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R/V Kairei Cruise Report

KR08-11

Technological development in seafloor mapping of active fault system and seafloor geodetic observation of acoustic transponder connected with a submarine cable using autonomous underwater vehicle

Sep. 18, 2008 － Sep. 26, 2008

Japan Agency for Marine－Earth Science and Technology

(JAMSTEC)

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1.1 Cruise number / Ship name：

KR08-11 / R/V Kairei

1.2 Title of the cruise：

“ Research dive by KAIKO 7000 II “

1.3 Title of the proposal：

“ Technological development in seafloor mapping of active fault system and seafloor geodetic observation of acoustic transponder connected with a submarine cable using autonomous underwater vehicle “

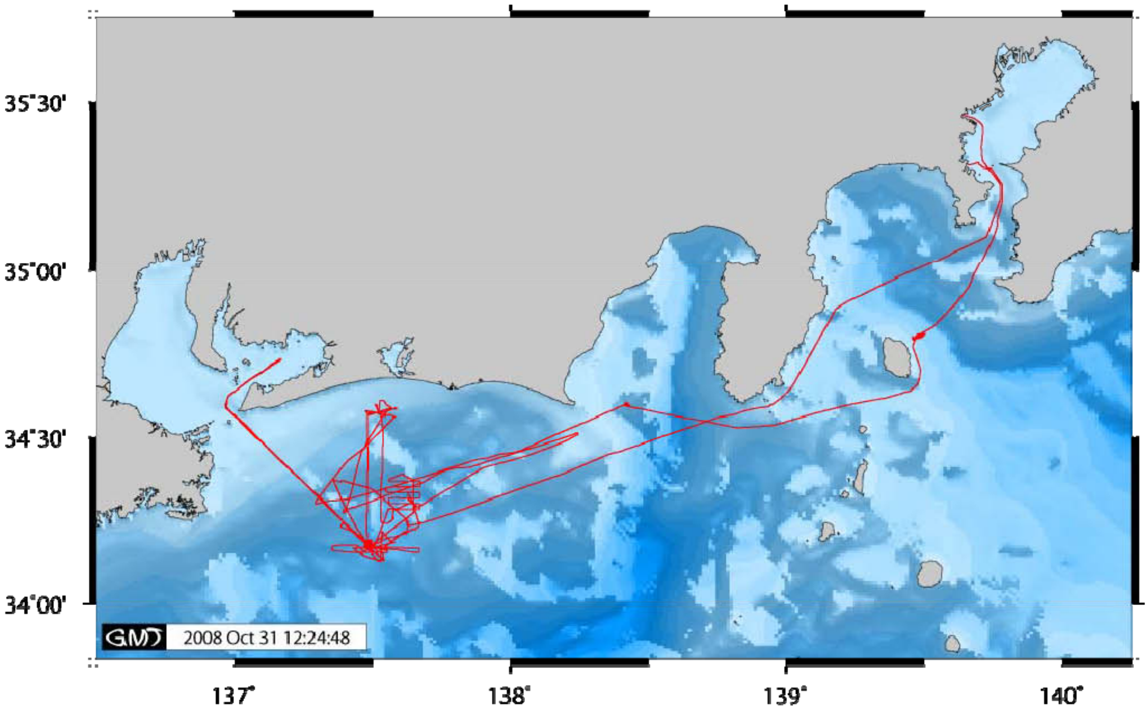
1.4 Cruise period / Port call:

Sep. 18, 2008 — Sep. 26, 2008 / Yokohama — JAMSTEC

1.5 Research Area：

Enshunada, Suruga Bay

1.6 Research Map：



Ship track of KR08-11 cruise

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3　Overview of observation：

3.1 Background and objectives

Institute of Industrial Science, University of Tokyo (IIS) has been developing methods that detect and monitor crustal deformation on the seafloor directly. It is activity for aiming to understand the mechanism of the big interplate earthquake. Project which IIS is now working on is to develop a highly sophisticated seafloor geodetic observation system for future generations. Several technological developments for the new system have been done in this project. One of them is seafloor transponder which can be connected to a submarine cable. One of main objectives of this cruise is to install the newly-developed seafloor transponder on the scientific submarine cable, which has been maintained by JAMSTEC, off Toyohashi in central Japan. Moreover, we conduct acoustic ranging procedures with IIS AUV “r2D4” to locate the position of the installed seafloor transponder just after its installation for checking how it works.

Another objective is to observe the fault systems distributed along the eastern Nankai trough. AUV “r2D4” is equipped with an interferometry sonar system. r2D4 with the sonar can approach the seafloor and acquire much more detailed bathymetric image of the seafloor than one obtained by a multibeam echo sounder equipped on the surface vessel. We conduct not only the seafloor mapping with the r2D4 but also the ROV “KAIKO 7000 II” seafloor visual observation. We aim to understand the status of the fault systems with the combination of detailed bathymetric and visual observation data

3.2 List of observation instruments

3.2.1 Submarine cable and junction unit

(1)Outline of the Tokai SCANNER

The ocean bottom observatory of Tokai SCANNER is located at 34°10.466N, 137°29.337E, at the water depth of 1,310m. It is about 60 km off Toyohashi (Fig.3-2-1-1). Electric power, communication line and precise time synchronization signal are provided to the observatory through the underwater optical cable, which enables longterm continuous observation.

Fig.3-2-1-2 shows the basic configuration of Tokai SCANNER. At the observatory, two sensor packages, S-SMAD and DOMES, had already been connected to the underwater optical cable through a junction unit. S-SMAD consists of ocean bottom seismometers, a pressure gauge and a differential pressure gauge, and DOMES consists of an overhauser absolute magnetometer, an electrometer, a tiltmeter and a subbottom thermometer.

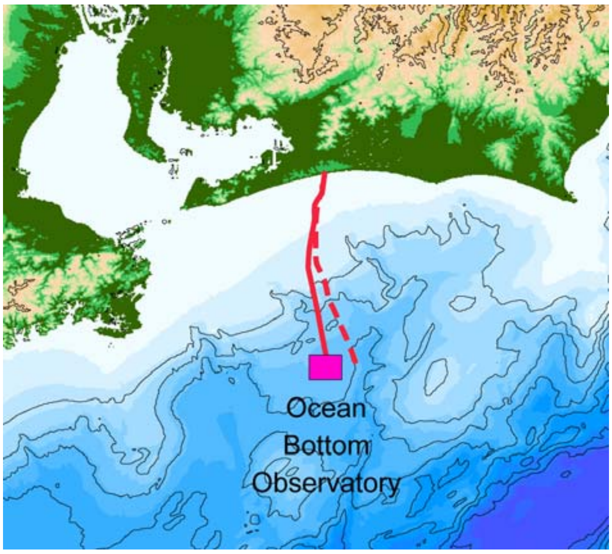


Fig.3-2-1-1 Cable route and location of Tokai-SCANNER

The landing station is linked to JAMSTEC Yokohama Laboratory via IP-VPN (128kbps). We can monitor and control all the sensors from Yokohama Laboratory.

The cables used for Tokai SCANNER had been a portion of a domestic optical telecommunication cable network called Japan Information Highway (JIH), which surrounds Japanese Islands and was constructed in 1999 by KDD (now KDDI). There were two cables connected to the landing station in Toyohashi.

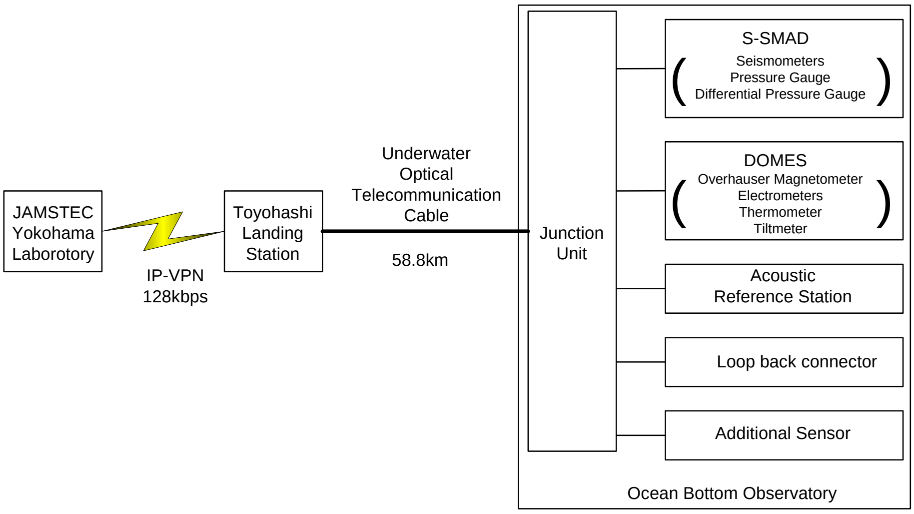


Fig.3-2-1-2 Basic configuration of Tokai-SCANNER

One was linked to Shima, and the other was linked to Ninomiya and Chikura. In 2003, an earth fault occurred in the landing portion of the east-side cable. In order to resume the communication service quickly, KDDI has directly connected two cables from Shima and Ninomiya/Chikura offshore, bypassing the landing portion of cables, and abandoned the landing cables. As the cables are laid on an area where Tokai earthquakes are anticipated to occur, these cables can be used for scientific monitoring. JAMSTEC has taken over the decommissioned cables to re-use them for scientific monitoring.

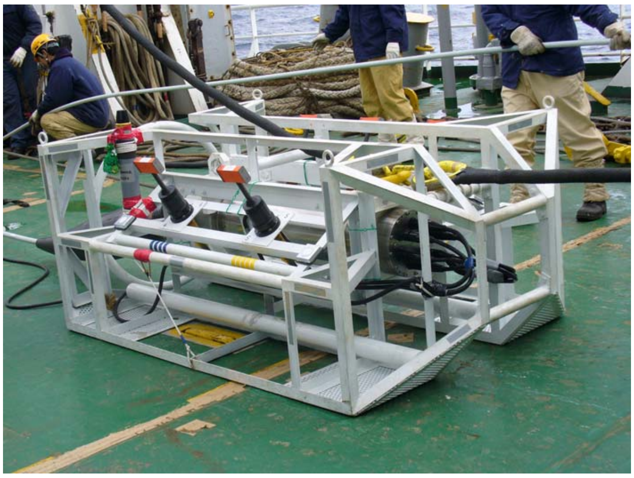


Fig.3-2-1-3 Photo of the junction unit

In March 2007, JAMSTEC connected the junction unit (Fig.3-2-1-3) to the end of the west-side cable. In the following month, JAMSTEC connected two sensor packages

S-SMAD and DOMES, and started longterm continuous observation.

(2) Sensor Interface

Five 9-pin ODI underwater mateable connectors are provided for connecting sensors. Table 3-2-1-1 shows the pin assignment and the principal interface specifications.

Details of the time synchronization signal is described in the following section.

Although the data signal interface between the junction unit and sensors is RS422, the data is transmission over the underwater optical cable with Ethernet protocol. Ethernet/RS422 converters (Xport) are provided in the junction unit and transform the data protocol. PCs in the landing station or JAMSTEC Yokohama Laboratory communicate with sensors via Ethernet.

