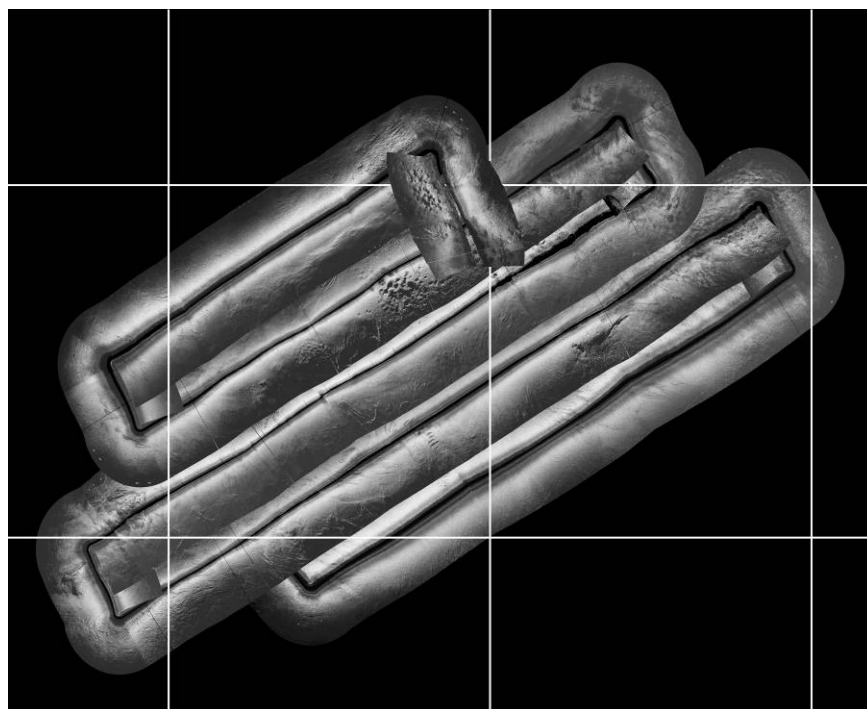


A Research on 2009 Deep Sea Investigation
KR 10 - 03

Cruise Report of the Daiyonyonaguni Knoll Expedition by Autonomous
Underwater Vehicles

**Development of the Methodology for Surveying Hydrothermal Vents
Covered by Strong Sea Currents**



Feb., 2010

Chief
Institute of Industrial Science, The University of Tokyo
Tamaki Ura

1. Introduction

1.1 Overview of the Investigation Research and its Significance

The plan for the investigation research cruise has been designed on the basis of our past achievements and experiences obtained from the histories of developments and deployments of our two Autonomous Underwater Vehicles (AUVs), r2D4 and Tuna-Sand (TS). The cruising type AUV 「r2D4」 takes the role of overall survey over the trough lines of Daiyonyonaguni undersea mountains by means of side-scan sonar, interferometry sonar, Mn-analyzer, three-component magnetometer, and CTDO. On the other hand, based on the preceding results obtained by r2D4, the hovering type AUV TS carries out more detailed and advanced investigations. The proposed approach realizes more efficient sea bed investigation, leading to the increase in investigation area. Such an approach composed of collaboration between two heterogeneous-type AUVs has been come true due to the improved performances and reliabilities of the two AUVs. We believe that our new approach based on our historical achievements suggests a potent evolution for the arrival of a new generation in undersea observation. Though it has been known to be one of the famous hydrothermal vent site, the Daiyonyonaguni area hardly allows the deployment of manned submersible or Remotely Operating Vehicle (ROV), for there always are strong sea currents, attributed to Kuroshio. While there have been many vigorous investigations by ROVs or manned submersibles in Hatoyama knoll, another famous sea area for undersea hydrothermal activities, it is felt that the Daiyonyonaguni recently attracts only a little attention, mainly due to the difficulty in deploying manned or tethered undersea vehicles under the strong sea currents. According to the cruise report YK04-05/Leg2 (chief: Takuro Nunoura) which summarizes a investigation dive for Daiyonyonaguni area, after it was first detected in 2000, the hydrothermal activities in this area were mainly observed in 2003, and continued until 2004.

In our cruise reported here, as a new challenge in underwater robotics technology, we have deployed our cruising type AUV r2D4 to some narrow-banded basins and troughs in Daiyonyonaguni area, pursuing to detect new undersea hydrothermal activities, as well as get technological progresses in deploying underwater robots. As the result of our cruise for undersea investigation research, we expect to derive a new methodology of sea bottom survey fed back to underwater robotic technology, and get a new discovery of scientific importance.

1.2 Dates and Summary of the Cruise (see Table 1, time table for investigation)

12 days, from 22th Jan. to 2nd Feb. 2010.

1.3 Support Vessel and Crew Members

(1) Vessel "Kairei" : 4,517/T

(2) Crew Members

Captain	Hitoshi Tanaka
Chief Engineer	Minoru Tsukada
Chief Officer	Naoto Kimura
Radio Officer	Masasi Takahashi
Boatswain	Kingo Nakamura

1.4 Area of Investigation (see Fig.1, hydrographic chart of the investigation area)

Though we principally aim at deploying the AUVs at the sea area of Daiyonyonaguni, considering the fact that there frequently happen severe sea conditions induced by winter monsoon, in order to optimize the allowed time for using support vessel, we prepared for two backup sites for investigation: The sites of Kuroshima knoll, located south of Ishigakijima, and southern cliff of Okinawa trough, located north of Ishigakijima. To the end of the cruise, however, we had no chance to visit the second backup site.

Yonaguni knoll (Depth range : 750 m ~ 1800 m)

Undersea area surrounded by the following five points:

24° 40' N 122° 37' E, 24° 52' N 122° 37' E
25° 00' N 122° 43' E, 25° 00' N 123° 00' E
24° 40' N 123° 00' E

Backup site

Kuroshima knoll (Depth range : 650 m ~ 2000 m)

Undersea area surrounded by the following latitudes and longitudes:

24° 00' N 123° 50' E
24° 18' N 124° 30' E

1.5 Anchorage sites

Port of Naha ~ Yokosuka (quay anchorage)

1.6 Members of investigation team

See attached Table2, the organization chart of the investigation team

2. Description of the Observation Equipments

2.1 r2D4

In 1984, Institute of Industrial Science (IIS), The University of Tokyo started to develop the AUVs for investigating Mid-Ocean Ridge, leading to the completion of the vehicles of R-One and r2D4. As a downsized version of the R-One, r2D4 was designed to be operable at the maximum depth of 4,000 m. As other characteristic features of r2D4, employments of Lithium-ion secondary battery and compact Inertial Navigation System (INS) are to be mentioned. Principal dimensions, specifications, and equipments of r2D4 are listed in Table 2.1.1. By the action of 1.5 kW main thruster, r2D4 can proceed at the maximum speed of 3.3 knots. As the yaw control mechanism as well the propulsion, main thruster can be deflected in horizontal plane within the range of 15°. The maximum roll and pitch angles are 25°, attainable by the action of two elevators. In case that the vehicle is to approach the sea bottom within a small altitude or make an urgent surfacing, two vertical thrusters are activated.

As the equipments for investigating undersea geological formations, dual-frequency (100 and 500 kHz) Side Scan Sonar (SSS), interferometry sonar, and CCD camera are installed in r2D4. In addition to these, CTDO (Conductivity, Temperature, Density, and dissolved Oxygen), three-component magnetometer, and GAMOS, the on-site chemical analyzer, are also implementable to the r2D4. Some of sensors mentioned are placed in the forebody extra payload space.

Table 2.1.1 Principal dimensions and equipments of r2D4.

Dimensions (m)	L4. 4 * W0. 96* H0. 81 (hull)
Weight (kgf)	1,600(in air) / -5(in water)
Max. Operating Depth (m)	4,000
Max. Speed (kts)	3. 3
Duration (hrs)	12 @ 3kts
Power source	Lithium ion battery (Rechargeable, 150V, 120Ah)
CPU For Navigation	MOTOROLA PowerPC 233MHz OS: Tornado II
CPU For Observation	ADVANTECH NS Geode 300MHz OS: Tornado II
Navigation System	Inertial Navigation system: FOG, DPR sonar, Forward looking sonar, Altitude sonar, Depth sensor, GPS, Satellite comm. , Acoustic comm. , Wireless LAN comm.
Observation Sensor	Side Scan Sonar, Interferometry Receive Sonar, CTDO, GAMOS 3-axis Terrestrial Magnetometer CCD camera

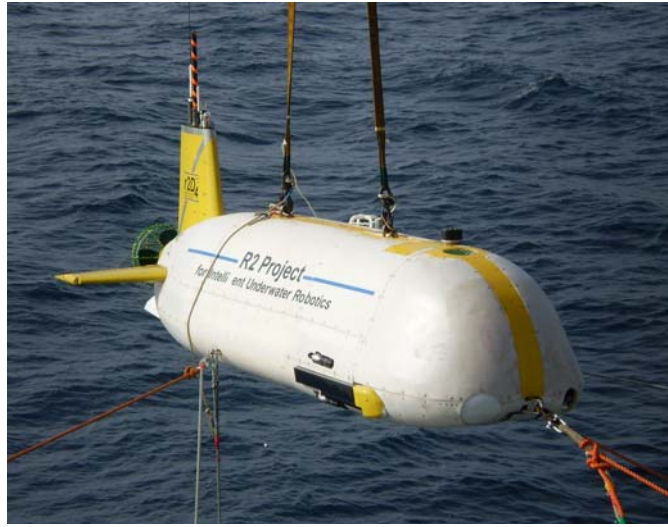


Figure 2.1.1 An overall feature of r2D4.

2.2 Tuna-Sand (TS)

Picture of an overall view of TS is shown in Fig. 2.2.1. General arrangement and vehicle specifications are shown in Fig. 2.2.2 and Table 2.2.1, respectively. TS is designed as an open-frame structure, pursuing the on-site robustness and enhanced operability. An AUV as it is, in response to a mission or on-site condition, TS is also alternatively operable as a Remotely Operating Vehicle (ROV), tethered by an optical fiber cable.

It is noted that equipped with an INS of highly accuracy, TS is able to compensate for its drift-induced position error by referring to seabed topography. By this position error compensating technology, we can deploy TS in an undersea environment even in which the position reference by GPS is fundamentally unavailable, achieving successful automatic navigation tracking the pre-defined reference waypoints.

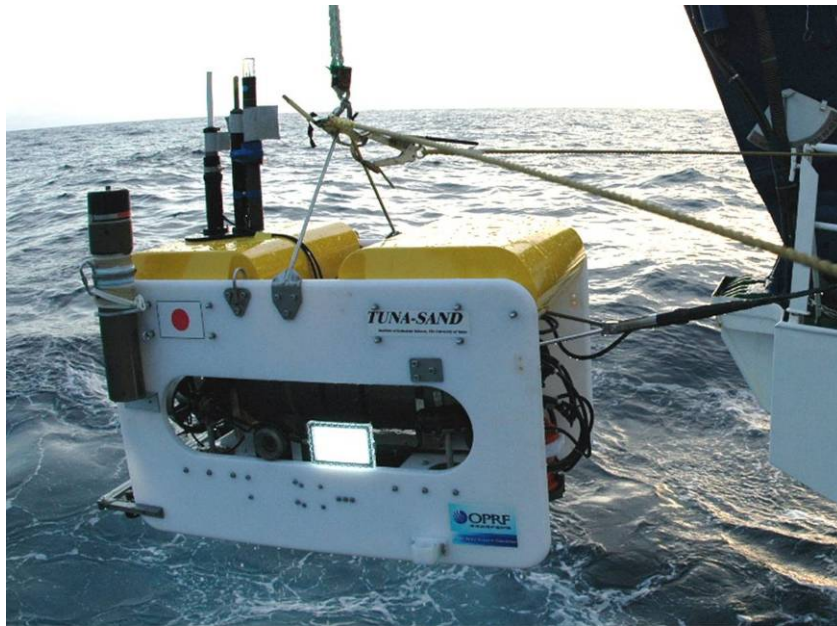


Figure 2.2.1 AUV TUNA-SAND (taken after completing #8 dive).

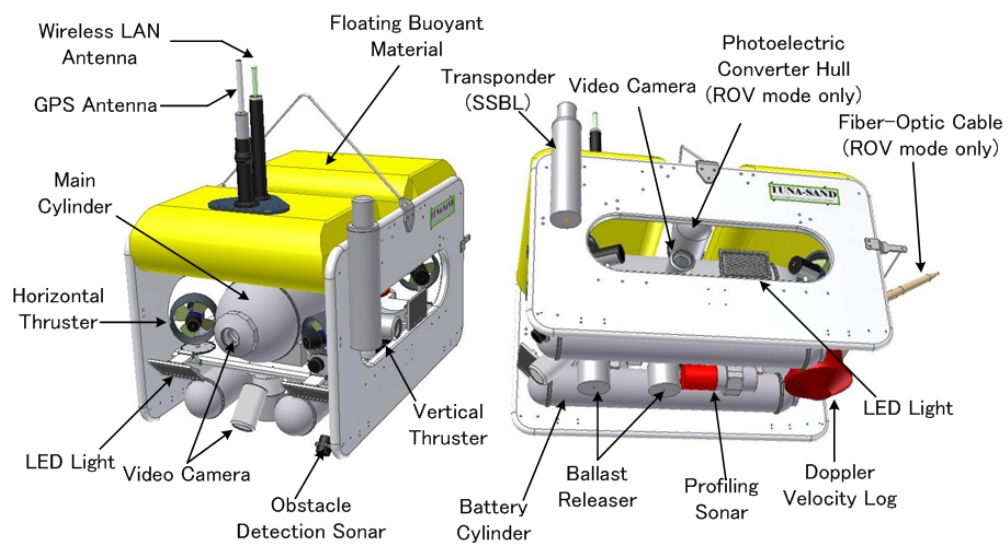


Figure 2.2.2 General arrangement of TUNA-SAND.

Table 2.2.1 Principal dimensions and equipments of Tuna-Sand.

Vehicle	
Size	1.1m(L)_0.7m(H)_0.7m(W)
Mass	240 kg
Max.speed	1.7 knot
Max.depth	1,500 m
Duration	4 hours
Actuators	Thrusters 220W _ 4, 100W _ 2
Power	Ni-H Battery 50.4V 9Ah _ 4
Communication	Wireless LAN, Fiber-Optic Comm.(ROV mode only)
CPU (Main)	NS Geode GX1-300MHz
CPU (Comm. with sensors)	NS Geode GX1-300MHz
OS	VxWorks
Sensors	
Inertial Navigation System	iXSea PHINS (FOG)
GPS	NovAtel OEM4-G2L
Doppler Velocity Log	RDI Navigator 600kHz
Depth	Mensor Series 6000
Obstacle Avoidance	Echo sounder × 3
SSBL	System Giken
Payload	
Camera	Hitachi KP-D20B(CCD) × 3
Lighting	LED light board _ 3
Bathymetry	Imagenex 881a Profiler 675 kHz

2.3 Observation Equipments

2.3.1 Side Scan Sonar

The Side Scan Sonar (SSS) called Klein System 2000 is embedded in r2D4. Having dual operating frequencies of 100 and 500 kHz, receivers and transmitters of the SSS are installed on both left and right sides of the vehicle. Once started to run, the system operates nearly full automatically, adjusting the scanning sensitivity adapting to the current vehicle altitude. The two operating frequencies are simultaneously activated during a survey work. For the acoustic pulse of 500 kHz, the system is able to cover 100 m scanning range (50 m, for each side) at the altitude of 20 m. However, when the vehicle altitude from sea bottom exceeds 50 m, acoustic image is hardly obtainable by 500 kHz. In most of surveys, images are mainly produced by the 100 kHz pulse within the altitude between 50 ~ 100 m. The maximum coverage range of our SSS system is 800 m (400 m, for each side). And in some cases, not only seabed topology, but also debris or hydrothermal activities might be detected by our SSS system.

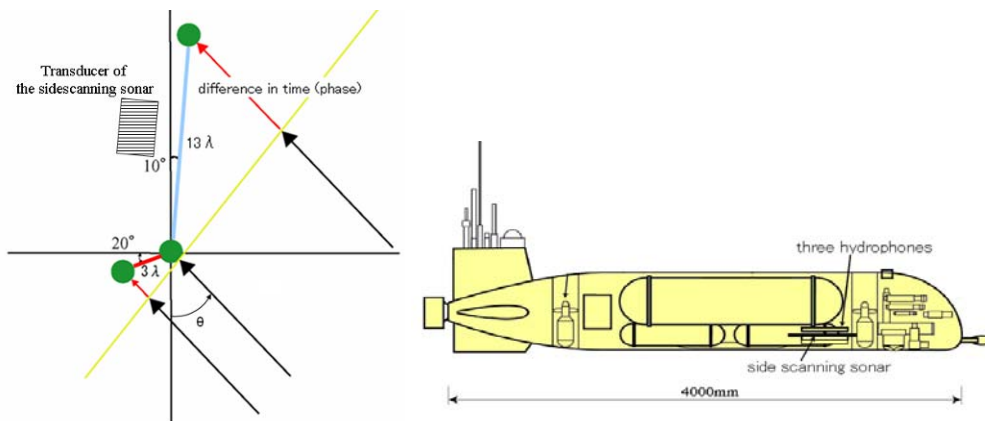


Figure 2.3.1.1 Side view of r2D4 (right) / Description of the acoustic ray direction identification system; Using 3 Hydrophones installed upper and lower sides of SSS, the system creates seabed topography.

2.3.2 Interferometry Sonar

Launched in Jul. 2003, r2D4 is an AUV oriented to a practical mission of surveying hydrothermal activities in Mid-Ocean Ridge. The overall length of r2D4 is 4 m. And it can operate continuously for 12 hours, having the maximum endurable depth of 4,000 m. As depicted in Fig. 2.3.1.1, with the extended array intervals of 3λ and 13λ (λ : Wavelength of the Acoustic Pulse), two sets of three L-shaped hydrophones are installed on the hull of r2D4, interposing the SSS between them. The way for an L-shaped array of interferometry sonar to map the bathymetric features of seabed is as follows. First, 100 kHz, fan-shaped acoustic pulse spreading laterally is emitted to seabed. Then, by measuring characteristic phase difference of the reflected acoustic scattering which is finely discrete-in-time, its direction of propagation can be estimated. The phase difference obtained here enables creation of detailed seabed topography.

While other interferometry sonar systems up until the present take basic platform in which the two hydrophones are arrayed with maximum 7λ interval, by taking L-shaped three hydrophones array, our system is able to clearly identify the direction of propagation using three phase differences obtained. In case the multi-beam SSS operates mounted on the hull of a surface vessel, resolution of the created seabed image deteriorates markedly due to the large acoustic footprint of orders of tens to hundreds of meters, brought about by the large propagation depth (thousands of meters, in general). On the contrary, since it can approach the seabed with an arbitrary low altitude, an AUV is one of the optimal platforms for SSS operation creating the image of highest achievable resolution.

