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Report on DELP 1987 Cruises in the Ogasawara Area

Part IV: Explosion Seismic Refraction Studies

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Abstract

The seismic velocity structure of lower crust and uppermost mantle along two track lines in the Ogasawara Trough were obtained by refraction experiments during DELP 1987 cruises. Seismic refraction surveys were carried out by using sixteen Ocean Bottom Seismographs combined with dynamite explosives. The crust of the trough consists of three or four layers. The top layer is about 2 km thick with P-wave velocity (Vp) of 2.0 km/s, and the second layer about 2 km thick with Vp of 3.6 km/s. The lower crust is about 10 km thick with average Vp of 6.3 km/s. The Moho depth is about 18 km in the northern part and about 20 km in the southern part of the trough below the sea surface. The Vp of the uppermost mantle is about 7.8-7.9 km/s and seems to be isotropic. The gravity anomaly pattern around the Ogasawara Trough is in good accordance with the seismic velocity structure.

1. Intoroduction

The Ogasawara (Bonin) area is characterized by the following features: 1) a change in the seismicity pattern and the dip of the Wadati-Benioff zone between the southern and northern parts of the Izu-Bonin Arc, 2) collision of a line of seamounts from the east with the Izu-Bonin Trench at the southern part of the Bonin Trough, 3) world's highest free air gravity anomaly over the Ogasawara Ridge area, 4) a larger negative free air gravity anomaly toward the south in spite of the larger bathymetric depth toward the north in the Ogasawara Trough, 5) the existence of a line of active volcanic islands to the west of the trough, and oblique alignments between older and younger tectonic features along the back-arc area of the Izu-Ogasawara Arc Trench system, 6) the oldest fragment of the Pacific plate (Late Jurassic age) is subducting underneath the Philippine Sea Plate along the Izu-Ogasawara Trench. To explain all these features of the area, detailed structural studies are needed.

Seismic velocity structures of the crust and uppermost mantle of the Izu-Ogasawara-Mariana area have been studied by several authors (HOTTA, 1970; LATRAILLE and HUSSONG, 1983; KARIG and RANKEN, 1983; BIBEE *et al.*, 1980; HOUTZ *et al.* 1980; AMBOS and HUSSONG, 1982; TANAHASHI *et al.*, 1981; SINTON and HUSSONG, 1983; HUSSONG and SINTON, 1983; HAMBERGER *et al.*, 1983; KASAHARA *et al.*, 1985). The most extensive structural study across the northern part of the Izu-Ogasawara Arc was done by HOTTA (1970). It was shown that there exists a thick layer with a seismic P-wave velocity of 5.39 km/s underneath the fore-arc area between the Shichito Ridge and the Izu-Ogasawara Trench.

The Ogasawara Trough is developed between the old volcanic (Ogasawara) ridge and the young volcanic (Shichito) ridge. The depth of the trough is mostly more than 4000 m, and the sea floor topography is flat. The structure and origin of the trough has not been well understood. TOMODA and FUJIMOTO (1982) considered that the trough is a "paleotrench" entrapped by collision of the Ogasawara Ridge with the Izu-Ogasawara Arc. HONZA and TAMAKI (1985) considered that the trough was formed by rifting in Tertiary time and is inactive at present. The sedimentary layer in the trough is very thick, and the acoustic basement has not been detected by reflection surveys. Although refraction survey using sonobuoy have been carried out in the trough (TANAHASHI *et al.*, 1981), the deeper structure remain unknown.

Detailed seismic refraction experiments were carried out to determine the seismic structure of the Ogasawara Trough during DELP 1987 cruises. The purpose of this experiment is to refine the results of previous studies based on new data with higher density and accuracy.

2. Experimental procedure and processing

Seismic refraction surveys were carried out by using Ocean Bottom Seismographs (OBS) combined with a number of dynamite charges as controlled seismic sources. The two refraction lines of this survey are shown as line A (N–S, 330 km long) and B (E–W, 120 km long) in Fig. 1.

