-8.1 km/s along two azimuthal direction which were selected as being parallel to the min. and max. directions of the Pn anisotropy proposed by OKADA *et al.* (1978).

**1. Introduction**

A seismic reflection/refraction experiment was designed to constrain the seismic structure of the Yamato Basin, the southeastern part of the Japan Sea. The purpose of this experiment was to confirm or revise the former interpretations by new data with higher accuracy. This part of the cruise report describes some preliminary results of the refraction studies obtained from ocean bottom seismograms of airgun and explosions. Multichannel seismic profiler studies are discussed in Part III

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of this report (TOKUYAMA *et al.*, 1987). More detailed seismic structures will be obtained by further analyses incorporating the seismic profiler data.

The structure of the basement of the oceanic basins deeper than a few kilometers is usually studied by seismic methods using natural earthquakes as well as artificial sound sources. Analyses of surface waves across the Japan Sea have shown that the lithospheric thickness of this area is about 30–40 km which is fairly thin compared with the normal oceanic lithosphere. (ABE and KANAMORI, 1970; EVANS *et al.*, 1978): There are a great deal of seismic studies on the crustal structure of the Japan Sea utilizing big airguns and dynamite shootings (ANDREYEVA and UDINTSEV, 1958; LUDWIG *et al.*, 1975).

Refraction methods using sonobuoys as well as the two-ship survey method (LUDWIG *et al.*, 1975) have revealed that there is a systematic difference in the structures between the Yamato Basin and the Japan Basin. It was shown that the Japan Basin seems to have a structure similar to that of a typical oceanic basin. The Yamato Basin, however, was estimated to have a crust thicker than the Japan Basin. It is not clear yet whether the Yamato Basin carries a characteristic feature of the normal oceanic basin. In addition to these findings, the Yamato Rise was found to show a typical continental crustal structure (MURAUCHI, 1966).

More recently, land observations of a large explosion in the Japan Sea suggested the existence of azimuthal anisotropy of Pn wave velocity, *i.e.*, a five percent higher velocity along the NW-SE direction (OKADA *et al.*, 1978).

The above results are not definitive yet due to insufficient azimuthal coverage as well as lengths of seismic track lines. It is also noted that the lateral heterogeneity was not taken into account in the analyses of the data. These limitations and assumptions have a certain influence on the determination of the structural parameters.

## 2. Experiment

A series of seismic reflection and refraction studies was carried out during July 15–28, 1985 in the Yamato Basin: southeastrn part of the Japan Sea. Twenty ocean bottom seismometers (OBS's) were deployed along two lines A and B (Fig. II-1 and II-2) in order to obtain seismic records of high resolution (high signal to noise ratio as well as wide frequency range) as recievers. Airguns and dynamite charges were used as controlled sound signal sources. The longer NE-SW trending line (Line A) has a length of 230 km which is sufficient to determine the seismic structure of the lowest part of the crust in this area. The other line

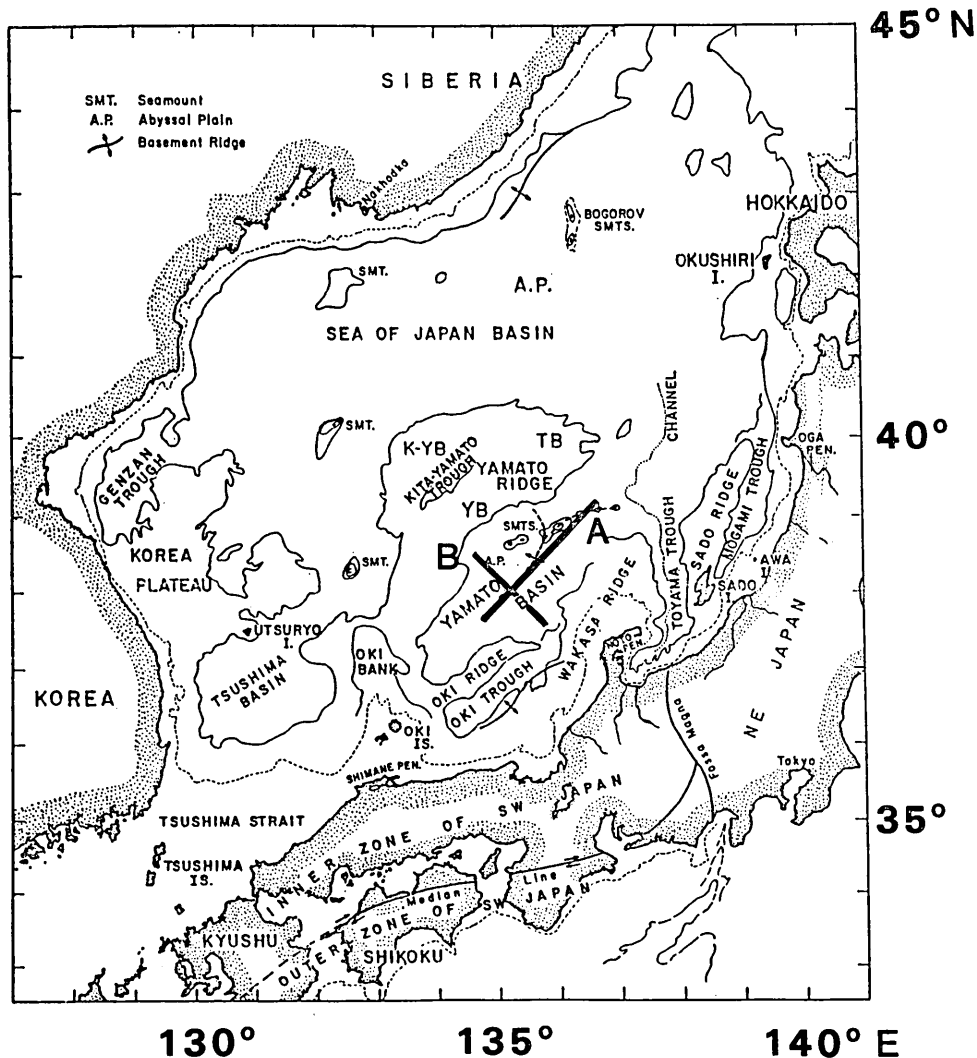


Fig. II-1. Map of the Japan Sea showing topography and locations of the present refraction profiles A and B in the Yamato Basin.