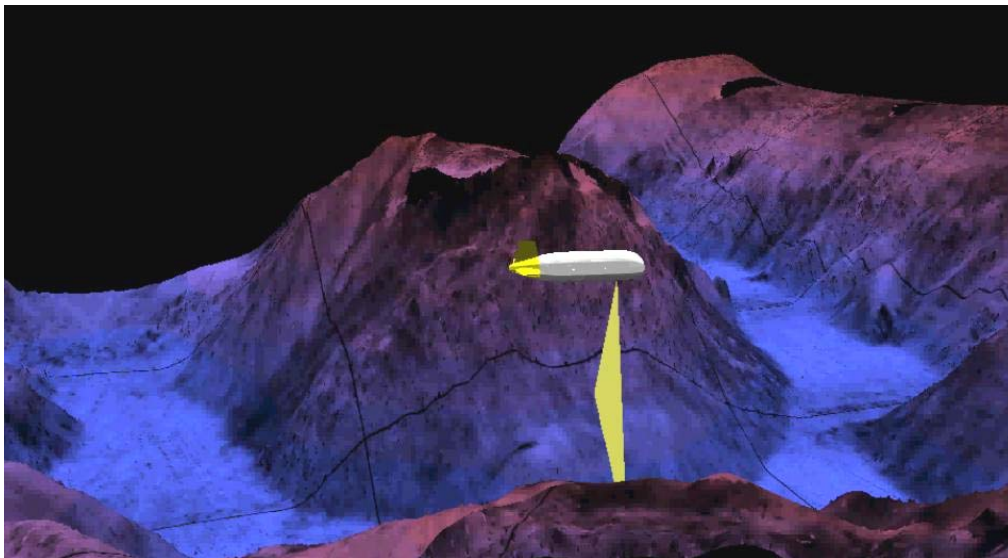


Fig. 2.3.2.1 r2D4 creating the Seabed Images over the Area of Myojinsho Caldera

2.3.3 CTO + Turbidity + pH Meter + Hydrogen Sulfide Meter

Sensors of Conductivity, Temperature, Water Depth on the basis of the SBE25 by Seabird Electronics Inc. are installed in r2D4. Moreover, backscattering turbidimeter (by Seapoint), pH meter (by Norimoto Electronics), oxidoreduction potentiometer (by Norimoto Electronics) are also loaded in the sensing unit of r2D4. With the sampling frequency of 24 kHz, the sensing unit of r2D4 runs throughout a dive. All the data taken by the sensing unit are transmitted to and processed by the PCPU of r2D4.

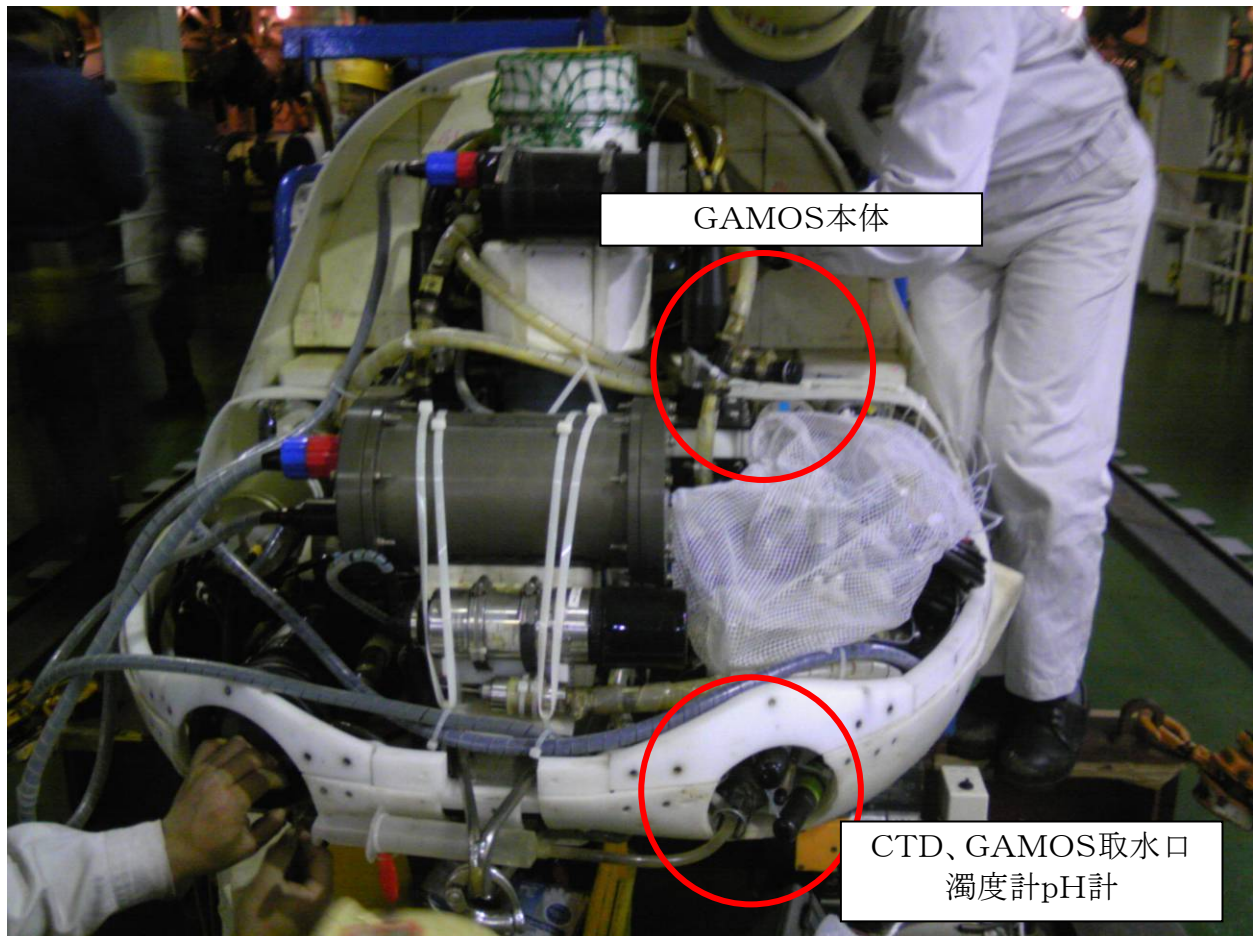


Fig. 2.3.3.1 Arrangement of the sensing unit. The circle in the figure indicates the sea water inlet for the sensing unit.

2.3.4 GAMOS - A Chemical Sensor

Installed in an undersea vehicle like r2D4 or a oceanographic sensing unit such as CTD-RMS, the GAMOS is an on-site chemical sensing unit which continuously measure the dissolved manganic concentration in undersea hydrothermal plumes, and describes its spatial distribution. Measurement by GAMOS is based on the flow-through chemical luminescence. If we stir together sample and three or four kinds of chemiluminescent reagent, by the characteristic reaction with Manganese, the liquid mixture exhibits luminescence which depends on the concentration of target element. By measuring this luminescence intensity, we can quantify the both elements.

GAMOS consists of the 1) Analyzer : chemiluminescent reagent feeder with artesian container equipped with switching valve 2) Controller : control unit and pressure vessel containing detection circuit. The 24 V power supply is fed to GAMOS from r2D4. The measurement by GAMOS is recorded in a data logger with the sampling frequency of 1 Hz. The measurement range of GAMOS is 1 ~ 4,000 nM.



Fig. 2.3.4.1 Feature of the GAMOS (Size Comparison with a cigarette packet)

2.3.5 3-Axis Magnetometer

In table 2.3.5.1, specifications of 3-Axis magnetometer installed in r2D4 are listed.

Table 2.3.5.1 Specifications of 3-Axis Magnetometer

Measurable Range	$\pm 70,000\text{nT}$
Resolution	1nT
Orthogonality	<0.1deg.
Linearity Error	<0.0015%
Sampling Rate	8 Hz
Power Supply	20~28Vdc
Power Consumption	200mAmax <100mA _{typ} (run at 24V)
Payload (in Air)	2.8kg
Payload (in Water)	1kg (1.8 kg of Buoyancy)
Circuit Payload (in Air)	8kg
Circuit Payload (in Water)	3kg (5 kg of Buoyancy)

3.1 r2D4

Starting and finishing times, their locations, and other recorded data of the mission are summarized in Table 3.1.1. Figures and Tables mentioned in this chapter put together in the end of this report.

3.1.1 Kuroshima Koll Dive

(1) Dive #65 : 24th Jan., 2010

[Plan] The purpose of this dive is field adjustment of r2D4, as well as the magnetic field investigation. Letting the vehicle submerged up to 1,100 m from the surface, we made some trials for deep-sea operation strategies. Refer to Fig. 3.1.1.1 for the planned navigation route.

[Result] Throughout the dive, r2D4 was disrupted by severe noise in forward looking sonar, leading to errant recognition of a virtual obstacle sensed to locate 80 m ahead of the vehicle. Until reaching 24_10N, the vehicle continued the dive ignoring the errant recognition, since the allowable safety altitude was set to be 600 m. However, right after exceeding the 24_10N northwards, r2D4 urgently took the emergent surfacing to avoid collision with the errant obstacle, since the safety altitude in that area was lowered to 100 m. By the vehicle position record 24_09.8N at the instant taken by SSBL, we can find the position error of 0_0.2N. The position error was anticipated to be accumulated during the initial submergence from the surface, since the vehicle has to rely on purely-inertial (INS-dependent) localization until it reaches the sea bed altitude below 200 m. During the emergent surfacing, large noise induced by the actions of two vertical thrusters makes the SSBL-based positioning unavailable. The situation caused more or less concern to vehicle operators, but by transmitting the command for emergent safety action followed by waiting for the surfacing, we succeeded in retrieving the vehicle. By referring to the recorded data, we hereafter are going to try to find out possible means to cope with the noise. Moreover, since we have found that the large position error is derived by the purely-inertial navigation, priority shall be given to the velocity reference relative to the water from the next dive.

SSBL-based navigation route and depth profile are shown in Figs. 3.1.1.2 and 3.1.1.3. The events related to the dive are summarized in Table 3.1.1.1.

(2) Dive #67 : 29th Jan., 2010

[Plan] The purpose of this dive is side scan imaging of seafloor area surrounded by the curve of 650 m depth. Another mission of this dive is the measurement of magnetic field in the area. Navigation by constant depth control suppresses the generation of pitch and roll, leading to the minimized disturbance to measurements by interferometry sonar and 3-axis magnetometer. Minimum allowable altitude is set to be 15 m. By this setting, the vehicle is slightly made to ascend around the top of the knoll. Refer to Fig. 3.1.1.4 for the planned navigation route.

[Result] Without any real time man-made command for any purpose, r2D4 completed the mission fully autonomously. Throughout the navigation of four hours, resulting position errors in east-west and north-south directions are 0.05". Making use of the navigation result obtained from the dive on 25th Jan., we could estimate the accurate velocity of the vehicle. As a result, by waiting for the surfacing of the vehicle at accurately estimated time and location, we could retrieve the vehicle without any difficulty.

SSBL-based navigation route and depth profile are shown in Figs. 3.1.1.5 and 3.1.1.6. The events related to the dive are summarized in Table 3.1.1.2.

3.1.2 Daiyonyonaguni Knoll Dive

(1) Dive #66 : 25th Jan., 2010

[Plan] The dive is designed to be a round trip navigation, taking its route as follows. Starting dive at the southern part of Nishiho, r2D4 is scheduled to update its underwater position at the depth of 1,400 m. Then, taking the route toward Nishihozawa from Takezawa, the area of known undersea hydrothermal activity. The returning route is designed 0.2' apart eastward from the departing route. The dive starting point was shifted (-0.2' , -0.2') southwestwards from the original one, since we observed the sea current of 1.8 knots heading for 30° from the north. After finishing the DVL-based undersea position update at the depth of 1,000 m, r2D4 starts way points tracking navigation. Refer to Fig. 3.1.2.1 for the planned route for navigation.

[Result] The dive started at 7:20 a.m. We anticipated that the resulting drift shall be about (-0.15' , 0.0') at the vehicle depth of 1,000 m. At the No. #1 waypoint, positioning deviation by INS from the SSBL position was (0.4' , 0.41') northeastward. During the position updating procedure, commands for correcting INS position are repeatedly transmitted to the vehicle by 3 times, taking correction amounts of (0.1' , 0.1'), (0.1' , 0.1'), and (0.2' , 0.2'), respectively. Positive correction amount corresponds to the position deviation northeastward.

If the vehicle conducts the position correction navigation following the test interval of 0.2' sided lattice, the residual position error becomes smaller than 0.05'. Again, we transmitted the position error correction command with its amount of (0.1' , 0.0'), for we had detected the 0.05' position error eastward at the vehicle position of 24_51N. When r2D4 finished over the half of the departing travel, captain of the support vessel recommended to surface the vehicle after passing the Mishihozawa area, because the sea state in the area worsened. Complying with the captain's recommendation, we transmitted the normal surfacing command. Safety depth for this dive was set to be 800 m, which means that it takes more or less long surfacing time for the vehicle is to ascend up to the depth, since the vertical thrusters do not run within this interval. After reaching the safety depth, surfacing speed increases due to the actions of the vertical thrusters. Completing the retrieving r2D4 during the forenoon, we came back to Kuroshima. Maximum wave heights of 3 m in the area caused some difficulties in diver's operations during the retrieval. We tied up the rope on anchoring eye and hanging ring. SBL-based navigation

route and depth profile are shown in Figs. 3.1.2.2 and 3.1.2.3. The events related to the dive are summarized in Table 3.1.2.1.

3.2 Tuna-Sand

Starting locations and times of the dives, as well as other noticeable dive-related data are summarized in Table 3.2.1. And dive reference points for each area are shown in Table 3.2.3.

Table 3.2.1 Related Data for Dives

No.	Date	Area	Start	Surface	Duration	Depth	Purpose
28	2010/1/24	Kuroshima	14:30	15:42	1:11	653.0	ゲイン調整、冷水湧出地帯の観測
29	2010/1/26	Ishigaki	8:30	10:46	2:16	365.0	試験潜航
30	2010/1/26	Kuroshima	14:32	15:42	1:10	639.1	冷水湧出地帯の観測
31	2010/1/28	Kuroshima	14:34	16:09	1:35	630.9	冷水湧出地帯の観測

Table 3.2.2 Reference Points for Dives

海域	緯度	経度	水深(概数)
Kuroshima	24-07.8N	124-11.5E	655
Ishigaki	24-13.2N	124-5.0E	370

3.2.1 Kuroshima Knoll Dive

(1) Dive #28 (Fully Autonomous, Tethered Dive)

Date : 24th Jan., 2010 (Sun)

Dive Point : Cold Seep Activity Area in Kuroshima Knoll (Reference Point : 24_7.8N, 124_11.5 E)

Purpose : Field test of Software, Observation of Cold Seep Activity

Weather : Cloudy, Beaufort 5, 4 m of Wave Height

Schedule : Refer to Table 3.2.1.1 for the detailed schedule. Remarkable events are,

13:30 Move Tuna-Sand to the Deck

14:30 Dive starts

15:16 Emergent Surfacing due to Voltage Drop

15:19 Communication failure happened

15:42 Retrieval completed

Payload : pH meter, CT sensor

Dive Summary : The large rolling cable friction caused maximum power runs of the thrusters. This runs are for generating altitude and position controlling forces, resulting in the abrupt voltage drop. Since the vehicle started the emergent surfacing for this voltage drop, we switched to the manual operation mode to control the vehicle manually. However,

communication failure also happened after 3 minutes, which made us to surface the vehicle to avoid potential accident.

Maximum Dive Depth : 653 m

<Special Notes>

To reduce the drift in horizontal plane during the pure inertial navigation, we programmed the motion control software to let the vehicle experience 360° yaw motions in both clockwise and counterclockwise directions. Vehicle headings are shown in Fig. 3.2.1.2.

In preparation to the future untethered operation, acoustic modem (by Evologics Inc.) communication was tested. We detected the bug in acoustic communication task in TS, after Dive #30. This bug causes abnormal operation of Sub-CPU program during the undersea acoustic command link, and finally stops the inter-CPU communication. From Dive #31, debugged software was applied.