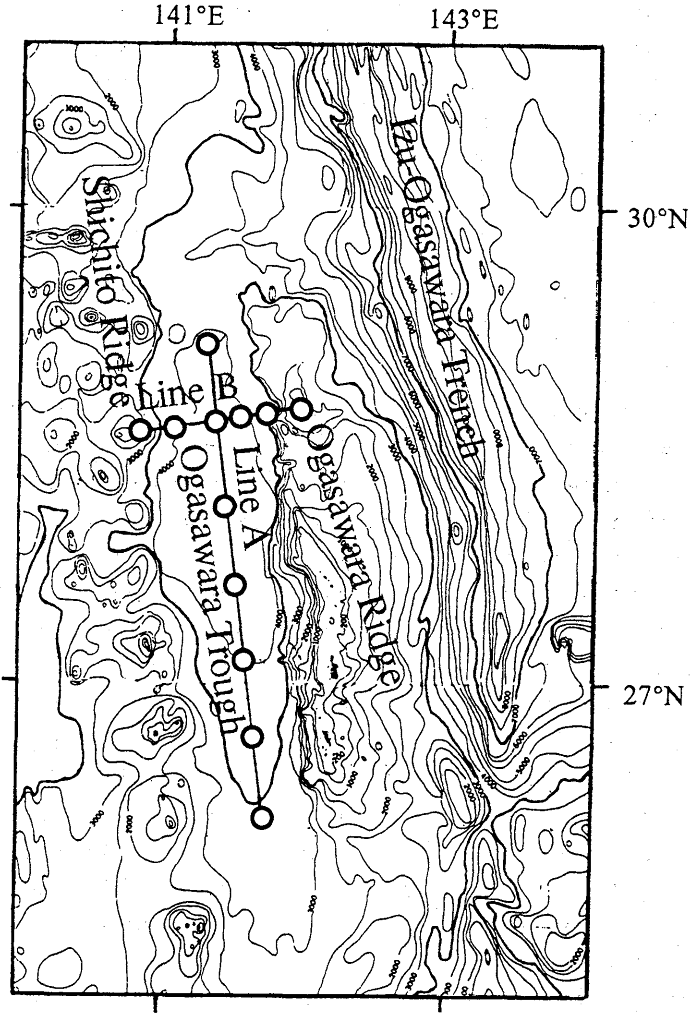


Fig. 1. Locations of DELP 1987 refraction experiments lines. Open circles represent positions of OBS's. Isobaths are in meters.

Table 1. Location and Water depths of OBSH.

Station Name	Latitude (deg-min. N)	Longitude (deg-min. E)	Water Depth (meter)
BT1	26-07.95	141-41.08	3455
BT2	26-37.95	141-37.12	3650
BT3	27-07.99	141-33.43	4005
BT4	27-37.99	141-29.70	4140
BT5	28-07.98	141-25.96	4160
BT6	28-45.64	141-22.02	4055
BT6-D*	28-40.74	141-22.12	4055
BT7	29-08.00	141-18.43	4010
BT12	28-35.11	140-49.52	2526
BT13	28-37.60	141-03.55	3925
BT14	28-42.13	141-30.67	4085
BT15	28-44.04	141.41.93	3915
BT16	28-46.60	141-56.39	1663
BT17	Abandoned.		
TK1	28-34.80	141-11.30	4050
TK2	28-37.20	141-34.00	4000

* D: digital OBSH

Sixteen OBS's were deployed along these lines. (Fig. 1, Table 1) All the OBS's were free-fall and either transponder or timer triggered pop-up type instruments. Dynamite charges were fired through fuse wires attached to primaries. These dynamite charges consisted of 154 shots: 95 shots (S1-S95) for line A and 39 shots (S101-S139) for line B (Table 2). Seismic signals were recorded on magnetic tapes mounted on the OBSs. All the analog seismic records of the dynamite explosions were converted to digital data, and stored on digital magnetic tapes prior to data processing. The seismic records obtained by digital OBS can be used directly for data processing. Almost all records showed high quality of signals (good signal to noise ratio). Particularly for large dynamite shots (dispersed charge of of 400 kg dynamite), the seismic signals could be observed even beyond 300 km from the shot point. The structure of the shallower part of the sedimentary layer obtained by multichannel seismic profiling and refraction data from airgun-OBS experiments of the same cruise are referred in the analyses for the deep crustal structure.

Some examples of seismogram recorded at station BT-7 from line A and BT-14 from line B are presented in Figs. 2a and 2b. Fig. 2a is an example of record sections obtained at station BT-7 located at the northern

Table 2. Data of explosions.

