

A kick-off drilling expedition at Iheya-North Knoll in Ore Genesis study of Ocean Resources in SIP

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A R&D project, led by Prof. Emer. Tetsuro Urabe of Univ. Tokyo, "Next-generation Technology for Ocean Resources Survey" started in FY2014, as a part of the Cross-ministerial Strategic Innovation Promotion Program (SIP). In the project, three types of ocean resources are targeted: seafloor hydrothermal deposit, Co-rich Mn-Fe Crust, and REY mud. The study on Genesis of Ocean Resources in this project aims to develop a screening technique for area having high potential of ocean resources as well as air-borne and/or satellite remote sensing technique for on-land resource exploration. Especially in the study on hydrothermal ore-deposits, higher level of achievement is required than those for other two types of ocean resources as the SIP program because of the recent advancement of the knowledge on this type of resource. The project goals not only include the establishment of a genetic model but also aim to propose an exploration technique for concealed ore bodies.

In July 2014, a non-riser drilling expedition was conducted at and around an active hydrothermal field on the Iheya-North Knoll by D/V Chikyu. Three active hydrothermal sites are known so far at this location. One has been known since late 1990s and is referred as the Iheya-North "Original" site to distinguish it from other two. At this site, more than 20 holes were drilled in IODP Exp.331, successfully obtaining a wide-range of lithology including polymetallic massive sulfide ores (Takai et al., 2011). Some of the holes showed apparent fluid discharge at the pulling out of the drill pipe. Numerous biological and geological observations have also been performed by the manned submersibles (Shinkai 2000 and 6500) and ROVs. Contrastingly, other two sites were recently located in early 2014, called the (Iheya-North) Natsu and Aki sites.

In Exp. 907 (CK14-04 Cruise), systematic LWD observations of six holes down to 340 mbsf were conducted to constrain the area of the fluid reservoir beneath seafloor followed by three coring holes down to 150 mbsf. Detailed results of LWD and coring were reported in this meeting (Saito et al. and Nozaki et al.). To protect the sensors from the anticipated high temperature of hydrothermal fluids, exceeding 300°C, a back-up pumping system was attached to maintain fluid-flow as coolant continuously even during pipe connection. The back-up circulation system, i.e. Non-Stop Driller (NSD), supplied the drill-fluid of approx. 500GPM (1.9kL/min) during the operation. This flow rate was determined to protect the sensors of logging tool under a range of reasonable flow-rate into borehole; however, the rate was overestimated. Recorded maximum temperature throughout the expedition was 84°C. In addition, no apparent discharges of the fluid forming black smoker was observed. Regardless of these observations, profiles of annular temperature and comparison between structural cross-section of seismic reflection survey, provides us the area of fluid reservoir beneath the Iheya-North Knoll was tabulated (Figure).

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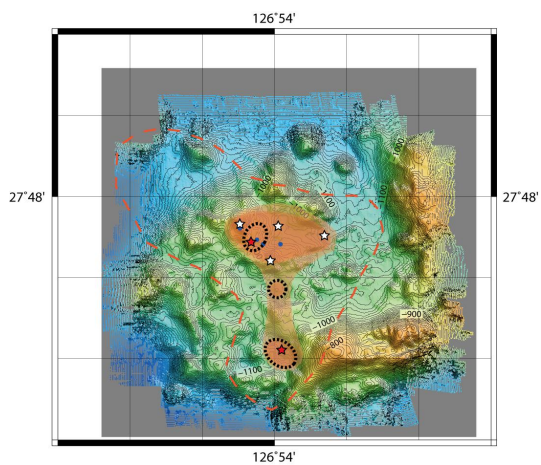
Figure; Estimated area of sub-seafloor Hydrothermal reservoir (Red-colored area). Open star: LWD site. Red-color-filled star: LWD and coring site. Broken circles indicated the areas of hydrothermal sites.

