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NATSUSHIMA Cruise Report

NT11-17

Yoron Knoll and Irabu Knoll

Nansei Islands, Japan

September 5 to September 10, 2011

Chief Scientist: Tatsuhiro Fukuba

(Institute of Industrial Science, University of Tokyo)

in collaboration with:

International Institute for Carbon-Neutral Energy Research, Kyushu University

Center for Advanced Marine Core Research, Kochi University,

&

Japan Agency for Marin-Earth Science and Technology

(JAMSTEC)

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Preface

This report describes preliminary information on the data taken during NT11-17 cruise by R/V Natsushima with ROV HyperDolphin from September 5 to 10, 2011.

NT11-17 cruise was conducted based on the proposal #S11-67 titled "A study on a hydrothermal plume mapping and a novel hydrothermal ore mine survey by *in situ* multi parameter measurements" (representative: Tatsuhiro Fukuba / University of Tokyo).

Purpose of the cruise is to examine the feasibility of the survey operation based on small-sized multi-parameter *in situ* chemical sensors and analyzers to obtain multi-component mapping data of hydrothermal plumes and to discover new hydrothermal ore deposits accompanied by hydrothermal plume eruptions.

In this cruise, the research works described in the following had been conducted mostly focusing on the hydrothermal activity in the Yoron Knoll and the Irabu Knoll area. We also conducted a survey operation at a caldera-like depression located at western Yoron Knoll area. As a result, any novel hydrothermally active sites were not discovered at the Yoron Knoll area during this cruise. However, we found that hydrothermal sites in the Yoron Knoll are strictly localized at the northeast slope. As a result of detailed study on the Irabu Knoll area, we found that the hydrothermal sites are still alive, and they are totally localized on the top of the knoll as previously reported.

Finally, I would like to thank all the members of the ROV HyperDolphin operation team (Chief: Yoshio Ohno), and the crewmembers of R/V Natsushima (Captain: Yoshiyuki Nakamura) for their dedicated efforts to make this cruise so successful.

September 2011
Tatsuhiro Fukuba (NT11-17 Chief Scientist)

Contents

1. Cruise information

Cruise ID: NT11-17

Name of vessel: R/V Natsushima

Title of the cruise: FY2011 Deep Sea Survey by ROV HyperDolphin in Nansei Islands

Title of the proposal: A study on a hydrothermal plume mapping and a novel hydrothermal ore mine survey by *in situ* multi parameter measurements

Cruise period: 6 days from September 5 to September 10, 2011

Ports of call: dep. Naha, ret. Ishigaki

Research area: Yoron Knoll and Irabu Knoll

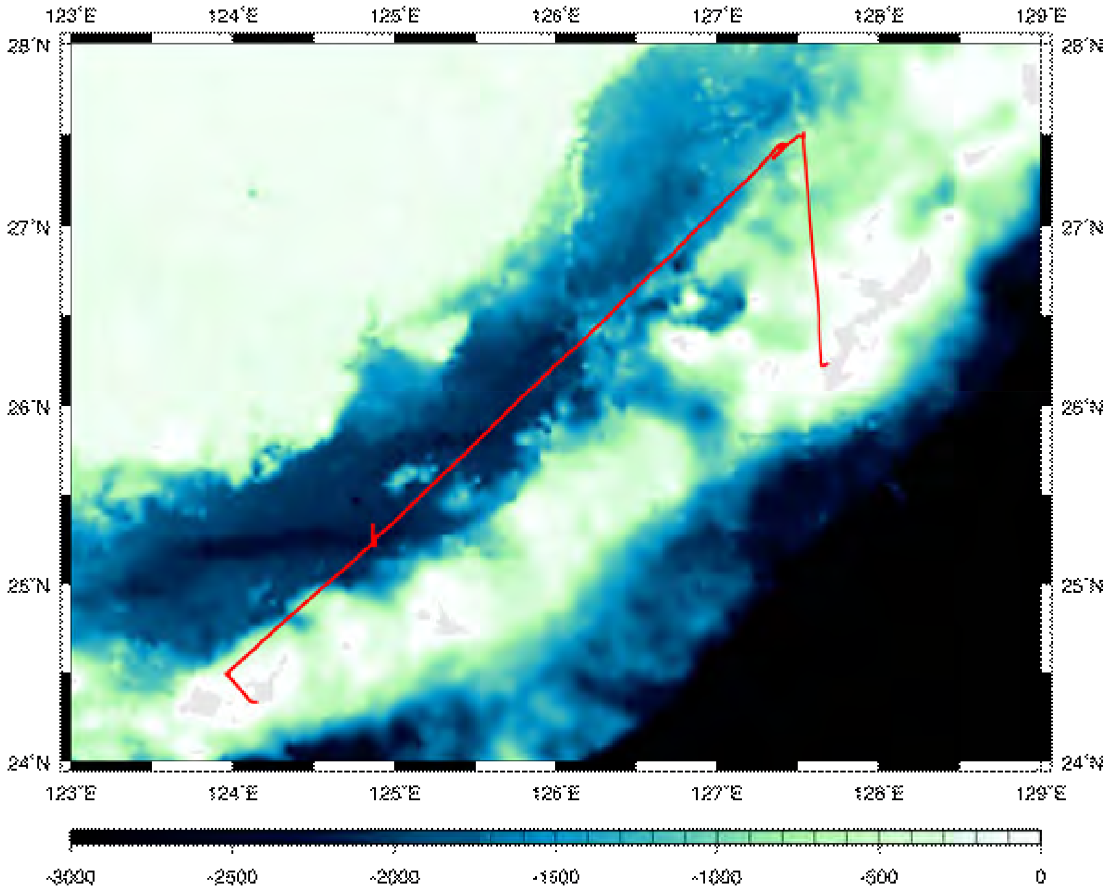


Fig. 1 Ship track of R/V Natsushima during NT11-17 cruise

2. Research map

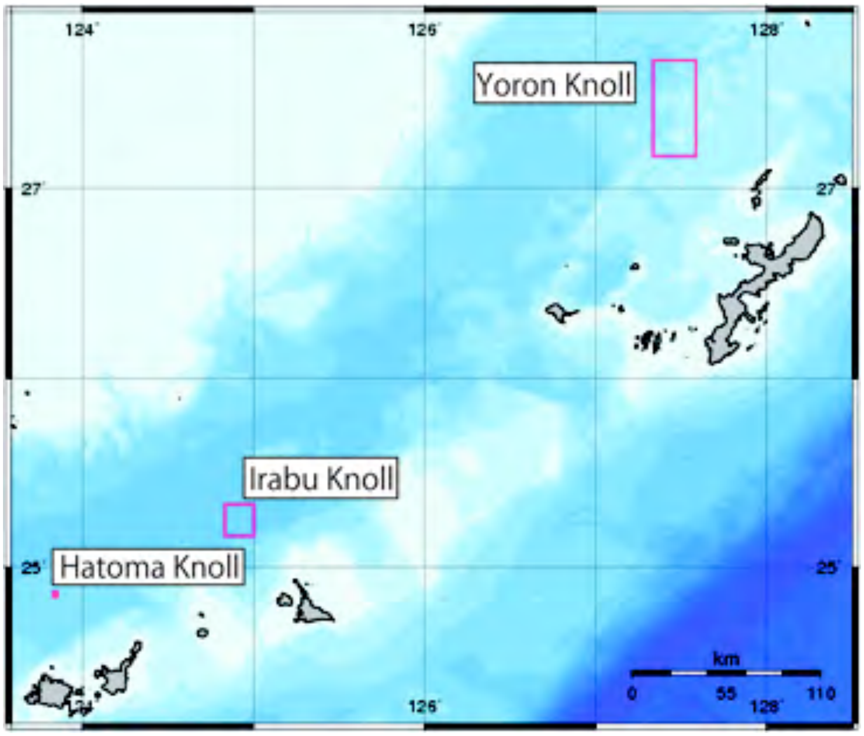


Fig. 2 Location of NT11-17 research area: The Nansei Islands, the Yoron Knoll, the Irabu Knoll, and the Hatoma Knoll. The Hatoma Knoll was defined as an alternative research area for the cruise.

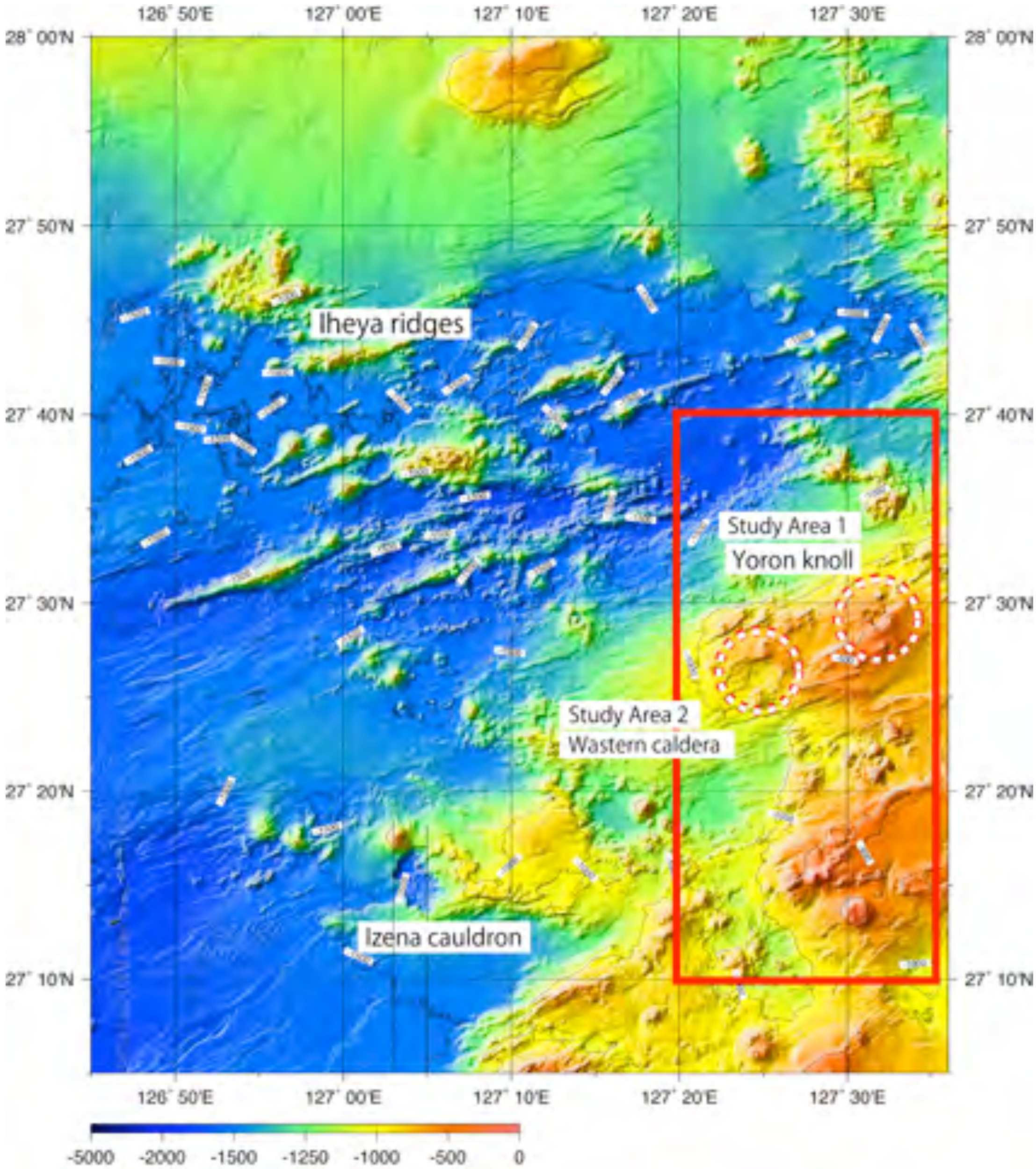


Fig. 3 Bathymetry map of the Iheya ridges, the Izena cauldron, and the Yoron Knoll area. Study area 1: The Yoron Knoll. Study area 2: Western caldera-like depression.