Table 3-2-1-1 Pin assignment of the underwater mateable connectors

Pin Number	Signal	Specification
1	+15V	15V/1A, isolated form other signal lines
2	Time Synchronization +	RS422
3	Time Synchronization -	RS422
4	+15V	15V/1A, isolated
5	Data RS422 Rx+	9,600/19,200/38,400/ 57,600 bps
6	Data RS422 Rx-	
7	Data RS422 Tx+	
8	Data RS422 Tx-	
9	GND	15V/1A, isolated

(3) Time Synchronization System

Fig.3-2-1-4 shows the block diagram of the time synchronization system. The NTP/GPS server in the terrestrial subsystem provides NMEA data, precise a 10 MHz clock and an 1PPS signal. The 1PPS signal is synchronized with the 10 MHz clock.

The underwater unit provides an 1PPS and NMEA data to sensors coded with 1.25Mbps carrier signal.

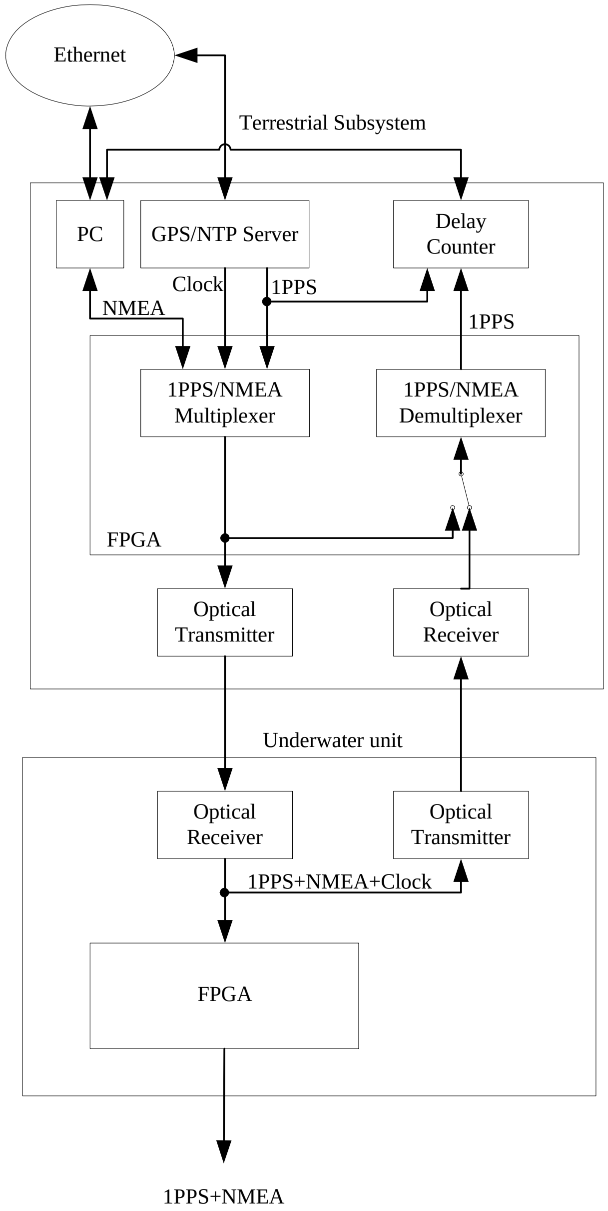


Fig.3-2-1-4 Block diagram of the time synchronization system

A loop-back circuit is implemented in the underwater unit to monitor the fluctuation of the transmission delay through the underwater optical cable. Fig.3-2-1-5 shows measured fluctuation of the transmission delay over four months. It can be confirmed that the transmission delay fluctuation is less than +/-2 nsec, which is negligible for acoustic positioning application. This indicates that if properly cancelling the transmission delay, the accuracy of the 1PPS signal could be better than several nano seconds.

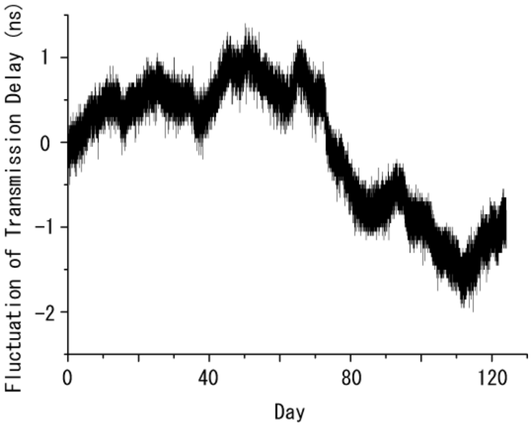


Fig.3-2-1-5 Fluctuation of the loop backed 1PPS's transmission delay. Converted to one-way transmission delay

3.2.2 Submarine cable transponder system

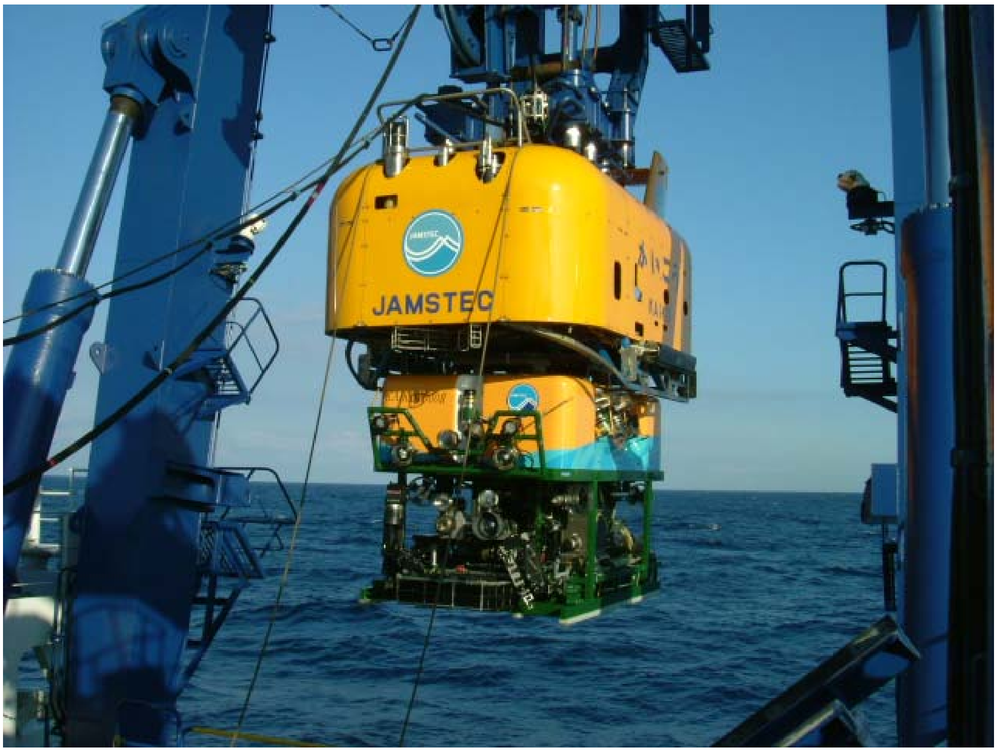
Submarine transponder system is a bench mark for seafloor geodetic observation. We measure the positions of the submarine transponder repeatedly and then detect seafloor movement or deformation as changes of the transponder position. Newly-developed submarine transponder is one which can be connected to the submarine cable system. The submarine transponder equips the time synchronization system which has developed by JAMSTEC. This time synchronization system functions as an interface between the submarine transponder and the submarine cable system. Power and precise GPS clock are fed to the submarine transponder through the submarine cable.

This transponder has two operational modes, that is, MT and PG modes. MT means "Mirror Transponder". The transponder functions as a signal retransmitter that receives a ranging signal from the sea surface unit and then transmits the signal back. All the seafloor transponders used in GPS/Acoustic seafloor geodesy work in this mode. PG means "Pinger". The transponder works as a signal transmitter. It transmits the ranging signal toward the surface in synchronization with GPS 1pps. We observe the signal at several points on the surface at once, and then the position of the transponder can be calculated even if only one shot. The PG mode is newly-developed and newly-equipped feature.

Fig 3-2-3 Appearance of the submarine cable transponder.

3.2.3 KAIKO 7000 II

KAIKO7000II is a remotely operated vehicle with the capable of diving to a maximum depth of 7,000 m. KAIKO7000II was used for connecting an acoustic station to the submarine cable which is laid off Toyohashi. In addition, it was also used for visual observation of the Enshu nada fault system.



3.2.4 r2D4

IIS started research and development of AUVs in 1984 targeting exploration of mid-ocean ridge systems. R-one and R-Two projects are series of large-scale projects that have culminated in the development of two AUVs, “R-One Robot” and “r2D4”. Here,”R” and “r” stand for “ridge”. The AUV “r2D4” was designed based on R-One Robot where the primary issues were downsizing and 4,000m maximum depth rating. This was established by introducing Lithium ion secondary battery packages and a compact INS.

A Dual frequency Side Scan Sonar, an Interfrometry Sonar and two CCD cameras are usually on board for terrain survey. In addition, as the payload sensors depending on missions, a CTDO unit, a three dimensional terrestrial magnetism meter, an in-site chemical analyzers are also to be prepared for survey of the hydrothermal area.

We selected the r2D4 as a testbed for surface platform of the new-generation seafloor geodetic observation system. Payloads and driving system of the r2D4 are reconfigured when we utilize the r2D4 as a surface platform in the seafloor geodetic survey. Sensors originally equipped and one of two vertical thrusters are removed, and then the on-board unit of the seafloor geodetic observation system is placed in fore payload bay.

Fig.3-2-4　Autonomous Underwater Vehicle “r2D4”

3.2.5 AUV "r2D4" mapping with Side-scanning sonar and L-array interferometry sonar

Multi-beam echo sounding from the sea surface has been the most useful method in order to reveal the deep seafloor topography so far. The observed bathymetry data of the interesting seafloor has been taken over several decades. However, it goes without saying that surveying closely above the sea bottom is the best for the purpose of revealing detail topography with high resolution.

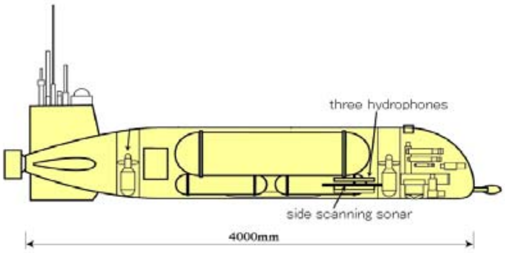


Fig.3-2-5-1 Three hydrophones in the L-shape and a side scanning sonar transducer mounted on the autonomous underwater vehicle r2D4 for swath bathymetry.

