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Report on DELP 1986 Cruises in the Northwestern Pacific Part II: Oceanic Crust of the Basin

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Abstract

A large scale seismic experiment was carried out in the northwestern Pacific Basin in 1986. Two long range profiles were shot using OBS's and explosives to investigate the nature of the lateral heterogeneity and anisotropy of an old oceanic lithosphere. An airgun array was also used as a controlled seismic source. Three airgun profiles were shot in order to obtain a detailed crustal structure of normal ocean type and to constrain the deeper structure obtained from the long range profiles.

A seismic wavespeed model for both P and S waves is presented. The model seems adequate to represent the crust sampled over 700 km distance. The model is in good areement with the model previously obtained near DSDP Hole 581C. However, our data do not substantiate the presence of LVZ in the lower crust.

1. Introduction

A large scale inter-university cooperative seismic experiment was carried out in the northwestern Pacific Basin in July, 1986 under DELP and the Earthquake Prediction Program. Two long range profiles were shot using 30 OBS's and 16 tons of explosives in order to investigate the detailed structure of the oceanic lithosphere. We also shot airgun-OBS profiles to study the details of the oceanic crust and to gain resolution of the deeper

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part. This paper presents results on crustal structure of the area.

Previously, few studies have been done in this area, probably because there are not many geological features. However, this was the very reason to choose this site for this experiment; what is normal oceanic crust? Unfortunately, the geomagnetic lineation does not seem to be continuous along our airgun profiles, which parallel M-series found further southward in the basin (NAKANISHI, personal com.). The age is inferred to be older than 100 Ma (HILDE *et al.*, 1976; NAKANISHI, *et al.*, 1989).

DUENNEBIER *et al.* (1987) reported the crustal structure in the vicinity of the DSDP Hole 581 C, which is located at the northeastern corner of our experiment. Their isolated-sensor analog continuous recording OBS at 43.9°N, 139.8°E received the Soviet 30-liter airgun shots and explosive shots. The profile was single-ended in the NS direction with about 55 km length. Their model has a low wavespeed zone both for P and S waves in the lower crust. It is similar to that obtained by ANOSOV *et al.* (1982) south of the Shatsky Rise. Another profile in the EW direction was shot and recorded by the OSS (Ocean sub-bottom seismograph) emplaced in

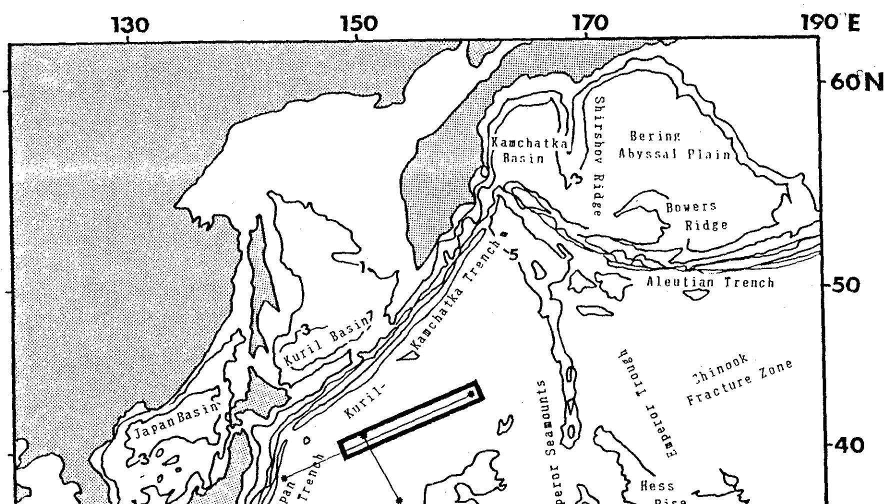

Fig. 1. General map of the northwestern Pacific region and the two long range seismic refraction profiles. A blow-up of the area shown by a rectangle is given in Fig. 2.

Hole 581 C. The record implied a difference in structure from the NS model. However, its relation to anisotropy or lateral heterogeneity remained unclear.

2. Experiment

Fig. 1 shows the general area map of the northwest Pacific Basin. The bathymetry is rather flat northwest of the Shatsky Rise. The airgun profiles were shot as shown in Fig. 2. Only a segmented portion of the long range profile could be covered due to airgun malfunctions. Airgun records from three OBS's (6, 10, and 17) were analyzed. Also, a single channel hydrophone streamer record was available.

We constructed an airgun towing device to tow two BOLT 1500 C airguns with large chambers (12 liters$\times$2) with 4 m spacing. A third airgun could be towed in an ordinary fashion from the other side of the ship. The output energy from a non-interactive airgun-array would be larger than that from a single airgun with the same total air chamber volume, since the output power of an airgun is proportional to the 1/3 power of the chamber volume. We achieved 4 m separation between guns to minimize interaction (*e.g.* VAAGE *et al.*, 1984).

These guns were towed at 5 knots at approximately 10 m depth. The air was compressed to 100 kg/cm^2 and exhausted every 60 sec. The shot times were corrected against a master clock with an accuracy of 10^{-9}, which was also used to calibrate the OBS clocks. The shot times of the three airguns were controlled by a micro-computer for synchronization.