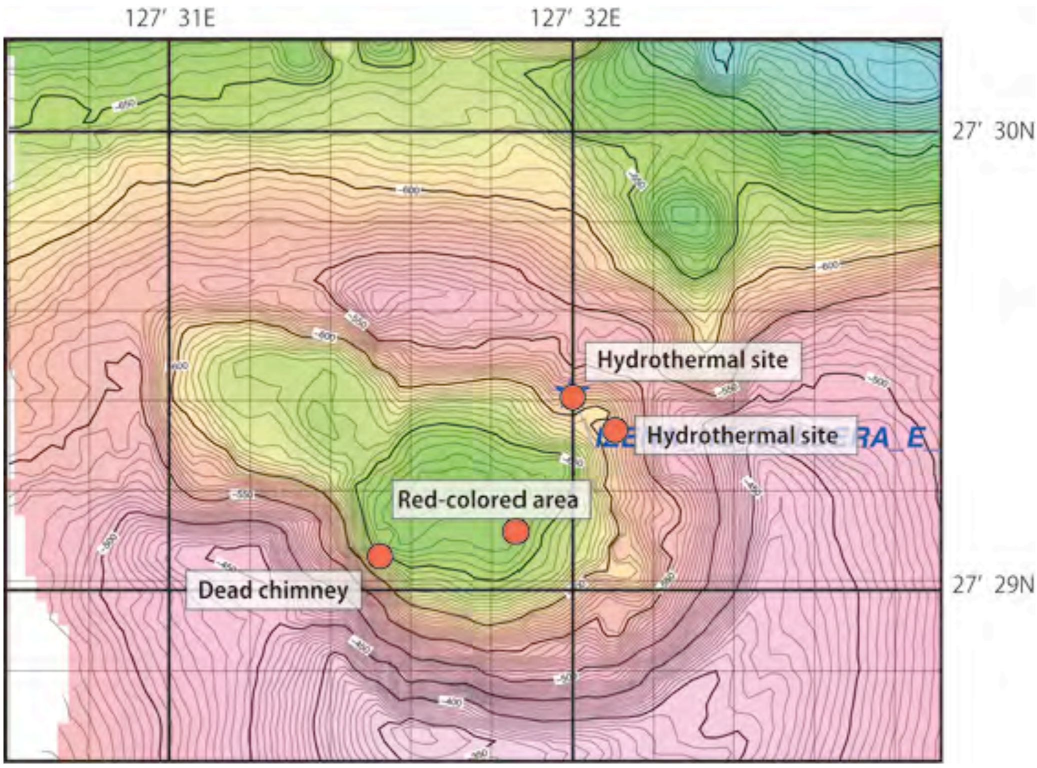


Fig.4 Bathymetry map of the Yoron Knoll (Previously called as the North-East (NE) Izena). Event-marks that were defined during NT10-16 cruise are shown.

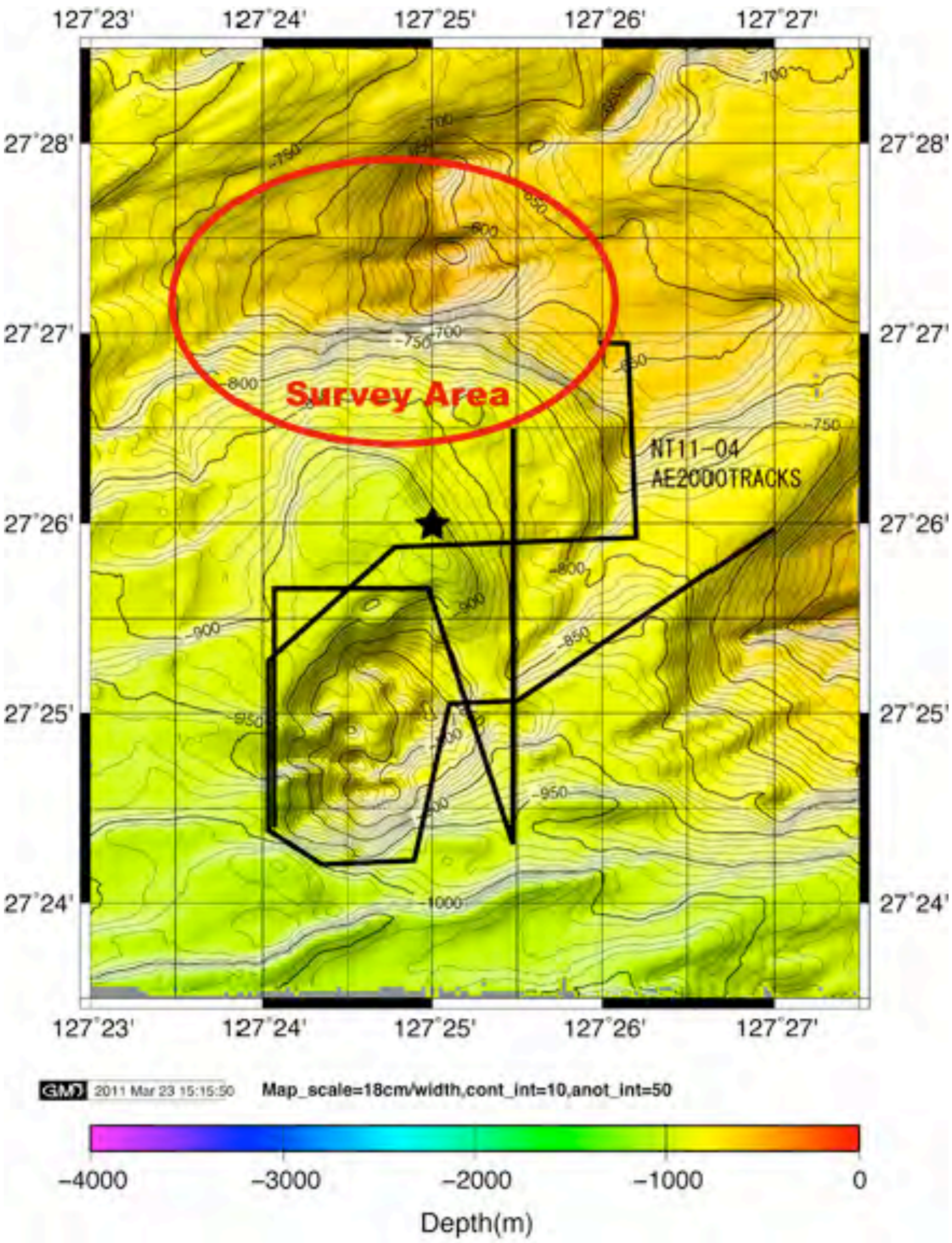


Fig.5 Bathymetry map of caldera-like depression located at western Yoron Knoll. The survey area is shown as a red circle. A track line of an AUV"AE2000" during NT11-04 scientific cruise is shown as a black line.

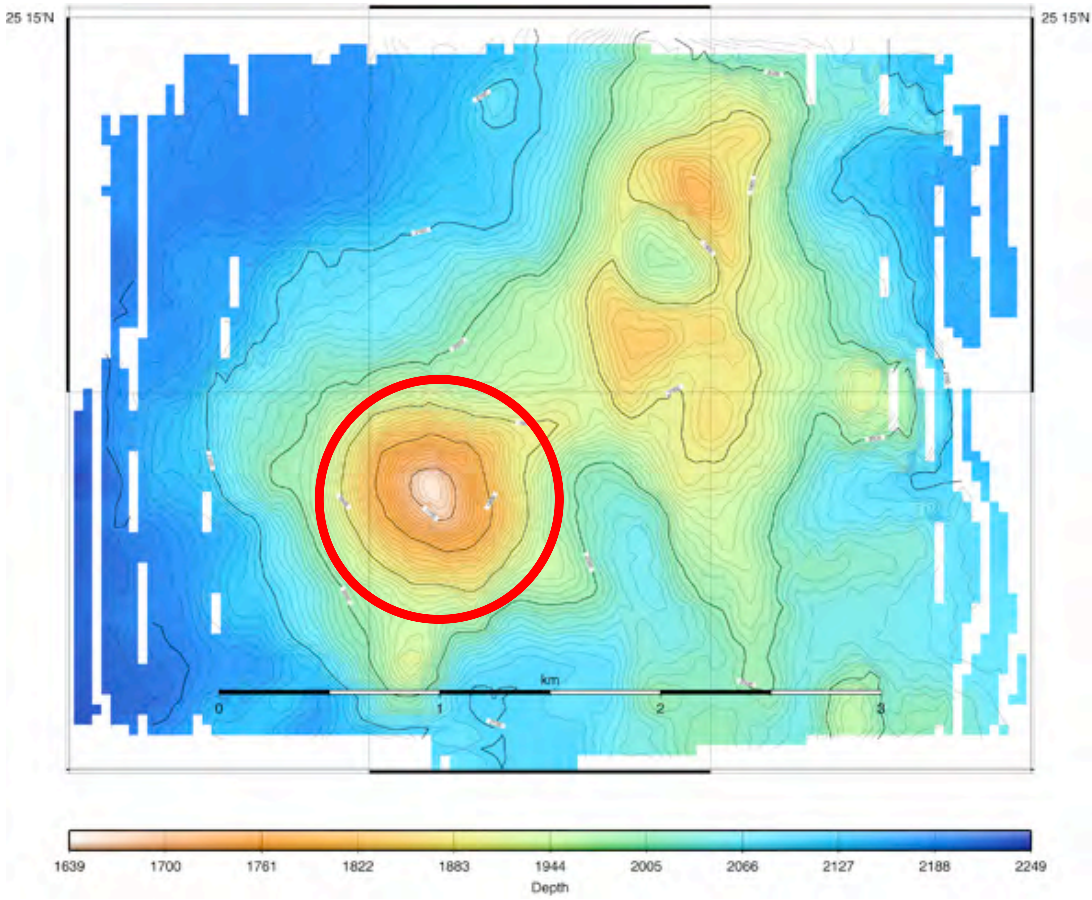


Fig.6 Bathymetry map of the Irabu Knoll. The survey area is shown as a red circle.

3. Researchers

3.1. Chief scientist:

Tatsuhiro Fukuba [IIS, University of Tokyo]

3.2. Representative of the science party

Tatsuhiro Fukuba [IIS, University of Tokyo]

3.3. Science party (*not onboard)

Teruo Fujii	[IIS, University of Tokyo]
Masanori Kyo	[IIS, University of Tokyo]
Christophe Provin	[IIS, University of Tokyo]
Blair Thornton	[IIS, University of Tokyo]
Adrian Bodenmann	[IIS, University of Tokyo]
Katsuo Mogi	[IIS, University of Tokyo]
Michinari Sunamura	[University of Tokyo]*
Takumi Sato	[University of Tokyo]
Tomoko Takahashi	[University of Tokyo]
Kei Okamura	[Kochi University]
Kiminori Shitashima	[I^2CNER, Kyusyu University]
Keigo Kitamura	[I^2CNER, Kyusyu University]
Yoshiaki Maeda	[CERES]

4. Observation

4.1 Introduction

With increasing demands on rare metal materials, hydrothermal ore deposits have been focused as one of the promised novel natural resources today. Hydrothermal ore deposits, which are rich in Cu, Zn, Pb, Au, Ag, and In etc., are formed as result of underwater volcanic activities. Some large-scale ore deposits had been discovered at the Okinawa Trough and the Izu-Ogasawara Arc, and detailed surveys toward practical developments are undergoing. Currently, the major method to survey hydrothermal ore deposits is based on application of acoustic apparatuses such as sub-bottom profilers, multinarrow beam echo sounders, and side-scan sonars. These acoustic apparatus can be equipped on a variety of research vessels and underwater vehicles including ROVs and AUVs for practical survey operations. In addition to such well-established acoustic apparatuses, novel *in situ* chemical sensors or analyzers should be developed to investigate the scale, quality, contents, and activity of hydrothermal ore deposit sites in detail. The key issues to develop the novel chemical sensors or analyzers are their sensitivity and portability. We have developed a series of state of the art electrochemical sensors. Furthermore, an advanced *in situ* chemical analyzer based on a microfluidics technology had been also developed for practical filed applications. Careful assessment of biological activity (or biomass) is also one of the important missions for sustainable development of ore deposits without mortal destruction of local biodiversity. In addition, a combinatorial analysis and visualization of chemical/biological data and graphical data will provides a novel approach for more detailed understanding of a variety of hydrothermal fields.

4.2 Objectives

One of the objectives of this scientific cruise is to carry out real-field evaluations of novel chemical sensors and analyzers developed for hydrothermal ore deposit surveys. For this purpose, we visited the Yoron Knoll (Previously called as the NE-Izena) area in the Okinawa Trough (Fig. 2) where hydrothermal active sites were newly discovered in 2010 (NT10-16). One another important mission in the Yoron Knoll area is to utilize a series of novel sensors and analyzers for practical survey of hydrothermally active sites at calder-like depression structure located at approximately 8 miles west of the Yoron Knoll. We also visited the Irabu Knoll for a hydrothermal plume mapping operation and a detailed survey on the previously discovered hydrothermal sites. Field-tests and feasibility studies of novel imaging tools to capture seabed images and vertical structure profiles are also important objectives of the research to realize combinatorial analyses and visualizations of the data. Collection of filed samples such as seawater and rock is also an important mission in this study to perform microbiological and petrologic analyses.

