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Multi-channel seismic reflection survey in the Izu-Ogasawara-Mariana island arc -KR06-13 cruise report –

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Abstract Multi-channel seismic (MCS) reflection experiments were carried out in KR06-13 cruise to investigate crustal structures and deformations of the arc-backarc transition zone in the Izu-Ogasawara-Mariana island arc, by using the R/V KAIREI of Japan Agency for Marine-Earth Science and Technology (JAMSTEC). Swath bathymetry, geomagnetic and gravity data are simultaneously observed during this cruise. Four MCS survey lines (Lines A02, A06, A07, and IBr12) with 1043.55km of total line length were obtained in this survey. An airgun array with a total capacity of 12,000 cubic inches (eight airguns with 1,500 cubic inches each) was shot with shot spacing of 50 m, air pressure of 2000 psi and towing depth of 10 m. These airgun signals are recorded on a 204-channel hydrophone streamer cable with group interval of 25 m. The record length and sampling interval were 18 sec and 4 msec, respectively. The MCS data has sufficient quality to assess the crustal deformation of the arc-backarc transition zone. The preliminary interpretations on the onboard processing result indicated unique features of the basement and sediment in the transition zone.

Keywords: Izu-Ogasawara-Mariana arc, Crustal structure, Multi-channel seismic reflection

1. Introduction

Oceanic island arc is one of the best fields to study a process of crustal growth, because the tectonics of oceanic island arc is simpler than that of continental island arc. The oceanic arc has grown by subduction of an oceanic crust beneath another oceanic crust, while an origin of a continental arc is separated from the continental margin with complex structure, which is developed by crustal accretion/erosion and collision (e.g., Karig et al., 1975).

The Izu-Ogasawara-Mariana island arc (IBM arc) is characterized by a typical intra-oceanic island arc involving trench, arc and backarc basin. The Pacific plate is subducting in direction of northwest beneath the Izu-Ogasawara arc in the Philippine Sea plate. The Shikoku basin and the Parece Vela basin, which lie western next to the IBM arc, heve a magnetic lineation pattern indicating typical oceanic crust structure (e.g., Okino et al., 1994; Okino et al., 1998). The evolution of the IBM arc had started in Eocene and the Shikoku basin opening in 30 Ma (e.g., Starn et al., 1993; Okino et al., 1994; Okino et al., 1998). During the backarc opening, it is known that the arc volcanism had been inactive in the northern IBM arc (Taylor, 1992). After the backarc opening ceased, the arc volcanism was activated again since Miocene age (e.g., Taylor 1992).

The northern Izu-Ogasawara arc has granitic middle crust with P-wave velocity (Vp) of 6 km/s and relatively thick lower crust according to a wide-angle seismic experiment (Suyehiro et al., 1996). And, the middle crust abruptly diminishes at the arc-backarc transition zone, while high velocity lower crust with 7.0-7.4 km/s can be seen in the thin crust of the eastern margin of the Shikoku basin without the middle crust. In the Mariana arc, very similar crustal structure was clarified by Takahashi et al. (accepted). The thick middle crust with P-wave velocity of 6 km/s beneath the arc region, and the heterogeneous lower crust including high velocity region beneath the arc-backarc transition zone have common characteristics. However, the significance and the origin of the high velocity lower crust have been still unknown yet. Recently, Nishizawa et al. (2006) indicated the structural variation of the arc-backarc transition zone in the northern Izu-Ogasawara arc using a wide-angle seismic data, but the tectonics and the related crustal deformation have not been clarified.

Between the arc-backarc transition zone of the Shikoku basin and that of the Parece Vela basin, there are structural differences. The northern transition zone of the Shikoku basin has a lot of en-echelon sea mount chains. Yamazaki and Yuasa (1992) suggested that these chains develop

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along the structural weak line like transform faults on the backarc oceanic crust. The chain cannot be seen at the transition zone with the Parece Vela basin. According to crustal structure of the arc-backarc transition zone between the West Mariana ridge and the Parece Vela basin and between the Mariana arc and the Mariana trough (Takahashi et al., accepted), the variation of the crustal thickness are small comparing with the example of the northern Izu-Ogasawara arc according to Nishizawa et al. (2006). In addition, the arc-backarc transition zone between the West Mariana ridge and the Parece Vela basin seems to have a large fault cutting entire crust like detachment fault indicating that the a part of the upper mantle has slow velocity of less than 8 km/s. However, these structural variations at the arc-backarc transition zone have been remained as unknown issues.

In order to clarify these unknown issues in the arc-backarc transition zone, multi-channel seismic (MCS) reflection survey is one of best tools. In particular, MCS is useful to detect faults including the detachment faults, the folding of the sedimentary layer and the deformation of the basement, and to image reflectivity within the crust. To know the nature of the high velocity lower crust located at the arc-backarc transition zone, the imaging of the reflectivity is indispensable.

In the Izu-Ogasawara intra-oceanic island arc system, we have been carrying out multi-channel seismic (MCS) reflection survey in the Izu-Ogasawara region since 2002 (e.g., Park et al., 2002). This paper reports the preliminary results of the data acquisition and the onboard data processing on MCS survey in KR06-13 cruise.

