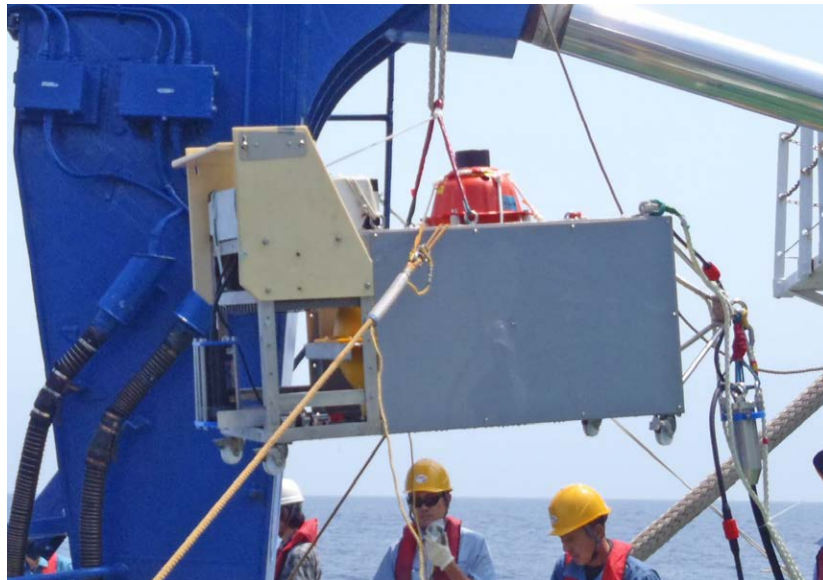


YOKOSUKA Cruise Report

YK17-13

**Studies of fracturing and pore fluid circulation
in the oceanic crust subducting along the Japan Trench
through electromagnetic survey**



Japan Trench off Sanriku

June 26, 2017 – July 3, 2017

**Japan Agency for Marine-Earth Science and Technology
(JAMSTEC)**

Contents

1. Cruise Information	1
2. Researchers	2
3. Observation	3
3.1. Introduction	3
3.2. Summary of the Cruise	6
3.2.1. Research items	6
3.2.2. Cruise schedule and operations	7
3.2.3. Ship track and observation points	8
3.3. Research Objectives	9
3.4. Instruments and Operation Methods	11
3.4.1. Ocean bottom electromagnetometer (OBEM) and ocean bottom electrometer (OBE)	11
3.4.2. Controlled source deep-tow system	13
3.5. Preliminary Results	14
3.5.1. Recovery of ocean bottom electromagnetometers (OBEMs)	14
3.5.2. Deployment and recovery of ocean bottom electrometers (OBEs)	14
3.5.3. Controlled-source electromagnetic (CSEM) experiment	15
4. Notice on Using	17
5. Acknowledgements	18
6. References	19
7. Appendices	21
7.1. Cruise Log	21
7.2. Survey Lines	23
7.3. R/V YOKOSUKA Crew and YKDT Operation Team	25

1. Cruise Information

Cruise ID:

YK17-13

Name of vessel:

R/V YOKOSUKA

Title of the cruise:

2017 Deep Sea Research

Studies of fracturing and pore fluid circulation in the oceanic crust subducting along the Japan Trench through electromagnetic survey

Title of proposal:

S17-12

Studies of fracturing and pore fluid circulation in the oceanic crust subducting along the Japan Trench through electromagnetic survey

Cruise period:

June 26, 2017 – July 3, 2017

Ports of departure / arrival:

2017 June 26 Dept. from Yokosuka

July 3 Arriv. at Yokosuka

Research area:

Japan Trench area off Sanriku

Research map:

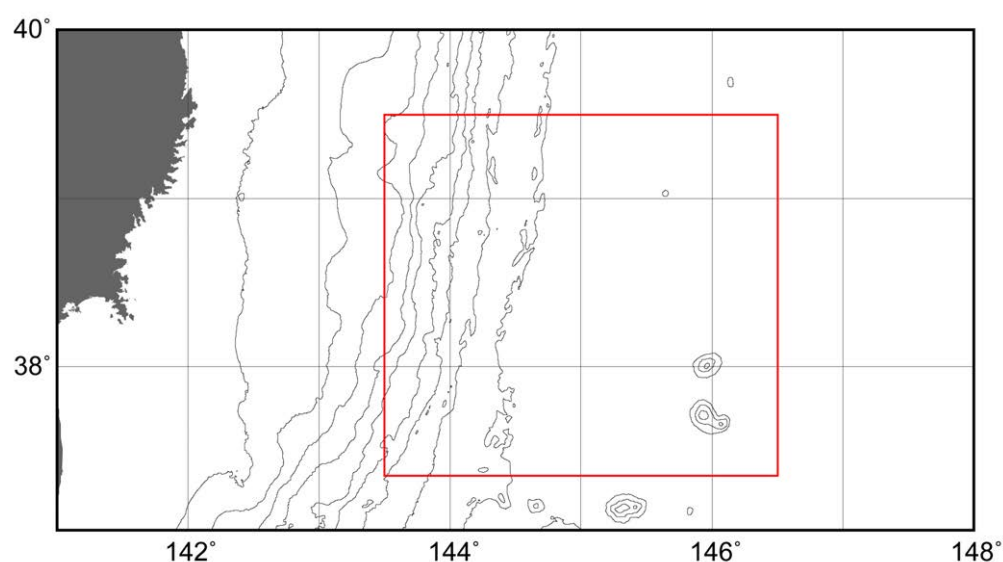


Figure 1-1. Proposed research area of YK17-13 cruise.

Ship track and observation points are shown in 3.2.3.

2. Researchers

Chief Scientist:

Makoto YAMANO Earthquake Research Institute, the University of Tokyo

Representative of the Science Party:

Makoto YAMANO Earthquake Research Institute, the University of Tokyo

Science Party:

Makoto YAMANO	Earthquake Research Institute, the University of Tokyo
Kiichiro KAWAMURA	Graduate School of Science and Engineering Yamaguchi University
Hiroshi ICHIHARA	Graduate School of Environmental Studies, Nagoya University
Hironori OTSUKA	Earthquake Research Institute, the University of Tokyo
Keiichi ISHIZU	Graduate School of Engineering, Kyoto University
Shinya SATO	Graduate School of Engineering, Kyoto University
Takafumi KASAYA	Research and Development Center for Earthquake and Tsunami Japan Agency for Marine-Earth Science and Technology
Shigeo MATSUDA	Clover tech Inc.
Yasuko TAKEI	Earthquake Research Institute, the University of Tokyo (shore-based)
Makoto UYESHIMA	Earthquake Research Institute, the University of Tokyo (shore-based)
Tadanori GOTO	Graduate School of Engineering, Kyoto University (shore-based)
Yoshifumi KAWADA	International Research Institute of Disaster Science Tohoku University (shore-based)
Shuichi KODAIRA	Research and Development Center for Earthquake and Tsunami Japan Agency for Marine-Earth Science and Technology (shore-based)
Gou FUJIE	Research and Development Center for Earthquake and Tsunami Japan Agency for Marine-Earth Science and Technology (shore-based)
Hideki HAMAMOTO	Center for Environmental Science in Saitama (shore-based)

Technical Support Staff

Tohru KODERA Nippon Marine Enterprises, Ltd.