Keywords: SIP, Iheya-North Knoll, Hydrothermal fluid reservoir, LWD

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Estimation of under-seafloor fluid on temperature and volume from the logging-while-drilling data

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In July of 2014, offshore drillings on Iheya-North Knoll, Okinawa Trough, was executed as part of Next-generation technology for ocean resources survey, which is a research program in Cross-ministerial Strategic Innovation Promotion Program (SIP). In this expedition, logging-while- drilling (LWD) and measuring-while-drilling (MWD) were inserted into 5 holes around Iheya-North (original) site (C9011 ? C9015) and in Iheya-North Aki site (C9016) to investigate spatial distribution of hydrothermal deposit and geothermal fluid reservoir. LWD tools are supplemented by a measurement-while-drilling tool that is located above the LWD tools in the bottom-hole-assembly. In this expedition, arcVISION and TeleScope were integrated as LWD and MWD respectively. The arcVISION obtained physical properties along borehole (resistivity, natural gamma-ray), and the TeleScope collected drilling mechanics data and transferred them to the surface by mud pulse telemetry. Both of these tools included annular pressure-while-drilling (APWD). Annular pressure and temperature were monitored by the APWD to detect possible exceedingly-high-temperature geofluid. In addition, drilling fluid was continuously circulated at sufficient flow rate to protect LWD tools against high temperature (non-stop driller system).

At C9012 and C9016, the arcVISION clearly detected temperature anomaly at 234 meter below the seafloor (mbsf) and 80 mbsf, respectively. Temperature quickly increases at that depth and it would reflect the existence of high-temperature heat source. During the drilling, however, drilling water was continuously circulated at high flow-rate (2600L/min) as stated above. Thus the measured temperature is not exactly in-situ temperature, but the profile of the temperature reflects the temperature variation of each stratigraphic layer of the bore hole.

To investigate the detail of the heat source, such as in-situ temperature and quantity of heat, we performed numerical analyses of thermal fluid and energy-balance, assuming two types of the heat source: A) hot fluid shifting with circulated water, and B) immobile layer like hot rock-bed. First, thermal fluid-flow analyses were conducted for estimation on how much the circulating water disturbed temperature of heat source. We combined equation of continuity, Navier-Stokes equation, and temperature equation. These equations were solved simultaneously with simplified Marker and Cell method. The fluid flow and its temperature between borehole wall and drilling pipe were simulated. The heat source temperature was also calculated by time. As the results, heat source A (fluid) could raise temperature of the circulation water as hot fluid injected and mixed with the cold water. On the other hand, heat source B was cooled by the circulation water immediately after the hot rock-bed was drilled. It should be required to have over 1000C of source temperature to make sure to keep the circulation water as warm as the thermometer measured at 234 mbsf in C9012A. APWD also recorded the abrupt rise in fluid pressure with the temperature anomaly for several minutes. Considering this synchronism between temperature and pressure, we assessed the high temperature fluid, such as geothermal fluid, is plausible as the heat source. Second, we estimated in-situ temperature and volume of the fluid heat source. From increase in temperature and flow rate of the circulation water, the quantity of heat supplied to the water was calculated as 3.5 GJ. This abundant heat would be brought by injection and mixing of geothermal fluid. The relationship between the temperature and injected volume of thermal fluid are constrained by the quantity of heat as: $V_f = 1.33 \times 10^5 / T_f^2 - 257 / T_f + 2.73$, where V_f is fluid volume injected to the borehole (m³) and T_f is fluid temperature (C). Thus, we estimated that the in-situ temperature and volume of the geothermal fluid are >150C and <6.3 respectively, causing the temperature anomaly in C9012A.

Keywords: hydrothermal deposit, geothermal fluid, Logging while drilling

Lithology, constituent mineral, geochemical composition of the drilled core obtained by CK14-04 Cruise, Okinawa Trough

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CK14-04 Cruise by D/V Chikyu was performed in the Iheya-North Knoll, Okinawa Trough from 8 to 26th, June 2014 to investigate the subseafloor hydraulic structure and geology. Six holes (C9011B, C9012A, C9013A, C9014A, C9015A and C9016A) were drilled for logging while drilling (LWD) as well as coring of three holes (C9015B, C9015C, C9016B). Holes C9015B and C9015C locate the flank of HRV (high radioactivity vent) mound in the Iheya-North Original site, whereas Hole C9016B is ca. 150 m north from the central part of hydrothermal activity in the Iheya-North Aki site where has been discovered in January 2014. Total coring lengths of Holes C9015B, C9015C and C9016B were 31, 30 and 150 m, respectively. In this presentation, we report the lithology and constituent minerals determined by visual core observation and XRD analysis together with downhole variations of the geochemical composition determined by ICP-QMS analysis. Based on these data, we discuss the geology, hydrothermal alteration, geochemical features and sulfide mineralization in the Iheya-North Knoll, Okinawa Trough.

