



R/V Kaiyo Cruise Report

KY12-12

Engineering Test of Autonomous Underwater Vehicles
for Underwater Resources Exploration

Sagami-Bay

October 4, 2012 – October 18, 2012

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

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1. Cruise Information

Cruise ID: KY12-12
Name of vessel: R/V Kaiyo
Title of the cruise: Engineering test of autonomous underwater vehicles for underwater resources exploration
Cruise period: Leg #1: 2012/10/4~2012/10/12 Yumeiruka
Leg #2: 2012/10/13~2012/10/18 Otohime
Ports of call: Pier of JAMSTEC ~ Sagami-Bay
Research area: Sagami-Bay (water depth of 80 m ~ 1,500m)

Research Map

Sea-trial was carried out in the area bounded by (34°55.0'N,139°13.5'E), (35°00.0'N,139°06.5'E), (35°14.0'N,139°13.0'E), (35°14.0'N,139°25.0'E), (34°55.0'N,139°25.0'E)

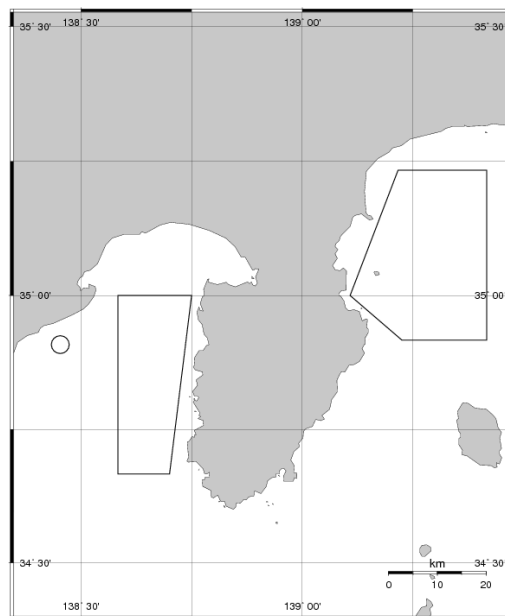


Figure 1 : Test area.

2. Researchers

Chief scientist: Hiroshi Yoshida, MARITEC, JAMSTEC

Science party (List)

Tadahiro Hyakudome, MARITEC, JAMSTEC

Shojiro Ishibashi, MARITEC, JAMSTEC

Makoto Sugawara, MARITEC, JAMSTEC

Takeshi Nakatani, MARITEC, JAMSTEC

Yutaka Ota, MARITEC, JAMSTEC
Hiroshi Ochi, MARITEC, JAMSTEC
Yoshitaka Watanabe, MARITEC, JAMSTEC
Takao Sawa, MARITEC, JAMSTEC
Yoshiyuki Nakano, MARITEC, JAMSTEC
Satoshi Tsukioka, MARITEC, JAMSTEC
Tsuyoshi Yoshiume, MARITEC, JAMSTEC
Junya Niikura, MARITEC, JAMSTEC
Kiyoshi Hirokawa, Mitsubishi Heavy Industries, Ltd.
Hitoshi Noda, Mitsubishi Heavy Industries, Ltd.
Yoshiaki Yamauchi, Mitsubishi Heavy Industries, Ltd.
Manabu Ikushima, Mitsubishi Heavy Industries, Ltd.
Yoshimi Kaneko, Mitsubishi Heavy Industries, Ltd.
Hakuo Nishizato, Mitsubishi Heavy Industries, Ltd.
Yoshinobu Kanenaga, Mitsubishi Heavy Industries, Ltd.
Hirohito Hosoi, Mitsubishi Heavy Industries, Ltd.
Mutsuo Takashima, Mitsubishi Heavy Industries, Ltd.
Kazuhiro Kanayama, Mitsubishi Heavy Industries, Ltd.
Kazuki Eguchi, Mitsubishi Heavy Industries, Ltd.
Kazunari Takahashi, Oki Seatec Co., Ltd.
Takashi Omura, Clover tech Inc.
Hiroyuki Miyake, Ryoyu System Giken
Takechika Kumagai, SAS Co., Ltd.