(Line B) perpendicular to Line A has a length of 130 km limited by the width of the basin. (Fig. II-2) Three types of OBS's were used in the experiment. Two of them were developed at the Earthquake Research Institute (ERI) (KASAHARA, 1981; NAGUMO *et al.*, 1982; KASAHARA *et al.*, 1984) and one at the Geophysical Institute (GI), the University of Tokyo with the cooperation of the Laboratory for Ocean Bottom Seismology, Hokkaido University (SHIMAMURA and ASADA, 1974; YAMADA, 1980; URABE and KANAZAWA, 1984). Four of twenty OBS's had digital recording systems and the rest had direct analog recording systems (DAR). All the

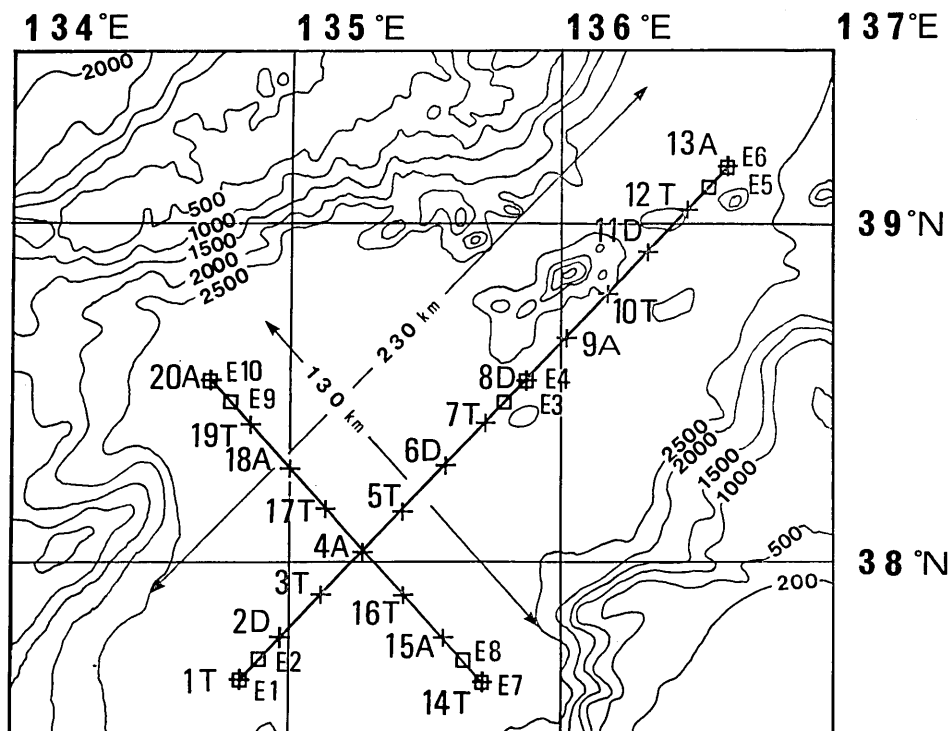


Fig. II-2. Positions of OBSs and large explosions. Crosses represent locations of OBSs, which are numbered and labeled A (acoustic command release type with an analogue recorder), D (an acoustic command release type with a digital recorder) and T (a timed release type). Squares indicate the positions of ten large explosions with a number and a label E. Isobaths are in meters.

OBS's were free-fall and either timer or transponder triggered pop-up type instruments and were successfully retrieved after the operation. The locations and the periods of observation for all OBS's are listed in Table II-1.

The sound sources consisted of ten large dynamite shots (300–500 kg) and 144 small dynamite shots (5, 10, 20 and 25 kg) amounting to five tons in total weight. They were mainly used to constrain the deep crust and the upper mantle structure. Information about large dynamite shots are listed in Table II-2. An airgun of large volume (20 liters) was also used in determining the seismic structure in the shallower part of the crust along the track Lines A and B. Shot instance of this airgun were controlled by regulating the pneumatic pressure from the research vessel. Therefore, there are some ambiguities in the shot instances. The corrections on the shot instances of the airgun were performed afterwards by using time records obtained by the hydrophone towed behind the research

Table II-1. Locations of ocean bottom seismographs and periods of observation.

OBS No	Type*	Latitude N		Longitude E		Depth (m)	Period JST	
		deg	min	deg	min		deployment	retrieval
1	T	37	39.99	134	49.98	2976	Jul 17 00:08	Jul 26 19:35
2	D	37	47.49	134	59.00	2994	Jul 18 13:58	Jul 26 22:11
3	T	37	55.02	135	07.91	2991	Jul 18 15:40	Jul 26 16:28
4	A	38	02.53	135	17.08	2994	Jul 18 06:34	Sep 15 11:32
5	T	38	09.94	135	26.00	2949	Jul 18 17:35	Jul 26 06:08
6	D	38	17.44	135	35.03	2982	Jul 18 18:37	Jul 27 10:18
7	T	38	24.97	135	43.98	3002	Jul 18 20:14	Jul 26 02:49
8	D	38	32.62	135	53.35	2722	Jul 18 21:31	Jul 27 13:42
9	A	38	39.98	136	02.10	2735	Jul 18 23:19	Sep 16 11:24
10	T	38	47.49	136	11.00	2720	Jul 19 00:57	Jul 25 23:03
11	D	38	55.05	136	20.06	2700	Jul 19 01:58	Jul 27 17:48
12	T	39	02.47	136	28.98	2647	Jul 19 03:55	Jul 25 19:21
13	A	39	10.05	136	38.01	2622	Jul 19 05:11	Sep 16 16:30
14	T	37	40.04	135	43.15	2854	Jul 17 04:50	Jul 27 05:26
15	A	37	47.62	135	34.29	2908	Jul 18 10:10	Sep 15 07:57
16	T	37	55.03	135	25.63	2961	Jul 18 08:32	Jul 27 02:30
17	T	38	09.92	135	08.38	3028	Jul 18 05:12	Jul 26 09:11
18	A	38	17.51	134	59.76	3020	Jul 18 03:05	Sep 15 15:17
19	T	38	25.24	134	50.98	3022	Jul 18 01:11	Jul 26 11:46
20	A	38	32.46	134	42.34	3023	Jul 17 23:06	Sep 15 17:42

\*A: acoustic command release type with an analogue recorder (ERI).

D: acoustic command release type with a digital recorder (ERI).

T: timed release type with an analogue recorder (GI).

Table II-2. Large explosions in DELP 1985 experiment.

No	Charge size (kg)	Shot time JST				Location				Depth (m)
		day	hrs	min	s	deg	N min	deg	E min	
E 1	500	Jul 20	18	51	17	37	40.05	134	50.01	2974
E 2	500	Jul 20	20	02	13	37	43.85	134	54.48	2986
E 3	300	Jul 20	08	25	13	38	28.70	135	48.56	2407
E 4	300	Jul 20	09	42	15	38	32.48	135	53.07	2334
E 5	500	Jul 19	12	35	19	39	06.08	136	33.56	2633
E 6	500	Jul 19	11	17	56	39	10.04	136	38.00	2621
E 7	350	Jul 21	09	08	43	37	39.98	135	42.98	2853
E 8	300	Jul 21	07	16	41	37	43.73	135	38.66	2879
E 9	300	Jul 21	18	53	05	38	28.80	134	46.76	3022
E 10	350	Jul 21	17	42	11	38	32.50	134	42.42	3024

vessel. The spacing between successive shootings of the airgun was about 350 meters. Another airgun with a nine liter chamber was used for obtaining continuous multichannel seismic reflection records.