3. Observation

3.1. Introduction

The temperature structure of the subducting oceanic plate, generally determined by the seafloor age, is one of the most important factors controlling the subsurface thermal structure of subduction zones. The Pacific plate subducting along the Japan Trench is very old, over 130 m.y., and thus supposed to be cold. Heat flow values measured on the seaward slope of the Japan Trench along a parallel of 38°45'N were, however, significantly higher than that expected from the seafloor age (Yamano et al., 2008). It indicates that the temperature structure of the incoming Pacific plate may be anomalous, which has an influence on the temperature distribution along the subduction plate interface. Aiming to investigate the extent and cause of the high heat flow anomaly, we conducted heat flow measurements along three E-W lines across the Japan Trench at latitudes of about 38 to 40°N (lines A, B, and C in Fig. 3.1-1). The obtained data, combined with the existing data, revealed the following features of heat flow distribution on the seaward side of the Japan Trench (Fig. 3.1-1; Yamano et al., 2014a).

1) On the seaward trench slope and trench outer rise along the three lines, heat flow is anomalously high, higher than 70 mW/m^2 , at many stations, while values normal for the seafloor age (about 50 mW/m^2) are observed at some stations. It suggests that high heat flow anomaly seaward of the Japan Trench extends at least over the northern half of the trench.

2) Significantly high heat flow (over 70 mW/m^2) was observed within about 150 km of the trench axis. The limited extent indicates that the anomaly is closely related to deformation of the Pacific plate associated with subduction.

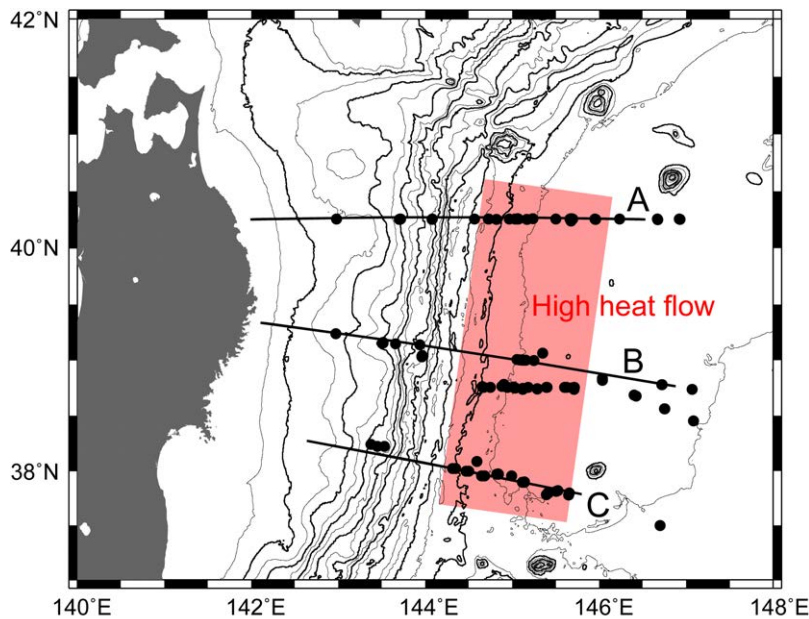


Figure 3.1-1. Heat flow measurement stations in the Japan Trench area off Sanriku (black dots) and the extent of high heat flow anomaly (reddish rectangle) (Yamano et

Possible causes of the heat flow anomaly are heat transport by pore fluid flow along normal faults developed on the seaward trench slope (e.g., Tsuru et al., 2000) and magma intrusion due to petit-spot volcanism (a peculiar type of intra-plate volcanism around the outer rise of the Japan Trench; e.g., Hirano et al., 2006). However, both mechanisms cannot yield the observed broad high average heat flow zone, though they may have produced some very local anomalies (Ray et al., 2015)

Seismic reflection and refraction surveys seaward of the Japan and Kuril trenches revealed that significant change in the seismic velocity structure of the oceanic crust occurs in the incoming Pacific plate (Fujie et al., 2013, Obana and Fujie, 2017): the compressional and shear wave velocities (V_p and V_s) decrease and the V_p/V_s ratio increases. The thickness of the anomalous velocity layer appears to increase toward the trench axis. Such changes in the seismic velocities probably represent increase in water content as a result of fracturing of the oceanic crust due to bending of the plate (Fujie et al., 2013). Seismic surveys conducted along a line parallel to the Japan Trench about 100 km seaward of the trench showed that the velocity structure also varies in the north-south direction (Fujie et al., 2016). It indicates that the density of fractures and the amount of water in the oceanic crust may vary along the trench as well.

The seismic velocity changes are found within 150 to 200 km of the trench axis, both off the Kuril Trench and off the Japan Trench, which appears to correspond with the extent of the high heat flow anomaly off the Japan Trench. Based on the correlation between the heat flow distribution and the seismic velocity structure, Kawada et al. (2014) proposed that the high heat flow observed seaward of the Japan Trench may be attributed to the following processes in the incoming Pacific plate (Fig. 3.1-2). Bending of the Pacific plate associated with subduction yields fractures in the oceanic crust, increasing the permeability of the crust. Development of fractures toward the trench leads to thickening of the permeable layer, which enhances vertical heat transport by pore fluid circulation from deeper part of the crust and raises the surface heat flow. They showed through numerical modeling that this process may yield a broad high heat flow anomaly at a scale of 100 km, as observed on the seaward side of the Japan Trench.

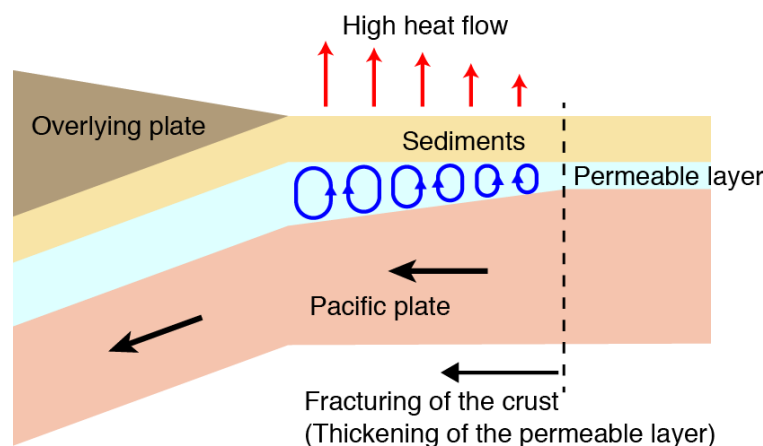


Figure 3.1-2. Hydrothermal heat mining model (Kawada et al., 2014). The permeable layer in the upper oceanic crust thickens toward the trench.

