

—Data Paper—

Multichannel seismic reflection data from the southern part of the Japan SeaTetsuo No^{1*}, Takeshi Sato¹, Shuichi Kodaira¹, Ryuta Arai¹, and Seiichi Miura¹

We conducted marine seismic surveys using a multichannel seismic reflection (MCS) system and ocean bottom seismographs in the southern part of the Japan Sea including the western Yamato Basin, starting in 2014, as part of the research project “Integrated Research Project on Seismic and Tsunami Hazards Around the Sea of Japan” funded by the Ministry of Education, Culture, Sports, Science and Technology of Japan. The objective in these surveys is to reveal the distribution of the active faults, and the relationship between the crustal structure and the tectonic history in the southern Japan Sea. In this data paper, we describe the acquisition and processing of the MCS data obtained by these surveys.

Complete data set is available via site :

http://www.godac.jamstec.go.jp/catalog/data_catalog/metadataDisp/JAMSTEC-R_27DP01?lang=en

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1 Research and Development Center for Earthquake and Tsunami (CEAT), Japan Agency for Marine-Earth Science and Technology (JAMSTEC)

***Corresponding author:**

Tetsuo No

Research and Development Center for Earthquake and Tsunami, Japan Agency for Marine-Earth Science and Technology
3173-25, Showa-machi, Kanazawa-ku, Yokohama, Kanagawa 236-0001, Japan
not@jamstec.go.jp

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1. Introduction

Damaging earthquakes in the Japan Sea have occurred mainly in the coastal areas of the Japan Islands. For example, the 1983 Nihonkai-Chubu earthquake and the 1993 Hokkaido Nansei-oki earthquake, which were both magnitude ≥ 7.5 earthquakes, caused substantial damage to coastal areas throughout the Japan Sea due to the tsunamis caused by these earthquakes. However, compared with the Pacific side, our understanding of the historical earthquakes on the Japan Sea side is inadequate (e.g., Usami et al., 2013). In addition, seismic activity on the Japan Sea side is also relatively low compared to that on the Pacific side, and thus fewer seismological observations and investigations have been conducted. In recent years, source fault models of large earthquakes that occurred in the Japan Sea have been reviewed through several research projects. As a part of these projects, we conducted marine seismic surveys using a multichannel seismic (MCS) system and ocean-bottom seismographs (OBSs) in the eastern part of the Japan Sea in the “Multidisciplinary Research Project for Construction of Fault Model in the High Strain Rate Zone” (No et al., 2014a; No et al., 2014b; Sato et al., 2014). The results of this research revealed the relationship between the distribution of crustal structure and seismic activity or shortening structures in the eastern part of the Japan Sea (No et al., 2014a; Sato et al., 2014). Moreover, several study groups have recently reexamined the distribution of active faults in the Japan Sea (e.g., Committee for Technical Investigation on Large-scale Earthquake in Sea of Japan, 2014; Arai et al., 2015), as conducting investigations into fault parameters in the Japan Sea is an important task. Research findings show that active faults in the Japan Sea are divided into at least two types. One type is formed when reverse faults are reactivated by inversion tectonics (e.g., Okamura et al., 1995). The other type is formed by a reverse fault occurring in the boundary of the crustal structure (No et al., 2014a). Therefore, revealing the relationship between the crustal structure and the tectonic history is important for understanding the seismotectonics in the Japan Sea.

Research on the crustal structure of the Yamato Basin, which is the only large basin in the Japan Sea that is capable of being fully investigated (due to the presence of an exclusive economic zone), contributes to the discussion on the active faults that formed in the land-side margin of this basin. Some studies of crustal structure have previously

been carried out in the western Yamato Basin (e.g., Ludwig et al., 1975; Katao, 1988; Hirata et al., 1989); however, these studies were not able to ascertain details of the spatial variations in the crustal structure and the relationship with active structures. Moreover, in the coastal area of the western Yamato Basin, the focal mechanism transitions from a reverse fault to a strike-slip fault (e.g., Mikumo and Ishikawa, 1987; Terakawa and Matsu'ura, 2010). Therefore, we conducted marine seismic surveys from the deep-sea research vessel (R/V) *Kairei* operated by the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) in the Japan Sea beginning in 2014 as part of the “Integrated Research Project on Seismic and Tsunami Hazards Around the Sea of Japan” conducted by the Ministry of Education, Culture, Sports, Science and Technology of Japan (MEXT).

In this data paper, we describe the acquisition and processing of the MCS data which were obtained in the southern part of the Japan Sea, including the western Yamato Basin, from 2014 to 2016.

2. Data acquisition

MCS surveys were carried out along 22 seismic lines on three cruises from 2014 to 2016 (KR14-08, KR15-11, and KR16-08), and seismic surveys using OBSs were conducted on three lines (Fig. 1). Some of the MCS survey lines were crooked to avoid fishing operations and maritime equipment in the survey area.

The KR14-08 cruise was carried out in the area off Ishikawa in July-August 2014 (Fig. 1). The survey covered the area from the continental shelf to the Yamato Basin and the Yamato Rise. MCS data were acquired along 10 lines (SJ1404, SJ1405, SJ1406, SJ1407, SJ1408, SJ1409, SJ1410, SJ14A, SJ14B, SJ14C, and SJ14D) with a total line length of approximately 2278 km. The OBS survey was conducted at line SJ1405 (Sato et al., 2018). This survey area was part of the source region of the 2007 Noto earthquake ($M_J 6.9$) (e.g., Sato et al., 2007). In addition, because ODP Leg 127 site 797 (Shipboard Scientific Party, 1990) was directly beneath our seismic survey line, we contributed to the study on the formation of the Yamato Basin by examining the relationship between the ODP results and our results.

