BULLETIN OF THE EARTHQUAKE
RESEARCH INSTITUTE
UNIVERSITY OF TOKYO
Vol. 64 (1989) pp. 149-162

Report on DELP 1987 Cruises in the Ogasawara Area

Part III: Seismic Refraction Experiment Using Airgun-OBSH for Fine Crustal Structure across the Ogasawara Trough along East-West Track Line

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(Received April 28, 1989)

Abstract

A refraction experiment using five sets of OBSH as receivers and an airgun as an artificial energy source was carried out to clarify the fine crustal structure in the Ogasawara Trough. The P (longitudinal) wave velocity structure of the sediments in the trough was determined. The structure model for the sediments consists of two layers, the upper layer with P wave velocity (Vp) of 1.8-2.2 km/s and the lower layer with Vp of 3.6-4.1 km/s. Although the entire thickness of the sediments decreases gradually from 5.5 km to 3.6 km toward the east, the upper layer shows an abrupt change in thickness at around the center of the trough, revealing discontinuity of the sedimentary structure from west to east. There is a bumpy unevenness of the interface underlying the sediments also in the central part of the trough. The location of this bump corresponds to the place where a fault-like dislocation structure is found by the multi-channel seismic reflection survey.

1. Introduction

Seismic reflection and refraction surveys were carried out in the Ogasawara Trough, an intra-arc basin located in the southern part of the Izu-Ogasawara arc and developed between the Shichito-Iwoto Ridge (active volcanic front) and the Ogasawara Ridge (Fig. 1). Recently, the Ogasawara Trough has been recognized to have been formed by past back-arc spread-

