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Wide-angle seismic profiling across the middle Izu-Ogasawara Arc – KR07-13 cruise –

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Abstract We carried out a wide-angle reflection and refraction experiment using 102 ocean bottom seismographs on a 679-km long seismic line crossing the middle Izu-Ogasawara Arc. The cruise was conducted by R/V Kairei of Japan Agency for Marine-Earth Science and Technology from September to October, 2007. The objectives of the cruise are to reveal the crustal and uppermantle structures across the middle Izu-Ogasawara Arc from Ogasawara Ridge to Shikoku Basin illuminating the structural variations associated with the arc evolution and back-arc openings. In this paper, we summarize the seismic experiment and show the acquired data of ocean bottom seismographs.

Keywords: Izu, Ogasawara, OBS, oceanic island arc, seismic

1. Introduction

The Izu-Ogasawara (Bonin)-Mariana Arc (IBM) is an oceanic island arc well studied, since oceanic island arcs are one of important tectonic region to generate continental crust of the earth. This was strongly promoted by the collaborated results of seismological and petrological studies[1)2)].

The IBM is located eastern edge of the Philippine Sea Plate subducting the Pacific Plate at the Izu-Ogasawara and Mariana Trenches (Figure 1). The Shikoku and Parece Vela Basins are well developed at the back-arc side of the IBM. Between the back-arc basins and the IBM, there are en echelon seamount chains with NE-SW directions. In the middle of the Izu-Ogasawara Arc, there is a tectonic line named Sofugan Tectonic Line (STL) with NE-SW trend bordering the northern and southern part of the Izu-Ogasawara Arc. In the southern part, the Ogasawara Ridge and the Ogasawara Trough are elongated parallel to the Izu-Ogasawara Arc.

The history of the Philippine Sea Plate development is well revealed by many papers[3)]. In this part, the history of the Philippine Sea Plate is overviewed mainly with the review of Stern et al.[3)]. At the beginning of the history which is about 50-45 Ma, the convergence of oceanic lithospheres occurred and the boninitic activity was also confirmed in this time[4)]. First arc activity was occurred about 40-30Ma, followed by the back-arc openings of the Shikoku and Parece Vela Basins in the period of 30-15 Ma, which is well documented by the geophysical papers[5)]. According to Okino et al.[5)], the rifting before the seafloor spreading was timing of 30-27 Ma, followed by the spreadings in E-W direction. The spreadings were continued during 27-23 Ma with the northward and southward propagations of Parece Vela Basin and Shikoku Basin, respectively. The propagations were reached and united together at 23 Ma and started the stable spreading until 20 Ma. Around 19 Ma, the spreading direction was changed to NE-SW direction with ridge segmentations and continued until 15 Ma. After the cease of the spreading, axial seamounts were formed in the Shikoku Basin until 12 Ma, although there was no axial seamount in the Parece Vela Basin[6)]. The Mariana Trough opening was initiated sometime after 10 Ma for rifting stage, followed by the seafloor spreading from 3-4 Ma[7)8)]. As mentioned here, the IBM area has a cyclic history of arc evolutions and back-arc openings.

Around the IBM, many seismic surveys have been conducted intensely to reveal the crustal structure understanding the arc evolution associated with the continental crustal forming since 1960's[9)]. The northern Izu-Ogasawara Arc transect using ocean bottom seismographs (OBS) reveals the middle crust with P-wave velocity of 6 km/s, which is thought to be an intermediate layer suggesting the formation of continental crust[1)]. The seismic

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survey using OBS in Mariana region confirmed the similar crustal characteristics with those of northern Izu-Ogasawara Arc suggesting transformation of the dense crustal materials to the upper mantle throughout the crustal evolution[2)]. According to Takahashi et al.[2)], observed lower crustal volume is much less than those of calculated volume with petrological modeling, which requires the evolution process returning the crustal materials to the mantle. Moreover, the seismic surveys on the Izu-Ogasawara volcanic arc show the structural variation along the arc[10)], which indicates that the evolution process varies along the arc.

The STL is a lineament with NE-SW trend bordering the northern and southern Izu-Ogasawara Arcs[11)] indicating the differences in topographic, geological and structural features and in distribution of hypocenters and back-arc depressions. Yuasa[11)] also suggests that the trend change of the minor ridge on the Shikoku and Parece Vela Basins seems to correspond the western extension of the STL. From the along-arc transect of OBS survey, crustal thickness is smallest around the STL about 10 km bordering the southern juvenile and northern mature arcs[10)]. The isotopic characteristics of rock samples also show the along-arc variation and two gaps at Latitudes 27.5 and 25 degrees, of which former gap locates around the STL[12)].

The Ogasawara Ridge is a topographic high locating in the forearc region of the Izu-Ogasawara Arc, thought to be a region holding the characteristics of old arc activity of the IBM because of the discovery of boninite[4)]. The middle crust of the Ogasawara Ridge has P-wave velocity of 6.5 km/s, which is meaningfully higher than those of current Izu-Ogasawara Arc, suggesting the difference of evolution process of arc activity [13)].

The tectonics at the transition zone between the arc and back-arc region is also an important to understand the evolutions of arcs and back-arc basins. According to Takahashi et al.[14)], the lower crust of the transition zone in northern Izu-Ogasawara Arc has high P-wave velocity about 7 km/s. This characteristic is also discovered in the transition zone in Mariana Region[2)]. From the MCS study,

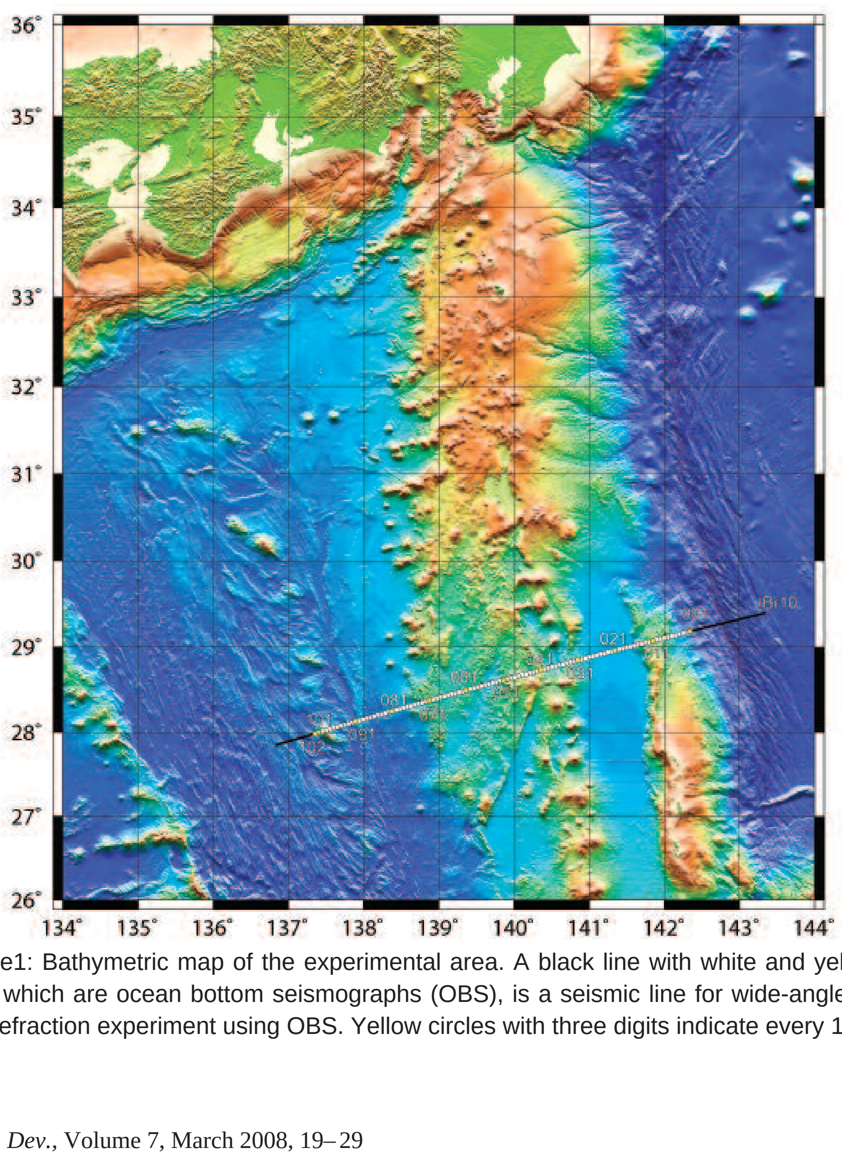

Figure1: Bathymetric map of the experimental area. A black line with white and yellow circles, which are ocean bottom seismographs (OBS), is a seismic line for wide-angle reflection/refraction experiment using OBS. Yellow circles with three digits indicate every 10 OBS.

there are normal faults cutting the sedimentary layer and the basement thought to be active not only the back-arc opening period before 15 Ma but also the period after the back-arc opening suspend[15].