4.3 *In situ* analyzer and sensors

4.3.1 Mn ion quantitative determination using an IISA-Mn

Manganese ion (Mn^{2+}) in seawater can be utilized as a useful marker element for hydrothermal activity survey operations because of its specificity. The major and reliable method for a highly sensitive and quantitative determination of Mn^{2+} is an *in situ* FIA (flow injection analysis) or CFA (continuous flow analysis) utilizing a luminol based chemiluminescence reaction. We have developed an IISA (Integrated *In Situ* Analyzer) –Mn (Fig. 7) for the purpose of Mn^{2+} CFA for hydrothermal activity survey. The most important characteristic of IISA-Mn is utilization of a "microfluidic device" (Fig. 8) as its core analytical element. By applying the microfluidic device and a micro pumping unit, a functionally integrated and highly miniaturized CFA apparatus was realized. In this cruise, IISA-Mn was mounted on the HPD for all dives to evaluating the system and for the practical operations to detect Mn^{2+} concentration anomalies. An ISFET-based pH sensor (IIS, Univ. of Tokyo, see section 4.3.4) and a standalone temperature recorder (Starmon mini, STAR ODDI, Iceland) were operated together to monitor pH and temperature anomalies of seawater sample analyzed by IISA-Mn *in situ*. The system was calibrated in situ using Mn^{2+} standard solutions before and after the survey operation. Chemiluminescence intensity data was monitored in real-time using a laptop PC and the data was recorded every 1 sec.

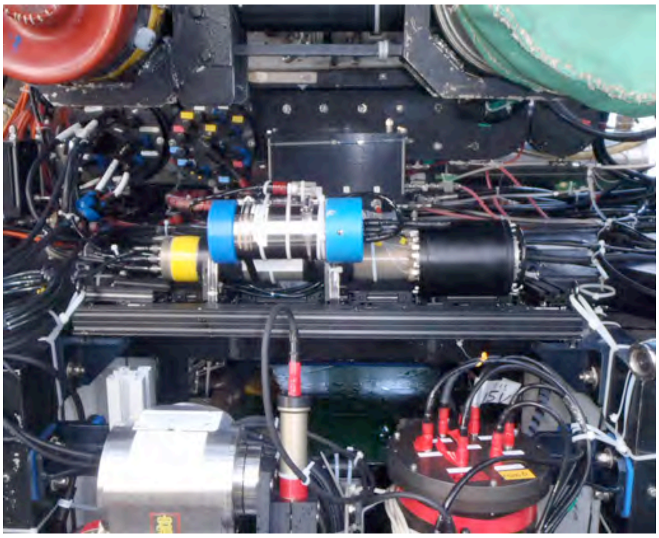


Fig. 7 IISA-Mn with the ISFET pH sensor and temperature recorder

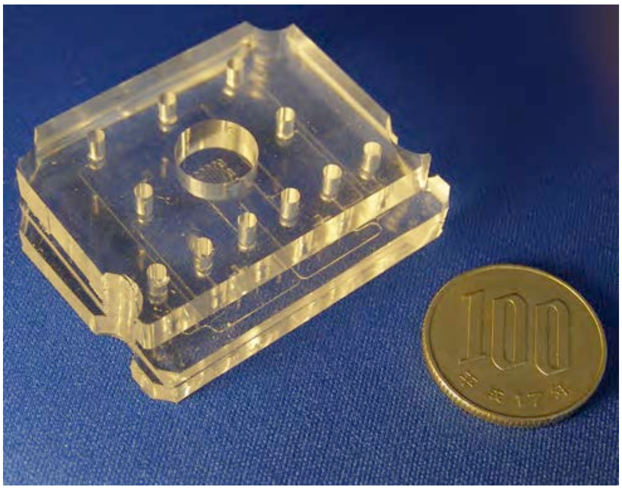


Fig. 8 Microfluidic device for IISA-Mn

4.3.2 Multi parameter chemical sensing

A real-time monitoring of conductivity, temperature, depth and turbidity using CTDT profiler (Fig. 9) was carried out in all dives. A real-time monitoring and offline measurement of pH/pCO_2 (partial pressure of CO_2)/ORP (oxidation-reduction potential) sensor (Figs. 9 and 10) was also conducted in all dives. The pH/pCO_2 sensor used a non-glass type pH electrode, ion-sensitive field-effect transistor (ISFET), and the ORP sensor employed Pt wire as a working electrode. These sensors applied a chloride ion selective electrode (Cl-ISE) as the reference electrode. In the pCO_2 sensor, both the ISFET-pH electrode and the Cl-ISE of the pH sensor are sealed in a unit with a gas permeable membrane (Teflon AF™) whose inside is filled with inner electrolyte solution with 1.5 % of NaCl. The pH sensor can detect pCO_2 change as inner solution pH change caused by permeation of carbon dioxide gas species through the membrane.

Fig. 9 Multi chemical sensor (off-line type) and the CTDT

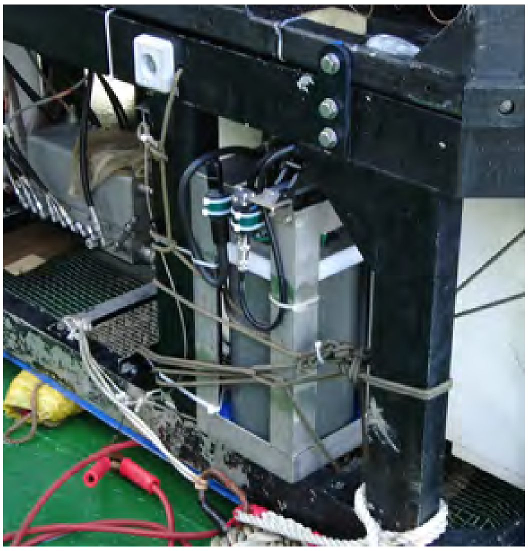


Fig. 10 Multi chemical sensor (real-time monitoring type)

4.3.3 H_2S determination using an electrochemical sensor “TANSAKUN”

In situ H_2S quantitative determination was conducted using an electrochemical sensor “TANSAKUN” (Fig. 11) mounted on HPD. H_2S was measured by a linear-sweep voltammetry using an Ag electrode. H_2S in surrounding water was concentrated on the Ag-electrode on TANSAKUN at -0.3 V v.s. an Ag/AgCl electrode for 10 seconds. Then, the concentrated H_2S was released by sweeping the voltage down to -1.3 V v.s. the Ag/AgCl electrode for 1 second. The electric current during the removal stage is correlated with the concentration of H_2S. H_2S concentration was calculated from the electric currents. The electric currents and the calculated H_2S concentration data were stored in a data logger inside a pressure housing.

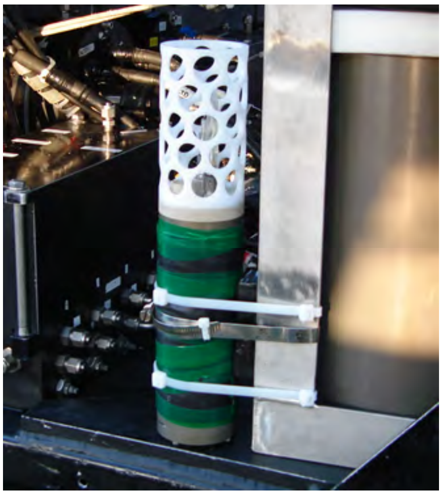


Fig. 11 TANSAKUN for H_2S measurement

4.3.4 pH measurement using ISFET pH sensors

ISFET (Ion-Sensitive Field-Effect Transistor) based pH sensors (Fig. 12) were used to detect low-pH anomalies in hydrothermal active areas. Three standalone pH sensors (CRIEPI, JAMSTEC, and Tokyo Univ.) were mounted on the ROV Hyper Dolphin (HPD) for all dives. One of the pH sensors was bundled with IISA-Mn. Two pH sensors were mounted at left and right front end of the HPD, respectively (Fig. 13). All of the pH sensors were calibrated onboard before and after the deployments using pH standard solutions (Amp, Tris) that were kept at 30 ˚C.

Fig. 12 ISFET pH sensor

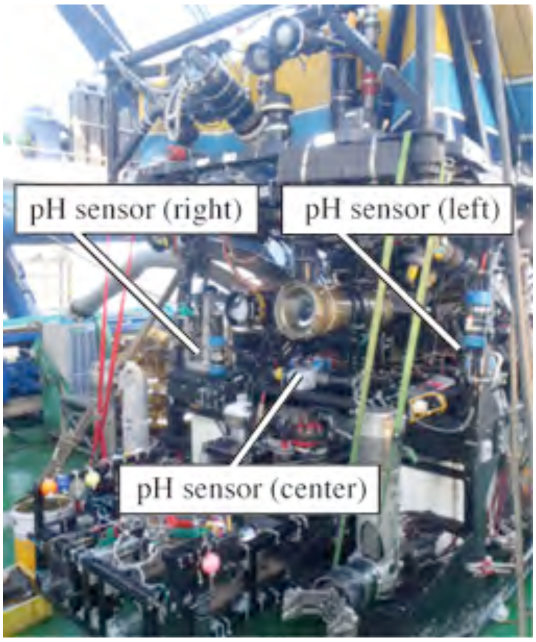


Fig. 13 ISFET pH sensors mounted on the HPD

4.3.5 Radioactivity mapping using an Rn sensor

In-situ Rn (gamma rays) sensor using plastic scintillator was installed to the HPD for all dives (Fig. 14). A plastic scintillator is made from polystyrene that doped scintillator such as NaI(Tl) and it absorbs radon like as liquid or crystal scintillator. The Rn sensor consisted of plastic scintillator that was painted with light-resistant paint, photomultiplier tube, preamplifier unit, high-voltage power supply, data logger and lithium-ion battery, and all parts were stored in a pressure case.

Fig. 14 Rn sensor

4.3.6 Local current measurement using ADCP

An ADCP (Acoustic Doppler Current Profiler) was employed for the observations of local current to understand dynamics of hydrothermal plumes. The ADCP (Fig. 15) was employed during dive #1318 and 1321. The measurements were conducted every 1 min with vertical resolution of 2 m.

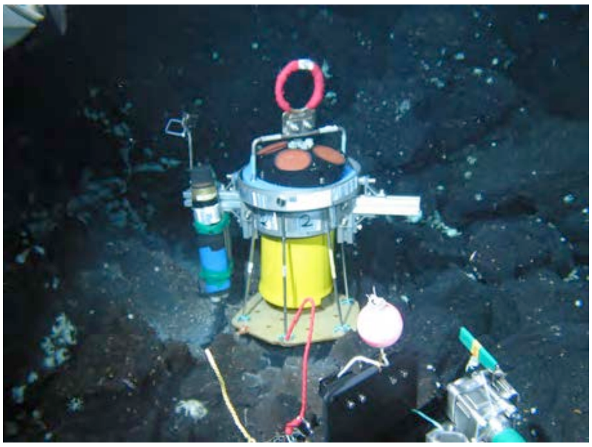


Fig. 15 ADCP with a transponder placed on the seabed (dive #1321)

4.4 Sample collections and onboard microbiological analysis

All water samples were collected by using Niskin water samplers and syringe water samplers (Tokyo Univ.) (Fig. 16). Collected water samples were immediately transferred to clean plastic tubes aseptically after each dive. Portions of samples were used for ATP content measurement assay. Particulate (microbial intracellular) ATP was quantitatively determined onboard using the collected water samples. 10 ml of seawater sample was filtrated using a polycarbonate membrane filter (Isopore™, Millipore, 0.22 μm pore size, 25 mm diameter) to capture microbial cells on the filter immediately after the sample retrieval. 3 filters were prepared for each water sample to perform the measurements in triplicate. A luciferin-luciferase based ATP quantitative determination reagent kit (ChekLite™ HS Kit (Kikkoman, Japan)) and desktop bioluminescence intensity measurement apparatus (Lumitester C-110, Kikkoman, Japan) was used for the assay. The ChekLite™ HS kit and Lumitester C-110 were used as shown in instruction manual. All bioluminescence measurements were performed 3 times to obtain average value.

1L of Niskin water samples were filtrated using a Sterivex™ filter unit (Millipore, 0.22 μm pore size) and a peristaltic pump. The filter units containing microbial cell archives were stored in -20˚C for the detailed molecular biological analysis.