Overlapping the broad high anomaly, large local variations at a scale of a few kilometers were found at some sites where concentrated measurements were made. For investigation of the origin of the local anomalies, we conducted a dense heat flow survey around 39°N along the line B (cf. Fig. 3.1-1) in 2014. Measurements were made at intervals of several hundred meters, in an area 60 to 80 km from the trench axis, where immature horst and graben structures are found. The obtained 20-km detailed profile shows a prominent sawtooth-like variation (60 to 110 mW/m²) at a scale of 3 to 5 km (Yamano and Kawada, 2017). This characteristic heat flow distribution has no apparent correlation with the basement topography and faults and might result from heterogeneity in deeper part of the oceanic crust.

In the hydrothermal heat mining model shown in Fig. 3.1-2, the thickness of the permeable layer increases uniformly toward the trench axis. Actual fracturing process of the oceanic crust must be heterogeneous, which may result in local variations in the thickness of the permeable layer and thus the amount of advective heat transport, i.e. surface heat flow.

Large-scale and local (heterogeneous) fracture development process inferred from the seismic velocity structure and heat flow distribution can be examined through electromagnetic surveys to reveal the electrical resistivity structure which reflects the distribution and connectivity of pore fluid.

3.2. Summary of the Cruise

3.2.1. Research items

(1) Marine magnetotelluric survey

Measurement of natural variations of electromagnetic fields on the seafloor with ocean bottom electromagnetometers (OBEMs) for about a year.

(2) Marine controlled-source electromagnetic (CSEM) survey

Measurement of electromagnetic fields generated by artificially controlled electric current using a deep-towed electromagnetic source system and ocean bottom electrometers (OBEs).

(3) Bathymetry survey

Bathymetry mapping with a multi narrow beam system.

3.2.2. Cruise schedule and operations

Date	Events, Operations
June 26	Leave Yokosuka
June 27	Arrive in the survey area Recovery of two OBEMs (C40 and C41) Deployment of four OBEs (A4E-6, A4E-5, A4E-4, and A4E-1)
June 28	Recovery of one OBEM (C42) Deployment of two OBEs (A4E-3 and A4E-2) Controlled-source electromagnetic survey with deep-towed system (Line 1) Controlled-source electromagnetic survey with deep-towed system (Line 2)
June 29	Controlled-source electromagnetic survey with deep-towed system (Line 2) Controlled-source electromagnetic survey with deep-towed system (Line 3)
June 30	Controlled-source electromagnetic survey with deep-towed system (Line 3) Controlled-source electromagnetic survey with deep-towed system (Line 4) Bathymetry survey
July 1	Recovery of six OBEs (A4E-1, A4E-2, A4E-3, A4E-4, A4E-5, and A4E-6) Bathymetry survey Leave the survey area
July 2	Transit to Yokosuka
July 3	Arrive at Yokosuka

Detailed cruise log is given in 7.1.

3.2.3. Ship track and observation points

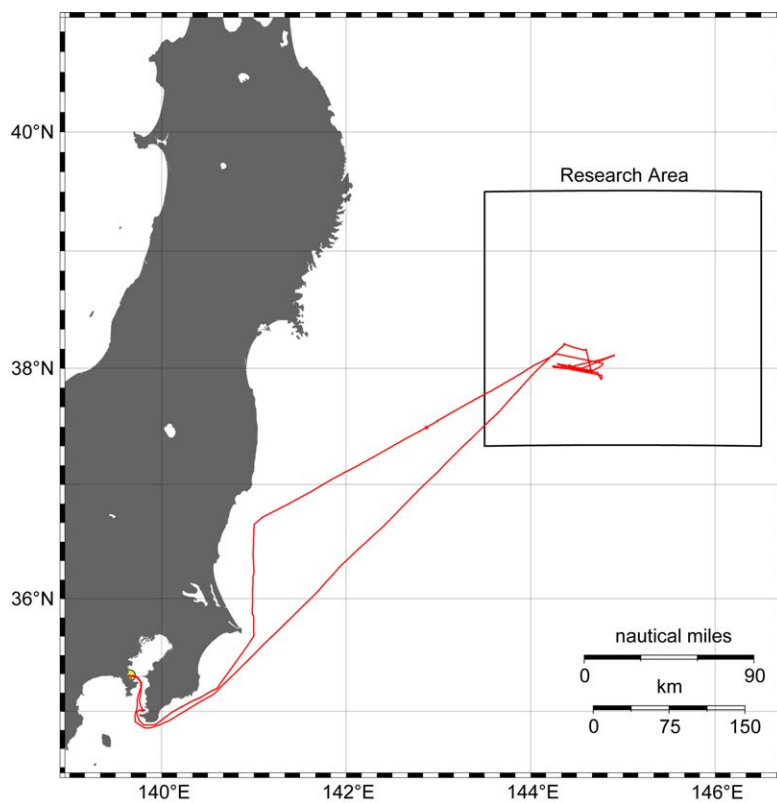


Figure 3.2-1. Ship track of YK17-13 cruise.

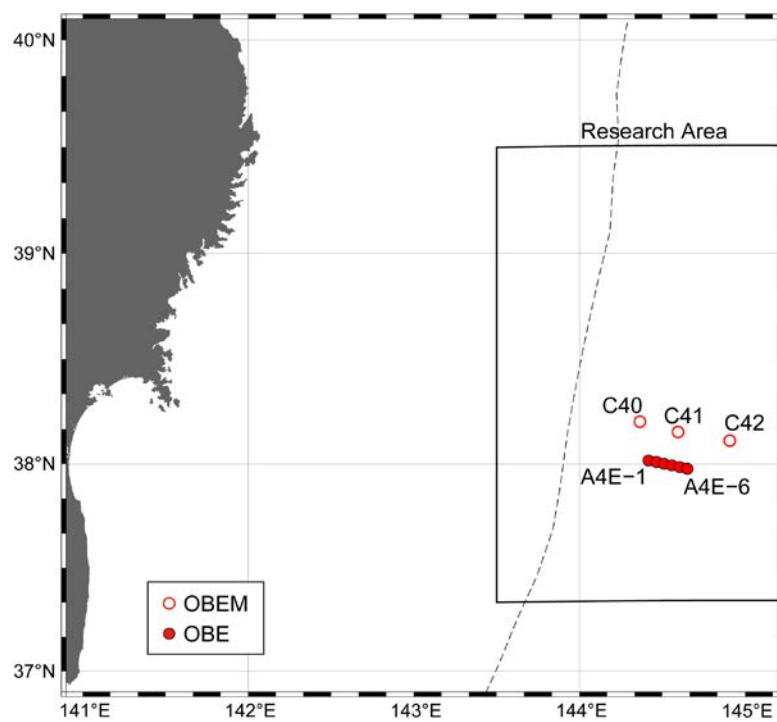


Figure 3.2-2. Locations of OBEM and OBE observation points.