The objectives of this survey are following five points: 1) to confirm the existence of high velocity (~6.5 km/s) middle crust in the northern part of the Ogasawara Ridge, 2) to confirm the P-wave velocity of lower crust in northern part of the Ogasawara Trough, 3) to reveal the across arc distribution of the thin crust around the STL, 4) to confirm the existence of high velocity (~7 km/s) and reflective lower crust in the transition zone between the arc and back-arc basin, and 5) to reveal the crustal and mantle structure of the Shikoku Basin including the axial seamount (Hakuho Seamount). To reveal the crustal structure of the middle Izu-Ogasawara Arc achieving the objectives, a wide-angle reflection and refraction experiment of OBS has been conducted on a seismic line (IBr10: Figure 1) from September to October, 2007. The cruise was KR07-13 conducted by the R/V Kairei of Japan Agency for Marine-Earth Science and Technology (JAMSTEC).

2. Experiment

The outline of the KR07-13 cruise and shiptracks are respectively shown by Table 1 and Figure 2. The R/V Kairei left the Yokohama port in September 30. OBS deployment was conducted from October 1 to 11, including first avoidance due to typhoon attack in the Mikawa Bay from October 6 to 9. During the OBS deployment,

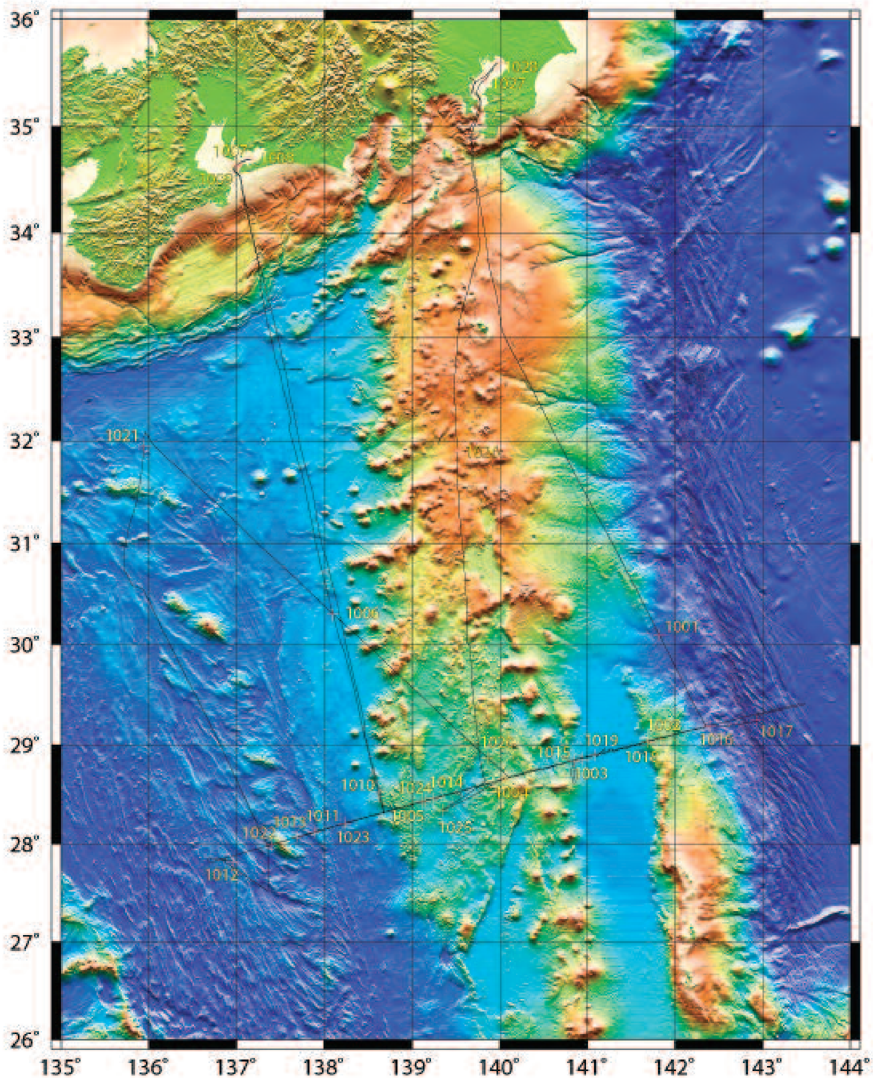

Figure2: Map for ship's track. Red crosses and yellow four-digits indicate the position at noon in global standard time and date, respectively.

three OBS were re-deployed since deployment troubles in Site005, Site073 and Site075. In October 12, float towing test for the new MCS system of R/V Kairei was conducted. The airgun shooting on the Line IBr10 was continued from October12 to 17 with 200-m interval for the OBS survey. After the airgun shooting, OBS were retrieved from October 17 to 25 including avoidance due to second typhoon attack off Shionomisaki from October 20 to 21. During the OBS retrievals, one OBS could not retrieve because of a recovery trouble in Site024. Finally, third avoidance due to typhoon attack in the Tokyo Bay from October 26 to 28 including transit from the survey area. The cruise was finished in October 29 arriving to the JAMSTEC port. Although there were three times of avoidance due to typhoon attack, a wide-angle reflection and refraction survey using 102 OBS was completed. The specifications of the OBS survey were basically same as those of surveys in Izu-Ogasawara region[16)17)].

2.1 Airgun shooting

The seismic source of the cruise was an airgun array of BOLT1500LL type on the R/V Kairei. Total chamber size was 12000 cu. in. (200l), which was composed of eight 1500 cu. in. airguns. Air pressure was 2000 psi (140 atm). Towing depth of the airgun array was about 10 m. The eight airguns were shot simultaneously within 1msec. The center of source (COS) was located 198.6 m behind from the vessel reference point (VRP), which was addition of 76.7 m from the VRP to the stern and 121.9 m from the stern to the COS (Figure 3).

The Line IBr10 was 679-km length from the Shikoku Basin to the Pacific Plate subducting beneath the Izu-Ogasawara Arc. The western and eastern ends of the Line IBr10 were extended outside of OBS locations: the western end was 62-km west from OBS102 and the eastern end was 111-km east from OBS001. The shooting interval was 200-m, which was about 97 s with 4 knot ship speed. Total shot number was 3396, which was continuously conducted without shooting interruption on the Line IBr10 (Table 2).

2.2 OBS

One hundred and two OBS were deployed with 5-km interval on the Line IBr10. The OBS and the digital recorder system were originally designed by Kanazawa and Shiobara[18)] and Shinohara et al.[19)]. The sensors of the OBS are 4.5 Hz geophones for one vertical and two horizontal components and one hydrophone. The signals recorded by hard disk drive (HDD) after 16 bit A/D converter with 100 Hz sampling rate (10 ms). The power supply for the electric is rechargeable battery, which is effective for one month survey. The time shifts between the internal clock of OBS and reference time (GPS) were measured before the deployment and after the retrieval for calibration during OBS deployment on seafloor.