### 3. Data acquisition and preliminary results

All the analog data were converted to digital records prior to data processing (KASAHARA, 1981; URABE and HIRATA, 1984). The seismic records of both the airgun as well as the dynamite were then stored in a series of digital magnetic tapes. The seismic records obtained by digital OBS's can use directly for data processing. Almost all records showed a good quality of signal to noise ratio as expected from experience obtained with the OBS systems deployed in the deep oceanic basins. However, some of the digital OBS's missed low level signals because the selection of the triggering parameters were not adjusted adequately. It is observed particularly for large dynamite shots that the sound signal could reach even beyond 200 km from the shot point to provide structural information on the deeper part of the crust and upper mantle. Some examples of seismograms are presented in Figs. II-3 through II-9. The main features which can be extracted from these figures will be described in the following.

#### 3.1. Sediments

The detailed structure of the sediments above the acoustic basement will be reported in Part III of this report. On the record sections of the 20 liter airgun at several stations (YB-4, 7, 13, 15, 16, 18), we can see refracted waves from velocity discontinuities in the sediments which appear as a later phase with apparent velocities lower than 3.5 km/s.

#### 3.2. Upper crust

The term "upper crust" is temporarily defined to mean the topmost part of the crust. This layer differs from the substratum with a higher velocity as described in the next section. A lateral inhomogeneity of seismic wave velocity structure is prominent in this part of the crust so that the appearance of the seismic record section differs from station to station. It is commonly observed, however, that the velocity increases continuously with increasing depth within this layer indicating some transient character of the layer from soft to hard conditions.

A P-wave velocity of about 3.5 km/s is identifiable in a couple of record sections from stations YB-9 and 13 (Fig. II-9) but not from other stations. The appearance of the first part of the arrivals of the seismic records varied depending on whether the basement has a layer of the

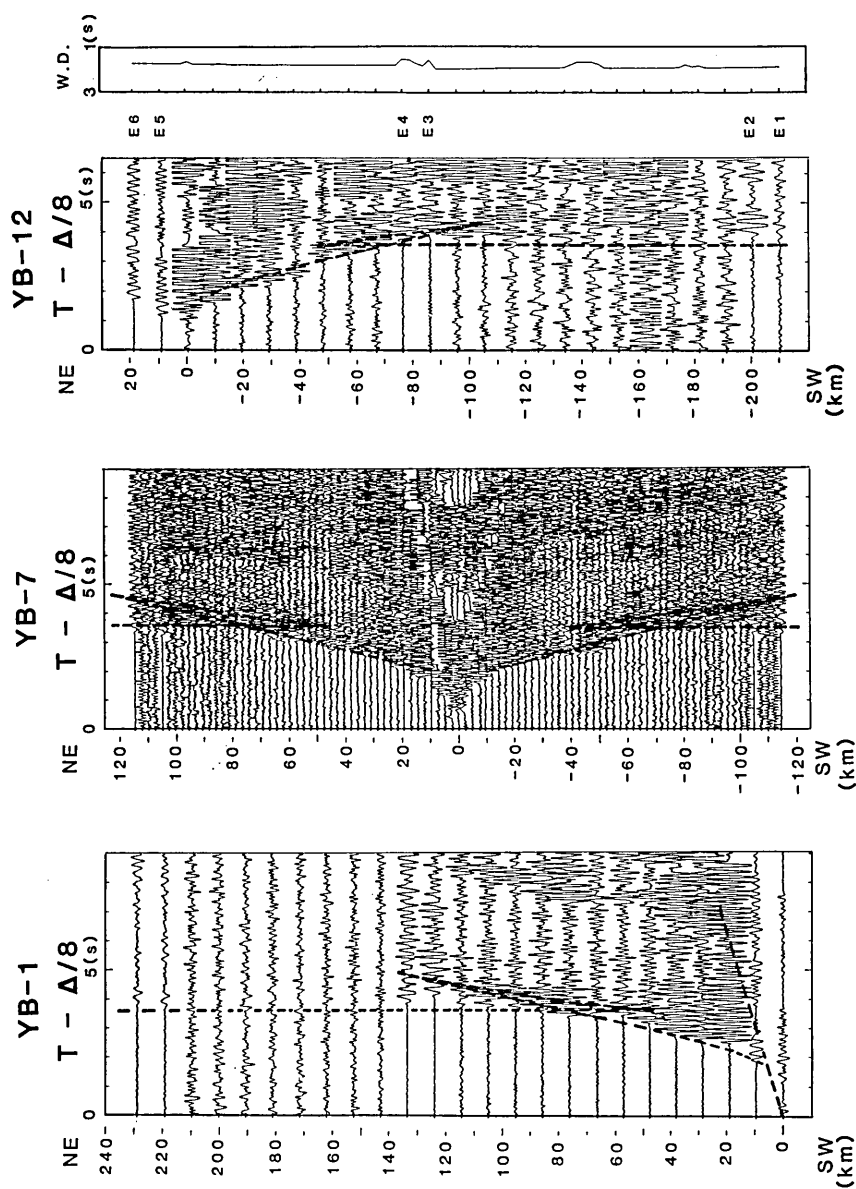


Fig. II-3. Examples of recorded seismograms obtained on Profile A. Records of three OBSs out of 13 are displayed on record sections with a reduction velocity of 8.0 km/s. Each panel consists of seismograms obtained by one OBS. Panels of YB-1 and YB-12 include records from ten large explosions and small explosions of 10, 20 and 25 kg in charge size. The record section of YB-7 includes those from small explosions of 5 kg. The Pn velocity of 8 km/s is clearly seen from the recorded seismograms. Broken lines show the calculated travel times for a preliminary velocity model (Model P) as shown in Fig. II-10. Amplitudes of each seismogram are corrected according to epicentral distances and charge sizes to improve a signal-to-noise ratio. One way travel time in a sea water column, which is displayed on the rightmost side in seconds, is reduced from individual travel time for correction of water depth.