Keywords: Okinawa Trough, Iheya-North Knoll, seafloor hydrothermal deposit, kuroko-type deposit, CK14-04 Cruise, Expedition 907

P-wave velocity structure in the southern Okinawa Trough

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The Okinawa Trough is a backarc basin under continental rifting tectonics by subduction of the Philippine Sea plate beneath the Eurasian plate at the Nansei-Shoto (Ryukyu) Trench. The rifting stage varies from north to south along the trough and the southern region is in most evolved stage. We carried out around ten seismic experiments in the southern Okinawa Trough to obtain detailed images of crustal thinning in this region. We shot six lines along several en echelon rifts that characterize the seafloor feature in the southern trough. Each seismic experiment consists of multichannel reflection seismic (MCS) profiling using 240 ch. and 3000 m long hydrophone streamer and wide-angle seismic refraction profiling using ocean bottom seismographs (OBSs) as receivers.

The crusts in the Okinawa Trough roughly have three layers of the upper, middle and lower crust, which is same as an island arc crust. P-wave velocity model beneath the Yaeyama Rift, the deepest rift in the Okinawa Trough, also consists of the three crustal layers. The crustal thickness is more than 10 km and significantly thicker than a standard oceanic crust. Many intrusion signals in MCS records characterize the crust below the rift.

Keywords: Okinawa Trough, rifting, marine seismics

MCS profiles of knolls scattered in the southern Okinawa trough

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In the Okinawa trough, recently new hydro-thermal sites has been reported by several organizations. Especially, relatively large hydrothermal sites (e.g. the Iheya north site, the Noho site, and the Gondou site) were found in the middle part of the Okinawa trough.

The Iheya north site is known as one of the most active hydrothermal field. In the field, Tsuji et al.(2012) pointed out that there is the strong reflector which has opposite polarity to that of the seafloor reflector, and this indicates the seismic velocity below the negative-polarity reflector is lower than that of the overlying sequence. On the other hand, in the southern part of the trough not so many large scale hydrothermal sites have been found.

The Japan Coast Guard (JCG) conducted high density topographic surveys using a multibeam echo sounder and seismic surveys using a multi-channel streamer cable. As a sample of the result of our seismic experiments, we choosed the MCS time section of the Tarama knoll. The tarama knoll is 3 km in diameter and 500 m in hight. It has a hydrothemal field on the east flank.

On the seismic profile, several signals which imply the volcanic activity were imaged, such as:

volcanic sediments layer is located on the top of the land-derived sediment layer;

a strong reflector which has oposite polarity is detected between the volcanic sediments and the land originated sediments; and
strong reflectors which seems from dykes and sills by penetration of magma was observed.

some of these characteristics are consistent with the Iheya north site. This opposite polarity layer, therefore, may indicate the water supply source of the Tarama knoll's hydrothemal system.

Keywords: MCS, knoll, hydrothermal, fault

Sub-seafloor structure of hydrothermal deposits in Hakurei site, Izena Hole, the Mid-Okinawa Trough by VCS survey