2. Data acquisition

In October 2006, we conducted an MCS reflection survey at the arc-backarc transition zone in the northern Izu-Ogasawara arc and northern Mariana arc-backarc system using the R/V KAIREI of Japan Agency for Marine-Earth Science and Technology (JAMSTEC). Although our survey was suspended for twelve days because of three typhoons and a tropical cyclone, we obtained MCS data of four survey lines (Line A02, A06, A07, and IBr12) with 1043.55km of total line length (Fig.1).

Line A02 located from the Nishi-Shichito ridge to the Kinan seamount chains with 184.55km of line length. The main objective of this study in Line A02 is to clarify the crustal variation including the deformation accompanied with the new volcanism after Miocene age and the imaging of the crustal reflectivity. Lines A06 and A07 covered between the northern end of the West Mariana ridge and the Parece Vela Basin, and the line length are 256.9km and 82.0km, respectively. The main objectives of these lines are similar with those of line A02. Three lines mentioned above are useful to clarify the differences among the crustal structure and deformation. Line IBr12 started from the west Mariana ridge to the Kaitoku seamount. The line length is 520.1km. This line covers the currently active volcanic front in the northern part and inactive arc in the West Mariana ridge. Line IBr12 was divided into two segments due to bad sea condition by a tropical cyclone. Survey line information and the shot logs are summarized in Table 1 and Table 2, respectively.

In this survey, we carried out not only MCS survey but also geophysical survey (bathymetry, gravity, geomagnetic) and OBS (Ocean bottom seismometer) retrieval operation for technical development. Swath bathymetry, gravity and geomagnetic survey were explored in the same MCS lines. Three OBSs deployed in July 2006 (KY06-08 cruise) were recovered off Hachijo-jima.

2.1 Source

To obtain MCS data in good quality, we shot an airgun array with a spacing of 50 m, which corresponds to 20-30 s in time depending on the vessel speed (average 4 knot).

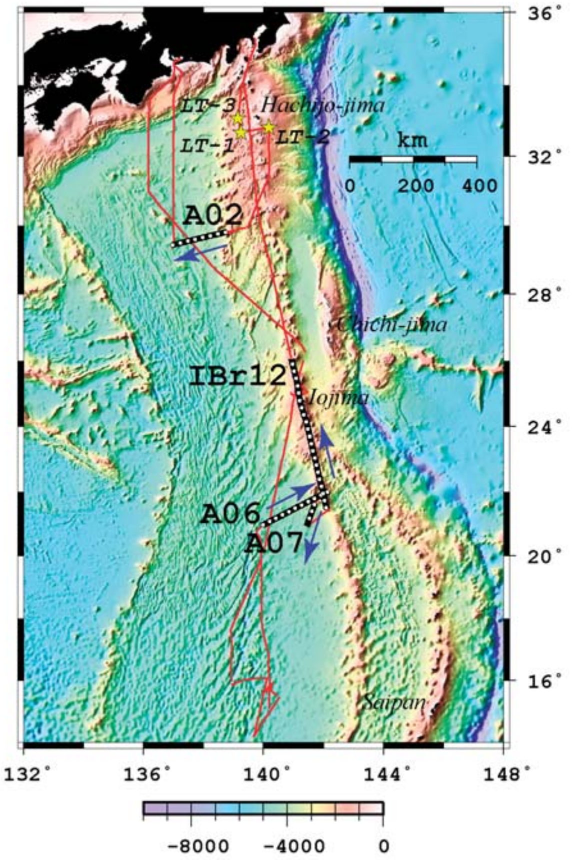

Figure 1: Location and index map of the survey area. Black lines show MCS lines, Yellow stars show OBS retrieval positions, Red line shows the ship tracks of R/V KAIREI.

The airgun array has total capacity of 12,000 cubic inches (about 200 liters), and consists of eight Bolt long life airguns with 1500 cubic inches (about 25 liters) each. The standard air pressure was 2000 psi (about 14 MPa). A depth of the airgun array during the experiment had been kept to be 10 m below the sea surface. Fig.2 shows two strings of sub-arrays deployed at the port and starboard sides of the vessel. Their width was expanded to 84.0 m by a paravane system and the central position of the array was set 197.0 m behind the ship antenna position. The troubles of airgun array system (e.g. air leak) did not occur in this survey.

2.2 Receiver

During the shooting, we towed a 204-channel hydrophone streamer cable (SYNTRAK RDA Streamer System, Sercel Inc.) , which received seismic signals from the subsurface. The streamer cable is composed of 68

Table 1: List of MCS survey lines and OBS retrieval position.