The KR15-11 cruise was carried out in the area off Fukui and Kyoto in August 2015. The survey covered the area from the continental shelf to the Yamato Basin

and the Kita-Oki Bank. MCS data were acquired along nine lines (SJ1502, SJ1503, SJ1506, SJ1507, SJ15A, SJ15B, SJ15C, SJ15FK, and SJ15MZ) with a total line length of approximately 1359 km. The OBS survey was conducted at line SJ15FK (Sato et al., 2016). In this survey area, several

earthquakes of $\geq M_{6.5}$ have occurred over the past 100 years (Japan Meteorological Agency, 2017). Primary active faults in this survey area have been suggested to exist in the margin of the Oki Trough and the marginal terrace (e.g., Okamura, 2013; Committee for Technical Investigation on

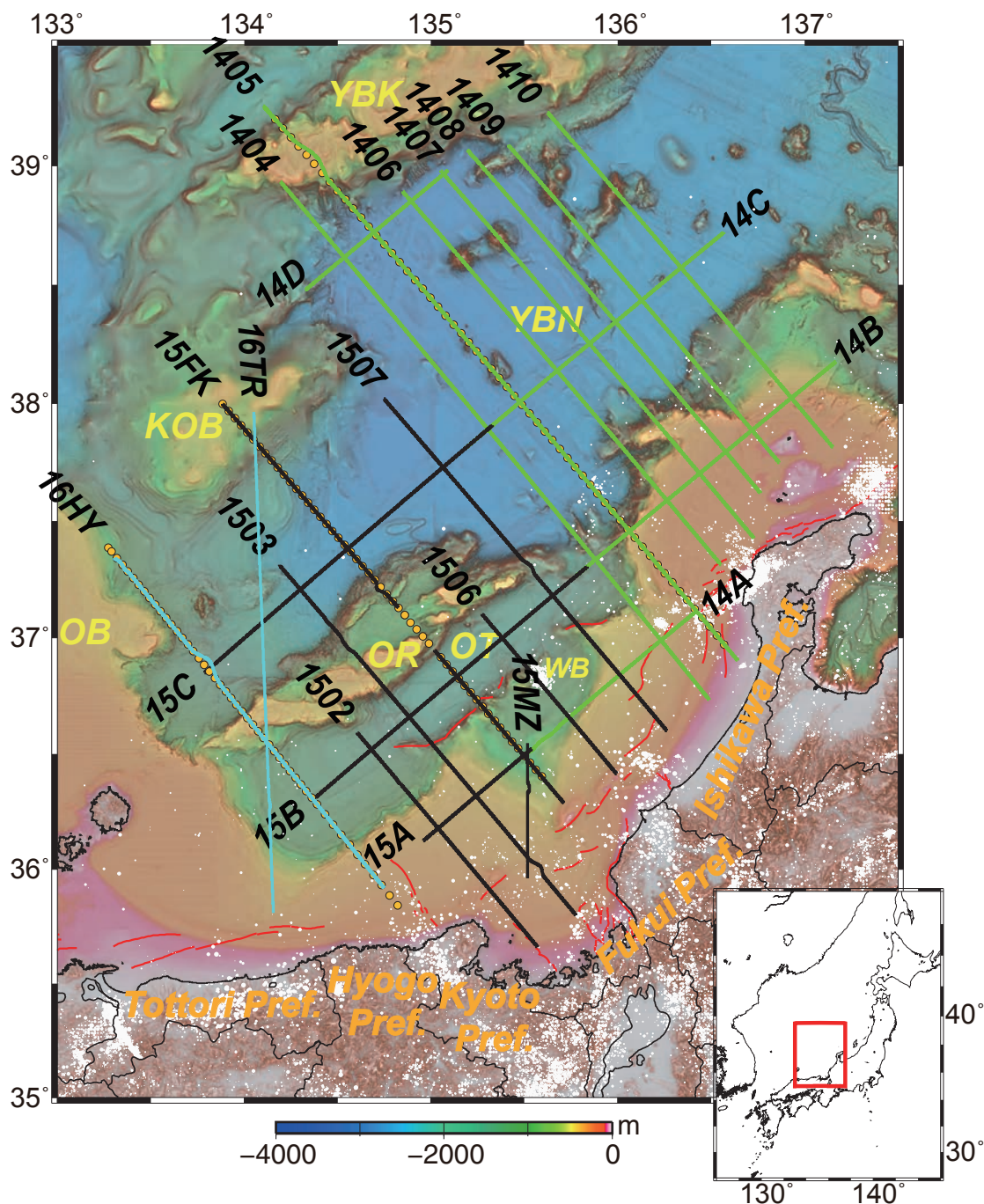


Fig. 1. Location maps of the survey areas. Solid lines are the MCS lines of the survey (green lines: KR14-08, black lines: KR1511, light blue lines: KR16-08), and yellow circles are the positions of the OBS sites. The alphanumeric characters by the side of each line are the line names (“SJ” is omitted). White dots are the epicenters of earthquakes with $M \geq 1.0$ and depth ≤ 50 km from 1925 to 2016 (Japan Meteorological Agency, 2017). Red lines show the active faults estimated by Okamura (2013). The topographic map was made by superposing a red relief image map and a semitransparent altitude tints map (No et al., 2016). YBN: Yamato Basin; YBK: Yamato Bank; OR: Oki Ridge; OT: Oki Trough; WB: Wakasa Basin; KOB: Kita-Oki Bank; OB: Oki Bank.

Large-scale Earthquake in Sea of Japan, 2014).

The KR16-08 cruise was carried out in the area off Hyogo and Tottori in July-August 2016. The survey covered the areas from the continental shelf to the Oki Bank and Yamato Basin. MCS data were acquired along two lines (SJ16HY and SJ16TR) with a total line length of approximately 440 km. The OBS survey was conducted at line SJ16HY (Sato et al., 2017). Line SJ16TR is the same line as in the seismic survey using OBSs off Tottori in 2002 (Sato et al., 2006). Seismic activity in the survey area of KR16-08 is relatively low in comparison with the survey areas of KR14-08 and KR15-11 (Japan Meteorological Agency, 2017), and the number of active faults is also limited (e.g., Okamura, 2013; Committee for Technical Investigation on Large-scale Earthquake in Sea of Japan, 2014; Arai et al., 2015).

For data acquisition in these surveys, we used the MCS system which was installed aboard the R/V *Kairei* (Miura, 2009) (Fig. 2, Table 1). We set the towing depths

of the seismic source and streamer cable to be deeper than those of conventional seismic surveys in this area (e.g. the integrated ocean drilling program (IODP) site survey and petroleum exploration). This is because low-frequency energy is necessary for imaging not only the sedimentary layer and basement but also the entire crustal structure down to the Moho as much as possible. By setting the towing depth deeper, notch frequencies due to the ghosting effect are moved lower. Therefore, source energy in the low-frequency band can effectively contribute to superior data for the deep seismic survey, though the energy in the high-frequency band decay due to the ghost notch effect (e.g., White et al., 2008; Singh et al., 2011).

To obtain high-quality MCS data, we shot an air gun array at a spacing of 50 m, which corresponds to a time interval of 20 to 30 s, depending on vessel speed (average 4.5 knots). The tuned air gun array had a maximum total capacity of 7800 cubic inches (about 130 liters), and consisted of 32 Bolt Annular Port air guns (Fig. 3, Table 1).



Fig. 2. MCS system aboard the R/V *Kairei* which acquired our data. For details of the R/V *Kairei*, refer to JAMSTEC (2018), and for more detail of the MCS system, refer to Miura (2009) and JAMSTEC (2017).