A new autonomous underwater vehicle r2D4 for operation to 4,000 meters was built for the purpose of seafloor mapping of the oceanic ridge having hydrothermal activity in July 2003. The AUV 4 meters long and 1.5 tons weigh is able to work for twelve hours. As shown in Fig.3-2-5-1, expanded L-array hydrophones and side scanning sonar with operating frequencies of 100 kHz are mounted on the AUV (Fig.3-2-5-2). The L-array interferometric technique plays an important role in highly resolve bathymetry mapping, not to mention backscatter imaging. In effect, three hydrophones are arranged at intervals of three and thirteen wavelengths in a shape of L on both sides, in addition to side scan sonar Klein System 2000 with operating frequencies of 100 kHz and 500 kHz(Fig.3-2-5-3). The L-shape array of hydrophones enables us to make phase difference measurement with high resolution and successfully.

Table 3-2-5-1 L-array interferometry parameter

Frequency	100(kHz)
Sampling Rate	400(kHz)
Received Channel	3ch for each side
Range	50～750(m) variable
Pulse Length	50～400(μsec) variable

Fig.3-2-5-2 Photo of the L-array interferometry sonar system

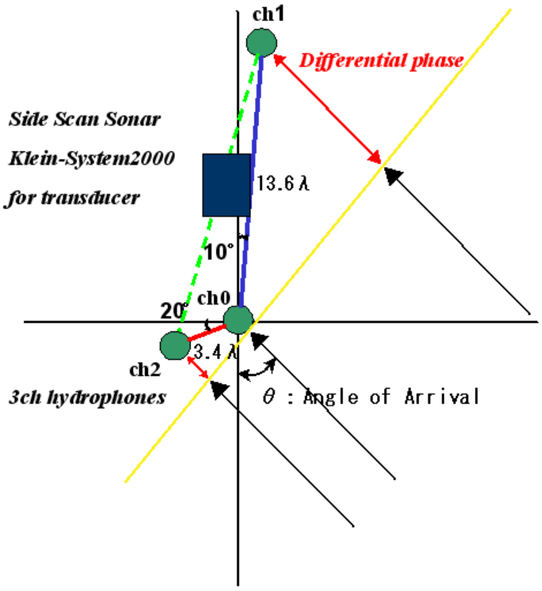


Fig. 3-2-5-3 Schematic image of the L-array interferometry technique using three row hydrophones for arrival direction of backscatter waves from the seafloor.

The simplest system of interferometry sonar has one transmitter and two hydrophones. The acoustic wave transmitted from transducer and reflected on seafloor is received on differential phase by each hydrophone, because their array is difference. If we can measure this phase difference, we can get an elevation angle of received echo at geometry, because we know distance of hydrophones and angle of array. And then we can get a transmission range of echo from time and acoustic velocity. From these processes we can get a coordinate data with depth at certain time. Applying this series of operation for time series we can measure the depth in swath at 1ping. Though interferometry system is more susceptibility to noise, because we have not been narrow the focus when we receive the signals like multi-beam echosounder. The intensity data of side scan sonar system will have some compensating benefits.

Already the interferometry sonar system with two hydrophones has been developed in England, but this system is unprecedented one, which arranges three hydrophones arrayed 2-dimensional L-shape. Generally, the longer the distance of two hydrophones is, we can get higher resolution data of phase difference, even though it becomes difficult to consider correct elevation angle of real seafloor from plural data appear in the same time. Consequentially, conventional interferometry sonar system which has two hydrophones, we can't array two hydrophones with long distance. In order to resolve essential defect described above we developed new designed interferometry sonar system, which has three hydrophones for each side of AUV, and they are arranged two-dimensional array of L-shape. Consequently we can eliminate a defect of conventional interferometry sonar that it is difficult to consider correct elevation angle of real seafloor from plural data in the same time. And it allows us to array one pair of hydrophones with long distance. In our system one pair of two hydrophones is 15.1 times wavelength of transmitter signals. This is longer than conventional one, so we can get higher resolution data of elevation angle.

3.3 Cruise log.

Date	Time	Log
2008/9/18	10:00	Onboard
	11:00	Depart from Yokohama
	13:00	Briefing about ship's life and safety
	21:00	Arrive at survey area
2008/9/19	05:31	Launch acoustic station
	06:55	Finish calibration of acoustic station
	07:23	Moored buoy surfaces
	07:30	Depart to Mikawa Bay to escape Typhoon
	11:05	Arrive at Mikawa Bay
2008/9/20	08:00	Depart from Mikawa Bay
	11:30	Arrive at survey area
	12:30	KAIKO starts to dive (7K#431 dive)
	14:44	Connect seafloor station to seafloor junction unit No.4
	14:50	Confirm energization
	15:15	KAIKO leaves the bottom
	16:10	KAIKO surfaces
2008/9/21	07:16	Launch r2D4
	07:17	Start acoustic ranging observation
	16:20	Finish acoustic ranging observation
2008/9/22	09:00	KAIKO starts to dive (7K#432 dive)
	10:10	Start visual observation of fault system
	15:20	Finish visual observation, KAIKO leaves the bottom
2008/9/23	06:30	Launch r2D4
	06:57	Start acoustic ranging observation
	13:00	Finish acoustic ranging observation
2008/9/24	12:30	Launch r2D4
	12:45	Start dive of r2D4, Topographic survey
	16:10	r2D4 surfaces
2008/9/25	05:00	Leave for Suruga Bay because of fishery operation
	09:30	Arrive at Suruga Bay
	10:10	Launch reference targets
	13:40	Launch r2D4
	13:45	Start dive of r2D4, Topographic survey
	16:00	r2D4 surfaces

	18:00	Reference targets surface
2008/9/26	09:00	Arrive at Yokosuka

3.4 Installation of submarine cable transponder on the Tokai SCANNER cable system by the KAIKO 7000 II operation

3.4.1 Mooring system for deployment of the submarine cable transponder

Weight of the submarine transponder is 134kg in the air. It exceeds the upper limit of the payloads with which the KAIKO 7000 II can carry. It is needed to transport the submarine cable transponder to the seafloor prior to the operation of the KAIKO 7000 II. Mooring system was designed by JAMSTEC and NME in order to deploy the submarine cable transponder to the seafloor. Buoyancy balance was adjusted carefully so that the mooring system absorbs a shock which could be given to the submarine cable transponder at the time of landing on the bottom.

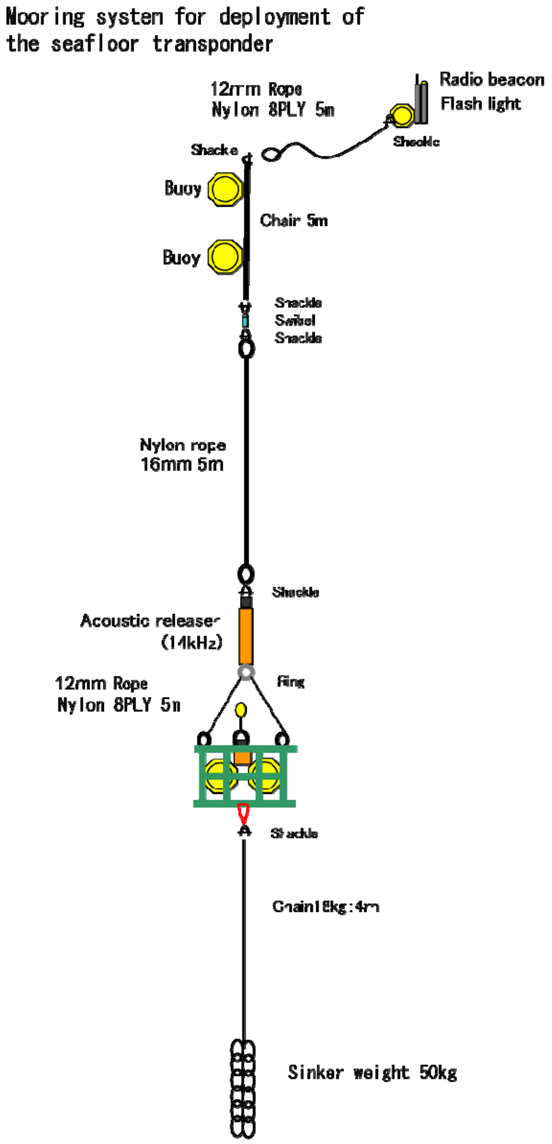


Fig.3-4-1 Mooring system for the submarine cable transponder.

3.4.2 Installation and operation check

(1) Installation

The submarine cable transponder was lowered by free fall, with the assistance of the mooring system, prior to the dive of the KAIKO 7000 II. After locating the position of the deployed submarine cable transponder by acoustic triangulation, the mooring system (buoys and acoustic releasing transponder) was released by acoustic control and then retrieved on the surface. The KAIKO 7000 II started diving toward the point where the submarine cable transponder landed. The sonar system equipped on the KAIKO 7000 II easily detected the submarine cable transponder on the seafloor and then the KAIKO 7000 II approached to it.

The KAIKO 7000 II released the main frame of the submarine cable transponder from the sinker weight and then grabbed it with the manipulator. The submarine cable transponder was carried to the side of the junction unit of the submarine cable (Tokai SCANNER) and set it there. The wet-mate connector was unbundled from the main frame and connected to the junction unit. The operator on duty at the Toyohashi landing station turned on power. It was observed by the video camera on the KAIKO 7000 II that the pilot lamp on the submarine cable transponder started to light. That was an indication that the power was supplied to the transponder system correctly. The KAIKO 7000 II left the bottom after having watched the surrounding area.

(2) Check of operation

Observation instruments branched from the Tokai SCANNER submarine cable are controlled and monitored from the Toyohashi landing station and JAMSTEC Yokohama Laboratory.

Operation check whether the installed transponder system works well or not had been done before the ranging measurement with the r2D4 started. Operators were dispatched to both the Toyohashi landing station and the JAMSTEC Yokohama Laboratory. After supplying the power to the submarine cable transponder, executing the commands to get the status of the transponder system and to change the operational mode had been tested from both Toyohashi and Yokohama.

3.4.3 Inspection result of the observatory

After connecting the acoustic reference station, Kaiko7000II visually inspected the junction unit and sensors. It was confirmed that hey were stably placed on the seafloor and no abnormal phenomenon has found. No corrosion even on galvanic anode was found (Fig.3-4-3-4, 3-4-3-5)

Fig. 3-4-3-1 shows the schematic plane view of the observatory. Fig. 3-4-3-2 is the whole view of the observatory. Fig.3-4-3-3 - Fig.3-4-3-7 show photos of the junction unit. Fig. 3-4-3-8 and fig. 3-4-3-9 show the view of S-SMAD and DOMES respectively.

The position of the junction unit was re-measured with Kaiko 7000 II. It was 34°10.4797N, 137°29.3337E, and the water depth was 1,313m. This position was actually the position of Kaiko 7000 II vehicle measured by Kairei when the vehicle moved very close to the junction unit. There is a little difference from the position measured by Natsushima and Hyper Dolphin.