3.3. Research Objectives

Heat flow and seismic velocity structure anomalies observed on the outer rise of the Japan Trench indicate that fracturing of the oceanic crust due to bending of the plate causes thickening of the permeable layer in oceanic crust and results in efficient pumping up of heat from beneath the permeable layer by pore fluid circulation (Kawada et al., 2014; Fig. 3.1-2). For investigation of this hydrothermal heat mining process, we started a research program of heat flow and electromagnetic surveys on the seaward side of the Japan Trench. Heat flow measurements are planned to be made mainly along the lines B and C in Fig. 3.1-1 so that the obtained data can be compared with the seismic velocity structure (Obana and Fujie, 2017). We also conduct electromagnetic surveys with the controlled-source electromagnetic method as well as with the passive magnetotelluric method to image the electrical resistivity structure of the oceanic crust and the uppermost mantle. The obtained results would allow us to delineate the spatial variation of the porosity and permeability with information on anisotropy.

Based on the results of these studies, we will be able to reveal how fractures and pore fluid circulation develop seaward of the trench and how water penetrates into the upper part of the incoming plate. Our final goal is evaluation of the influence of these processes on the thermal structure and water distribution around the plate interface, the seismogenic zone of large thrust earthquakes.

In 2014, we made dense heat flow measurements along the line B on KS-14-17 cruise of the R/V SHINSEI MARU and found prominent heat flow variations at a scale of 3 to 5 km (Yamano and Kawada, 2017). We also conducted a preliminary electromagnetic survey with a controlled-source towed just above the seafloor on KY14-10 cruise of the R/V KAIYO (Yamano et al., 2014b) and showed that it is possible to obtain information on the resistivity structure to depth of a few km in deep sea areas with water depths over 5000 m. Based on these initial results, we applied for a research grant (JSPS KAKENHI) and was funded for “Investigation of pore fluid circulation in the upper part of incoming plate and evaluation of its influence on seismogenic zone of large thrust earthquakes” (2015 to 2017).

Specific objectives of this research cruise

On this cruise, YK17-13, we conduct controlled-source electromagnetic (CSEM) surveys on the outer rise of the Japan Trench, along the line C in Fig. 3.1-1 around 38°N. In the original research proposal, we planned surveys along the line B. The seismic velocity structure along a line parallel to the Japan Trench about 100 km seaward of the trench, however, indicates that the crustal structure around the line B may not be typical of the northern Japan Trench (Fujie et al., 2016). Various geophysical surveys have recently been made around the line C (Obana and Fujie, 2017; Obana et al., 2018) and target sites of IODP drilling proposal “Bending fault

hydrology of the old incoming plate” are located on this line (Morishita et al., 2017). We therefore selected CSEM survey sites of this cruise along the line C.

Another objective of this cruise is recovery of ocean bottom electromagnetometers (OBEMs) deployed during KS-16-15 cruise of the R/V SHINSEI MARU in October, 2016. They are located about 20 km north of the line C. The obtained data are used for magnetotelluric analysis to investigate the resistivity structure of deeper layers (down to around 100 km).

3.4. Instruments and Operation Methods

3.4.1 Ocean bottom electromagnetometer (OBEM) and ocean bottom electrometer (OBE)

The OBEM system can measure time variations of three components of magnetic field, two components of horizontal electric field, instrumental tilts, and temperature. It mainly consists of one 17-inch glass sphere, sensor unit in aluminum/titanium pressure housing and electrode arm unit with arm holding mechanism (Fig. 3.4-1). The glass sphere contains data logger and a lithium battery pack. The sensor unit has a high-accuracy fluxgate magnetometer, tiltmeter and thermometer. The electrodes are Ag-AgCl equilibrium type made by Clover tech Inc. For electric field, four voltage differences between the electrodes on the tip of the pipes and the ground electrode are measured. The self-potentials of the electrodes were monitored in laboratory in advance of the seafloor observation and pairs with high enough coherence were selected, in order to reduce the noise due to the voltage drift of electrodes themselves. A transponder unit, a radio beacon and a flashlight are also mounted on the OBEM. The acoustic system can communicate with the SSBL system of the ship and it is easy for us to detect its position in the sea or on the seafloor. The battery life of the acoustic system is two years.

Design concepts of this type of OBEM system are miniaturization, a high sampling rate, easy assembly and recovery operations, and low costs of construction and operation. The arm-folding mechanism, with which electrode arms are folded when OBEM is in surfacing (Fig.3.4-2), enables recovery operation even on a small ship that is not equipped with an A-frame (Kasaya et al., 2006; Kasaya and Goto, 2009).

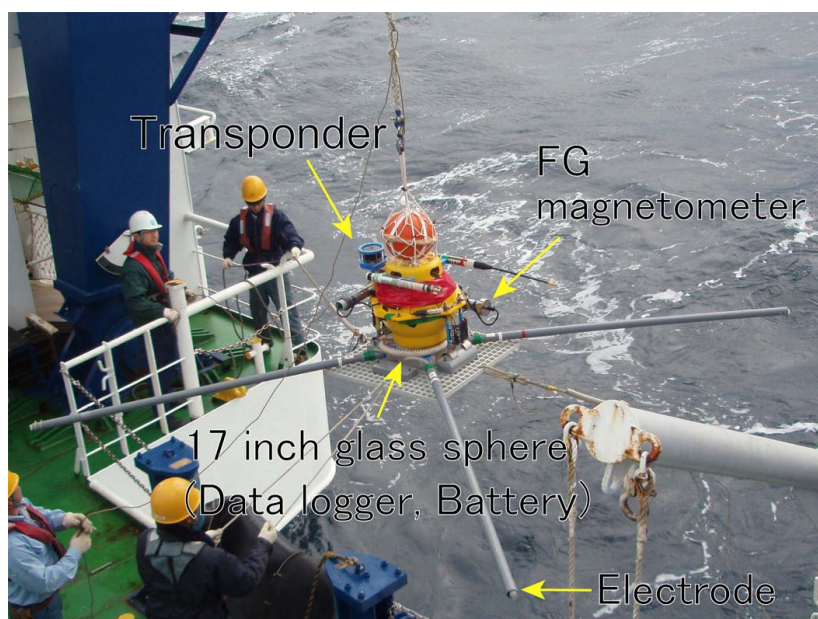


Figure 3.4-1. OBEM system.

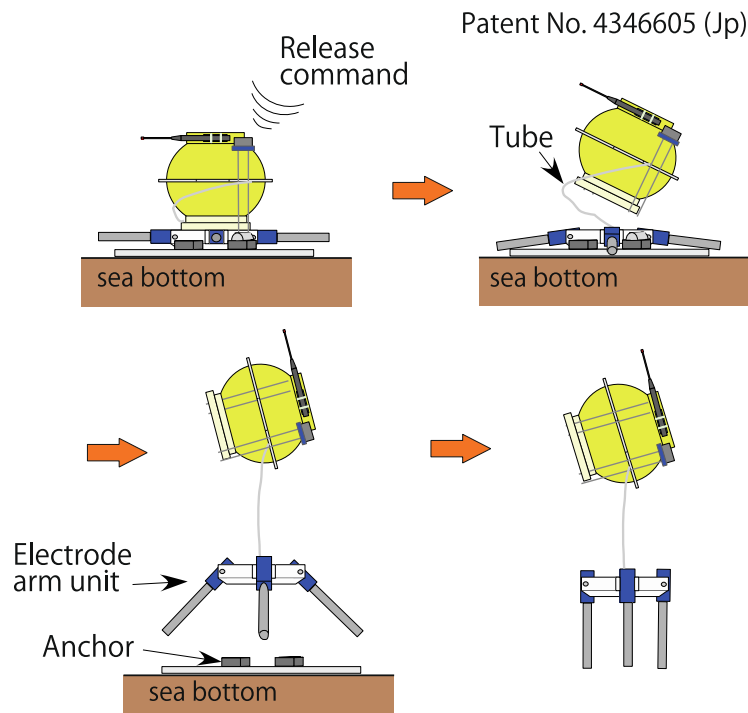


Figure 3.4-2. Electrode arm-folding mechanism.