The parameters of the three airgun profiles are given in Table 1. The ship positioning was chiefly done by LORAN-C with the aid of NNSS and GPS. LORAN-C was not operating properly during Profile I, so that

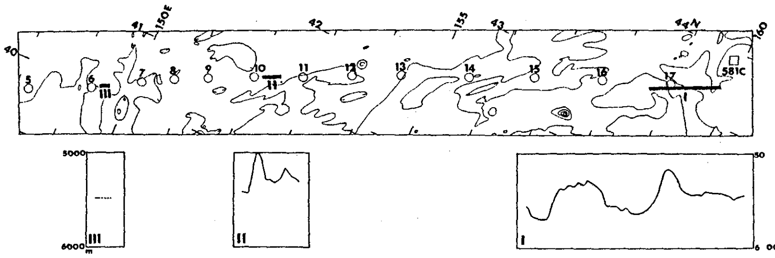

Fig. 2. Airgun profiles I, II, and III are shown by thick lines. Three portions of EW long range profile were shot by either 12$\times$2 or 12$\times$3 liter airguns. Circles are OBS's. Sea floor topography along profiles from PDR readings is also shown.

Table 1. Airgun Profiles.

DATE	TIME (JST)	LAT	LON	DEPTH	SHOT*	
Profile I						
Airgun configuration: 2-gun (24 liters)						
JUL 19	17 : 44				001	
	18 : 30	43 42.51	160 11.74	5487	032	
	20 : 07	43 26.90	159 39.29	5595	135	NNSS
	20 : 53	43 24.43	159 33.14	5454		NNSS
	21 : 57	43 20.97	159 25.37	5169	245	NNSS
	22 : 41	43 18.55	159 19.72	5474	289	NNSS
	23 : 37	43 15.91	159 12.18	5690		NNSS
	23 : 44	43 15.61	159 11.34			NNSS
JUL 20	00 : 31	43 13.24	159 05.07	5491	399	NNSS
	00 : 44	43 12.79	159 03.49	5611		NNSS
	01 : 22	43 10.91	158 58.53	5441		NNSS
	01 : 30	43 10.55	158 57.60	5409	458	NNSS
	02 : 30	43 08.40	158 45.36	5371	518	NNSS
	02 : 47	43 07.62	158 48.10	5315	535	NNSS
	04 : 17	43 04.16	158 37.57	5752		NNSS
	04 : 34	43 03.57	158 35.49	5860	642	NNSS
	05 : 00	43 11.38	158 48.26	5693	668	
Profile II						
Airgun configuration: 3-gun (36 liters)						
JUL 21	19 : 23	41 10.98	152 23.71	5254	001	
	20 : 00	41 09.88	152 19.59	5279		
	21 : 00	41 07.33	152 12.88	5087		
	21 : 41	41 05.27	152 07.88	5492	158	
	21 : 56	41 04.34	152 05.97			NNSS
	21 : 56	41 04.59	152 06.14	5422		
Profile III						
Airgun configuration: 3-gun (36 liters)						
JUL 22	17 : 46	40 07.25	149 33.84	5372	001	
	18 : 21	40 05.33	149 29.80			NNSS
	18 : 21	40 05.65	149 30.04	5460		
	18 : 42	40 04.68	149 27.64	5472	079	

* pressure was 100 kg/cm^2 and shot interval was 60 s throughout.

positions by NNSS fixes were mainly adopted. OBS positions are taken from the position of the ship at deployment (Table 2).

The OBS's which recorded airgun signals were of two types; with and without a hydrophone other than the three component geophones (Table 2). Both had analog cassette recorders enabling six recording channels of signals plus the time code channel to be used.

Table 2. OBS parameters.

Profile	OBS	LAT	LON	Cepth	Coverage (E+ W−)
I	17	43°15.32′	158°57·03′	5564 m	+83 km (18 : 30) to −41 (05 : 00)
II	10	41 01.31	151 58.40	5303	+40 to +15
III	06	40 00.46	149 17.47	5330	+26 to +16

* OBSH 06 had a 3 Hz vertical and two-component 4.5 Hz horizontal geophones and a hydrophone. Two channels with high (90 dB) and low (62 dB) gains were assigned for the vertical. Two channels were for horizontal components with 66 dB gain each. The hydrophone signal was divided into normal 60 dB gain and high frequency rectified 66 dB gain channels.
* OBS 10 and 17 had 4.5 Hz 3-component geophones divided into 3-gain vertical, 2-gain horizontal and other horizontal channels.