MCS Line information

Line ID	Start position	End Position	SP number	Line Length
A02	29° 49.7093′ N 138° 47.4516′ E	29° 26.2120′ N 136° 56.4058′ E	931 - 9235	415.20 km
A06	20° 57.4764′ N 139° 58.9565′ E	22° 1.4814′ N 142° 11.1115′ E	960 - 6098	256.90 km
A07	21° 37.8131′ N 141° 42.6893′ E	20° 55.9179′ N 141° 26.8365′ E	930 - 2570	82.00 km
IBr12	21° 28.7900′ N 142° 6.2742′ E	25° 7.5988′ N 141° 9.4100′ E	931 - 9235	415.20 km
			Total Line Length	1169.30 km

OBS retrieval position

Site	Position	Depth
LT-1	32° 40.5402′ N 139° 14.3857′ E	750.7 m
LT-2	32° 49.1769′ N 140° 11.1937′ E	917.9 m
LT-3	33° 4.3538′ N 139° 8.8843′ E	1528.5 m

Table 2: Activity logs during KR06-13 cruise.

Date	Remarks
September-30	Departure from JAMSTEC
October-01	Retrieval of 3 long-term OBSs deployed on KY0608 cruise
October-02	Adjustment of investment equipments and start A02 airgun shooting
October-03	Finish A02 airgun shooting
October-04	Transit to the Mikawa bay to refuge from the typhoon No.16 and No.17
October-05	Stand by all day in the Mikawa bay due to bad weather and sea condition
October-06	Stand by all day in the Mikawa bay due to bad weather and sea condition
October-07	Stand by all day in the Mikawa bay due to bad weather and sea condition
October-08	Departure from the Mikawa bay and transit to survey area
October-09	Transit
October-10	Refuge from the typhoon No.18 on the ocean
October-11	Refuge from the typhoon No.18 on the ocean
October-12	Refuge from the typhoon No.18 on the ocean
October-13	Refuge from the typhoon No.18 on the ocean
October-14	Refuge from the typhoon No.18 on the ocean
October-15	Transit to A06
October-16	Start A06 airgun shooting
October-17	Finish A06 airgun shooting
October-18	A07 airgun shooting
October-19	Start IBr12 airgun shooting
October-20	IBr12 airgun shooting all day
October-21	Stop shooting due to bad weather and sea condition, and retrieve all equipments
October-22	Restart IBr12 airgun shooting
October-23	Finish IBr12 shooting, and retrieve all equipments
October-24	Transit to JAMSTEC
October-25	Arrival at JAMSTEC