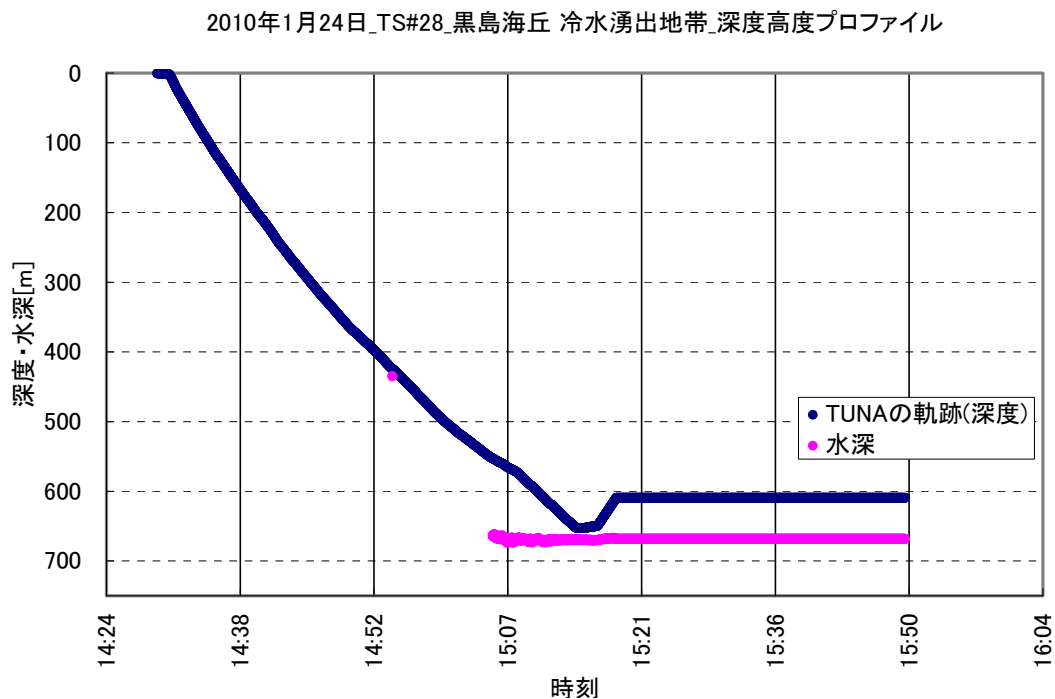


Fig. 3.2.1.1 Depth Profile during Dive #28

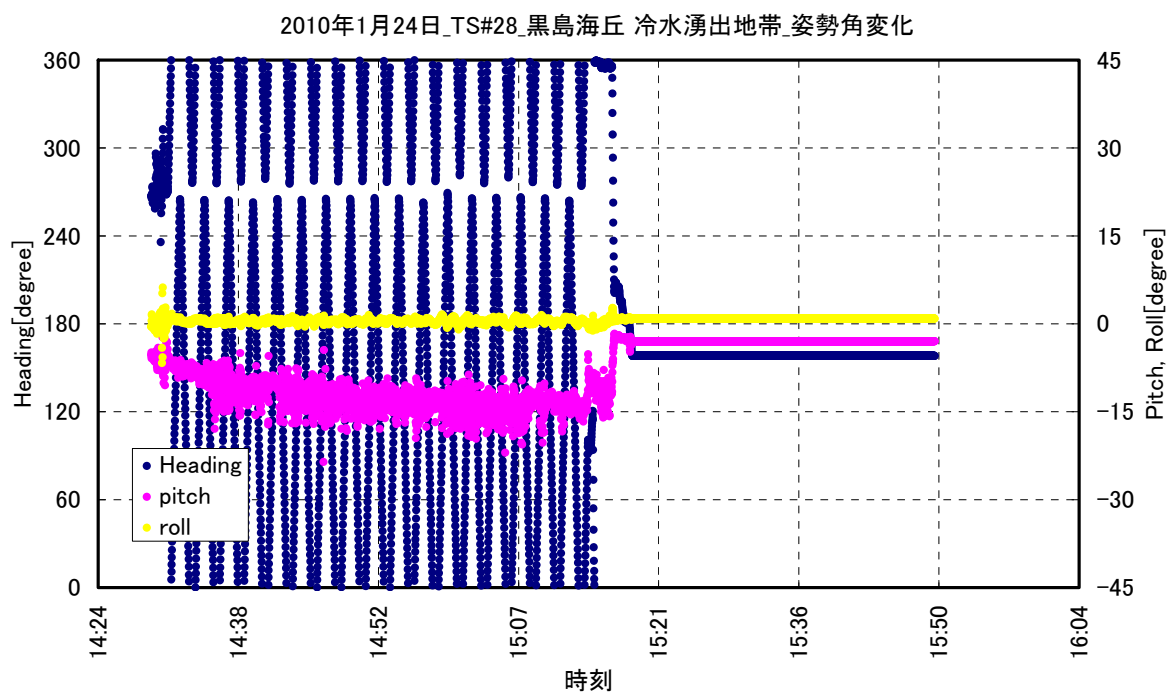


Fig. 3.2.1.2 Vehicle Attitudes during Dive #28

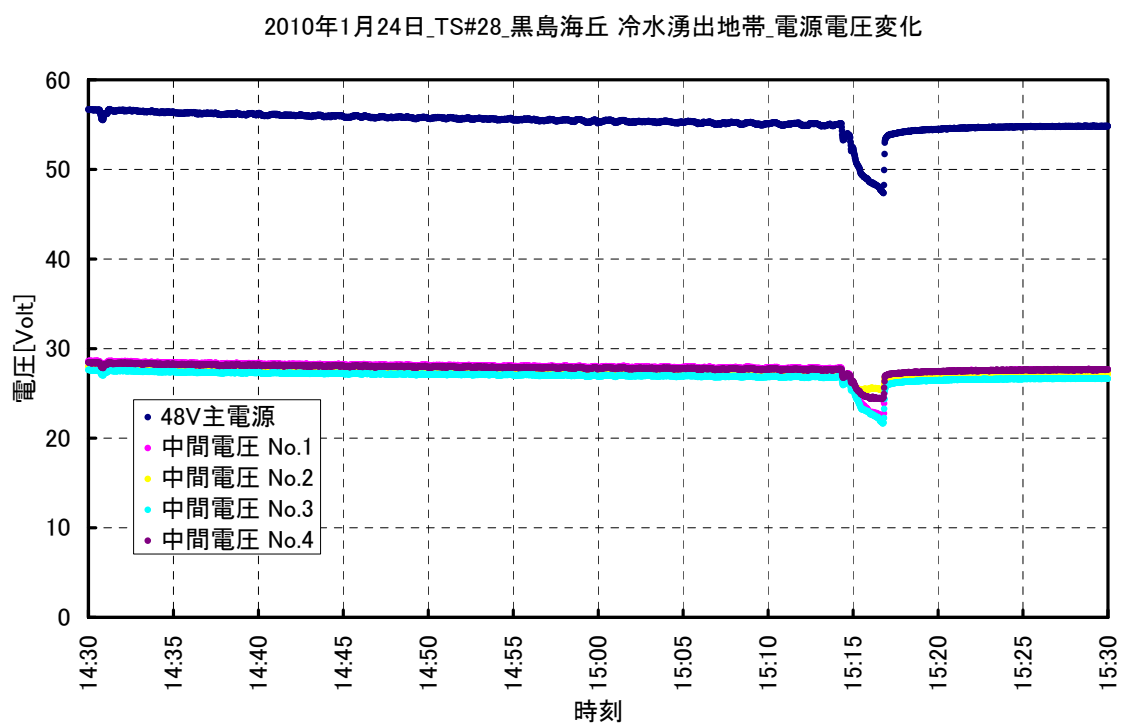


Fig. 3.2.1.3 Time History of Voltages during Dive #28

Table 3.2.1.1 Event Logs during Dive #28

13:10	Drawing out A-Frame.
13:30	Move TS to Deck.
13:40	Connecting Power Cable. Starting-up TS. Starts Static Test.
13:45	Operation Test.
14:10	Finishing Static Test. Switch External to Internal Power Supply
14:15	Preparing for the Dive (Test for Loading/Unloading Ballasts. Loads the Ballast)
14:20	Turn on the Trigger Signal for GR Camera
14:29:36	Starts the "Queuing Mode" in Dive Mission Program. Confirm LED Light in On
14:30:36	Starts the Dive. Released from the Tether.
14:31:07	Switch to the "Submerge Mode" in Dive Mission Program.
15:14:18	Switch to the "Static Test Mode" in Dive Mission Program. Release the Ballast.
(↑ Escaped the False Decision of being near the Seabed, even though Severe Noise was taken at the Depth of 424 m)	
※ We set the Near Bottom Collision is to be activated under the condition of over 500 m depth, as well as of repeated occurrences larger than a critical no.	
15:14:48	Switch to the "Observation Mode" in Dive Mission Program.
15:16:45	Starts Emergent Surfacing due to Voltage Drop.
15:18:54	Communication Failure happens between Sub-CPU (for Serial Communication) and Main-CPU (for Navigation).
15:35:00	Winching up the Cable. TS surfaced.
15:42:00	Retrieval by A-Frame.

(2) Dive #29 (Tethered, Fully Autonomous Dive)

Date : 26th Jan., 2010 (Tue)

Dive Point : Undersea Ridge off the Southwestern Ishigakijima (Reference Point : 24_13.2N, 124_5.0 E)

Weather : Cloudy, Beaufort 6, Wave Height 4 m

Schedule : Refer to Table 3.2.1.2 for the detailed schedule. Remarkable events are as follows.

07:00 Move TS to the Deck

08:30 Dive starts

10:58 Retrieval completed

Payloads :

15:42 Retrieval completed

Payload : pH meter, CT sensor

Dive Summary : Initial failure in GPS positioning retards the start of dive. Though still intermittent, GPS positioning recovered afterwards. Whereas the vehicle was successfully tracking the reference navigation route, vehicle unwillingly stopped due to issuing of the false command of "Stopping Thrusters" on the vehicle control GUI (Before the Dive #30, an improvement of installing Fail-Safe mode in GUI was made.). Route tracking restarted thereafter. Total 223 sheets of seabed images, including 3 images taken without flash lamp, have been obtained by the GR camera. Some samples of images are shown in Fig. 3.2.1.5. Moreover, Fig. 3.2.1.6 shows the mosaiced image created by assembling 116 individual photo images. After surfaced, a test for the wireless LAN communication was done. Though succeeded in communication between the distance of 150 m, we could not achieve the self-homing of the vehicle, owing to the severe drift by waves and sea currents.

Maximum Dive Depth : 365 m

<Special Notes>

High-resolution sea bottom images by a digital camera (GR camera) became to be available from this dive. While we had failed in taking images during dive #28 by the vehicle trouble, we succeeded in taking sea bottom images for the first time in this dive. However, since vehicle troubles also happened during dives #30 and #31, #29 is said to be the only dive that obtained the sea bottom images.

Though ① and ② were taken under quite similar environmental conditions, lower half part of ② is mostly covered in white. This is because while the flash light reached every corner in taking ①, in taking ② on the other hand, long exposure time by automatic camera adjustment was set due to the flash light merely covering lower half part of the area. Reason of flash light coverage difference shown in these two pictures is thought to be the smaller distance to the object in ②, caused by the rising slant of sea bottom. To settle this problem, coverage area of flash light should be designed to reach every corner in the picture, even for the object such as slant sea bottom.

Though we designed installation of the flash to sufficiently cover the whole area of the picture, vibration loosened the pinning of the camera, letting the direction of flash light downward. By reinforcing the flash pinning, we fixed the direction of flash light in a more reliable manner. It is noted that in this area, optical reflection on the sea bottom was very strong since the bottom is covered with white sand of coral origin. In the next mission, it is necessary to adjust ISO sensitivity and altitude of the vehicle adapting to the bottom material.

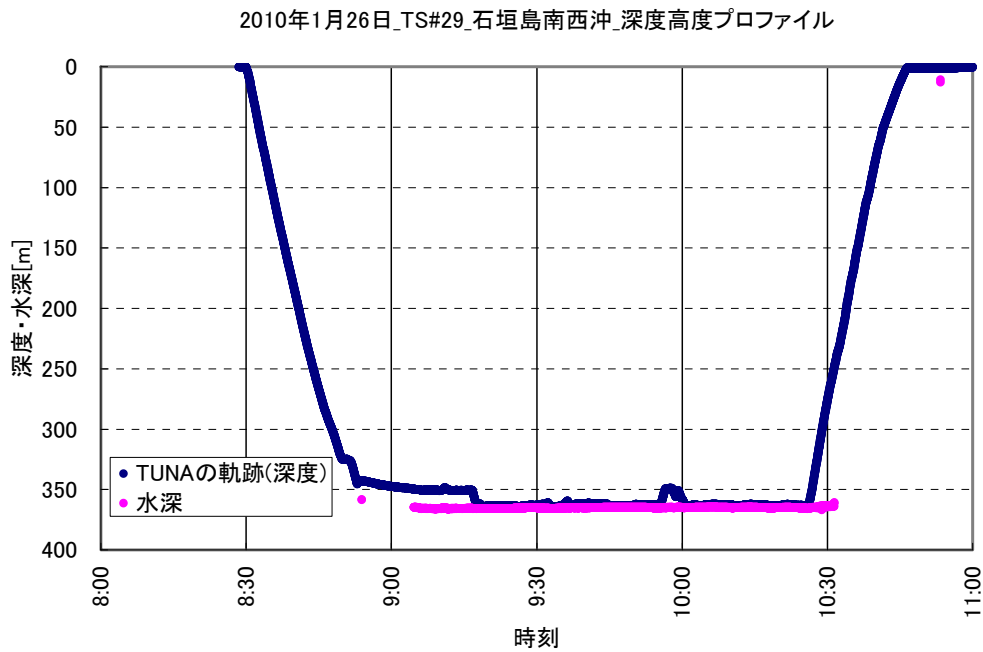


Fig. 3.2.1.4 Depth Profile during Dive #29.

Table 3.2.1.2 Event Logs during Dive #29

06:00 Severe Sea Condition in Kuroshima Knoll Area
06:20 Change the Observation Area (Changed to the Ridge off the Southwestern Ishigakijima)
⇒ Keeping over 1 km distance from the undersea cable laid between 24_10.0N and 13.0N.
07:00 Draw out A-Frame, and Move TS to Deck.
07:10 Connect Power Cable. Start-up TS. Restart-up TS due to GPS Positioning Failure.
07:35 GPS Positioning Starts. Start Static Test by restarting-up the PHINS. Operation Test.
08:20 Finish Static Test. Switch External to Internal Power Supply.
08:25 Prepare for the Dive (Test of Loading/Unloading Ballasts. Loads the Ballast)
08:28:32 Start the "Queuing Mode" in Dive Mission Program. Confirm LED Light is On.
08:30:01 Released from the Tether. Dive Starts.
08:30:41 Switch to the "Submerge Mode" in Dive Mission Program.
08:49:55 Transmit the SSBL Positioning (13, 131).
08:53:02 Transmit the SSBL Positioning (19, 141).
08:52:55 Switch to the "Static Test Mode" in Dive Mission Program. Release the Front Ballast.
08:53:55 Switch to the "Observation Mode" in Dive Mission Program (Target Altitude of 15 m).
09:10:23 Stops the Dive Mission by issuing False "Off Command" in GUI
09:11:01 Start Route Tracking Program
09:40:01, 09:41:14 Command of revising current vehicle position was issued, though aimed at designating a destination in GUI (caused by old version of dll).
09:55:28 Start the Dive Mission.
10:46:27 TS Surfaced.
10:58:02 Retrieval by Crane.

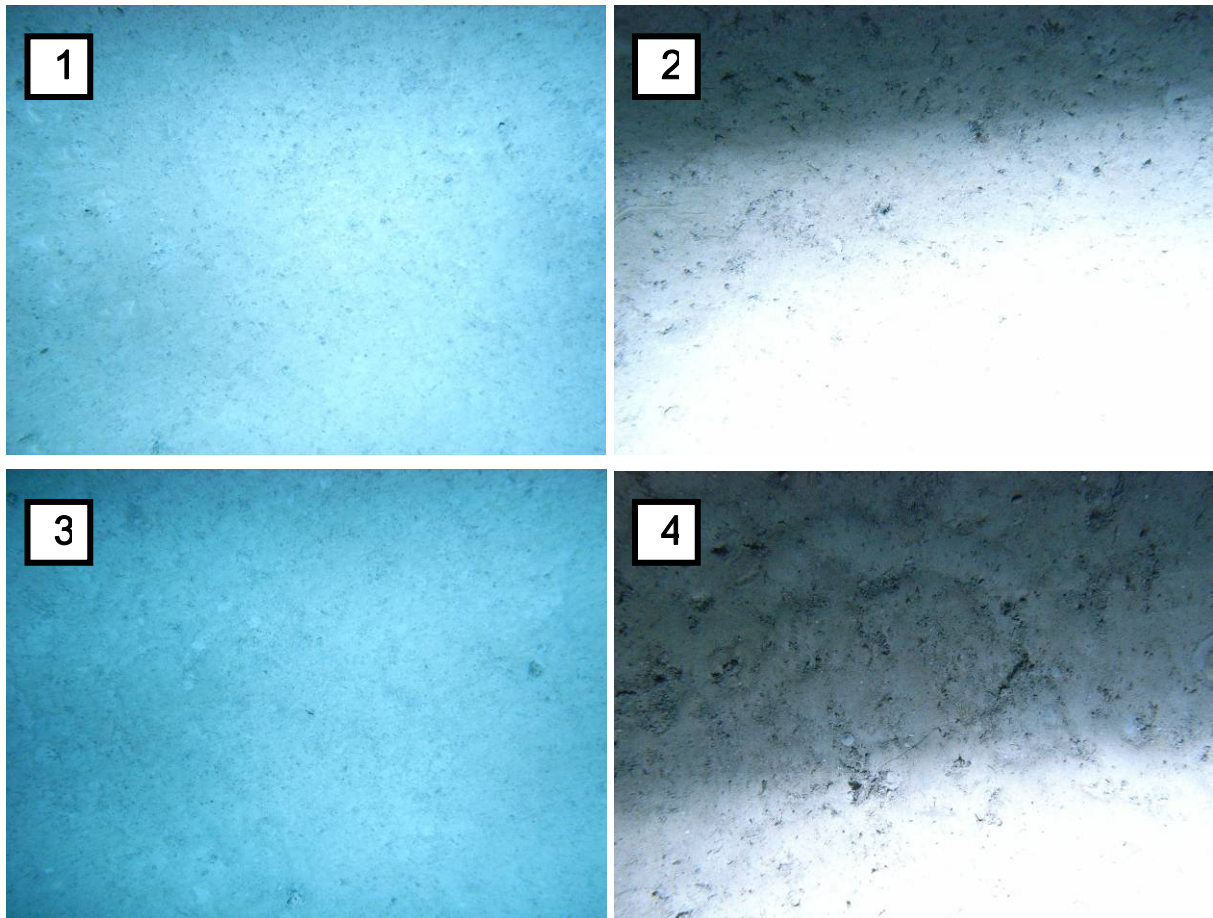


Fig. 3.2.1.5 GR Camera Images obtained during Dive #29

- ① : R0018980.JPG 9:19:06 1.55 m Altitude, 7.5° Descending Pitch
- ② : R0018982.JPG 9:19:28 1.72 m Altitude, 7.6° Descending Pitch
- ③ : R0019039.JPG 9:32:58 3.28 m Altitude, 6.2° Descending Pitch
- ④ : R0019051.JPG 9:34:36 1.78 m Altitude, 12.8° Descending Pitch

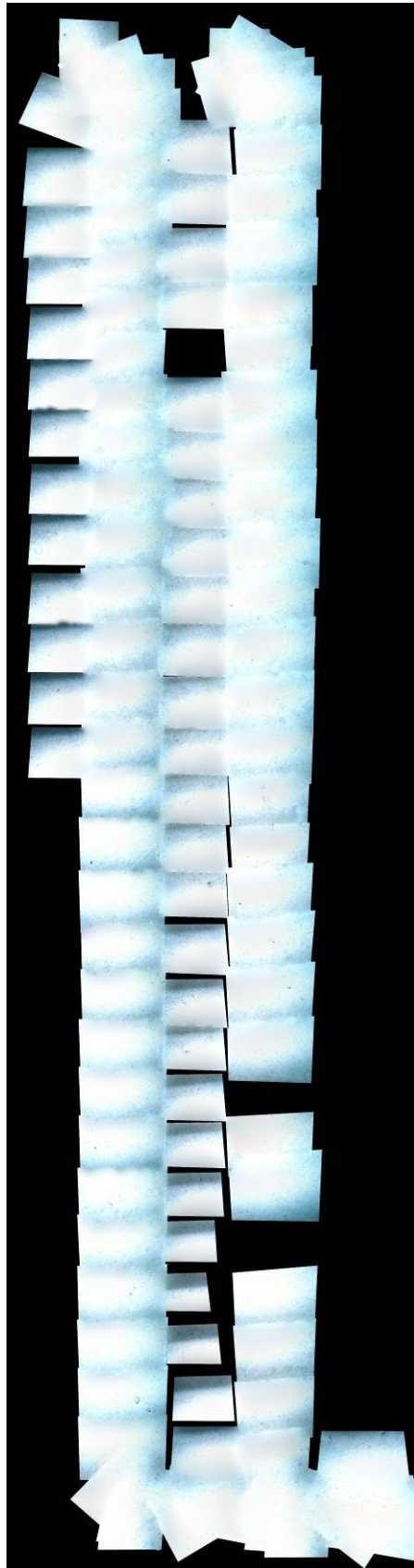


Fig. 3.2.1.6 Mosaiced image of the sea bed created by dive #29 (32×8 m)
(Rotated by 90° counterclockwise. Left direction corresponds to the north)

(3) Dive #30 (Fully Autonomous, Tethered Dive)

Date : 28th Jan., 2010 (Thu)

Dive Point : Cold Seep Activity Area in Kuroshima Knoll (Reference Point : 24_7.8N, 124_11.5 E)

Weather : Cloudy, Beaufort 6, 4 m of Wave Height

Schedule : Refer to Table 3.2.1.3 for the detailed schedule. Remarkable events are as follows.