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Seafloor hydrothermal deposits are formed in the deep sea around hydrothermal venting sites, where abundant metals precipitate. The seafloor locations of hydrothermal deposits are revealed by the exploration of geophysical, geochemical and submersible investigations. Hydrothermal deposits are known to form chimneys or mounds. Scale of hydrothermal mound is thought to be a hundred meters square by recent surveys. The sub-seafloor distribution of hydrothermal deposits are identified partially by drilling core data, however, a continuous structure has not been fully understood yet. To improve the quality of the sub-seafloor imaging of hydrothermal deposits, high-resolution geophysical data acquisition is required. We conducted two Vertical Cable Seismic (VCS) surveys at Hakurei site, Izena Hole in the Mid-Okinawa Trough to reveal sub-seafloor structure of hydrothermal deposits. In September 2011, we carried out 28 survey lines around the hydrothermal mound in the Hakurei site using an air-gun source during KY11-E04 cruise. In August 2013, we carried out 28 survey lines around the southern part of KY11E-04 survey area in the Hakurei site using a sparker source during KY13-E02 cruise. VCS surveys successfully imaged the shallow sub-seafloor structures of the hydrothermal field. We identified a mound shape reflector at the sub-seafloor. In addition, we estimated the seismic velocity at the sub-seafloor by the common reflection point (CRP) gathers. Some of the reflectors of the CRP gather show high velocity zone at the sub-seafloor. Previous drilling survey reported that hydrothermal deposits are buried by volcanic sediment in the Hakurei site. These results suggested that high velocity zone between reflectors at sub-seafloor is sediment-buried hydrothermal deposit.

Keywords: Hydrothermal deposits, VCS survey, Mid-Okinawa Trough, Sub-seafloor structure

Hydrothermal sulfide/sulfate and alteration minerals obtained by drilling below the Iheya North Knoll hydrothermal field

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Seafloor drilling through active hydrothermal fields at the Iheya North Knoll in the middle Okinawa Trough provided a unique opportunity to directly access the subseafloor structure. Following IODP (Integrated Ocean Drilling Program) Expedition 331 conducted in 2010, CK14-04 cruise was performed by D/V Chikyu in 2014. We will report occurrence and mineralogical characteristics of sulfide minerals and alteration minerals in obtained sediment core samples by these drilling expeditions.

Drilled sites have been laid out from the NBC mound associated with active venting of 311 C hydrothermal fluid (27 47.4'N, 126 53.86'E, depth=1000m). Among them, occurrence of ore forming sulfide minerals were identified in sediment collected from Site C0016 just beside the NBC mound, from Site C0013 (100 m east from the NBC mound), from Site C0014 (450 m east from the NBC mound), Site C9015 (another mound in the west side of the NBC mound), and Site C9016 (150 m apart from Aki hydrothermal field which is located about 3 km south of the NBC mound).

From Site C0016B beside the mound, massive sulfide ore of ~60 cm length was recovered from the first core (0-9 mbsf=meters below the seafloor). The ore looked like "black ore" in appearance and was composed of euhedral sphalerite, galena, chalcopyrite and pyrite which grain size up to a few 100 μm. It is notable that the ore include significant amount of clay minerals in the matrix. At the same drilled site, silicified sediment associated with vein sulfide consisted mainly of pyrite and chalcopyrite was abundant in the third core (27-45 mbsf). Dominant clay minerals in sediment at this depth were chlorite and illite.

From Site C0013 located at 100 m east from the NBC mound, intensely altered sediment including sphalerite, galena and pyrite was obtained from 0-16 mbsf. In the same sediment layer, occurrence of copper sulfides showed variation from covellite and tetrahedrite at a few meters below the seafloor to chalcopyrite at ~10 mbsf. These sulfides are euhedral which grain size increased toward deeper depth and usually surrounded by clay minerals and/or sulfate minerals. Dominant clay minerals showed change along depth from smectite at a few meters below the seafloor to chlorite and/or chlorite-smectite mixed layer minerals at a deeper depth.

From Site C9015 at another hydrothermal mound, sulfide mineral enriched veins were recognized in sediment from 18-23.5 mbsf. These portions included sulfide minerals such as sphalerite, chalcopyrite, pyrite and galena, sulfate minerals such as anhydrite and/or barite, clay minerals and quartz.

From Site C9016 a few km away from the NBC mound, occurrence of sphalerite, galena and barite within altered sediment obtained from 9-11 mbsf was notable. Dominant clay minerals in the sediment were kaolin minerals, which variation along depth is discussed in Tsutsumi et al. (poster presentation in this meeting).