No.	Charge Size (kg)	Shot Time (JST)				Latitude N		Longitude E	
		day	hr.	min.	sec.	deg.	min.	deg.	min.
S1	400	Nov.12	9	27	22.54	26	7.93	141	40.97
S2	20	Nov.12	10	21	38.28	26	8.06	141	40.93
S3	5	Nov.12	10	36	53.14	26	10.03	141	40.74
S4	5	Nov.12	10	51	55.52	26	12.06	141	40.43
S5	20	Nov.12	11	5	54.23	26	14.08	141	40.23
S6	5	Nov.12	11	20	22.44	26	16.08	141	39.99
S7	5	Nov.12	11	34	26.09	26	18.02	141	39.75
S8	20	Nov.12	11	48	52.45	26	20.02	141	39.48
S9	5	Nov.12	12	3	27.63	26	22.08	141	39.21
S10	5	Nov.12	12	18	20.10	26	24.12	141	39.07
S11	20	Nov.12	12	32	26.18	26	26.03	141	38.74
S12	5	Nov.12	12	47	28.91	26	28.09	141	38.49
S13	5	Nov.12	13	1	59.10	26	30.07	141	38.24
S14	20	Nov.12	13	16	25.51	26	32.05	141	37.01
S15	5	Nov.12	13	31	41.44	26	34.04	141	38.73
S16	5	Nov.12	13	46	6.99	26	36.03	141	37.52
S17	20	Nov.12	14	0	26.00	26	38.03	141	37.22
S18	5	Nov.12	14	15	25.53	26	40.05	141	37.00
S19	5	Nov.12	14	30	0.06	26	42.07	141	36.76
S20	20	Nov.12	14	44	15.88	26	44.02	141	36.49
S21	5	Nov.12	14	58	27.90	26	46.04	141	36.27
S22	5	Nov.12	15	12	49.88	26	48.06	141	36.00
S23	20	Nov.12	15	27	1.59	26	50.04	141	35.75
S24	5	Nov.12	15	41	13.79	26	52.03	141	35.45
S25	5	Nov.12	15	54	59.62	26	54.05	141	35.22
S26	20	Nov.12	16	8	54.19	26	56.02	141	34.96
S27	5	Nov.12	16	22	53.83	26	58.06	141	34.78
S28	5	Nov.12	16	36	30.37	27	0.04	141	34.47
S29	20	Nov.12	16	49	55.56	27	2.04	141	34.18
S30	5	Nov.12	17	3	10.94	27	4.03	141	33.97
S31	5	Nov.12	17	16	48.52	27	6.07	141	33.77
S32	300	Nov.12	17	34	31.98	27	8.06	141	33.49
S33	20	Nov.13	6	36	56.96	27	8.08	141	33.53
S34	5	Nov.13	6	50	11.14	27	10.06	141	33.26
S35	5	Nov.13	7	3	47.41	27	12.08	141	33.02
S36	20	Nov.13	7	16	58.99	27	14.03	141	32.74
S37	5	Nov.13	7	30	20.84	27	16.04	141	32.53
S38	5	Nov.13	7	44	2.46	27	18.04	141	32.27
S39	20	Nov.13	7	57	39.88	27	20.07	141	32.00
S40	5	Nov.13	8	10	55.87	27	22.02	141	31.78
S41	5	Nov.13	8	24	55.79	27	24.08	141	31.49
S42	20	Nov.13	8	38	44.69	27	26.08	141	31.32
S43	5	Nov.13	8	53	19.84	27	28.10	141	30.04
S44	5	Nov.13	9	6	19.13	27	30.07	141	30.78
S45	20	Nov.13	9	19	50.43	27	32.05	141	30.51
S46	5	Nov.13	9	33	19.66	27	34.03	141	30.24
S47	5	Nov.13	9	46	51.67	27	36.07	141	29.98
S48	20	Nov.13	10	0	17.82	27	38.04	141	29.76

Table 2. (continued)