All of the water samples collected using the glass syringe water samplers were stored in plastic bottle in 4 ˚C for detailed chemical analysis (e.g. Mn and Fe concentration measurements)

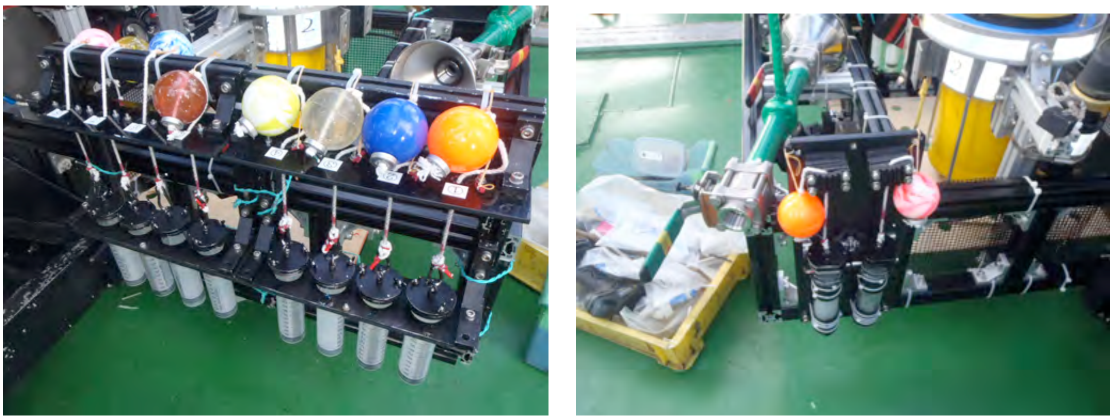


Fig. 16 Plastic syringe water samplers (left) and glass syringe sampler (right)

4.5 Seafloor mapping operation using the ROV

4.5.1 3D seafloor image mapping using "SeaXerocks"

"SeaXerocks" (Fig. 17) is an automated apparatus to acquire seafloor images and ruggedness information simultaneously in situ for creating 3D model map of the seafloor. A vertically mounted sheet laser projects a line on the seafloor, making a 90° angle with the forward moving direction of the ROV, and an LED panel illuminates the area in front of that line. A camera mounted a certain distance in front of the laser and LED panel records continuous images of the seafloor as the ROV moves forward. The camera's mounting angle is adjusted so that its field of view contains the illuminated area of seafloor and extends up to the laser line projection. Throughout the dive position and orientation data supplied by a DVL and depth sensor is recorded.

A similar method is used, with the difference that the ROV stands still during the scan and an actuated sheet laser is used to scan the hydrothermal chimney.

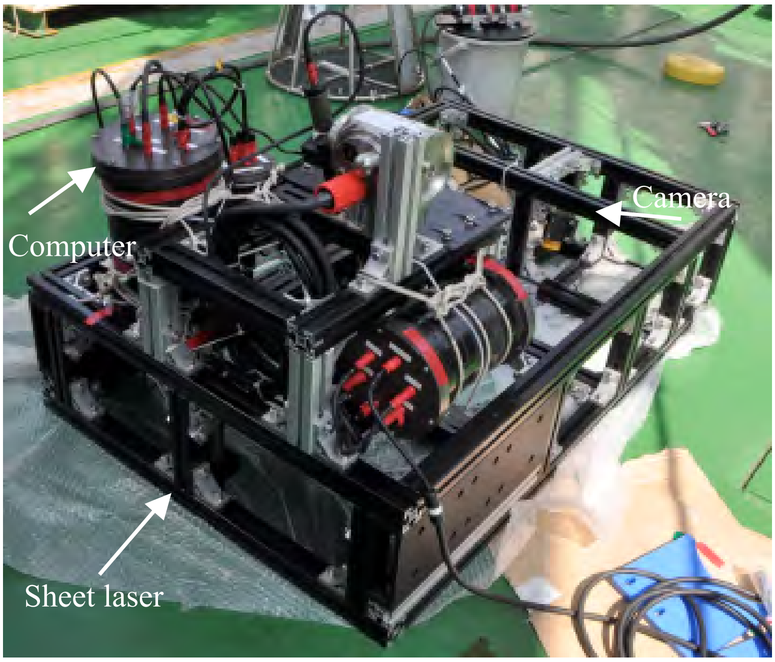


Fig. 17 Sample basket with the devices for mapping of the seafloor attached

4.6 Sampling of rocks and analysis

Series of rock samples including 1) Dead chimneys, 2) Active chimneys, and 3) cap rocks were collected utilizing manipulators of HPD during all dive operations. All rock samples will be analyzed on its elemental composition in laboratory afterwards. All samples were stored for further analysis and sample archival after photographing and radioactivity testing onboard.

4.7 Seafloor mapping operation

Prior to dive #1320 and 1321, seafloor-mapping operations were conducted using MBES (Multi Beam Echosounder) equipped on R/V Natsushima.

5. Preliminary research results

5.1 Result of *in situ* analyzer and sensors operation

5.1.1 Mn ion quantitative determination

IISA-Mn was operated for all 4 dives conducted during this cruise. During dive #1318 to explore the Yoron Knoll, IISA-Mn had a trouble on a valve system, and any meaningful data about Mn concentration anomaly was not obtained. During the next dive (#1319) at the western caldera like depression, faint increases of chemiluminescence intensity signals correspond to Mn concentration anomalies were observed near sea bottom with black/orange-discolored cracks. For the dive #1320 and #1321 conducted at the Irabu Knoll, clear increases of chemiluminescence intensity were observed when HPD approached to active hydrothermal sites at top of the knoll (Fig. 18). On the other hand, when the HPD moved away from the hydrothermal sites, the chemiluminescence signals were fallen down to the background level immediately. In addition, system calibration was successfully performed for all dives by using Mn standard solutions *in situ*. Here, we could successfully certify functionality of IISA-Mn in real deep-sea environment.

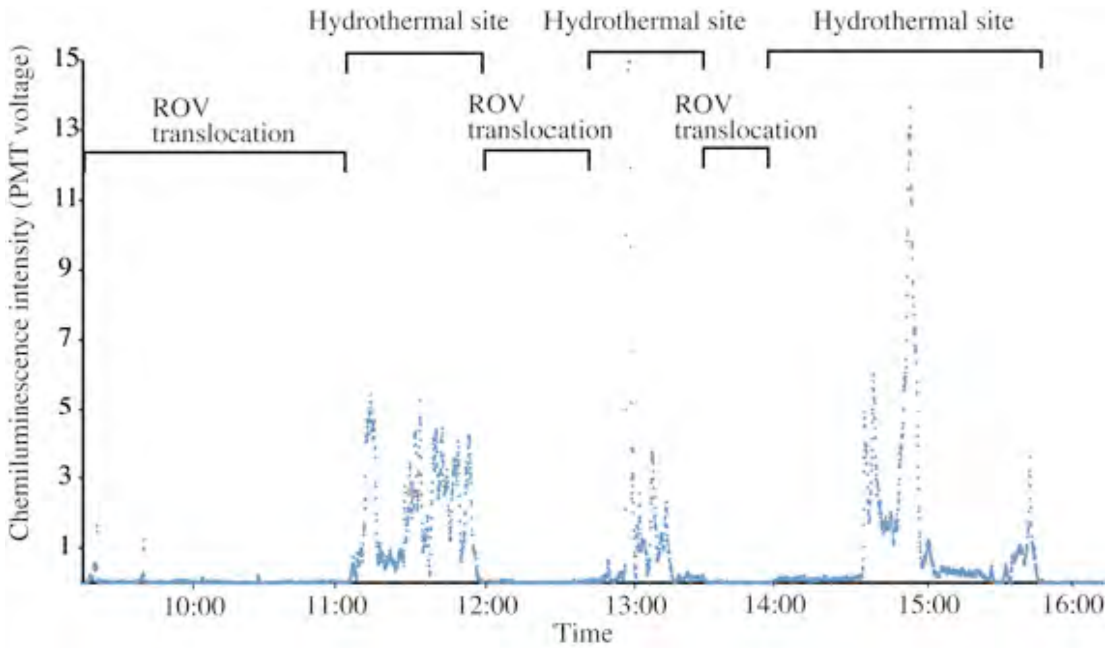


Fig. 18 Chemiluminescence intensity (corresponds to the Mn concentration) anomalies observed during the Dive #1320.

5.1.2 Multi parameter chemical sensing

Real-time monitoring of conductivity, temperature, depth, turbidity, and pH/pCO_2/ORP was carried out using the CTDT profiler and chemical sensors. The sensors detected anomalies of these parameters when the HPD approached to hydrothermal sites except for dive #1319 conducted at western Yoron Knoll. The results of in-situ measurement of pH, pCO_2, and ORP at dive #1320 are shown in Figure 19.

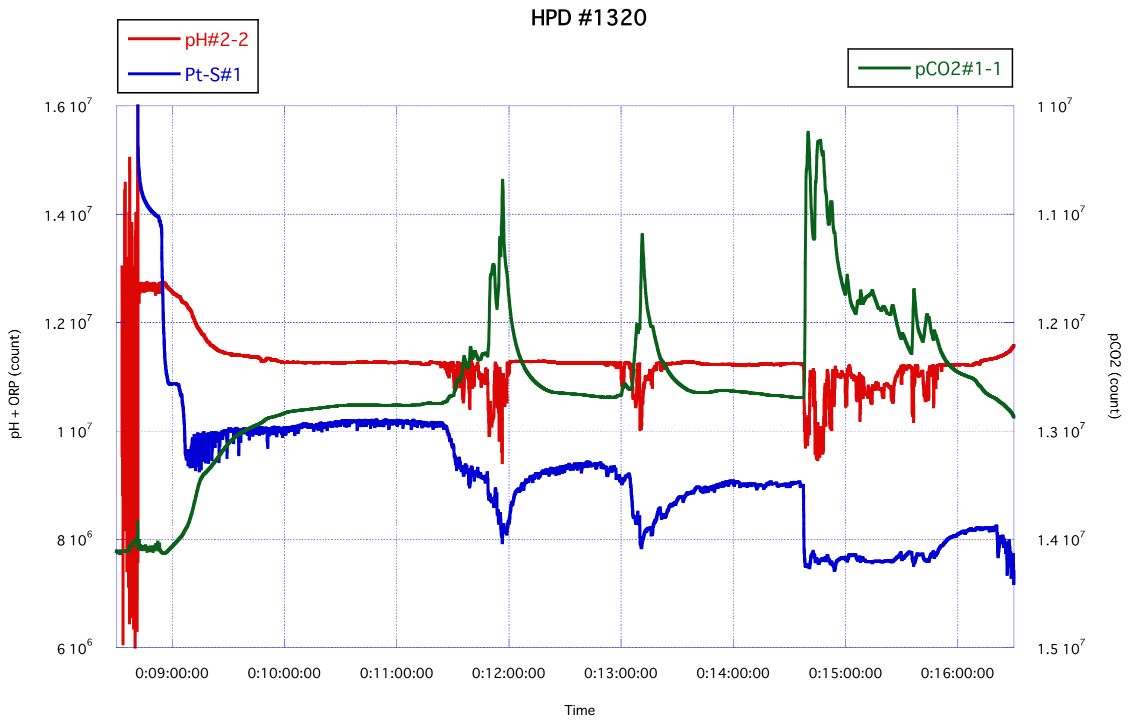


Fig. 19 *In-situ* time variation of pH, pCO2 and ORP on dive #1320

5.1.3 H_2S quantitative determination

TANSAKUN was operated for all 4 dives conducted during this cruise. During dive #1318 to explore the Yoron Knoll, TANSAKUN had a trouble on a data logging system, and no data was obtained. During the next dive (#1319) at the western caldera like depression, small increase around the detection limit (< 2μmol/L) of H_2S were observed near sea bottom. For the dive #1320 and #1321 conducted at the Irabu Knoll, clear increases of H_2S intensity were observed when HPD approached to active hydrothermal sites at top of the knoll (Fig. 20). In conclusion, H_2S measurement by TANSAKUN was conducted successfully.

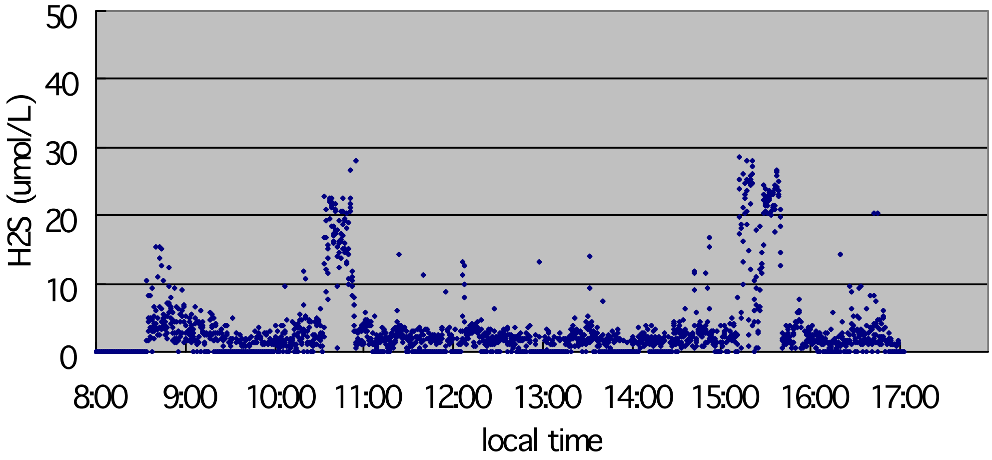


Fig. 20 H_2S Concentrations during dive #1321

5.1.4 pH measurement using ISFET pH sensors

Three ISFET pH sensors were mounted to the HPD for all dives and in situ pH data were successfully obtained. Low-pH anomalies were detected during HPD dive #1318, #1320, and #1321. Fig. 21 shows results of the dive #1320 at the Irabu Knoll using ISFET pH sensor. When the HPD approached to active hydrothermal sites at the top of the knoll, apparent low-pH anomalies were observed. The lowest pH recorded during this dive was approximately 6.1. On the other hand, no pH anomaly was observed during dive #1319 conducted at the western caldera like depression. It implies absence of active hydrothermal sites at the survey area.

