doi : 10.17596/0003061

YOKOSUKA Cruise Report

YK12-14

Evaluation of hybrid submersible gravity observation system for exploration of seafloor hydrothermal deposits by using an underwater vehicle

Sagami-bay

Sep.6, 2012-Sep.10, 2012

Japan Agency for Marine-Earth Science and Technology

(JAMSTEC)

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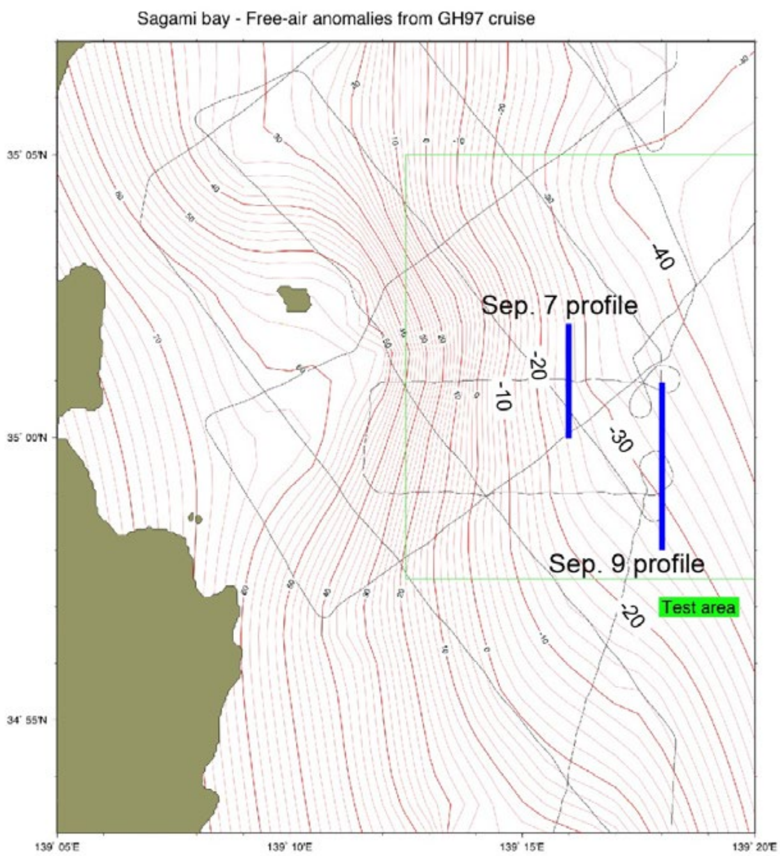
1. Cruise Information

- Cruise ID YK12-14
- Name of vessel YOKOSUKA and URASHIMA
- Title of the cruise Evaluation of hybrid submersible gravity observation system for exploration of seafloor hydrothermal deposits by using an underwater vehicle
- Title of proposal Evaluation of hybrid submersible gravity observation system for exploration of seafloor hydrothermal deposits by using an underwater vehicle
- Cruise period From September 6th, 2012 to September 10th, 2012
- Ports of call From Yokosuka (JAMSTEC) to Yokosuka (JAMSTEC)
- Research area Sagami-bay area
- Research Map



2. Researchers

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● Representative of the science party [Affiliation]

Masanao SHINOHARA [Earthquake Research Institute, University of Tokyo]

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3. Observation

- Background and objectives of the cruise,

Gravity is one of the powerful indices to profile underground structures. Surface ship gravimeters are popular tool for the purpose of collecting gravity values in marine region. They enable us to obtain gravity values from large area easily, while the resolutions are relatively low because of the distance between the sea surface and bottom. Otherwise, ocean bottom gravimeters are able to be observed gravity with high resolution, but they have still covered few limited sites so that they are designed to make observation in quiet only. In some cases, such as hydrothermal deposit survey, the medium performance both in resolution and size of survey area are required (Fig. 1). Because technology of remote operated vehicle (ROV) and autonomous underwater vehicle (AUV) is been developing, there is a possibility to measure the gravity by using ROV or AUV.

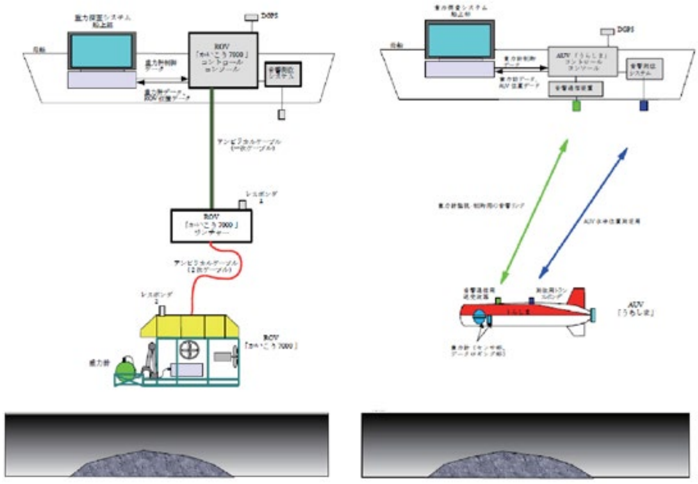

Fig.1 Concepts of submersible gravity measurement system using ROV and AUV.