3. Test Equipment

3.1 Cruising AUV, Yumeiruka

The cruising AUV named *Yumeiruka* (5 m long, 2.7 tons in weight) is developed for exploration of underwater minerals. Yumeiruka as shown in Figure 3.1 has a streamline shape to reduce hydro resistance. Its frame is made from aluminum alloy. The mechanically-formed syntactic forms attached into the frame make the vehicle buoyant. Its surface is covered with separated thin FRPs. Cross arranged four 400 Watts direct drive thrusters at rear make propulsion. Two X-rudders are mounted on the bow and the stern to control the vehicle highly maneuverable. Its controllable speed with the rudders is between 2 and 3 knots. The rudder area and aspect ratio were optimized by the balance between the control range of the simultaneous heading and course control and the rudder overhang length from the body. Figure 3.2 shows the device arrangement of Yumeiruka. A buoyancy compensator adjusts the vehicle weight to near-neutral. The compensator consists of a pressure hull with capacity of 30 liters, an oil bladder, a pump and valves.

Its buoyancy is adjusted by transferring the oil between the pressure hull and the bladder. A small inertial navigation system (INS) consisting of three ring laser gyros developed by JAMSTEC & JAE enables high accuracy positioning of the vehicle with a 600 kHz Doppler velocity log (DVL), a GPS and acoustic navigation systems (ANSs). Its navigation modes, a DVL-INS hybrid mode and so on, are automatically or manually selected. The AUV system has user-selectable three ANS functions: a super short base-line (SSBL), a long base-line (LBL), and a virtual LBL acoustic positioning system. The VLBL enables simple operation configuration by one transponder pre-installed on the sea-floor. Other sensors for navigation are an altimeter and a depth meter.

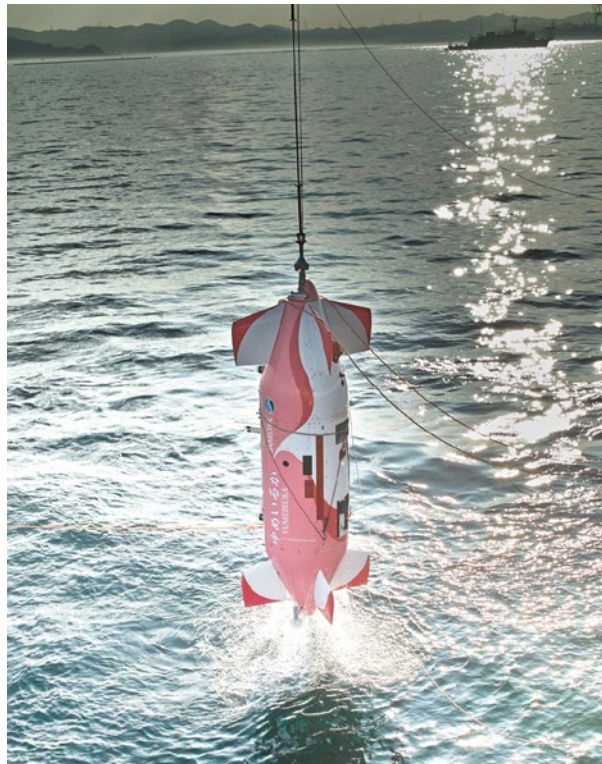


Fig. 3.1 Overview of Yumeiruka.

