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MCS seismic profiling of an oceanic island arc in the southern Izu-Ogasawara arc-backarc area – KR0607 cruise –

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Abstract We carried out a deep seismic survey using a large airgun array with total capacity of 12,000 cubic inches and a 204-channel multi-channel hydrophone streamer system (MCS) in the southern Izu-Ogasawara arc-backarc area. The survey was conducted on the R/V Kairei of the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) during 5 July -- 27 July 2006 (KR0607 cruise). Objectives of this cruise were to obtain crustal deformation data of the southern Izu-Ogasawara arc area, which was formed in the Eocene, Miocene, and by the currently active arc. During this cruise, three MCS seismic lines were set along the Ogasawara Ridge and across the entire southern Izu-Ogasawara arc.

Keywords: Izu-Ogasawara arc-backarc system, Crustal structure, MCS

1. Introduction

The Izu-Ogasawara arc lies along the eastern margin of the Philippine Sea plate and extends over 1500 km from Sagami Bay to the northern end of the Mariana Trough. The northern and southern parts of the Izu-Ogasawara arc are divided by the Sofugan tectonic line based on differences of several geoscientific characteristics such as topography, chemical composition of volcanic rocks and seismic activity (e.g. Yuasa, 1992).

The old cretaceous Pacific plate subducts WNW-ward from the Ogasawara Trench (Stern *et al*., 2003). The Ogasawara Plateau collides with the southern Ogasawara Ridge and the topography of the Ogasawara Ridge changes drastically there, which suggests that the collision of the Ogasawara Plateau influences the arc crustal deformation.

The southern Izu-Ogasawara arc-backarc system is a good example for the study of crustal growth processes in oceanic island arc-backarc systems because the three parallel topographic highs, which are separated by two troughs, were formed in different ages. These highs are the Ogasawara Ridge, the present volcanic arc, and the Nishi-Shichito Ridge (Honza and Tamaki, 1985), which are located between the Izu-Ogasawara Trench and the Shikoku Basin. The two troughs are the Ogasawara Trough and the Nishinoshima Trough: the former is located between the Ogasawara Ridge and the present volcanic arc; the latter is located between the present volcanic arc and the Nishi-Shichito Ridge as an old rift zone of the northern end of the Parece Vela Basin and the Sofugan tectonic line, which is located at the western wall of the Nishinoshima Trough (Yuasa, 1985). The Ogasawara Ridge, which is located on the eastern side, was formed in the Eocene age (e.g. Bloomer *et al*., 1995). The Nishi-Shichito Ridge, which is located westward from the present volcanic arc, was formed after the Oligocene age (e.g. Bloomer *et al*., 1995). Based on detailed mapping of magnetic anomalies and topography, the Shikoku Basin was formed from 30 to 15 Ma (Okino *et al*., 1994). As described above, in the southern Izu-Ogasawara arc-backarc system, crustal deformation might vary depending on the tectonic stage at each location. We must know the crustal deformation in response to these tectonic stages to understand the crustal growth history.

Objectives of this research are to determine the crustal deformation of the southern Izu-Ogasawara arc-backarc system and to investigate the variation of structures associated with tectonic age.

2. Experiment

We carried out a deep seismic survey using a large airgun array with total capacity of 12,000 cubic inches and 204-channel hydrophone streamer system (MCS) in the southern Izu-Ogasawara arc-backarc area to achieve the

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above objectives (Fig. 1). The survey was conducted on the R/V Kairei of the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) during 5–27 July 2006 (KR0607 cruise).

The R/V Kairei departed from JAMSTEC on 5 July and started MCS experiments from the southern end of the Line OGr1 on 7 July. The MCS survey on the Line OGr1 was carried out during six days. After this survey, we moved to the eastern end of the Line IBr10 and started the MCS survey again. The IBr10 survey was carried out during 13–17 July. Subsequently, we covered Line A03 on 18 and 19 July. On 20 July, we returned to the IBr10 survey. The last survey was carried out on the OGr4 during 21–25 July. We left the survey area on 25 July and arrived at JAMSTEC on 27 July. These activities are listed in Table 1.

To clarify the arc structure of each tectonic stage and characteristics of the oceanic arc-backarc, long seismic lines covering the entire area such as the Eocene old arc, active volcanic arc, and the old arc are indispensable. Considering the above issues, we set three long lines with lengths of about 600 km in the eastern end (OGr1), northern end (IBr10), and southern end (OGr4) of the southern Izu-Ogasawara arc-backarc area. The existing lines, SPr2 across the center of this area and IBr3 along the volcanic front, are helpful to elucidate the crustal deformation of this region.

Three newly surveyed cross-arc lines and one along-arc line are shown in Fig. 1. Lines IBr10 and OGr4 cut across these ridges and basins. The northern transect, Line IBr10, runs across the northern end of the Ogasawara Ridge, the volcanic front, the Sofugan tectonic line, the Nishi-Shichito Ridge and the Hakuho Seamount. The southern transect, Line OGr4, cuts across the southern Ogasawara Ridge, the southern side of the Kaitoku Seamount, the Nishi-Kaitoku Seamount and the southern extension of the Kinan Seamount chain. Line OGr1 lies along the Eocene Ogasawara Ridge; Line A03 is located on the arc-backarc transition zone.