Table1: Activity log during KR0713 cruise

Date	Remarks
September 30	Departure from Yokohama
October 01	OBS deployment (Site#001-Site#005)
October 02	OBS deployment (Site#006-Site#023)
October 03	OBS deployment (Site#024-Site#039)
October 04	OBS deployment (Site#040-Site#058)
October 05	OBS deployment (Site#059-Site#074)
October 06	Avoidance due to typhoon attack
October 07	Avoidance due to typhoon attack
October 08	Avoidance due to typhoon attack
October 09	Avoidance due to typhoon attack
October 10	OBS deployment (Site#075-Site#085)
October 11	OBS deployment (Site#086-Site#102)
October 12	Float towing test & IBr10 airgun shooting
October 13	IBr10 airgun shooting
October 14	IBr10 airgun shooting
October 15	IBr10 airgun shooting
October 16	IBr10 airgun shooting
October 17	IBr10 airgun shooting & OBS retrieval (Site#001-Site#005)
October 18	OBS retrieval (Site#007-Site#023)
October 19	OBS retrieval (Site#025-Site#038)
October 20	OBS retrieval (Site#039-Site#046) & Avoidance due to typhoon attack
October 21	Avoidance due to typhoon attack
October 22	OBS retrieval (Site#102-Site#091)
October 23	OBS retrieval (Site#090-Site#074)
October 24	OBS retrieval (Site#073-Site#053)
October 25	OBS retrieval (Site#052-Site#047)
October 26	Avoidance due to typhoon attack
October 27	Avoidance due to typhoon attack
October 28	Avoidance due to typhoon attack
October 29	Arrival to JAMSTEC

The transponders of Kaiyodenshi type (KYD) and System Giken type (SYG) were used for communication in seawater to cut iron anchor and to measure the distance. Although the descending speeds for both types are about 82 m per minute, cutting time and ascending speed are different each other. The cutting times for iron anchor are about 15 minutes for KYD and 22 minutes for SYG, respectively. The ascending speeds for KYD and SYG are respectively 63 m per minutes and 68 m per minutes. For this survey, 60 KYD and 42 SYG were used (Table 3).

We deployed 102 OBS taking acoustic communication between the R/V Kairei and OBS to measure the location on seafloor. Most OBS were located within 200-m diameter from planned position, which was the airgun shooting interval. However, several OBS were positioned about 300-m away from the aimed position because of currents. Moreover, several OBS were deployed away from the first planned position avoiding the steep slope depending on the bathymetry.

2.3 Navigation Systems

The navigation of the survey was StarFire system, which was a Differential Global Positioning System (DGPS), enabling to navigate the R/V Kairei within 0.4 m

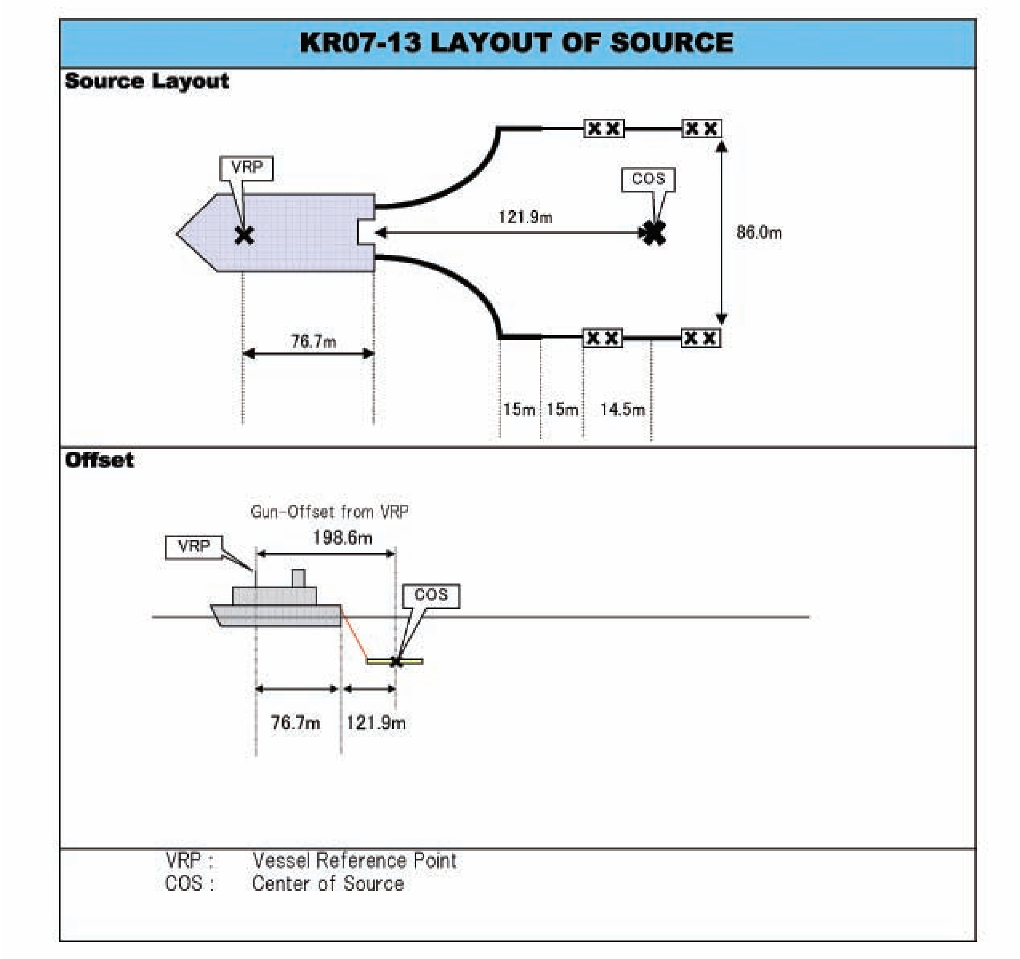

Figure3: Geometry of the airgun system for OBS survey

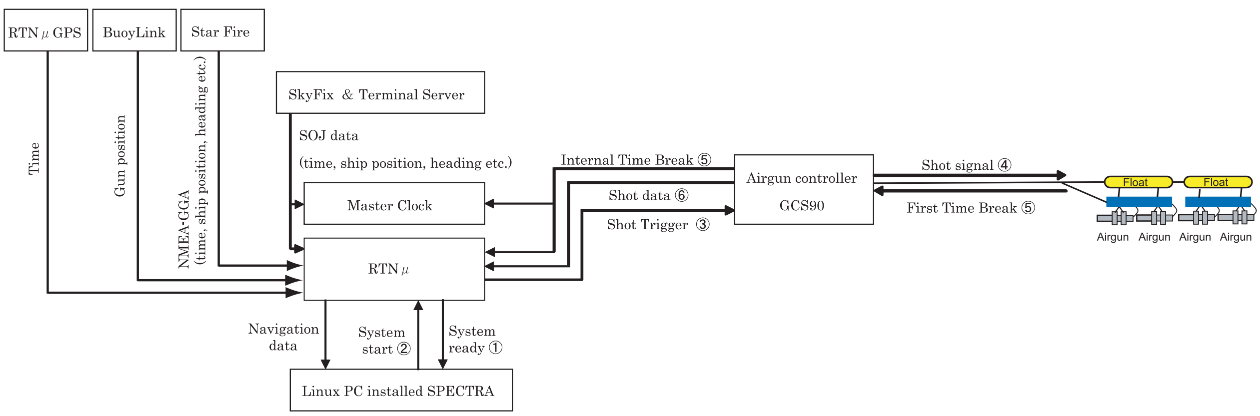

Figure4: Navigation system of R/V Kairei.

accuracy. The software SPECTRA of Concept Inc. was used to control the navigation system. The positioning data from the StarFire was sent to RTNμ (a network interface made by Concept Inc.) via a terminal server in the LAN system of the R/V Kairei. The RTNμ acquire the time signal of the StarFire from the original antenna. The navigation data is sent to the PC Linux machine installing the SPECTRA. The shottime and shotpoint (SP) were set by the SPECTRA and trigger signals were sent to the recording system and the airgun control system (GCS90).