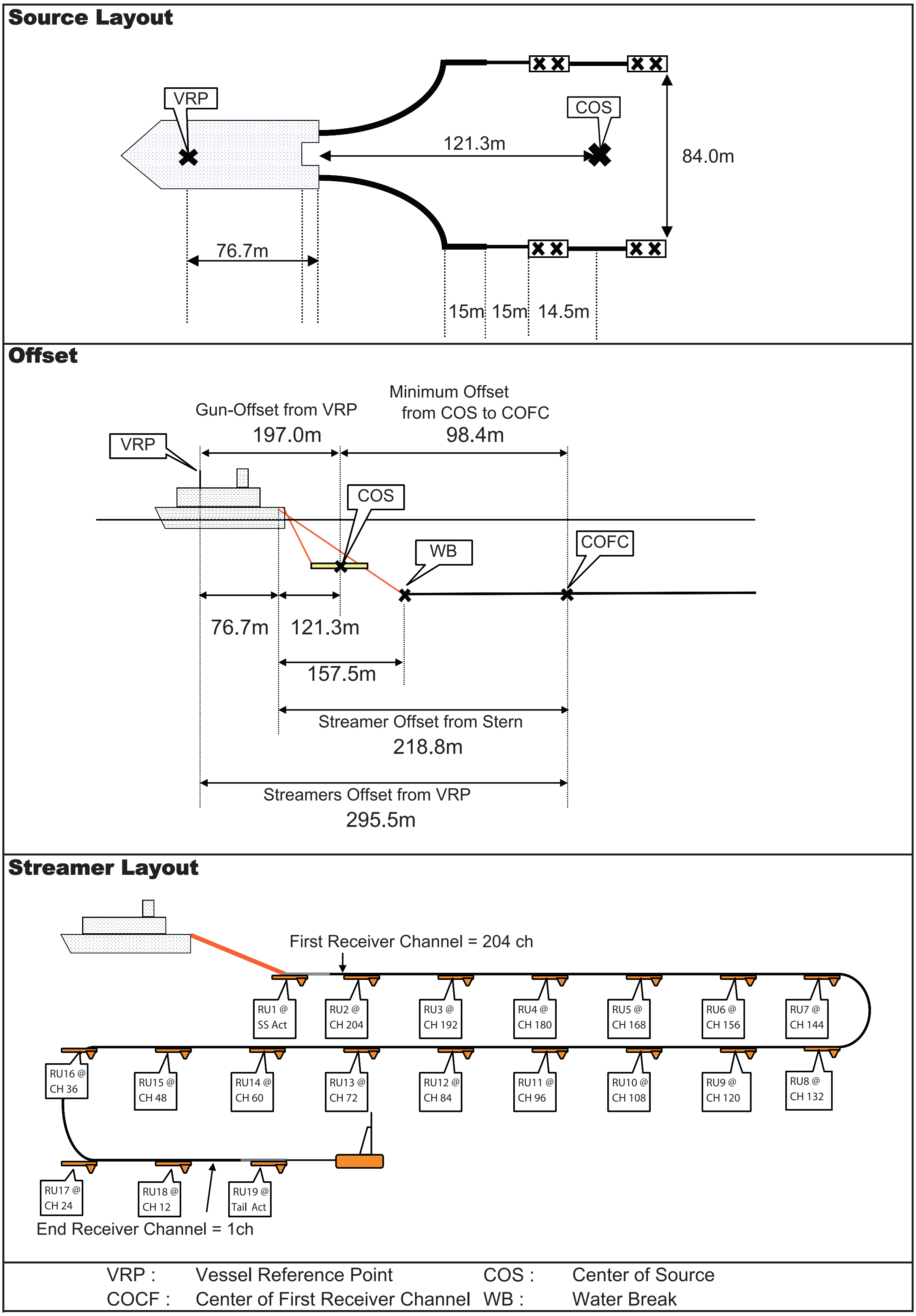

Figure 2: Geometry of airgun system and the streamer cable. Top figure shows the source (airgun system) layout, middle one represents source-receiver offset, and bottom one is streamer cable configuration.

active sections, and each active section is 75 m long consisting of three receiver groups (channels). The active modules including 24 bit A/D converters are inserted in every four active sections which collect seismic data. The interval of each group is 25 m. The lengths of total active section and lead-in cable are 5100 m (75 m × 68) and 110 m, respectively. Hydrophone sensors (Benthos Reduce Diameter Array hydrophone) 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 was controlled to be 15 m below sea surface by the depth controller called Bird (I/O DigiCOURSE streamer depth controllers).

Large spike noises were frequently recorded in seismic channel 69 and channel 162 during the observation of A06, A07 and IBr12. Therefore, we omitted these noise records in data processing.

The streamer cable feathering influenced the quality of seismic records and the distribution of CMP (Common mid point) fold. Fig.3 shows the direction of the streamer cable feathering on four MCS lines.

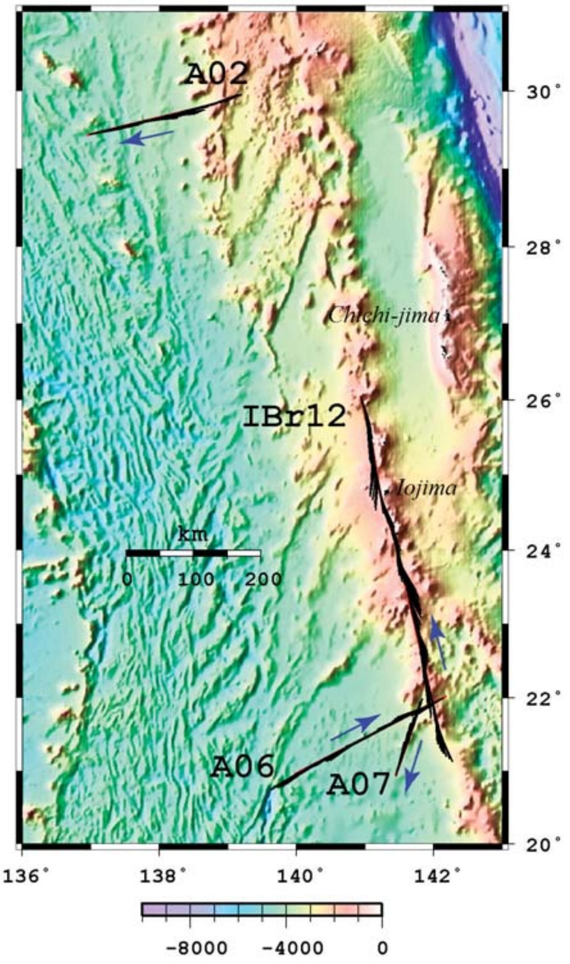

Figure 3: The cable feathering map of the MCS lines. Black lines show the direction of the cable feathering. Red lines show the MCS lines.

2.3 Recording and navigation systems

The recording system is "SYNTRAK 960-24 Multiple Streamer Telemetry System" of Sercel Inc., and recorded seismic data onto 3590E tapes with SEG-D 8048 Rev.1 format. We set system delay to be 150 msec. The sampling rate was 4 msec and the record length was 18 sec.

The Differential Global Positioning System (DGPS) was used for the positioning. We adopted StarFire system as a main positioning system and SkyFix as a backup. The accuracy was reported to be about 0.4 m in StarFire (NAVCOM's DGPS service) and 5 m in SkyFix (Fugro's DGPS service). As navigation software for seismic data acquisition, we used the SPECTRA 2D of Concept Systems Ltd.. Positioning data collected from StarFire as well as SkyFix were sent to RTNμ (The Real Time Navigation Unit of Concept Systems Ltd.) via a terminal server connected to LAN in the vessel. The RTNμ obtained time signals of DGPS (StarFire) from the original antenna. Then, the navigation data was sent to the Linux machine, the SPECTRA server. Shot times and Shot Point (SP) were set on the SPECTRA and then a trigger signal was sent to the recording system and the gun controller (Sercel GCS90), as follows.