Our target is to detect gravity anomalies less than 1 mgal by using an underwater vehicle. This setting is roughly equivalent to find a typical hydrothermal deposit with a dimension of 0.5 km x 0.5 km x 10 m and a density contrast of 1 g/cm^3 when the sensor is positioned 50 m above the seafloor. To obtain a position and amount of seafloor hydrothermal deposit that has a diamond shape with a diameter of 400m, 20m thick at the center and density difference of 1 g/cm^3, a resolution of gravity measurement should be approximately 0.1 mgal. In addition, measurement must be carried out 50m above a seafloor. AUV is suitable for such measurement near seafloor (Fig. 2). Compared to gravimeters, gravity gradiometers are insensitive to common disturbances such as parallel acceleration, thermal drift, and apparent gravity effect (Eötvös effect); however, during measurement using a mobile object, they are sensitive to centrifugal acceleration associated with instrument rotation, which should be removed by controlling the instrument's vertical orientation. Therefore, we have developed a two-dimensional forced gimbal whose orientations are controlled referred to both fiber-optic gyroscopes and tiltmeters.

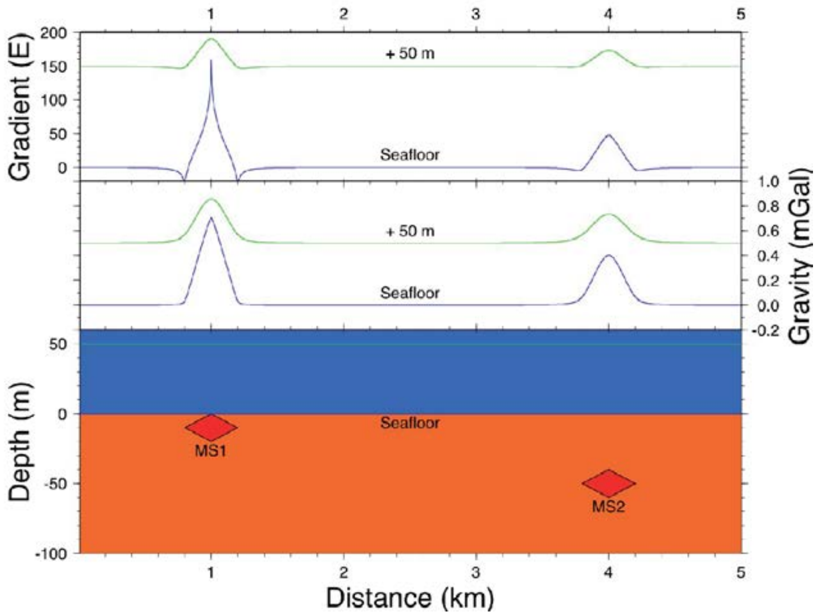

Fig.2 Estimated gravity (middle) and gradient (upper) variations are on a model (bottom). The model has two same shape deposits, MS1 and MS2, which have density differences of 1g/cm^3 against background.

For a survey of a seafloor hydrothermal deposit, we have been developing a submersible gravimeter system on underwater vehicles. And we carried out the first evaluation of our gravimeter system using the URASHIMA during YK12-14.

- Instruments and methods

Gravimeter system

We had to resolve some problems such as noise reduction, robustness and downsizing for an underwater gravimeter for exploration. Our hybrid gravimeter system consists of an underwater gravimeter and an underwater gravity gradiometer. We adopted Micro-g LaCoste S-174 as a gravity sensor for the gravimeter system (Fig. 3 and Table 1).

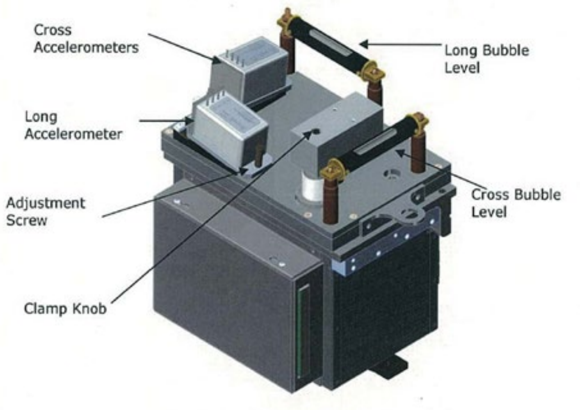

Fig.3 Gravity sensor (Micro-g LaCoste S-174).