The schematic diagrams of navigation and recording system is shown by Figure 4. At first, SPECTRA send the starting signal (System-start-signal) to the central control device bia RTNμ (Real Time Navigation Unit). Secondly, SPECTRA send the trigger signal (Shot-trigger) to the airgun control system (GCS90). The GCS90 sends the signal (Internal-time-break-signal) back to the RTNμ , and simultaneously send the trigger signal to each airgun. The wave forms recorded by the monitor hydrophone are sent to the GCS90 and the airgun position is sent to the RTNμ .

3. OBS Data

The recording condition was good enough to identify the airgun signals to 250-km offset distances in some data. Figure 5 shows vertical component data of OBS019, 048 and 078. All traces were processed by 3-12 Hz band pass filter, deconvolution, and auto gain control of 2 sec.

OBS019 was located in the Ogasawara Trough, which is between the Ogasawara Ridge and the Izu-Ogasawara Arc. Apparent velocities of first arrivals in eastern side of the OBS in 9-12 km, 18-40 km, 40-54 km, 54-76 km and 76-93 km are 4.4 km/s, 6-7 km/s, 9 km/s, 5.2 km/s and 6.2 km/s, respectively. Those in western side of the OBS in 9-13 km, 13-17 km, 20-42 km, 45-57 km and 57-72 km are 3.1 km/s, 6.4 km/s, 7 km/s, 8 km/s and 8.6 km/s, respectively. The apparent velocity over 72 km west is continuously changed by seafloor topography until 200 km offset. The later reflection phases are observed in east side of the OBS in 15 km, 60 km and 100 km, and in west side of the OBS in 40 km, 60 km and 70 km.

OBS048 was on the Izu-Ogasawara Arc region. Apparent velocities of first arrivals in eastern side of the OBS in 4-12 km, 12-25 km, 25-32 km, 32-41 km, 41-48 km, 72-82 km, 82-110 km and 110-127 km are respectively 4.1 km/s, 5.0 km/s, 8.9 km/s, 5.8 km/s, 5.0 km/s, 5.5 km/s, 6.3 km/s and 8.6 km/s. Those in western side of the OBS in 4-6 km, 6-9 km, 18-32 km, 32-40 km, 40-53 km, 53-77 km and 77-89 km are 3.1 km/s, 5.4 km/s, 5.2 km/s, 7.1 km/s, about 10 km/s, 7.5 km/s and 7.0 km/s, respectively. The apparent velocity between 48 and 72 km east of the OBS was continuously changed about 8 km/s for seafloor topography. In both sides of the OBS, there are clear later phases thought to be reflection signals from deep interfaces in 40-km offset distances.

OBS096 was positioned near the eastern edge of the Shikoku Basin. Apparent velocities of first arrivals in eastern side of the OBS in 6-9 km, 9-14 km, 14-21 km, 34-53 km, 63-100 km and 100-115 km are 4.3 km/s, 5.6 km/s, 6.7 km/s, 7 km/s, 8.6 km/s and 6.3 km/s, respectively. The apparent velocity between 48 and 72 km are continuously changed about 8 km/s. Those in western side of the OBS in 6-8 km, 8-13 km and 13-17 km are 4.0 km/s, 4.9 km/s and 6.3 km/s, respectively. The apparent velocity over 17 km west is about 8 km/s and continuously changed by seafloor topography.

From the general information of these OBS records, the crustal thickness is suggested as thick in arc and forearc region. For example, the OBS019 data shows that the intercept time of the first arrival of 7 km/s in west side is about 6 s. On the other hand in backarc region, the crustal thickness seemed to be thin, especially in the Shikoku Basin.

For an example of horizontal component, figure 6 shows the two horizontal component data of OBS078. All traces were processed by 3-12 Hz band pass filter, deconvolution, and auto gain control of 2 sec. In the western side of the OBS between 20 and 40 km offset and 11 sec, there are clear signals with 4.2 km/s apparent velocity, which are thought to be converted signals from P to S at deep interfaces.

4. Summary

We have conducted a seismic survey in the middle Izu-Ogasawara region of wide-angle reflection and refraction experiment using 102 OBS during September to October, 2007. The data acquisition of the OBS survey was successfully finished, although there were three interruptions of typhoon attacks. Acquired data quality is good. For example, some of the OBS data of vertical component have clear first arrivals until an offset of 250 km. Some clear signals in horizontal component data are thought to be P-S converted signals at the deep interfaces. From the information of apparent velocities and intercept times of OBS data, the crustal thicknesses of the middle Izu-Ogasawara Arc and the forearc region are thick, whereas the crustal thickness in the Shikoku Vela Basin is thin. In the future, we will constrain the velocity model transecting the middle Izu-Ogasawara Arc, followed by the interpretation for arc evolution and formation of back-arc basins using the OBS data.

Table2: Airgun shooting log

IBr10obs_0	Time (UTC)	Latitude (N)	Longitude (E)	Depth (m)	SP
First shot	2007/10/12 10:30	27° 49.6308′	136° 45.1800′	4579	963
First good shot	2007/10/12 10:30	27° 49.6308′	136° 45.1800′	4579	963
Last good shot	2007/10/16 14:59	29° 25.1894′	143° 27.4072′	6108	4358
Last shot	2007/10/16 14:59	29° 25.1894′	143° 27.4072′	6108	4358

Table3: OBS information. The "KYD" and "SYG" indicate the type of transponder Kaiyodenshi and System-Giken, respectively.