The OBE system is designed for controlled source survey with over 1 kHz sampling. The electric circuit and battery are contained in a cylinder type aluminum pressure case (Fig. 3.4-3). This system is also a pop-up type using the same arm-folding system as the OBEM system. The electrodes are Ag-AgCl equilibrium type made by Clover tech Inc. For electric field, five voltage differences between the electrodes on the tip of the pipes and the ground electrode are measured. A transponder unit, radio beacon and a flashlight are also mounted on the OBE.



Figure 3.4-3. Photo of a pop-up type OBE system.

3.4.2. Controlled-source deep-tow system

On this cruise, we conducted deep-towed controlled-source electromagnetic surveys using R/V YOKOSUKA and the deep-tow system developed by JAMSTEC. Figure 3.4-4 shows a schematic drawing of the controlled electromagnetic survey on this cruise. Our controlled source deep-tow system consists of main deep tow including a transmitter unit and a main control unit, and a tail buoy unit with a 200 meters towing cable. The main control unit can record transmitting signal data with 1 kHz sampling and CTD data with 1 Hz sampling. The transmitter unit uses the Insulated Gate Bipolar Transistor (IGBT) as a current transmitting control and switching device. AC 1200 V is supplied through the optical-electric cable to a transformer on the deep tow and converted into AC 100 V. Although the maximum output power capacity of this transmitter is designed to be 10 kW, the electric power was below about 3 kW in this operation because of capacity limitation of the winch cable.

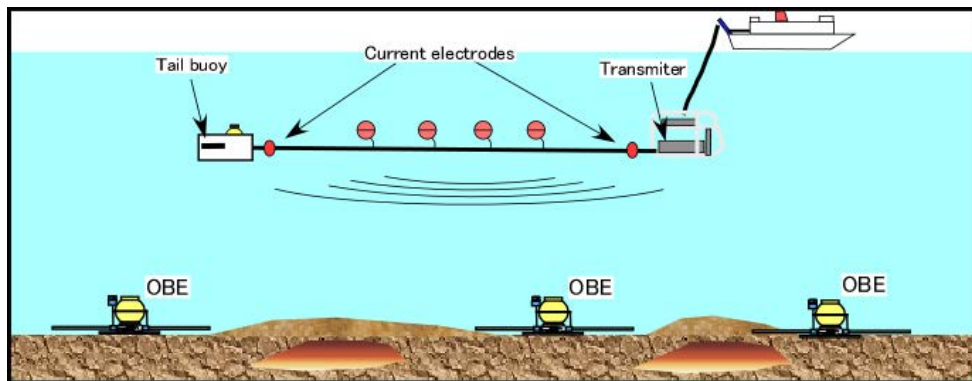


Figure 3.4-4. Configuration of controlled-source electromagnetic survey.

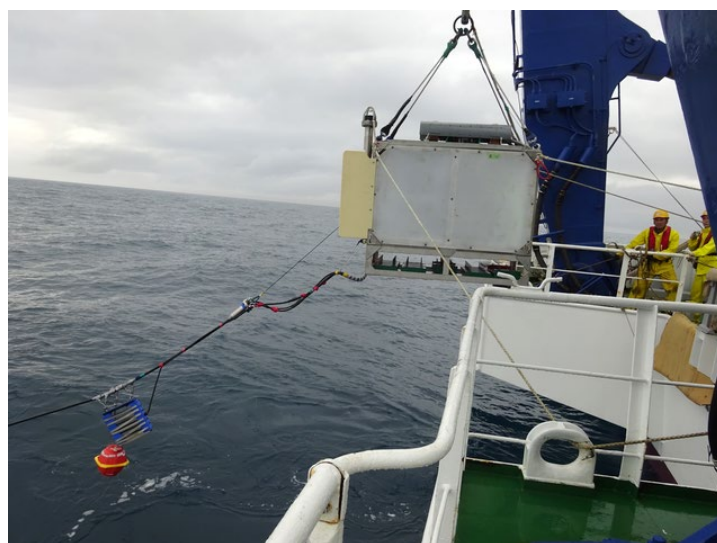


Figure 3.4-5. Photo of the controlled-source deep-tow system.

3.5. Preliminary Results

3.5.1. Recovery of ocean bottom electromagnetometers (OBEMs)

We retrieved three OBEMs (Fig. 3.4-1) at the sites C40, C41 and C42. These OBEMs were deployed on the KS-16-15 cruise in October 2017. We sent the acoustic weight-release signal through the SSBL system of R/V YOKOSUKA. The OBEMs were found with eyes and radio beacon signal soon after the surfacing. Arms of the OBEMs are folded when the OBEM is floating for easy recovery by the ship (Fig. 3.4-2). The OBEMs were hooked and lifted up onto the deck on the starboard side. Conditions of the OBEMs were checked after removing the arm-unit, sensor unit and transponder. Then the glass-spheres were opened to check condition of the inside, to compare the OBEM clock with NTP clocks and, to read out the data. Recovery information including the clock comparison result is listed in Table 3.5-1. The glass-sphere of OBEM KYT04 (site C40), whose ascending rate was significantly slow (Table 3.5-1) compared to the normal rate (about 40 m/min), was inundated by seawater. The height of water was about 10 cm from bottom of the glass-sphere. The data logger was damaged and data could not be retrieved from the CompactFlash card, although it does not seem to be damaged. On the other hand, high quality time series data were obtained at the sites C41 and C42.

Table 3.5-1. OBEM recovery information

Site ID	OBEM ID	Releasing duration (min)	Ascent rate (m/min)	On deck time (JST)	Clock set time (UTC)	Clock compared time (UTC)	Time diff. (sec)
C40	KYT04	15	24.9	17/6/27 13:28	16/10/2 19:46:10	N/A	N/A
C41	KYT03	15	32.2	17/6/27 17:45	16/10/2 21:32:28	17/6/27 13:45:18	36.671
C42	TOK02	13	29.2	17/6/28 6:19	16/10/3 00:15:10	17/6/27 21:40:46	50.726

3.5.2. Deployment and recovery of ocean bottom electrometers (OBEs)

Six OBEs were deployed to receive electromagnetic signals transmitted from the controlled source deep-tow system. Specifications and positioning information of the OBEs are listed in Tables 3.5-1 and 3.5-2, respectively. After the controlled source EM surveys, the OBEs were retrieved using the acoustic weight-release system. The SSBL system of R/V YOKOSUKA was used for acoustic communication between the ship and the OBEs. The OBEs were found with eyes and radio beacon signal soon after the surfacing. The OBEs are equipped with the arm-folding system (Fig. 3.4-2) as the OBEMs. The OBEMs were hooked and lifted up onto the

deck on the starboard side. Conditions of the OBEMs were checked after removing the arm-unit, sensor unit and transponder.