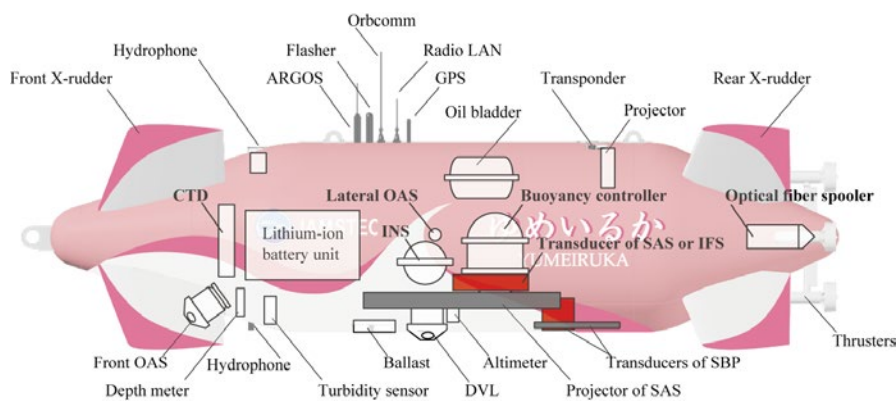


Fig. 3.2 Configuration of Yumeiruka.

Table 3.1 : Specifications of Yumeiruka

<i>Items</i>	<i>Value</i>	<i>Unit</i>	<i>Remarks</i>
Dimension	5.0 x 1.2 x 1.2	m	
Weight	2.7	t	in air
Working depth	3,000	m	
Endurance	16	hours	
Speed	2	knots	3 kt max.
Propulsions	4 x 400W thrusters		
Sensors	INS, DVL, GPS, SSBL, LBL, VLBL Depth meter, Obstacle avoidance sonar, altimeter		
Scientific payloads	CTD-DO, Fluorometer & Turbidity sensor, pH sensor, Interferometry sonar, Synthetic aperture Sonar, Sub-bottom profiler		

3.2 Launch and recovery system

A sketch of the new launch-recovery system is shown in Figure 3.3. This prototype system is designed to fit the R/V Kaiyo which is equipped with a large A frame crane. The system consists of a vehicle platform with a raising base which is rotated by two hydraulic cylinders to 120 degrees. The vehicle is hung from the raising base with a vehicle hanger and arrested to the base with an arresting rope. The vehicle is forced outward by a dumper. If you loosen the arresting rope, the vehicle is pushed out of the base by the dumper. To uncouple the vehicle from the base, the vehicle hanger is hoisting up by the 7 ton crane, and then the hanger has whole of the vehicle weight. After that, the A frame crane moves outward to release the vehicle on the sea surface.

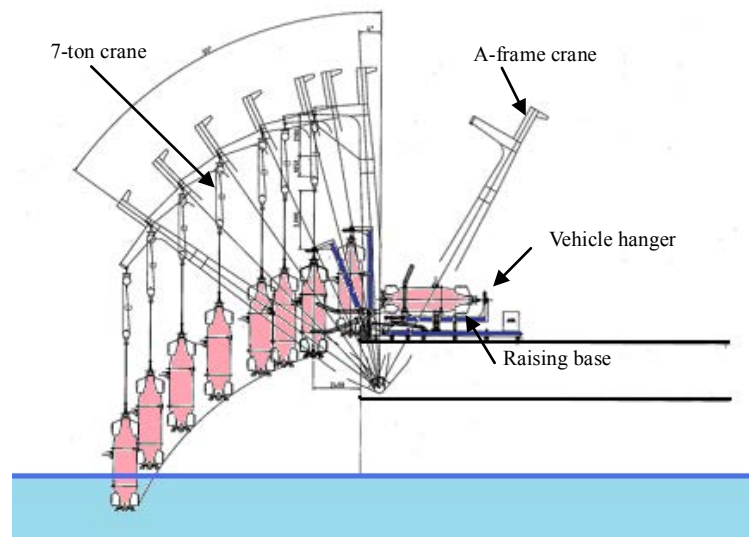


Fig. 3.3 Vertical launcher

3.3 Working AUV, Otohime

The Working AUV named *Otohime* is an AUV for short range cruising but for highly resolution observations. The AUV aims to take detail CO₂ map and bathymetry near the sea-floor. This small vehicle hovers to measure CO₂ and to take picture. It can approach to the sea- floor up to 1 m in altitude. Its body shape is rather like remotely operated vehicles than AUVs. A photo of Otohime is shown in Figure 3.4. Table 3.2 shows the main specifications.