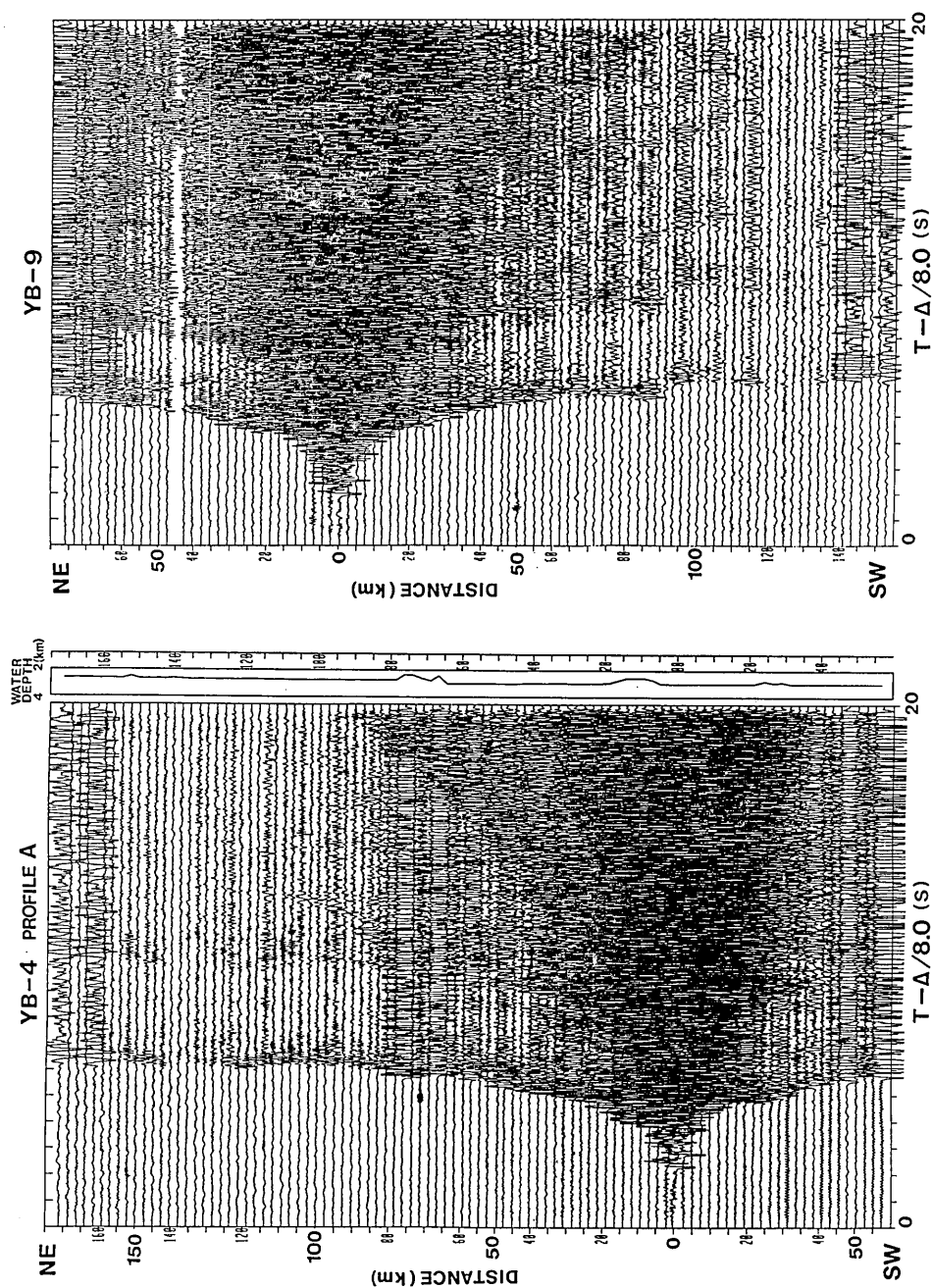


Fig. II-4. Examples of recorded seismograms obtained on Profile A. The reduction velocity is 8.0 km/s. All explosions on this profile are displayed. No amplitude corrections are adopted. For correction of bottom topography, one way travel time of difference between OBS's depth and water depth at explosion point are reduced from individual travel time.



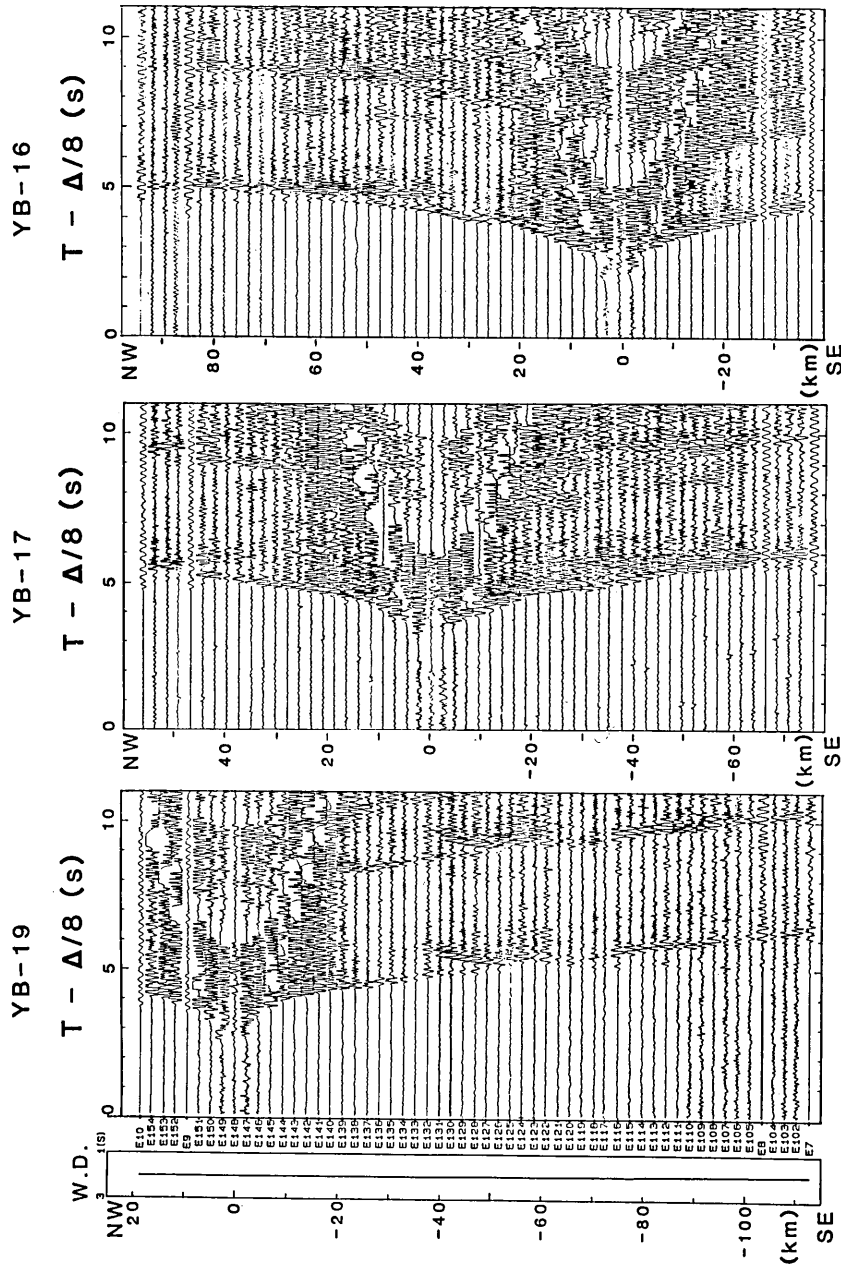


Fig. II-5. Examples of recorded seismograms obtained on Profile B. Each panel consists of records from all explosions on the profile. Amplitude corrections due to epicentral distance and charge size are performed. No correction due to water depth is made because of flat sea floor on the profile. Greater than 8.0 km/s of Pn velocity is clearly seen. Note that, since the thickness of sedimentary layer changes along the profile even though the water depth is constant, it is necessary to consider variation in the velocity and the thickness of the sedimentary layer to estimate the true velocity of Pn phase.