13:25 Move Tuna-Sand to the Deck

14:32 Dive starts

15:42 Retrieval completed

Payload : pH meter, CT sensor

Dive Description : Calm sea state enabled the Kuroshima Knoll dive. Static test was successfully completed by initiating the GPS positioning after 3 minutes of the vehicle starting-up. As was done in Dive #28, until TS reaches the sea bed, acoustic link with support vessel was being established via transducers suspended on the port side. Results of this acoustic communication are shown in Table 3.2.1.4. All 16 trials of communication succeeded. However, as was indicated in the description of dive #28, the bug in acoustic communication task brought about abnormal operation by Sub-CPU, resulting in abrupt communication failure between the main CPU. Before the dive #31, we installed revised software, completing the debugging.

Maximum Dive Depth : 639 m

Table 3.2.1.3 Event Logs during Dive #30

13:25 Move TS to Deck.

13:30 Connect Power Cable. Start-up TS. Start Static Test.

13:35 GPS Positioning Starts. Operation Test.

14:15 Finish Static Test. Switch External to Internal Power Supply. Turn on the Trigger Signal for GR Camera. Do Test Shooting.

14:25 Prepare for the Dive (Test of Loading/Unloading Ballasts. Loads the Ballast)

14:31:08 Start the "Queuing Mode" in Dive Mission Program. Confirm LED Light is On.

14:32:36 Released from the Tether. Dive Starts.

15:07:09 Transmit the SSBL Positioning.

15:07:42 Switch to the "Static Test Mode" in Dive Mission Program. Release the Front Ballast.

(↑ Escaped the False Decision of being near the Seabed, even though Severe Noise was taken at the Depth of 424 m)

※ We set the Near Bottom Collision is to be activated under the condition of over 500 m depth, as well as of repeated occurrences larger than a critical no.

15:08:42 Switch to the "Observation Mode" in Dive Mission Program (Target Altitude of 15 m).

15:12:19 Disconnection between Sub-CPU (for Serial Link) and Main CPU (for Vehicle

Control).

15:12:23 Switch to the "Surfacing Mode" in Dive Mission Program due to the Malfunction Detection.

15:12:25 Terminate the Dive Mission Program. Start Emergent Surfacing.

15:17:16 Failed in receiving any sensor data, we made the vehicle surface for avoiding danger.

15:42 Retrieve the Vehicle by Crane.

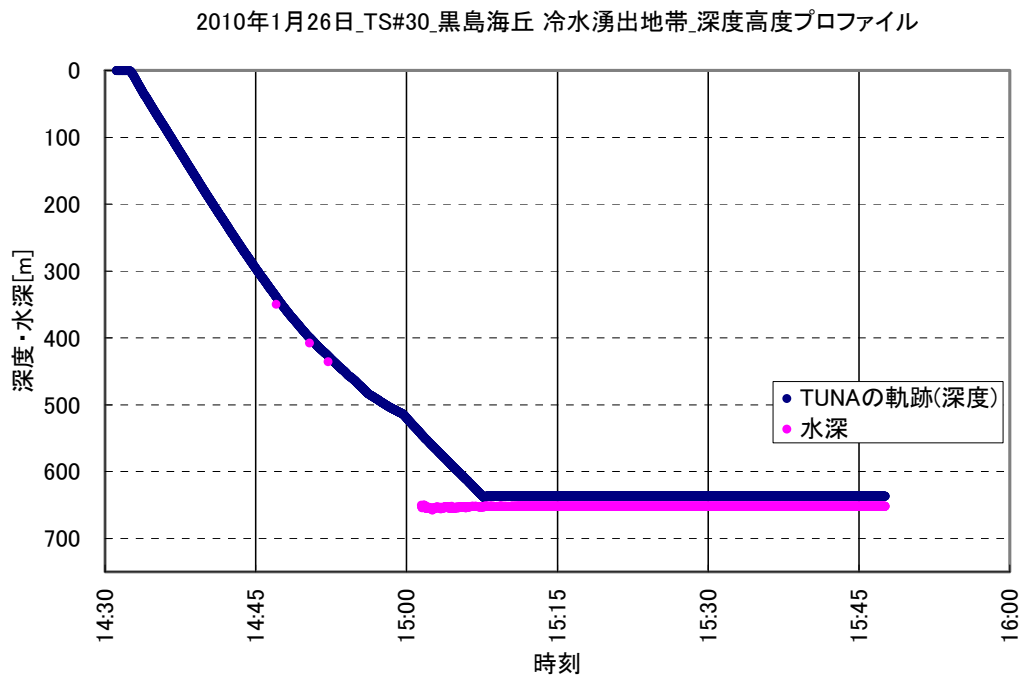


Fig. 3.2.1.7 Depth Profile during Dive #30

Table 3.2.1.4 Results of Acoustic Communication during Dive #30

通し番号	船上传信時刻	Tuna送受信時刻	(秒)		往復時間	TS深度
			Down	Up		
1	14:44:00	14:44:02	02	06	08	275.8
2	14:44:35	14:44:41	06	02	08	290.2
3	14:45:10	14:45:15	05	03	08	302.2
4	14:45:40	14:45:42	02	08	10	311.6
5	14:46:10	14:46:15	05	02	07	323.2
6	14:46:40	14:46:51	11	02	13	335.6
7	14:47:15	14:48:00	45	18	01:03	359.1
8	14:48:35	14:48:37	02	11	13	370.4
9	14:49:10	14:49:18	08	09	17	382.2
10	14:49:45	14:49:46	01	10	11	390.7
11	14:50:15	14:50:20	05	16	21	400.1
12	14:50:55	14:50:59	04	20	24	410.3
13	14:51:40	14:51:41	01	13	14	420.6
14	14:52:10	14:52:13	03	05	08	427.9
15	14:52:40	14:52:43	03	08	11	435.5
16	14:53:10	14:53:21	11	05	16	444.7
平均			07	09	16	

(4) Dive #31 (ROV Mode Dive)

Date : 30th Jan., 2010 (Sat)

Dive Point : Cold Seep Activity Area in Kuroshima Knoll (Reference Point : 24_7.8N, 124_11.5 E)

Weather : Cloudy, Beaufort 3, 2 m of Wave Height

Schedule : Refer to Table 3.2.1.5 for the detailed schedule. Remarkable events are as follows.

13:20 Move TS to Deck.

14:24 Released from the Tether. Dive Starts.

16:09 Retrieval Completed.

Payload : pH meter, CT sensor

Dive Description : Since the GPS positioning did not function properly, TS was in static test using DVL after reaching the sea bottom. Horizontal positioning depended on the SSBL. After the mission, vendor made investigation and reported that the inside of antenna mold was broken. As a remedy hereafter, we have decided to always prepare for a redundant conventional GPS antenna (to be removed right before the dive). In addition, since we found that the GPS positioning on the deck of support vessel is not so fine, we have decided to install another GPS antenna on the bridge of the support vessel and transmit the received signal to the vehicle via wireless LAN, as the 2nd GPS positioning mean. After reaching the sea bottom, heading control, and position control subsequently, failed as the tether tangled by the stream strongly pulled the vehicle. The situation happened can be recognized by Fig. 3.2.1.8. While the vehicle destined for (0 , 0) initially, due to the strong tension applied from the tether, it could not follow correct heading reference even after reaching the vicinity of destination. As a result, the vehicle failed in reaching the destination, continuing to get forward. In the outer sea region where the effect of current is prominent, it is preferable to select untethered vehicle operation.

Maximum Dive Depth : 630 m

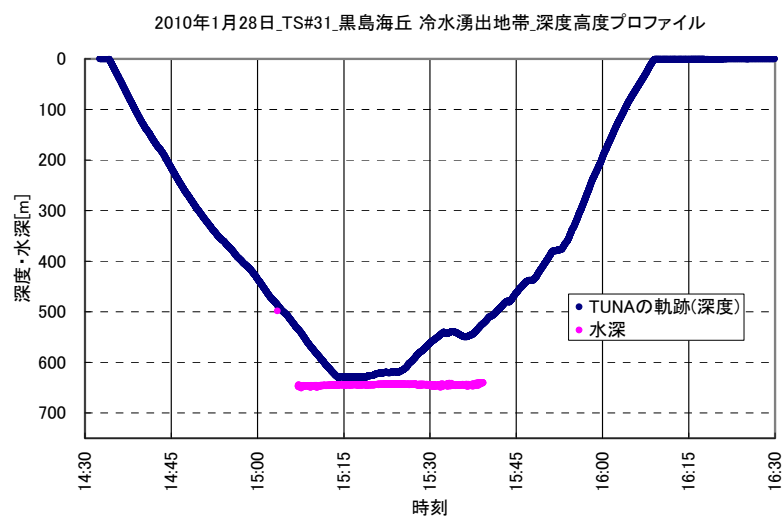


Fig. 3.2.1.8 Depth Profile during Dive #31

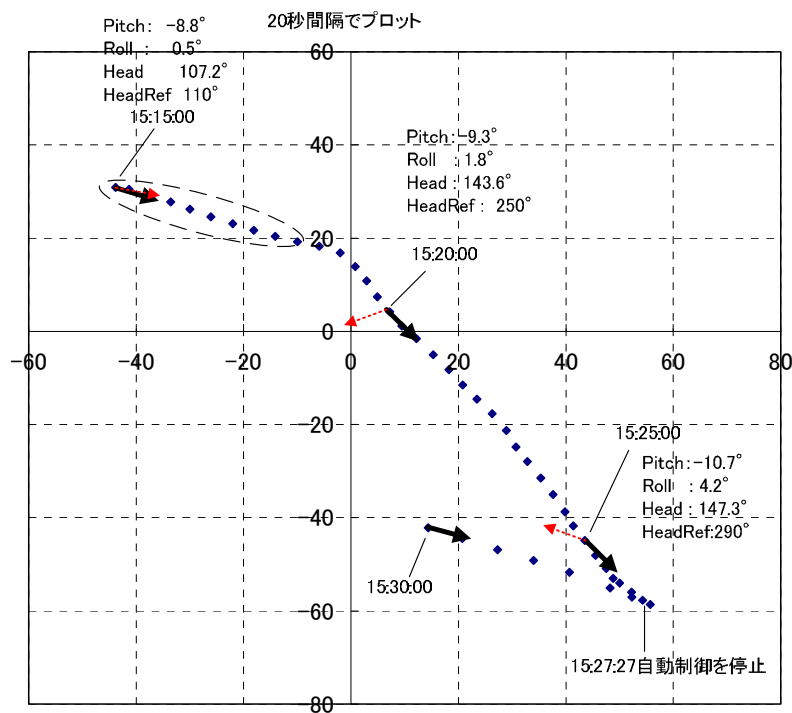


Fig. 3.2.1.9 Uncontrollable Situation happened (2D Plot)
 (Blue marks indicate vehicle position per every second. Black arrows represent vehicle headings.
 Red dotted arrows represent heading reference. All data are taken from INS).

Table 3.2.1.5 Event Logs during Dive #31

13:20	Move TS to Deck.
13:30	Connect Power Cable. Start-up TS. Start Static Test. GPS Positioning Failed, However.
13:40	Operation Test.
13:50	Change the Dive Starting Time
14:00	Continue to GPS Positioning Failure. (7 Satellites were found to be available by a Portable GPS, However)
14:20	Decide to perform Static Test near the Bottom. Finish Static Test.
14:25	Switch External to Internal Power Supply.
14:25	Prepare for the Dive (Test of Loading/Unloading Ballast. Unloaded: 8 kg, Loaded : 5 kg)
14:34:08	Released from the Tether. Dive Starts.
15:07:22	Turn on the PHINS near the Bottom.
15:07:38	Restart the PHINS. PHINS starts to generate Outputs (105.6 m of Altitude).
15:12:40	Finish Rough Alignments.
15:13:57	SSBL Position Transmission by GUI.
15:14:01	Near the Bottom, Start the "Queuing Mode" in Dive Mission Program.
	SSBL Position Transmission by GUI.

15:14:01 Switch to the "Submerge Mode" in Dive Mission Program.
15:14:06 Switch to the "Static Test Mode" in Dive Mission Program. Release the Front Ballast.
15:15:06 Switch to the "Observation Mode" in Dive Mission Program (Target Altitude of 15 m)
15:27:25 Terminate the Dive Mission Program Manually, due to the Drift happened.
16:09:07 Surfaced. Retries GPS Positioning at the Surface.
16:20 GPS Positioning was Unavailable.
16:30 Complete the Retrieval.

4. Observation Results

4.1 Daiyonyonaguni Knoll

4.1.1 Side Scan Data

In Fig. 4.1.1.1, side scan data along the trough lines between Hotakaike and Nishihozawa, acquired from the dive starting from Daiyonyonagunikaiyutakezawa are shown. Spots for hydrothermal activities already known are marked in the lower right part in the figure, which is consistent with the results found in Ref. 1.

4.1.2 Sensor Data

During the Daiyonyonaguni dive, near the known sites for hydrothermal vents, we had large outlying observations in turbidity, manganese concentration, and pH data. Though not finally clarified yet, we took another noticeable outlying observation, along in the trough running northwards. This implies multiple hydrothermal activities in this site.

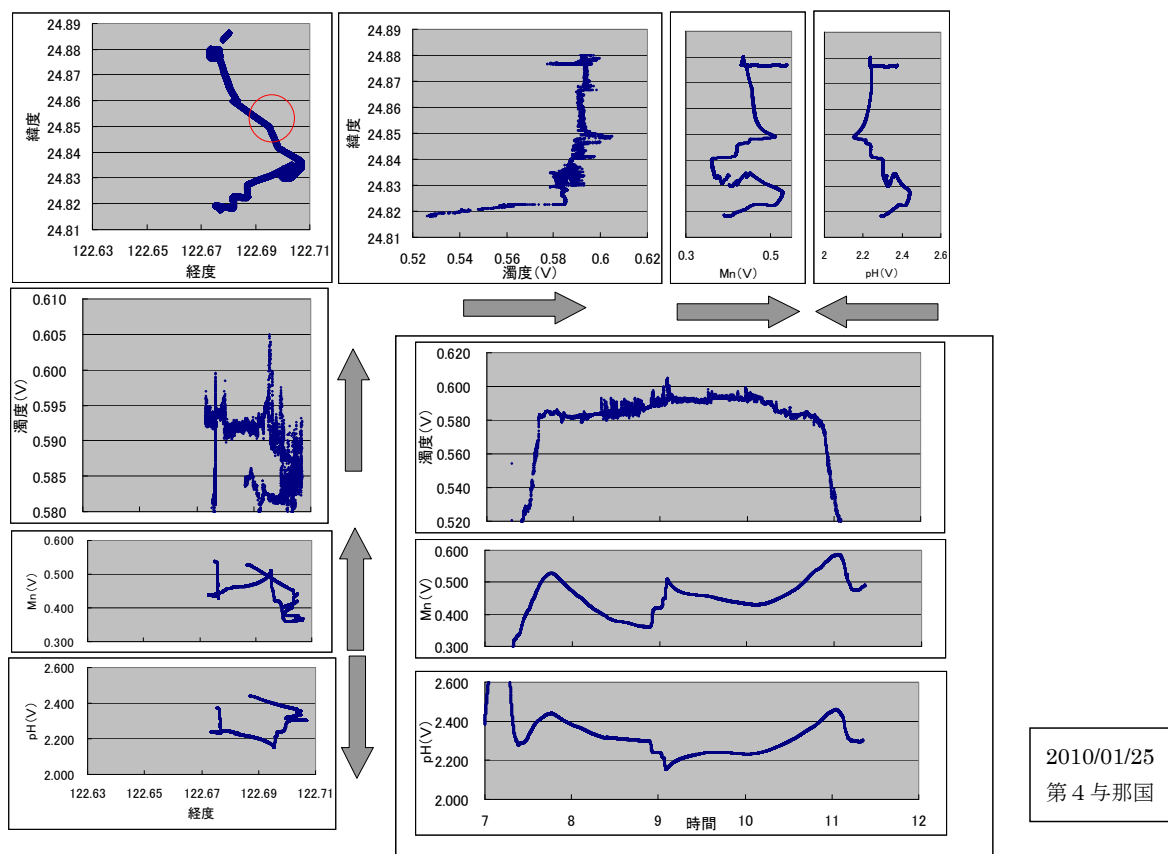


Fig. 4.1.2.1 Outlying Observations in Turbidity, Manganese Concentration, and pH taken in Daiyonyonaguni Site (Directions of Arrows indicate Outlying Observations)

4.1.3 Results by Chemical Sensors

In Kuroshima Knoll site, we did not have any outlying observation by GAMOS, a sensor for measuring manganese concentration, and by turbidimeter which principally detects metallic sulfide, as the site is characterized by the methane hydrate. In respect of pH and oxidation-reduction potential (ORP) however, we could have a few outlying observations. Concerning these observations, two possibilities are to be addressed. That is, the detections could be arisen from 1) plume carried by sea currents, or 2) the new hydrothermal vents not found yet.