Parameter		Test conditions
Sensor Temp	60.4 deg C	Thermo stated at the noose
Ambient Temp/sensitivity	< 0.05 mGal/deg C	Tested in range 27-53 deg C
Clamp Unclamp Repeats	0.1 mGal	
Sensor Drift	< 1 mGal/month	Linear drift
Sensor Noise	0.12 mGal/√ Hz	
Sensor Noise @ 100s	0.012 mGal	
Static Precision	< 0.050 mGal	

Table 1 Specifications of the gravity sensor S-174.

The gravity sensor is mounted on a gimbal control unit with an inertial navigation sensor (a fiber gyroscope, IXSEA PHINS) to keep vertical. These are stored in a sphere vessel made of titanium alloy (125 kgf in air, 32 kgf in water) and it is available in 3500 m below sea surface. For acquisition of high resolution gravity data, the gravity sensor must keep a constant temperature (60.4°C) (Figs. 4, 5 and 6) and avoid effect of magnetic field of the Earth (Fig. 7). The sensor is heated and is totally covered with thermal insulation and sheet of permalloy for magnetic shielding.

Fig.4 Adiabatic insulation. The spring of S-174 requires constant high temperature, 60.4 °C. We increase adiabatic insulation additionally.

Fig.5 Cooling test.

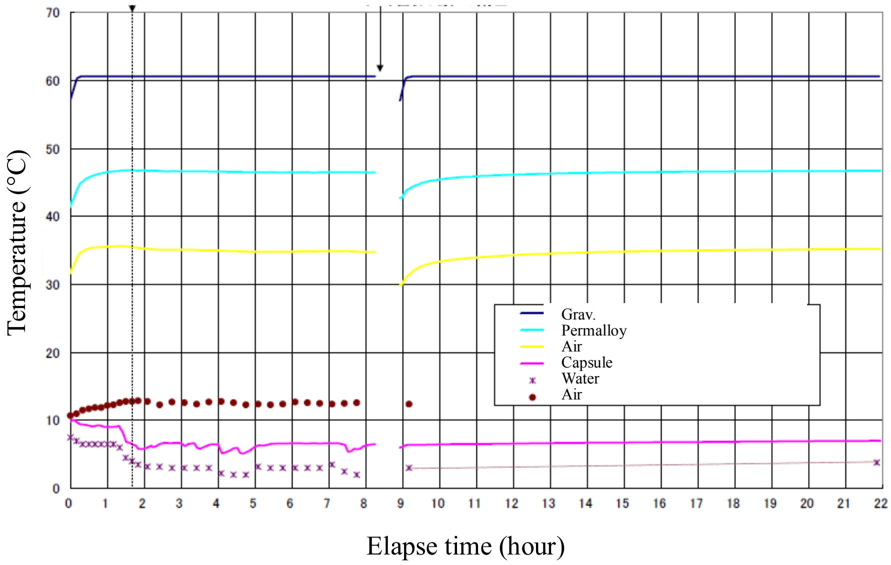

Fig.6 Results of the cooling test. We conformed that outside temperature does not affect the system.

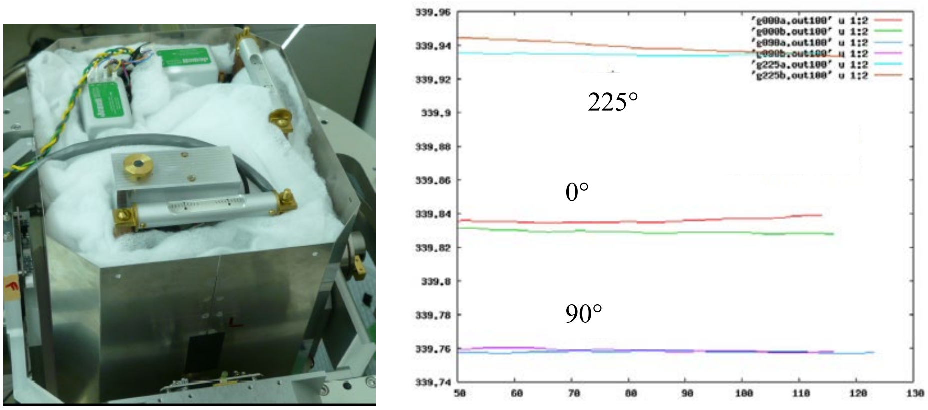

Fig.7 The permaaloy case contains the gravity sensor and DC servo motors for the gimbal system. Magnetic effects are reduced from 0.2 mgal to less than 0.001 mgal.

In order to reduce high frequency noise due to mainly the vehicle motion, the data are decimated using low-pass filter and stored at sampling rates of approximately 100 Hz. The logging system and control unit for communication to/from ship is stored another cylinder-shape canister (22 kgf in air, 10 kgf in water) (Figs. 8, 9 and 10).