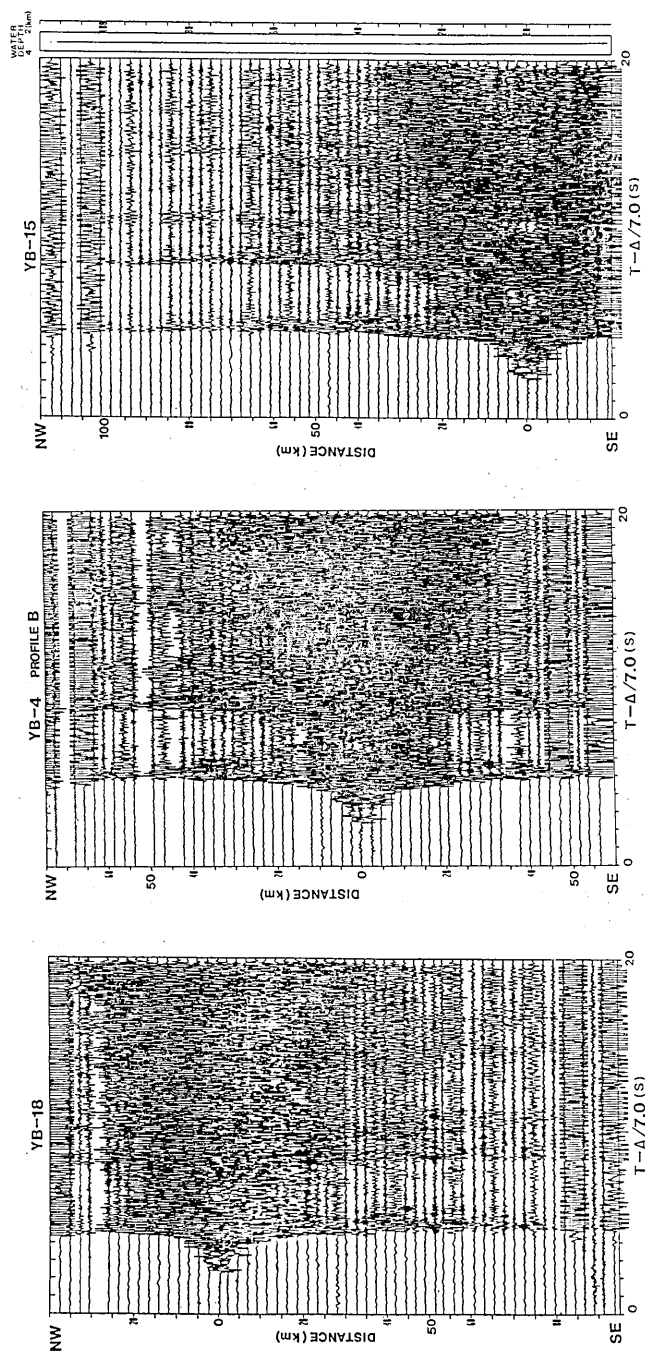


Fig. II-6. Examples of seismograms recorded on Profile B. Each panel consist of record from all explosions on this profile. The reduction velocity is 7.0 km/s. No amplitude corrections are adopted. Bottom topography corrections as same as in Fig. II-4 are performed.

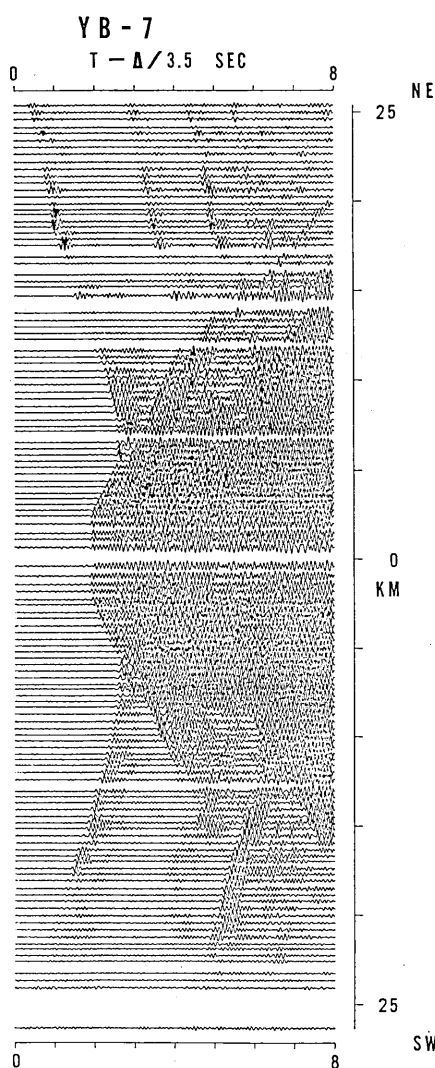


Fig. II-7.

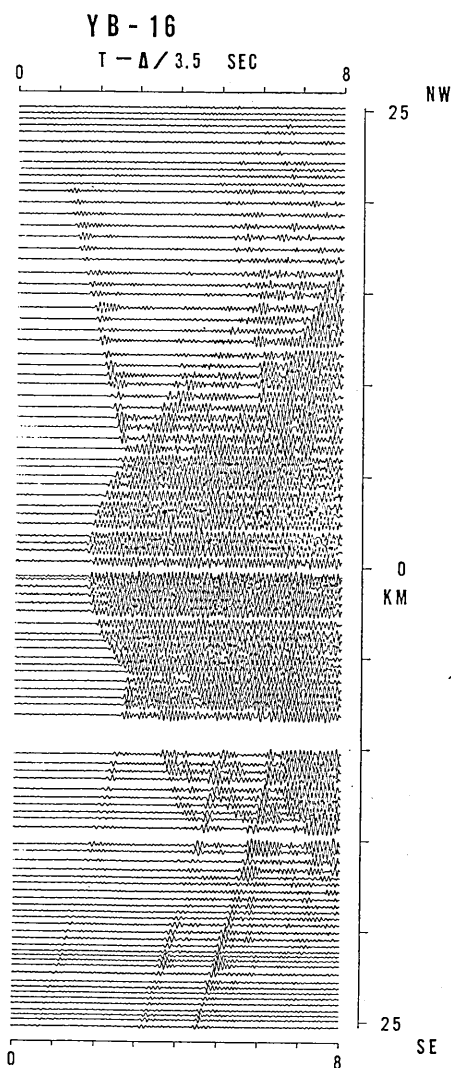


Fig. II-8.