Fig. 3.4 Overview of Otohime

Table 3.2 Specifications of Otohime

#	Items	Specification	Remarks
1	Length	2.6 m	
2	Weight	740 kg	
3	Working depth	3,000 m	Max.
4	Speed	0 ~ 1.2 knots	
5	Min. Altitude	1 m	Landing capabiliy
6	Turn radius	-	
7	Endurance	8 hours	
8	Sensors	Hybrid pH-CO ₂ sensor, Stereo vision camera, High resolution still camera, HD-SDI camera, Hi-rate strobes, Side scan sonar, CTD meter, Manipulator	
9	Actuators	400W azimuth thruster x 2 Vertical and horizontal rudders	
10	Communication	High-speed acoustic, Optical fiber, WiFi	
11	Navigation	INS, DVL, CTD, SSBL, LBL, VLBL	

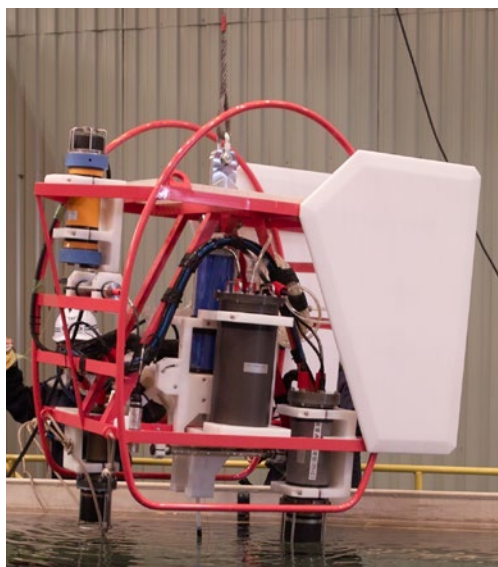


Fig. 3.5 Deep tow for relaying acoustic communication (DeeTRAC).