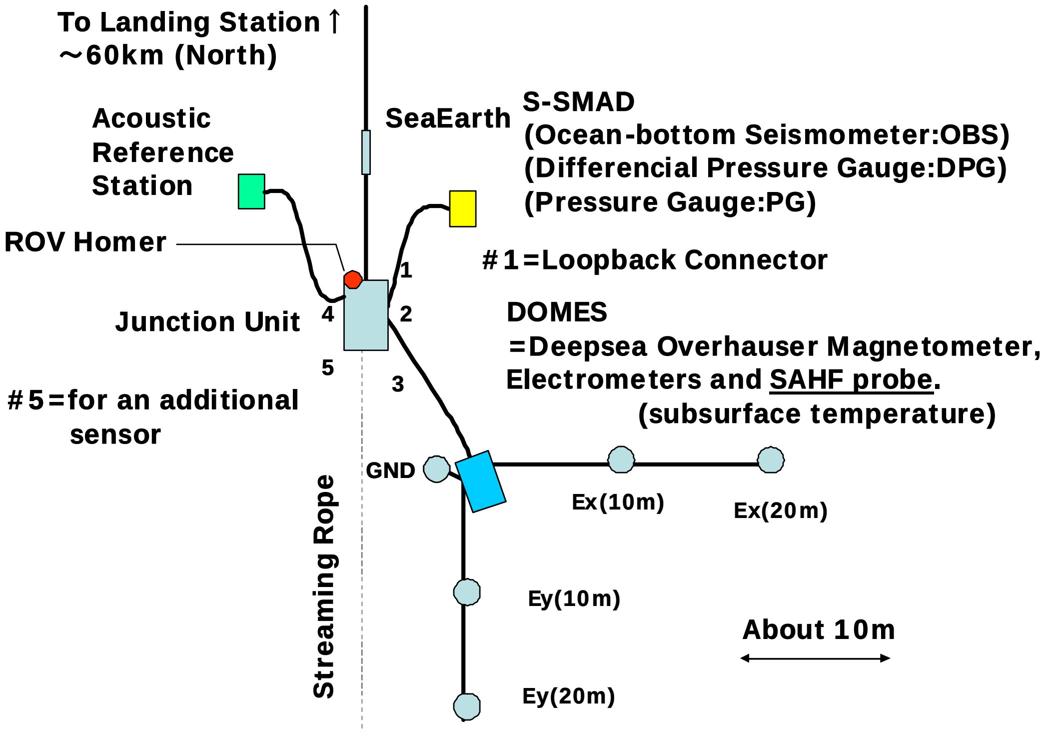


Fig.3-4-3-1 Schematic plane view of the observatory

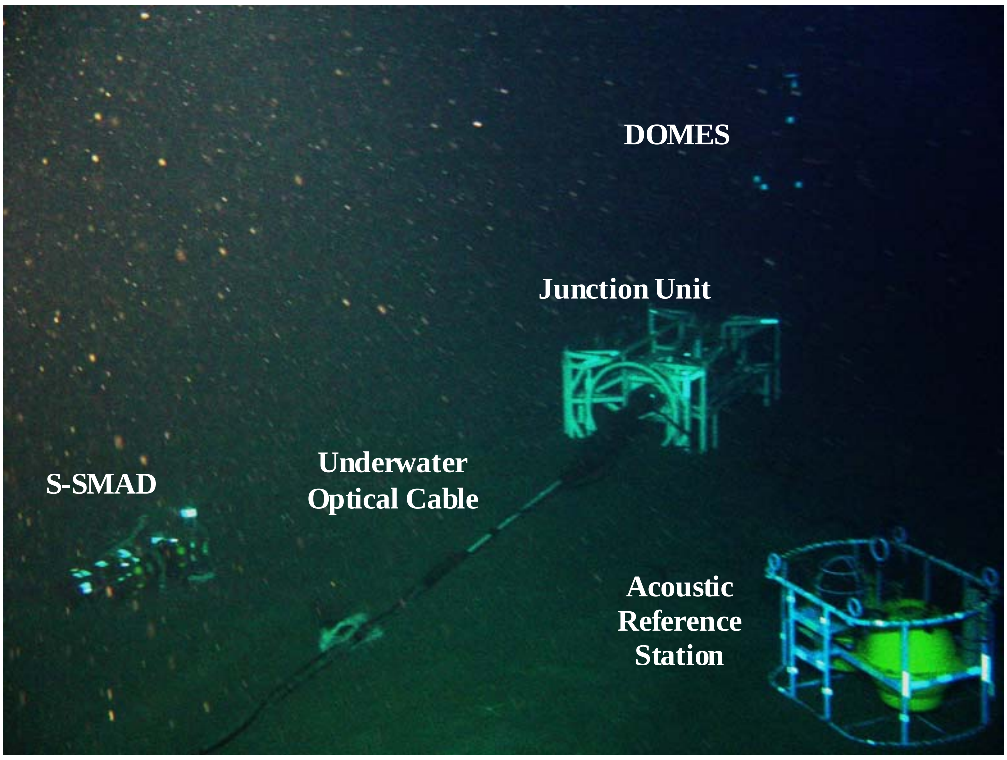


Fig.3-4-3-2 Photo of the observatory

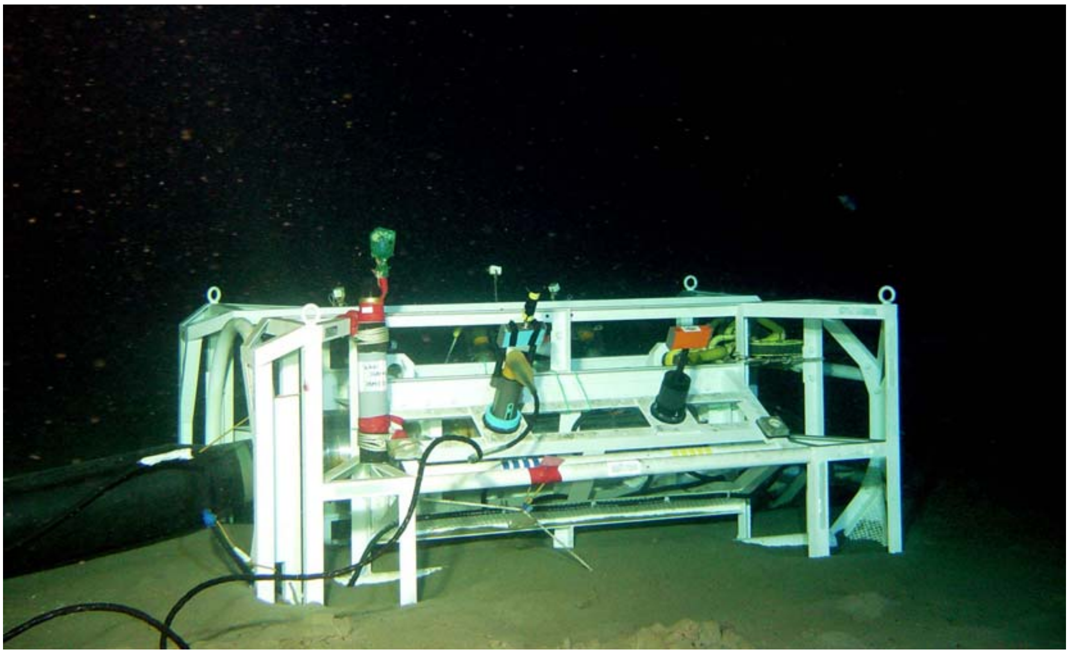


Fig.3-4-3-3 Photo of the junction unit - 1

Fig.3-4-3-4 Photo of the junction unit - 2

A galvanic anode and an underwater mateable connector for acoustic reference station

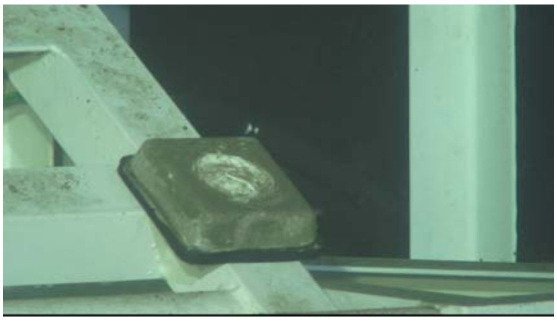


Fig.3-4-3-5 Photo of junction unit - 3

Another galvanic anode

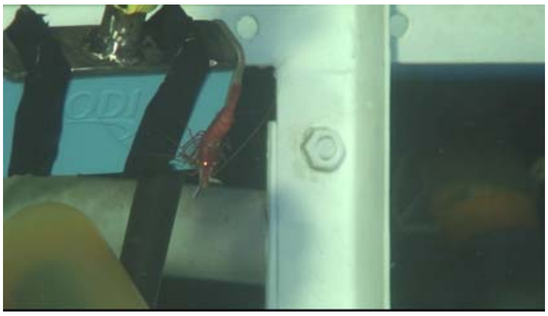


Fig.3-4-3-6 Photo of the junction unit - 4

Fig.3-4-3-7 Photo of the junction unit - 5

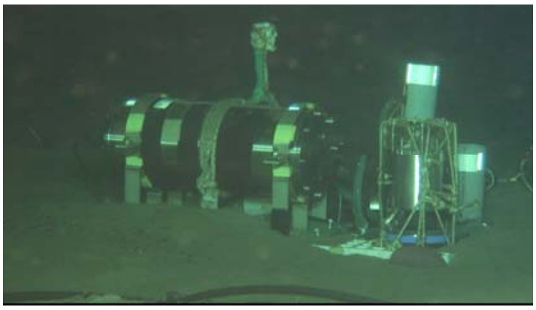


Fig.3-4-3-8 Photo of S-SMAD

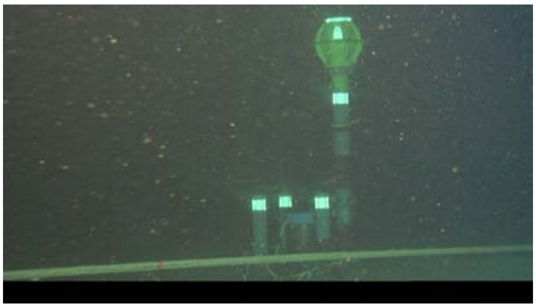


Fig.3-4-3-9 Photo of DOMES

3.5 Observations based on AUV “r2D4”

3.5.1 Control of r2D4 for seafloor mapping

Navigation of the r2D4 is controlled by a Doppler hybrid INS based on fiber optic gyro. And while on the sea surface, the position is modified by GPS. The navigation system includes a depth sensor, an altimeter, and a forward-looking sonar for obstacle avoidance. The communication systems are a SSBL acoustic positioning and communication system (in subsea), a wireless LAN for control and data link (on surface). And an ORBCOMM, a low earth-orbit satellite communication system is also embedded to notify the surfacing point of the vehicle to support vessel.

Though the position accuracy obtained by INS installed on the r2D4 is sufficiently high, authority of it is lost when the aid from DVL becomes unavailable. When the vehicle is subjected to carry out a bottom tracking below the altitude of 200m, it is the interval until reaching that altitude during which significantly large position error accumulates owing to the lost DVL aid.

Since the r2D4 can approach the sea bottom closely, high frequency acoustic waves are available without significant absorption to achieve the image of the high resolution. The INS aided by the DVL navigation makes it possible to highly control its track line, especially altitude. The r2D4 can keep its altitude constant during mapping. And then, the swath width of the sonar is kept constant. We can achieve the uniformly high resolution image of the sea bottom.