The standard air pressure was 2000 psi (about 14 MPa).

During the experiment, the air gun array depth was kept at 10 m below the sea surface. During air gun shooting, we towed a 444-channel hydrophone streamer cable with a group interval of 12.5 m (Sentinel Digital Streamer System, Sercel Inc.) (Fig. 4, Table 1). Hydrophone sensors (Benthos Reduced Diameter Array hydrophone) with a sensitivity of 19.7 V/Bar were used. The signals from eight sensors in the same group (channel) were stacked prior to A/D conversion and the interval between each group was 12.5 m. The length of the cable was about 6 km, and the towing depth of the streamer cable was maintained at 12 m below the sea surface by depth controllers called Birds (I/O DigiCOURSE streamer depth controllers).

A Sercel Seal System Ver. 5.2 recording system, manufactured by Sercel Inc., was used in the survey, and this

system collected seismic data on Linear Tape-Open (LTO) tapes in SEG-D 8058 Rev. 1 format. The system delay was set to 200 ms, the sampling rate was 2 ms, and the recording length was 16 s.

A differential global positioning system (DGPS) was used for positioning. We used NAVCOM's StarFire

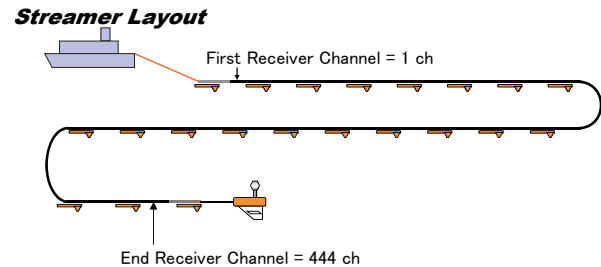


Fig. 4. Streamer cable configuration during the MCS survey.

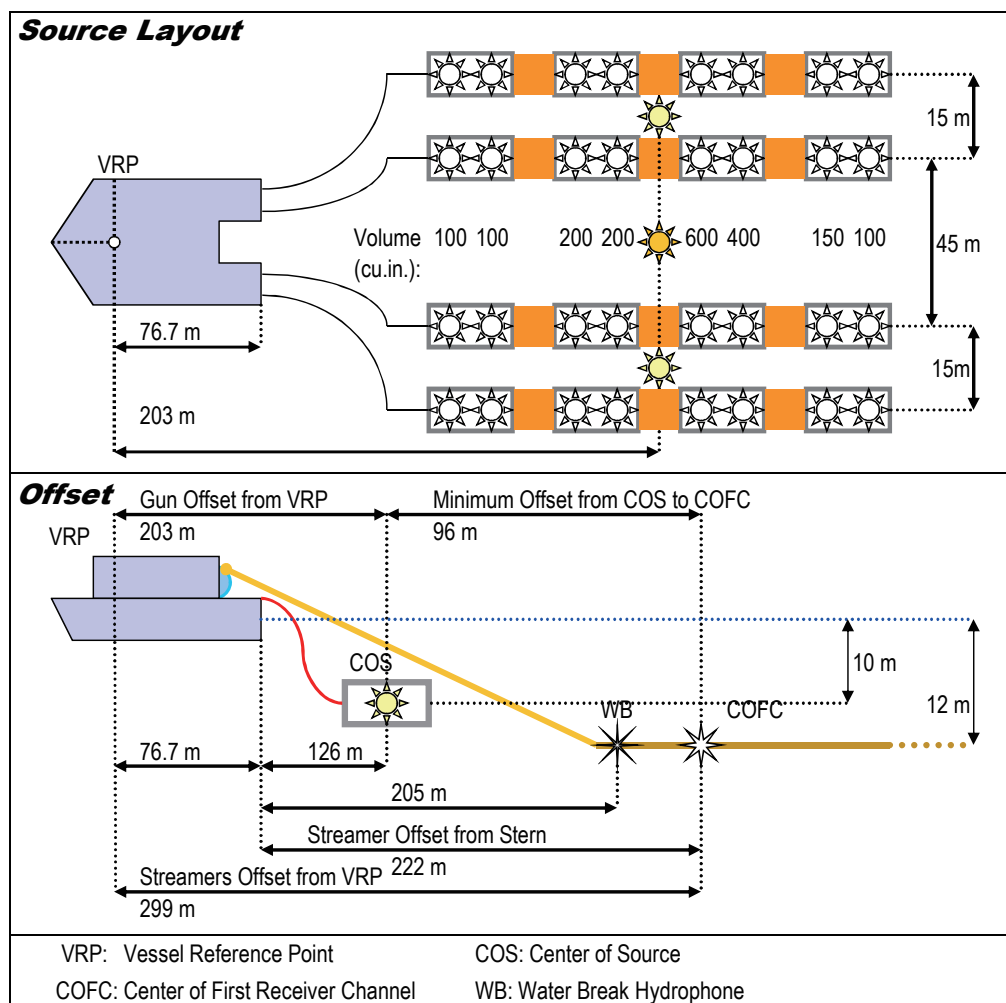


Fig. 3. Vessel towing geometry during the MCS survey. Top figure shows the source (air gun system) layout, and bottom figure shows source–receiver depth and position, and navigation offsets.

as the main positioning system and used Fugro's StarFix as a backup. SPECTRA 2D (Concept Systems Ltd.) was used as our navigation software for seismic data acquisition. Positioning data collected from both StarFire and StarFix were sent to a Power Real Time Navigation Unit (PowerRTNU) (Concept Systems Ltd.) via a terminal server connected to a local area network (LAN) aboard the vessel. Shot information, such as shot times, shot point number (SP), coordinates, and depth, were set on SPECTRA, and then a trigger signal was sent to the recording system and the gun controller (ION DigiSHOT Ver.3.1). The main navigation parameters were as follows: survey datum was WGS84; map projection was UTM (Universal Transverse Mercator); and UTM zone parameter was 53 N.

Table 1. List of data acquisition parameters and instruments in this report.