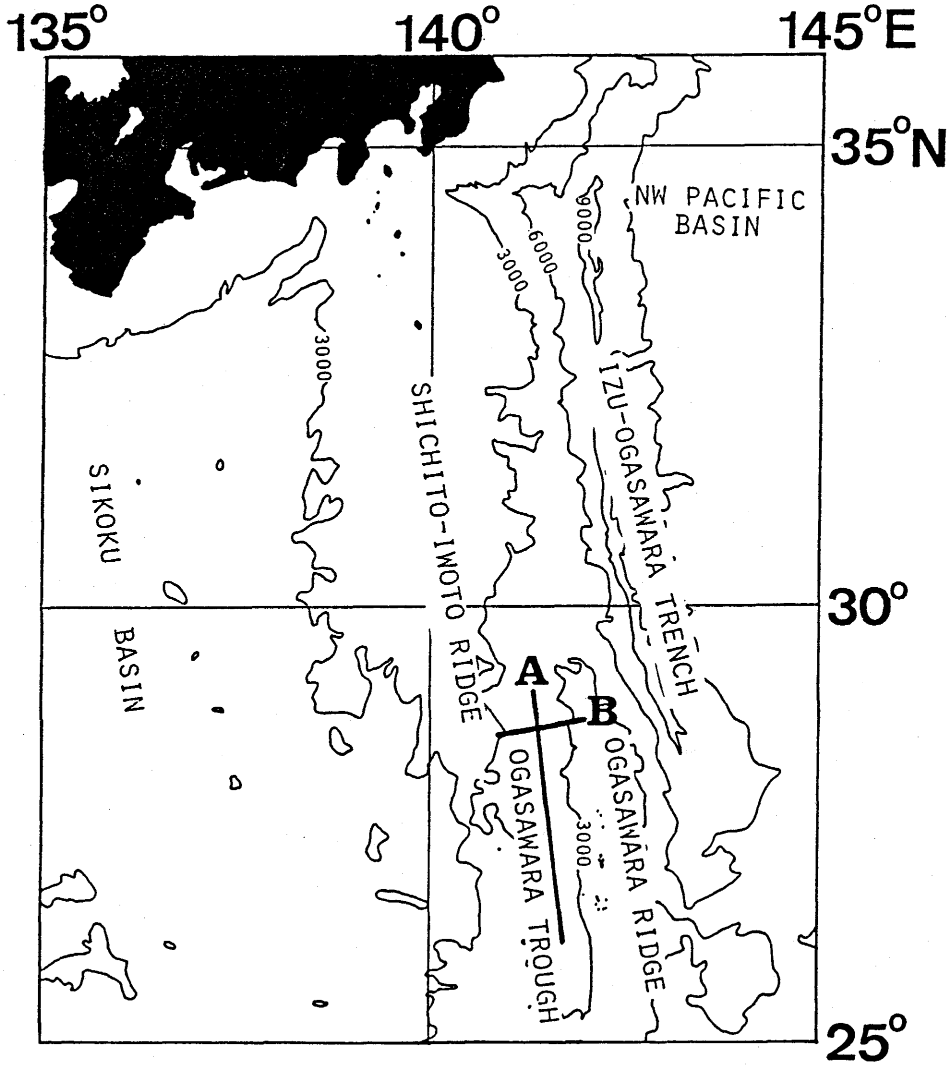

Fig. 1. Map of the Izu-Bonin arc region showing the seafloor topography. Locations of the refraction experiment lines A and B in the Ogasawara Trough are shown.

ing and is inactive during the recent period (HONZA and TAMAKI, 1985).

To understand the origin and geologic evolution of the trough, it is essential to clarify the crustal structure of the trough. However, in the Izu-Ogasawara arc region, there are a few previous studies on the seismic velocity structure using a refraction method (HOTTA, 1970; HOUTZ *et al.*, 1980; TANAHASHI *et al.*, 1981). Especially, in the Ogasawara Trough, the only previous refraction study by TANAHASHI *et al.* (1981) has revealed the P-wave velocity of the sedimentary layers using a radio sonobuoy, but the deeper structure remains unknown.

The subject of the present experiment was to reveal the seismic structure in the Ogasawara Trough which has been studied little to date. In this paper we will describe some preliminary results on sedimentary layers by a refraction survey using an airgun and OBSH (Ocean Bottom Seismograph and Hydrophone) system. Studies on multi-channel seismic profiling and another refraction experiment using explosive sources are discussed in the papers by ABE *et al.* (this issue) and KATAO *et al.* (this issue), respectively.

2. Outline of the experiment

A series of seismic reflection and refration experiments were carried out along two lines A and B (Figs. 1 and 2) in the Ogasawara Trough. The present study uses the results of the refraction experiment along Line B. The track line was E-W trending perpendicular to the N-S trough axis, and had a length of 130 km. Table 1 lists the locations of five OBSH stations: BT-12 through BT-16 deployed along this line. Positions of OBSHs were determined at the ship positions using LORAN-C and NNSS systems at the deployment of the OBSHs.

Each of five OBSHs used in this study was of free-fall and pop-up type by acoustic release and was equipped with three component seismo-

Table 1. Locations of OBSH stations.

Station	Latitude	Longitude	Depth (m)
BT-12	N28°35.12′	E140°49.49′	2565
BT-13	28°37.60′	141° 3.55′	3925
BT-14	28°42.15′	141°30.67′	4085
BT-15	28°44.01′	141°41.97′	3915
BT-16	28°46.58′	141°56.40′	1663