2.1 Airgun shooting

The airgun array, with total capacity of 12,000 cubic inches, consists of eight Bolt long-life airguns, each with 1,500 cubic inches' capacity. The air pressure sent to the chambers is 2,000 psi. The seismic experiment apparatus is shown in Fig. 2. Two floats with two airguns each are deployed respectively from the port and starboard sides. The airgun array is 29 m long _ 88 m wide. The airgun's shooting position is 197 m behind the ship position (respective distances from ship antenna to tail of the ship and from the tail of the ship to the center of the airgun array are 76.7 m and 120.3 m). A StarFire differential global positioning system (DGPS) was used as a seismic navigation system. The accuracy of the shooting position is about 5 m.

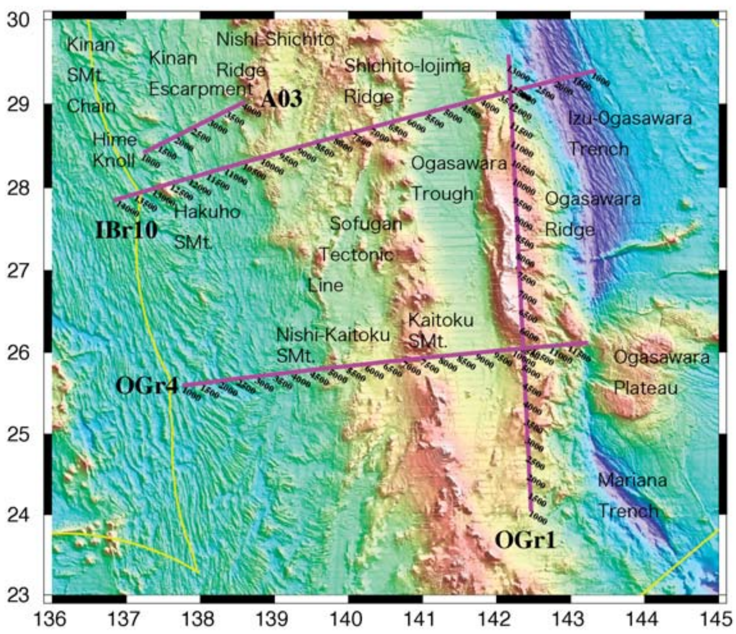

Figure 1: Map of the experimental area. Thick magenta lines show MCS lines. Labeled numbers represent the field shot point number.

Table 1: Activity log during the KR0607 cruise.

Date	Remarks
July 05	Departure from Yokosuka, JAMSTEC
July 06	Transit to the southern end of OGr1
July 07	OGr1 airgun shooting
July 08	OGr1 airgun shooting
July 09	OGr1 airgun shooting
July 10	OGr1 airgun shooting
July 11	OGr1 airgun shooting
July 12	OGr1 airgun shooting and transit to the eastern end of IBr10
July 13	IBr10 airgun shooting
July 14	IBr10 airgun shooting
July 15	IBr10 airgun shooting
July 16	IBr10 airgun shooting
July 17	IBr10 airgun shooting and transit to the western end of A03
July 18	A03 airgun shooting
July 19	A03 airgun shooting and transit to the IBr10
July 20	IBr10 airgun shooting and transit to the western end of OGr4
July 21	OGr4 airgun shooting
July 22	OGr4 airgun shooting
July 23	OGr4 airgun shooting
July 24	OGr4 airgun shooting
July 25	OGr4 airgun shooting and transit to JAMSTEC
July 26	Transit
July 27	Transit and arrival at JAMSTEC HQ