Site	Cast				Recovery				OBS Calibration position					Transponder
	Time	Vessel position			Time	Vessel position								
	UTC	Lat(N)	Lon(E)	Depth	UTC	Lat(N)	Lon(E)	Depth	Lat(N)	Lon(E)	Depth	x	y	
1	2007/10/01 04:31:50	29_10.8913	142_20.6809	5049	2007/10/17 06:23:00	29_10.8993	142_20.4959	5045	29_10.9591	142_20.6017	5037.5	108.0	−154.7	SYG
2	2007/10/01 06:13:55	29_10.2393	142_17.6986	4717	2007/10/17 08:01:00	29_10.2094	142_17.4531	4709	29_10.2734	142_17.6061	4711.9	54.0	−152.0	SYG
3	2007/10/01 07:50:19	29_09.5632	142_14.7030	4419	2007/10/17 11:28:00	29_09.4086	142_14.3180	4390	29_09.5359	142_14.6454	4401.2	−94.0	−94.0	SYG
4	2007/10/01 09:11:59	29_08.9264	142_11.6889	3961	2007/10/17 14:32:13	29_08.9724	142_11.3301	3913	29_08.9596	142_11.5718	3953.8	58.0	−220.0	KYD
5_1	2007/10/01 10:35:32	29_08.2677	142_08.7069	3660	−	−	−	−	−	−	−	−	−	KYD
5_2	2007/10/01 12:33:03	29_08.2666	142_08.7112	3657	2007/10/17 14:46:47	29_08.4091	142_08.2794	3624	29_08.2967	142_08.5335	3639.7	52.0	−290.0	KYD
6	2007/10/01 17:09:00	29_07.6140	142_05.7183	3425	2007/10/17 15:53:00	29_07.8614	142_05.5780	3437	29_07.7030	142_05.7830	3433.5	176.0	106.0	KYD
7	2007/10/01 18:31:51	29_06.9450	142_02.7164	3077	2007/10/17 16:59:00	29_07.1579	142_02.5689	3027	29_06.9859	142_02.7380	3069.3	74.0	20.0	KYD
8	2007/10/01 19:47:04	29_06.2822	141_59.7200	2648	2007/10/17 17:57:00	29_06.4413	141_59.4974	2644	29_06.2666	141_59.7279	2637.9	−30.0	−4.0	KYD
9	2007/10/01 20:57:57	29_05.6195	141_56.7337	2695	2007/10/17 18:59:00	29_05.8469	141_56.2944	2678	29_05.6630	141_56.6391	2684.2	82.0	−180.0	KYD
10	2007/10/01 22:05:11	29_04.9547	141_53.7486	2431	2007/10/17 20:11:00	29_05.2819	141_53.2609	2500	29_05.0140	141_53.7371	2442.4	112.0	−14.0	KYD
11	2007/10/01 23:14:41	29_04.2794	141_50.7496	2586	2007/10/17 21:08:00	29_04.5645	141_50.3880	2579	29_04.3542	141_50.6174	2574.4	124.0	−222.0	KYD
12	2007/10/02 00:23:31	29_03.6183	141_47.7581	2543	2007/10/17 22:04:00	29_03.8190	141_47.4077	2553	29_03.6576	141_47.6600	2550.1	70.0	−168.0	KYD
13	2007/10/02 01:37:59	29_02.9555	141_44.7781	2593	2007/10/17 23:08:44	29_03.1163	141_44.4988	2651	29_02.9890	141_44.7278	2597.8	70.0	−74.0	KYD
14	2007/10/02 02:43:02	29_02.2849	141_41.7843	2818	2007/10/18 00:09:53	29_02.4286	141_41.5823	2902	29_02.3312	141_41.7703	2835.6	92.0	−22.0	KYD
15	2007/10/02 03:51:43	29_01.6061	141_38.7825	3278	2007/10/18 01:20:26	29_01.7576	141_38.6291	3239	29_01.6518	141_38.8123	3274.2	76.0	26.0	KYD
16	2007/10/02 05:27:28	29_00.9138	141_35.6969	3894	2007/10/18 02:37:52	29_01.0305	141_35.5056	3891	29_00.8973	141_35.5982	3909.4	−8.0	−112.0	KYD
17	2007/10/02 06:46:13	29_00.2615	141_32.8200	3948	2007/10/18 04:00:00	29_00.3715	141_32.6771	3818	29_00.2908	141_32.8023	3933.2	46.0	−26.0	SYG
18	2007/10/02 08:03:49	28_59.5900	141_29.8317	3978	2007/10/18 05:29:00	28_59.6293	141_29.6751	3984	28_59.5918	141_29.7812	3976.2	0.0	−116.0	SYG
19	2007/10/02 09:26:16	28_58.9157	141_26.8459	4014	2007/10/18 06:55:00	28_58.9659	141_26.6621	4015	28_58.9578	141_26.7539	4014.6	76.0	−150.0	SYG
20	2007/10/02 10:47:05	28_58.2408	141_23.8501	4026	2007/10/18 08:19:00	28_58.3144	141_23.5688	4028	28_58.2891	141_23.7180	4028.2	90.0	−232.0	SYG
21	2007/10/02 12:04:23	28_57.5641	141_20.8870	4034	2007/10/18 09:40:00	28_57.6538	141_20.5874	4034	28_57.6194	141_20.7528	4134.5	104.0	−200.0	SYG
22	2007/10/02 13:25:15	28_56.8816	141_17.8872	4036	2007/10/18 11:05:09	28_56.9725	141_17.6211	4038	28_56.9452	141_17.8251	4035.1	112.0	−108.0	SYG
23	2007/10/02 14:44:17	28_56.2062	141_14.8958	4025	2007/10/18 12:48:30	28_56.3835	141_14.4881	4023	28_56.2657	141_14.8772	4038.0	112.0	−50.0	SYG
24	2007/10/02 16:10:51	28_55.5261	141_11.9164	4024	−	−	−	−	28_55.5428	141_11.9288	4025.6	34.0	6.0	SYG
25	2007/10/02 17:33:20	28_54.8469	141_08.9412	4023	2007/10/17 22:16:00	28_54.9841	141_08.7648	4020	28_54.8773	141_08.9686	4025.8	64.0	42.0	SYG
26	2007/10/02 18:57:30	28_54.1580	141_05.9568	4014	2007/10/18 23:43:40	28_54.3318	141_05.6878	4013	28_54.1641	141_05.9513	4024.2	8.0	−16.0	SYG
27	2007/10/02 20:23:03	28_53.4763	141_02.9819	3989	2007/10/19 01:11:06	28_53.6256	141_02.7524	3977	28_53.4965	141_03.0096	3985.7	38.0	48.0	SYG
28	2007/10/02 21:46:26	28_52.7879	141_00.0076	3888	2007/10/19 02:26:24	28_52.8589	140_59.7652	3888	28_52.7562	140_59.9900	3886.1	−64.0	−16.0	KYD
29	2007/10/02 23:10:56	28_52.1039	140_57.0181	3768	2007/10/19 03:45:00	28_52.1723	140_56.7161	3731	28_52.0431	140_56.9966	3752.3	−114.0	−38.0	KYD
30	2007/10/03 00:30:08	28_51.4133	140_54.0359	3811	2007/10/19 04:57:00	28_51.4340	140_53.7087	3600	28_51.4003	140_53.9586	3594.5	−32.0	−134.0	KYD
31	2007/10/03 01:44:22	28_50.7315	140_51.0570	3463	2007/10/19 06:16:00	28_50.7332	140_50.8038	3433	28_50.6600	140_51.0515	3451.9	−128.0	−18.0	KYD
32	2007/10/03 04:51:52	28_50.0413	140_48.0792	3343	2007/10/19 07:27:00	28_50.0950	140_47.8084	3350	28_50.0486	140_48.0297	3349.7	16.0	−90.0	KYD
33	2007/10/03 06:06:13	28_49.3486	140_45.1066	3093	2007/10/19 08:31:00	28_49.3875	140_44.8909	3079	28_49.3667	140_45.0440	3090.4	32.0	−104.0	KYD