No.	Charge Size (kg)	Shot Time (JST)				Latitude N		Longitude E	
		day	hr.	min.	sec.	deg.	min.	deg.	min.
S49	5	Nov.13	10	13	49.50	27	40.05	141	29.50
S50	5	Nov.13	10	27	18.22	27	42.05	141	29.23
S51	20	Nov.13	10	40	22.50	27	44.01	141	28.98
S52	5	Nov.13	10	53	53.75	27	46.07	141	28.72
S53	5	Nov.13	11	6	20.64	27	48.02	141	28.45
S54	20	Nov.13	11	19	38.43	27	50.15	141	28.24
S55	5	Nov.13	11	31	22.66	27	52.03	141	28.03
S56	5	Nov.13	11	43	49.38	27	54.01	141	27.73
S57	20	Nov.13	11	56	33.71	27	56.04	141	27.53
S58	5	Nov.13	12	8	32.66	27	58.02	141	27.23
S59	5	Nov.13	12	21	9.69	28	0.06	141	27.01
S60	20	Nov.13	12	34	1.02	28	2.13	141	26.75
S61	5	Nov.13	12	46	10.56	28	4.08	141	26.52
S62	5	Nov.13	12	58	48.46	28	6.03	141	26.22
S63	300	Nov.13	13	40	58.32	28	7.99	141	26.01
S64	20	Nov.13	14	14	27.06	28	8.04	141	25.99
S65	5	Nov.13	14	27	16.56	28	10.04	141	25.78
S66	5	Nov.13	14	39	38.26	28	12.06	141	25.47
S67	20	Nov.13	14	51	30.23	28	14.03	141	25.26
S68	5	Nov.13	15	3	28.66	28	16.02	141	25.01
S69	5	Nov.13	15	15	55.17	28	18.02	141	24.77
S70	20	Nov.13	15	28	18.43	28	20.03	141	24.51
S71	5	Nov.13	15	40	24.74	28	22.04	141	24.25
S72	5	Nov.13	15	52	19.69	28	24.02	141	24.01
S73	20	Nov.13	16	10	52.25	28	26.02	141	23.69
S74	5	Nov.13	16	18	58.28	28	28.03	141	23.48
S75	5	Nov.13	16	32	9.08	28	30.04	141	23.30
S76	20	Nov.13	16	45	17.36	28	32.02	141	22.97
S77	5	Nov.13	16	53	32.89	28	34.03	141	22.73
S78	5	Nov.13	17	11	32.93	28	36.04	141	22.49
S79	20	Nov.13	17	23	58.51	28	38.05	141	22.24
S80	5	Nov.13	17	36	5.83	28	40.01	141	21.99
S81	5	Nov.13	17	48	26.68	28	42.02	141	21.75
S82	20	Nov.13	18	1	11.35	28	44.01	141	21.50
S83	5	Nov.13	18	13	46.52	28	46.10	141	21.21
S84	5	Nov.13	18	26	42.59	28	48.03	141	20.96
S85	20	Nov.13	18	39	9.13	28	50.00	141	20.76
S86	5	Nov.13	18	51	58.75	28	52.04	141	20.49
S87	5	Nov.13	19	5	9.25	28	54.06	141	20.25
S88	20	Nov.13	19	18	16.27	28	56.00	141	20.02
S89	5	Nov.13	19	31	20.07	28	57.99	141	19.74
S90	5	Nov.13	19	44	35.79	29	0.01	141	19.47
S91	20	Nov.13	19	57	41.93	29	2.03	141	19.29
S92	5	Nov.13	20	10	39.78	29	4.06	141	19.01
S93	5	Nov.13	20	23	28.44	29	5.99	141	18.74
S94	20	Nov.13	20	36	33.65	29	8.01	141	18.54
S95	400	Nov.13	20	59	50.39	29	7.97	141	18.49

Table 2. (continued)

No.	Charge Size (kg)	Shot Time (JST)				Latitude N		Longitude E	
		day	hr.	min.	sec.	deg.	min.	deg.	min.
S101	200	Nov.14	13	49	26.03	28	35.10	140	49.47
S102	25	Nov.14	13	36	32.92	28	35.40	140	51.23
S103	25	Nov.14	13	27	2.63	28	35.72	140	52.99
S104	25	Nov.14	13	17	30.50	28	36.03	140	54.74
S105	25	Nov.14	13	7	29.45	28	36.34	140	56.56
S106	25	Nov.14	12	58	2.20	28	36.64	140	58.30
S107	25	Nov.14	12	48	47.41	28	36.95	141	0.04
S108	25	Nov.14	12	39	30.65	28	37.26	141	1.78
S109	25	Nov.14	12	30	36.14	28	37.54	141	3.42
S110	25	Nov.14	12	20	34.59	28	37.88	141	5.33
S111	25	Nov.14	12	11	15.50	28	38.20	141	7.06
S112	25	Nov.14	12	2	2.42	28	38.50	141	8.79
S113	25	Nov.14	11	52	33.55	28	38.79	141	10.58
S114	25	Nov.14	11	43	3.15	28	39.10	141	12.33
S115	25	Nov.14	11	33	30.71	28	39.42	141	14.10
S116	25	Nov.14	11	24	2.80	28	39.71	141	15.84
S117	25	Nov.14	11	14	1.75	28	40.03	141	17.65
S118	25	Nov.14	11	4	31.67	28	40.31	141	19.41
S119	25	Nov.14	10	55	11.15	28	40.60	141	21.10
S120	100	Nov.14	10	54	16.61	28	40.76	141	21.95
S121	25	Nov.14	10	36	41.81	28	41.21	141	24.63
S122	25	Nov.14	10	25	59.52	28	41.53	141	26.40
S123	25	Nov.14	10	16	2.18	28	41.82	141	28.15
S124	25	Nov.14	10	6	6.47	28	42.15	141	29.92
S125	25	Nov.14	9	56	1.01	28	42.45	141	31.71
S126	25	Nov.14	9	46	5.54	28	42.73	141	33.49
S127	25	Nov.14	9	36	29.16	28	43.02	141	35.20
S128	25	Nov.14	9	26	32.23	28	43.34	141	37.00
S129	25	Nov.14	9	17	4.36	28	43.60	141	38.70
S130	25	Nov.14	9	06	59.37	28	43.95	141	40.49
S131	25	Nov.14	8	56	32.14	28	44.23	141	42.34
S132	25	Nov.14	8	47	0.87	28	44.50	141	44.00
S133	25	Nov.14	8	36	32.13	28	44.80	141	45.75
S134	25	Nov.14	8	26	3.20	28	45.10	141	47.54
S135	25	Nov.14	8	16	0.45	28	45.43	141	49.25
S136	25	Nov.14	8	5	31.22	28	45.73	141	51.04
S137	25	Nov.14	7	55	1.83	28	45.98	141	52.82
S138	25	Nov.14	7	42	31.99	28	46.27	141	54.58
S139	200	Nov.14	7	0	14.60	28	46.54	141	56.57