SOURCE	
Gun Type	BOLT ANNULAR PORT GUN
Gun Controller Type	ION DigiSHOT Ver.7.0
Shot Type	SIMULTANEOUS
Shot Mode	Distance
Shot Point Interval	50 m
Gun Configuration	1950 cu.in. × 4 strings (standard)
Total Volume	7800 cu.in. (standard)
Gun Depth	10 m
Air Pressure	2000 psi
RECEIVER	
Cable Type	SERCEL SENTINEL Digital Streamer
Number of Channel	444
Channel Interval	12.5 (12ch/section) m
Channel of Hyd Groups	8
Hydrophone Type	Sercel Flexible Hydrophone
Hydrophone Sensitivity	19.7 V/bar
Cable Depth	12 m
Cable Controller	ION PCS (System3 ver7.2)
RECORDING	
Instrument	SERCEL SEAL SYSTEM Ver.5.2
Sample Rate	2.0 msec
Recording Length	16 s
Low Cut Filter	3.0 Hz (Combined -3 dB cut-off)
Analog Frequency	3.0 Hz
Digital Frequency	N/A
Digital High Cut Filter	200 Hz @ 370 dB/Oct
High Cut Filter Type	Linear Phase
Pre Amplifier Gain	0 dB
System Delay (Aim Point)	200 ms
NAVIGATION	
Instrument	SPECTRA Integrated Navigation System
Navigation Data Format	UKOOA P1/90, P2/91
Primary Positioning	STARFIRE DGPS
Backup Positioning	STARFIX_XP_2 DGPS
GEODETIC PARAMETER	
Datum	WGS-84
Projection	UTM
Zone	53

3. Data processing

MCS data were processed using conventional processing schemes (e.g., Yilmaz, 2001) including enhanced noise suppression processes (Table 2). We processed data on 16 lines using the ProMAX/SeisSpace (Landmark) installed in the seismic data analysis server at the Yokohama Institute of JAMSTEC, and JGI Inc. carried out the processing of five lines (SJ14B, SJ1506, SJ15MZ, SJ16HY, and SJ16TR). The main processes applied for all the MCS lines are given in the following subsections. Details of all processing parameters and processing (e.g., direct wave suppression, predictive deconvolution along radial trace, and τ -p deconvolution) which were applied only to some seismic lines are omitted from the description in this paper. The results of the data processing are shown in Figs. 5 to 10.

3.1 Format conversion

The field data (SEG-D format) were read and converted into the internal format of the data processing software.

3.2 Geometry application

In regard to each trace header, we input seismic line information such as the common midpoint (CMP), the coordinates of the source point and receiver point, and the offset distance using the navigation data.

3.3 Recording delay removal

Since the recording time of the seismic recording system includes a 200 ms delay from the shot time of the air gun array, a correction was made for this delay time.

3.4 Datum correction

In order to set the datum plane as mean sea level, static correction was performed by referring to the depths of the seismic source and streamer cable, and the velocity in the seawater (1500 m/s).

3.5 Prefiltering

Since the shot gather data as a whole included low-frequency noise, a band pass filter was applied to the data.

3.6 Signature deconvolution

Signature deconvolution was applied in order to conduct minimum phase conversion and debubbling. First,

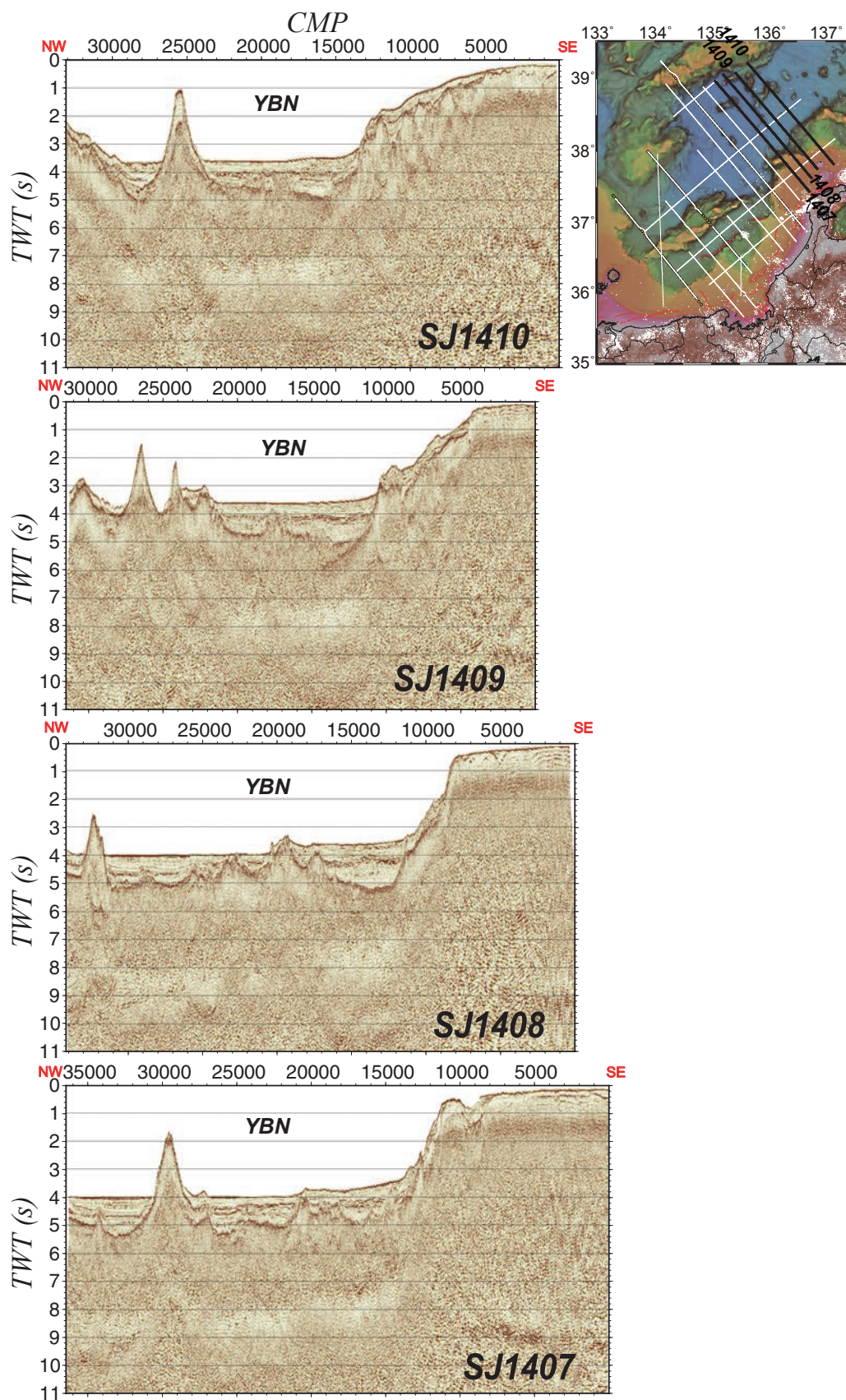


Fig. 5. Time-migrated seismic sections of lines SJ1410, SJ149, SJ148, and SJ147. YBN: Yamato Basin.