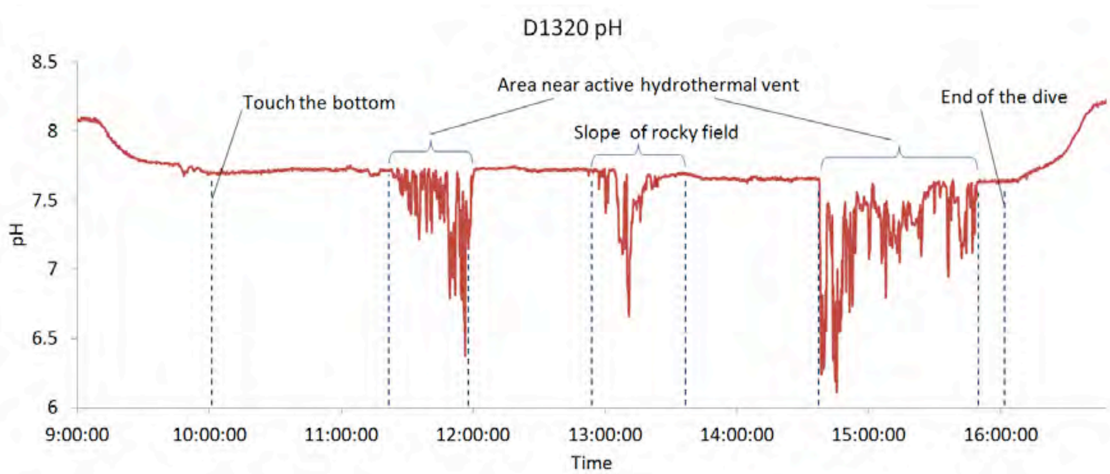


Fig. 21 Result of *in-situ* pH measurement using ISFET pH sensor during dive #1320

5.1.5 Radioactivity mapping

As a result, the sensor was able to detect small Rn anomalies during dive #1318 and 1321. The Rn sensor had a problem on dive #1320 and data was not obtained. No radioactivity anomalies were detected during dive #1319.

5.1.6 Local current measurement using ADCP

As a result of the measurement at Yoron knoll, a local current data at depth of 500 to 600 m was successfully obtained as shown in Table 1. The result shows that east to south current predominated at the depth less than 530 m, and NW to SW current predominated at deeper layer.

For Irabu knoll, a local current data at the depth of 1600 to 1650 m was successfully obtained as shown in Table 2. Because of absent of traceable particulate matters for the acoustic Doppler measurements, current data at the depth less than 1600 was not obtained. As a result, predominance of NNW to NNE current was measured in 1610 to 1650 m layer.

Table 1 #1318 dive ADCP preliminary data

Depth	N-S component (mm/s)		E-W component (mm/s)		Up component (mm/s)		Vector(mm/s)		Temperature	
mean	Average	RMS	Average	RMS	Average	RMS	mean	flow	mean	STD
(m)	mm/sec	mm/sec	mm/sec	mm/sec	mm/sec	mm/sec	mm/sec	deg	°C	°C
500	-36.739	58.134	8.38	43.46	5.84	15.23	37.68	167.2		
510	-31.894	57.640	34.35	78.89	4.67	26.47	46.88	132.9		
520	-16.051	41.859	37.58	51.33	1.45	10.05	40.87	113.1		
530	-0.551	29.030	8.30	36.68	1.32	9.45	8.32	93.8		
540	1.314	30.774	-17.15	39.45	1.90	14.79	17.20	274.4		
550	1.640	41.167	-27.52	46.68	1.97	13.82	27.57	273.4		
560	16.185	54.464	-28.37	51.36	-0.10	14.77	32.67	299.7		
570	24.358	52.916	-22.07	44.83	-0.54	10.51	32.87	317.8		
580	20.628	35.555	-8.07	29.60	-0.78	9.36	22.15	338.6		
590	-3.103	30.555	-7.60	35.94	-0.57	8.82	8.21	247.8		
600	11.440	43.742	-4.42	31.50	-96.71	98.45	12.26	338.9		
	Position	Latitude 27-29.394N		Longtide 127-31.997E			Depth:605m		10.28	0.20
	2011/9/6 10:00-15:40									

Table 2 #1321 dive ADCP preliminary data

Depth	N-S component (mm/s)		E-W component (mm/s)		Up component (mm/s)		Vector(mm/s)	Temperature		
mean	Average	RMS	Average	RMS	Average	RMS	mean	flow	mean	STD
(m)	mm/sec	mm/sec	mm/sec	mm/sec	mm/sec	mm/sec	mm/sec	deg	°C	°C
1610	154.504	548.892	-73.14	361.31	-31.72	220.11	170.94	334.7		
1620	108.475	133.087	12.92	61.92	3.05	24.93	109.24	6.8		
1630	89.696	106.448	11.54	58.93	12.61	32.88	90.43	7.3		
1640	29.315	52.642	-62.53	76.19	44.22	48.85	69.06	295.1		
1650	17.413	32.922	-24.47	40.42	27.05	30.86	30.04	305.4		
	Position	Latitude 25-13.764N		Longtide 124-52.194E			Depth:1654m		4.07	0.12
	2011/9/9 11:05-15:40									

5.2 Result of onboard microbiological analysis

5.2.1 Microbial ATP content

Total ATP contents were successfully measured onboard by using the luciferin-luciferase assay. Preliminary results from #1320 samples are shown in Table 1. Total ATP concentrations were around 0.3 to 1.5 pM for most of samples except for the samples from Niskin water samplers. Samples exclude 1320-C4(S) was collected near active hydrothermal vent. Sample 1320-C7(S) collected near the hydrothermal site with high turbidity showed apparently low ATP concentration compare to the other samples. It implies that the hydrothermal plume observed there with relatively higher turbidity than the other plumes has lower microbial activity or biomass. Detailed analysis of such differences will reveal interactions between geochemical properties and local ecosystems. 1320-C3, C4, C6 and C8 showed almost same level of ATP concentration. Sample 1320-C3(S) and 1320-NR were collected at the same location using syringe water sampler and Niskin water sampler, respectively. However, the 1320-NR showed apparently higher ATP value than 1320-C3(S) collected by using the syringe water sampler. ATP content measurements results during the other dives in this cruise showed same tendency (data not shown here). This fact implies that there is possibility of contaminations on Niskin water samplers.

Table 3. Preliminary result of ATP quantification (#1320 dive)

Sample No. N:Niskin S:Syringe	ATP concentration (pmol/L)	SD	Comment
1320-C3(S)	1.5	±0.4	Sampling point was the same as that of 1320-NR.
1320-C4(S)	1.3	±0.3	There was rocky field.
1320-C6(S)	1.1	±0.4	Near a hydrothermal site
1320-C7(S)	0.3	±0.1	Near a hydrothermal site, high turbidity.
1320-C8(S)	0.7	±0.3	Sampling point was the same as that of 1320-NY.
1320-NR(N)	6.4	±2.4	Sampling point is the same as that of 1320-C3.
1320-NY(N)	N/D	N/D	Data was not obtained. (Sample lost)

5.3 Seafloor mapping operation using the ROV

5.3.1 3D seafloor image mapping using "SeaXerocks"

During all the dives, 3 dimensional seafloor image data was obtained using a prototype mapping device "SeaXerocks" (Tokyo Univ., Fig. 17), mounted on the ROV. Measurements were made from an altitude of 2 to 3m off the seafloor, and the obtained data will be processed to generate 3D color reconstructions of the surveyed areas. This data will be assessed to determine the dimensions of visible hydrothermal anomalies on the seafloor.

After the dive, the data is copied and processed by an algorithm to reconstruct the scanned seafloor in color in 3D. First the laser line is extracted, which allows to calculated the bathymetry, then color is matched to each bathymetry point from a frame showing that area illuminated by the LED panel.

Figure 22 shows a reconstructed patch of seafloor from the NT11-17 cruise. It provides accurate information about the terrain and sizes of rocks. The red discoloration indicates that it is a potentially interesting area for further investigation.

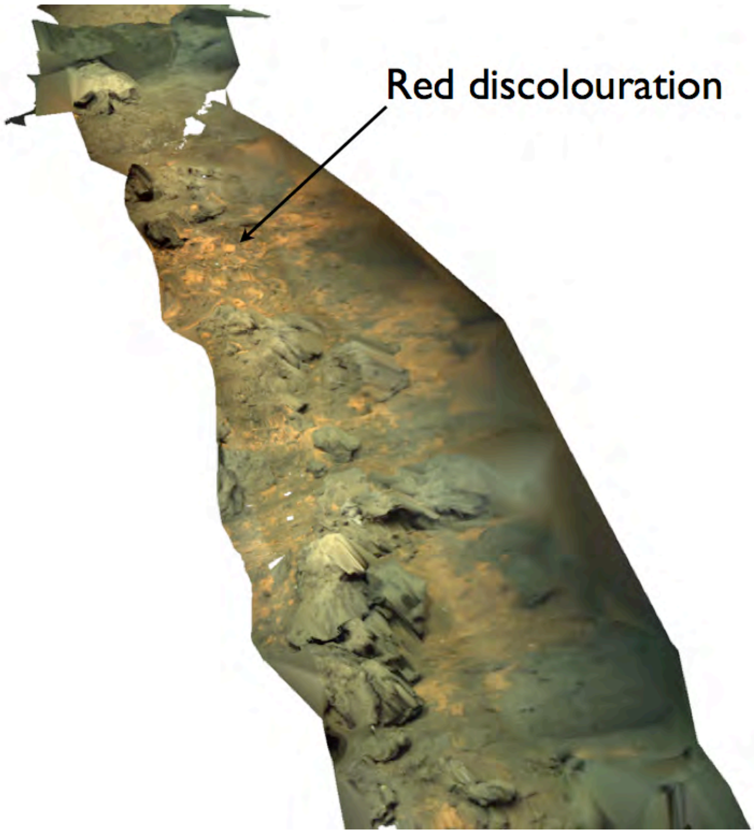


Fig. 22 3D reconstruction of a patch of seafloor generated from data recorded with the "seaXerocks" mapping device

The ROV rests in front of a chimney during the scan and a camera records images continuously, while the sheet laser angle is saved for each frame. The light sectioning method is used in post processing to reconstruct the shape of the chimney accurately. Data from dive #1318 is currently processed.

5.4 Seafloor mapping operation

Result of the seafloor mapping using the MBES is shown in Fig. 23. A 3D bathymetry image of the Irabu Knoll area was drawn by using Surfer 10 software (Golden Co., USA) (Fig. 24). A northern complex of knolls and a caldera-like depression, and the western knolls are clearly visualized.