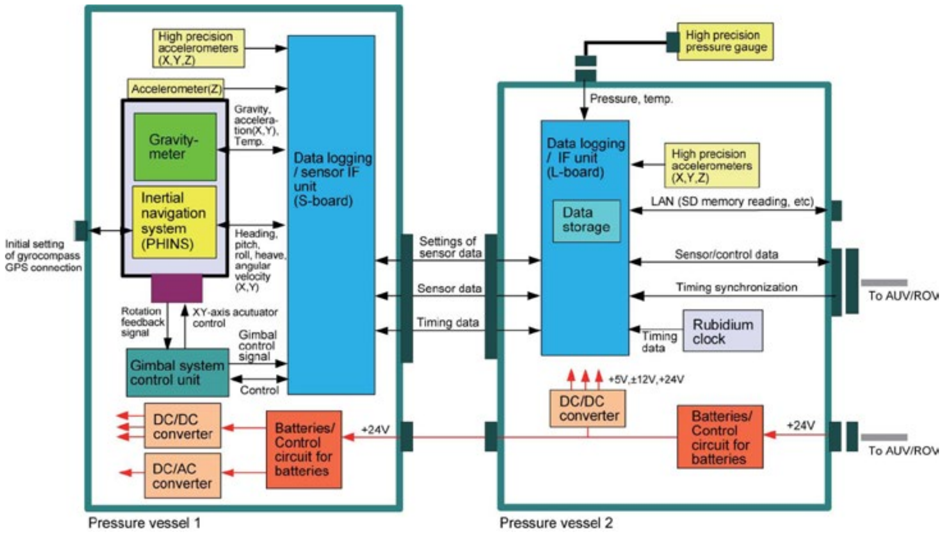

Fig. 8 Systematic diagram of the gravimeter system.

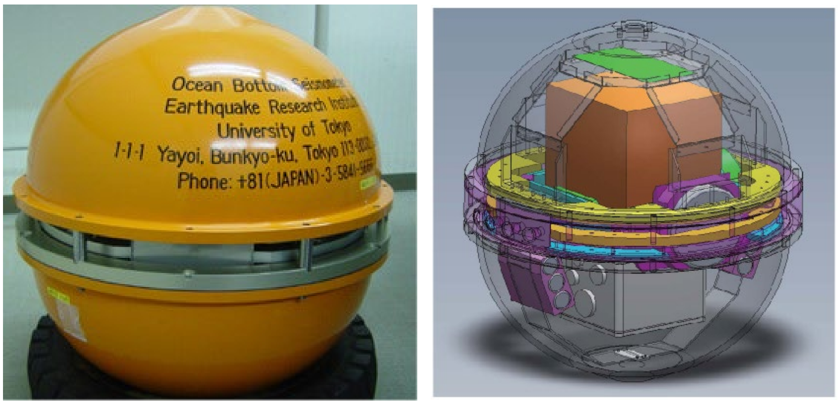

Fig.9 Sensor unit of the gravimeter system and perspective.

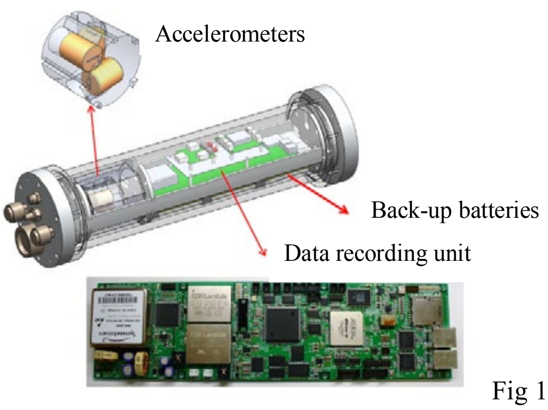

Fig 10. Data acquisition unit.

We made gravity measurement experiments to examine the effectiveness of the gimbal system and filtering application. The gravimeter was set on a machine simulating pitch and roll motions with a period of 16 s and amplitude of 7.5 degrees, which is greater than expected in actual vehicle motions. We applied two-step low-pass filtering with 1 s and 150 s Gaussian filters to the collected data. The filtering widths correspond to a spatial resolution of 0.1 km order after applied if the vehicle speed be 2 knots. The RMS errors of pitch and roll motions are 0.04 mgal and 0.02 mgal, respectively, after processing of the filtering, tilt and earth tide corrections and removal of linear temporal drift. This is satisfied with our requirement to detect gravity anomalies enough (Fig. 11).