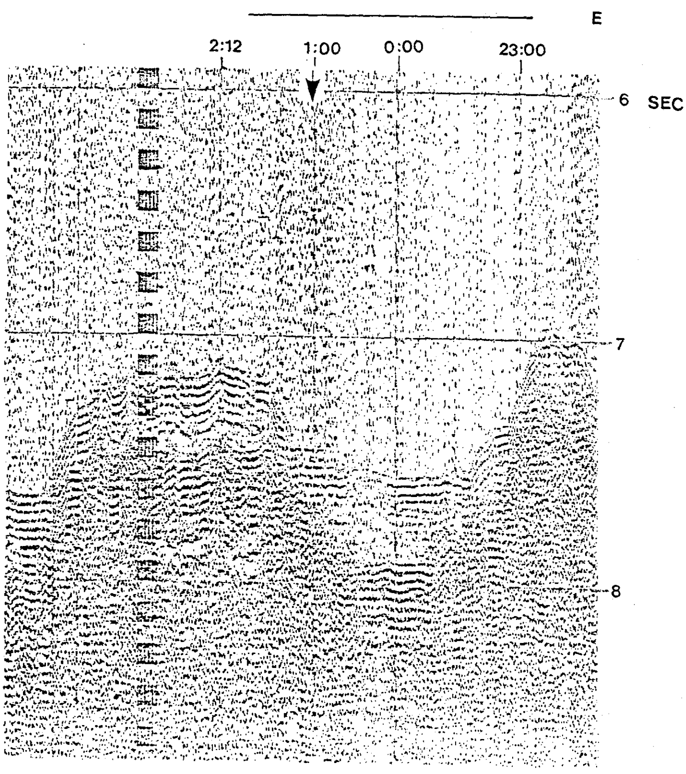

Fig. 3. Airgun shots recorded by a single channel hydrophone streamer for Profile I. The position of OBS 17 is shown by an arrow.

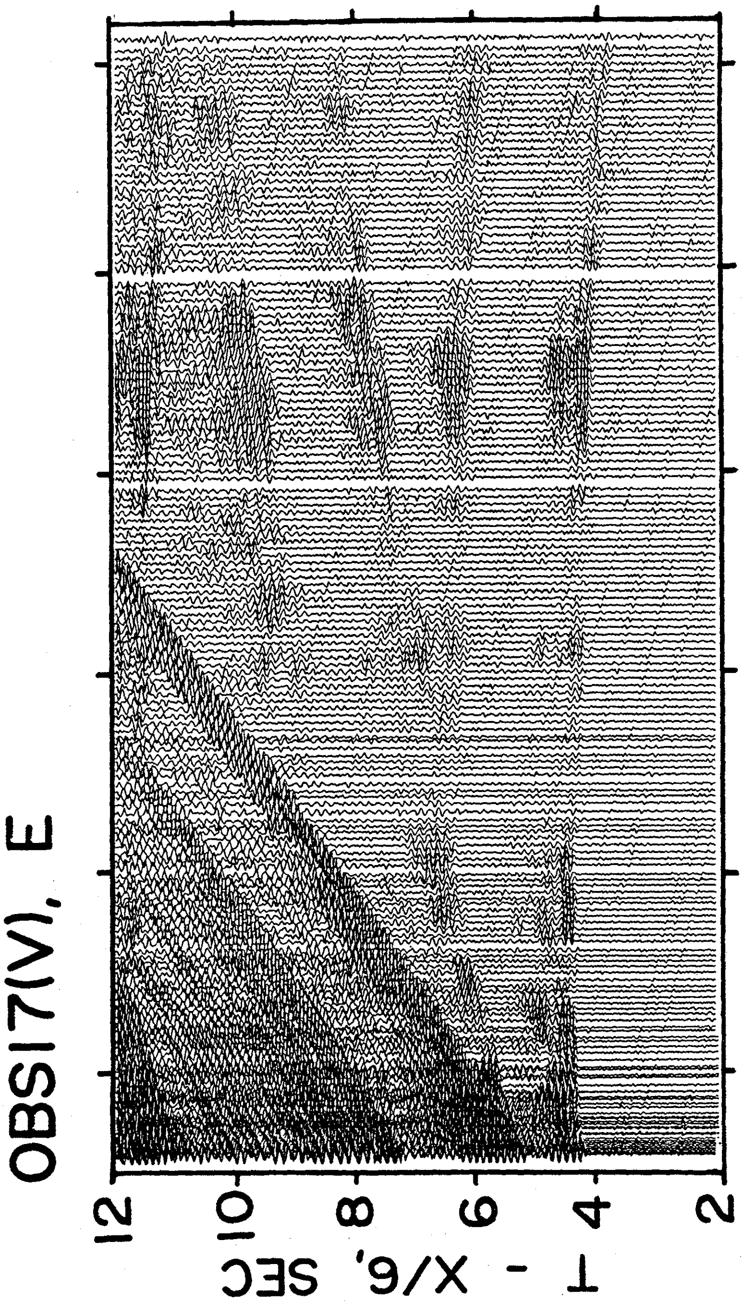

Fig. 4. Vertical record section of eastern part of OBS 17 for Profile I. Signals with infinite apparent wavespeed are time code cross-talks.