In summary, occurrence of sphalerite and/or galena was limited in rather shallow depth (0-24 mbsf), but ubiquitous for drilled sites located with intervals of a few hundred meters to a few kilometer. This distribution should be interpreted as related to hydrothermal structure below active hydrothermal fields. Mineralogical texture of these sulfides was characterized as surrounded by clay and/or sulfate minerals, which is quite distinctive from that recognized in typical "black ore". This difference would be one of important problems if we consider seafloor sulfide deposits are a modern analogue of kuroko-type ore deposits. Whether the mineralization center has not been drilled yet or the hydrothermal activity at the Iheya North Knoll has not reached yet to the main mineralization stage?

Keywords: Seafloor massive sulfide mineral deposits, seafloor drilling, kuroko-type ore deposits, hydrothermal clay mineral

ESR dating of barite in sea-floor hydrothermal sulfide deposits in comparison with disequilibrium dating

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The evolution of the hydrothermal fields is one of the important issues. Dating methods using disequilibrium between radioisotopes such as U-Th method (e.g. You and Bickle, 1998), ²²⁶Ra-²¹⁰Pb and ²²⁸Ra-²²⁸Th method (Noguchi et al., 2011) have been employed for such studies.

Okumura et al., (2010) made the first practical application of ESR (electron spin resonance) dating technique to a sample of submarine hydrothermal barite to obtain preliminary ages, while Kasuya et al., (1991) pointed out the possibility ESR dating. Toyoda et al., (2011) determined the optimum condition for ESR measurement while Sato et al., (2011) confirmed that the signal is thermally stable enough for an age range of several thousand years. Recently it was shown that this method is also practically applicable to barite, especially those in sea-floor hydrothermal sulfide deposits (Takamasa et al., 2013).

ESR, ²²⁶Ra-²¹⁰Pb, and ²²⁸Ra-²²⁸Th ages were determined for barite crystals extracted from hydrothermal sulfide deposits taken at hydrothermal fields taken from Okinawa Trough. The ESR ages range 4.1 to 16000 years where the ages obtained by the three methods coincide in the samples up to 15 years while, for the other older samples, the ²²⁸Ra-²²⁸Th ages are the youngest and ESR ages, the oldest and the ²²⁶Ra-²¹⁰Pb ages in between. The samples with younger ESR ages show younger ²²⁶Ra-²¹⁰Pb ages and those with older ESR ages show older ²²⁶Ra-²¹⁰Pb ages with no detection of ²²⁸Ra. This tendency of the ages is explained by more than two hydrothermal events that formed the sulfide deposits where barite crystals with different ages are mixed together in the examined portions of the samples. While ESR method gives the averaged ages, ²²⁶Ra-²¹⁰Pb and ²²⁸Ra-²²⁸Th ages are underestimated because of decay of the parent nuclides.

Based on the results of ESR measurements, for which the applicability of wide age range is shown in the present study, the order of ages of the 6 hydrothermal fields would be arranged, from young to old as follows; Yoron Hole field, Irabu Knoll field, Daiyon-Yonaguni Knoll field, Hatoma Knoll field, being nearly equal to Iheya North Knoll field. ESR is a practical dating method of hydrothermal barite, however, calibration for the absolute age determination would be still an issue.

Keywords: barite, hydrothermal activities, electron spin resonance, radioactive disequilibrium, dating