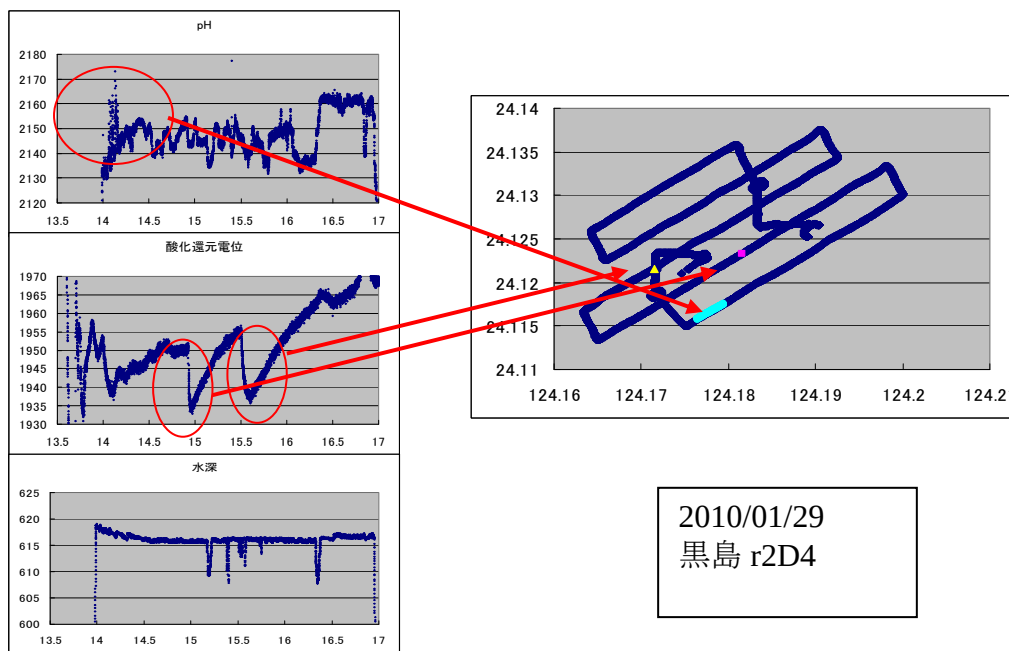


Fig. 4.1.3.1 Outlying observations in oxidation-reduction potential (ORP), and pH taken in Kuroshima Knoll site.

4.2 Kuroshima Knoll

4.2.1 Side Scan Data

In Figs. 4.2.1.1 and 4.2.1.2, side scan data covering most of above 700 m region in Kuroshima Knoll site are shown. Transmitter and receiver of side scan sonar are fitted pairwise on left and right sides of r2D4. As a result, shade in the created image remains away from the r2D4. If we simply stitch the images together, it is not easy to comprehend the integrated image, for the direction of each shade is diverse. In this respect, we show the mosaiced images of seabed perspective views, seen from North in Fig. 4.2.1.1, and South in Fig. 4.2.1.2.

5. Future Perspectives and Suggestions

In this navigation, by suggesting a new methodology for surveying sea bottom of complex topography, we completed the survey of troughs in Daiyonyonaguni Knoll. In applying our new survey methodology, cruising type AUV is deployed first. And then, hovering type AUV undertakes second mission of making fine and detailed survey over the points of outlying observation such as abnormal bottom topography or potential hydrothermal vent, which are detected during the cruising type AUV mission. Our approach is believed to propose a potent mean, reinforcing the discovery of new sites of unknown hydrothermal vents.

Despite severe sea condition, we deployed the cruising type AUV r2D4 over an area of known hydrothermal vent (we named it Takazawa). We succeeded in acquiring high-resolution side scan images over this area, making the vehicle navigate covering 300 m wide ridge running north-south (Takezawa - Hotakaike - Nishihozawa). At first, r2D4 was planned to make a round trip, following the survey line being two cables apart in east and west. However, as the sea moved to more and more severe state, we changed the navigation plan as to command forced surfacing, after letting the vehicle turn around the north end of Nishihozawa. The key issue of this dive was how accurately we can control the vehicle to follow the reference survey line under the environment of strong current. To achieve this, at the beginning of the dive, after reaching the depth of 1400 m with the maximum descending speed, vehicle receives acoustic signal carrying corrected position of it. Making use of vessel-mounted SSBL positioning, precise position of the vehicle is computed by the unit of 0.1 cables. By replacing with the received value, position in INS record is updated. As a result of our method updating vehicle position as explained, we succeeded in completing the survey keeping the course deviation less than 0.5 cables.

Though we were equipped with new mean to achieve low altitude survey over the narrow-band ridge such as Daiyonyonaguni, severe sea conditions made us achieve a single dive only.

During the Kuroshima Knoll survey, by exploiting the full opportunities available, we succeeded in creating sea bottom topography of 1 m altitude by an interferometry sonar, as well as high-resolution wide range side scan image. We found a few large pockmarks in the site, which had not been reported in the survey results by Dolphin-3K or Shinkai 2000.

By deploying the hovering type AUV Tuna-Sand (TS), we also tried automated image taking of sea bed. Though TS could not be deployed in Daiyonyonaguni area, as we completed its basic operation tests, we confirm that it is possible to realize on-site cooperation between cruising type and hovering type AUVs. On the basis of achievements obtained from this cruise, in order to make best use of the allowed shiptime, we are planning to apply a new survey strategy to Daiyonyonaguni survey such that cruising type AUV makes wide range image mapping of the sea bed during nighttime, followed by the high-resolution image mapping by hovering type AUV (or ROV) during daytime.

6. Acknowledgement

The author would like to express thanks to all crew members of "Yokosuka", including Captain Tanaka. Thanks to their every effort, all dives were conducted without any serious accident. The author think that however, difficulties related to the releasing and retrieving vehicle are remained to be improved. This should be done by way of vehicle design or invention of new kinds of jigs.

3.1 Tables and Figures

Table 3.1.1 List of dives

Dive No.	Date	Location	Dive Start			Surface Time	Submerge Time	Max Depth
			Latitude	Longitude	Time			
			Deg:Min:Sec		Hr:Min	Hr:Min	Hr:Min	m
65	24	Kuroshima	24:09:24N	124:11:06E	9:41	10:52	1:10	604
66	25	Daiyonyonaguni	24:49:08N	122:40:32E	7:20	11:08	3:48	1343
67	29	Kuroshima	24:07:23N	124:10:39E	13:39	17:21	3:41	610

Table 3.1.1.1 Event table for dive #65

9:41:33	Dive program starts
9:41:33	course:1 ptn:3
9:47:59	Finish Ptn3 at Keetime
9:48:00	course:2 ptn:3
9:54:09	Finish Ptn3 at Keetime
9:54:09	course:3 ptn:3
9:56:48	evasion check 1 order
9:56:48	evasion ptn101 (SC)// chk1
10:33:48	course:3 ptn:3
10:36:20	dive Ballast Release
10:36:21	Dive program stops
11:23:11	Entire program stops

Fig. 3.1.1.1 Planned route for dive #65

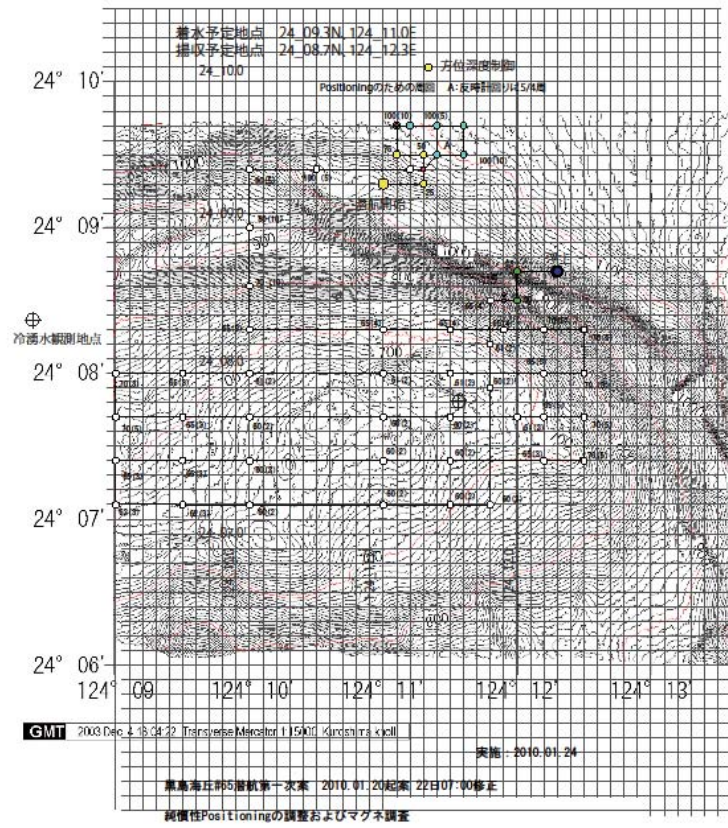


Fig. 3.1.1.2 Horizontal SSBL positions in dive #65

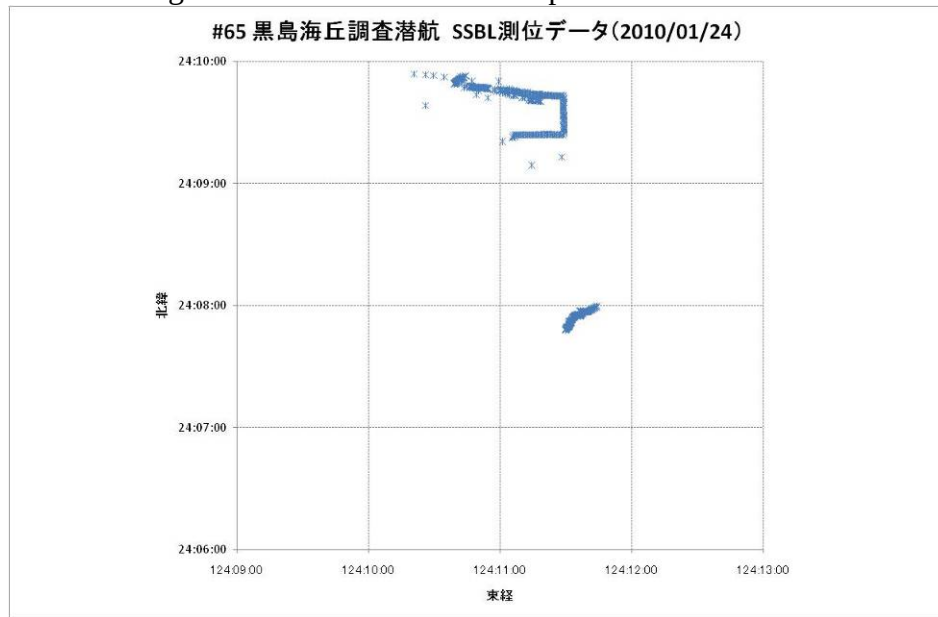


Fig. 3.1.1.3 Depth profile during dive #65

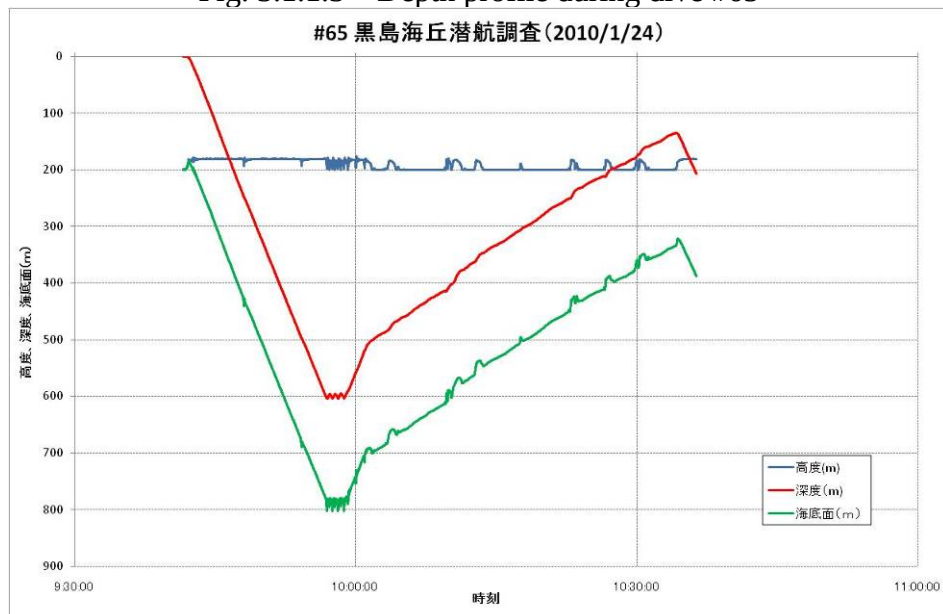


Table 3.1.1.2 Event table for dive #67

13:39:32	Dive program starts
13:39:32	course:1 ptn:4
13:46:43	Finish Ptn4 at PointZone & DepthZone
13:46:43	course:2 ptn:4
13:53:07	Finish Ptn4 at PointZone & DepthZone
13:53:07	course:3 ptn:17
13:53:07	Ptn17 (ballast for Dive power ON)
13:53:07	Ptn17 (ballast for regulation power OFF)
13:53:07	Ptn17 (ballast for float power OFF)
13:53:08	course:4 ptn:16
13:53:08	Ptn16 (SSS/IFS power ON)
13:53:08	course:5 ptn:12
13:53:08	Ptn12 (Portrait Processor ON)
13:53:08	course:6 ptn:3
13:53:24	Finish Ptn3 at Keetime
13:53:24	course:7 ptn:3
13:53:54	Finish Ptn3 at Keetime
13:53:54	course:8 ptn:3
13:54:22	Finish Ptn3 at Keetime
13:54:23	course:9 ptn:3
13:55:11	Finish Ptn3 at Keetime
13:55:11	course:10 ptn:3
13:55:40	Finish Ptn3 at Keetime
13:55:41	course:11 ptn:3
13:56:14	Finish Ptn3 at Keetime
13:56:14	course:12 ptn:3
13:56:47	Finish Ptn3 at Keetime
13:56:48	course:13 ptn:6
14:02:05	Finish Ptn6 at PointZone
14:02:05	course:14 ptn:6
14:11:20	Finish Ptn6 at PointZone
14:11:20	course:15 ptn:6
14:20:20	Finish Ptn6 at PointZone
14:20:20	course:16 ptn:6
14:29:17	Finish Ptn6 at PointZone
14:29:17	course:17 ptn:6
14:33:03	Finish Ptn6 at PointZone
14:33:03	course:18 ptn:6
14:43:53	Finish Ptn6 at PointZone
14:43:53	course:19 ptn:6
14:54:44	Finish Ptn6 at PointZone
14:54:44	course:20 ptn:6
15:05:50	Finish Ptn6 at PointZone
15:05:50	course:21 ptn:6
15:17:10	Finish Ptn6 at PointZone

15:17:10	course:22 ptn:6
15:21:14	Finish Ptn6 at PointZone
15:21:14	course:23 ptn:6
15:22:49	evasion check 2 order
15:22:49	dive Ballast Release
15:22:49	evasion ptn111 (turn over)// chk2
15:30:18	Finish Ptn6 at PointZone
15:30:18	course:24 ptn:6
15:30:39	evasion check 2 order
15:30:39	dive Ballast Release
15:30:40	evasion ptn111 (turn over)// chk2
15:34:37	newfly normal course ptn continue
15:39:09	Finish Ptn6 at PointZone
15:39:09	course:25 ptn:6
15:43:46	evasion check 2 order
15:43:46	dive Ballast Release
15:43:47	evasion ptn111 (turn over)// chk2
15:44:46	newfly normal course ptn continue
15:47:57	Finish Ptn6 at PointZone
15:47:57	course:26 ptn:6
15:52:29	Finish Ptn6 at PointZone
15:52:29	course:27 ptn:6
15:56:29	Finish Ptn6 at PointZone
15:56:29	course:28 ptn:6
16:02:15	Finish Ptn6 at PointZone
16:02:15	course:29 ptn:6
16:13:47	Finish Ptn6 at PointZone
16:13:47	course:30 ptn:6
16:25:36	Finish Ptn6 at PointZone
16:25:36	course:31 ptn:6
16:31:12	Finish Ptn6 at PointZone
16:31:12	course:32 ptn:6
16:35:17	Finish Ptn6 at PointZone
16:35:17	course:33 ptn:6
16:39:50	Finish Ptn6 at PointZone
16:39:50	course:34 ptn:6
16:48:36	Finish Ptn6 at PointZone
16:48:36	course:35 ptn:6
16:53:01	Finish Ptn6 at PointZone
16:53:01	course:36 ptn:6
16:57:02	Finish Ptn6 at PointZone
16:57:02	course:37 ptn:4
17:01:42	Finish Ptn4 at PointZone & DepthZone
17:01:42	course:38 ptn:3
17:02:06	Finish Ptn3 at Keetime

17:02:06	course:39 ptn:3
17:02:41	Finish Ptn3 at Keetime
17:02:41	course:40 ptn:3
17:03:12	Finish Ptn3 at Keetime
17:03:12	course:41 ptn:3
17:04:02	Finish Ptn3 at Keetime
17:04:02	course:42 ptn:3
17:04:34	Finish Ptn3 at Keetime
17:04:34	course:43 ptn:3
17:05:10	Finish Ptn3 at Keetime
17:05:10	course:44 ptn:3
17:05:43	Finish Ptn3 at Keetime
17:05:43	course:45 ptn:12
17:05:43	Ptn12 (Portrait Processer OFF)
17:05:44	course:46 ptn:16
17:05:44	Ptn16 (SSS/IFS power OFF)
17:05:44	course:47 ptn:17
17:05:44	Ptn17 (ballast for Dive power ON)
17:05:44	Ptn17 (ballast for regulation power ON)
17:05:44	Ptn17 (ballast for float power ON)
17:05:44	course:48 ptn:4
17:12:12	Finish Ptn4 at PointZone & DepthZone
17:12:12	course:49 ptn:4
17:19:38	Finish Ptn4 at PointZone & DepthZone
17:19:38	course:50 ptn:3
17:19:51	Finish Ptn3 at Keetime
17:19:52	Dive program stops
17:40:08	Entire program stops