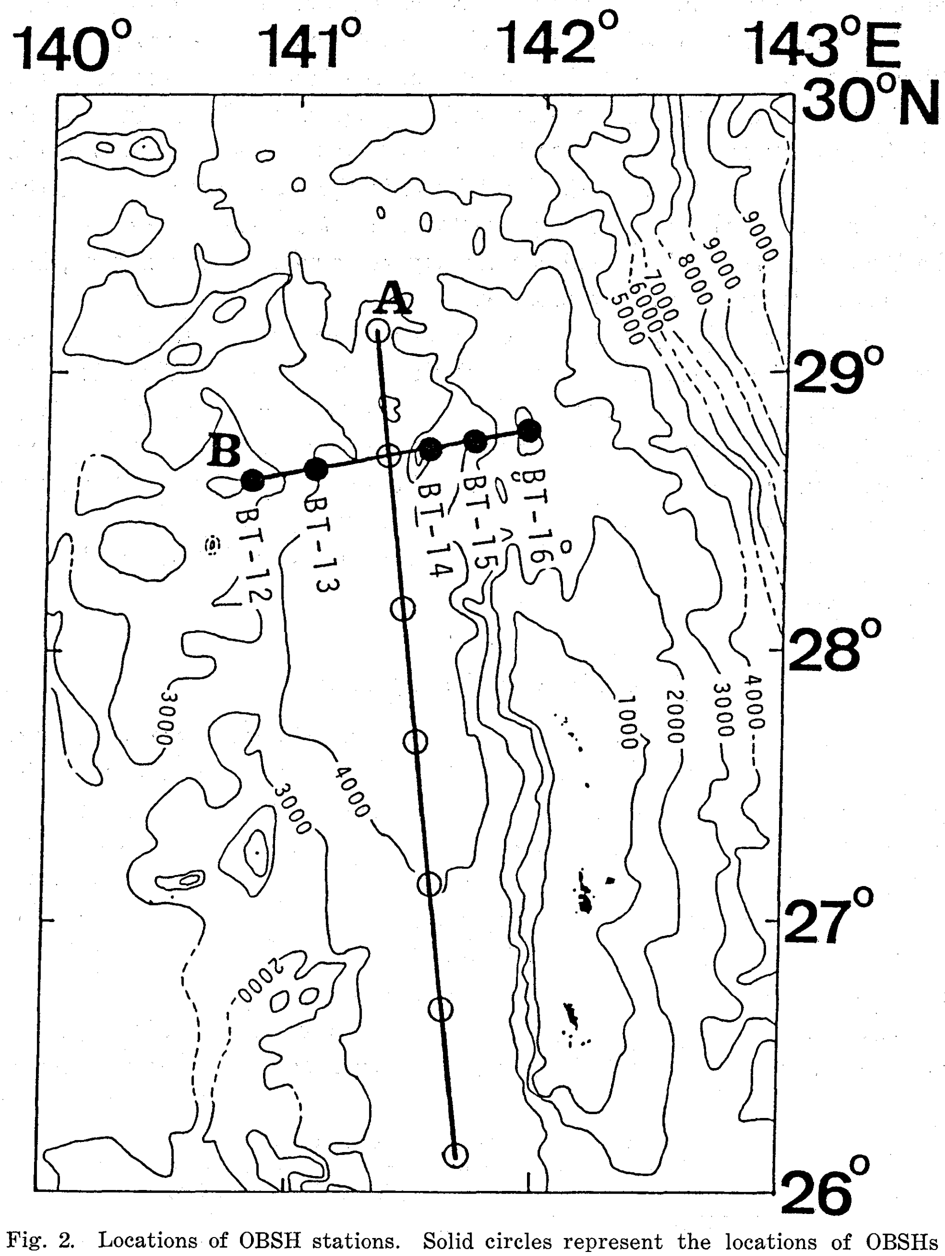

Fig. 2. Locations of OBSH stations. Solid circles represent the locations of OBSHs used in this study, which are named BT-12 - BT-16. Open circles indicate the position of OBSHs deployed along Line A for the refraction profile using explosive sources.

graphs, a hydrophone, a recording system, and a time code generator. All the OBSHs were successfully retrieved after the operation.

The controlled source, a 12 liter airgun (Bolt-1500 C), was fired every 50-80 seconds at a pressure of 10 MPa. This gave us shot intervals of approximately 100-160 meters which were dense enough to clarify a fine seismic velocity structure of the upper crust in the trough.

3. Data Acquisition and Analysis

The output signals of three component seismographs and a hydrophone were continuously recorded on cassette tapes with BCD coded time signals by direct recording. These signals were digitized prior to further process-