First, a system-start-signal generated from the SPECTRA is sent to the recording system via the RTNμ, and soon after, the recording system send back a reply signal to the SPECTRA when the system is ready for recording. Second, the 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 sends back an internal-time-break-signal to the RTNμ and recording system, and also sends trigger-signals to the eight airguns as shooting orders just after receiving the trigger signal from the SPECTRA. At the same timing with 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 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. After that, the position data of both the airgun and streamer cable are stored into the SPECTRA via the RTNμ and are also sent to the recording system. The position data are output to ASCII file with UKOOA P1/90 and UKOOA P2/91 format. Finally, the seismic data are output to a tape drive and recorded on 3590E tapes. The recording system and gun controller are connected via RTNμ as shown in Fig.4.

The QC (Quality Control) and processing of UKOOA navigation data were done by SeisPos (an offline navigation post-processing and QC software of FGPS Ltd.).

3. Onboard processing and preliminary interpretation of MCS data

Raw data (Shot gather data) were processed onboard for the purpose of QC and preliminary interpretation of crustal structures in the study areas. The QC and processing were done by ProMAX 2D (a product of Landmark). The onboard data processing was conducted to preserve relative amplitudes under the conventional processing scheme, as shown in Fig.5, which contains trace header edit, noisy-trace editing, 2D marine geometry set, band-pass filtering(3-125 Hz), datum correction, amplitude compensation by T**2 (T is two way traveltime), predictive deconvolution with 24ms-length predictive distance and a 250 ms-length operator, velocity analysis with interval of 500 CMP, NMO(Normal Moveout) correction, multiple suppression by radon filter, muting, CMP stacking band-pass filtering(4-50 Hz) and poststack time migration.

According to the QC of seismic data, the percentages of removed traces in each survey lines were 0.18% (A02),

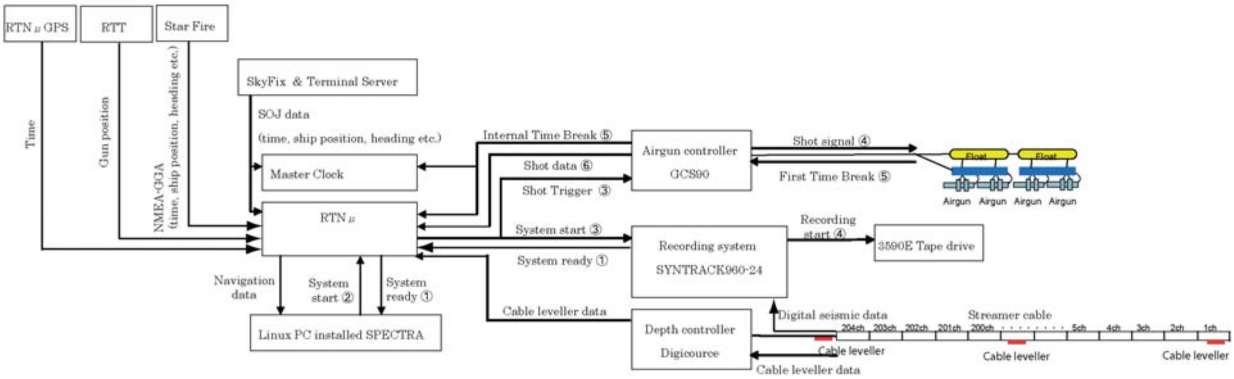

Figure 4: MCS recording system on R/V KAIREI. Circled numerals show the signal transfer flow in the system.

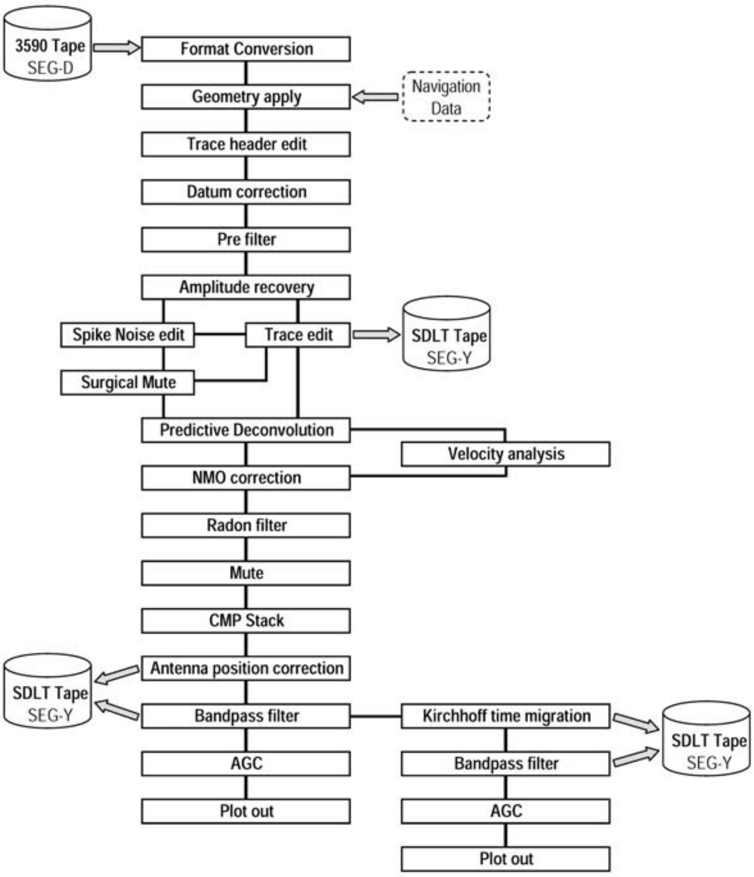

Figure 5: Flow chart of onboard data processing.