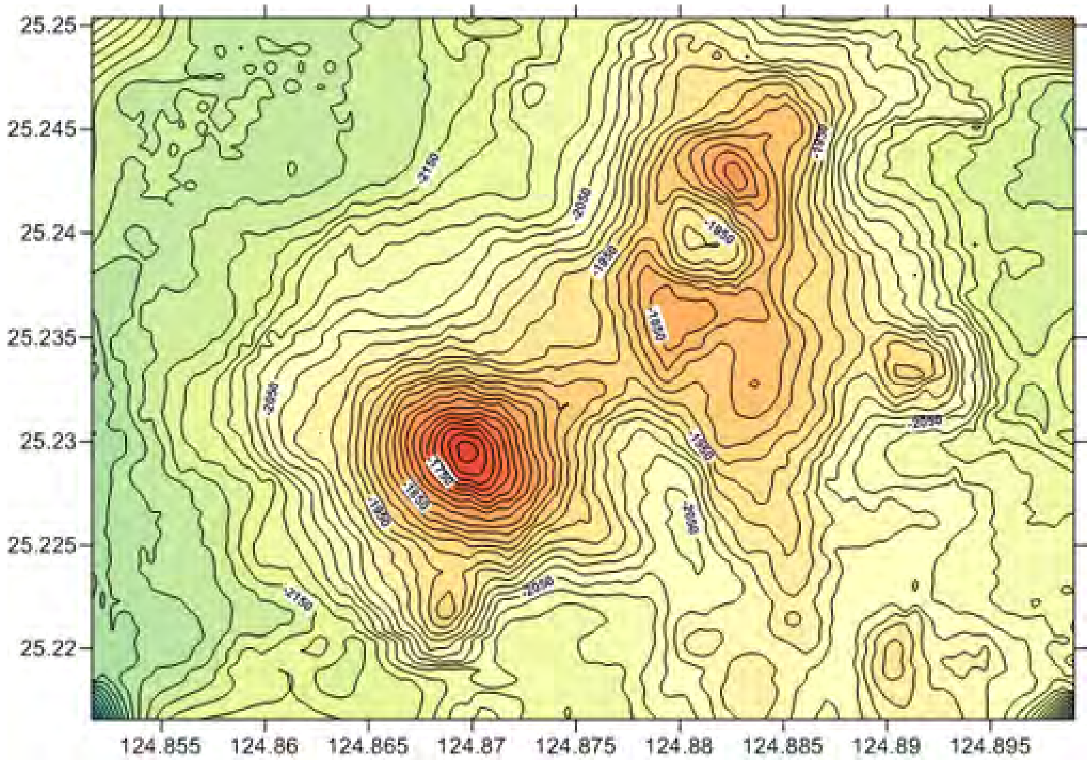


Fig. 23 Bathymetry map of the Irabu Knoll area

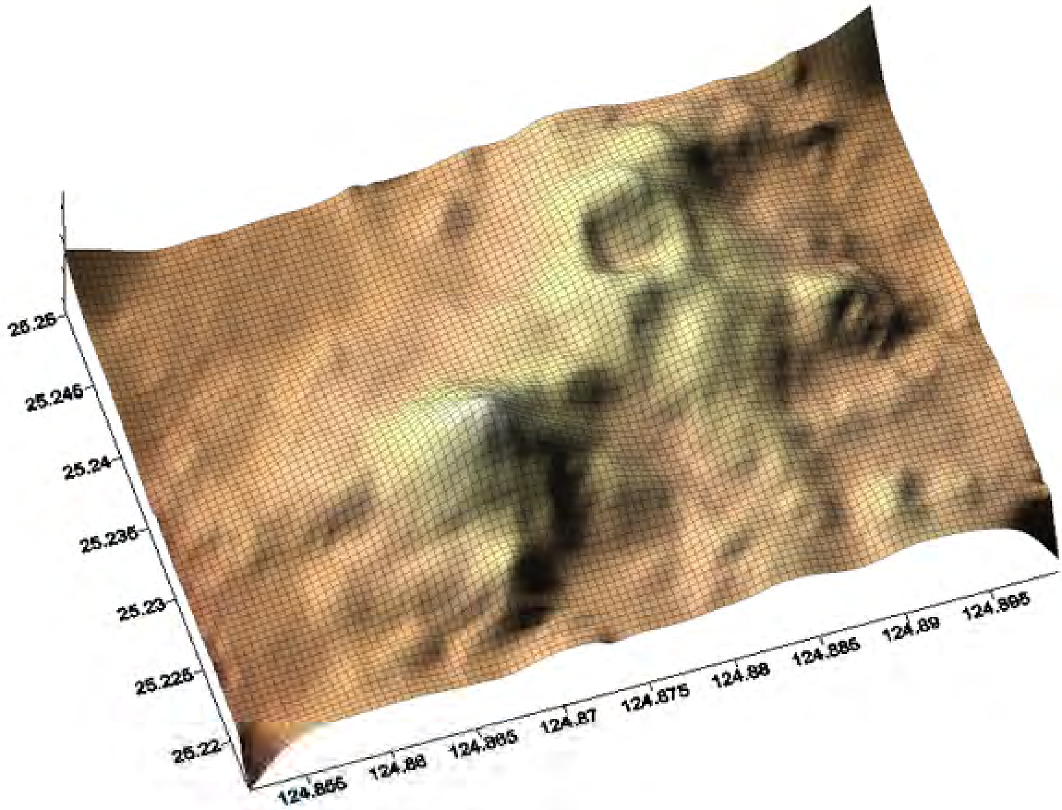


Fig. 24 3D Bathymetry image of the Irabu Knoll area

5.5 Dive information

Totally 4 dives were planned to be conducted during NT11-17 cruise, and all dives were successfully conducted as planned. The following apparatuses were mounted on the HPD according as the purpose of the dive.

- IISA-Mn (IIS, Univ. of Tokyo)
- ISFET pH sensors (IIS, Univ. of Tokyo)
- Temperature recorder (IIS, Univ. of Tokyo)
- Multi-chemical Sensors ver. 1 (conductivity, temperature, depth, turbidity, and pH/pCO_2/ORP) (Kyushu Univ.)
- Multi chemical Sensors ver. 2 (conductivity, temperature, turbidity, DO, pH, pCO_2, and ORP) (Kyushu Univ.)
- TANSAKUN H_2S Sensor (Kochi Univ.)
- Temperature sensor (Kochi Univ.)
- SeaXerocks (IIS, Univ. of Tokyo)
- Plastic syringe water samplers (IIS, Univ. of Tokyo) 8 samples
- Glass syringe water samplers (IIS, Univ. of Tokyo) 1-2 samples
- Niskin water samplers 1-2 samples

Dive #1318

The first dive of the cruise (#1318) was conducted at the Yoron knoll area. Dive track of this dive is shown in Fig. 26. At the beginning of the dive, the ADCP was deployed at the foot of northeast slope. During the dive, HPD approached to hydrothermal sites "Achijah" (Fig. 27), "Heajah", and "Deeji" chimney (Fig. 28) site in northeast slope of the knoll. Water and rock samples were successfully collected around active chimneys. After sampling operations and observation of hydrothermal site, HPD cruised to the west for hydrothermal site survey using chemical sensors and analyzers. As a result of survey operation at western slope of the knoll, no novel hydrothermal site was discovered. We also visited dead chimneys (Fig. 29) to obtain 3D images. Prior to finish the dive, an active chimney sample was collected (Fig. 30), and the ADCP was retrieved.

Fig. 25 HPD with payload appartuses and sensors for dive #1318

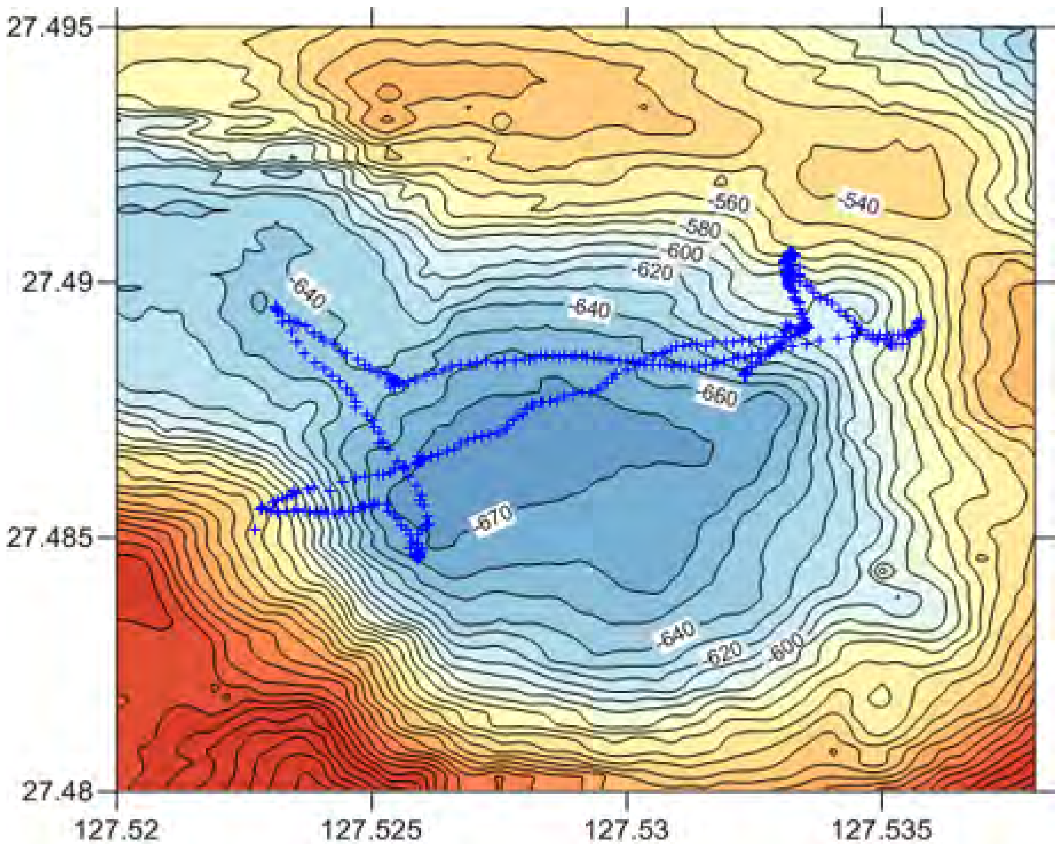


Fig. 26 Hyper-Dolphin dive track on dive #1318 at the Yoron knoll

Fig. 27 Active chimney

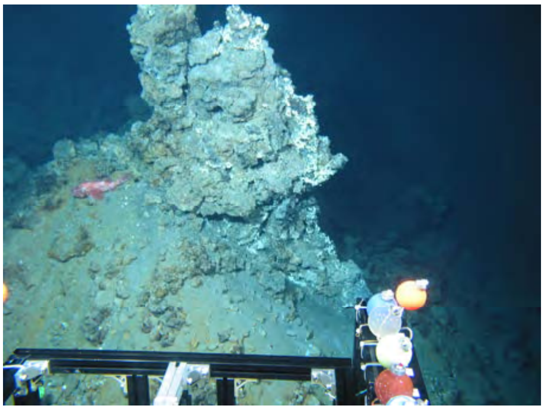


Fig. 28 “Deeji” chimney

Fig. 29 Dead chimney

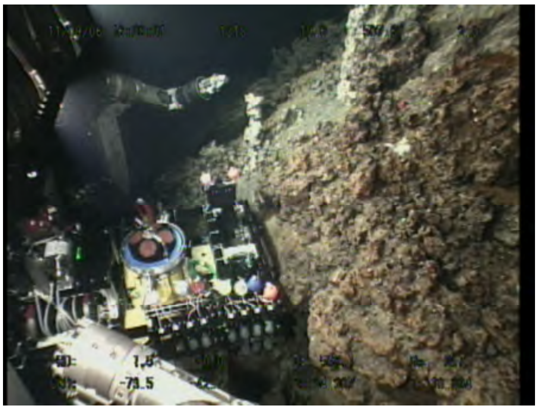


Fig. 30 Chimney sample collection

Dive #1319

The second dive (#1319) was performed at the western caldera-like depression near the Yoron knoll to survey novel hydrothermal activity. HPD approached to northern slope of the depression and climbed up to depth of 720 m. After reaching to 720 m deep, HPD cruised to east. Fig. 32 shows dive track of the HPD. Sensors and analyzers were successfully operated during the dive. During the dive, weak anomalies of Mn concentration were observed in places, and we discovered cracks and discoloration of the seafloor (Fig. 33). However, any active chimneys were not discovered. During the survey operation, water samples were successfully collected.