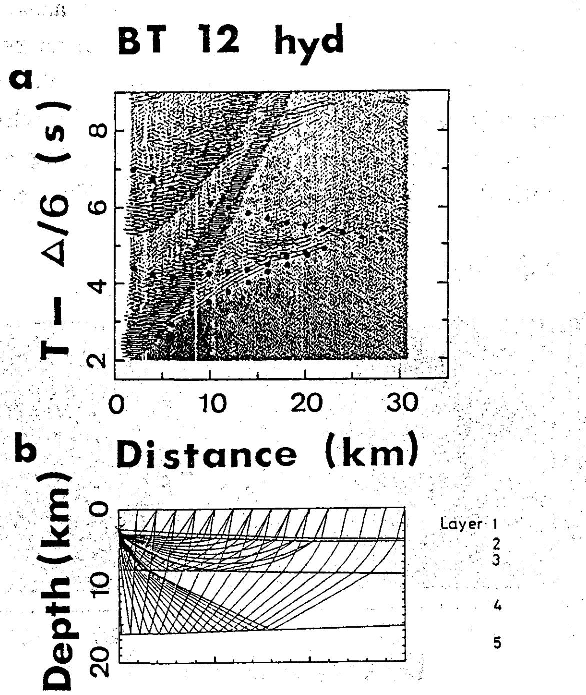

Fig. 3. a) Observed seismograms for BT-12 with plots of travel times calculated from the P wave velocity model shown below. Because of malfunction of the vertical component, hydrophone records are shown. The reduction velocity is 6.0 km/s. The data are band-pass filtered and the gain factor proportional to the square of the distance to enhance the distant seismograms. b) Velocity structure model and ray paths derived from two dimensional ray tracing. The top layer is the water layer. P wave velocity is that shown in Fig. 6 for each layer.

ing. The obtained digital data were sampled at the rate of 10 Hz. Thereafter, the digital record sections were prepared using shot time data corrected for the clock drift of each OBSH.

For the determination of shot-receiver distances, we used arrival times of direct water waves on the rectified hydrophone records and the water depths of the deployment locations of OBSH which were measured by 12 kHz PDR (Precision Depth Recorder). We assumed a constant water wave velocity of 1.5 km/s in this calculation.

Figs. 3 through 5 show the record sections obtained from three OBSHs, BT-12 through BT-14. Each trace in the record sections is digitally filtered with Butterworth band pass filter of bandwidth 5-12 Hz to suppress noise, and the amplitude is multiplied by the gain factor proportional to the square of the distance to enhance the distant phases.

Using the travel time data of refracted as well as reflected waves, in the present analyses we sought a structure model which consists of several homogeneous velocity layers. We derived a model in which the observed travel times fit the calculated ones obtained by using a two-dimensional ray tracing method with accuracy of ± 0.1 s. The computer program

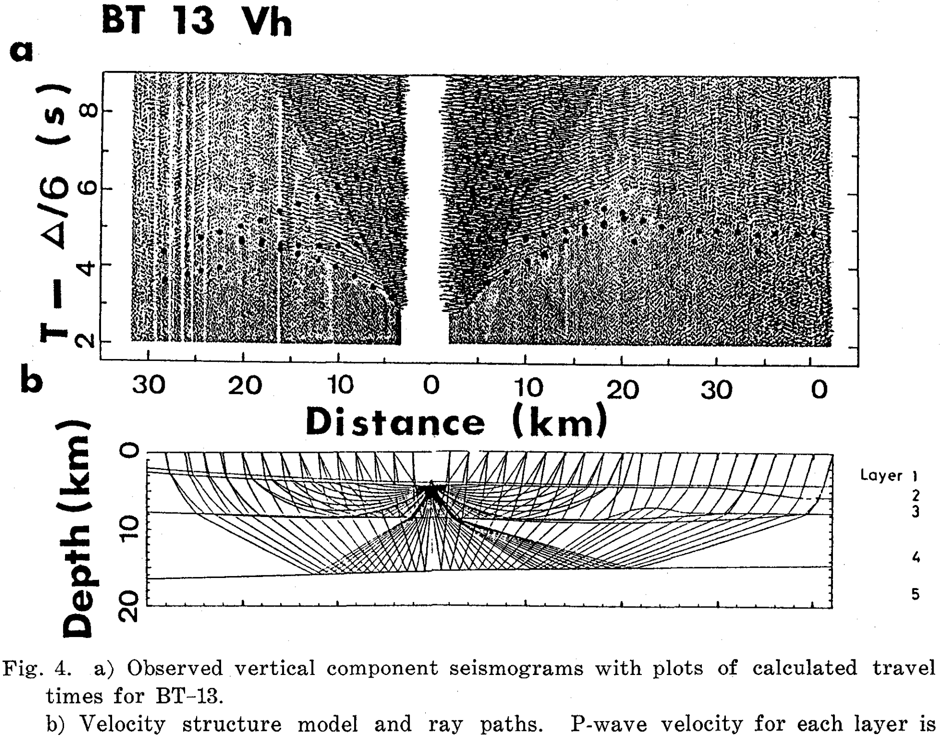

Fig. 4. a) Observed vertical component seismograms with plots of calculated travel times for BT-13.
b) Velocity structure model and ray paths. P-wave velocity for each layer is shown in Fig. 6.