end of line A. The reduction velocity is 8.0 km/s. The refraction phase from lower crust appears as first break at distance beyond 20 km, and can be traced up to about 60 km. The apparent velocity of this phase is about 6.0 km/s, and it increases continuously with distance. The Pn phases are observed at distance range beyond 60 km from the station. The apparent velocity of Pn is slightly less than 8.0 km/s. The intercept time of Pn is about 8 sec.

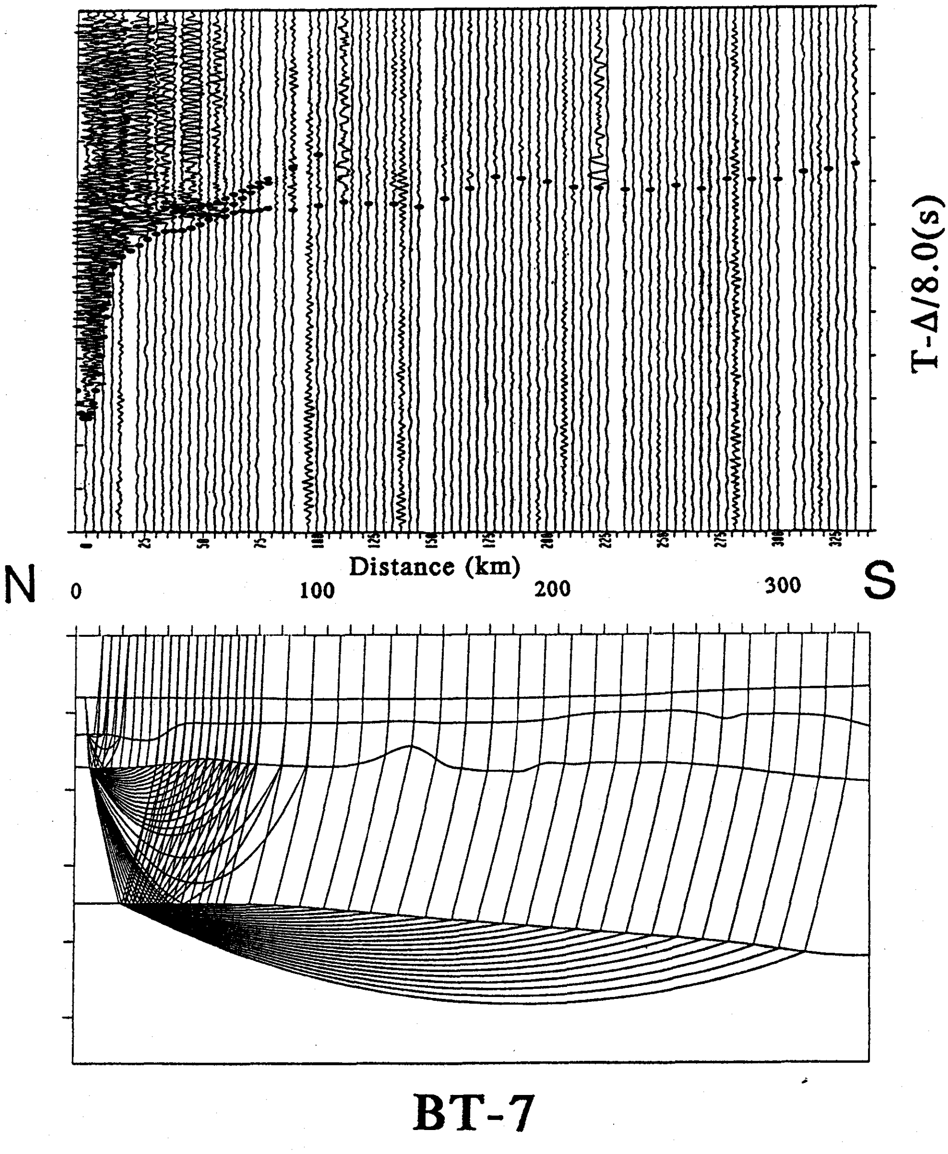
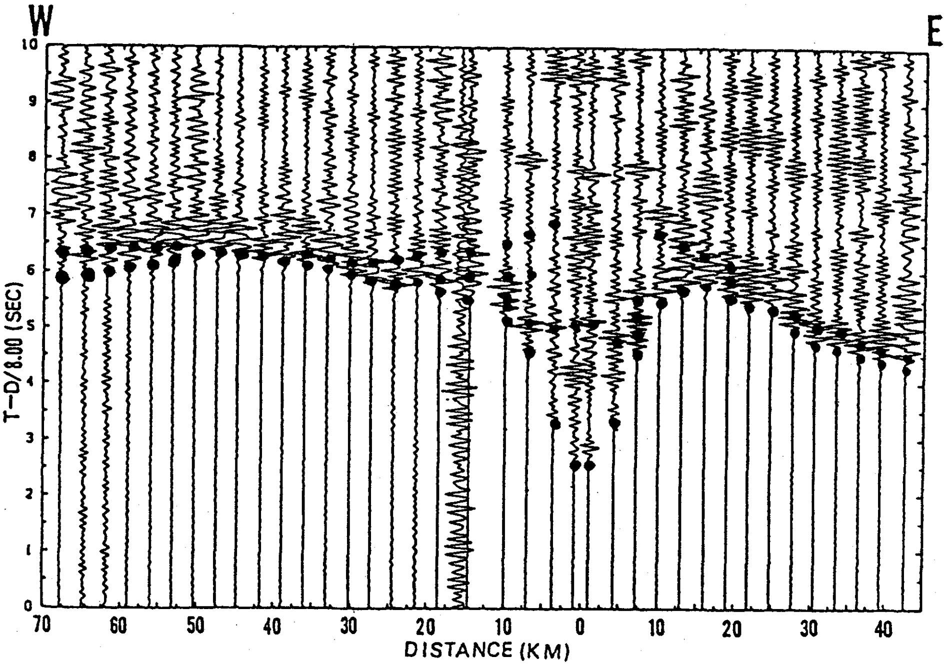