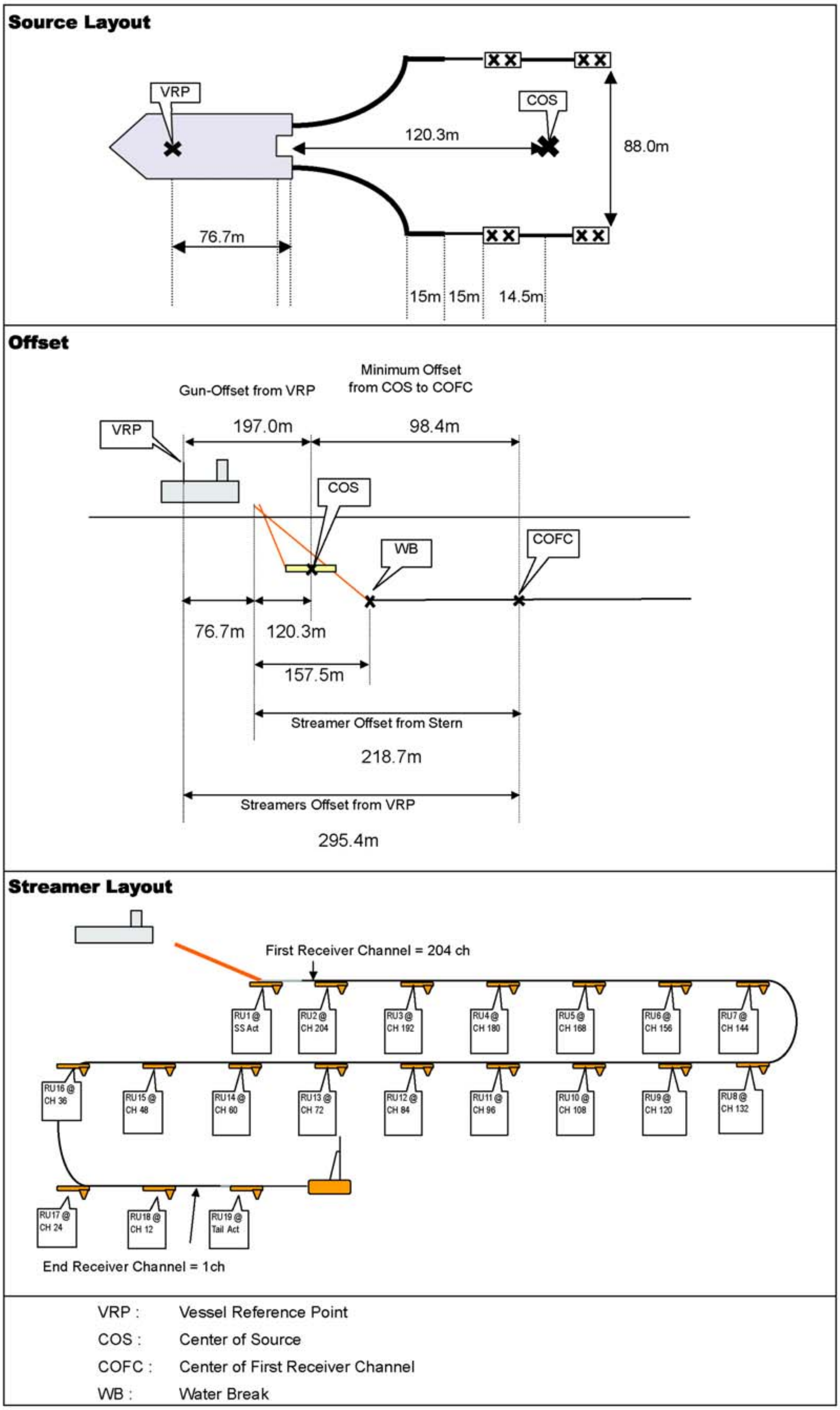

Figure 2: Geometry of the airgun system and the hydrophone streamer.

2.2 Receiver

As a receiver, 204-channel hydrophone streamer cable (Sercel) is used. The streamer cable comprises 68 active sections, each 75 m long, and three receiver groups (channels). The active modules, including 24-bit A/D converters, are installed every four active sections and send the digitized seismic data to a recording system on the vessel. The group interval is 25 m. The total length of the streamer cable, adding active sections to lead-in cable, is 5210 m (active section, 75 m _ 68; lead-in cable, 110 m). Hydrophone sensors (reduced diameter array hydrophone; Benthos Inc.) with sensitivity of 20 V/Bar are used; the signals from 32 sensors in the same group (channel) are stacked before A/D conversion. The towing depth of the streamer cable is maintained at 15 m below the sea surface by a depth controller (Bird; DigiCOURSE System3).

2.3 Recording and navigation systems

The recording system of the R/V Kairei (SYNTRAK960-24; Sercel) outputs seismic data onto 3590E tapes with SEG-D 8048 format. The system delay is set to about 150 ms. The water delay is set to 0–6000 ms. depending on the water depth. The sampling rate is 4 ms; the record length is 18 s.

The DGPS is used for positioning. The StarFire system is adopted as a main positioning system and SkyFix is used as a backup. The accuracy of positioning is about 0.4 m in StarFire and about 5 m in SkyFix. Navigation software is used for seismic data acquisition (SPECTRA; Concept Inc.) Positioning data of the StarFire and SkyFix are sent to a network interface (RTNμ; Concept Inc.) via a terminal server. The interface obtains DGPS time signals (StarFire) from the original antenna. Then, the navigation data are sent to the SPECTRA machine (PC Linux). SPECTRA sets shot times and shot points (SPs) and sends a trigger signal to the recording system and the gun controller (GCS90), as follows.