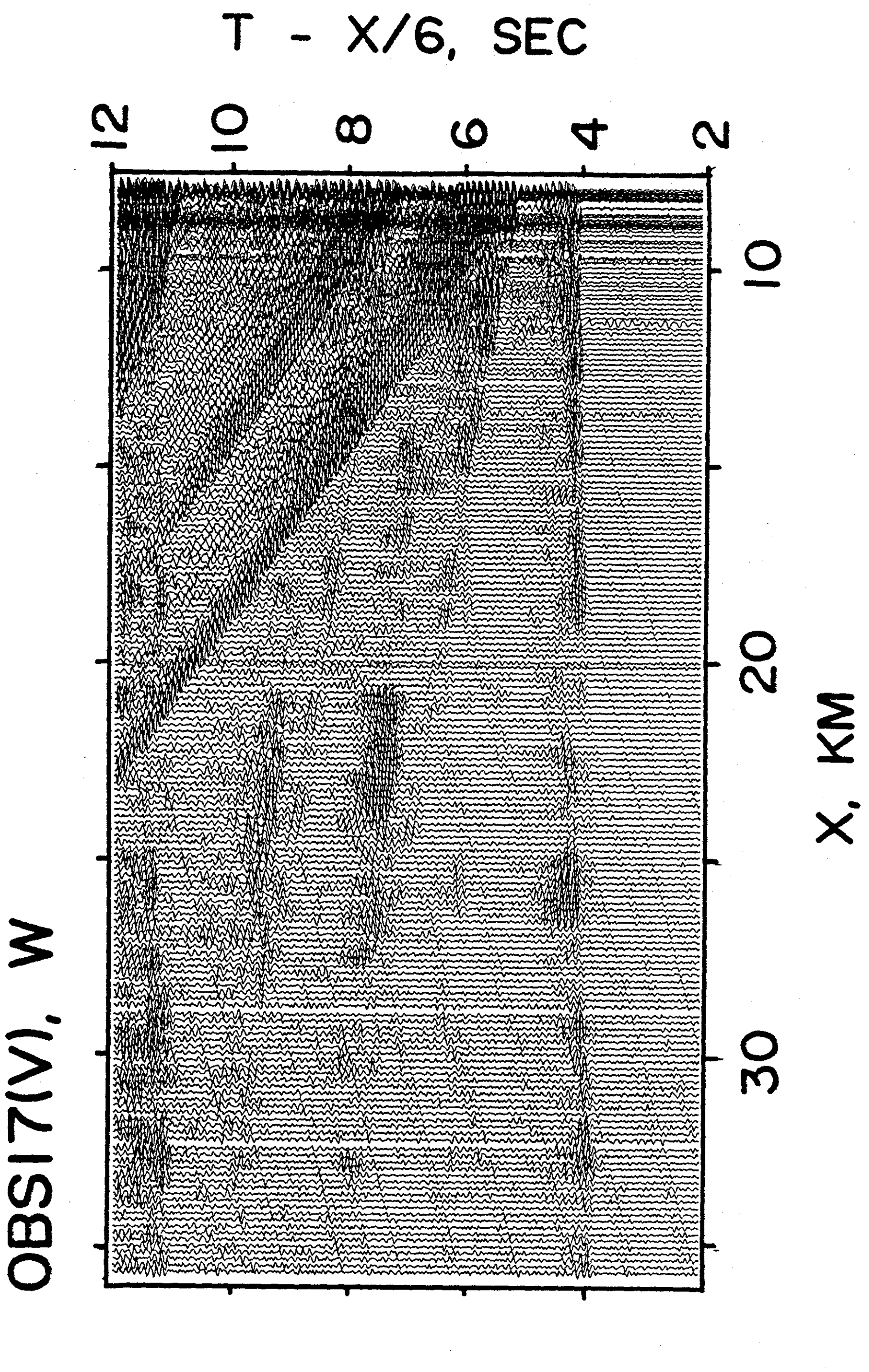

Fig. 5. Vertical record section of western part of OBS 17 for Profile I.

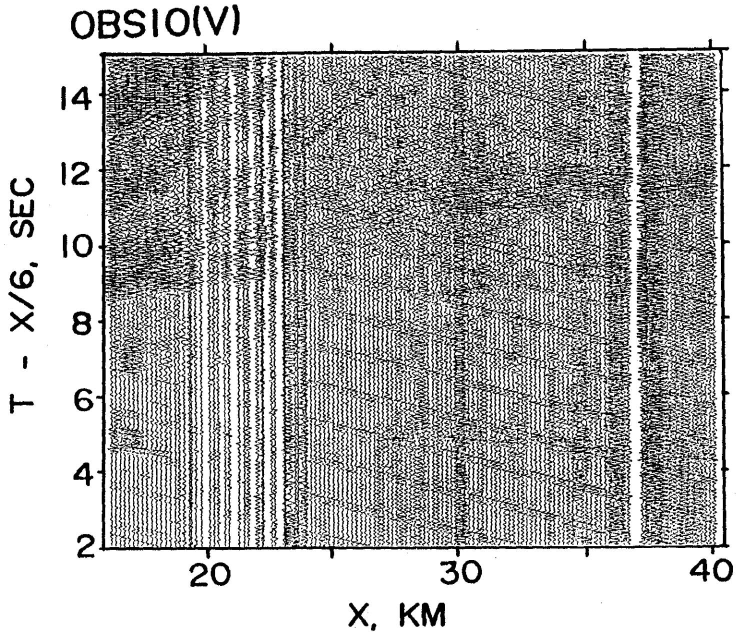

Fig. 6. Vertical record section of OBS 10 for Profile II.