Fig. 2(a)

Fig. 2. (Above) Examples of record sections. Vertical component of geophone record. Dots represent theoretical travel times based on ray tracing. (Below) Model and ray diagram. a: for BT-7 of line A and b: for BT-14 of line B.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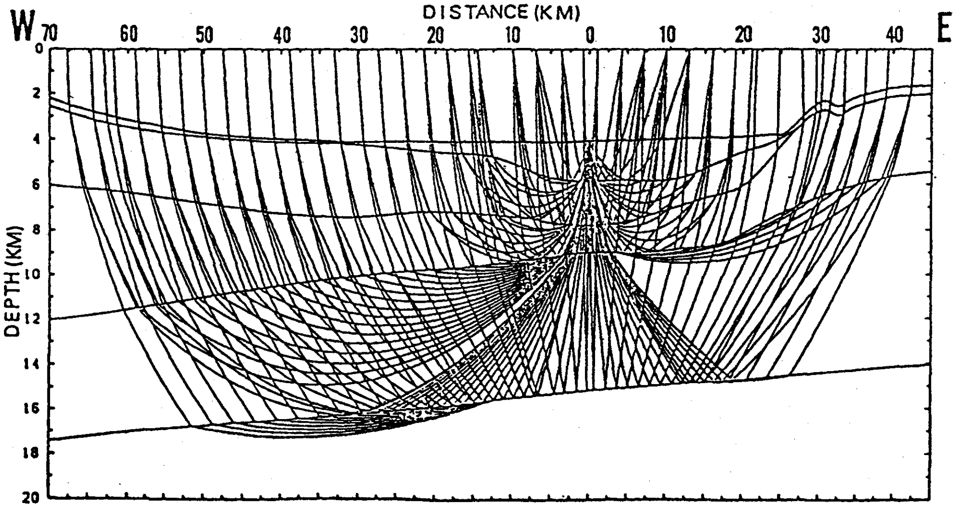
DISTANCE (KM)


DISTANCE (KM)
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DEPTH (KM)
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16
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20

Fig. 2(b)

A record section of dynamite shots along line B obtained at the station BT-14 is shown in Fig. 2b. The reduction velocity is 8.0 km/s. Refracted waves from the lower part of the crust (apparent velocity of about 6 km/s) and reflection from the Moho can be seen on this section. Toward both ends of the profile, travel times become shorter with water depth variation. It is difficult to identify Pn because of the short length of the line.

The velocity structure was modeled using two-dimensional ray tracing. Models were refined by trial and error, until calculated travel times coincide with observed travel times within 0.1 sec. Some examples of the ray tracing calculation are presented in Figs. 2a and 2b (bottom figures). The characteristic arrival times anticipated for various phases of reflected and refracted waves are marked with solid circles on the time distance record sections. Main features which can be deduced from these figures will be described below.