Table 3.5-2. OBE specifications

Site ID	OBE ID	VCUBE S/N	T/D ID	Acoustic command code	Dipole length (m)
A4E-1	OBE-3	012	JX-1243	6F-1	5.44
A4E-2	OBE-5	3100	JX-1202	1D-1	5.44
A4E-3	OBE-2	015	JX-1203	7A-1	5.44
A4E-4	OBE-1	007	JX-1285	8F-1	5.44
A4E-5	OBE-6	017	JX-1276	2E-1	5.44
A4E-6	OBE-4	016	JX-1242	6C-1	5.44

Table 3.5-3. OBE positioning information

Site ID	Launch date and time (JST)		Recovery date and time (JST)		Settlement position		Settlement depth (m)
A4E-1	‘17/6/27	21:34	‘17/7/1	4:39	38-00.9725N	144-25.1054E	5971
A4E-2	‘17/6/28	8:35	‘17/7/1	5:32	38-00.5433N	144-27.9393E	5868
A4E-3	‘17/6/28	7:49	‘17/7/1	8:34	37-59.9837N	144-30.6802E	5969
A4E-4	‘17/6/27	20:37	‘17/7/1	9:30	37-59.5600N	144-33.5259E	5840
A4E-5	‘17/6/27	19:53	‘17/7/1	12:23	37-59.0942N	144-36.3584E	5724
A4E-6	‘17/6/27	19:09	‘17/7/1	13:24	37-58.5807N	144-39.1077E	5600

3.5.3. Controlled-source electromagnetic (CSEM) experiment

Overnight towing operations of the CSEM system were carried out from June 28 to 30. Dive information and tracks are given in 7.2. First and second dives were quitted before starting survey due to troubles with the tail buoy. In the third dive, we reached the planned operation depth and could start electrical current transmission on the survey line over the site A4E-1. However, an acoustic transponder on the main deep tow stopped responding before reaching the site A4E-2, then we decided to recover the system. After adding another transponder unit, we started the 4th dive. Every instrument worked well through the 4th dive, and we could finish the planned survey line. During the dives, we monitored all the data including altimeter and monitoring camera, various controlling parameters of the deep tow (Fig.3.5-1).



Figure 3.5-1. Onboard monitoring system.

4. Notice on Using

This cruise report is a preliminary documentation as of the end of the cruise.

This report may not be corrected even if changes on contents (i.e. taxonomic classifications) may be found after its publication. This report may also be changed without notice. Data on this cruise report may be raw or unprocessed. If you are going to use or refer to the data written on this report, please ask the Chief Scientist for latest information.

Users of data or results on this cruise report are requested to submit their results to the Data Management Group of JAMSTEC.

5. Acknowledgements

We are grateful to Captain E. Ukekura, the officers and the crew of the R/V YOKOSUKA, ROV Operation Manager T. Sakurai and the YKDT operation team for skillful operations of the ship, deep-two system and research equipment. We also extend our thanks to T. Kodera for giving us great assistance in research works throughout the cruise. The staff of the Department of Ship Operation, Marine Technology and Engineering Center, especially T. Komuku, made excellent arrangements for the cruise.

The research conducted on this cruise was partly supported by JSPS KAKENHI Grant Number JP15H03715.

6. References

- Fujie, G., S. Kodaira, M. Yamashita, T. Sato, T. Takahashi, and N. Takahashi, 2013, Systematic changes in the incoming plate structure at the Kuril trench, *Geophys. Res. Lett.*, **40**, 88-93, doi:10.1029/2012GL054340.
- Fujie G., S. Kodaira, T. Sato, and T. Takahashi, 2016, Along-trench variations in the seismic structure of the incoming Pacific plate at the outer rise of the northern Japan Trench, *Geophys. Res. Lett.*, **43**, 666-673, doi:10.1002/2015GL067363.
- Hirano, N., E. Takahashi, J. Yamamoto, N. Abe, S.P. Ingle, I. Kaneoka, T. Hirata, J. Kimura, T. Ishii, Y. Ogawa, S. Machida, and K. Suyehiro, 2006, Volcanism in response to plate flexure, *Science*, **313**, 1426-1428.
- Kasaya, T. and T. Goto, 2009, A small ocean bottom electromagnetometer and ocean bottom electrometer system with an arm-folding mechanism (Technical Report), *Exploration Geophysics*, **40**, 41-48; *Butsuri-Tansa*, **62**, 41-48; *Mulli-Tamsa*, **12**, 41-48.
- Kasaya, T., T. Goto, and R. Takagi, 2006, Marine electromagnetic observation technique and its development –For crustal structure survey–, *Butsuri-Tansa*, **59**, 585-594 (in Japanese with English abstract).
- Kawada, Y., M. Yamano, and N. Seama, 2014, Hydrothermal heat mining in an incoming oceanic plate due to aquifer thickening: Explaining the high heat flow anomaly observed around the Japan Trench, *Geochem. Geophys. Geosyst.*, **15**, 1580-1599, doi:10.1002/2014GC005285.
- Morishita, T., G. Fujie, M. Yamano, M. Nakanishi, K. Obana, Y. Nakamura, S. Saito, S. Kodaira, J. Kimura, J. Kuroda, and S. Ono, 2017, Overview of the drilling project on the bend-fault hydrology in old incoming plate, *J. Geogr. (Chigaku Zasshi)*, **126**, 247-262, doi:10.5026/jgeography.126.247, (in Japanese with English abstract).
- Obana, K. and G. Fujie, 2017, Outer-rise seismology: Crustal structure and seismic activity of the incoming Pacific plate in the trench-outer rise region, *J. Geogr. (Chigaku Zasshi)*, **126**, 113-123, doi:10.5026/jgeography.126.113, (in Japanese with English abstract).
- Obana K., Y. Nakamura, G. Fujie, S. Kodaira, Y. Kaiho, Y. Yamamoto, and S. Miura, 2018, Seismicity in the source areas of the 1896 and 1933 Sanriku earthquakes and implications for large near-trench earthquake faults, *Geophys. J. Int.*, **212**, 2061-2072, doi:10.1093/gji/ggx532.
- Ray, L., Y. Kawada, H. Hamamoto, and M. Yamano, 2015, Multiple-scale hydrothermal circulation in 135 Ma oceanic crust of the Japan Trench outer rise: Numerical models constrained with heat flow observations, *Geochem. Geophys. Geosyst.*, **16**, 2711-2724, doi:10.1002/2015gc005771.
- Tsuru, T., J.-O., Park, N. Takahashi, S. Kodaira, Y. Kido, Y. Kaneda, and Y. Kono, 2000,

- Tectonic features of the Japan Trench convergent margin off Sanriku, northeastern Japan, revealed by multichannel seismic reflection data, *J. Geophys. Res.*, **105**, 16403-16413.
- Yamano, M. and Y. Kawada, 2017, Heat flow anomalies near trenches: Heat transport by fluid circulation in oceanic crust, *J. Geogr. (Chigaku Zasshi)*, **126**, 147-161, doi:10.5026/jgeography.126.147, (in Japanese with English abstract).
- Yamano, M., M. Kinoshita, and S. Goto, 2008, High heat flow anomalies on an old oceanic plate observed seaward of the Japan Trench, *Int. J. Earth Sci.*, **97**, 345-352.
- Yamano, M., H. Hamamoto, Y. Kawada, and S. Goto, 2014a, Heat flow anomaly on the seaward side of the Japan Trench associated with deformation of the incoming Pacific plate, *Earth Planet. Sci. Lett.*, **407**, 196-204, doi: 10.1016/j.epsl.2014.09.039.
- Yamano, M. and others, 2014b, KAIYO Cruise Report, KY14-10, Studies of fracturing and pore fluid circulation in the oceanic crust subducting along the Japan Trench through heat flow and electromagnetic surveys, http://www.godac.jamstec.go.jp/catalog/data/doc_catalog/media/KY14-10_all.pdf.