Fig. 3.1.1.4 Planned route for dive #67

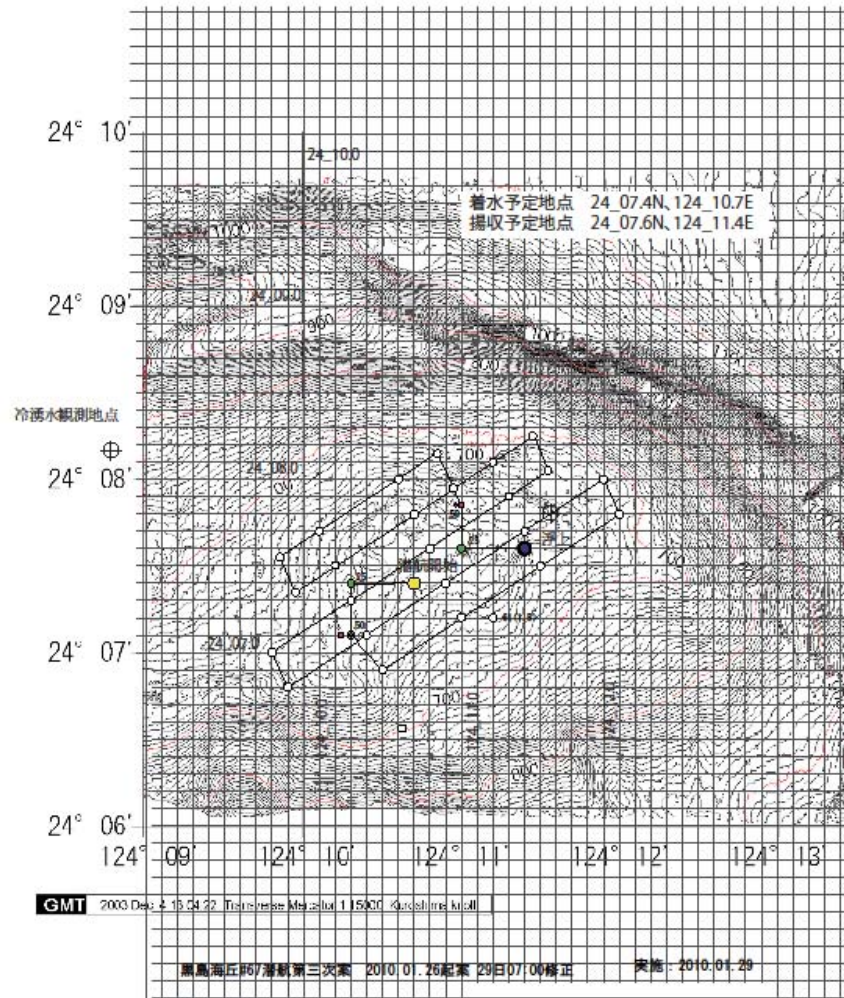


Fig. 3.1.1.5 Horizontal SSBL positions in dive #67

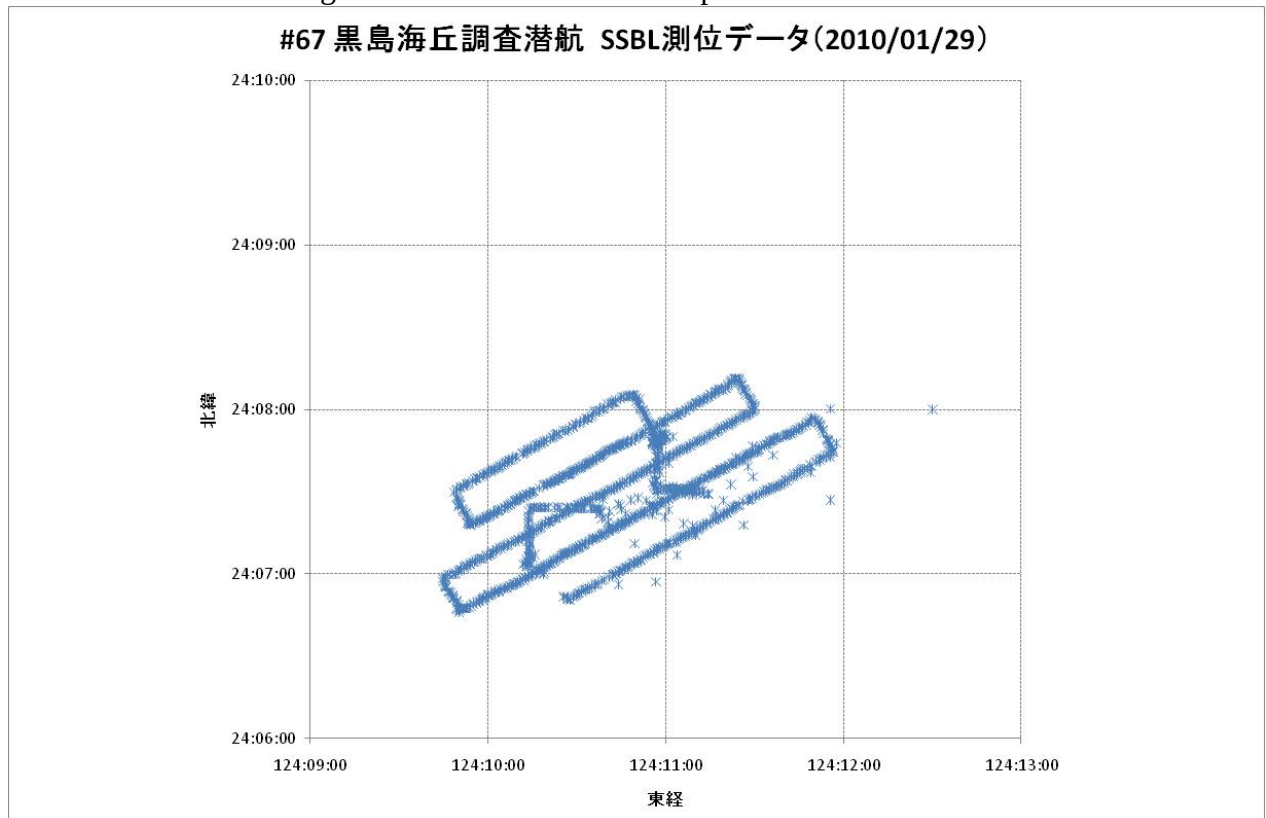


Fig. 3.1.1.6 Depth profile during dive #67

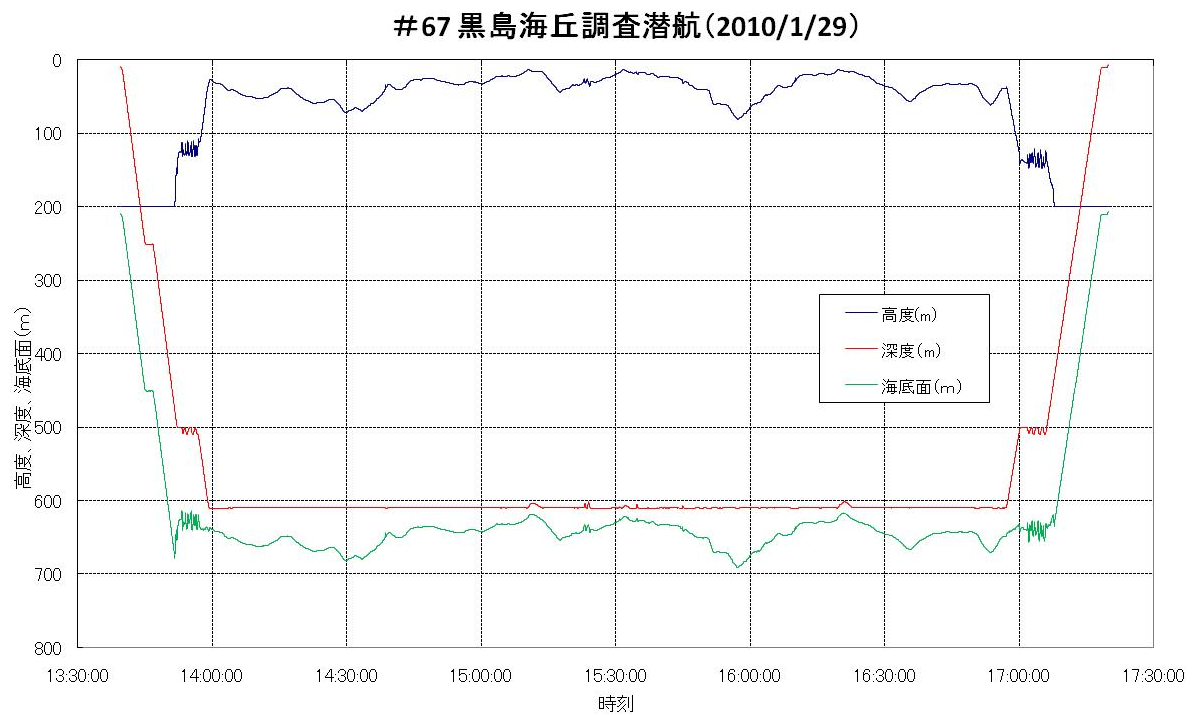


Table 3.1.2.1 Event table for dive #66

7:20:38	Dive program starts
7:20:38	course:1 ptn:3
7:28:45	Finish Ptn3 at Keetime
7:28:45	course:2 ptn:3
7:34:13	Finish Ptn3 at Keetime
7:34:13	course:3 ptn:3
7:39:52	Finish Ptn3 at Keetime
7:39:52	course:4 ptn:3
7:45:34	Finish Ptn3 at Keetime
7:45:34	course:5 ptn:6
8:05:23	Finish Ptn6 at PointZone
8:05:24	course:6 ptn:17
8:05:24	Ptn17 (ballast for Dive power ON)
8:05:24	Ptn17 (ballast for regulation power OFF)
8:05:24	Ptn17 (ballast for float power OFF)
8:05:24	course:7 ptn:6
8:07:34	Finish Ptn6 at PointZone
8:07:35	course:8 ptn:6
8:10:54	Finish Ptn6 at PointZone
8:10:55	course:9 ptn:6
8:16:09	Finish Ptn6 at PointZone
8:16:09	course:10 ptn:6
8:16:54	Finish Ptn6 at PointZone
8:16:55	course:11 ptn:6
8:19:22	Finish Ptn6 at PointZone
8:19:23	course:12 ptn:6
8:25:41	Finish Ptn6 at PointZone
8:25:41	course:13 ptn:6
8:29:14	Finish Ptn6 at PointZone
8:29:14	course:14 ptn:6
8:30:11	Finish Ptn6 at PointZone
8:30:12	course:15 ptn:6
8:32:58	Finish Ptn6 at PointZone
8:32:59	course:16 ptn:6
8:34:48	Finish Ptn6 at PointZone
8:34:49	course:17 ptn:16
8:34:49	Ptn16 (SSS/IFS power ON)
8:34:49	course:18 ptn:12
8:34:49	Ptn12 (Portrait Processor ON)
8:34:49	course:19 ptn:3
8:35:07	Finish Ptn3 at Keetime
8:35:07	course:20 ptn:3
8:35:47	Finish Ptn3 at Keetime
8:35:47	course:21 ptn:3
8:36:25	Finish Ptn3 at Keetime

8:36:25	course:22 ptn:3
8:37:25	Finish Ptn3 at Keetime
8:37:25	course:23 ptn:3
8:37:53	Finish Ptn3 at Keetime
8:37:53	course:24 ptn:3
8:38:26	Finish Ptn3 at Keetime
8:38:26	course:25 ptn:3
8:38:59	Finish Ptn3 at Keetime
8:38:59	course:26 ptn:6
8:41:51	Finish Ptn6 at PointZone
8:41:52	course:27 ptn:6
8:42:52	Finish Ptn6 at PointZone
8:42:52	course:28 ptn:6
8:45:54	Finish Ptn6 at PointZone
8:45:54	course:29 ptn:6
8:56:06	Finish Ptn6 at PointZone
8:56:06	course:30 ptn:6
9:06:16	Finish Ptn6 at PointZone
9:06:16	course:31 ptn:6
9:24:34	Finish Ptn6 at PointZone
9:24:35	course:32 ptn:6
9:33:08	Finish Ptn6 at PointZone
9:33:09	course:33 ptn:6
9:45:54	Finish Ptn6 at PointZone
9:45:55	course:34 ptn:6
9:46:49	Finish Ptn6 at PointZone
9:46:49	course:35 ptn:6
9:49:29	Finish Ptn6 at PointZone
9:49:29	course:36 ptn:6
9:50:28	Finish Ptn6 at PointZone
9:50:28	course:37 ptn:6
9:53:31	Finish Ptn6 at PointZone
9:53:31	course:38 ptn:6
9:54:28	Finish Ptn6 at PointZone
9:54:28	course:39 ptn:6
9:57:08	Finish Ptn6 at PointZone
9:57:08	course:40 ptn:6
9:58:07	Finish Ptn6 at PointZone
9:58:07	course:41 ptn:6
10:00:46	dive Ballast Release
10:00:46	潜航プログラムストップ
10:45:47	Finish Ptn1 at VTH/ELV/SPL
11:08:33	Ptn20 (spiral) output
11:08:33	Finish Ptn20 at float to 0m
11:32:52	全プログラム停止

Fig. 3.1.2.1 Planned route for dive #66.

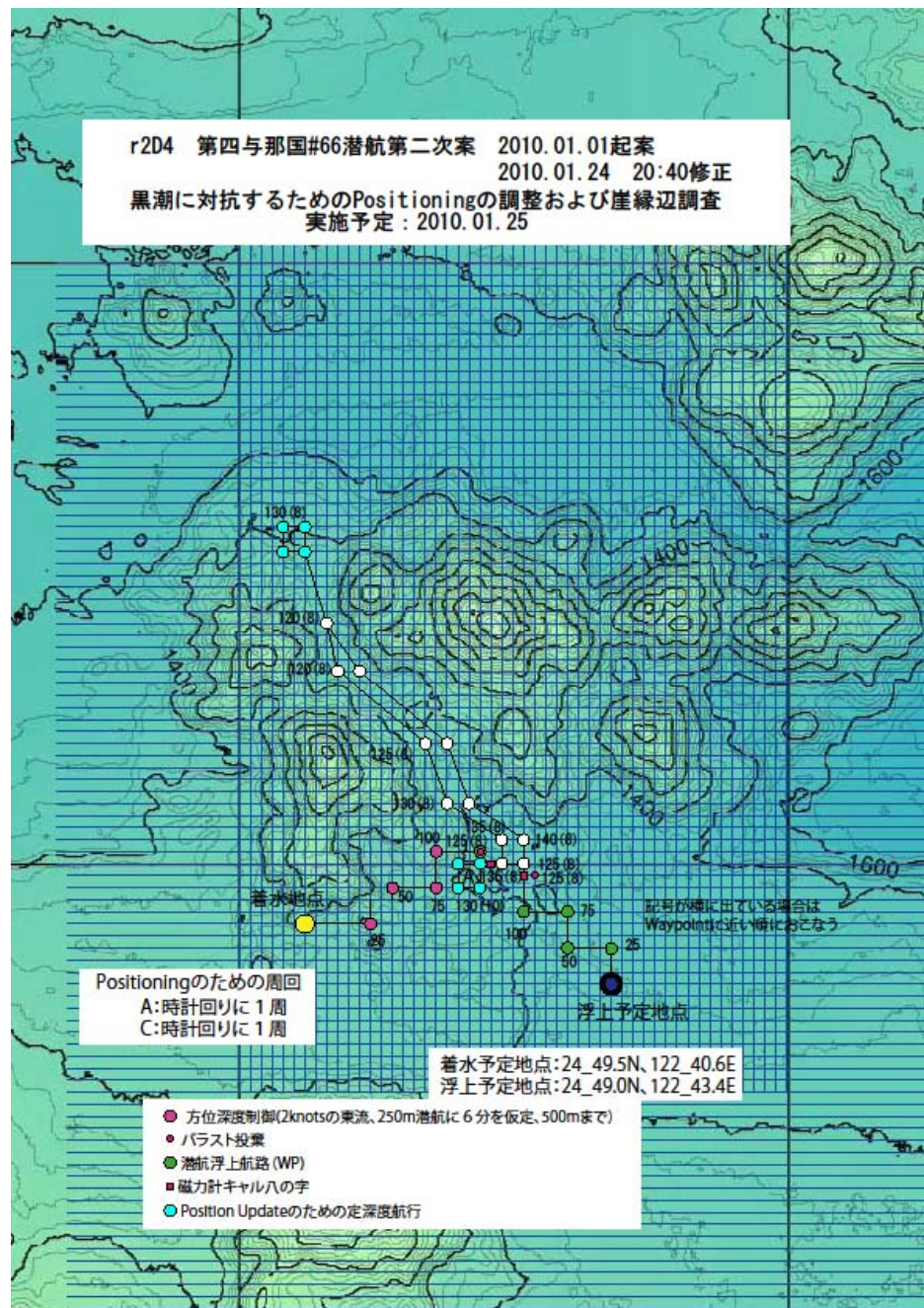


Fig. 3.1.2.2 Horizontal SSBL positions in dive #66

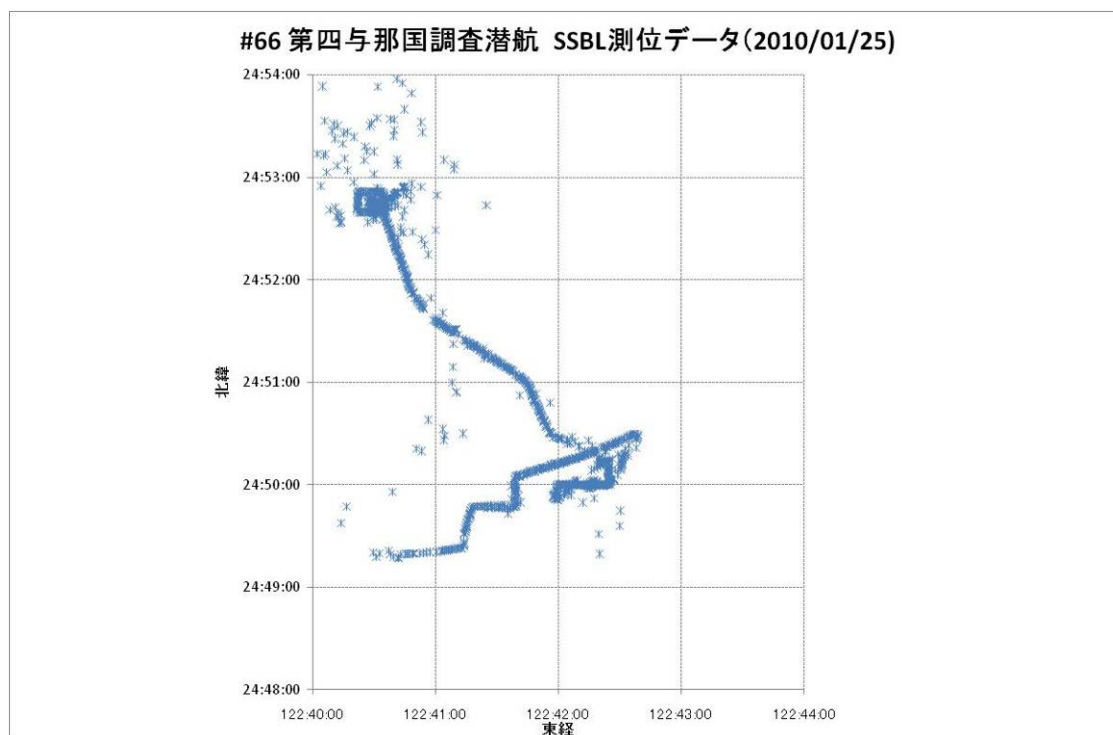


Fig. 3.1.2.3 Depth Profile during dive #66.