34	2007/10/03 07:41:10	28_48.5908	140_41.8814	3160	2007/10/19 09:40:00	28_48.5553	140_41.5162	3153	28_48.5874	140_41.7411	3157.5	−4.0	−248.0	KYD
35	2007/10/03 08:47:31	28_47.9648	140_39.1468	3136	2007/10/19 10:50:00	28_48.0353	140_38.7535	3149	28_47.9327	140_39.0784	3143.4	−60.0	−126.0	KYD
36	2007/10/03 09:55:51	28_47.2670	140_36.1632	3785	2007/10/19 12:07:45	28_47.3348	140_35.7359	3791	28_47.2314	140_36.0307	3862.5	−74.0	−244.0	KYD
37	2007/10/03 11:36:54	28_46.6336	140_33.4813	3646	2007/10/19 13:27:33	28_46.6223	140_33.0332	3580	28_46.5277	140_33.2562	3658.1	−168.0	−294.0	KYD
38	2007/10/03 12:52:58	28_45.8789	140_30.2263	3315	2007/10/19 14:40:43	28_45.9293	140_29.9300	3362	28_45.9024	140_30.1293	3331.5	40.0	−168.0	KYD
39	2007/10/03 14:05:03	28_45.1775	140_27.2559	3361	2007/10/19 15:48:00	28_45.2784	140_26.9834	3304	28_45.1913	140_27.1586	3333.6	14.0	−164.0	KYD
40	2007/10/03 15:42:00	28_44.4178	140_24.0127	2567	2007/10/19 16:50:00	28_44.5647	140_23.7073	2596	28_44.4473	140_23.8616	2564.2	62.0	−254.0	KYD
41	2007/10/03 16:41:17	28_43.7624	140_21.3040	2202	2007/10/19 17:45:00	28_43.9771	140_21.1475	2196	28_43.8742	140_21.2763	2195.8	162.0	−60.0	KYD
42	2007/10/03 17:46:18	28_43.0938	140_18.3307	2403	2007/10/19 18:41:00	28_43.2872	140_18.2211	2421	28_43.1782	140_18.2986	2407.4	170.0	−74.0	KYD
43	2007/10/03 18:53:08	28_42.3879	140_15.3724	2958	2007/10/19 19:42:00	28_42.5611	140_15.3459	2971	28_42.4564	140_15.4055	2959.3	132.0	52.0	KYD
44	2007/10/03 20:10:08	28_41.6833	140_12.4023	2908	2007/10/19 20:45:00	28_41.7704	140_12.4441	2922	28_41.7083	140_12.4333	2909.8	44.0	48.0	KYD
45	2007/10/03 21:19:59	28_40.9819	140_09.4283	2653	2007/10/19 21:44:00	28_40.9891	140_09.4289	2661	28_40.9877	140_09.4863	2645.6	16.0	84.0	KYD
46	2007/10/03 22:28:36	28_40.2794	140_06.4666	2544	2007/10/19 22:42:00	28_40.2870	140_06.4409	2544	28_40.2538	140_06.5142	2557.8	−38.0	78.0	KYD
47	2007/10/03 23:33:24	28_39.5688	140_03.4826	2302	2007/10/24 20:40:00	28_39.6470	140_03.3722	2298	28_39.5438	140_03.5169	2287.9	−46.0	30.0	KYD
48	2007/10/04 00:37:20	28_38.8609	140_00.5250	2400	2007/10/24 19:42:00	28_38.9409	140_00.3478	2421	28_38.8545	140_00.5068	2400.7	−14.0	−40.0	KYD
49	2007/10/04 01:40:41	28_38.1588	139_57.5567	2594	2007/10/24 18:48:00	28_38.2458	139_57.3660	2620	28_38.1624	139_57.5354	2609.8	52.0	−48.0	KYD
50	2007/10/04 02:47:12	28_37.4413	139_54.5836	2417	2007/10/24 17:48:00	28_37.4387	139_54.3612	2216	28_37.4193	139_54.5476	2394.4	−48.0	−84.0	KYD
51	2007/10/04 03:51:31	28_36.6813	139_51.3943	2681	2007/10/24 16:27:00	28_36.7086	139_51.2668	2682	28_36.6951	139_51.4225	2683.3	24.0	32.0	KYD
52	2007/10/04 04:56:32	28_36.0233	139_48.6694	2837	2007/10/24 15:29:00	28_35.9751	139_48.5326	2882	28_36.0049	139_48.6585	2844.0	−36.0	−18.0	KYD
53	2007/10/04 06:03:24	28_35.2978	139_45.7023	3074	2007/10/24 14:26:59	28_35.2480	139_45.6551	3049	28_35.2885	139_45.6898	3074.3	−44.0	−26.0	KYD
54	2007/10/04 07:16:38	28_34.5989	139_42.7426	3613	2007/10/24 13:21:14	28_34.6674	139_42.7316	3615	28_34.5894	139_42.7303	3616.6	−18.0	−20.0	KYD
55	2007/10/04 08:37:57	28_33.8930	139_39.7716	3610	2007/10/24 12:00:05	28_34.0674	139_39.6553	3615	28_33.9216	139_39.7704	3610.0	68.0	−16.0	KYD
56	2007/10/04 10:11:18	28_33.1683	139_36.8164	3529	2007/10/24 10:49:00	28_33.1820	139_36.7240	3527	28_33.0742	139_36.7215	3513.3	−176.0	−158.0	KYD
57	2007/10/04 11:45:07	28_32.4500	139_33.6567	3460	2007/10/24 09:35:00	28_32.4169	139_33.6338	3449	28_32.3643	139_33.7334	3455.1	−164.0	−202.0	KYD
58	2007/10/04 13:51:25	28_31.7379	139_30.8942	3183	2007/10/24 08:21:00	28_31.6754	139_30.5120	3145	28_31.6782	139_30.7265	3166.3	−106.0	−278.0	KYD
59	2007/10/04 15:20:22	28_31.0063	139_27.9384	3088	2007/10/24 07:13:00	28_30.9735	139_27.6388	3103	28_30.9933	139_27.8120	3091.6	−44.0	−204.0	KYD
60	2007/10/04 16:39:13	28_30.3004	139_24.9829	3129	2007/10/24 06:07:00	28_30.2356	139_24.7008	3131	28_30.2639	139_24.9009	3124.2	−62.0	−126.0	KYD
61	2007/10/04 17:56:01	28_29.5716	139_22.0204	3142	2007/10/24 05:05:00	28_29.5153	139_21.7905	3140	28_29.5324	139_21.9338	3145.2	−82.0	−140.0	KYD
62	2007/10/04 19:06:40	28_28.8524	139_19.0640	3242	2007/10/24 04:03:00	28_28.6986	139_18.9399	3242	28_28.8540	139_19.0668	3246.8	−2.0	8.0	KYD
63	2007/10/04 20:21:56	28_28.1282	139_16.1098	3261	2007/10/24 02:53:38	28_28.0431	139_16.0878	3258	28_28.1399	139_16.1538	3265.5	14.0	80.0	KYD
64	2007/10/04 21:33:16	28_27.4098	139_13.1529	3223	2007/10/24 01:46:37	28_27.3301	139_13.2071	3224	28_27.4084	139_13.1914	3226.2	0.0	70.0	KYD
65	2007/10/04 22:43:38	28_26.6785	139_10.1898	3209	2007/10/24 00:43:05	28_26.6155	139_10.3378	3210	28_26.6586	139_10.2160	3210.2	−46.0	38.0	KYD
66	2007/10/04 23:56:41	28_25.9553	139_07.2339	3210	2007/10/23 23:34:34	28_25.8622	139_07.3343	3209	28_25.8774	139_07.2291	3208.1	−148.0	−14.0	KYD
67	2007/10/05 01:09:00	28_25.2258	139_04.2789	3178	2007/10/23 22:25:00	28_25.1682	139_04.3399	3178	28_25.1849	139_04.2600	3179.9	−84.0	−38.0	KYD
68	2007/10/05 02:22:44	28_24.4934	139_01.3209	2968	2007/10/23 21:22:00	28_24.3855	139_01.3369	3025	28_24.4633	139_01.2930	2982.6	−72.0	−60.0	KYD