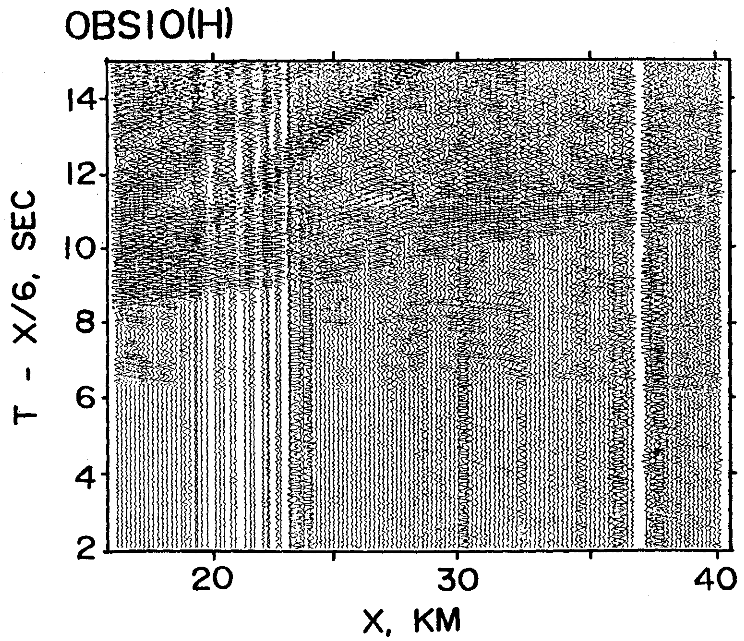

Fig. 7. Horizontal record section of OBS 10 for Profile II. First P arrivals in vertical section (Fig. 6) are unobservable.

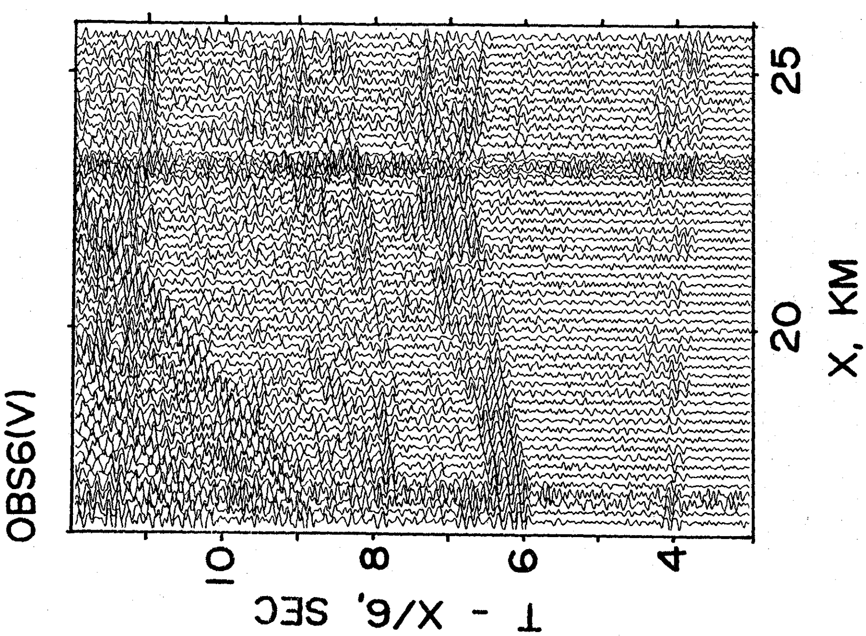

Fig. 8. Vertical record section of OBSH6 for Profile III.

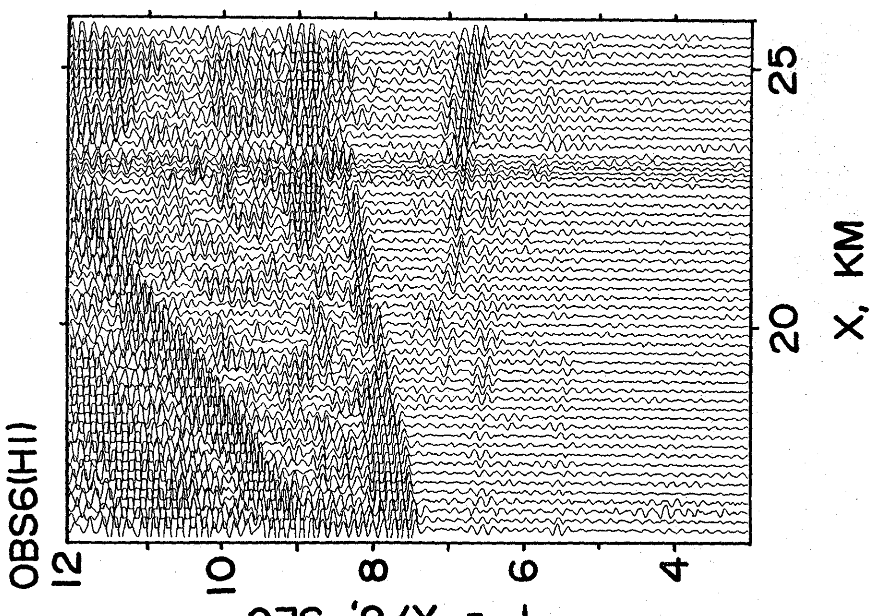

Fig. 9. Horizontal (H1) record section of OBSH6 for Profile III.