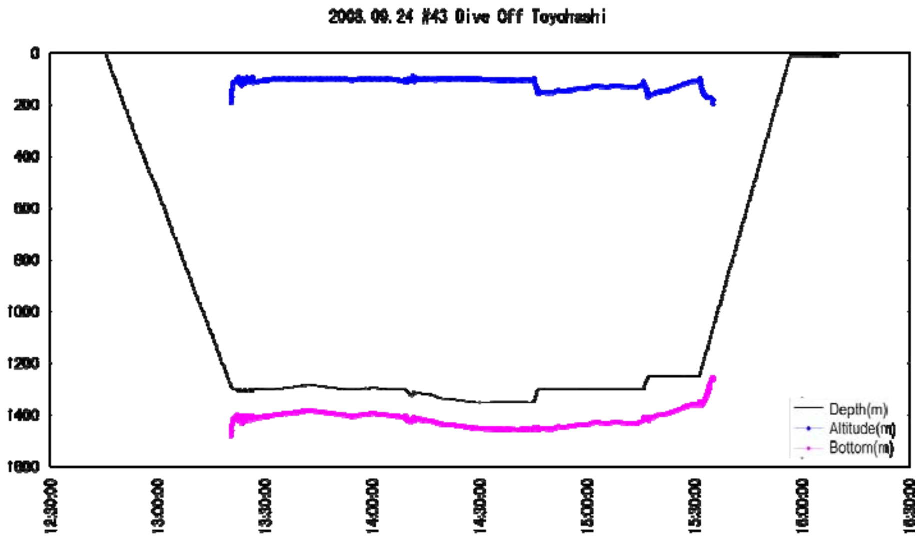


Fig.3-5-1-1 Vertical profile of #43 Dive (Sep. 24, 2008)

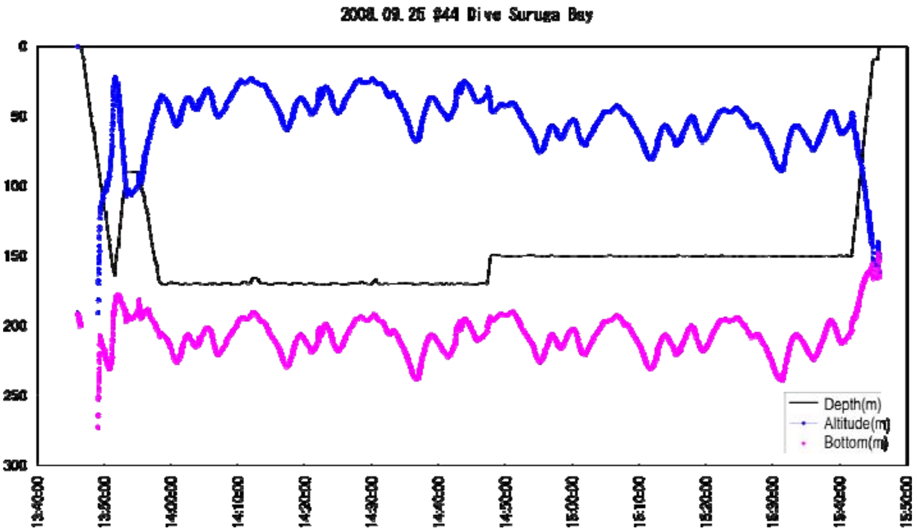


Fig.3-5-1-2 Vertical profile of #44 Dive (Sep. 25, 2008)

3.5.2 Control of r2D4 for seafloor geodetic observation

The r2D4 cruises at the depth of 0.5～1.0m during acoustic ranging measurements for seafloor geodetic observation. Not only the GPS antenna of the seafloor geodetic observation but also the one inherently equipped on the r2D4 for its navigation are in the air during observation. The r2D4 can trace the scheduled line correctly, updating its positions aided directly from GPS. It has an advantage to use the r2D4 as a surface platform for the seafloor geodetic observation. The waypoints that are carefully considered and distributed on the schedule line keep the r2D4 away from abrupt movement of the body when the r2D4 changes its course.

The actuators of the r2D4 are electrical motor ones. They make no loud noise during operation, and then ideal acoustic environment is supplied for the acoustic ranging. This is another advantage in using the r2D4 for seafloor geodetic survey.

Fig.3-5-2-1 Photo of the r2D4 during seafloor geodetic survey

3.5.3 Mooring system of reference object for seafloor mapping

The interferometry sonar equipped on the r2D4 can acquire higher resolution image of the seafloor than ones acquired by conventional MBESs equipped on the surface research vessels. How high resolution does the combination of the interferometry sonar and the r2D4 achieve in seafloor mapping? This is a question that we want to know.

We decided to deploy the reference object whose dimensions were known on the seafloor, in order to understand the resolution quantitatively. Three oil drums chained each other were chosen as a reference object. The mooring system for the reference was designed as shown in Fig.3-5-3. Two sets of the moored reference objects were deployed in the target area for the seafloor mapping. If the acoustic image obtained by the interferometry sonar on the r2D4 would delineate the oil drums, we could say that the mapping system achieves the resolution, at least, equivalent to the dimensions of the oil drum, that is, Φ60cm X L90cm.

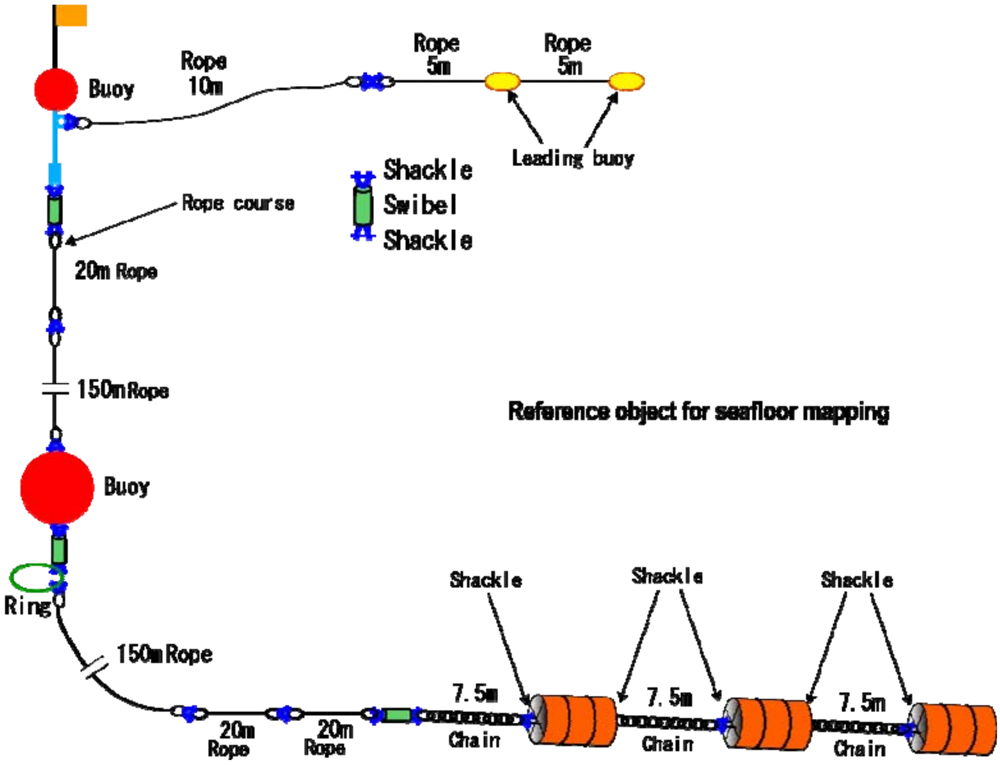


Fig.3-5-3 Moored seafloor reference for seafloor mapping

3.6 Method of seafloor geodesy and results

GPS/Acoustic seafloor geodetic observation method is one of the few methods that can detect and monitor the seafloor crustal movement directly. The GPS/Acoustic method (system) requires an acoustic mirror transponder as a seafloor reference station, at least one GPS reference station on land and an on-board unit that provides interface between kinematic GPS and underwater acoustic ranging. The concept of this seafloor geodetic observation system is to measure the acoustic ranges to the set of acoustic transponders on the seafloor from the ship-board transducer. The location of the surface transducer is determined using the GPS system and the dynamic motion sensor. The measurements are conducted repeatedly as the ship drifts over the seafloor reference station. The location of the seafloor reference station is determined from these acoustic ranges and the positions of the ship-board transducer, with the sound speed profiles deduced from CTD, XBT and XCTD measurements.

Institute of Industrial Science, University of Tokyo launched a project supported by the Japan Society for the Science Promotion of Science (JSPS) as the Grants in Aid for Scientific Research. In this project, we are aiming at developing new-generation seafloor geodetic observation system that conquers difficulties inherent with the current system. Central idea of this project is to utilize techniques of underwater robot (Autonomous Underwater Vehicle) and submarine cable in order to take measurements, in place of using the research vessels that are used as an observation platform in the current system.

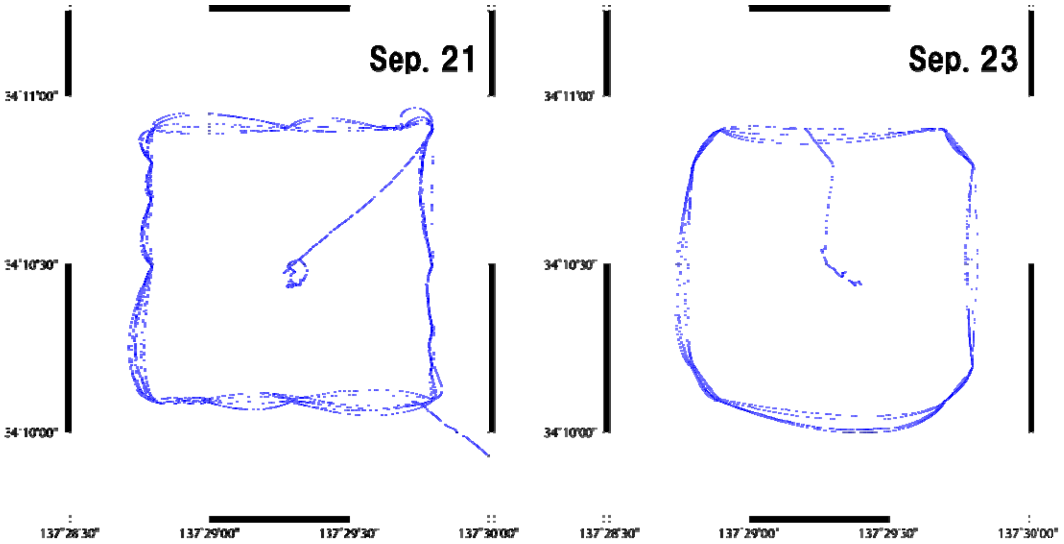


Fig.3-6-1 Track lines of r2D4 during seafloor geodetic observations

We conducted seafloor geodetic observations on September 21 and 23 September, 2008. Observational instruments that we used were ones developed in the JSPS project described above. The submarine cable transponder installed on the Tokai SCANNER is one of them. We selected the r2D4 as a surface platform and install the newly-developed on-board unit on it.