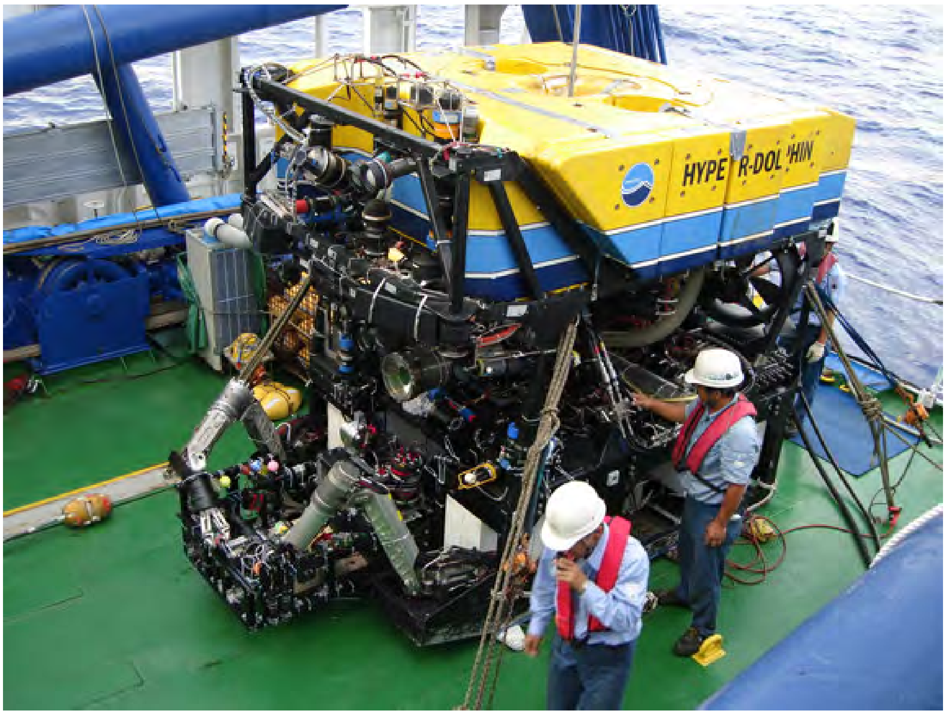


Fig. 31 HPD with payload apparatuses and sensors for dive #1319

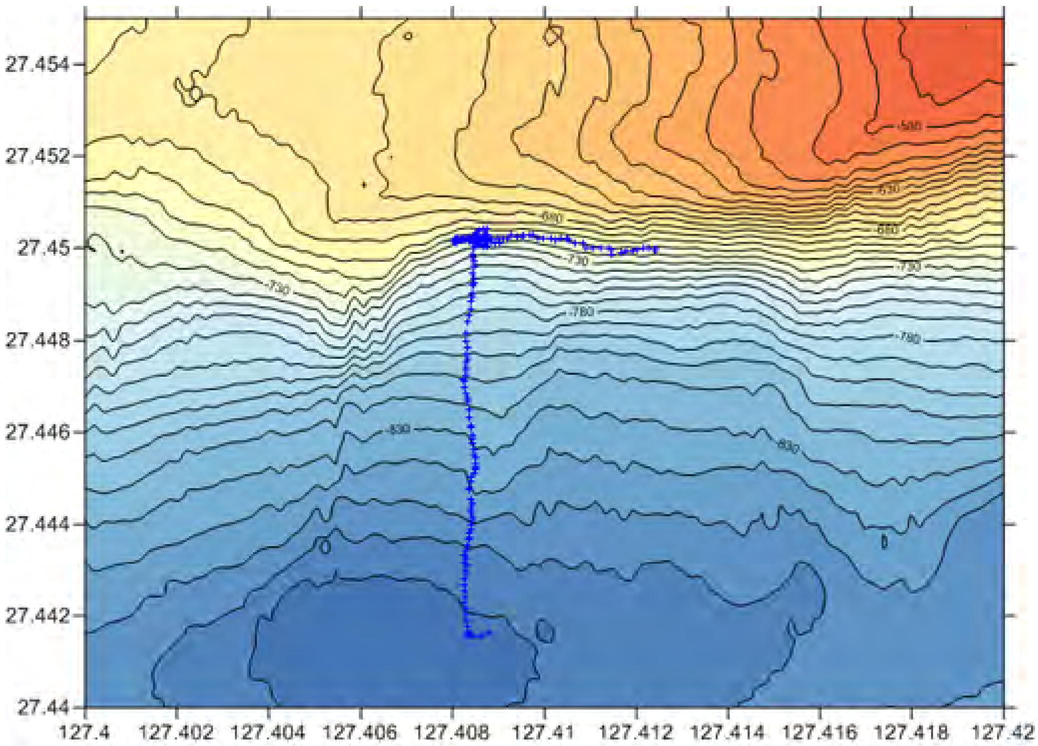


Fig. 32 Hyper-Dolphin dive track on dive #1319 at the western caldera-like depression

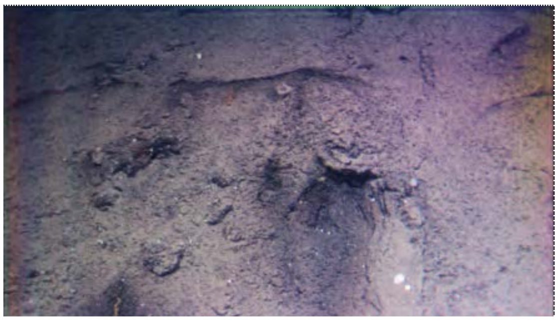
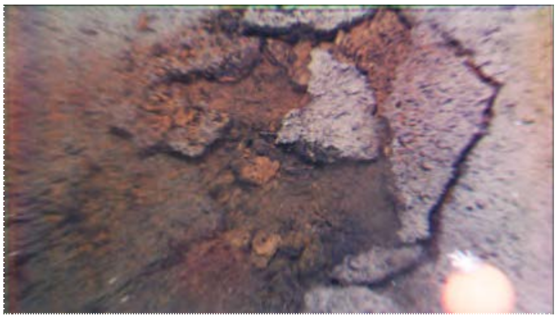
 

Fig. 33 Cracks (left) and discolorations of the seafloor (right)

Dive #1320

For the third dive (#1320), HPD dived to the western knoll at the Irabu Knoll area. Fig. 35 shows dive track of the HPD. First, HPD landed at southeast foot of the knoll. Then, HPD climbed up the knoll to the top. At the top of the knoll, hydrothermal active sites accompany a lot of chimneys and dense local ecosystem (Fig. 36) were identified. These sites are identical to the sites previously discovered during KY00-06 scientific cruise. We successfully identified a 6K marker previously installed there (Fig. 37). Temperature measurement of hydrothermal fluid was conduced and temperature of 67 ˚C was measured. After the identification and a detailed observation of the sites, we tried to discover the other hydrothermal sites at southern and northeastern slope of the knoll. However, no novel sites were discovered. Hydrothermal sites on this knoll seem localized at the top of the knoll. Local ecosystem included crustaceans such as shrimps, crabs, and barnacles (Figs. 36 and 38). Water and rock samples were successfully obtained during the dive.

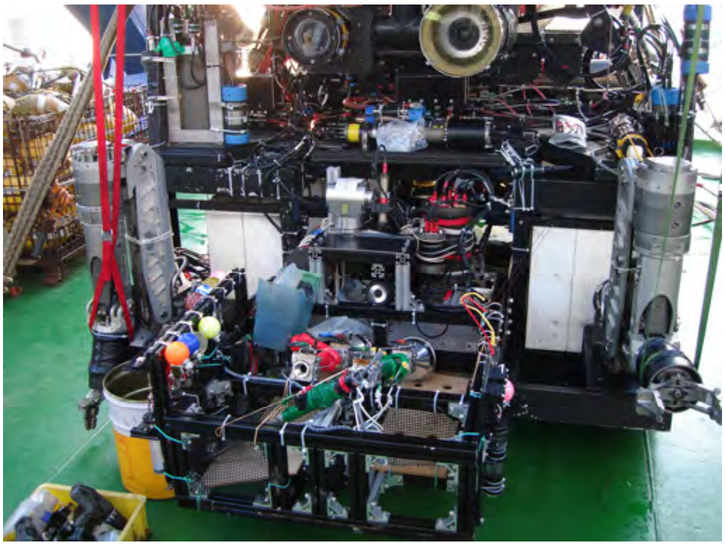


Fig. 34 HPD with payload apparatuses and sensors for dive #1320

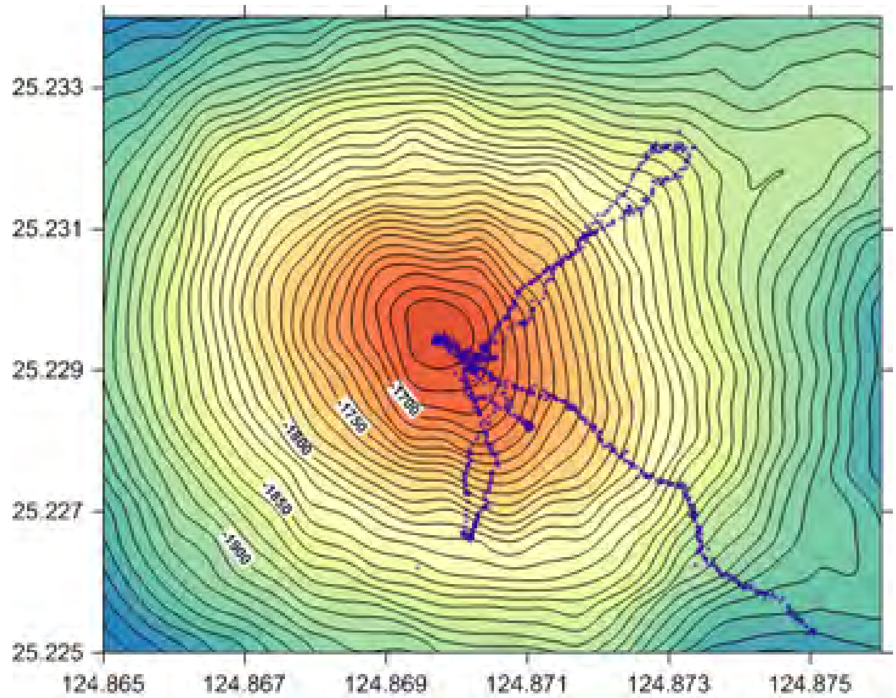


Fig. 35 Hyper-Dolphin dive track on dive #1320 at western knoll of the Irabu Knoll area