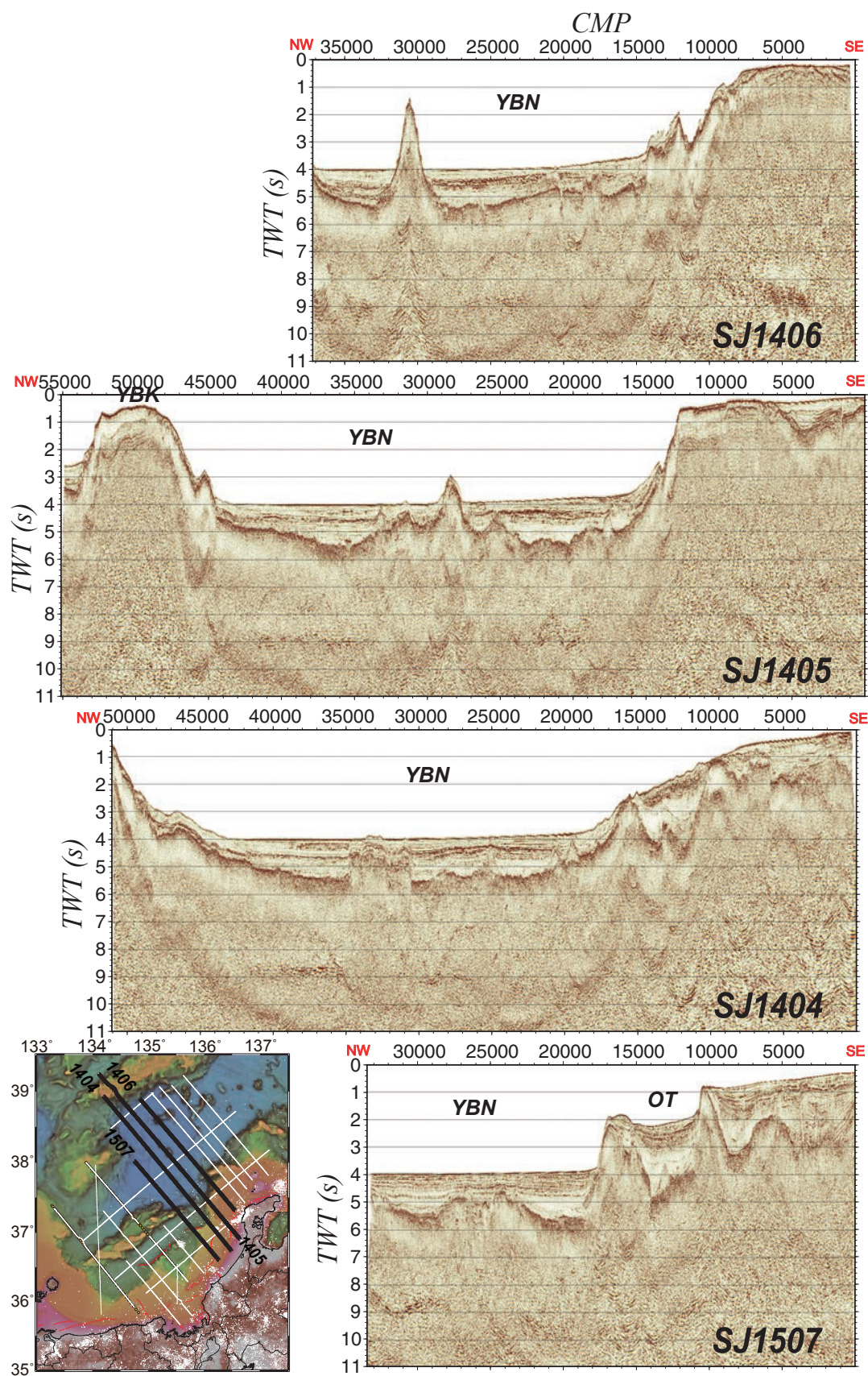


Fig. 6. Time-migrated seismic sections of lines SJ1406, SJ145 SJ144, and SJ157. YBN: Yamato Basin; YBK: Yamato Bank; OT: Oki Trough.