Fig. II-7. Examples of seismograms recorded at YB-7 due to airgun shooting along the profile A. The reduction velocity is 3.5 km/s. It is clear that a seismic phase coming below the sedimentary layer has a velocity greater than 3.5 km/s and increases gradually with depth; no 3.5 km/s-layer is seen in the record section.

Fig. II-8. Examples of seismograms recorded at YB-16 due to airgun shooting along the profile B. The reduction velocity is 3.5 km/s-layer is identified in the record section.

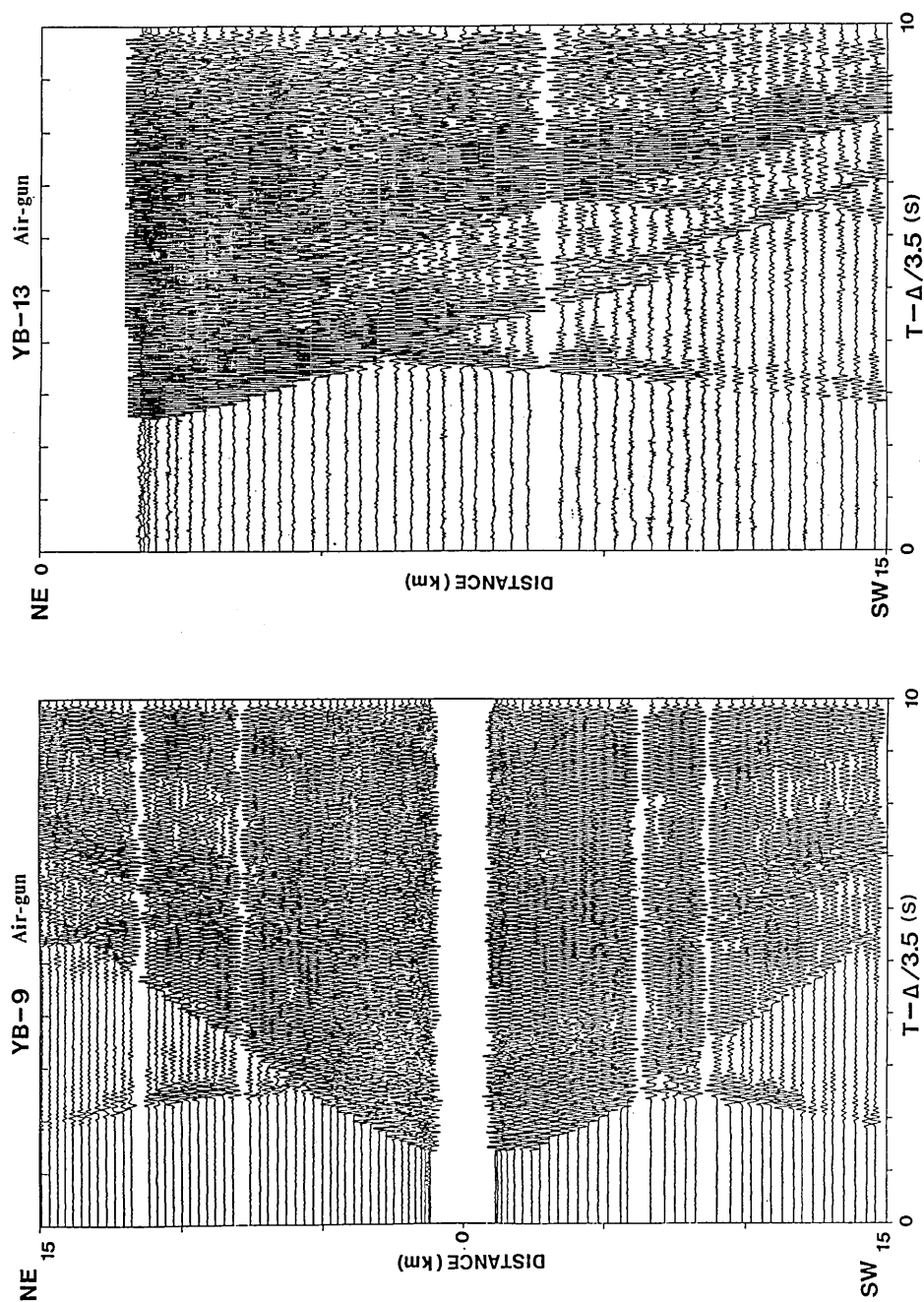


Fig. II-9. Examples of seismograms recorded at YB-9 and YB-13 due to airgun shooting along the Profile A. The reduction velocity is 3.5 km/s. The 3.5 km/s-layer is seen at epicentral distance 6-9 km.

velocity of 3.5 km/s or 4 km/s. Record sections of YB-4 and 9 show a lineup of first breaks having an apparent velocity around 6 km/s. However, it is quite possible that some lateral inhomogeneity, for example, topography of basement, may cause this feature. This problem has to be studied in detail in reference to various factors which have an influence on the seismic records.

### 3.3. Lower crust

The "lower crust" denotes the lower part of the crust underlying the upper crust defined above down to the Moho-discontinuity. Refracted waves from this layer can be observed on the record sections from every station. This phase appears as a first break at distances beyond 30-40 km from the shot points and can easily be traced all along the record section.

### 3.4. Pn velocity

Apparent P-wave velocity of the topmost layer of the mantle shows 8.0 km/s or higher along both Lines A and B. This phase becomes a first arrival beyond about 90 km for Line A and 60 km for Line B.

### 3.5. Crustal thickness

The crustal thickness of the Yamato Basin can be obtained in the first approximation from the Pn phase by assuming a constant-velocity flat-layered model. If we assume for simplicity the sedimentary structure given by LUDWIG *et al.* (1975), the average structure represented by the record section of station YB-7 gives the crustal thickness of 15 km, that is to say, the Moho-discontinuity can be at around 18 km subsurface depth. This shows that the crustal thickness is greater than the normal oceanic basins. However, this estimation can vary and the following factors shall be taken into account in further studies.

(1) Change of gradient in the velocity distribution with depth in the upper crust.

(2) Lateral inhomogeneity in the velocity structure.

(3) Topographic features from reflection study.