2.36% (A06), 2.48% (A07) and 0.59% (IBr12). As a result, the number of CMP fold ranges dispersed in the part of removed traces. CMP fold maps of each lines are shown in Fig.6.

Resulting MCS profiles (poststack migration section) from Figs. 7 to 10, clearly exhibit sedimentary covers on the acoustic basement, which evidenced that all of the raw data observed has good enough quality to interpret sedimentary structures and then meets the primary requirement. Although we will process and interpret MCS data at the laboratory in detail, the preliminary interpretations from the onboard processing are as following:

Line A02:

The eastern margin of the Shikoku basin has clearly two sedimentary layers. However, the western Shikoku basin from the Kinan escarpment doesn’t have these layers. These seismic characteristics are very similar to the MCS data in the Shikoku basin (e.g. No et al., 2005). The details are as follows.

⇒ The thickness of the sedimentary layer in the Nishi-Shichito ridge is about 1sec (Two-way travel time, TWT) thinner than that in the Shikoku basin.

⇒ The sediment in the Shikoku basin gradually thickens eastward from about 0.5 sec to about 1.5 sec, and what is more, the reflectors within the sediment are more continuous in the eastern part of the Shikoku basin than the western part.

⇒ The basement of the whole Shikoku basin is clear, however, the sediment-basement interface in the eastern margin of the Shikoku basin is unclear. Moreover, in the area, low frequency reflectors are seen in the crust.

⇒ The knolls buried in the sediments are identified on the eastern side of the Kinan Escarpment.

⇒ The reflection from the Moho was not imaged in the onboard processing data.