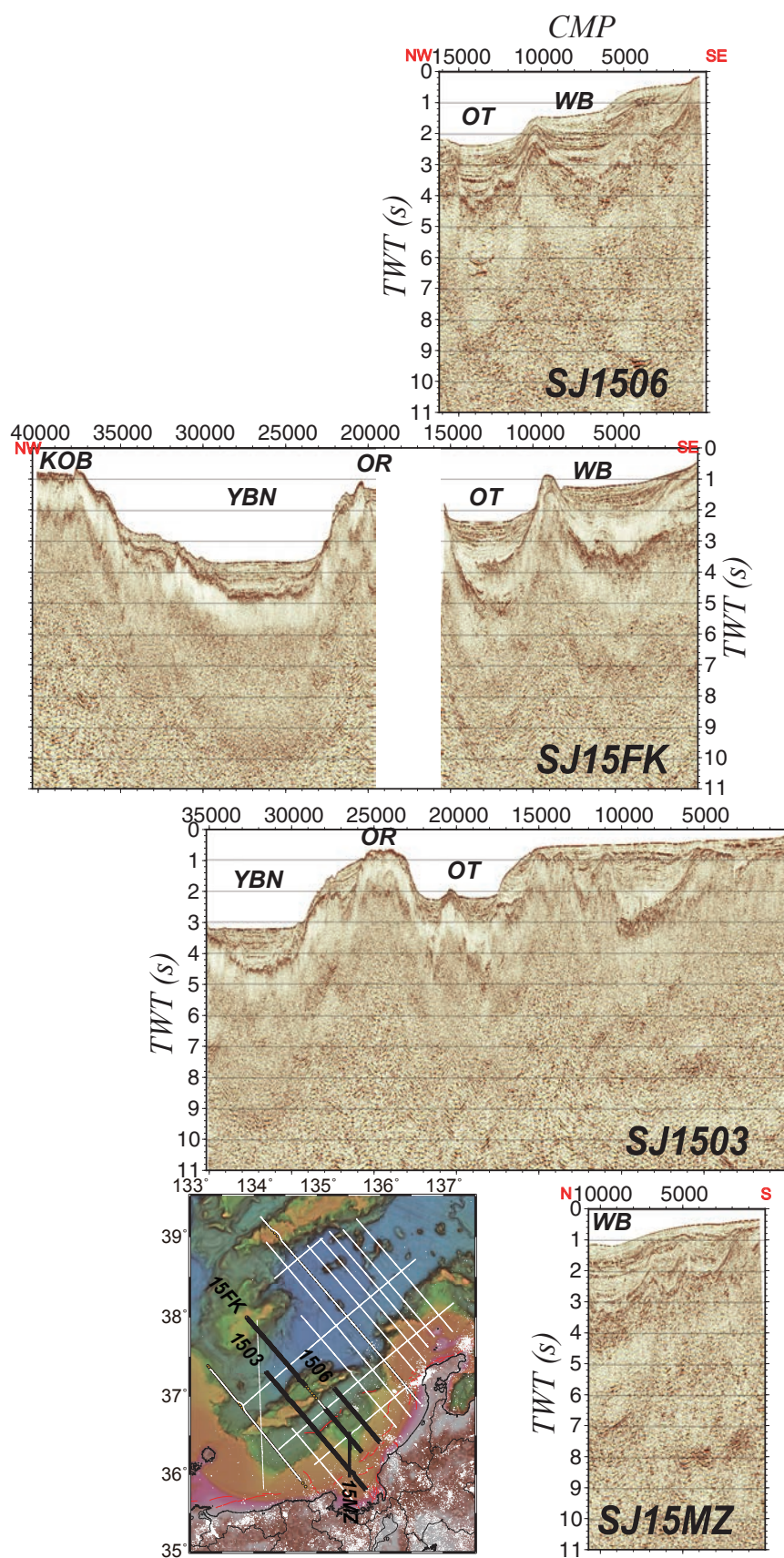


Fig. 7. Time-migrated seismic sections of lines SJ1506, SJ15FK, SJ1503, and SJ15MZ. YBN: Yamato Basin; OR: Oki Ridge; OT: Oki Trough; WB: Wakasa Basin; KOB: Kita-Oki Bank.

based on the waveform of the sea bottom, the near offset recording was stacked and averaged, and the basic wavelet of the acquisition record was extracted. Next, a minimum phase conversion was performed using the extracted basic wavelet.

3.7 F-X prediction filter

We used a complex predictive filter in the frequency-space domain on common offset data and shot gather data to suppress random noise and improve the S/N

ratio.

3.8 Surface-related multiple elimination processing

To suppress “surface-related” type multiple reflections due to the sea surface, surface related multiple elimination (SRME) processing was applied. This method can predict and suppress the unwanted multiple reflections based on wave theory. The multiple reflections are predicted from the primary reflections by convolving traces of the shot gather data, and shot gather data containing only predicted

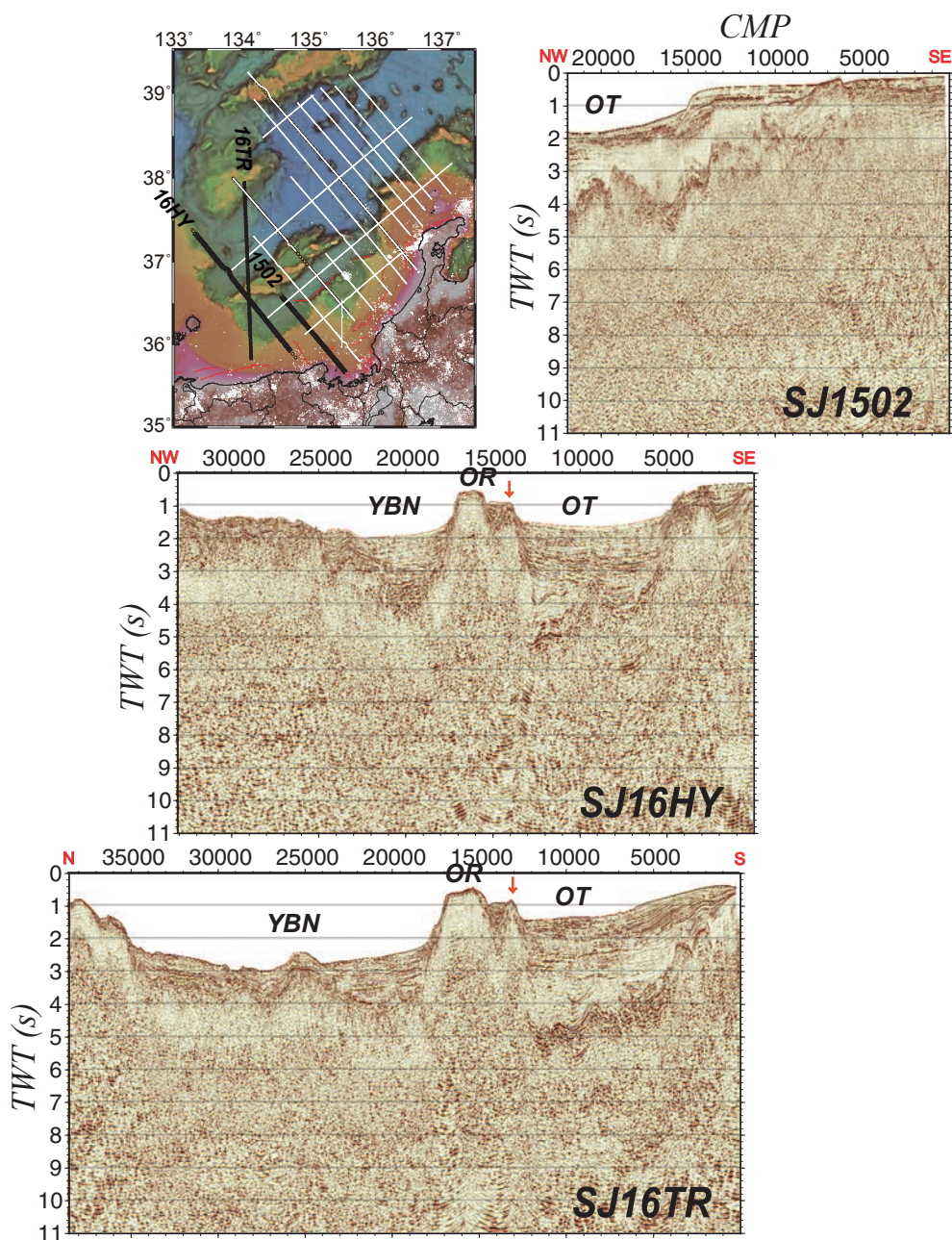


Fig. 8. Time-migrated seismic sections of lines SJ1502, SJ16HY, and SJ16TR. Red arrows indicate the intersection of lines SJ16HY and SJ16TR. YBN: Yamato Basin; OR: Oki Ridge; OT: Oki Trough.