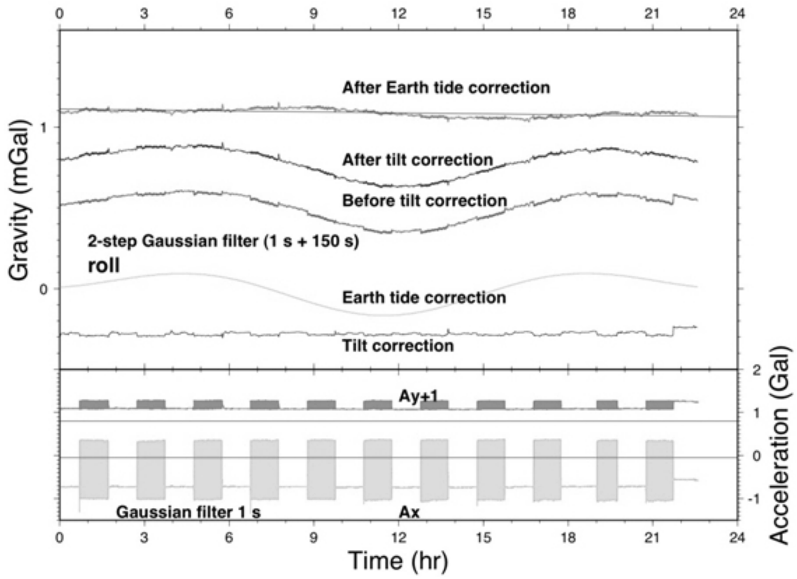

Fig 11. Results of data evaluation on land. RMS deviations are less than 0.1 mgal after 2-step Gaussian filter, Earth tide and tilt adjustment.

Gravity gradiometer

We develop a gravity gradiometer system to search for ore deposits located below the seafloor. The instrument comprises two vertically separated, astatic pendulums (Fig. 12), and the gravity gradient can be obtained from the differential signal between these gravity sensors. Estimation of root-mean-square (RMS) noise (7 E in (2-100) mHz) shows that the gravity gradiometer attained the resolution required for detection of typical ore deposits.

Fig. 12 A developed accelerometer as a gravity sensor.

To be used for submarine application, the whole instrument should remain vertical to reduce centrifugal acceleration involved with rotation of a submersible vehicle. We constructed a two-dimensional gimbal which is supported by hinges to freely rotate without friction, and whose orientation is sensed by gyroscopes and tiltmeters. The gimbal is successfully controlled to vertical within required precision. From these results, by combining the gravity gradiometer with the two-dimensional forced gimbal, detectability of the typical ore deposit can be obtained. The system is now installed in a pressure-proof vessel, made of titanium alloy, with 500mm in diameter and 700mm in height, and the vessel is implemented in an AUV together with a gravimeter (Fig. 13).

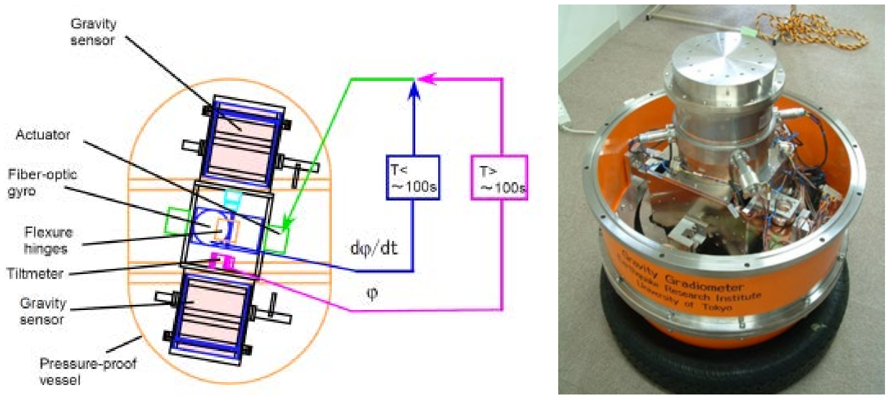

Fig. 13 Left: Schematic diagram of the feedback system of the forced gimbal. Two feedback loops are included; at high frequencies (<~100s), a gyroscope is used to reduce instant rotation through feedback circuit, while verticality is obtained at low frequencies (>~100s) from a tiltmeter. Right: A two-dimensional forced gimbal installed in a pressure vessel.

- Research results and future plans

The first cruise was carried out in September 2012 to evaluate this gravimeter and gravity gradiometer jointly by using an autonomous underwater vehicle, URASHIMA (Figs. 14 and 15). The first measurement was performed in Sagami-Bay. The whole system is controlled and monitored via acoustic link of the URASHIMA. We obtained gravity and miscellaneous data multiple traces along two tracks (Figs. 16 and 17). One of the tracks is above relatively flat sea bed, and the other is not. From these surveys, we obtained the gravity data and supplemental data for compensation of the gravity data with good quality (Fig. 18). From preliminary analyses, the resolution of the gravity data from the first practical measurement is estimated to reach 0.1 mgal. The data have enough qualities to evaluate the performance of the system. At present, we continue to analysis and improve the system for practical use.