Preliminary report of AUV URASHIMA dives at Tarama and Irabu hydrothermal fields

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We conducted four AUV URASHIMA dives at Tarama and Irabu Knolls in the Okinawa Trough to reveal the origin and extent of these hydrothermal systems and their geological and geophysical background. The structure, fluid geochemistry and associated ecosystem of hydrothermal systems are highly diverse and the diversity is constrained by the surrounding geological setting. The Okinawa Trough is located at back arc area of the Ryukyu arc-trench system and is considered to be in transitional stage from continental rifting to oceanic crust formation. Many hydrothermal fields have been recently discovered in the area and they are characterized by the influence of rich sediment supply both from arc and continent. In August 2014, we carried out two dives at Tarama Knoll and other two dives at Irabu Knoll during YK14-16 cruise. The survey objectives are 1) to conduct high-resolution, three dimensional mapping of two sites using multiple sensors equipped on the AUV, 2) to compare two sites of different host rocks and tectonic settings, and 3) to identify an unknown high-temperature vent site at the Tarama Knoll. The AUV was generally operated at constant altitude mode (alt.=100m). We succeeded to cover whole area of these two knolls, using multi beam echo-sounder, side-scan sonar, sub-bottom profiler, three-component magnetometer, CTD, ADCP, pH/ORP/turbidity sensors, and water sampling using 24-channel MINIMONE sampler. The Irabu Knoll is located within the back arc rift axis and consists of three topographic highs. Three hydrothermal vents were reported on the knoll in previous surveys and all hydrothermal systems are hosted by basaltic basement. In dive 181 and 184, we confirmed three known hydrothermal vents and revealed the surrounding detailed geology. Magnetic anomaly is extremely high in general, supporting the idea that the hydrothermal fields are hosted by fresh basalt and maybe by active magmatism. The Tarama Knoll is located about 20 miles west of the Irabu Knoll, at the arc-side terrace of the back arc rift. Previous ROV survey reported a low temperature shimmering hosted by rhyolitic rocks at the top of the knoll and the extent of turbid seawater at the southern slope of the knoll that may indicate an existence of unknown high temperature hydrothermal vent site. We covered the whole knoll in Dive 182 and 183. We detected strong plume anomaly at the eastern slope of the knoll by geochemical sensors. We also detected the plume ejection from the seafloor in water column records of multi beam echo sounder and side-scan sonar, leading the identification of exact point of new vent site.

Keywords: hydrothermalism, AUV, Okinawa Trough, seafloor morphology, magnetic anomaly, hydrothermal plume

Deepsea Magnetism on Tarama and Irabu Hydrothermal Fields

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Magnetic signatures of oceanic lithosphere is changed by hydrothermal alteration, therefore magnetization contrast derived from magnetic anomaly provide us information about spatial extent of hydrothermal alteration zones. Previous studies reported both reduced and enhanced magnetization at different hydrothermal fields, suggesting the destruction and production of magnetic minerals are controlled by geological and tectonic background. In order to characterize magnetic response of arc/backarc hydrothermal systems, we investigated two hydrothermal fields of the southern Okinawa Trough. The Irabu knoll is located on the axial area of backarc rift and consists of basaltic lavas. The Tarama knoll is located between backarc and arc sides along with dacite to rhyolite. Previous surveys reported hydrothermal venting on both knolls. During the cruise YK14-16, we conducted near-seafloor magnetic measurements using autonomous underwater vehicle (AUV) URASHIMA. The vector geomagnetic field was measured by fluxgate-type magnetometer at an altitude of ~100 m with the whole area of the Irabu and Tarama knolls. The correction of vehicle magnetization was successfully done using data obtained during 8-figure rotation loops. The amplitude variation of observed magnetic anomaly is up to 12000 nT at the Irabu knoll and 1000 nT at the Tarama knoll. Sea-surface anomaly also shows larger amplitude variation at the Irabu knoll (760 nT) than Tarama knoll (460 nT). These observations suggest the difference of hosted rock type, i.e. the Tarama knoll is hosted by basaltic rock with large amount of titanomagnetites. In addition to the magnetic signature of the Tarama and Irabu knolls, we will discuss relationship between magnetization distribution and locations of confirmed hydrothermal vent fields.

Keywords: near-seafloor magnetic anomaly, seafloor hydrothermal system, Okinawa Trough, AUV URASHIMA

Underwater gravity survey using autonomous underwater vehicle in Izena caldera, the middle Okinawa Trough

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It is known that there are seafloor mineral deposits around Japan islands. Gravity survey is one of powerful methods to obtain density structure in crust, especially for exploration of underground deposits. In marine area, surface ship gravimeter and ocean bottom gravimeters are often used. Recently the system which can survey a wide area quickly with a higher resolution is required to obtain a high-resolution structure below seafloor. In addition, recent technology of autonomous underwater vehicle (AUV) enables us measure gravity in underwater environment. To estimate structure, measurement of both gravity and gravity gradient has an advantage for precise estimation. A required accuracy of the measurement was estimated by using model calculation. From an expected model of seafloor deposits, it is found that a resolution of gravity measurement should be approximately 0.1 mgal, and 10 eotvos for gradient to estimate deposit below seafloor.