3. Seismic stratigraphy

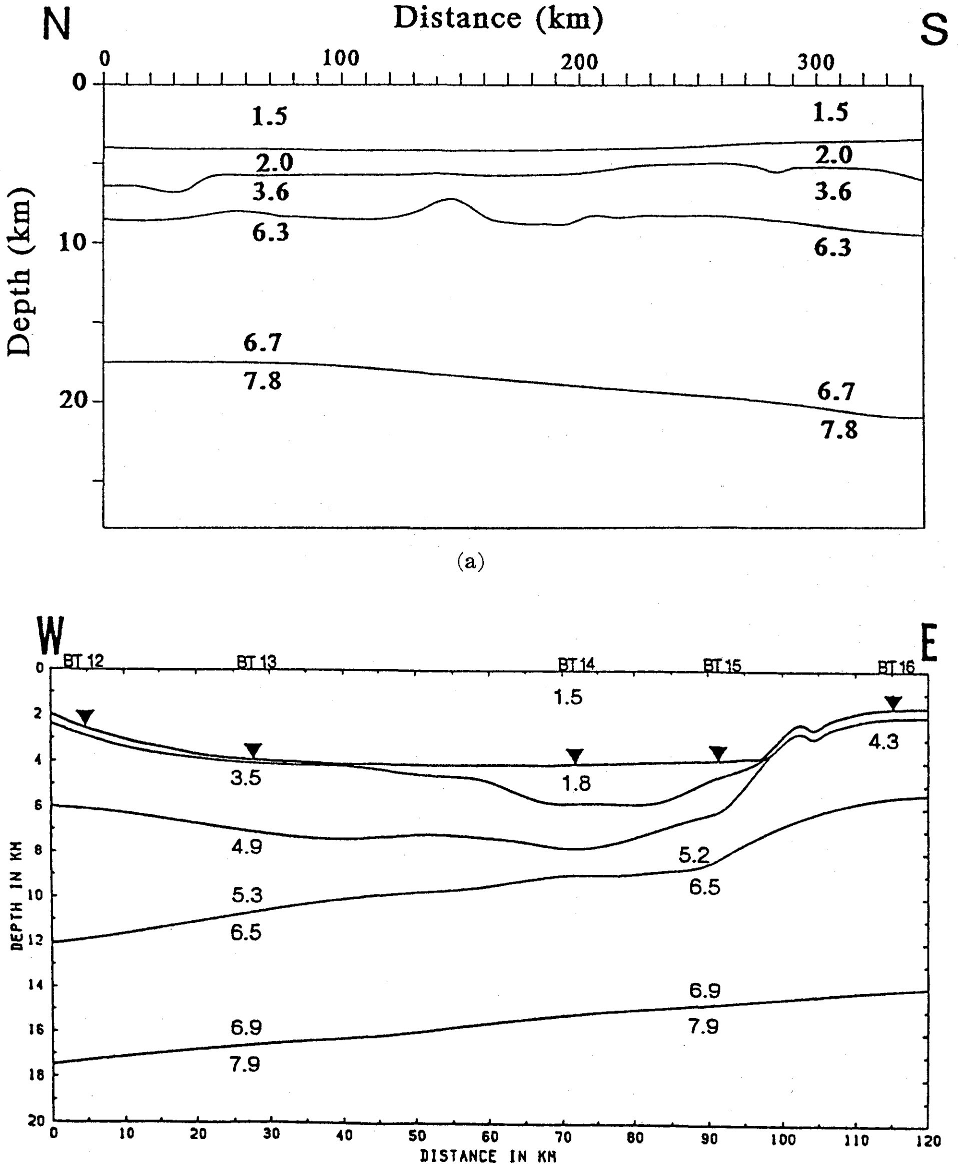
Model of seismic velocity structures of the Ogasawara Trough are shown in Figs. 3a and 3b for each of the track lines A and B (Fig. 1).

3-1. Sediments

The P-wave velocity (Vp) structure of the sediments above the acoustic basement is reported in Part II (ABE *et al.*, this issue) and Part III (HINO *et al.*, this issue). These results are used to construct the lower crust and upper mantle structure of the trough. The boundary between the soft sediment of Vp 1.8-2.0 km/s and the lower sediment of Vp 2.0-3.6 km/s is irregular, reflecting the dislocation structure as inferred from results of Part II and Part III of this issue.

3-2. Lower Crust

The term "lower crust" is tentatively used here as indicating the basement layers between the bottom of the sediment and the Moho discontinuity. Below the sediment layer, one or two layers with Vp of 4.9-6.5 km/s is recognized. In the model for line B, this part of the crust consists of upper layer (Vp=4.9 km/s) and lower layer (Vp=6.5 km/s). A layer with Vp of 6.3 km/s represents this part of the crust in the model for line A. Because high density airgun shooting was not carried out along line A, it is difficult to know the detailed structure of this layer. This layer is thicker on the eastern side toward the Ogasawara Ridge and also on the southern side of the trough.