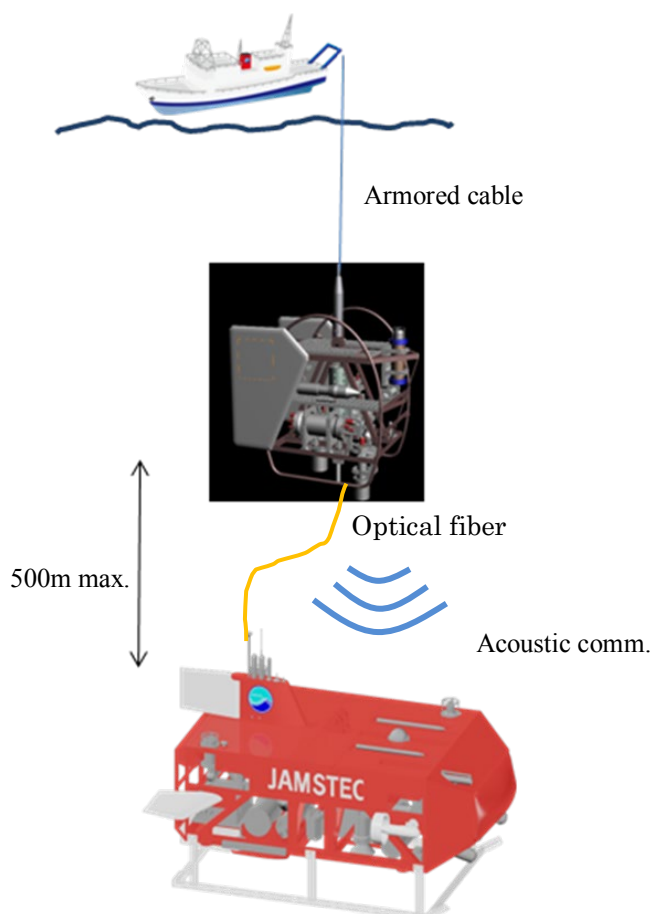


Fig. 3.6 Otohime and DeeTRAC

4. Engineering Test

4.1 Number of dives

Leg #1: Yumeiruka	2 dives	(Dive#1 ~ Dive#2)
Leg #2: Otohime	2 dives	(Dive#1 ~ Dive#2)

4.2 Schedule and result

1) Leg #1

The departing date was delayed because the ballast system of the Yumeiruka was troubled just before the leaving date planed first. Through the sea trial, the acoustic communication system was not working right, and all dives were thus done by the optical fiber communication. This means that the vehicle drops the surfacing ballast if the optical communication is lost despite autonomous control.

Table 4.1 List of results in the Leg #1.

Date	Plan	Place	Result
Dec. 4	System debug in port	Pier of JAMSTEC	Good
Dec. 5	Training of launch & recovery	Pier of JAMSTEC	Good
Dec. 6	Leaving the pier Training of launch & recovery System check on the board	Yokouska 4th district	Good Good
Dec. 7	Acoustic communication test the new projector down link comm.(MSK) up link comm. (QPSK) the transponders	Sagami-Bay	The acoustic wave propagation characteristics were obtained. This could not use during sea-tial due to short service range of the down link.
Dec. 8	Test dives up to 60 m (dive#1) ✓ adjust neutral buoyancy with VBT ✓ sequence for surfacing ✓ diving procedure ✓ manual cruising	Teishi-Knoll, Sagami-Bay	The weather became bad and then the test was aborted.
Dec. 9	Retry the test dives up to 60 m (dive#1)	Teishi-Knoll, Sagami-Bay	Achieved the Dive #1
Dec. 10	Test dives up to 60 m (dive#2) ✓ autonomous cruising ✓ scenario cruising	Teishi-Knoll, Sagami-Bay	The test cancelled due to bad weather.
Dec. 11	Retry the test dives up to 60 m (dive#2)	Teishi-Knoll, Sagami-Bay	Achieved the Dive #2
Dec. 12	Arrival in port Unloading the equipment	Pier of JAMSTEC	

In the dive #1 and #2, we achieved check and measurement of the following items:

- ① neutral buoyancy and the body balance,
- ② ways of the launch and recovery,
- ③ the basic functions of the vehicle software and hardware in the sea water,

- ④ how to dive to the deep-sea,
- ⑤ remote control manually by the optical fiber communication,
- ⑥ autonomous cruising with some of the motion control algorithms,
- ⑦ pH sensor and the interferometry sonar, and
- ⑧ characteristics of the acoustic communication system.

The vehicle electric and software system was fairly stable despite the first sea-trial. An unstable state transition in the system was not observed. There was not fatal error in the motion control algorithms. Its parameters were not perfectly optimized but they had no problem for cruising. The parameters will be optimized by using this test results and others. As a result, the autonomous cruising and the scenario cruising were achieved.

We detected some minor bugs in this earlier version of the system software and some of them were removed. A few hardware bugs were also found and fixed. The most serious problem that we encountered was the recovery method. This problem was already solved by changing number of the ropes and its length as following:

- ✓ before; a 40 m guided rope and two 40 m anchoring ropes which were connected with a small buoy separated from the vehicle body in surfacing, and
- ✓ after; a 20 m guided rope connected with the buoy and two 5 m anchoring ropes fixed on the front of the body.

The dive chances were somewhat less because the weather was changeable and there were some bad weather. We executed 40% - 50 % of test items but we get good achievements for the first sea-trial.

2) Leg #2

Table 4.2 List of results in the Leg #2.