From these objectives and specification, we have developed an underwater gravity measurement system for exploration below a seafloor using an AUV. Our system consists of an underwater gravimeter and an underwater gravity gradiometer. For gravimeter system, the sensor is mounted on a gimbal mechanism to keep vertical. The system is controlled and monitored via acoustic link of the AUV. The gradiometer has two gravimeter aligned vertical at a distances of 50 cm. For practical observation in the sea, we choose AUV Urashima belonging to Japan Agency for Marine-Earth Science and Technology. Because the Urashima is large AUV, Urashima has enough space for installation of the underwater gravity measurement system and stable navigation is possible. All the power is supplied from the Urashima and acoustic communication system on the Urashima enable real-time monitoring during observation. The first observation was carried out in September 2012 in Sagami-Bay, Japan. For the observation, the Urashima was navigated at the constant speed and constant depth on the profiles. We succeeded in obtaining gravity data and other data for compensation of the gravity data along both tracks with good quality. The obtained gravity data were low passed to reduce noise first. Our system has a high-precision water depth meter with resolution of less than 1 cm. Effect of vertical acceleration, which was calculated from these data, was removed from the gravity data. In addition, we made tilt correction using horizontal accelerometers. Finally ordinary data processing for onboard gravimeter were applied. After the data processing, the data from each track show good agreement, and standard deviation of the data are 0.1 mgal. In other words, our system is estimated to have accuracy or repeatability of 0.1 mgal. From comparison with the data between underwater gravimeter and onboard gravimeter, it is found that the underwater gravimeter system recorded more detailed changes of gravity, which seems to correspond to topography mainly.

In August 2014, we carried second gravity survey using our underwater gravity measurement system in the southern region of Izena caldera, the middle Okinawa Trough, where seafloor deposits were found. The survey area is approximately 2 x 2 km. The Urashima was navigated on 15 profiles in the survey area at constant speed and depth. We obtained the data from both gravimeter and gradiometer with good quality for all the profiles. From the obtained gravity data, we estimate gravity anomaly map in the Izena caldera through the processing for noise reduction, which is described above. After the processing, we obtained a free-water gravity anomaly, which corresponds to the seafloor topography. Because the AUV Urashima also has multi-narrow beam echo sounder, detailed seafloor topography was obtained. We also estimate Bouguer anomaly using the detailed topography and assuming density.

Deep-sea magnetic and acoustic surveys using AUVs in the Bayonnaise knoll and Myojin knoll calderas

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The Bayonnaise knoll and Myojin knoll calderas in the Izu-Ogasawara arc have been noted for large sulfide ore deposits called the Hakurei and Sunrise deposits. We conducted deep-sea magnetic and acoustic surveys in the two calderas on board the AUV Urashima during the cruises YK14-10 and 11 by the R/V Yokosuka (JAMSTEC) in June 2014. Two dive surveys were carried out in the Bayonnaise knoll caldera (travel distance of 46 km in total) to complete mapping the magnetic anomalies inside the caldera together with results of previous surveys. Other two dive surveys were conducted in the Myojin knoll caldera (52 km in total), which were the first AUV surveys in the caldera, and data were successfully obtained in the Sunrise deposit, the central cone, and a part of the northern caldera wall.