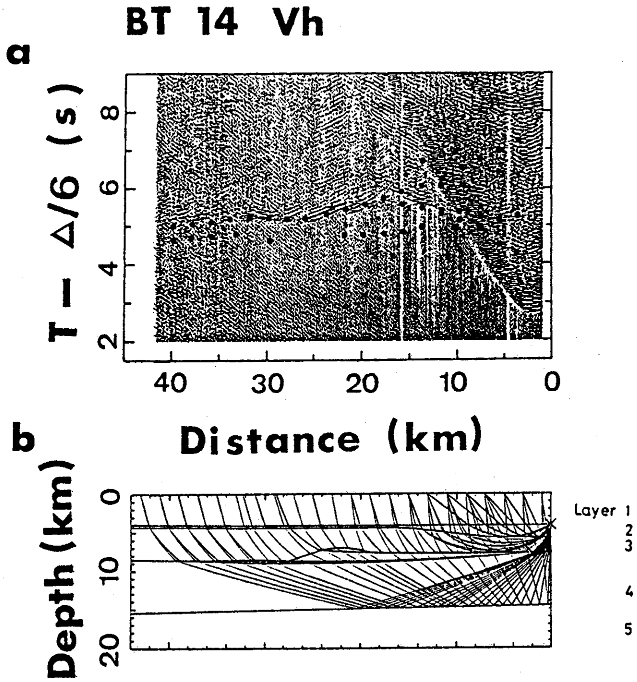

Fig. 5. Same as Fig. 4, but for BT-14.

used in the calculation of travel times was SEISOBS (HIRATA and SHINJO, 1986) which was a modified version of SEIS83 (ČERVENÝ and PŠENČÍK, 1983) particularly for OBS receivers. This ray tracing program treated a refracted wave as a diving wave in a medium with a vertical velocity gradient but not as a pure head wave. Thus by assuming a velocity gradient for each layer, we could determine an average velocity value.

We must also note here that it was often impossible to explain observed travel time curves by a homogeneous model although we tried to construct a model without any lateral heterogeneities. Even when lateral heterogeneities were introduced, we constrained them within the shallower part of the structure and made them as smooth as possible. In such a case, we referred to the records of the multi-channel seismic profiling along the same track line (ABE *et al.*, this issue).

4. Results

Missing of shots due to mechanical malfunctioning of the airgun (between BT-14 and 15) and the steep sea floor topography (between BT-15 and 16) made the travel time analyses difficult. We will show a preliminary crustal structure between BT12 and 14 revealed by our travel time analyses using two dimensional ray tracing.

Throughout the present analyses, we exclusively examine record sections of high gain vertical component (V_h; 96dB) because of their high signal-to-noise ratio. Only for the OBSH station BT-12, the hydrophone (hyd) records are analyzed since the records of the V_h component are not available owing to malfunction throughout the observation period.

For the reason that there seems to exist a large lateral changes in the structure, we divide the present model into two parts: 1. eastern side slope of the Shichito-Iwoto Ridge where the structure shows a little lateral change and 2. bottom of the Ogasawara Trough where a significant change in the structure is recognized. We can identify as many as five layers, which are named Layer 1-Layer 5 including the sea-water layer (Layer 1), and the basement (Layer 4), and the Moho discontinuity in most of the eastern side of the surveyed area.

4-1. The western side slope of the Shichito-Iwoto Ridge

OBSH stations BT-12 and BT-13 were located halfway upslope and at the foot of the Shichito-Iwoto Ridge, respectively. Figs. 3 and 4 show the record sections obtained from these two OBSH stations. These two record sections are similar to each other; thus the structure beneath this area may not change significantly. Since no signals from Layer 2 are observed, the P wave velocity for the layer is assumed to be 1.8-2.0 km/s in the ray tracing model.