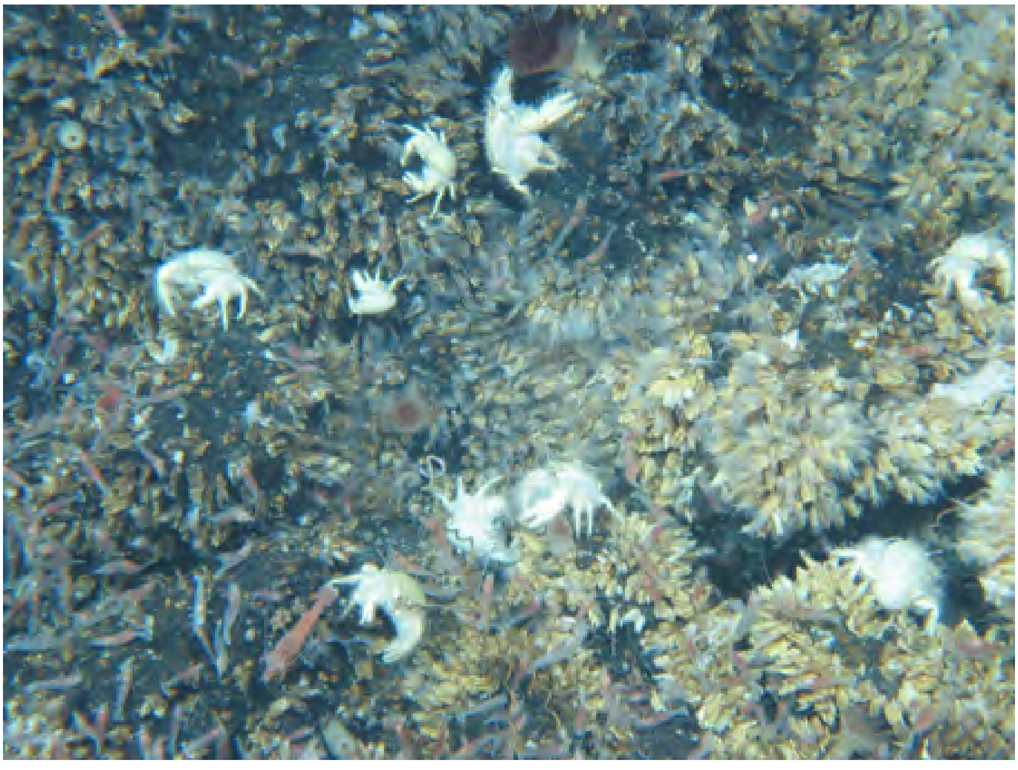


Fig. 36 Hydrothermal biosphere at the Irabu Knoll

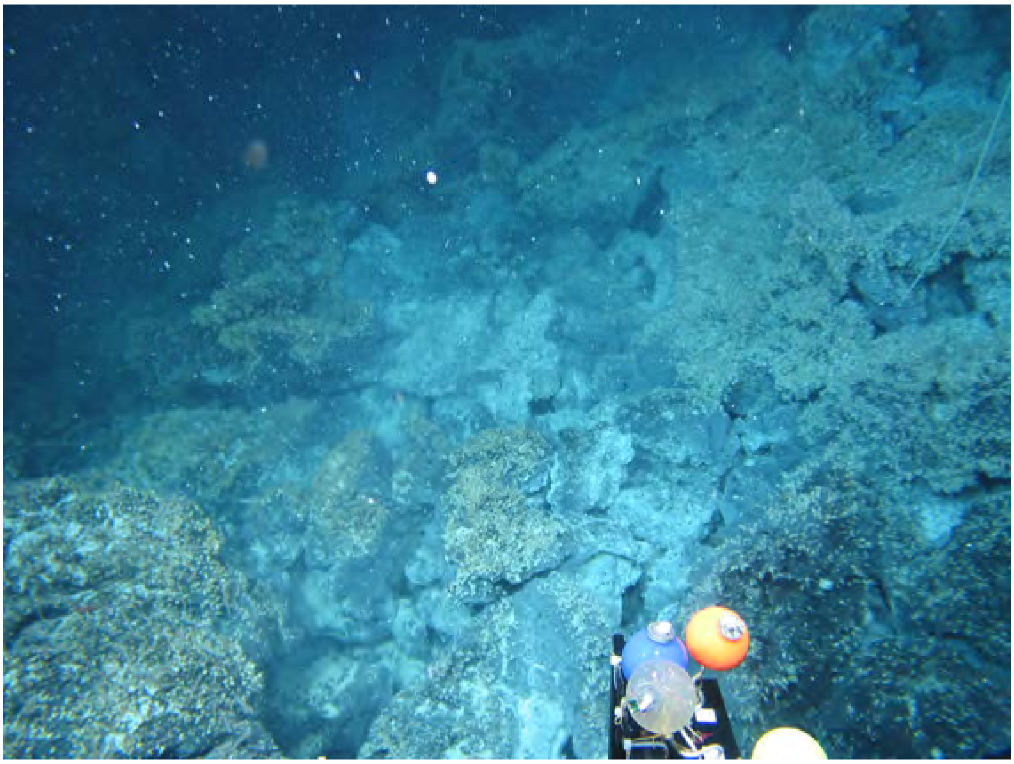


Fig. 37 Hydrothermal site near the 6K marker

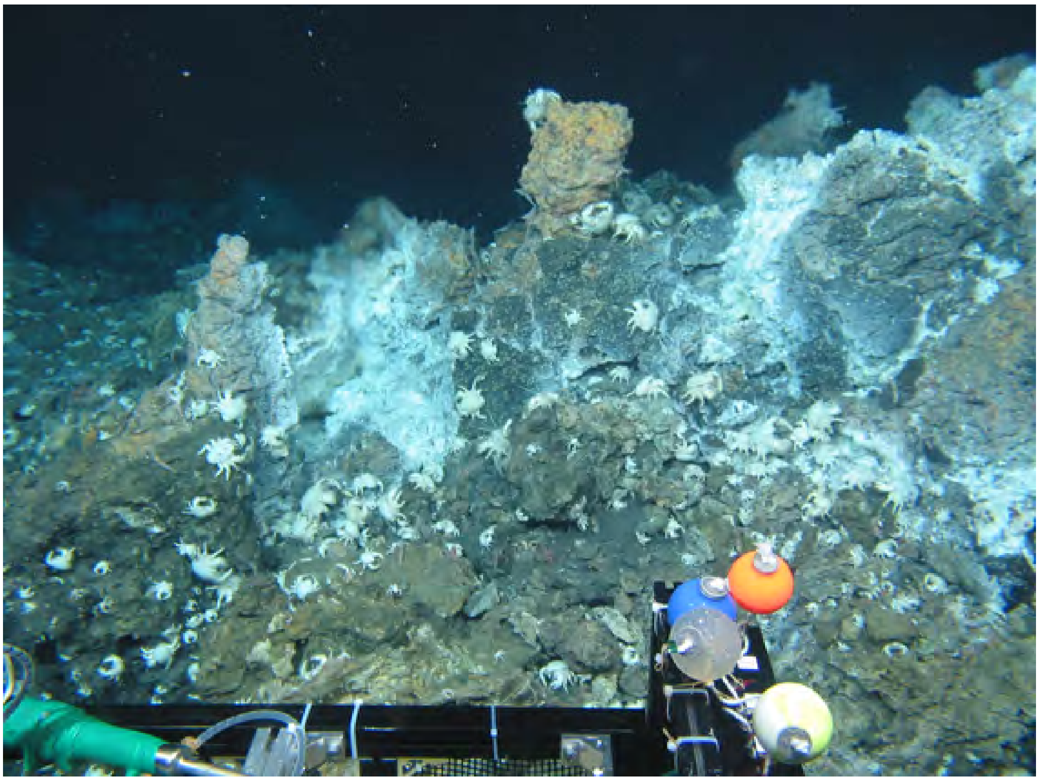


Fig. 38 Hydrothermal chimneys and crustaceans

Dive #1321

The last dive (#1321) was conducted for mapping operation of the hydrothermal plume drifted from the Irabu Knoll hydrothermal sites identified at the to of the knoll. First, HPD landed at the top of the knoll for ADCP deployment. After the deployment, HPD cruised at the depth of 1,628, 1,618, and 1,608 m as shown in Fig. 40. At the end of the dive, the ADCP was retrieved. Water and rock samples were successfully collected during the dive (Fig. 41).

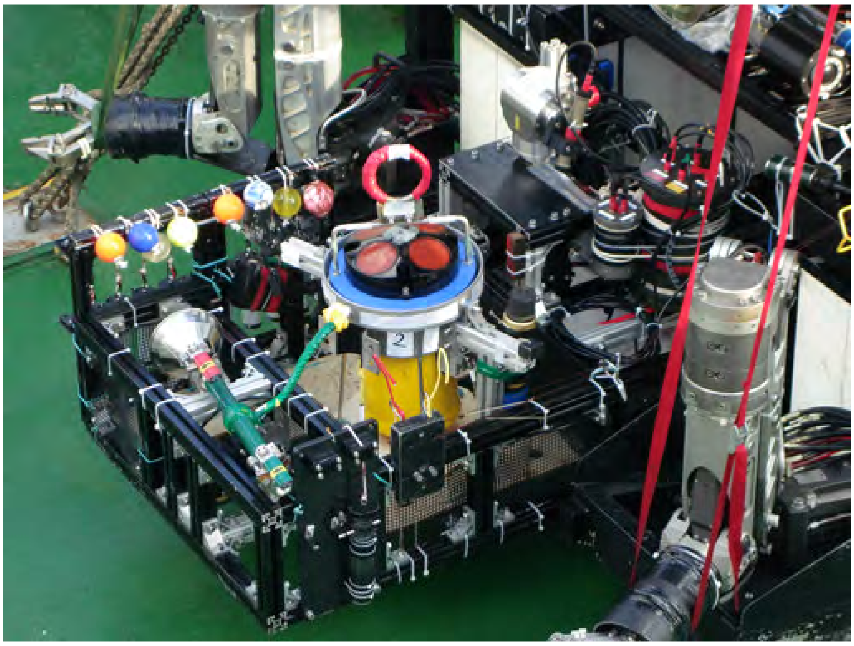


Fig. 39 Payload apparatuses and sensors for dive #1321

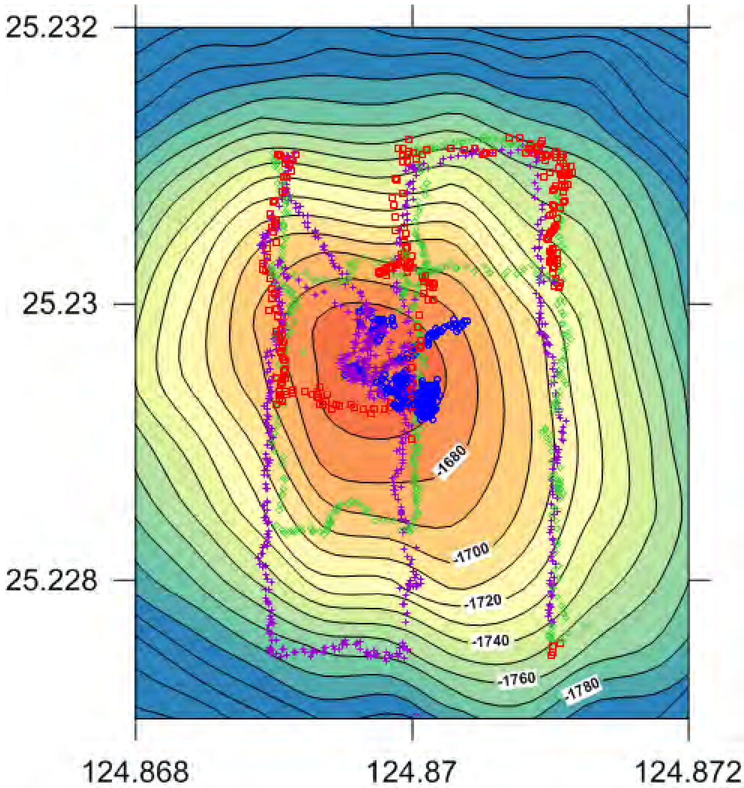


Fig. 40 Hyper-Dolphin dive track on dive #1321 for hydrothermal plume mapping operation. Rectangular grid track lines, purple: 1628 (1623 to 1633) m, green: 1618 (1613 to 1623) m, and red: 1608 (1603 to 1613) m are shown here. Blue track shows track line deeper than 1623 m.

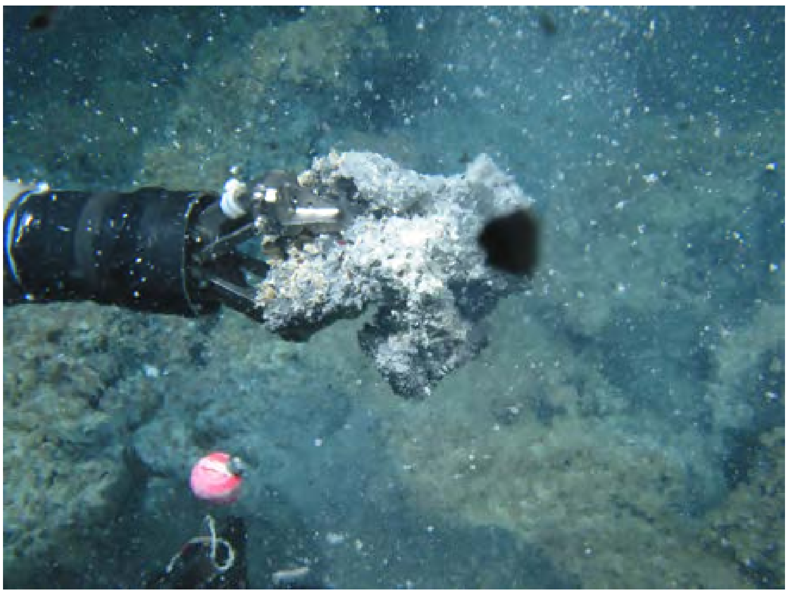


Fig. 41　Rock sample collected at the end of the dive

6. Proposal for the future plans

Through this cruise, potential of novel *in situ* chemical sensors and analyzers were successfully demonstrated. The data from the *in situ* sensors and analyzers were fully utilized for hydrothermal activity survey and detailed analysis in real environment. Improvement of the reliability and stability of the sensors and analyzers should be continuously conducted. Development of standalone type sensors is also one of the important issues to realize an advanced survey operations utilizing AUVs.

7. Acknowledgment

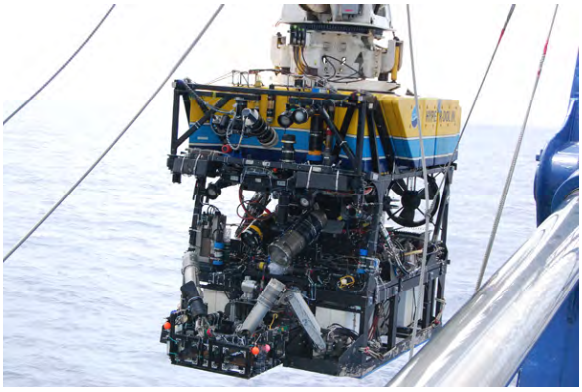
I would like to thank all the members of the ROV HyperDolphin operation team (Chief: Yoshio Ohno), and the crewmembers of R/V Natsushima (Captain: Yoshiyuki Nakamura) for their dedicated efforts to make this cruise so successful. I also would like to thank Mr. Takuya Onodera (Nippon Marine Enterprises, LTD) for his helpful assistance on all scientific activities onboard.

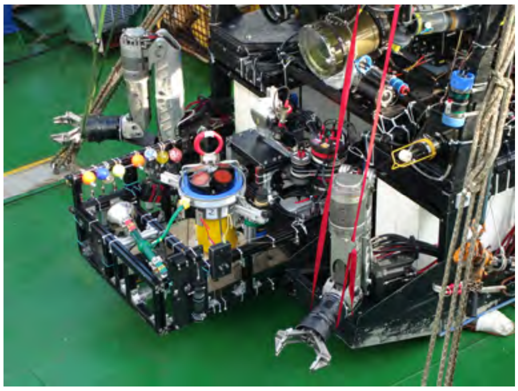
8. Appendix

8.1 Appendix supplied as electrical files

a. List of samples
b. Shipboard log
c. List of crews
d. Specification of vessel, instrument & submersible vessel

8.2 Cruise photos



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