First, a system-start signal generated by SPECTRA is sent to the recording system via the interface. Soon thereafter, the recording system sends a reply signal to the SPECTRA when the system is ready for recording. Second, SPECTRA sends a trigger signal to the gun controller and the recording system sends a data-acquisition start signal to the streamer cable. The gun controller returns an internal-time-break-signal to the interface and recording system, and sends trigger signals to the eight airguns as shooting orders immediately after receiving the trigger signal from SPECTRA. Simultaneous with the shot, the gun controller starts to gather both position data of the airgun sub-arrays from the airgun positioning system (RGPS) and first breaks of near-field shot records from monitor hydrophones of nearby guns. Then seismic data are transmitted from the active modules to the recording system and position data of the streamer are sent from the depth controllers (commonly called birds). Subsequently, position data of both the airgun and streamer cable are stored into the SPECTRA via the interface and are also sent to the recording system. Finally, the seismic data are output to a tape drive and recorded on tapes (3590E). The recording system and gun controller are connected the interface, as depicted in Fig. 3.

2.4 Onboard data processing

Raw MCS reflection data are processed on-board for quality control and preliminary interpretation in the study areas. The onboard data processing is conducted, preserving relative amplitudes under the conventional processing scheme, as shown in Fig. 4, which contains noisy-trace editing, 5–100 Hz band-pass filtering, amplitude compensation by T**2 (where T is two-way travel time), velocity

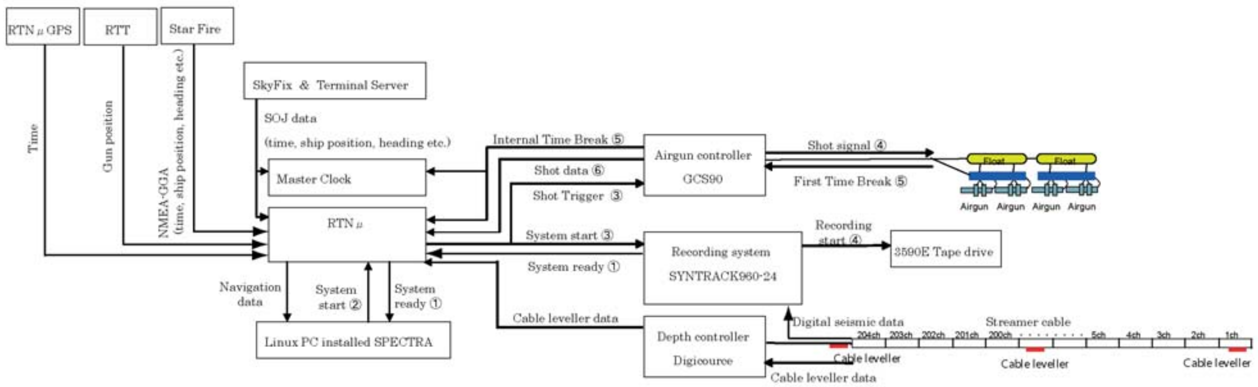

Figure 3: MCS recording system of R/V Kairei. Circled numerals show the signal transfer flow in the system.

Table 2: Airgun shooting log.

OGr1	Time (UTC)	Latitude (N)	Longitude (E)	Depth (m)	SP
First shot	2006.07.07 13:20:33	24° 1.0794′	142° 28.3362′	2983.0	890
First good shot	2006.07.07 13:49:08	24° 2.5945′	142° 28.2547′	2909.4	946
Last good shot	2006.07.12 14:54:15	29° 35.2205′	142° 9.8075′	5536.7	13244
Last shot	2006.07.12 14:54:15	29° 35.2205′	142° 9.8075′	5536.7	13244

IBr10	Time (UTC)	Latitude (N)	Longitude (E)	Depth (m)	SP
First shot	2006.07.13 06:21:51	29° 24.1292′	143° 22.3390′	6069.0	881
First good shot	2006.07.13 06:44:47	29° 23.7931′	143° 20.7738′	6068.0	933
Last good shot	2006.07.17 12:19:11	27° 50.7503′	136° 49.5006′	4244.0	14142
Last shot	2006.07.17 12:19:11	27° 50.7503′	136° 49.5006′	4244.0	14142

A03	Time (UTC)	Latitude (N)	Longitude (E)	Depth (m)	SP
First shot	2006.07.18 08:31:42	28° 23.5247′	137° 10.7325′	4266.0	881
First good shot	2006.07.18 08:51:19	28° 24.1314′	137° 12.0640′	4422.0	930
Last good shot	2006.07.19 07:56:30	29° 5.4344′	138° 45.3038′	2098.6	4330
Last shot	2006.07.19 07:56:30	29° 5.4344′	138° 45.3038′	2098.6	4330

OGr4	Time (UTC)	Latitude (N)	Longitude (E)	Depth (m)	SP
First shot	2006.07.21 05:01:19	25° 35.5186′	137° 43.7678′	5035.0	883
First good shot	2006.07.21 05:25:55	25° 35.7341′	137° 45.6925′	5251.2	948
Last good shot	2006.07.24 22:30:24	26° 7.1937′	143° 14.4671′	2728.8	11993
Last shot	2006.07.24 22:30:24	26° 7.1937′	143° 14.4671′	2728.8	11993