The preliminary result of this study is shown as Model P in Fig. II-10, where Model 150, the flat-layered model with constant velocity derived by LUDWIG *et al.* (1975), is also shown for comparison. The fundamental difference in these two models is that the Model P has a steep velocity gradient in the upper crust. Fig. II-11 shows calculated travel times for both models with observed seismograms. It is clear that the arrival of the phase corresponding to the 5.3-5.5 km/s layer of the Model 150 is not observed in the present record section. The travel time cal-

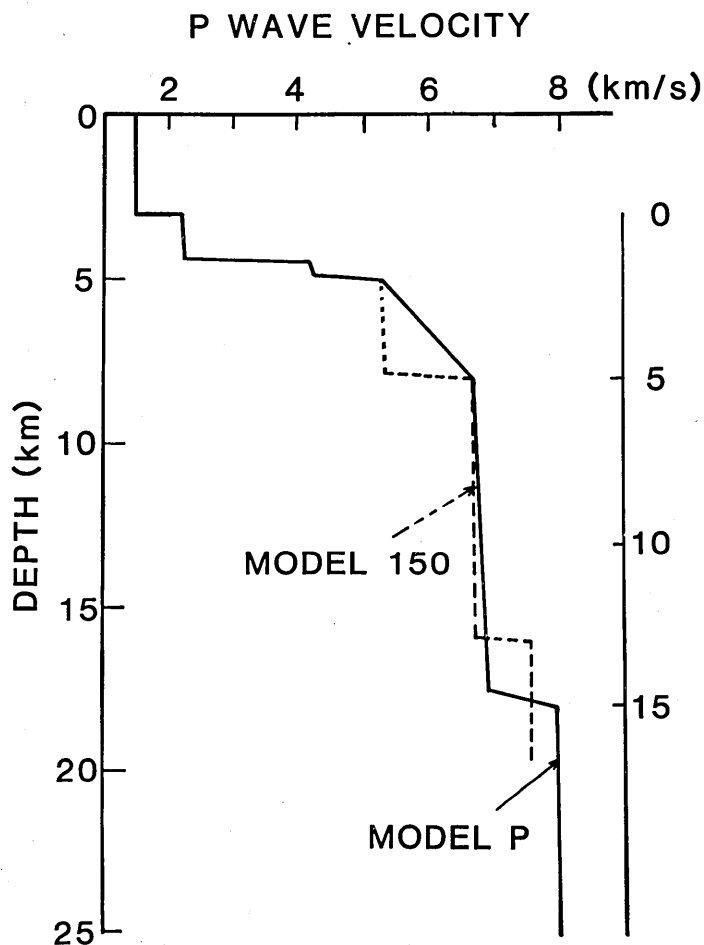


Fig. II-10. A proposed preliminary velocity model for the Yamato Basin (Model P) with comparison of Model 150 which is based on the results for site 150 of LUDWIG *et al.* (1975).

culated by our Model P is superimposed on Fig. II-3. We think that the general feature of the velocity structure can be well explained by the present one-dimensional model even though there are many variations of structure from station to station, especially in the upper crust.

#### 4. Results and discussion

The most important result of this preliminary report is that the P-wave velocity in the topmost part of the upper mantle ( $P_n$ ) is as high as that of the normal oceanic mantle. The previous study in the Yamato

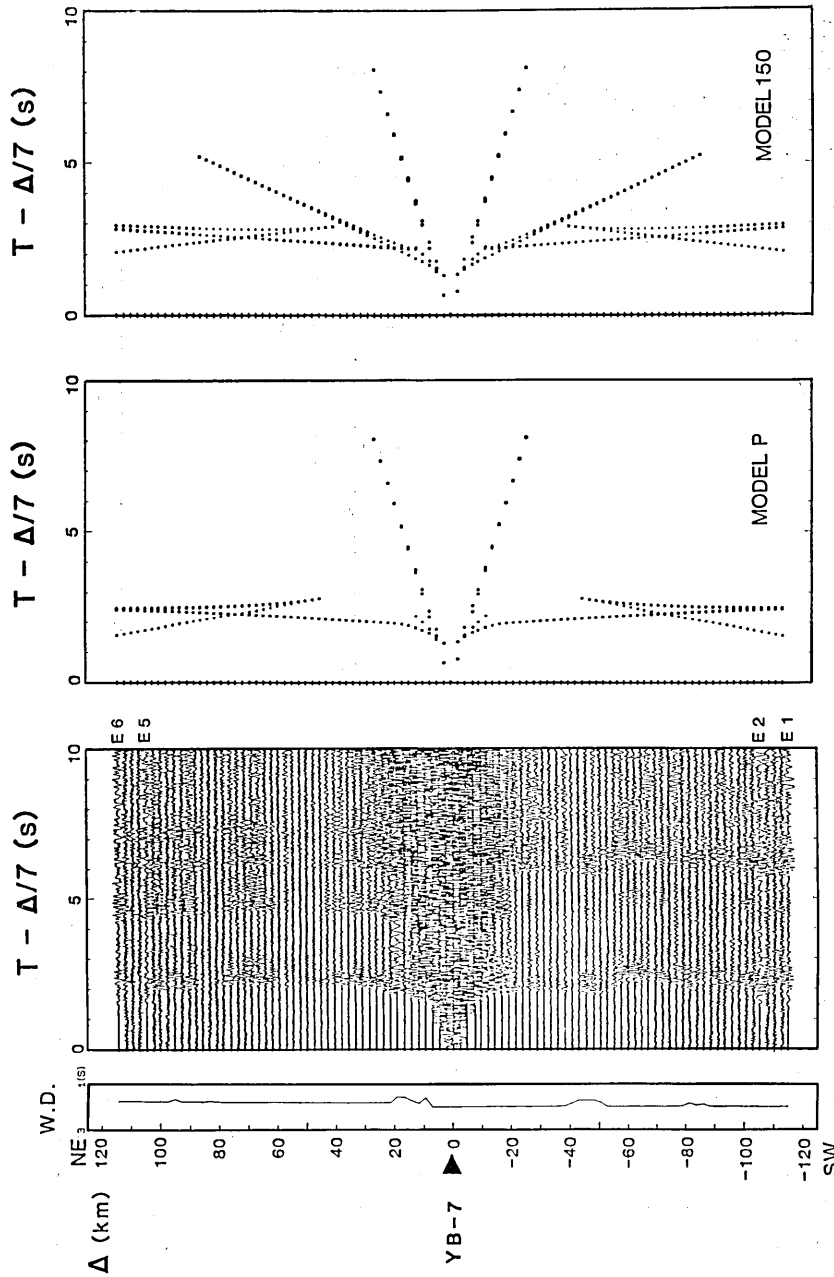


Fig. II-11. Calculated travel-times for Model P and Model 150 in an epicentral range within 110 km. Observed seismograms obtained at YB-7 are also shown for comparison. The reduction velocity is 7.0 km/s. Differences in travel-time curves for these models are prominent in the branch of 5.3 km/s-layer. No later phase for 5.3 km/s is clear in observed seismograms. Since the Pn phase becomes the first arrival in the epicentral range beyond 80 km in both models, it is necessary to measure seismic signals at distances of more than 100 km. Calculated traveltimes beyond 100 km in epicentral distances are displayed in Fig. II-3 on the observed record sections.