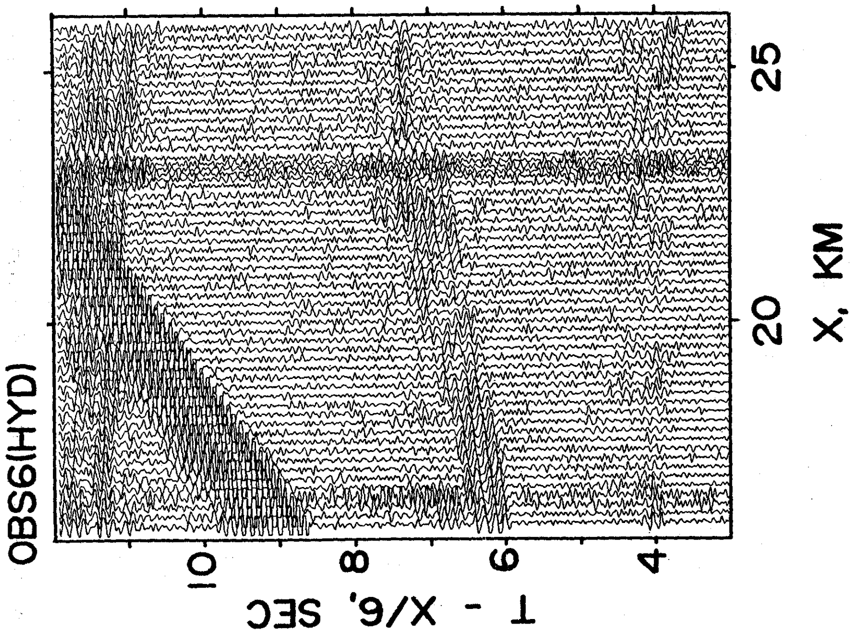

Fig. 11. Hydrophone record section of OBSH6 Profile III.

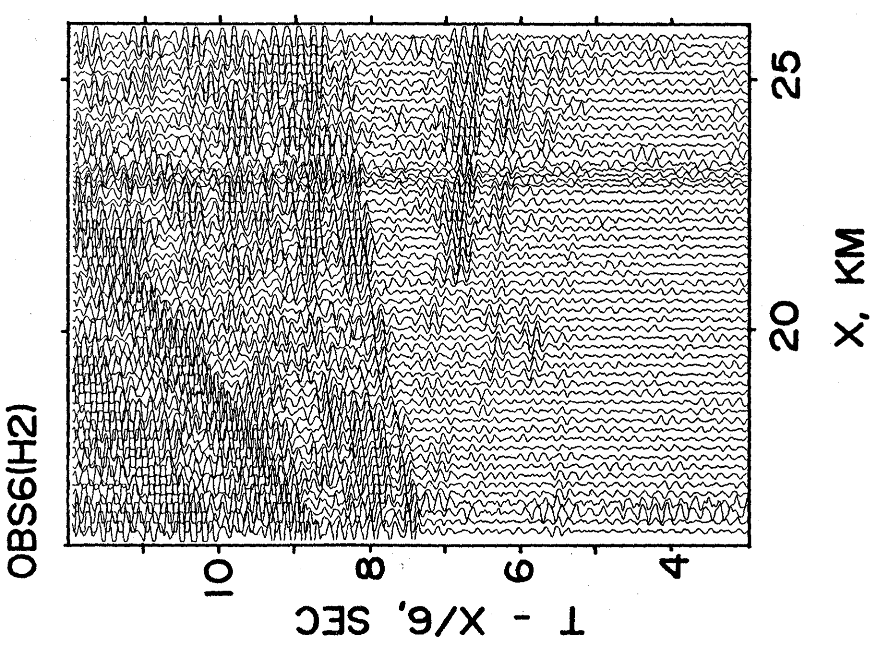

Fig. 10. Horizontal (H2) record section of OBSH6 for Profile III.

3. Data

3.1 Seafloor Topography

The water depth change over the airgun profiles is shown in Fig. 2. The encountered maximum slopes were two degrees for Profile I, about four degrees for Profile II, and almost flat for Profile III.

3.2 Single Channel Streamer Record

Fig. 3 shows the hydrophone record for Profile I. The top sedimentary layer with about 0.34 s two-way travel time thickness can be recognized to conform to the seafloor topography.

3.3 OBS/H Records

We have studied records from three OBS's within about 100 km range in line from airgun profiles because mantle refracted signals were hardly observed beyond 60 km (Fig. 2; Table 2). OBSH's had cross talk problems except OBSH 6. As the OBS 7 failed to record time codes, its data were not used.

The analog data originally stored on cassette tapes were digitally transformed at a sampling rate of 110 Hz. Distances were calculated from waterwave travel times assuming 1.5 km/s sound wave speed in water.

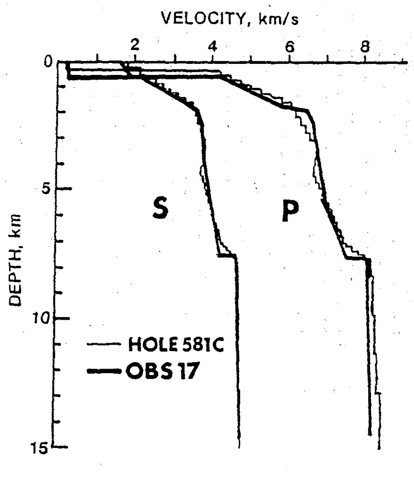

Fig. 12. Proposed model for the crust in the vicinity of OBS 17. Both P and S wave speeds are obtained and compared with those near DSDP Hole 581C (DUENNEBIER *et al.*, 1987). Overall characteristics are similar to each other but there is no low velocity zone in our model.