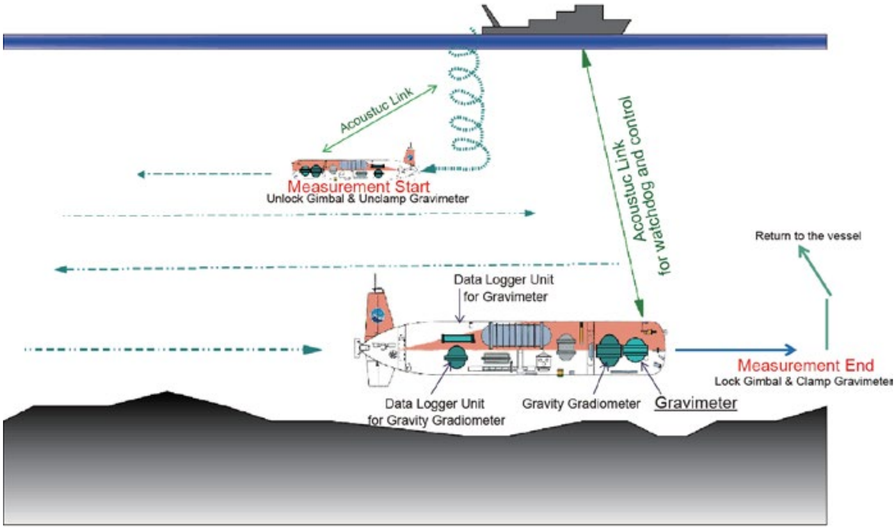

Fig. 14 Schematic of YK12-14 cruise measurement

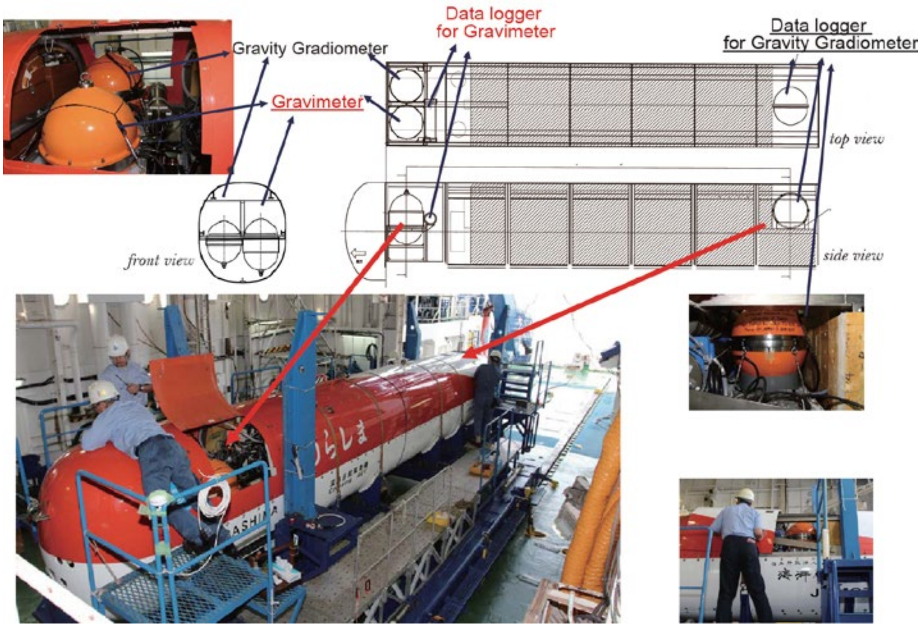

Fig.15 Layout of the system on the URASHIMA

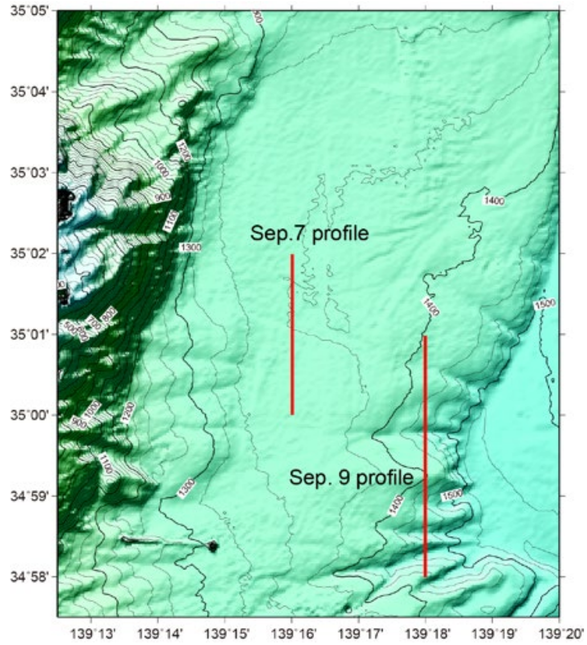

Fig. 16 Position of the profiles with bathymetry and gravity anomalies.