(a)

(b)

Fig. 3. P-wave velocity structures obtained by the present study. a: for line A and b: for line B. Numerals in figure represent P-wave velocity in km/s.

3-3. Moho discontinuity and upper mantle velocity

The Moho discontinuity can be defined by the appearance of refracted waves through the uppermost mantle as well as wide angle reflection from the discontinuity interface. The average subsurface depth of the Moho discontinuity is determined to be around 18 km in the northern part and 20 km in the southern part of the trough. The Vp of the uppermost mantle of the trough is about 7.8–8.0 km/s. The velocity in the upper mantle was not anisotoropic so far as could be determined from the seismic records obtained along two lines A and B.

4. Discussion

The Ogasawara Trough has intermediate crustal thickness between continental and oceanic. The crust has a predominant 6.3 km/s layer, and the velocity gradient in the upper layer is much smaller than that in an oceanic layer 2. The crustal structre of the Ogasawara Trough in not identical to that of the typical oceanic crust.

HONZA and TAMAKI (1985) suggested that the Ogasawara Trough was formed as a back-arc basin in the early Oligocene. Detailed reflection studies of 1987 cruise show that the basement of the trough dips eastward in a stepwise manner. This feature can be interpreted as caused by normal faults which were formed in a tensional stress field during rifting of the trough in the Tertiary period (ABE *et al.*, in this issue). Spreading of the Ogasawara trough might have ceased at the stage of rifting of the island arc crust. After that, volcaniclastic sediments supplied from the Shichito Ridge covered the trough area and formed thick sediment layers.

As shown in our models, the Moho discontinuity beneath the Ogasawara Trough is not flat. Along line B (Fig. 3a), the sedimentary basement uplifts toward the Ogasawara Ridge and the depth of the Moho also decreases toward the east. These structural features suggest that the remarkably large gravity anomaly over the Ogasawara Ridge can be explained by crustal thinning model of ISHIHARA *et al.* (1981). The deepening of the Moho discontinuity toward the south along line A is consistent with the pattern of negative free air gravity anomaly (ISHIHARA *et al.*, 1981 ; GEOLOGICAL SURVEY OF JAPAN, 1982). There are two negative depressions in the free air gravity anomaly, a weak one as low as −100 mgal in the northern part and −200 mgal in the southern part of the trough. This distribution is partly interpreted by assuming that the basement or mantle layer dips deeper toward the south. A qualitative judgement shows that the seismic structure of the Moho discontinuity can explain the pattern of the free air gravity anomaly fairly well. The reason for this deepening of the Moho discontinuity could be drag on the subducting Pacific lithosphere underneath this region or simple fragmentation of the lithospheric mass of this part of the Philippine Sea plate due to collision with the seamount chain. Additional information on the mechanical features of this area and southern part of the Ogasawara system are needed to interpret this depression in detail.

5. Summary

1) The seismic velocity structure of the Ogasawa Trough was revealed by refraction experiments using OBSs and explosives.

2) Approximately, the crustal structure of the Ogasawara Trough can be divided into 3 layers. The average Vp of these layers are 2.0, 3.6, 6.3 km/s respectively. The thickness of these layers varies from place to place. The Vp of the uppermost mantle is about 7.5–7.9 km/s and seems to be isotropic. Crustal thickness is about 13–15 km.

3) The velocity structure and crustal thickness of the Ogasawara Trough are not those of oceanic crust.

4) The southern part of the sedimentary basement as well as the Moho discontinuity of the trough are deeper than those in the northern part. The eastern part of the sedimentary basement and the Moho discontinuity uplift toward the Ogasawara Ridge.

5) The gravity anomaly pattern around the Ogasawara Trough is in good accordance with the crustal structure and the depth variation of the Moho discontinuity.

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DELP 1987年度　小笠原海域航海報告

VI　発破による地震波速度構造探査

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DELP1987航海では小笠原トラフにおいて屈折法探査実験が行われ，2つの直交する測線に沿った地殻および上部マントル地震波速度構造が求められた．この探査には海底地震計とダイナマイト発破とを組み合わせて用いた．小笠原トラフの地殻は3ないし4層からなっている．最上層はP波速度(Vp)2.0km/secで厚さ約2km，第2層はVp 3.6km/sで厚さ2kmである．下部地殻は厚さ約10kmでその平均的なP波速度は6.3km/sである．モホ面の深さはトラフ中央部で海面下約17kmで，東に向かって上昇し，南にむかって下降している．最上部マントルの速度は7.8-7.9km/sで等方的であると思われる．地震波速度構造は小笠原トラフ周辺のフリーエア重力異常分布と整合的である．