7. Appendices

7.1. Cruise Log

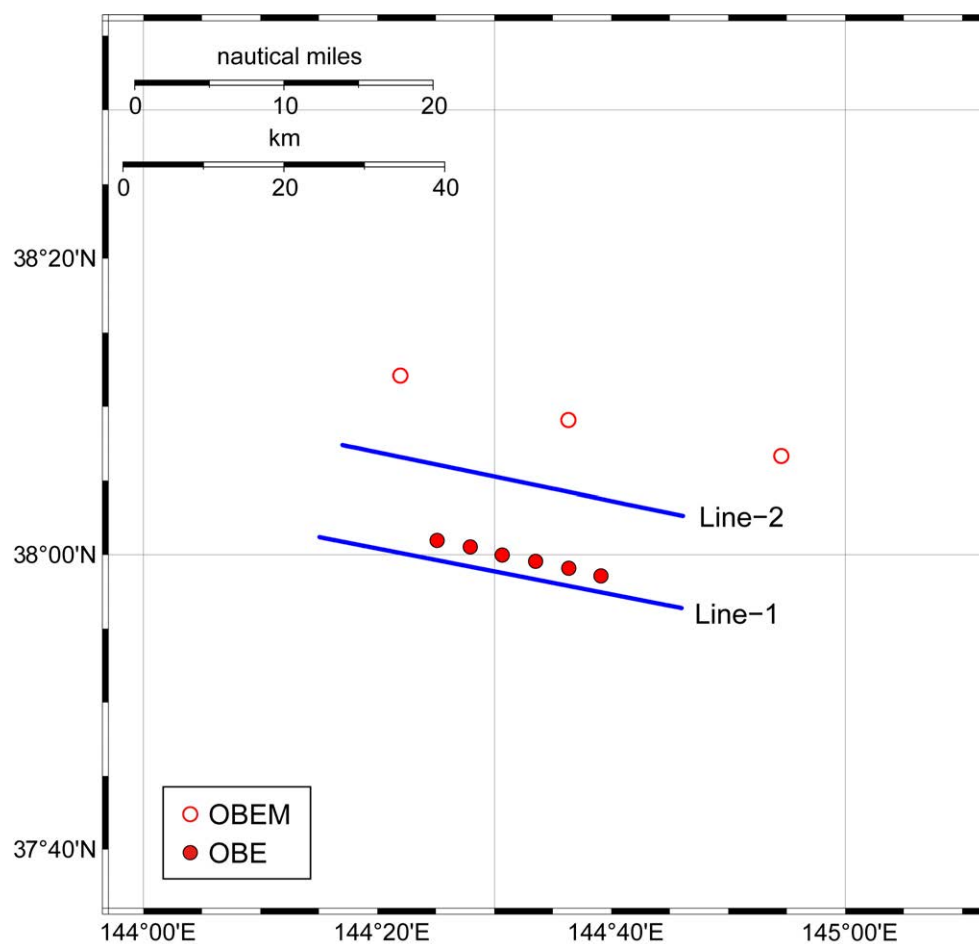
Date	Local Time	Description	Ship position Weather/Wind/Sea condition (Noon@JST)
26-Jun	08:00	Onboard "YOKOSUKA" at JAMSTEC	34-52.5'N, 139-57.5'E
	09:00	"YOKOSUKA" departure from JAMSTEC	Overcast / ENE-4 /
	10:00-10:35	Onboard safety guidance for scientists at No.1 Lab.	3 (Slight)
	16:40-17:00	Konpira ceremony	
27-Jun	09:00	Arrived at research area, off Sanriku	38-12.5'N, 144-21.9'E
	09:07	Release command to OBEM at C40	Overcast / ESE-4 /
	09:43	XBT at 38-12.105'N, 144-21.831'E	3 (Slight)
	13:17	OBEM_C40 on surface	
	13:27	Recovered OBEM_C40	
	13:35-14:30	Shift to next site (C41) from C40	
	14:35	Release command to OBEM at C41	
	17:41	OBEM_C41 on surface	
	17:50	Recovered OBEM_C41	
	19:09	Launched OBE at A4E-6	
	19:25	XBT at 37-58.320'N, 144-38.466'E	
	19:52	Launched OBE at A4E-5	
	20:36	Launched OBE at A4E-4	
	21:34	Launched OBE at A4E-1	
	23:56	Started position calibration for three OBEs (A4E-5, A4E-4, A4E-1)	
28-Jun	01:50	Finished position calibration for three OBEs (A4E-5, A4E-4, A4E-1)	37-59.7'N, 144-32.9'E
	03:45	Release command to OBEM at C42	Overcast / SE-4 /
	06:18	Recovered OBEM_C42	3 (Slight)
	07:49	Launched OBE at A4E-3	
	08:34	Launched OBE at A4E-2	
	10:06-11:33	Position calibration for OBE at A4E-6	
	12:16-14:17	Position calibration for OBE at A4E-3	
	14:37-15:02	Position calibration for OBE at A4E-2	

	17:22	Launched deep-tow CSEM system (Line 1)	
	20:21	Recovered deep-tow CSEM system	
	21:35	Launched deep-tow CSEM system (Line 2)	
29-Jun	07:52	Recovered deep-tow CSEM system	38-01.9'N, 144-19.4'E
	10:18	Launched deep-tow CSEM system (Line 3)	Fine but Cloudy /
			WSW-2 / 2 (Smooth)
30-Jun	02:00	Recovered deep-tow CSEM system	37-58.7'N, 144-36.6'E
	02:54	Launched deep-tow CSEM system (Line 4)	Cloudy / South-4 /
	22:03	Recovered deep-tow CSEM system	3 (Slight)
	22:23	Started MBES mapping	
1-Jul	00:53	Finished MBES mapping	37-59.4'N, 144-36.3'E
	02:03	Release command to OBE at A4E-1	Overcast / SW-4 /
	03:04	Release command to OBE at A4E-2	3 (Slight)
	04:38	Recovered OBE_A4E-1	
	05:31	Recovered OBE_A4E-2	
	06:00	Release command to OBE at A4E-3	
	07:00	Release command to OBE at A4E-4	
	08:34	Recovered OBE_A4E-3	
	09:30	Recovered OBE_A4E-4	
	09:55	Release command to OBE at A4E-5	
	10:55	Release command to OBE at A4E-6	
	12:23	Recovered OBE_A4E-5	
	13:24	Recovered OBE_A4E-6	
	13:37-13:59	Figure of eight running for calibration three component magnetometer	
	14:36-17:00	MBES mapping	
	17:00	Left research area for JAMSTEC	
2-Jul		Shift to JAMSTEC	35-28.6'N, 140-50.4'E
			Cloudy / South-2 /
			1 (Calm)
3-Jul	08:45	Arrived at JAMSTEC, Completed YK17-13	
	10:00	Get off "YOKOSUKA" at JAMSTEC	