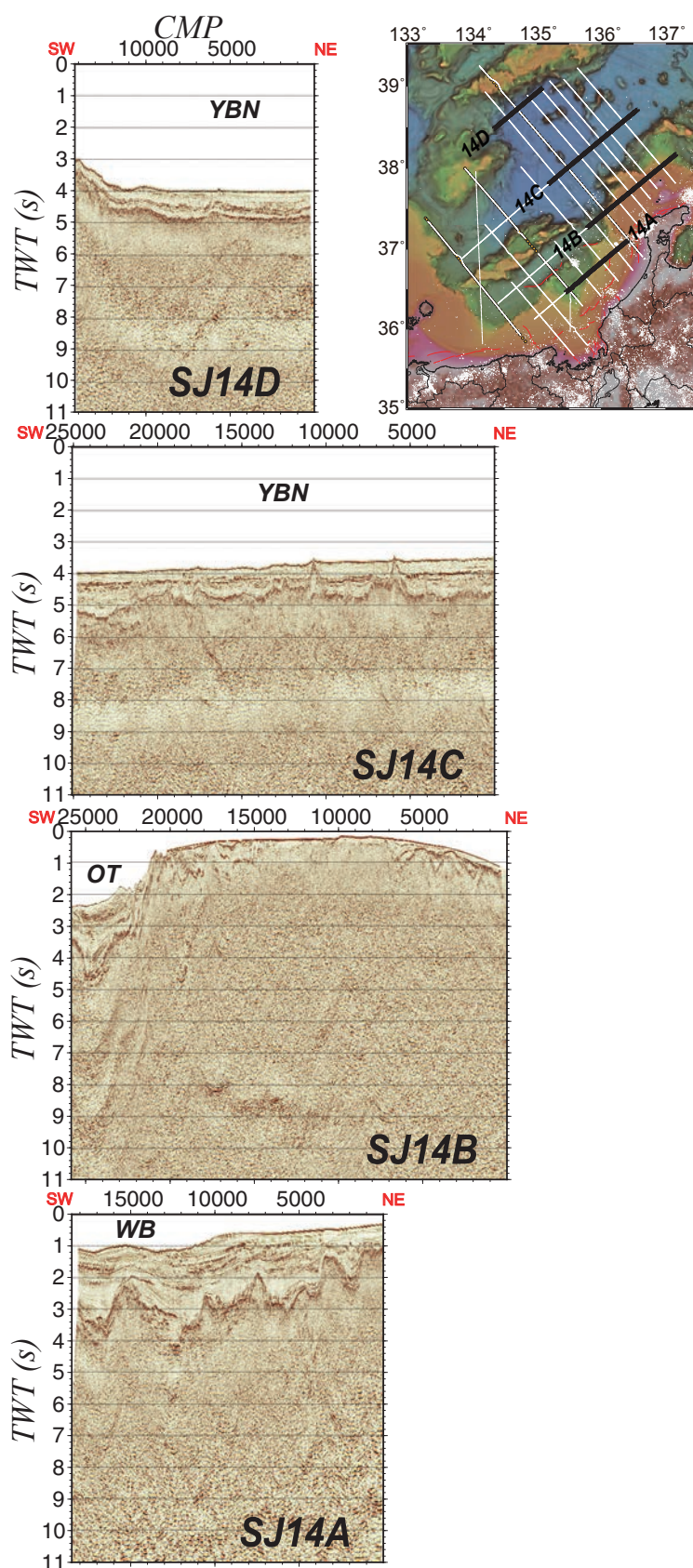


Fig. 9. Time-migrated seismic sections of lines SJ14A, SJ14B, SJ14C, and SJ14D. YBN: Yamato Basin; OT: Oki Trough; WB: Wakasa Basin.

multiple reflections are synthesized. Synthesized multiple reflections were subtracted from the seismic data by means of adaptive subtraction with a least squares filter.

3.9 Suppression of coherent noise

For the purpose of removing scattered waves from the side and refracted waves, a velocity filter for the frequency–wave number domain was applied to the shot gather data.

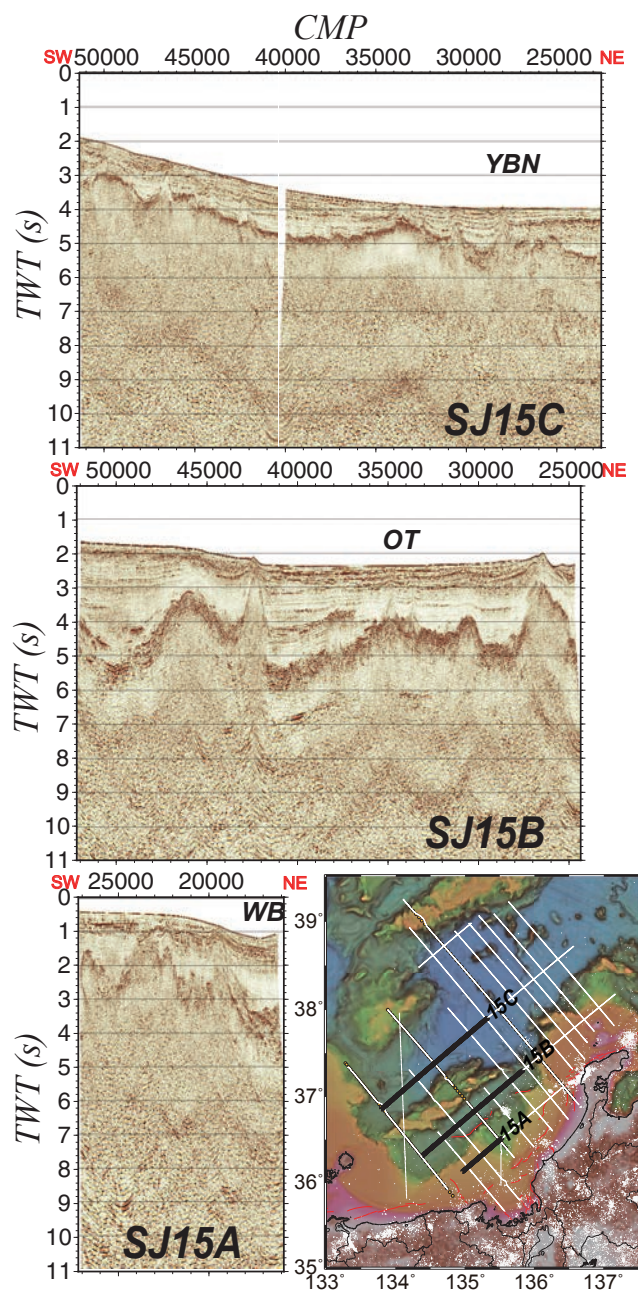


Fig. 10. Time-migrated seismic sections of lines SJ15A, SJ15B, and SJ15C. YBN: Yamato Basin; OT: Oki Trough; WB: Wakasa Basin.