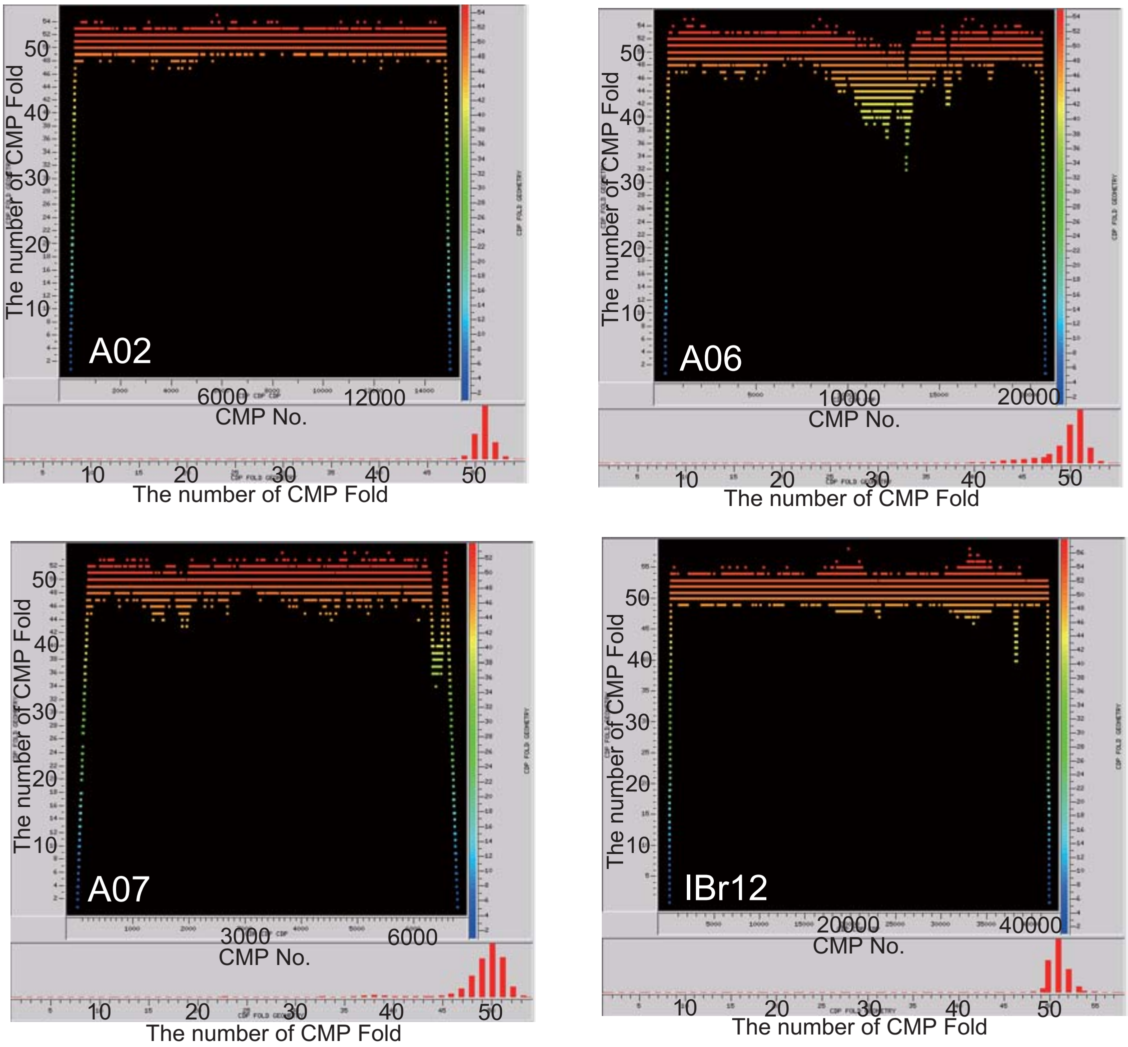

Figure 6: CMP fold map after trace edit. Vertical axis shows the number of CMP fold. Horizontal axis shows CMP No. The histogram shows frequency distribution of CMP fold.

Line A06 & A07:

The main characteristics of these profiles are thickness distribution of the sedimentary layers and the deep crustal reflector with low frequency. These characteristics are common to those of the southern Izu-Ogasawara arc (e.g. Takizawa et al., 2006). The details are as follows.

⇒ The thickness of the sediment in the Parece Vela Basin is less than about 1 sec (TWT). The faults in the sediment of the eastern basin mainly dip northeastward on these lines. The faults of the western basin, by contrast, mainly dip southwestward.

⇒ The knolls buried in the sediments are identified on the western part of basin on A06.

⇒ The low frequency reflectors inclining east are identified under the basement in the eastern margin of the basin.

Line IBr12:

The important characteristic of this profile is thin sedimentary layer. No et al (2006) pointed out that the sedimentary layer along the volcanic front becomes thin from the north to the south. On this line, the characteristics become remarkable. The details are as follows.

⇒ The thickness of the sediment is relatively thin comparing with the northern Izu-Ogasawara arc. The maximum thickness is 0.6 sec (TWT).

⇒ The sedimentary thickness becomes thin more on the West Mariana ridge. The maximum thickness is about 0.3-0.4 sec (TWT).

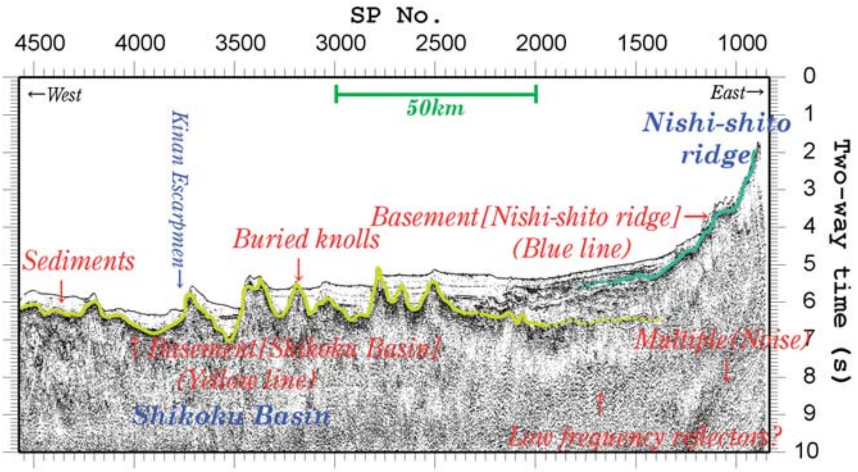

Figure 7: Poststack time migration section of line A02.