The survey line was designed as a square having 1nm long side and its center was at the position of the installed submarine cable transponder. The r2D4 had revolved along the line at the depth of 0.7-1.0m. Acoustic ranging to the seafloor transponder was repeated at the interval of 20 sec during the r2D4 cruised. XCTD observation was carried out every two hours to understand the change of the sound speed profile.

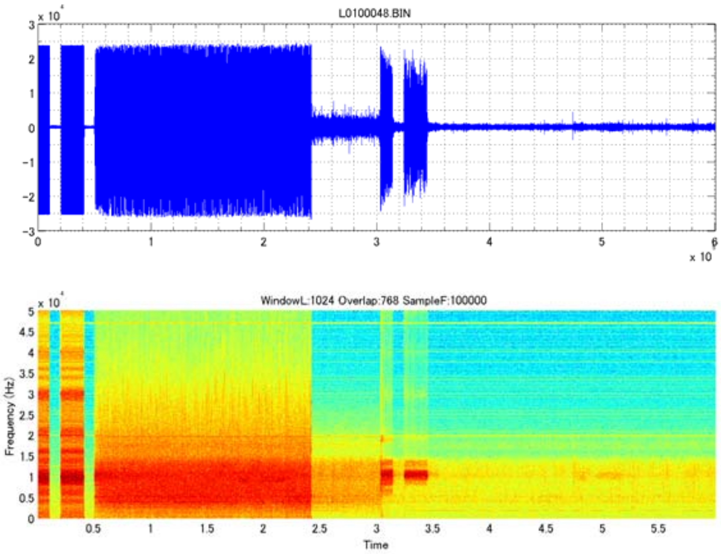


Fig.3-6-2 An example of recorded ranging signal (Upper) and its spectrogram (Lower).

3.7 Preliminary results of seafloor mapping based on the AUV "r2D4"

3.7.1 Results of interferometry seafloor mapping

(1) Outline of the operation and results

The AUV has dived two times during the KR08-11 cruise for the purpose of seafloor mapping underwater 1,250 to 1,300 meters and performance test of interferometry sonar and sidescan sonar.

Table 3-7-1 Summay of the observation data

AUV dive date	Operating hours	Logged data of Sidescan Sonar	Logged data of L-array interferometry sonar
September 24 (43rd dive)	2h6m	1.27GB	25.4GB
September 25 (44th dive)	1h52m	1.13GB	22.7GB
Total	3h58m	2.4GB	48.1GB

(2) The results of survey by r2D4 (Side-scanning sonar imaging and interferometry depth profile)

A mosaic map of side-scanning sonar backscatter with a resolution of 1 meters was prepared through No. 43rd dives and 10ping interferometry depth profile of 44th of r2D4

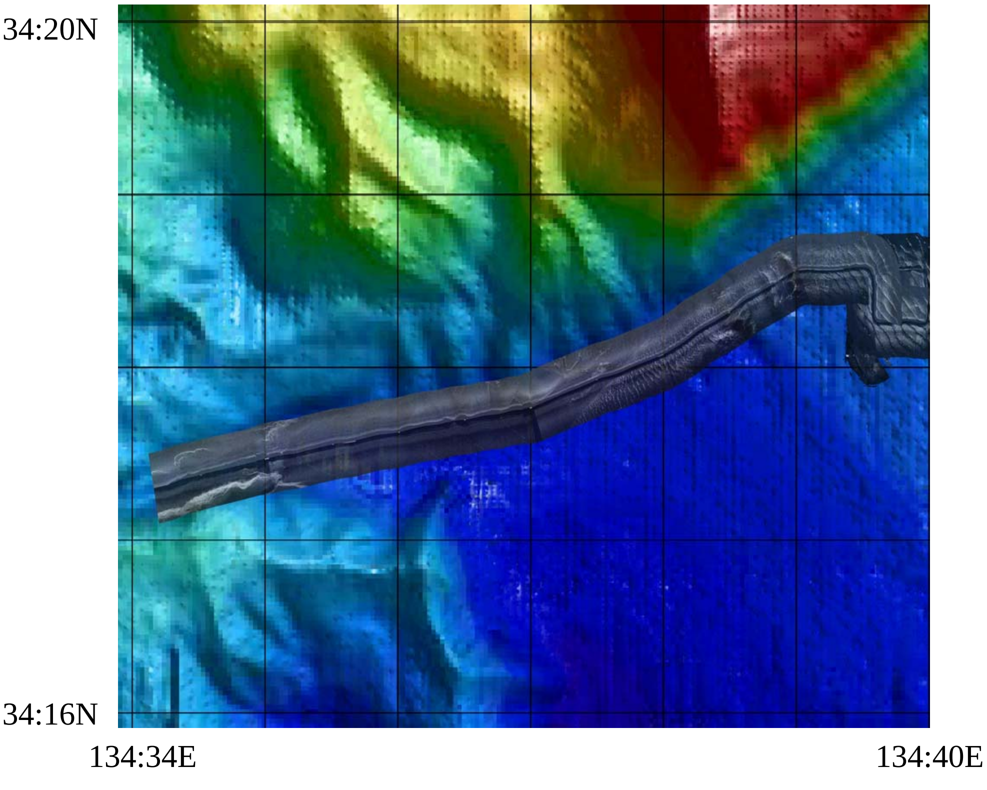


Fig.3-7-1 A backscatter mosaic map with the side-scanning sonar through No. 43rd dives of r2D4 with a resolution of 1 meter on SeaBeam terrain map.

Fig.3-7-2　A close up map of the side-scan backscatter mosaic map during the No. 43rd dive of r2D4 with a resolution of 1 meters .（about 4200m×2000m）

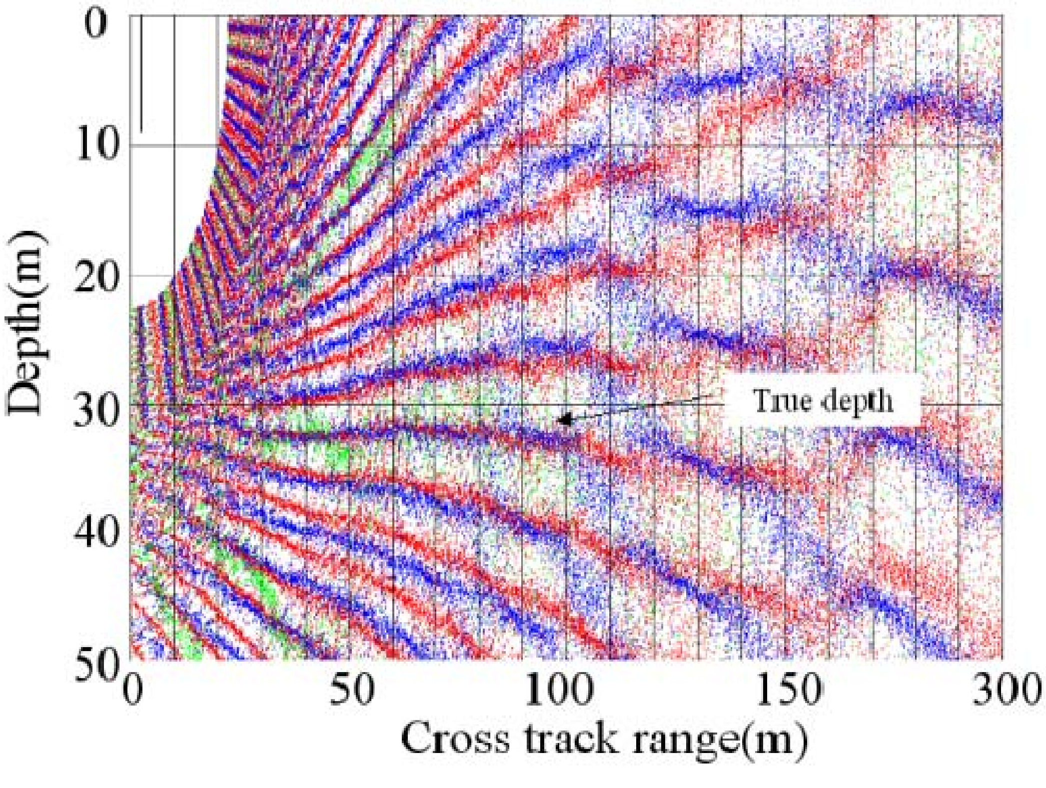


Fig.3-7-3　 Interferometry depth profile of 44th dive of r2D4

3.7.2 Preliminary results of r2D4 survey of Enshu Fault System

Date: September 24, 2008

Place: Enshu Fault along the Tenryu Submarine Canyon

Deformation of Enshu Faults system in the Tenryu Submarine Canyon was found in 7KII Dive # 432 of KR08-11 cruise (See Chapter 8). Detailed side scan sonar images have been collected using r2D4.

Fig.3-7-2 An example of SSS image on r2D4 dive.

Fig.3-7-2 shows some different scaled NW-SE direction linear structures on the sea floor of the Tenryu Submarine Canyon. Northwestern side of figure shows a white and dark zone of SW-NE direction that is similar direction of Enshu Faults. Only preliminary image on r2D4 dive was shown in this cruise report. More detailed interpretation of the data will plan in the recently.

3.8. Enshu Faults system and tectonics of the upper forearc slope around the Tokai SCANNER (Kohsaku Arai)

The study area around the Tokai SCANNER is located on the upper forearc slope of the eastern Nankai subduction zone. The width of the continental shelf is 30 km south of Ise Bay and decreases to 5 km off of Hamamatsu. Small submarine canyons cut the shelf slope northwest to southeast and reach the Enshu Trough. The Enshu Trough is about 100 km long and 40 km wide with a northeast to southwest trend (Sakurai and Sato, 1983). The central uplift (Inoma and Sasaki, 1979) composed of 5-10 km long anticlines trending northeast to southwest has developed northwest of the Enshu Trough. Enshu faults system may continue more than 100 km. Northeastern Enshu Faults have developed along the central uplift, however, southwestern area of Fig 8-1 composed of along three anticlinal axes. Tokai SCANNER is located around the middle anitiiclinal axis. Many normal faults (Atumi-Hantou oki Faults) are traced in the area about 70 km long and 15 km wide from 137°10' to 137°47' on shelf to upper shelf slope (Fig.3-8-1).