3.10 Predictive deconvolution

The observed seismic waveform was deformed as a result of various factors including reverberation, multiple reflection, absorption effect of strata, and the characteristic of the seismic source and recording system. Deconvolution was applied in order to convert such wavelets into waveforms close to the impulse and improve the resolution.

3.11 Gain recovery

Geometrical attenuation recovery processing was performed to compensate for changes in amplitude characteristics resulting from geometrical attenuation caused by the propagation of elastic waves from the seismic source.

3.12 CMP sorting

CMP sorting was performed so that the primary header was CMP and the secondary header was offset.

3.13 Stacking velocity analysis

To obtain the velocities used for normal moveout correction, velocity analysis using a constant velocity stack and velocity spectra was carried out.

3.14 Normal moveout correction

Normal moveout (NMO) correction was conducted according to the stacking velocity determined by velocity analysis. In addition, stretching mute was applied during NMO correction.

3.15 Demultiple processing using parabolic Radon transform

To eliminate remnant multiple reflections, we applied demultiple processing using parabolic Radon transform to CMP gather data after NMO correction. The parabolic Radon transform is a method of reconstructing data by adding various parabolas with vertices at a zero offset distance to CMP gather data. The multiple reflected wave that could be expressed approximately by parabolic trajectory were separated from the primary reflected wave that could be aligned horizontally by NMO correction. Multiple suppression processing was performed by subtracting the extracted multiple reflection wave from the original CMP gather data.

3.16 Mute processing

A mute processing was designed and applied to CMP gather data to remove the NMO stretching and the refracted wave remaining on the far offset side.

3.17 CMP stacking

CMP stacking processing was carried out on the CMP gather data after applying the above processing.

3.18 Bandpass filter

Based on the results of studying parameters such as the effective frequency band of the imaging as a whole, a bandpass filter was applied.

3.19 F-X prediction filter

An F-X predictive filter was applied to suppress random noise and improve the relative S/N ratio in the frequency-space domain with respect to the poststack data.

3.20 Poststack time migration

Time migration was applied for the purpose of moving the reflection point to the actual position and restoring the diffracted wave to the diffraction point.

4. Expected use of the data

The MCS data are expected to contribute to an understanding of the distribution of active faults and the construction of source fault models in the southern part of the Japan Sea. Furthermore, they will contribute also to the study of crust formation in the southern part of the Japan Sea. As a result, we expect to facilitate a much greater understanding about seismotectonics and the formation of the Japan Sea. In addition, since previous seismic reflection surveys of the survey areas were limited to the purpose of petroleum exploration (e.g., Japanese Association for Petroleum Technology, 1993) and geological survey (e.g., Geological Survey of Japan, 2001), it is expected that our data will be useful in updating studies made using past seismic data.

5. Accessibility

Information on these surveys and the MCS data are available on the Crustal Structural Database Site (Kido et al., 2006) of JAMSTEC. Website addresses are as follows:

Table 2. List of data processing modules in this report. The processing modules marked with asterisks were applied to only some seismic lines.

Processing	Remarks
3.1 Format conversion	
3.2 Geometry application	
3.3 Recording delay removal	
3.4 Datum correction	
3.5 Prefiltering	
3.6 Signature deconvolution	
* Direct wave suppression	Applied to only SJ14B, 1502, 1503, 15FK, 1506, 15MZ, 15A, 16HY, 16TR.
3.8 F-X prediction filter	
3.9 Surface-related multiple elimination processing	
* "Predictive deconvolution along radial trace" or "r-p deconvolution"	Applied to only SJ14B, 1404, 1405, 1406, 1407, 1408, 1409, 1410, 1506, 15MZ, 16HY, 16TR.
3.10 Suppression of coherent noise	
3.11 Predictive deconvolution	
3.12 Gain recovery	
* F-X trace interpolation	Applied to only SJ14B, 1506, 15MZ.
3.13 CMP sorting	
3.14 Stacking velocity analysis	
3.15 Normal moveout correction	
3.16 Demultiple processing using parabolic Radon transform	
3.17 Mute processing	
3.18 CMP stacking	
3.19 Bandpass filter	
3.20 F-X prediction filter	
3.21 Poststack time migration	

● **KR14-08:**

http://www.jamstec.go.jp/jamstec-e/IFREE_center/data-e/cruise_data-e/KR14-08-e.html

(English version) [Accessed 1 June 2018]

http://www.jamstec.go.jp/jamstec-j/IFREE_center/data/cruise_data/KR14-08.html

(Japanese version) [Accessed 1 June 2018]

● **KR15-11:**

http://www.jamstec.go.jp/jamstec-e/IFREE_center/data-e/cruise_data-e/KR15-11js-e.html

(English version) [Accessed 1 June 2018]

http://www.jamstec.go.jp/jamstec-j/IFREE_center/data/cruise_data/KR15-11js.html

(Japanese version) [Accessed 1 June 2018]

● **KR16-08:**

http://www.jamstec.go.jp/jamstec-e/IFREE_center/data-e/cruise_data-e/KR16-08-e.html

(English version) [Accessed 1 June 2018]

http://www.jamstec.go.jp/jamstec-j/IFREE_center/data/cruise_data/KR16-08.html

(Japanese version) [Accessed 1 June 2018]

Available data types and format are as follows:

- Shot gather data (Raw data, SEG-D format)
- Shot gather data (Output data after “3.5 Prefiltering”, SEG-Y format)
- Stack data (Output data after “3.17 CMP stacking”, SEG-Y format)
- Migration data (Output data after “3.20 Poststack time migration”, SEG-Y format)
- Navigation data (UKOOA P1/90, P2/91 format)
- General information of data acquisition, layout of source and receiver, and observer logs (PDF format)

In order to obtain the original data, it is necessary to send the request to the following web address by e-mail, since the original data cannot be downloaded from the web pages directly due to their large volume:

http://www.jamstec.go.jp/jamstec-e/IFREE_center/question-e.html

(English version) [Accessed 1 June 2018]

http://www.jamstec.go.jp/jamstec-j/IFREE_center/entry.html

(Japanese version) [Accessed 1 June 2018]

6. Usage notes and ownership

The MCS data of this paper follow the data policies of the following websites:

http://www.jamstec.go.jp/e/database/data_policy.html

(English version) [Accessed 1 June 2018]

http://www.jamstec.go.jp/jamstec-j/IFREE_center/policy.html (Japanese version) [Accessed 1 June 2018]

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