OBS 17 recorded Profile I signals (Fig. 4, 5). Of about 670 shots spanning 80 km on the eastern side and 40 km on the western side, P_n arrivals could be observed as far as 55 km to the east and to the end of the western profile. P to S converted phases were also observed.

Profile II shots were recorded by OBS 10 (Figs. 6, 7) over the range of 15 to 40 km on the eastern side. The S/N ratio was not as good as for Profile I. Arrivals from the lower crust are hardly observed. P to S converted phase was well observed.

Profile III shots were recorded by OBSH 6 (Figs. 8-11) covering a small range of 16 to 26 km on the eastern side. A comparison of the vertical component record and the hydrophone channel allows easier phase identification. P to S converted phases are unobservable on the hydrophone channel.

3.4 Results

A two-dimensional ray tracing scheme was adopted to model the observations. This was necessary mainly to incorporate topography corrections. Lateral change in structure at depths was not required.

We have modeled the P and S wavespeed structure in the vicinity of OBS 17 using first and later arrivals and amplitude information (Fig. 12).

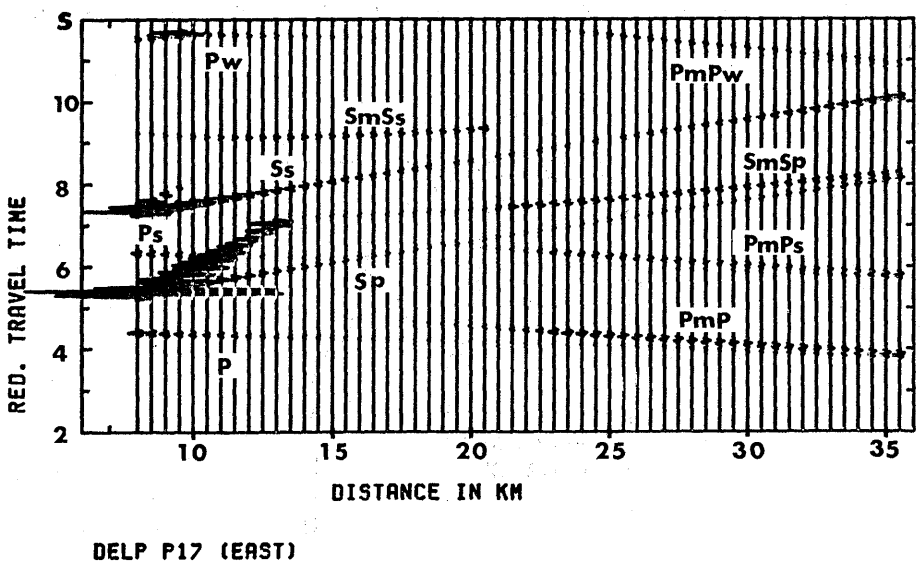

Fig. 13. Synthetic seismograms produced for OBS 17 (Figs. 4, 5) using the proposed model. Phase identifications are also given. An "s" means that the phase was in shear mode in the sedimentary layer. A "w" means multiple in the water layer.

The record sections and the model show quite good similarity with those of DUENNEBIER *et al.* (1987). Both P and S wavespeeds rapidly increase in Layer 2 of about 1.5 km thickness. A more gradual speed increase in Layer 3 explains the data. The crustal thickness is about 6 km.

The crustal low wavespeed zone suggested near Hole 581 C was not incorporated in our model, which requires detailed amplitude analysis together with detailed knowledge of topmost sediment irregularity. In our case, we had to take into account that Profile I was offset from OBS 17 by 7.9 km due to navigational problem.

Fig. 13 shows seismograms synthesized by the ray method for OBS 17 to be compared with Fig. 4. P to S or S to P conversions at the bottom of the top sedimentary layer produced various later phases. It can be seen that waves mostly propagated as shear waves are clearly cbserved.

Fig. 14 shows schematically the phase identification for OBS 10 records (Figs. 5, 6). The S wave is better observed in the horizontal component. Phase identifications for OBSH 6 records (Figs. 7-11) are shown in Fig. 15. Here, the additional hydrophone channel could tell whether the observed phase was compressional or torsional.

The travel time difference between the two seismic phases P an P_s

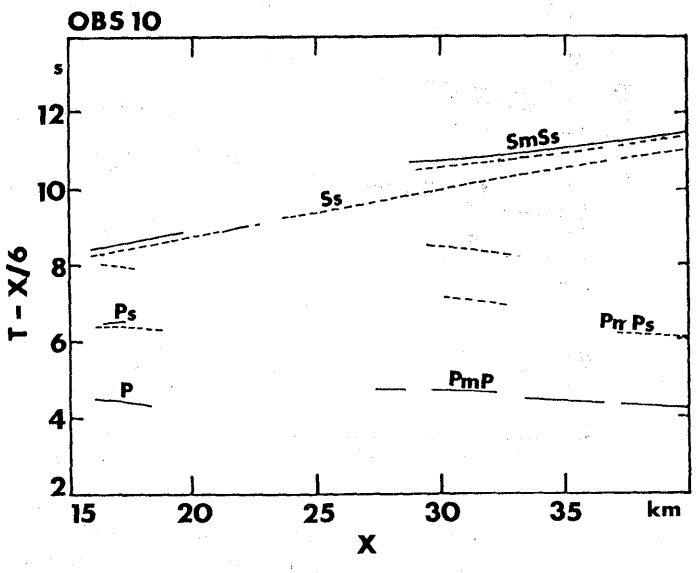

Fig. 14. Schematic figure showing phase identifications for OBS 10 records (Figs. 6, 7). Nomenclatures are the same as in Fig. 13. Solid and dotted lines are readings from vertical and horizontal components, respectively.