69	2007/10/05 03:36:53	28_23.7124	138_58.1490	2879	2007/10/23 20:20:00	28_23.6384	138_58.1425	2878	28_23.6845	138_58.1428	2890.6	−50.0	−10.0	KYD
70	2007/10/05 04:43:19	28_23.0456	138_55.4176	2817	2007/10/23 19:15:00	28_22.9549	138_55.4022	2827	28_23.0461	138_55.4304	2818.9	6.0	10.0	KYD
71	2007/10/05 05:52:52	28_22.3094	138_52.4663	2710	2007/10/23 18:09:00	28_22.2069	138_52.3621	2713	28_22.3287	138_52.4236	2711.1	28.0	−80.0	KYD
72	2007/10/05 07:00:37	28_21.6616	138_49.7558	3044	2007/10/23 17:07:00	28_21.5738	138_49.6706	2999	28_21.6673	138_49.7745	3056.6	38.0	−20.0	KYD
73_1	2007/10/05 08:10:01	28_20.8498	138_46.5728	3517	2007/10/05 10:26:00	28_20.5913	138_46.5399	3531	−	−	−	−	−	KYD
73_2	2007/10/05 10:42:29	28_20.8345	138_46.5791	3526	2007/10/23 16:00:00	28_20.6753	138_46.3993	3533	28_20.7861	138_46.5306	3523.8	−110.0	−66.7	KYD
74	2007/10/05 11:55:33	28_20.1125	138_43.6167	3546	2007/10/23 14:45:36	28_19.8856	138_43.6775	3566	28_19.9471	138_43.6973	3553.7	−303.3	123.3	KYD
75_1	2007/10/05 13:12:24	28_19.3726	138_40.6634	3807	2007/10/05 14:58:00	28_19.1012	138_40.5773	3613	−	−	−	−	−	KYD
75_2	2007/10/10 01:05:12	28_19.3744	138_40.6799	3808	2007/10/23 13:35:55	28_19.2613	138_40.7424	3607	28_19.3465	138_40.7794	3603.9	−54.0	174.0	SYG
76	2007/10/10 02:27:14	28_18.6376	138_37.7276	3678	2007/10/23 12:10:42	28_18.5091	138_37.8700	3671	28_18.6109	138_37.8078	3669.7	−52.0	136.0	SYG
77	2007/10/10 03:46:38	28_17.8938	138_34.7760	3872	2007/10/23 10:50:00	28_17.2935	138_34.8417	3876	28_17.8701	138_34.8125	3869.0	−58.0	58.0	SYG
78	2007/10/10 05:06:27	28_17.1568	138_31.8239	3990	2007/10/23 09:28:00	28_17.2935	138_31.8292	3982	28_17.4216	138_31.8448	3974.1	478.0	24.0	SYG
79	2007/10/10 06:27:43	28_16.4239	138_28.8777	3967	2007/10/23 08:01:00	28_16.2723	138_28.7734	3988	28_16.3927	138_28.8827	3956.3	−56.0	−2.0	SYG
80	2007/10/10 07:50:23	28_15.6827	138_25.9314	4095	2007/10/23 06:36:00	28_15.5060	138_25.8405	4121	28_15.6551	138_25.9372	4105.3	−50.0	−2.0	SYG
81	2007/10/10 09:12:00	28_14.9355	138_22.9907	4180	2007/10/23 05:11:00	28_14.8149	138_22.8961	4179	28_14.9447	138_23.0486	4182.0	8.0	90.0	SYG
82	2007/10/10 10:32:55	28_14.1897	138_20.0523	4222	2007/10/23 03:43:00	28_14.0957	138_20.0582	4222	28_14.2386	138_20.1264	4218.4	76.0	126.0	SYG
83	2007/10/10 11:57:24	28_13.4487	138_17.1044	4393	2007/10/23 02:19:38	28_13.3509	138_17.1953	4390	28_13.4935	138_17.1438	4392.8	74.0	62.0	SYG
84	2007/10/10 13:20:48	28_12.7144	138_14.1471	4487	2007/10/23 00:48:19	28_12.7002	138_14.3325	4467	28_12.7788	138_14.1863	4462.1	130.0	38.0	SYG
85	2007/10/10 14:48:49	28_11.9558	138_11.2180	4462	2007/10/22 23:18:34	28_11.8974	138_11.3599	4469	28_11.9743	138_11.3322	4456.8	22.0	182.0	SYG
86	2007/10/10 16:21:03	28_11.2130	138_08.2781	4554	2007/10/22 21:43:00	28_11.1457	138_08.3492	4559	28_11.2467	138_08.3309	4548.2	58.0	84.0	SYG
87	2007/10/10 17:53:04	28_10.4684	138_05.3315	4550	2007/10/22 20:19:00	28_10.3570	138_05.3035	4544	28_10.4433	138_05.3242	4534.1	−44.0	−24.0	SYG
88	2007/10/10 19:23:17	28_09.7171	138_02.3972	4382	2007/10/22 18:45:00	28_09.4496	138_02.3358	4386	28_09.6615	138_02.4086	4379.7	−104.0	16.0	SYG
89	2007/10/10 20:52:35	28_08.9657	137_59.4584	4189	2007/10/22 17:17:00	28_08.7419	137_59.3801	4153	28_08.9557	137_59.4728	4186.3	−22.0	22.0	SYG
90	2007/10/10 22:20:09	28_08.2138	137_56.5154	4208	2007/10/22 15:53:00	28_08.0383	137_56.4507	4216	28_08.2358	137_56.5488	4210.0	36.0	46.0	SYG
91	2007/10/10 23:44:55	28_07.4626	137_53.5890	4607	2007/10/23 14:11:07	28_07.3149	137_53.6363	4538	28_07.4747	137_53.6194	4624.0	20.0	60.0	SYG
92	2007/10/11 01:12:00	28_06.7162	137_50.6521	4648	2007/10/23 12:40:50	28_06.5790	137_50.7683	4652	28_06.7301	137_50.7053	4673.9	36.0	98.0	SYG
93	2007/10/11 02:39:42	28_05.9817	137_47.7918	4445	2007/10/23 11:06:03	28_05.8781	137_47.8496	4480	28_05.9897	137_47.8219	4443.8	24.0	52.0	SYG
94	2007/10/11 04:02:49	28_05.1986	137_44.7677	4464	2007/10/22 09:35:00	28_05.1305	137_44.8050	4470	28_05.2321	137_44.7363	4468.2	58.0	−60.0	SYG
95	2007/10/11 05:24:50	28_04.4467	137_41.8380	4071	2007/10/22 08:03:00	28_04.4225	137_41.8455	4067	28_04.4788	137_41.7802	4068.8	64.0	−94.0	SYG
96	2007/10/11 06:42:22	28_03.6826	137_38.9020	4080	2007/10/22 06:36:00	28_03.6962	137_38.8832	4084	28_03.7061	137_38.9422	4080.6	36.0	64.0	SYG
97	2007/10/11 08:00:49	28_02.9239	137_35.9677	3981	2007/10/22 05:14:00	28_02.9311	137_35.9622	3983	28_02.9562	137_35.9998	3981.3	52.0	50.0	SYG
98	2007/10/11 09:23:47	28_02.1706	137_33.0377	3212	2007/10/22 03:54:00	28_02.1711	137_33.0871	3191	28_02.1900	137_33.0324	3217.7	40.0	−6.0	SYG
99	2007/10/11 10:39:00	28_01.3347	137_29.8198	1872	2007/10/22 02:38:09	28_01.3083	137_29.8926	1896	28_01.3678	137_29.8800	1857.7	68.0	98.0	SYG
100	2007/10/11 11:33:36	28_00.6760	137_27.2945	2514	2007/10/22 01:38:09	28_00.6664	137_27.3886	2459	28_00.7480	137_27.3692	2465.2	130.0	126.0	SYG
101	2007/10/11 12:39:59	27_59.8624	137_24.1583	4077	2007/10/22 00:38:37	27_59.7957	137_24.2087	4061	27_59.8207	137_24.1515	4064.1	−78.0	−16.0	SYG
102	2007/10/11 14:01:01	27_59.1198	137_21.3089	4704	2007/10/21 23:03:30	27_59.1869	137_21.4892	4699	27_59.1985	137_21.3859	4700.1	146.0	124.0	SYG