Although the water depth increases gradually to the east, it appears that the apparent velocity of the first arrivals observed on both record sections at distances from 4 to 20 km is almost the same, i.e., about 4 km/s. Because a very small change in the thickness of Layer 2 is observed on the records of multi-channel seismic profiler (ABE *et al.*, this issue), the first arrivals at BT-12 must travel in the vicinity of the station faster than those at BT-13. Thus there seems to be a lateral velocity decrease toward the east in Layer 3.

Later arrivals with a large amplitude observed at distances from 4 to 20 km are interpreted as the wide angle reflection arrivals from the bottom of Layer 3. It is shown from the travel times of these arrivals that the thickness of Layer 3 increases toward the summit of the Shichito-Iwoto Ridge.

At distances larger than 20 km, some vague but coherent signals appear. These phases are assumed to be PmP phases. However, the refraction arrivals from Layer 4, which are supposed to be the first arrivals, can hardly be observed on the record sections. Assuming a P wave velocity of 6.5 km/s for Layer 4, the velocity previously determined value for the lowest part of the crust in the northern part of the Izu-Ogasawara arc by HOTTA (1970), we can infer that the depth of the Moho discontinuity is around 15 km below the sea-surface based upon the arrivals of PmP.

4-2. Central to eastern part of the Trough

In Fig. 5, the record section obtained from BT-14 located at approximately the center of the Ogasawara Trough is shown. On this record section we can identify a later phase as the reflected wave from the bottom of Layer 2. Analyzing the travel time curve of there reflected arrivals, we can estimate the P-wave velocity value for the layer as 1.8-2.2 km/s, which is consistent with our assumed velocity in the previous subsection.

The record section from BT-14 differs significantly from that obtained from BT-13 in the next three points. i) Reflection arrivals from the interface between Layer 2 and Layer 3 cannot be discriminated owing to smearing by reverberation of direct water waves at BT-13, though they were clearly observed at BT-14 as mentioned above. ii) Arrivals from Layer 3 recorded at BT-14 are about 1 second later than those at BT-13. iii) Both refraction and reflection arrivals from Layer 3 are observed only at the distance 10-18 km for BT-14 compared to those in the range of 4-18 km for BT-13. These differences suggest that Layer 2 is thicker under BT-14 than under BT-13.

The travel time of PmP arrivals observed at BT-14 are only about 0.2-0.3 seconds later than those at BT-13, while the difference in travel times of the arrivals from the shallower part are quite large as mentioned above. Provided that Layer 2 thickens abruptly right beneath station BT-14, both the travel time differences of arrivals from the shallow part and of PmP phases can be explained.

Let us explain why this model can explain the observations qualitatively. Refer to the ray-diagram shown in Figs. 4b) and 5b). In our model, both PmP phases for BT-13 and 14 propagate through the sedimentary 'pond' (where Layer 2 is thick) once, right beneath the shot point and the OBSH receiver, respectively. Therefore the travel time difference is not large. As for the other phases from the shallow part, those observed at BT-14 pass the 'pond' twice whereas those at BT-13 do not pass the 'pond'; then the difference in the travel times between them becomes large. Thus we can explain the travel times for all arrivals basically by a model in which Layer 2 changes its thickness from 5 to 15 km west of

BT-14.

In Figs. 4 and 5, PmP arrivals show a couple of convex features in common, for example between 20 and 30 km. These features cannot be explained by the variations of thickness or P wave velocity of Layer 2. It is suspected that the interface between Layer 3 and Layer 4 is not smooth. We try to model one of these convex travel time curves of PmP adjusting the interface by making a bump. Though this swelling of the interface is not constrained because of the poor density of shooting just above the swelling in this study, it can explain the convexity of PmP travel time curve well.

5. Discussion

The P-wave velocity structure model of the Ogasawara Trough obtained by analyzing data from three of the five sets of OBSH, from BT-12 through BT-14, is shown in Fig. 6. P-wave velocity values in Fig. 6 are vertically averaged since the vertical velocity gradient in each layer cannot be resolved by the present analyses.