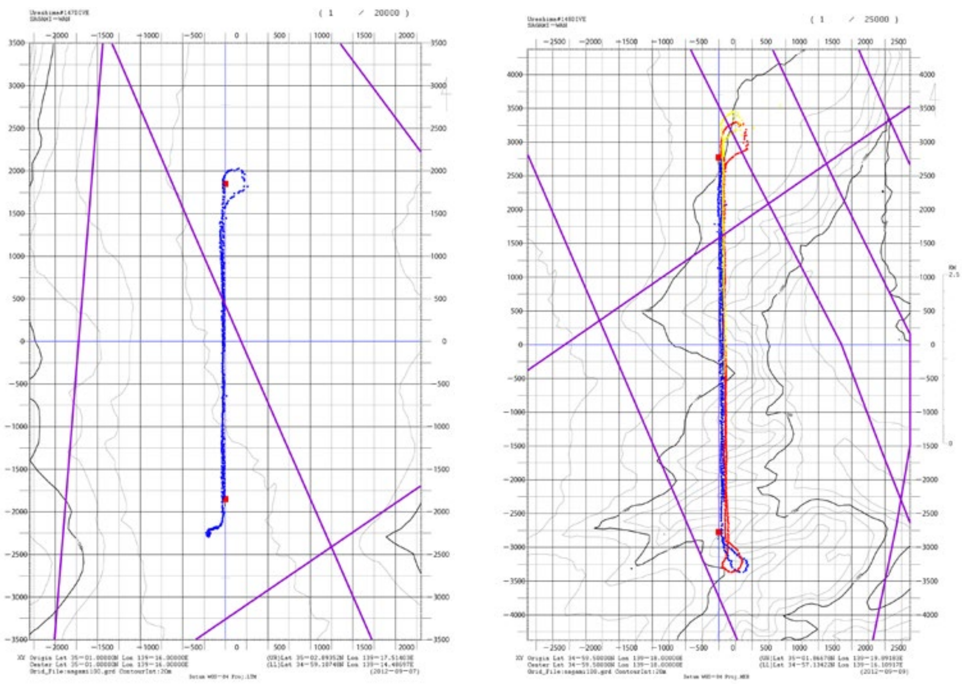

Fig. 17 dive tracks of dive #147 (Left) and #148 (Right)

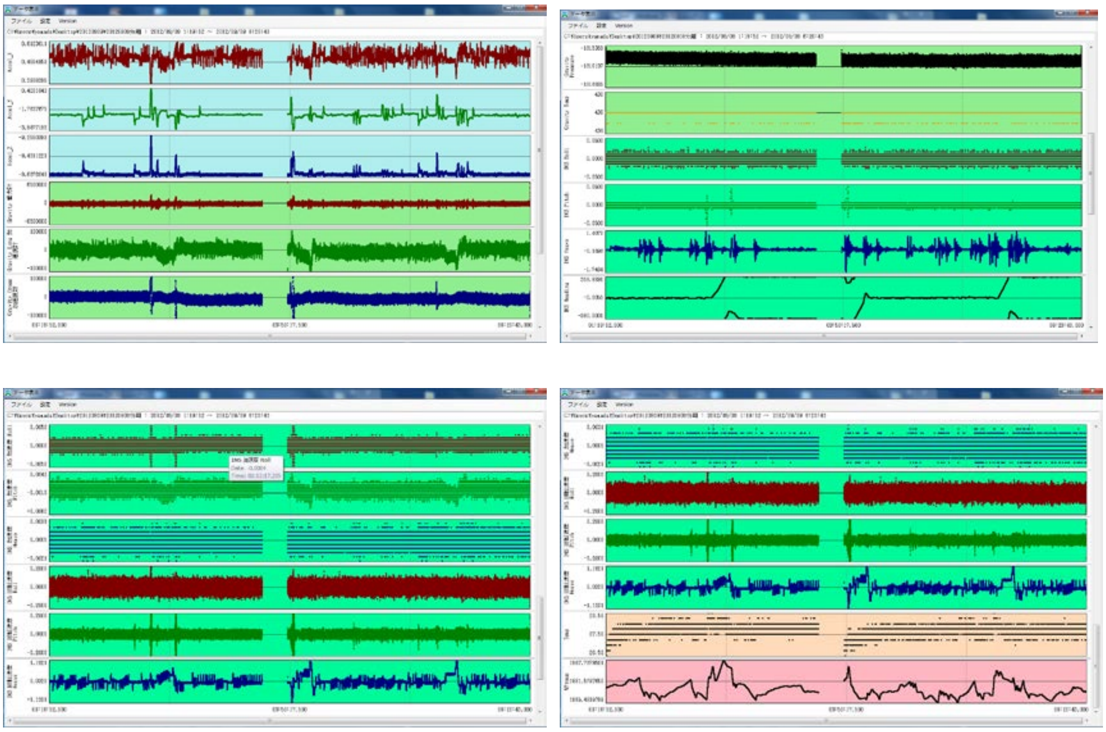

Fig 18. Gravity and miscellaneous data obtained during the dive.