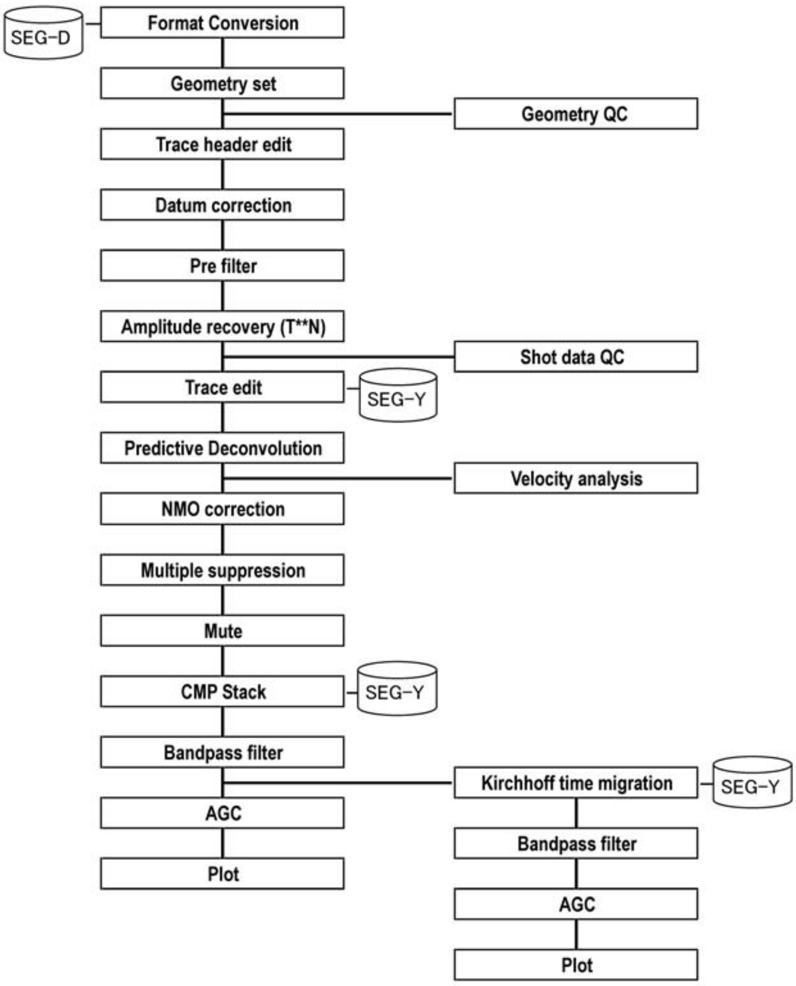

Figure 4: Flow chart of on-board processing of MCS data.

analysis with shot point (SP) number intervals of 20, multiple suppression muting, CDP stacking, and post-stack time migration.

3. MCS Data

In this chapter, we introduce examples of the seismic data obtained by MCS profiles along the Ogasawara Ridge (OGr1), the northern transect of the survey area (IBr10), the backarc transect (A03), and the southern transect (OGr4). The quality of data is sufficient for our objectives.

3.1 OGr1: Along the Ogasawara Ridge (Fig. 5)

Multiple reflection phases degrade the deeper image, particularly for the shallow region. This Line OGr1 runs through the IBr10 crossing point, along the Ogasawara Ridge, then through the OGr4 crossing point to the southern extension of the Ogasawara Ridge.

In the south from the OGr4 crossing, a sedimentary layer on the basement high (e.g. SP2000, SP3500 and SP5000) is highly deformed. The basins between these basement highs are filled by thicker, less deformed sediments.

The area north from the OGr4 crossing is divided into three major blocks based on topographic features: the off-Hahajima southward dipping shallow block (off-Hahajima block: SP5500–7500); the off-Chichijima and the off-Mukojima shallow block (off-Chichijima block: SP7500–9250); and the northward dipping slope of the north Ogasawara Ridge (north block: SP9250–line end). The off-Hahajima block is characterized by a highly deformed seismic basement (SP6000–6500) and a smooth shallow basement near Hahajima. At the edge of the seismic basement (SP6500, SP6600, SP7000 and SP7800), the horizontal deposited sediment layer forms a terrace. The Chichijima block and Hahajima block divide the wide V-shaped submarine canyon. The shallow basements near Chichijima and Mukojima are smooth, but the latter shows indentation. In the north block, a smooth bathymetric slope is formed by the sedimentary layers, which cover the buried terrace and rough seismic basement.