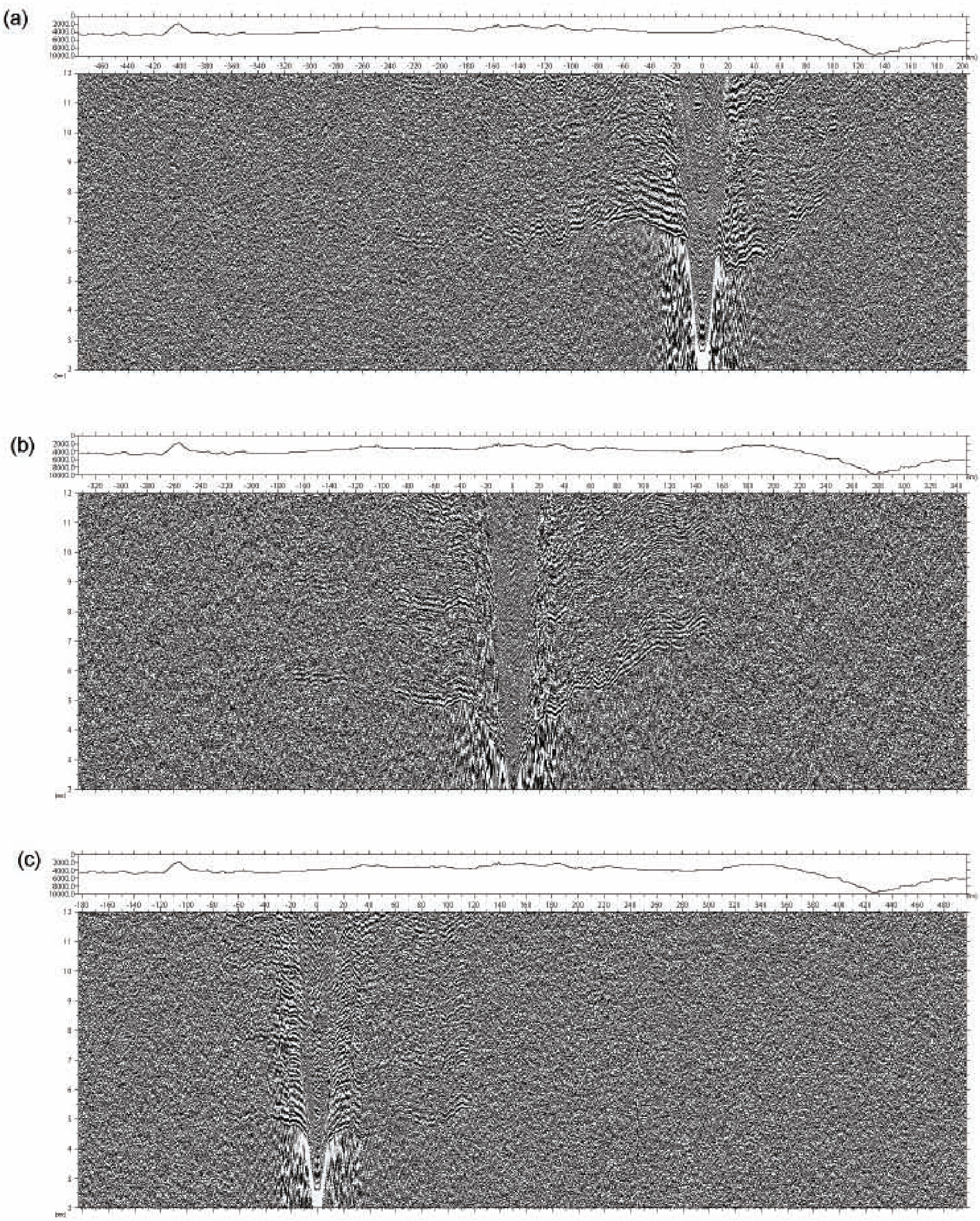

Figure5: OBS data of vertical component of three sites: (a) Site019, (b) Site048, and (c) Site078. All traces are filtered by 3-12 Hz. Vertical and horizontal axes are offsets from OBS and reduced travel-times by 8 km/s, respectively. The bathymetries of the OBS data are also shown above the sections.

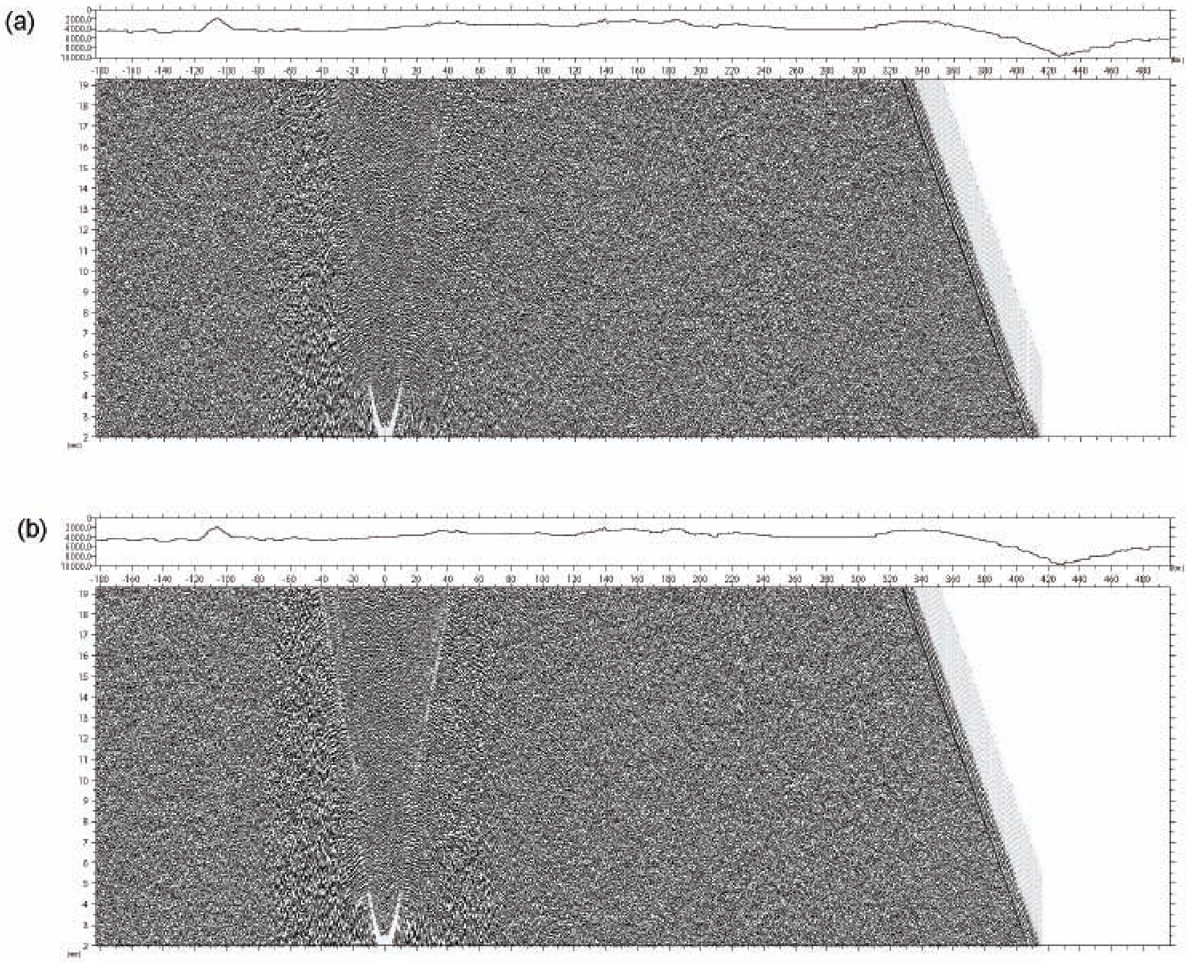

Figure6: OBS data of horizontal component of Site078: (a) H1, and (b) H2. All traces are filtered by 3-12 Hz. Vertical and horizontal axes are offsets from OBS and reduced traveltimes by 4.6 km/s, respectively. The bathymetries of the OBS data are also shown above the sections.

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Technician	Kozue Kurihara
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Technician	Mitsuteru Kuno
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Technician	Keisuke Ohnishi
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Chief Officer	Satoshi Susami
Second Officer	Naoto Kimura
Third Officer	Takeshi Egashira
Third Officer	Yuki Furukawa
Chief Engineer	Kiyonori Kajinishi
First Engineer	Masahiro Kajihara
Second Engineer	Saburo Sakaemura
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