The whole thickness of the top two sedimentary layers gradually becomes thin towards the east. However, the thickness of the upper sedimentary layer, Layer 2, shows an abrupt change at around the center of the trough. And this sharp change in the thickness of Layer 2 may be regarded as the representation of the east-west discontinuity in the sedi-

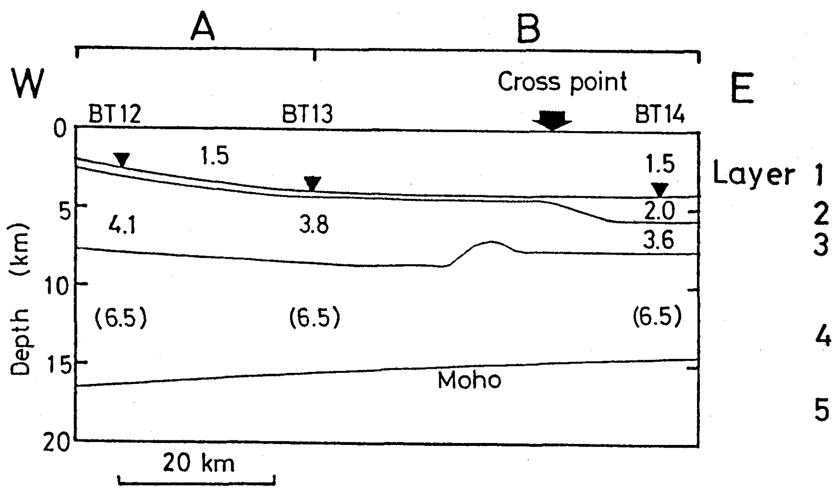

Fig. 6. Preliminary P-wave velocity structure model of the Ogasawara Trough. Averaged velocity value for each layer is given in units of km/s and that in brackets is assumed.

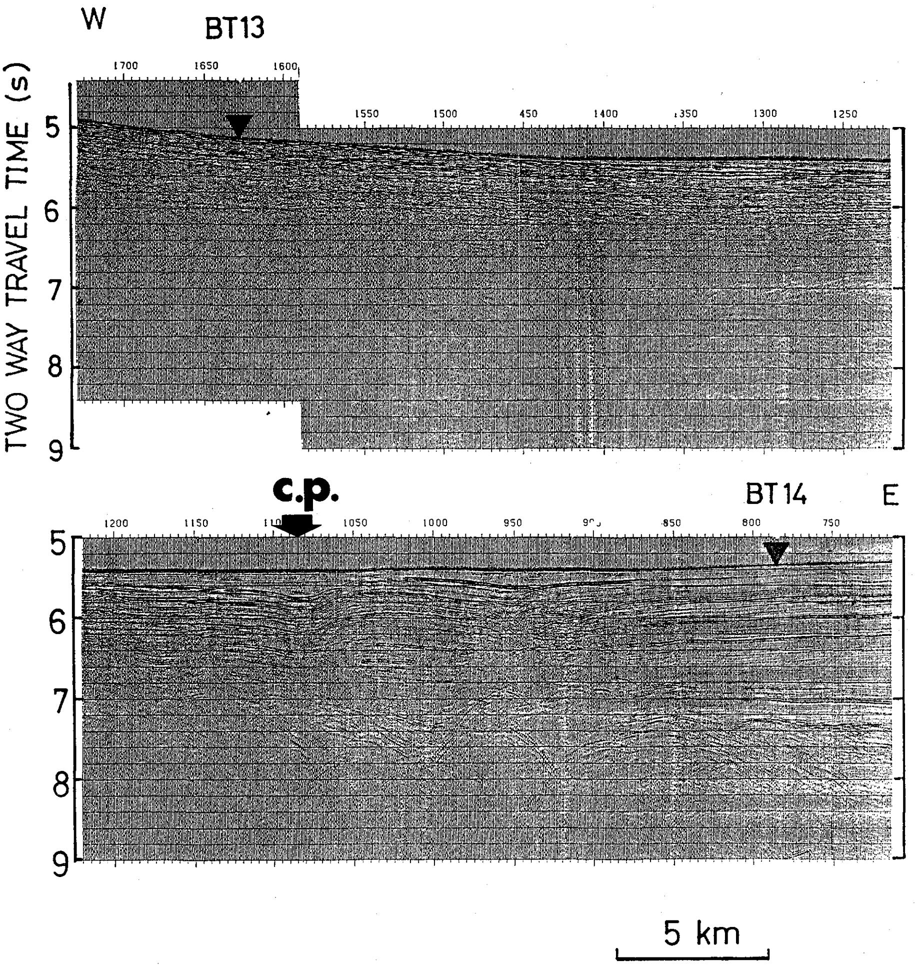

Fig. 7. Seismic profile obtained by the multi-channel reflection experiment conducted during the same cruise (ABE *et al.*, this issue) for the part corresponding to the region between BT-12 and BT-14. Triangles show locations of OBSH stations. Cross point ('c. p.') with the N-S trending line, Line A, is also indicated by an arrow.

mentary structure.