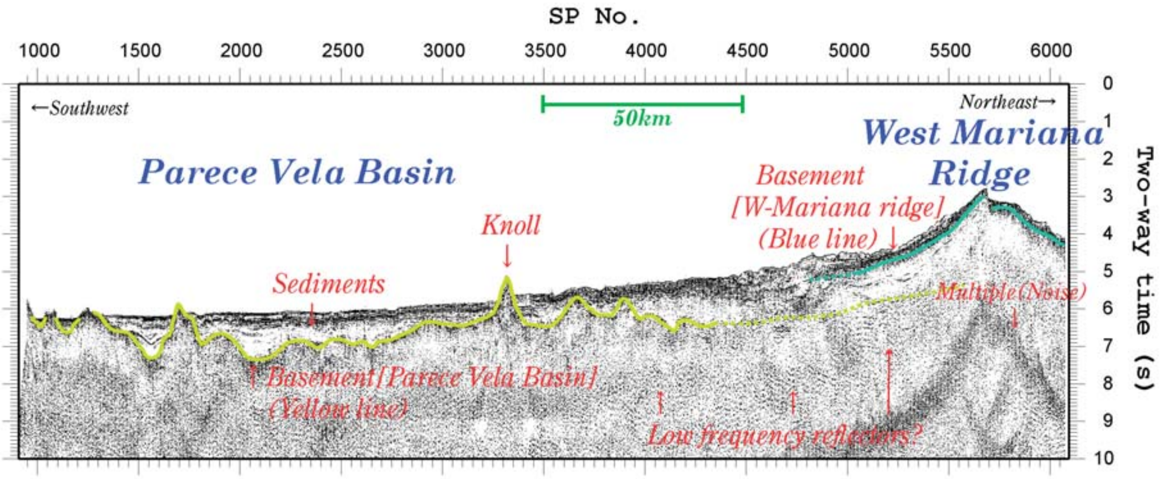

Figure 8: Poststack time migration section of lineA06.

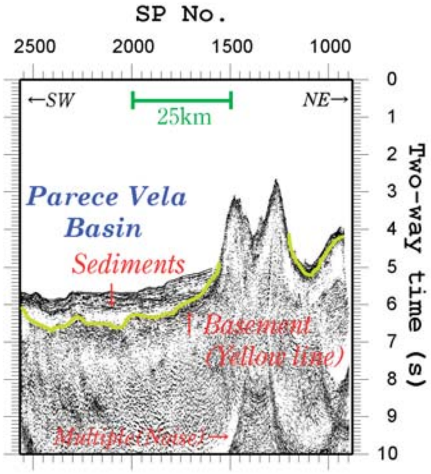

Figure 9: Poststack time migration section of line A07.

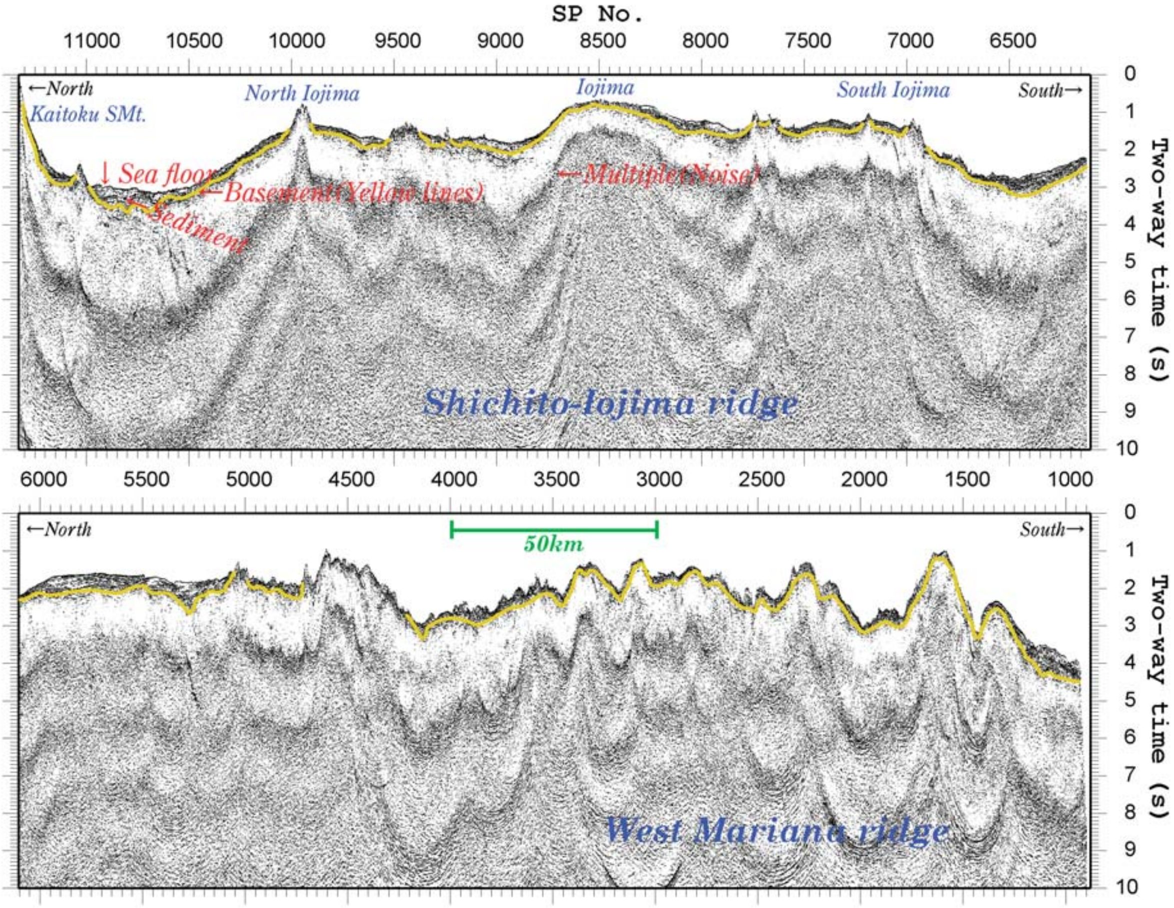

Figure 10: Poststack time migration section of line IBr12.

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