(P_s produced by the presence of top sedimentary layer), denoted T_{sp}, was 1.9 s for OBS's 17 and 1.5 s for OBSH 6. The apparent wavespeeds are similar among different OBS records. However, compared to OBS 17 records, the arrivals observed by OBS 10 are later by about 0.3 s although the depth for OBS 10 was 0.26 km shallower and the sea floor was about 0.1 km shallower for Profile II. If the same T_{sp} indicates the same sediment thickness, then the crust beneath Profile II may be thicker than beneath Profile I. Earlier arrivals at OBSH 6 can be explained by thinner sediments since T_{sp} is smaller.

4. Conclusions

An airgun array was used as a controlled source to study crustal structure in the northwestern Pacific Basin of more than 100 Ma. OBS

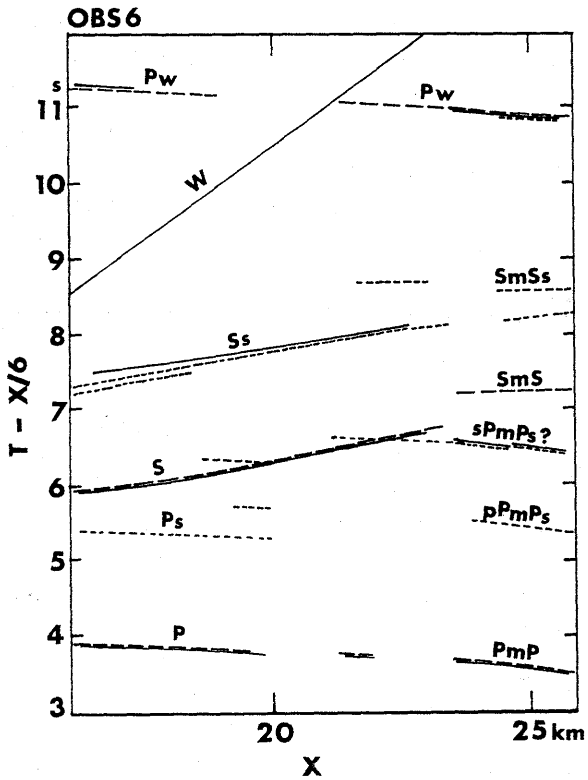

Fig. 15. Schematic figure showing phase identifications for OBSH6 records (Figs. 8-11). "W" means direct wave through water. "pP_mP_s" means P multiply reflected in the sedimentary layer then reflected from the Moho and converted to S at the bottom of the sedimentary layer. Broken lines are readings from hydrophone records. Other nomenclatures are the same as in Fig. 14.

records were obtained to reveal both the P and S wavespeed structures (Fig. 12). Our model is quite similar to the model obtained by DUENNEBIER *et al.* (1987). However, it is difficult to differentiate between a model with or without the crustal low wavespeed zone from our data.

Three profiles (total length about 170 km) spanned about 700 km in the Basin. The obtained data could be explained by crustal structure models with the same wavespeeds but possibly with changes in thicknesses. Results from explosive sources are expected to resolve this feature.

Acknowledgements

We thank the officers and crew aboard M/V Wakashio Maru for their skilful assistance at sea. OBSH 6 was deployed and retrieved by M/V Kaiko 3. Iimura wrote the codes for airgun synchronized shooting. OBS's were developed at Geophysical Institute, the University of Tokyo and the Laboratory for Ocean Bottom Seismology, Hokkaido University.

We used a ray tracing code originally developed by ČERVENÝ and PŠENČIK (1981) and modified for OBS seismograms.

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Part 11 海洋底地殻地震波速度構造

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1986年北西太平洋海盆において大規模地震探査実験が行なわれた．2本の長距離測線から，火薬とOBS を用いて古い海洋リソスフィアの水平不均質と異方性を調べるためである．エアガンアレーも制御震源として用いた．標準海洋地殻を詳しく求めるためおよび，大規模構造の深部の解像度をあげるため3本のエアガン測線データも得た．

この報告はエアガン/OBS による地殻のPおよびS波速度モデルを提出する．約 6 km の地殻の上部の第2層は厚さ約 1.5 km で速度勾配が大きい．第3層へは速度勾配の変化のみで説明できモホ直上まで 6.4 から 7.4 km/s と緩やかに変わる．測線は水平距離 700 km にわたる地殻の3ヶ所をサンプルしたが，ひとつのモデルでほぼ代表できる．またこのモデルは測線東の延長にある DSDP581C の孔近辺で得られた結果とも合う．ただし下部地殻の低速度層の存在は今回の結果からは制約できなかった．

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