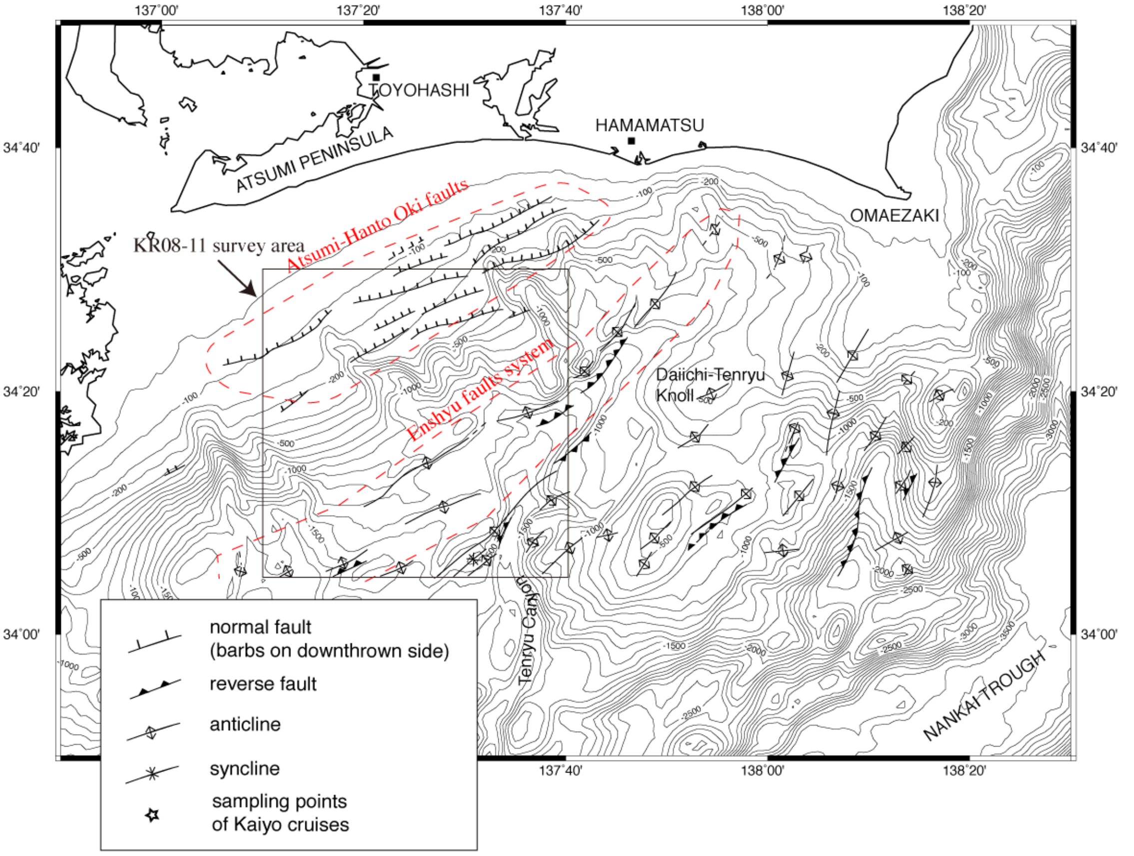


Fig.3-8-1. Structural summary map of the study area (modified after Arai et al., 2006). Atsumi-Hanto Oki faults and Enshu faults systems were objects of this cruise (red dashed circle).

(1) Results of 7KII Dive # 432

Date: September 22, 2008

Place: Enshu Fault along the Tenryu Submarine Canyon

Observer: K. ARAI

The ROV sea bottom observation was carried out using “Kaiko 7K II” dive # 432 to look for closely indications of activity of Enshu Fault. The dive carried out from water depth in 1427 until 879 meters with track starting from sea floor of Tenryu Submarine Canyon up to the central uplift zone. The dive traverse based on the detailed bathymetric mapping on this cruise (Fig.3-8-2). Bathymetric image shows the two different direction of deformation. One is the northeast direction along Enshu Faults and the other one is cross to the Enshu Faults.

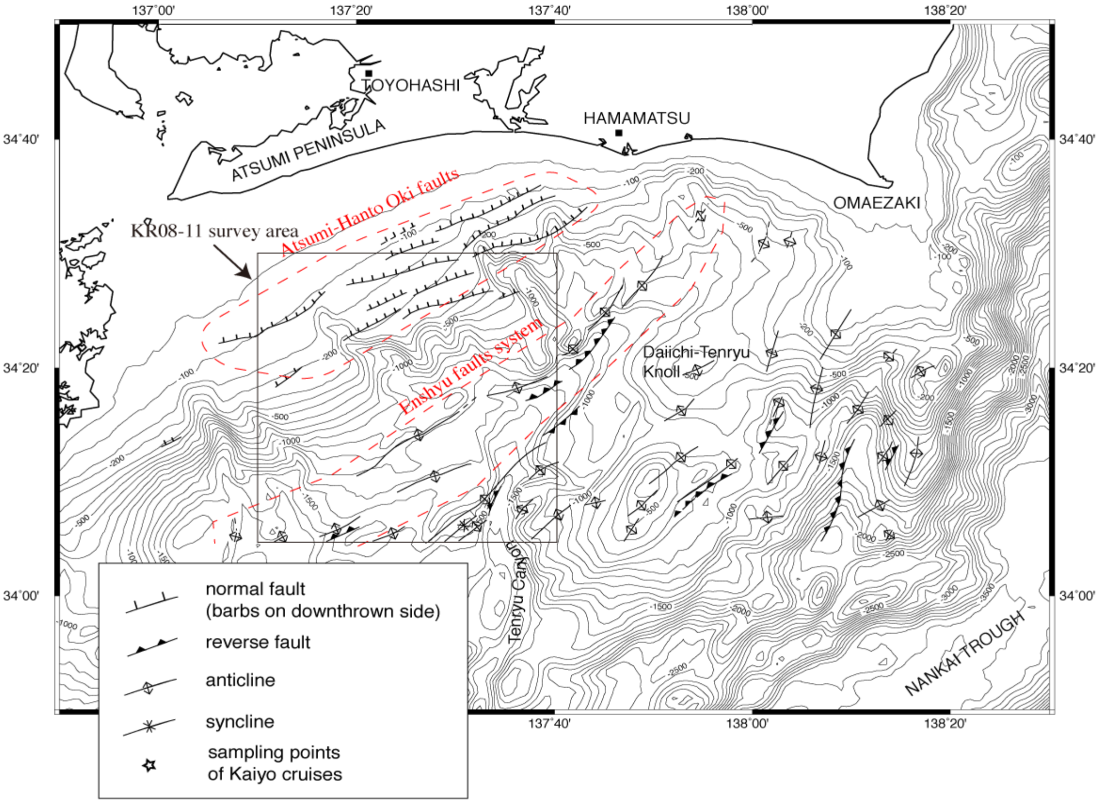


Fig.3-8-2 SeaBeam 2100 image shows the central uplift along the Tenryu Submarine Canyon. Black lines are bathymetric mapping survey track.

Simplified root map was shown in Fig.3-8-3. 7KII arrive sea floor of 1422 m in water depth at 10:11 (local time). Base of the Tenryu Submarine Canyon is characterized flat sandy mud. Some burrows were observed (Image 2008 0922 1012JST).

Detailed log file has provided in dataset. Some selected images from the dive are presented below:

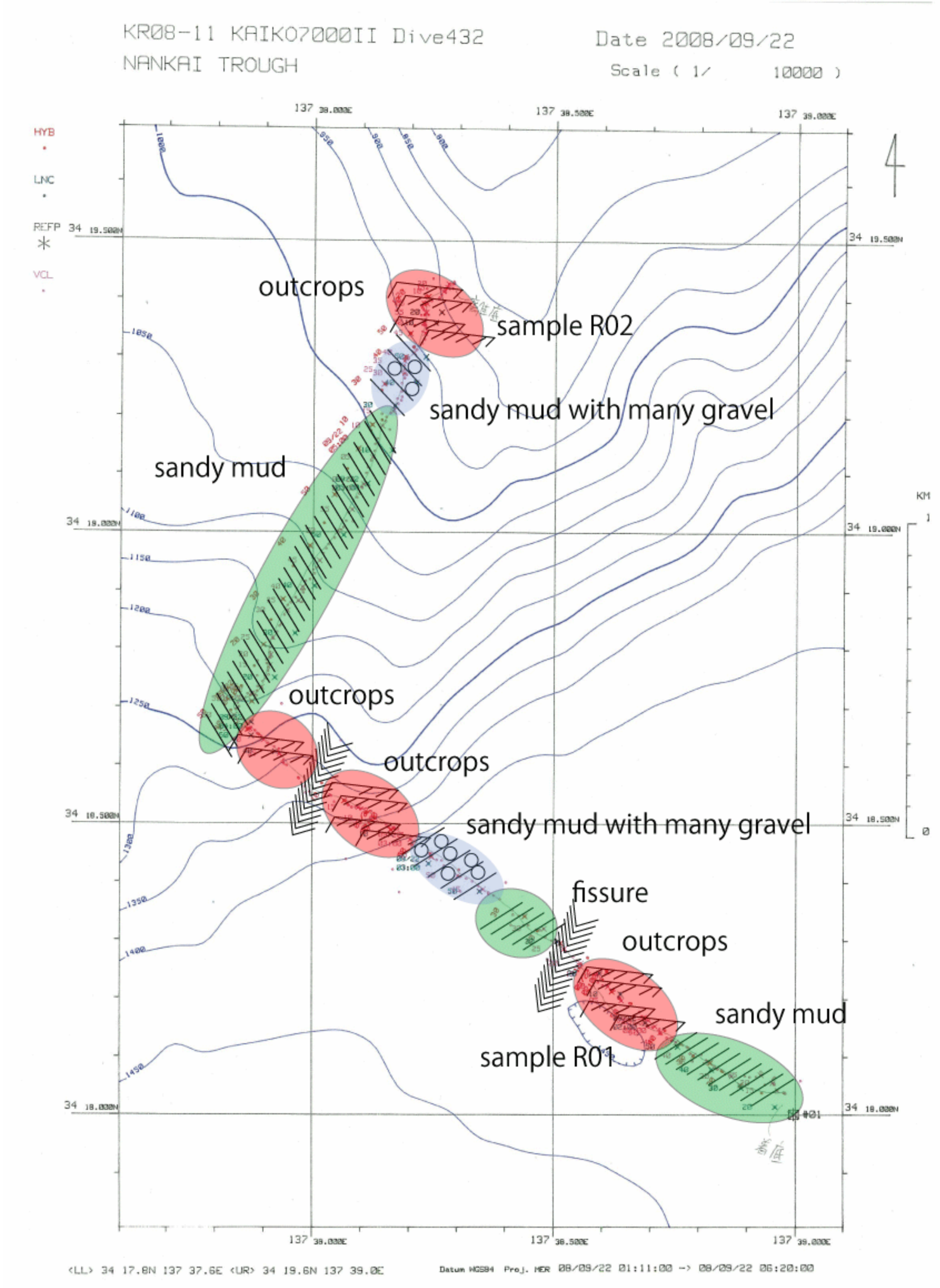


Fig. 3-8-3 Simplified root map of Dive #432.

Image 2008 0922 1012JST The image shows sea bottom on the Tenryu Submarine Canyon. Sandy mud sea floor was observed.