3.2 IBr10: The Northern transect (Fig. 6)

Line IBr10 runs across the Pacific plate, northern end of the Ogasawara Ridge, the volcanic front, the Sofugan tectonic line, the Nishi-Shichito Ridge and the Hakuho Seamount. Horst and graven structures developed on the

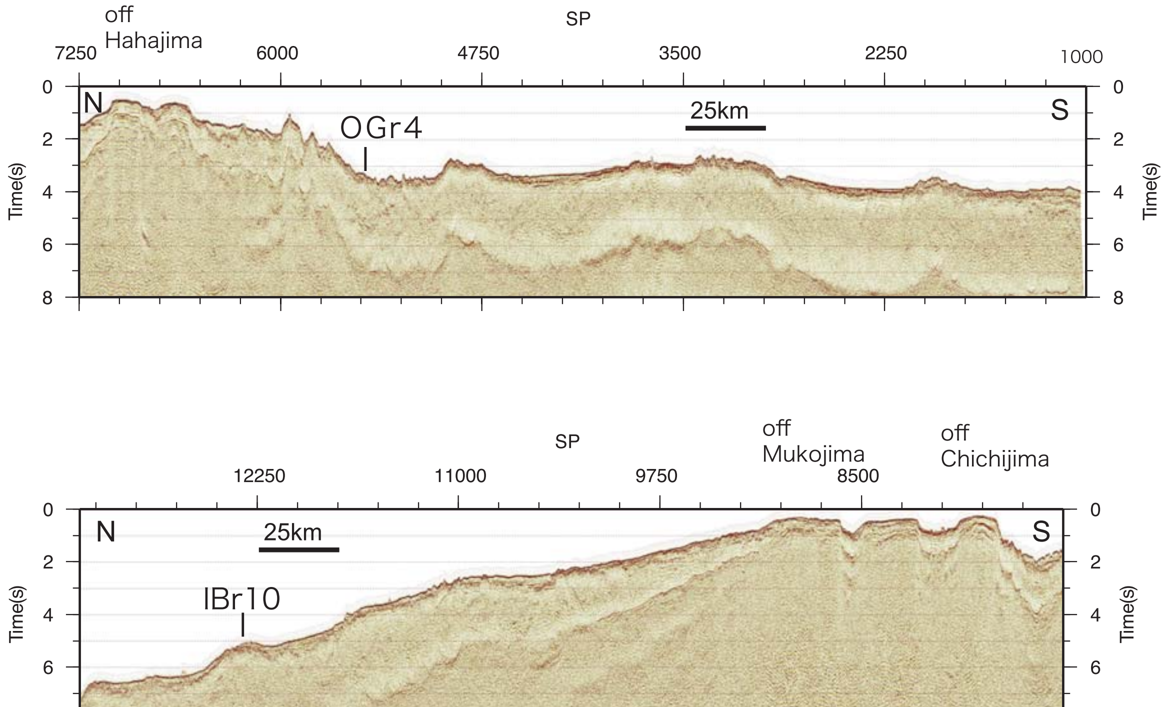

Figure 5: MCS profile of OGr1: Along the Ogasawara Ridge.

subducting Pacific plate during the Mesozoic age. The deep reflector of the subducting plate can be traced near SP 3000, 42.5 km from the trench axis.

In the north end of the Ogasawara Ridge, basement blocks tilt toward the inner arc. The north end of the Ogasawara Trough is characterized by thick sediments (SP 5000), a basement high at the center (SP 5250), a thick sedimentary layer supplied from the volcanic arc (SP5250–6250), and the Ogasawara Ridge.

Sharp rifting is dominant behind the volcanic front. The seismic line crosses between the volcanoes along the volcanic front. For that reason, it is too difficult to see the topographic high beneath the volcanic front because of the thick sediments. On the backarc side of these rifting zones, basements are rough, but a thicker sedimentary layer covers the topographic low. Especially, in the basin of the eastern side of Nishi-Shichito Ridge, thick sediment of one-second two-way time fills the basin horizontally (SP9500–9750).

In the arc-backarc transition zone, the basement gradually deepens toward the Kinan escarpment zone and the sedimentary layer covers the basement continuously. This part is characterized by the reflective phase below the seismic basement (SP11000). From the Kinan escarpment to the Hakuho Seamount in the Kinan Seamount chain, the sedimentary cover becomes thinner.