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- Cruise log

2012/09/06

Weather: Blue sky/ Wind direction: SSW/ Wind scale: 3 (Gentle breeze)/ Wave scale: 1 (Smooth)/ Swell scale: 0 (No swell)/ Visibility: 8 miles

12:30	Onboard
13:00	Let go all shore lines. Left YOKOSUKA for research area (Sagami Bay).
14:30 - 15:00	Carried out shipboard education & training for scientists.
15:30 - 16:10	Scientific meeting And General Briefing about URASHIMA.
15:50	Arrived at research area.
15:53 - 16:11	Carried out eight figure running.
16:14	Released XBT at <35-01.3438N, 139-18.7531E>.
16:40 - 17:00	Praying for the safety of this cruise (Konpira ceremony).

2012/09/07

Weather: Fine but Cloudy/ Wind direction: NNE/ Wind scale: 2 (Light breeze)/ Wave scale: 2 (Smooth)/ Swell scale: 1 (Low swell)/ Visibility: 6 miles

07:31	Launched URASHIMA.
07:32	URASHIMA dove and started operation #147.
12:53	URASHIMA refloated.
13:09	Hoisted up URASHIMA.
13:18	Recovered URASHIMA and finished operation.
17:30 - 18:00	Scientific meeting And General Briefing about URASHIMA.

2012/09/08

Weather: Fine but Cloudy/ Wind direction: ---/ Wind scale: 0 (Calm)/ Wave scale: 1 (Calm)/ Swell scale: 1 (Low swell)/ Visibility: 8 miles

07:18	Hoisted up URASHIMA.
07:33	Recovered URASHIMA.
08:20	Suspended URASHIMA operation due to mechanical trouble.

2012/09/09

Weather: Fine but Cloudy/ Wind direction: SE/ Wind scale: 3 (Gentle breeze)/ Wave scale: 2 (Smooth)/ Swell scale: 1 (Low swell)/ Visibility: 8 miles

07:14	Launched URASHIMA.
07:15	URASHIMA dove and started operation #148.

16:15	URASHIMA refloated.
16:35	Hoisted up URASHIMA.
16:43	Recovered URASHIMA and finished operation.
17:00	Left the survey area for Tateyama.
19:09	Arrived at Tateyama.

2012/09/10

Weather: Fine but cloudy/ Wind direction: South/ Wind scale: 4 (Moderate breeze)/ Wave scale: 3 (Slight)/ Swell scale: 1 (Low swell, short)/ Visibility: 8miles

05:30	Finished MNBES mapping survey. Left survey area for YOKOSUKA.
	Time of Arrived was 9:30, 2012/09/24

- URASHIMA operation team

Operation Manager	Satoshi Ogura
1st Submersible Staff	Shinobu Omika
1st Submersible Staff	Masanobu Yanagitani
2nd Submersible Staff	Keigo Suzuki
2nd Submersible Staff	Akihisa Ishikawa
2nd Submersible Staff	Takuma Onishi

- Ship crews

Captain	Ukekura Eiko
Chief Officer	Yasuhiko Sammori
2nd Officer	Shozo Fujii
3rd Officer	Hiroharu Omae
Chief Engineer	Eiji Sakaguchi
1st Engineer	Kimio Matsukawa
2nd Engineer	Daisuke Gibu
3rd Engineer	Kota Kataoka
Chief Electronic Operator	Takehito Hattori
2nd Electronic Operator	Yosuke Komaki
3rd Electronic Operator	Ryousuke Komatsu
Boat Swain	Masanori Ohata
Able Seaman	Kazumi Ogasawara
Able Seaman	Yuki Yoshino
Able Seaman	Takuya Miyashita

Sailor	Shinsuke Uzuki
Sailor	Toru Nakanishi
No.1 Oiler	Kozo Miura
Oiler	Katsuyuki Miyazaki
Oiler	Yoshinori Kawai
Assistant Oiler	Eiji Aratake
Assistant Oiler	Toru Hidaka
Assistant Oiler	Naoto Mituo
Chief Steward	Sueto Sasaki
Steward	Shigeto Ariyama
Steward	Yoshinobu Hasatani
Steward	Tatsunari Onoue
Steward	Toru Wada