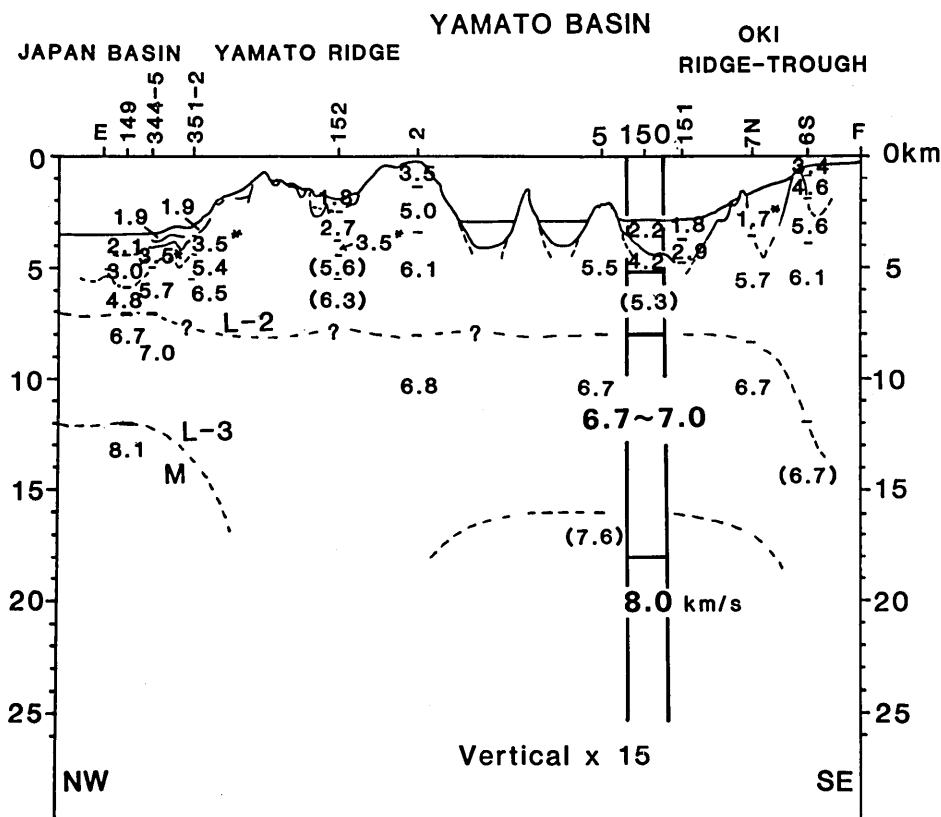


Fig. II-12. The preliminary results of the present study shown in a column at site 150 are compared with the previous results. Structures obtained by the previous studies are reproduced from Fig. 9 of LUDWIG *et al.* (1975).

Basin (LUDWIG *et al.*, 1975) suggested that the Pn velocity is about 7.6 km/s which is about five percent lower than the value obtained by the present model (Fig. II-12).

An anisotropic structure proposed by OKADA *et al.* (1987) suggests that the Pn velocity should be the lowest in the direction N55E. No indication of the anisotropic features of this magnitude could be found in the present observations and the apparent Pn wave velocity is in the range 8.0–8.1 km/s for two azimuthal directions which were selected as being parallel to the mini-max direction as proposed by OKADA *et al.* (1978). Obviously our data are less biased by lateral inhomogeneity. It is likely that there is no difference in Pn velocity along two lines A and B in the Yamato Basin. However, two-dimensional analyses must be performed to confirm this conclusion in further studies.



The main advantage in our observational condition as compared to the previous studies are the length of refraction lines, which is more than 200 km, and high signal to noise ratio of receivers. As seen in the recorded seismograms and travel time curves in Fig. II-11, if the total length of the profiles is limited to less than 100 km, it is difficult to determine the Pn velocity accurately.

The Moho-discontinuity at about a 18 km subsurface depth seems to be nearly twice as deep as that of the ordinary oceanic basins. This result is a natural extension of studies by MURAUCHI (1972) and LUDWIG *et al.* (1975).

It is quite difficult to determine a detailed seismic velocity structure in the upper part of the crust due to lateral inhomogeneity as well as the steep velocity gradient which is commonly observed in the oceanic crust. Had a flat-layered and laterally homogeneous structure been assumed, the seismic structure of the Yamato Basin is neither typically oceanic nor continental. A highly detailed two-dimensional analysis have to be performed by taking into account later phases, amplitude information, structure and topography of sediment layer which is obtained by multichannel profiler.

As to the thickness of the lithospheric plate of this area, it is important to refer to the results obtained by the surface wave studies. The thickness of the lithosphere beneath the Japan Basin is only 30-40 km (ABE and KANAMORI, 1970; EVANS *et al.*, 1978). If the lithosphere beneath the Yamato Basin has the same thickness as the Japan Basin, 30 to 50 percent of the lithospheric thickness is being occupied by the crustal materials in the Yamato Basin.

## 5. Conclusion

A detailed refraction measurement in the Yamato Basin, the south-eastern part of the Japan Sea, was conducted. Twenty OBS's were deployed and all of them were successfully retrieved with data of seismic signals of good quality, *i.e.*, high signal to noise ratio. Track lines for the present seismic surveys were aligned NE-SW (55 from north) and NW-SE (145) each 230 and 130 km long. Preliminary analyses show that the apparent Pn velocity beneath the Yamato Basin ranges 8.0-8.1 km/s without significant difference along the two track lines\*.

A trend of change in P wave velocity in the crust is similar to that of the typical oceanic crust, *i.e.*, a steep increase with depth in the upper crust. However, the subsurface depth of the Moho-discontinuity is about

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\* Added in proof: As regards the Pn anisotropy, its existence has been detected in the following detailed studies. The results will be published in near future.

18 km which is twice as deep as that of the typical oceanic basin. Therefore, the crust beneath the Yamato Basin can be characterized as neither oceanic nor continental.

The quality of retrieved seismograms were very good and the effect of lateral inhomogeneity on the preliminary results described so far in this report will be small. Further analysis, including two dimensional modelling of the velocity structure and waveform analyses, will enable us to extract much more valuable information on the structure of the crust and upper mantle beneath the Yamato Basin.

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## DELP 1985 年度日本海研究航海報告

### II. 大和海盆における屈折法地震探査

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大和海盆下の地殻及び上部マントル構造を調べるために、高密度の屈折法地震探査を行なった。測線 A (北東—南西方向, 測線長 230 km) およびこれに直交する測線 B (北西—南東方向, 測線長 130 km) に 20 台の海底地震計を投入した。音源には 154 発の火薬発破 (最大薬量 500 kg, 総計 5 トン) を用い、さらに全測線上でエアガンをかけた。

大和海盆の地殻は大きな速度勾配をもち、海洋性地殻に似た速度構造をもっている。しかし、モホ面の深さは約 18 km で通常の海洋地殻の 2 倍近い厚さがあり、典型的な海洋地殻とも大陸性地殻とも言えない。従来報告されていた Pn 異方性の速度最大および最小方向に平行に配置した AB 両測線で、Pn みかけ速度はともに 8.0-8.1 km/s であった。また、大和海盆に広く分布すると言われていた 3.5 km/s 層は一部の観測点でしか観測されず、局所的にしか存在しないと考えられる。