Date	Plan	Place	Result
Dec. 12	Loading the equipment Test of the DeeTRAC	Pier of JAMSTEC	Good
Dec. 13	Training of launch & recovery	Pier of JAMSTEC	Good
Dec. 14	Leaving the pier Buoyancy adjustment on the sea System check on the board	Sagami-Bay	Good Good
Dec. 15	Acoustic navigation system check the transponder for emergency the transponder add on	Teishi-Knoll, Sagami-Bay	Good
Dec. 16	Test dives up to 100 m (dive#1) ✓ manual cruising via optical fiber ✓ try to take some pictures ✓ adjust the HCS and the SSS	Teishi-Knoll, Sagami-Bay	Achieved the Dive #1
Dec. 17	High speed acoustic link test using Otohime (dive#2)	Teishi-Knoll, Sagami-Bay	Achieved the first acoustic link between the DeeTrac

			and Otohme. (Dive #2)
Dec. 18	Arrival in port Unloading the equipment	Pier of JAMSTEC	

In the dive #1 and #2, we achieved check and measurement of the following items:

- ①. neutral buoyancy and the body balance,
- ②. ways of the launch and recovery,
- ③. the basic functions of the vehicle software and hardware in the sea water,
- ④. how to dive to the deep-sea,
- ⑤. remote control manually by the optical fiber communication,
- ⑥. the still camera, the HCS, and the side scan sonar,
- ⑦. underwater operation of the DeeTrac, and
- ⑧. camera image transmission by the high speed acoustic communication.

Although implement and adjustment of the control system software and hardware of Otohime were not completed, the system worked right and stable because essential parts of the system were carefully tested and checked. The body balance was stable and thus we achieved a manual cruising which kept altitude constant.

4.3 Details

1) Dive #2, Leg#1

Fig. 4.1 and 4.2 show the track chart of dive #2 recorded by the ANS and the INS, respectively. In this dive, we tested autonomous performance of the no-point cruisings and a combination of the way-point and the way-line cruising by a scenario. The vehicle was first guided manually to the start point (red cross) in Fig. 4.1. Solid blue circle indicates the real start point. The no-point cruising tests were started in the vicinity of 34.98N, 139.17E, in depth of 130 m. We also tested the scenario cruising. The blue solid square in Fig. 4.2 denotes the start point of the scenario. At 12:15 the scenario was started. Under the scenario planed, the vehicle cruises toward the goal (red cross) keeping depth of 100 m and makes seafloor observation with the IFS. But in fact, it was not that easy to complete the scenario. In the 3rd minute after, the optical communication was lost by a fiber broken and the vehicle then entered the trouble avoidance mode to surface itself.

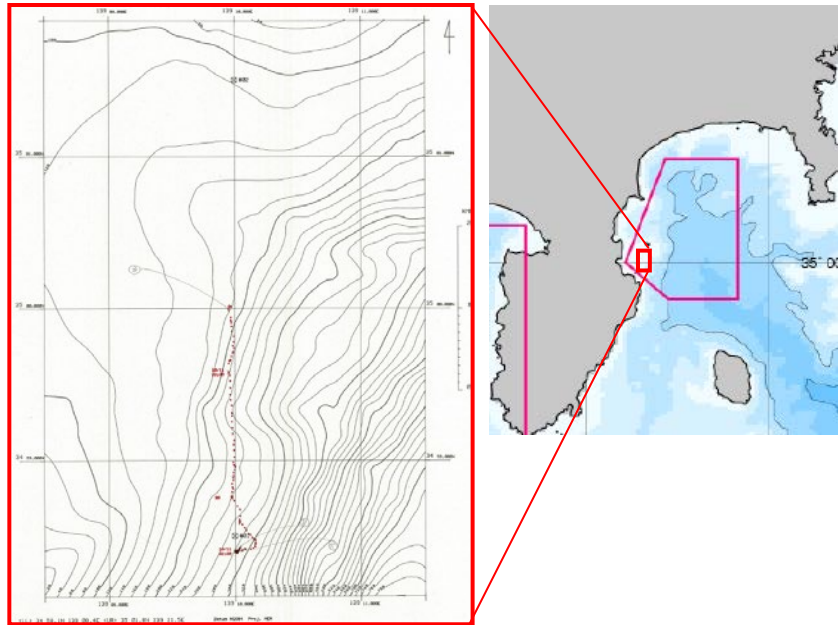


Fig. 4.1 Test area and the cruising track of dive #2 recorded by the acoustic navigation system.