#66 第四与那国調査潜航(2010.1.25)

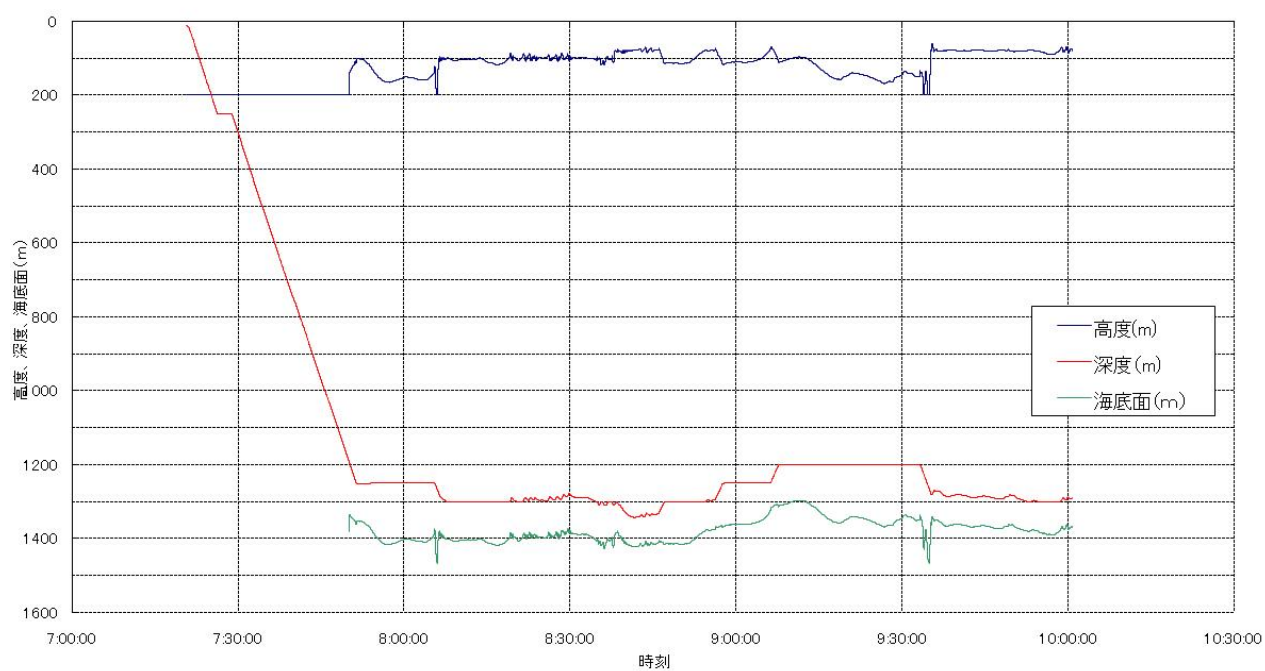


Fig. 4.1.1.1 Side scan image of the ridge in Daiyonyonagunikaikyutakezawa-Hotakaiké-Nishihozawa.

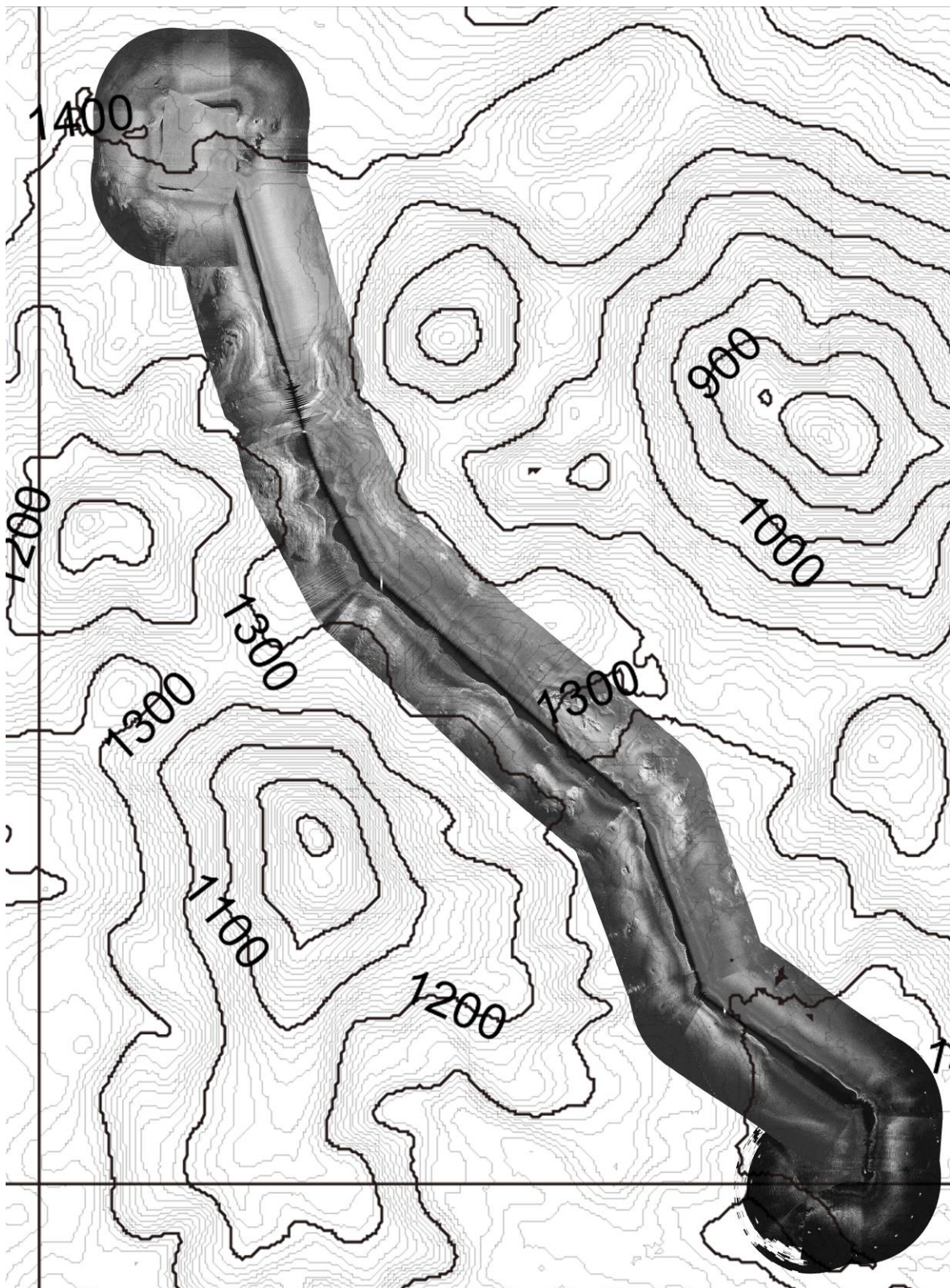


Fig. 4.2.1.1 Side scan image of Kuroshima Knoll (1) perspective view seen from north.

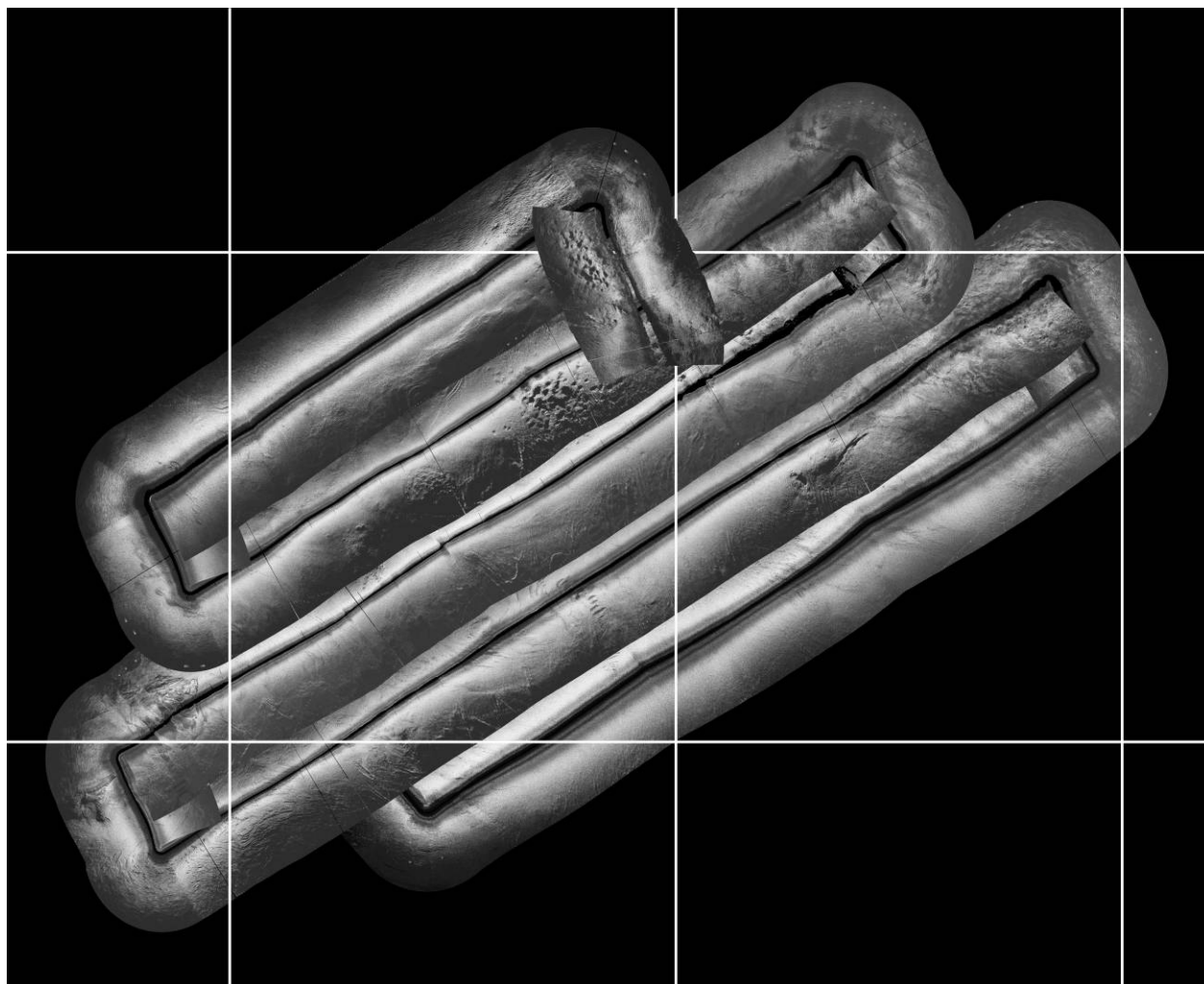
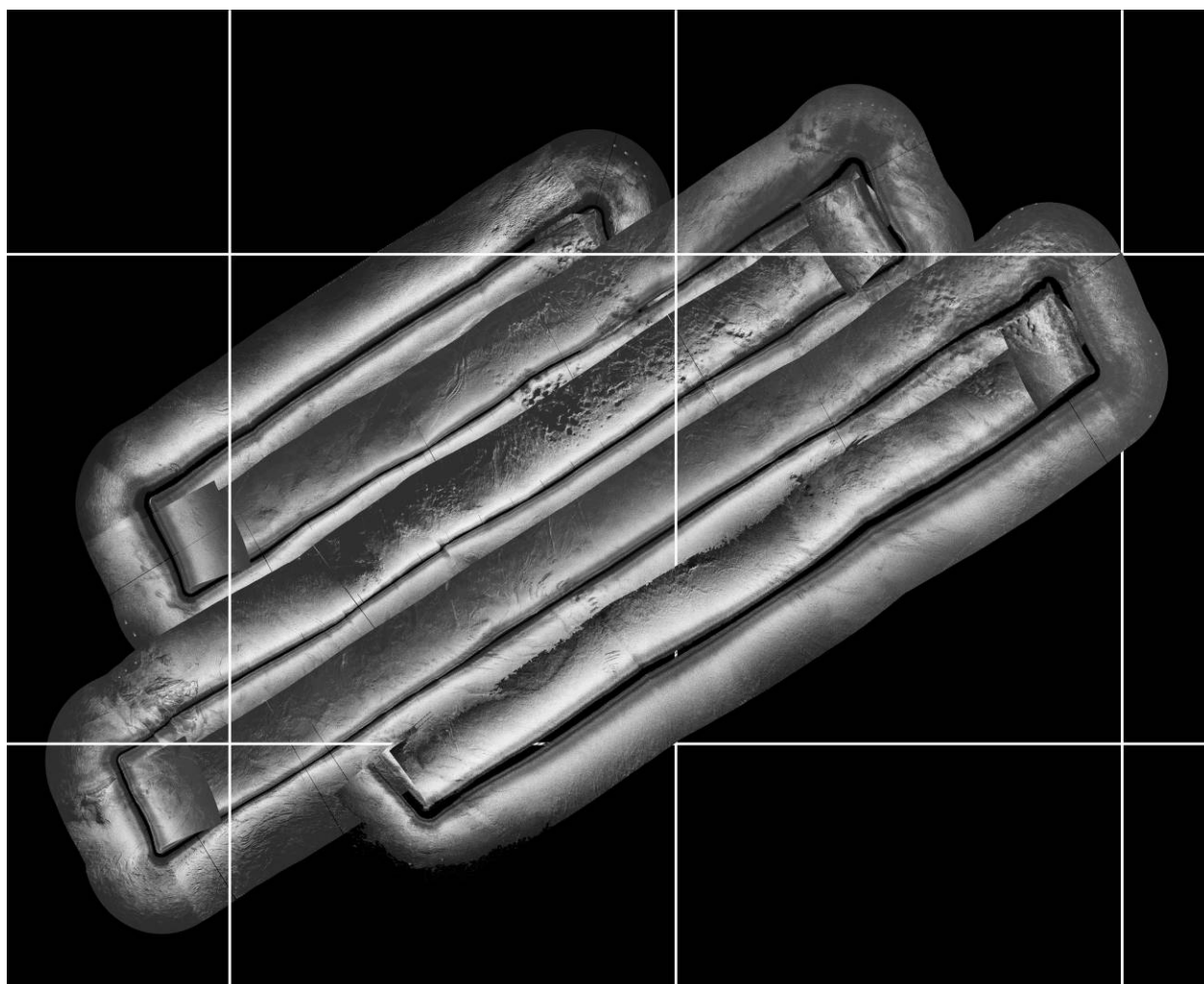


Fig. 4.2.1.2 Side scan image of Kuroshima Knoll (2) perspective view seen from south.



Appendices

Table-1	Survey Schedule.
Figure-1	Hydrographic Chart for Survey Area.
Table-2	Organization of Survey Team.
Reference-1	Standard Schedule for Dive Operation.
Reference-2	Photos of Payloads.

Table-1

Survey schedule for KR10-03.

Date	「Kaiei」	Site	Description
2010			
1.20 (Wed)	Arrival in Port	Naha	Boarding
	Adjusting Vehicles		Hard-wiring
	Loading Vehicles		
21 (Thu)	Adjusting Vehicles		Exercises for Surface landing and Retrieval
22 (Fri)	Leaving Port	Leaving Naha	
	Storm Avoidance	Nakajo Bay	
23 (Sat)	Returning to Port	Nakajo Bay	
24 (Sun)	Operation	Kuroshima Knoll	Deploying r2D4 Testing TS
25 (Mon)	Operation	Daiyonyonaguni Knoll	Deploying r2D4
26 (Tue)	Operation MNBS Measurement	Kuroshima Knoll	Testing TS MNBS measurement at Kuroshima
27 (Wed)	Operation MNBS Measurement	Daiyonyonaguni Knoll	Adjusting r2D4 Adjusting TS MNBS measurement at Yonaguni
28 (Thu)	Operation MNBS Measurement	Kuroshima Knoll	Adjusting r2D4 Deploying TS MNBS measurement at Yonaguni
29 (Fri)	Operation・Returning to Port	Kuroshima Knoll Leaving Kuroshima Knoll	Deploying r2D4
30 (Sat)	Returning to Port		
31 (Sun)	Returning to Port		
2.1 (Mon)	Returning to Port		
2 (Tue)	Arrival in Port	Arrival at Yokosuka	Disembarkation

Figure-1

KR10-03 Hydrographic Chart for Survey Area

1) Daiyonyonaguni Knoll

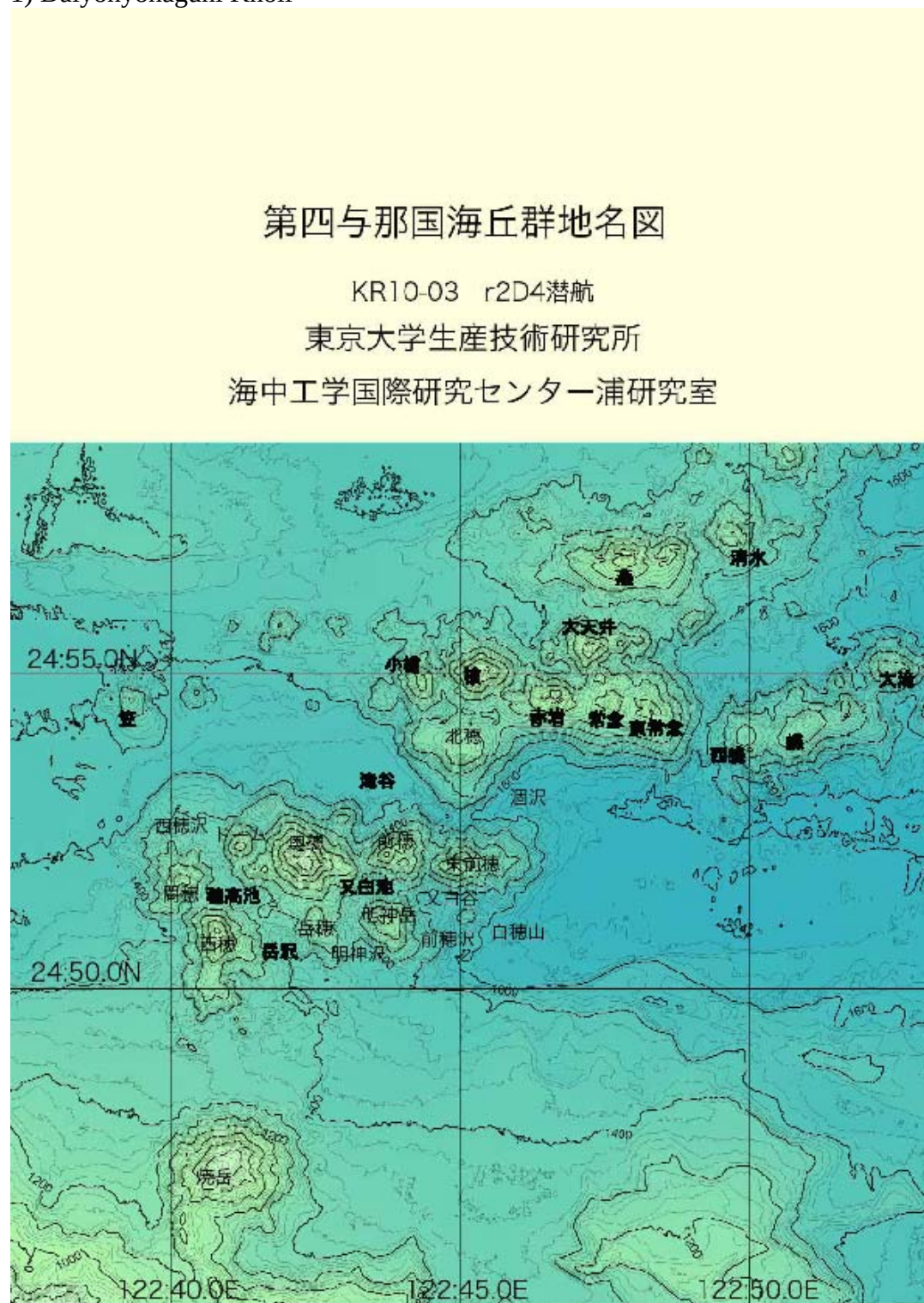


Figure-1-1 Enlarged Hydrographic Chart for Daiyonyonagunikaikyu : Names of Hills and Troughs are Tentative.