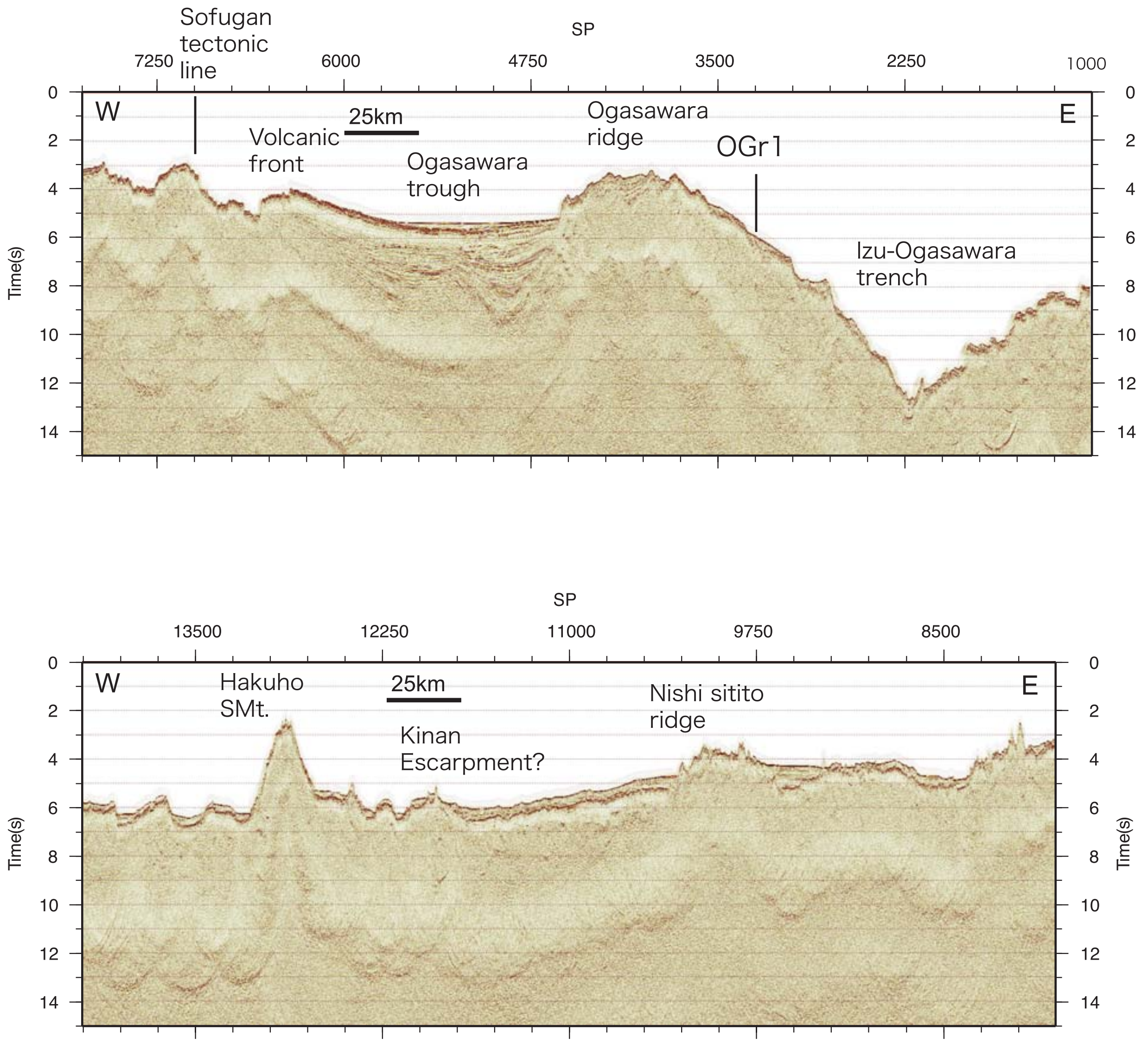

Figure 6: MCS profile of IBr10: The northern transect.

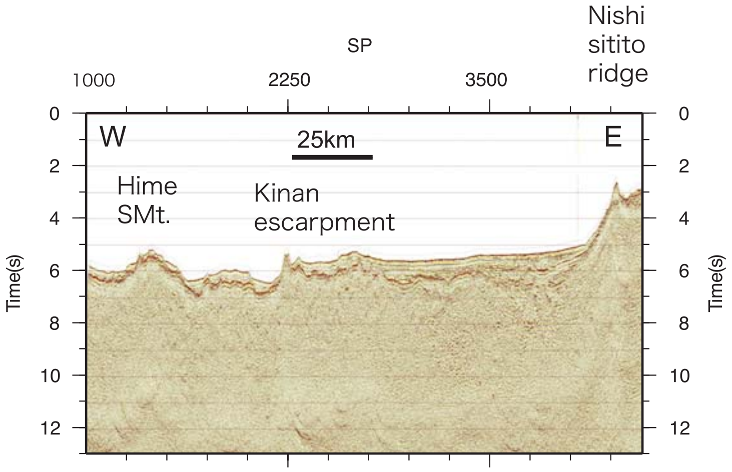

Figure 7: MCS profile of A03: The backarc transect.