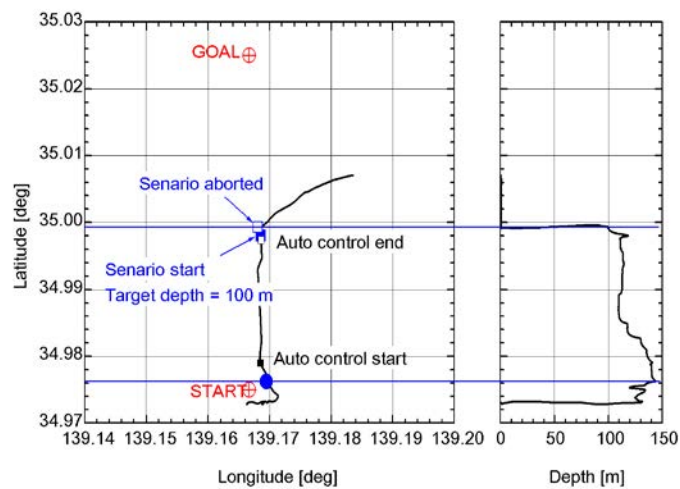


Fig. 4.2 Cruising tracks recorded by the INS of dive #2. Left: the track drawn by the data obtained by the INS-DVL. Right: depth trajectory.

2) Dive #1, Leg #2

We performed a cruising and observation test around the caldera of Teishi-Knoll in the dive #1 of Otohime. The cruising track obtained by the ANS is shown in Fig. 4.3. The heading of the vehicle was not kept due to external sea current and manual operation. The AUV obtained some still camera images (Fig. 4.4) and an image of side scan sonar (Fig. 4.5).

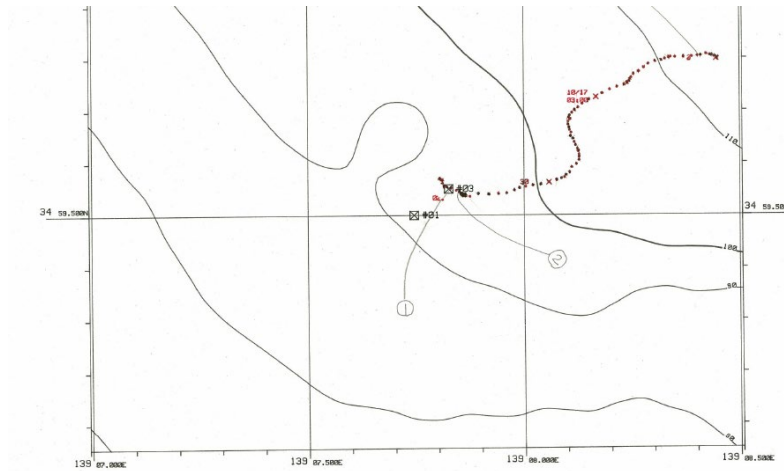


Fig. 4.3 The cruising track of dive #1 recorded by the acoustic navigation system.