7.2. Survey Lines

Bathymetry Survey Lines

Line No.	Start			End		
	Local Time	Latitude	Longitude	Local Time	Latitude	Longitude
1	2017/06/30 22:23	37-56.390'N	144-46.006'E	2017/07/01 00:53	38-01.201'N	144-15.052'E
2	2017/07/01 14:36	38-02.634'N	144-46.143'E	2017/07/01 17:00	38-07.402'N	144-17.011'E

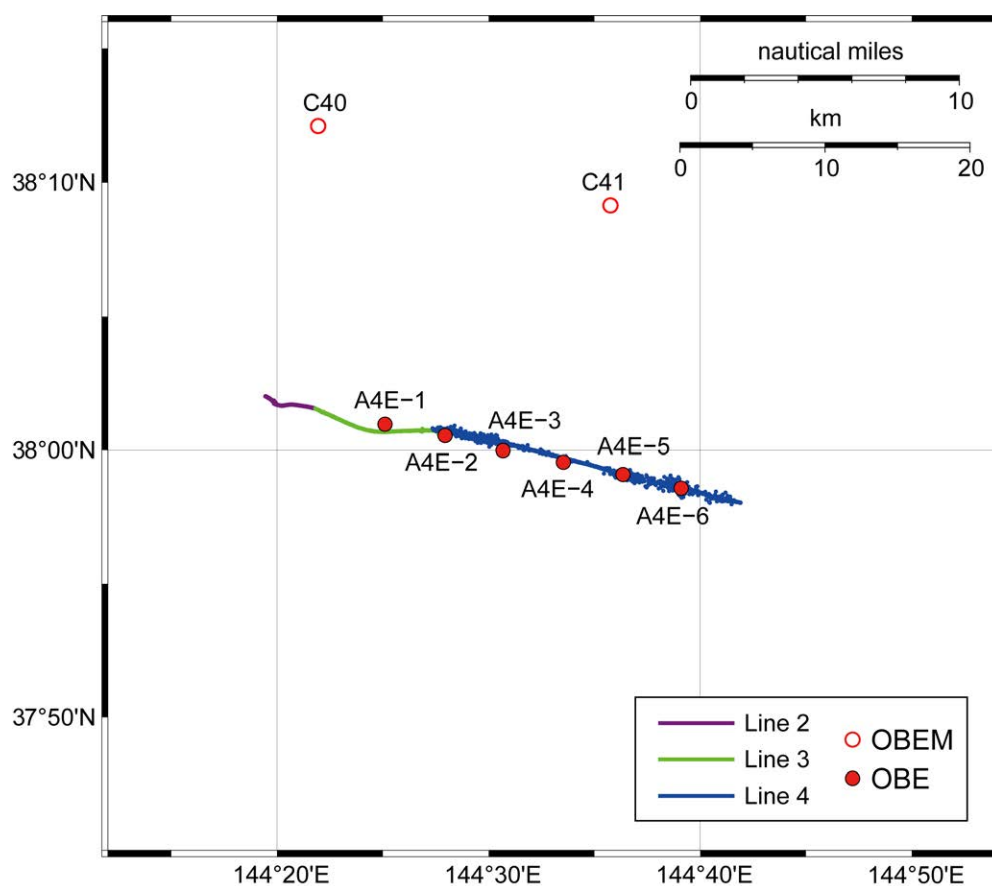


CSEM Survey Lines

Line No.		Local Time	Latitude	Longitude	Depth
1	Start	2017/06/28 17:43	-----	-----	-----
	End	2017/06/28 19:35	-----	-----	-----
2	Start	2017/06/29 01:02	38-02.021'N	144-19.447'E	5,513m
	End	2017/06/29 05:03	38-01.557'N	144-21.805'E	5,506m
3	Start	2017/06/29 16:12	38-01.548'N	144-21.835'E	5,735m
	End	2017/06/29 22:55	-----	-----	-----
4	Start	2017/06/30 05:43	38-00.768'N	144-27.481'E	5,974m
	End	2017/06/30 19:10	37-58.026'N	144-41.916'E	5,509m

Start time is "start survey", End time is "finish survey"

Deep-tow CSEM system did not reach the bottom in Line 1 operation. Start time is "start dive", End time is "start winding up cable".



7.3. R/V YOKOSUKA Crew and YKDT Operation Team

R/V YOKOSUKA Crew

Captain	Eiko UKEKURA
Chief Officer	Hiroyuki KATO
1st Officer	Satoshi SUSAMI
2nd Officer	Toshio OHARA
3rd Officer	Yuki ITO
Chief Engineer	Eiji SAKAGUCHI
1st Engineer	Shinichi IKUTA
Jr. 1st Engineer	Daisuke GIBU
2nd Engineer	Yuji YAMAGUCHI
3rd Engineer	Shohei MIYAZAKI
Jr. 3rd Engineer	Keito SHIMADA
Chief Radio Operator	Yousuke KOMAKI
2nd Radio Operator	Takaaki SHIROZUME
3rd Radio Operator	Ryosuke MATSUI
Jr. 3rd Radio Operator	Youhei SUGIMOTO
Boat Swain	Kaname HIROSAKI
Sailor	Kazumi OGASAWARA
Sailor	Takuya MIYASHITA
Sailor	Takumi MIURA
Sailor	Hiroataka SHIGETA
Sailor	Kaito MURATA
Sailor	Tsuyoshi CHIMOTO
Sailor	Keisuke ISOBE
No.1 Oiler	Yukihiro YAMAGUCHI
Oiler	Toru HIDAKA
Oiler	Toshishige MATSUI
Oiler	Shinya SUGI
Oiler	Shota SHIMOHATA
Oiler	Yuji HIGASHIGAWA
Chief Steward	Sueto SASAKI
Steward	Hideo FUKUMURA

Steward	Tsuyoshi NAGATOMO
Steward	Hironobu HODOKUMA
Steward	Seiya MATSUMOTO
Steward	Kimina ABE

YKDT Operation Team

Submersible Tec. Manager	Toshiaki SAKURAI
1st Submersible Tec. Officer	Mitsuhiro UEKI
2nd Submersible Tec. Officer	Keigo SUZUKI
2nd Submersible Tec. Officer	Yousuke CHIDA
2nd Submersible Tec. Officer	Hirofumi UEKI