Fig. 7 shows the record obtained by a multi-channel seismic profiler (ABE *et al.*, this issue) in the eastern part of the modeled area in the present refraction study (part B by our nomenclature). It is recognized that acoustically transparent layers with distinct reflectors in the eastern side are contaminated by opaque materials at about 5 km west of the location of OBSH station BT-14. The location of this abrupt change in the sedimentary layers and that of the structure discontinuity in our model are almost the same. Layers 2 and 3 in our velocity model seem to correspond to the transparent layers and the opaque materials respectively.

Also, several faults on the acoustic basement are recognized in Fig. 7. The bump of the interface between Layer 3 and Layer 4 assumed in the present refraction study may correspond to these faults.

The results of another refraction experiment using explosive sources and OBSHs along Line A (KATAO *et al.*, this issue) show that the P wave velocity for the lowest part of the crust is 6.3–6.7 km/s and that the depth to the Moho discontinuity is about 18 km subsurface at the cross point. Since both their and our models contain several assumptions, i. e., the shallower structure for the model of KATAO *et al.* and the velocity of the lower crust in the present model, it is difficult to compare them in detail.

6. Conciusions

We conducted a refraction experiment using an airgun-OBSH system in the Ogasawara Trough along a track line approximately perpendicular to the trough axis. Preliminary analyses from three of the five OBSH stations along this track line, BT-12 through BT-14, revealed the fine P-wave velocity structure of the upper crust in the trough. The sediment structure consists of two layers, the upper layer with a P-wave velocity of 1.8–2.2 km/s and the lower layer with that of 3.6–4.1 km/s. The total thickness of the sedimentary layers decreases gradually from 5.5 km to 3.6 km toward the east in the trough. The sediment structure changes suddenly around the center of the trough, i. e., the lower layer occupies most of the sediments in the western part, while the upper layer with a lower velocity is thick in the eastern part.

It appears that the interface underlying the sediments shows unevenness around the central part of the trough where several faults are identified by study of the multi-channel seismic profile. This unevenness of the interface may be a manifestation of these faults.

Although no refraction arrivals from the lowest part of the crust were observed at any OBSH station, arrivals of PmP were available. Assuming the P wave velocity for the lowest part of the crust from the previously published result, we estimated the depth to the Moho discontinuity at around 15 km.

Since the present model involves some uncertainties in the deeper part, it could be refined through analysis of observations of explosions along the same track line as the present airgun-OBSH experiment for further consideration of tectonic complexities around the Ogasawara Trough.

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DELP 1987年度　小笠原海域航海報告

III：エアガン－ハイドロフォン付海底地震計による屈折法地殻構造探査

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小笠原トラフ下の地殻精密構造を調べるために，5台のハイドロフォン付海底地震計とエアガンを用いた屈折法地震探査を行なった．エアガンの測線はトラフ軸に直交する東西の測線（測線長 130 km）で，エアガンを約 100-180 m おきに高密度でショットさせることにより，トラフ軸を横切る方向の構造の変化をとらえることができた．

小笠原トラフ下の堆積層は2層からなる速度構造をもっており，全体の厚さは東に向かって 5.5-3.6 km と徐々に薄くなっている．最上部堆積層の P 波速度は 1.8-2.2 km/s，その下の層の P 波速度は 3.6-4.1 km/s である．最上部堆積層の厚さはトラフのほぼ中央で急激に東側にむかって厚くなっていて，トラフ内の堆積構造は東西で異なっている．トラフの中央部ではこれらの堆積層の下側の境界面が平旦でないことが PmP の走時から示され，このことはマルチ・チャンネル反射探査で音響基盤に認められた断層の存在と調和的である．