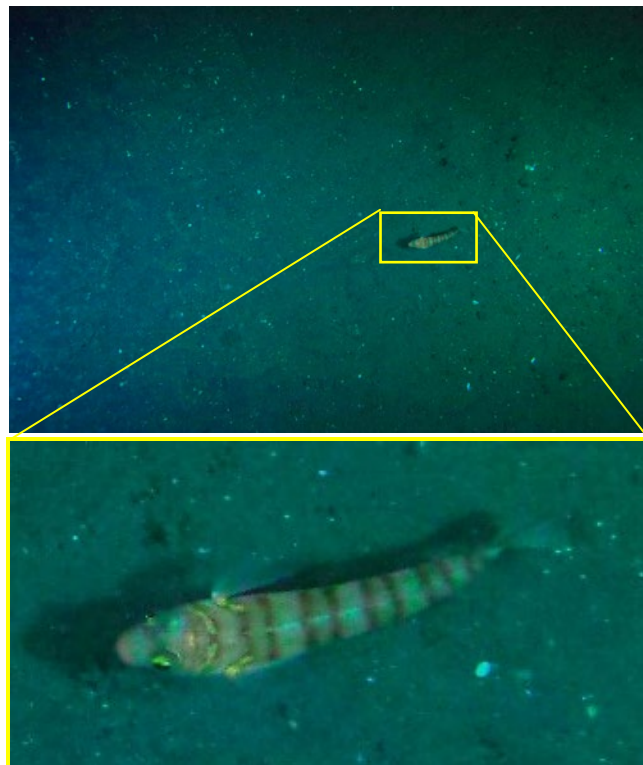


Fig.4.4 An example of the still camera image taken at altitude of 2 meters.

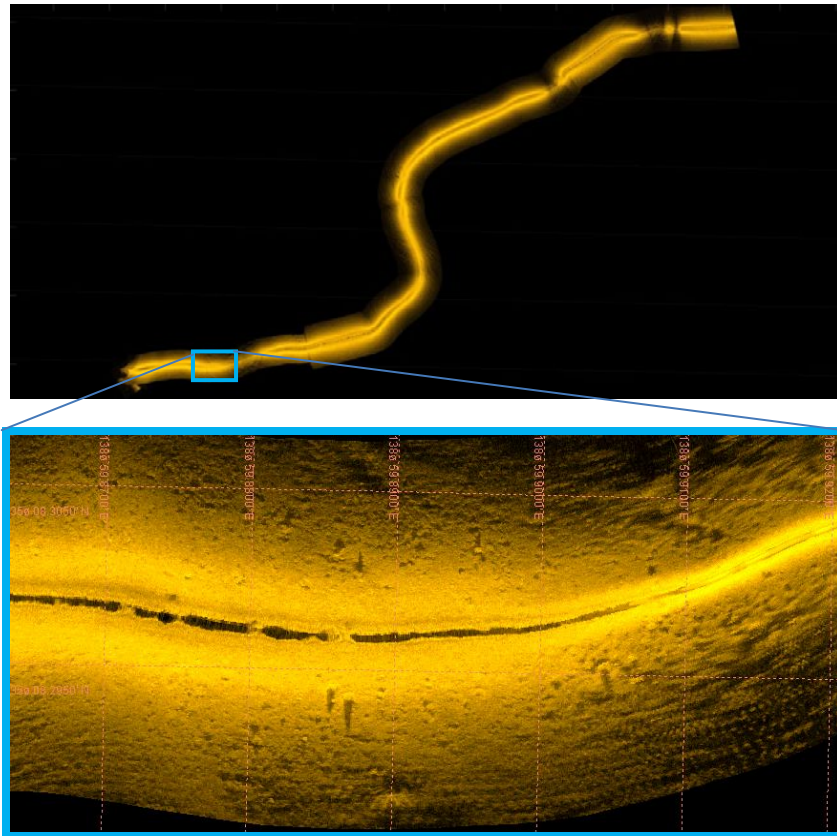


Fig 4.5 An obtained side scan sonar image. The cruising track is like a serpentine course because of external force and manual control. Altitude measured was between 1 – 4 meters.

5. Notice on Using

Notice on using: Insert the following notice to users regarding the data and samples obtained.

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

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

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