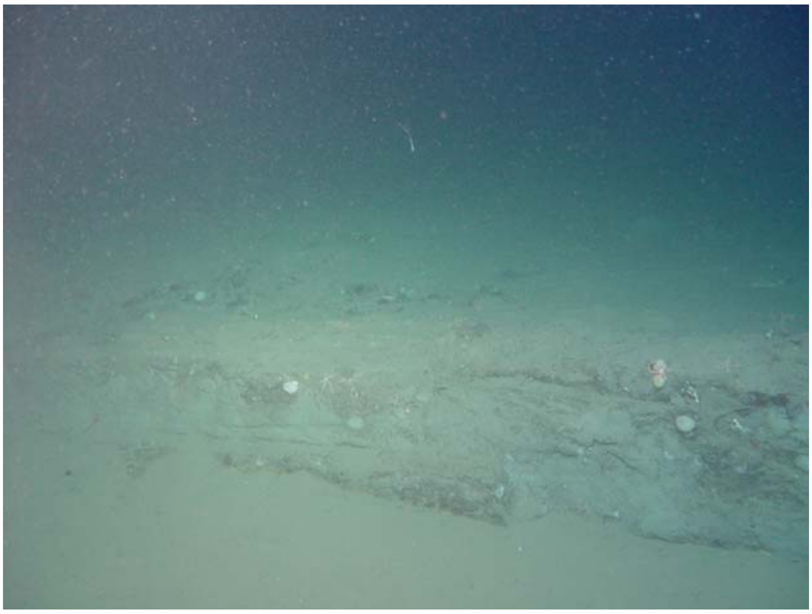


Image 2008 0922 1050JST The image shows outcrop of sea floor on the Tenryu Submarine Canyon. Biota encrusted on hard mudstone. Muddy sediments covered on outcrop.

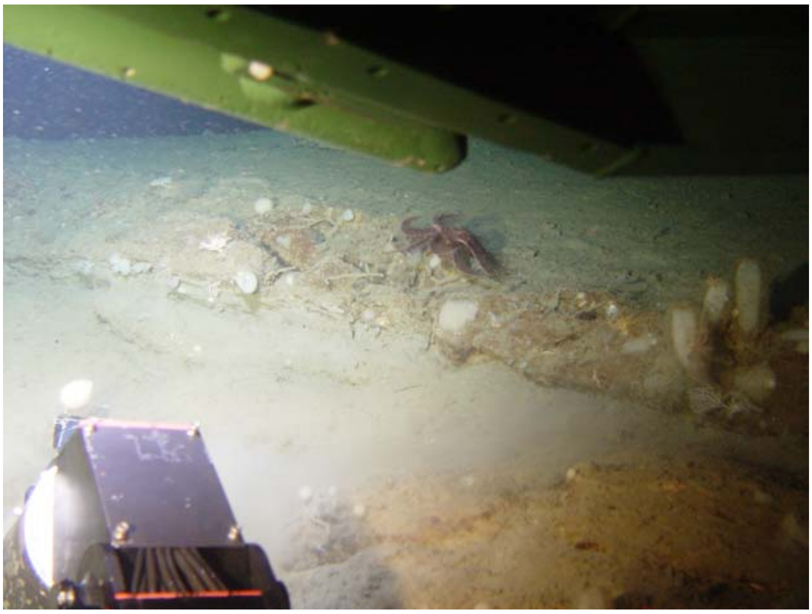


Image 2008 0922 1105JST The image shows sampling point of 7KII#432-R01. Siltstone cropped out on this area.

We found 10 to several ten cm scaled step on the sea floor of the Tenryu Submarine Canyon of 1431 m in water depth at 10:49 (Image 2008 0922 1050JST). Outcrop was slightly covered with modern sediments and was encrusted by biota. Gray siltstone sample (7KII#432-R01) was corrected at 11:07 (Image 2008 0922 1105JST). Sample list is provided in table 1. After got the sample, we found fissure structure in bottom floor (11:22). Depth of fissure was more than 20 m and width was reached about 50 m. Northwest of fissure is characterized sandy mud sediment of flat sea floor. Rocks are scattered around the foot of central uplift (11:37), subsequently, the outcrops as Image 2008 0922 1201JST were found. Outcrop makes several terraces in the image. Outcrop was slightly covered with modern sediments and was encrusted by biota.

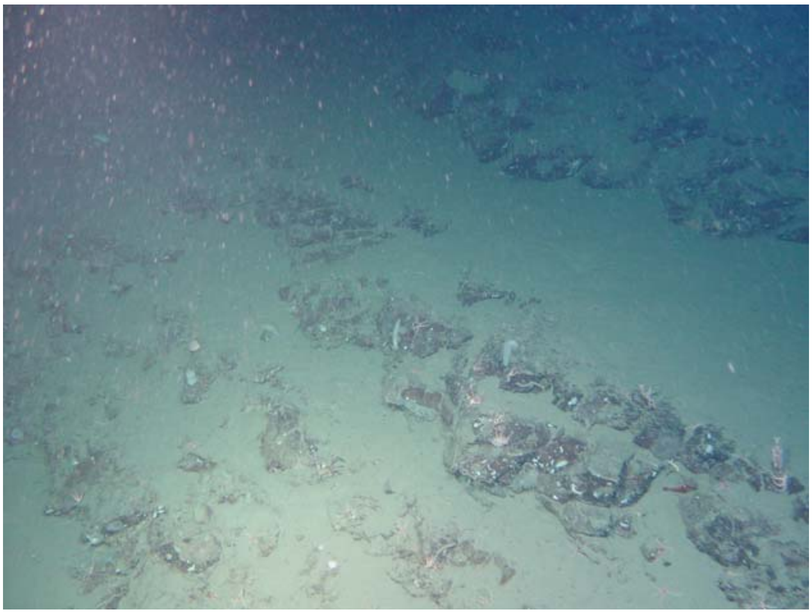


Image 2008 0922 1201JST The image shows outcrop view on the foot of central uplift. Alternated layers are composed the outcrop.

Modern muddy sediment covered the slope of central uplift at 12:35 (Image 2008 0922 1250JST). The survey line changed to northeast direction (20 degree). Rocks are scattered area around 970 m in water depth (14:25), subsequently, the outcrops as Image 2008 0922 1449JST were found. Modern sediment of this area is slightly coarser than before. Outcrop is covered by modern sediment (Image 2008 0922 1449JST). Dark olive gray very fine sandstone sample (7KII#432-R02) was corrected at 14:51 (Image 2008 0922 1451JST).

Image 2008 0922 1250JST The image shows muddy sediments on the halfway up the central uplift. Burrows occur and make irregular features on sea floor.

Image 2008 0922 1449JST The image shows outcrop of top area of central uplift. Muddy sediments covered on outcrop.

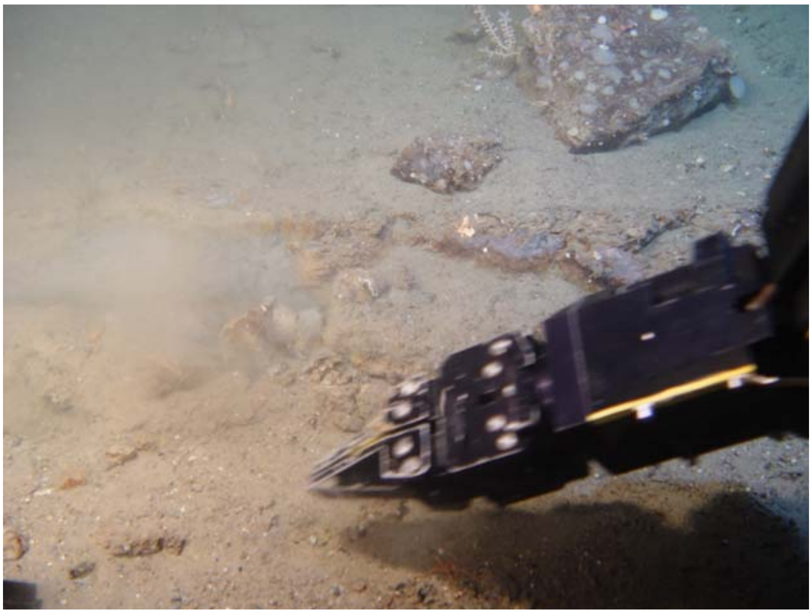


Image 2008 0922 1451JST The image shows sampling point of 7KII#432-R01. Silty sandstone cropped out on this area.

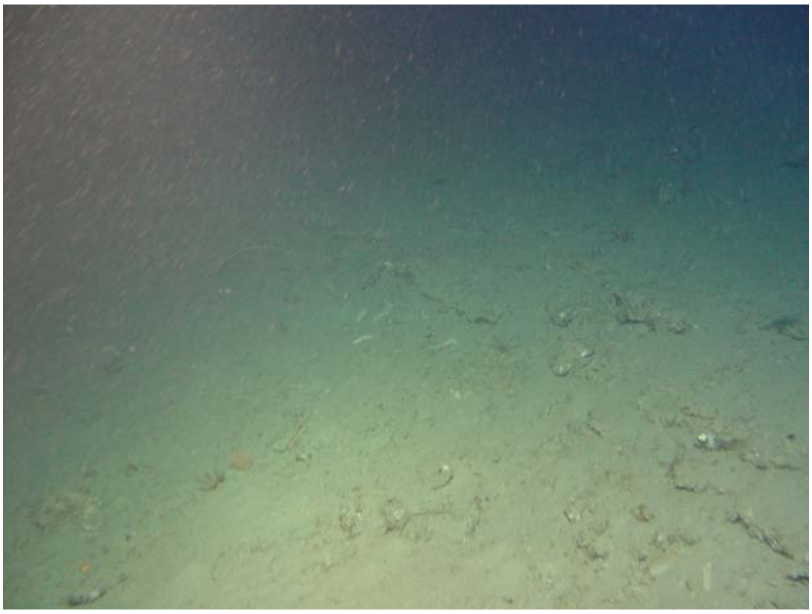


Image 2008 0922 1516JST The image shows sampling point of 7KII#432-R01. Siltstone cropped out on this area.

Table 3-8-1 Sample list of KAIKO 7000 II #432

sample no	Date: Time	location	depth (m)	descriptions		large	others	sampling
7KII#432-R01	2008.9.22: 11:07 (LST)	34-18.20N, 137-38.68E	1427	gray (7.5Y 5/1) siltstone with black particle (mica), faintly laminated		15x12x7 cm, 12x8x2 cm, 6x5x3 cm and many small pieces		AIST (age)
7KII#432-R02	2008.9.22: 14:51 (LST)	34-19.36N, 137-38.23E	916	dark olive gray (5GY 4/1) very fine sandstone, massive, mica particle are included, outside of rokcs changed to blownish color by alternation, burrow within the brownish part and biota encrusted outside		23x13x11 cm, 9x8x7 cm, 8x7x5 cm, 5x5x5 cm, 5x4x2 cm, 4x3x3 cm and many small pieces		AIST (age)

Arai, K. (2008) Geological Map Enshu Nada. Marine Geology Map Series, no. 65 (CD), Geological Survey of Japan, AIST (in Japanese with English Absrtact).

Arai, K., Okamura, Y., Ikehara, K., Ashi, J., Soh, W. and Kinoshita, M. (2006) Active faults and tectonics on the upper forearc slope off Hamamatsu City, central Japan, Journal of Geological Society of Japan, 112, 749-759 (in Japanese with English Absrtact)

Sakurai, M. and Sato, T. (1983) Geological structure of Outer Ridge off Tokai District. Report of Hydrographic Researches, 18, 23-35, (in Japanese with English Absrtact).

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Users of data or results of this cruise are requested to submit their results to Data Integration and Analysis Group (DIAG), JAMSTEC.