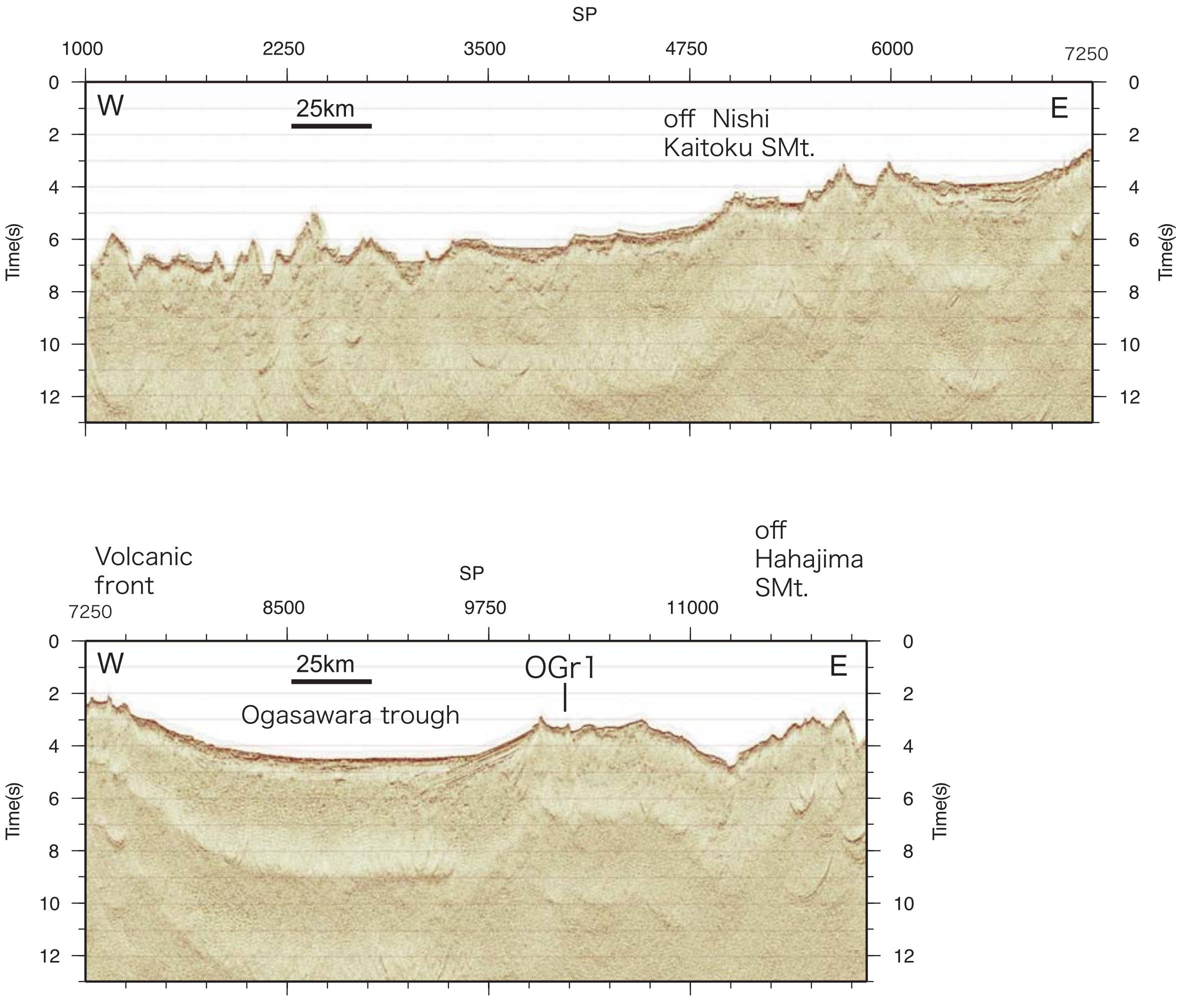

Figure 8: MCS profile of OGr4: The southern transect.

3.3 A03: backarc transect (Fig. 7)

This profile extends from the Nishi-Shichito Ridge to the Kinan Seamount chain. Characteristics of the sedimentary layer and basement resemble those of IBr10, and the reflective phase below the seismic basement (SP3750) can be conformed at a two way time of 7–8 s, which is greater than that of the IBr10 phase. The buried cone intrusions from basements are distributed near the Kinan escarpment.

3.4 OGr4: The Southern transect (Fig. 8)

Line OGr4 cuts across the southern Ogasawara Ridge, the southern side of the Kaitoku Seamount, the Nishi-Kaitoku Seamount, and the southern extension of the Kinan Seamount chain.

A rough basement (SP1000–2500) and the tilted crustal block are major characteristics beneath the Shikoku Basin. A considerable reflective phase below the seismic basement (SP4500) is apparent in the western side of the Nishi Kaitoku Seamount. Currently active areas are covered by deformed sediments. Bathymetry becomes shallower from the backarc side to the volcanic front simply and the sedimentary layer becomes thinner. The Ogasawara Trough is filled with thick sediment; it dips eastward gently and abuts against the westward-dipping sedimentary layer on the eastern wall of the Ogasawara Trough (SP9500). The Ogasawara Ridge is covered by folded sediment (SP10000–11000). The part off the Hahajima Seamount is characterized by an arc-ward dipping basement and sub-basement reflective phase in this block (SP11200–11800).

Because of the bad weather conditions, the eastern part of the planned OGr4 was not surveyed. That area will be surveyed during a later cruise

4. Summary

This paper summarized the specifications and arrangements of seismic experiments carried out in the southern Izu-Ogasawara arc area and introduced seismic data. We will investigate structural variations across the arc-backarc system and the general oceanic arc to clarify oceanic arc growth at different tectonic stages.

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Steward	Koji Kirita
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