Backup Site : Kuroshima Knoll

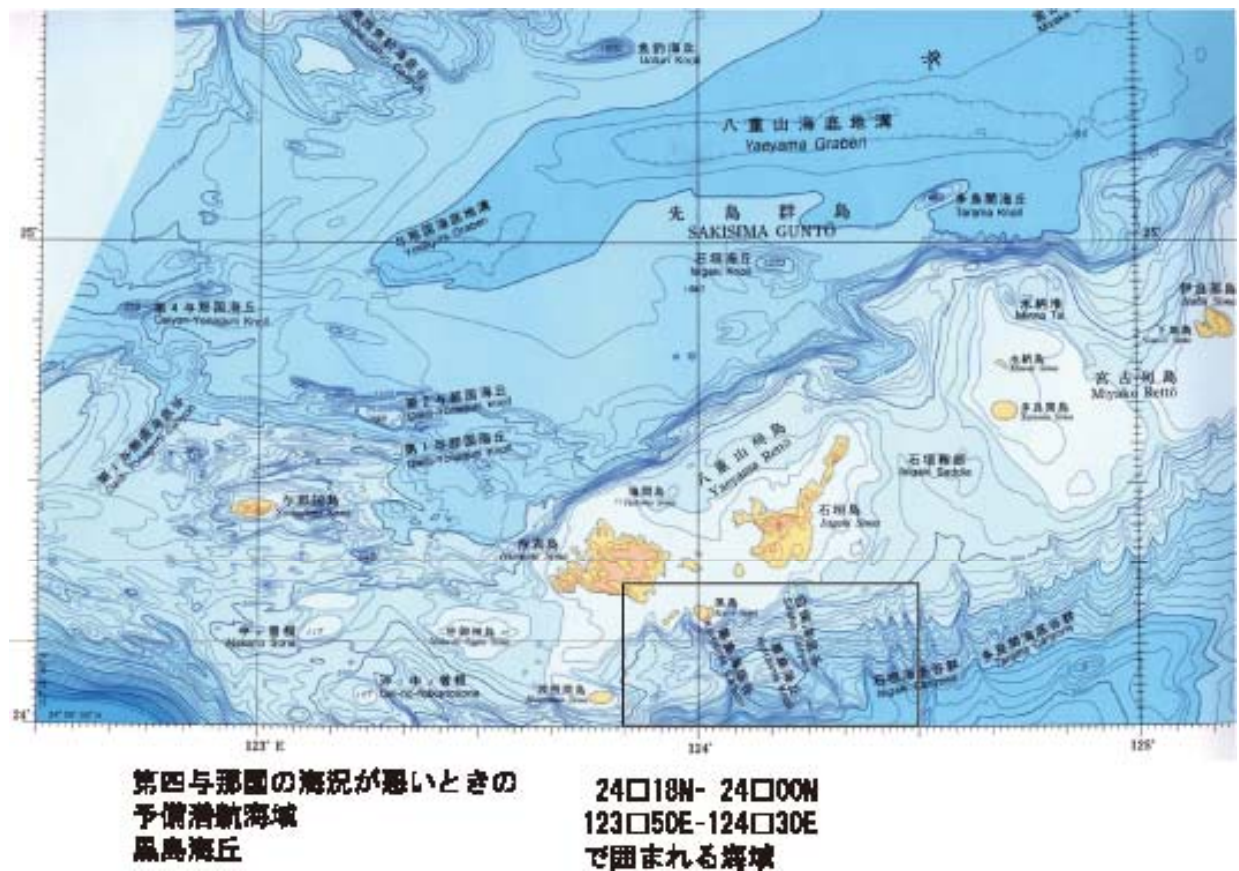


Figure-1-2 Kuroshima Knoll Area.

Survey Region

Region surrounded by latitudes and longitudes of

24°00.0'N	123°50.0'E
24°18.0'N	124°30.0'E

Survey Team Members

Name	Affiliation	Title	Function
Tamaki Ura	IIS, The University of Tokyo	Professor	Director, Dive Planning and Supervising.
Takashi Sakamaki	IIS, The University of Tokyo	Technical Specialist	Hardware Adjustment of TS. Supporting Dive. Overall Support.
Takeshi Nakatani	IIS, The University of Tokyo	Researcher	Hardware and Software Adjustment of TS. Dive Planning and Supervising.
Yasuhiro Ogawa	IIS, The University of Tokyo	Graduate Student	Supporting Operation of TS. Corresponding and Adjusting Operation.
Kei Okamura	Kochi University	Associate Professor	Chemical Analysis and Supporting Dive Planning.
Kenji Nagahashi	Mitsui Shipbuilding	Assistant Manager	Adjusting and Directing the Operation of r2D4.
Takeshi Nakane	Mitsui Shipbuilding	Assistant Manager	Hardware Adjustment of r2D4
Hisashi Koyama	Mitsui Shipbuilding	Officer	Management and Analysis of Sonar Data
Tadamasa Kohata	Sea Tech	Senior Officer	Electric Adjustment of r2D4
Yuji Oyabu	Cosmo System	Officer	Software Adjustment, Supporting Dive.
Norio Yamaoka	Cosmo System	Officer	Supporting Dive Planning and Dive.
Shinichi Hosoya	Nichi Kaiji	Technical Staff	Overall Support, Correspondence Supporting.

Standard Schedule for Dive Operation

Following is the description of standard schedule for a dive operation. Times marked are indications, adjustable corresponding to sea state or progress of work. Maintenance and adjustment for individual payload are to be done, complying with requirements.

1) Operations for r2D4

The Day Before

- 2000 Checking up the dive route.
- 2100 Deciding points for releasing and retrieval. Notify the crews of support vessel of them.
- 2300 Deciding dive route.

Action Date

0530 Arriving at survey site. Determining whether dive is feasible or not. If feasible (infeasible, take counsel together),

- 0630 Moving r2D4 to deck. Drawing out A-frame crane.
- 0700 Fixing stationary relative to the support vessel. Starting alignment.
- 0730 Starting the releasing operations.
- 0800 Releasing vehicle onto the sea.

Keeping vehicle tethered and floating on surface for 5 minutes, in order to activate GPS positioning.

0805 Making vehicle untethered. Starting Dive. During dive, support vessel keeps tracing with r2D4. Vehicle follows the commanded trajectory. Keeping on checking the position of r2D4 by SSBL. When necessary, stop the support vessel and deploying transducers for setting up underwater acoustic link. In case of emergency, command vehicle to unconditionally surface via acoustic link.

- 1500 Vehicle surfaced. Detected. Boat approaches for retrieval.
- 1530 Connecting to main and anti-vibrating tethers. Retrieving the vehicle.
- 1540 Wet cleaning.
- 1550 Moving to the garage. Downloading data. Adjustments. Charging battery.
- 1900 Discussing feedback to the dive.
- 2300 Battery charge finished (dive time + α)

2) Operations for Tuna-Sand

ROV Mode (Tethered)

- 0730 Moving TS to deck. Drawing out A-frame crane.
- 0800 Fixing stationary relative to the support vessel. Starting alignment.
- 0830 Deploying by stern of the vehicle. Reeling out and taking in the tether manually.
- 1200 Retrieval.

AUV Mode (untethered)

- 0730 Moving TS to deck. Drawing out A-frame crane.
- 0800 Fixing stationary relative to the support vessel. Starting alignment.
- 0830 Deploying by stern of the vehicle. Reeling out and taking in the tether manually.
- 1200 Vehicle surfaced. Detected. Approaching for retrieval.
- 1230 Retrieval.

Photos of Payloads and Operation Scenes



R2D4 : 4.4 m Overall length, 1.6 ton weight.
Adjusting in the garage, Preparation for dive.

Moving to the stern on the deck, Aligning INS and
Confirmed normal operation.



Lifting up the vehicle.
Drawing out A-frame.



Catching the r2D4 floating.



Retrieval.



R2D4 is being lifted up from the surface.



Chief officer directing the retrieval of r2D4.

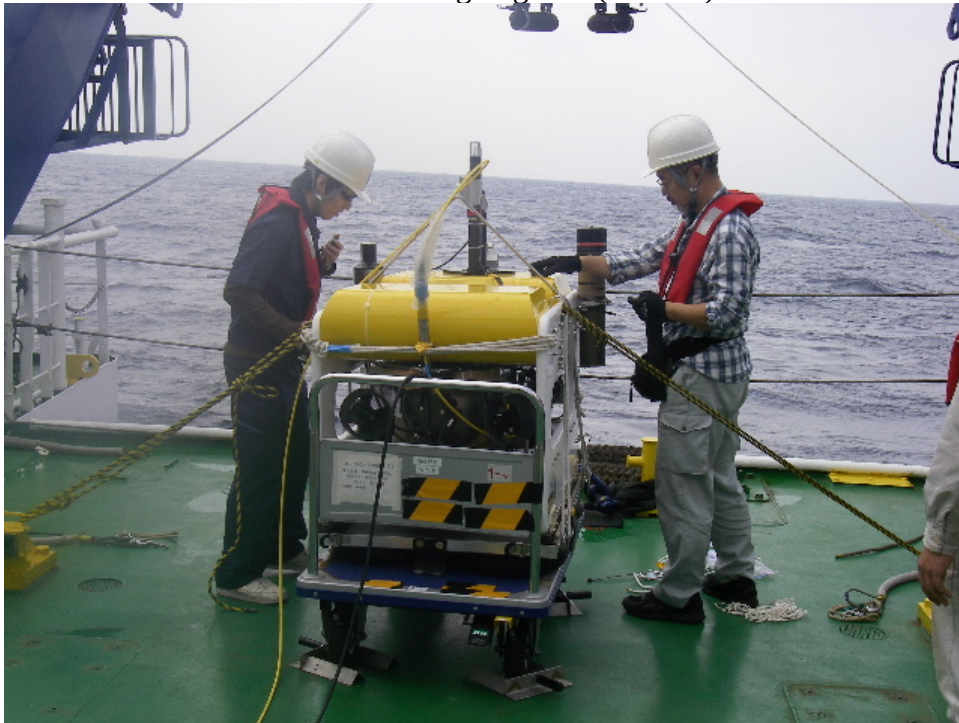


R2D4 has been laid on the carriage.

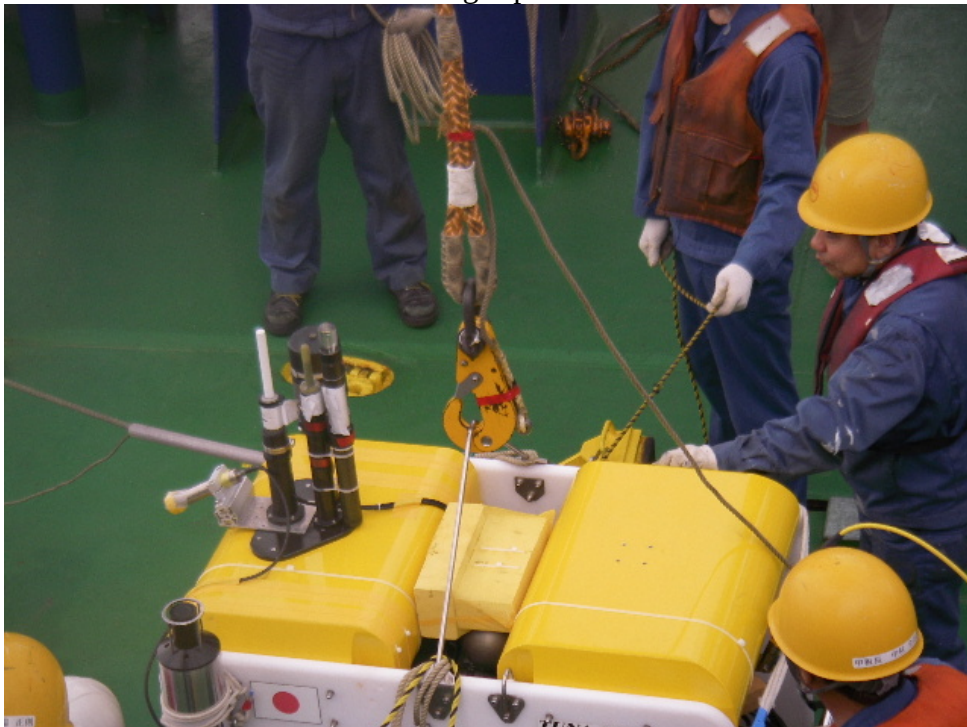


Tuna-Sand

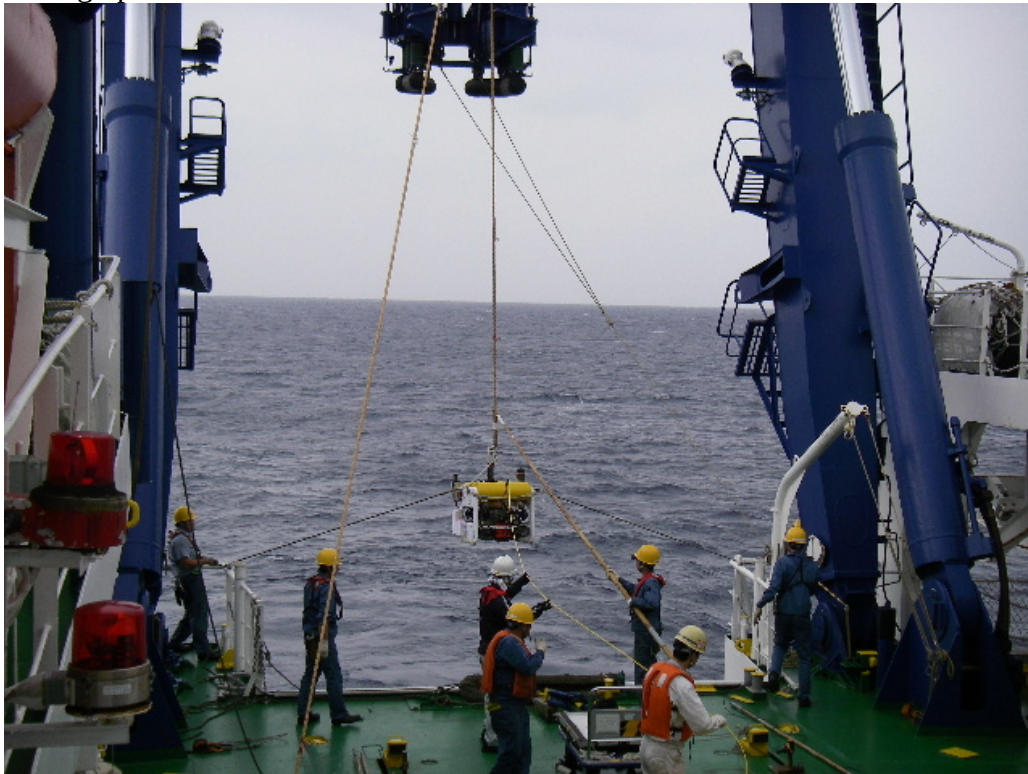
Moved to the stern on the deck. Aligning INS (30 min.). Confirmed normal operation.



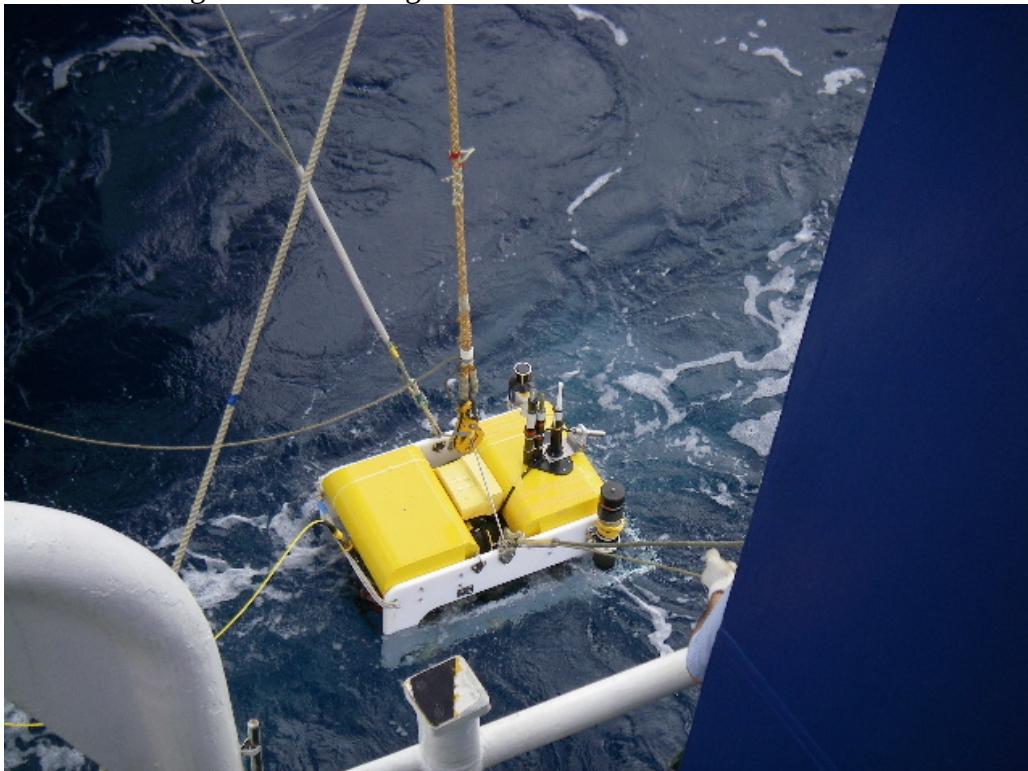
Hook for A-frame and Anti-vibrating ropes on both sides



Lifting up Tuna-Sand.



Surface landing and Untethering.



Cable handling (taken at Rolling up operation).



Adjustment in garage, preparation for dive (Replacement of battery).