A high-resolution bathymetric map of the Bayonnaise knoll caldera created from the multi-beam data shows many tectonic landforms which are probably associated with the back-arc rifting. A large north-south fault cutting the caldera rim in the south-east, a landslide landform in the central cone, a tabular, north-south trending scarp of the central depression, and an explosive fault north of the central depression seem to link in a north-south direction. In addition to the crater row in the western caldera floor, many northwest-southeast striking faults have been found in the caldera rim in the northwest of the crater row. These features indicate the existence of an extensional field in a northeast-southwest direction, which is different from the nearly east-west direction of the rifting. Results of magnetic analyses show that a small hill in the northern caldera floor is strongly magnetized, in contrast to dacitic central cones which possess low magnetization. The hill is considered to belong to a basaltic knoll chain going through the caldera. It appears that the topography of the caldera has been rapidly changing due to tectonic and volcanic activities associated with the rifting. The magnetic structure is generally characterized by a north-south trending high-magnetization belt associated with the knoll chain going through the caldera. Local low-magnetization zones appear in the southeastern caldera wall including the Hakurei hydrothermal field, around the central depression, and in the northeastern caldera wall. The topography near the top of the eastern wall of the central depression is characterized by rough and uneven surface, and some constructions are clearly cone-shaped. Considering that the area is associated with low magnetizations, they are possibly hydrothermal constructions.

Bathymetric survey in the Sunrise field of the Myojin knoll caldera has revealed that several ridges with chimneys on top grow in a direction perpendicular to bathymetric contours in the caldera wall. Hydrothermal plumes were clearly captured in side-scan sonar images. On the other hand, magnetic anomalies are generally small in this area and show no particular features in the hydrothermal field. The central cone is covered with several lava flows going down 500-800 m distance from the top. There are many corrugations and small projections on the surface of the lava flows, which contrasts to smooth surfaces of the caldera floor. High magnetization is localized on the top of the central cone, and zones of relatively high magnetization continue almost along the lava flows.

A common feature among the Hakurei and Sunrise deposits is that sulfide mounds tend to grow in a direction perpendicular to local bathymetric contours. The Hakurei site is clearly associated with low magnetizations, while no particular magnetic feature is recognized in the Sunrise deposit. It may be because silicic host rocks originally have low magnetization, and therefore, the effect of demagnetization due to hydrothermal alteration is not significant. However, data in a wider area over the Sunrise deposit is required to come to a conclusion on the magnetic structure of the Sunrise deposit.

Keywords: hydrothermal deposits, AUV

Electrical resistivity structure of the oceanic crust around hydrothermal vent sites on East Pacific Rise at N9 50'

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We report results of a Magnetometric Resistivity (MMR) survey around hydrothermal vent sites on East Pacific Rise (EPR) at N9 50'. The MMR method is one of the controlled methods, which is used to estimate electrical resistivity structure of the oceanic crust. The magnetic fields induced by 200 vertical bipole electric current source transmission points were recorded by 10 OBMs (Ocean Bottom Magnetometer) which were deployed in the on-axis, and further off-axis to a distance of approximately 4km. We estimated one-dimensional resistivity structure from all the data, and it indicates the three layers with different resistivity, presenting an average resistivity structure in the study area. The most upper layer has low resistivity, implying high porosity layer, the middle layer has high resistivity representing dike, and the bottommost layer has low resistivity, which is probably in association with the magma chamber or mashed melt zone. We introduce the magnetic field anomaly in order to determine the distribution of anomalous resistivity bodies in the oceanic crust. The magnetic field anomaly was calculated from the observed magnetic field data by subtracting magnetic field induced by the vertical bipole electric current source transmission in the average resistivity structure. Magnetic field anomaly map for the each OBM was obtained by plotting the magnetic field anomaly at each source transmission point. The magnetic field anomaly maps present the location of local anomalous resistivity bodies, which are possible due to hydrothermal vent actives and small-scale ridge tectonics.

Keywords: EPR, Magnetometric Resistivity method, controlled source method, hydrothermal vent

Chemical composition and stratigraphy of sea floor sediments in Kikai Caldera and Nagahama Bay, Satsuma Iwo-jima Island

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Satsuma Iwo-Jima Island, with volcanic activities, is located about 40km south of Kyushu Island, Japan. This island is one of the best places to observe a shallow water hydrothermal system. Nagahama Bay, in the south of Satsuma Iwo-Jima Island, is partly separated from open sea. The seawater appears dark reddish brown due to suspended ferric hydroxide produced by the mixing of volcanic fluids and seawater (Ninomiya & kiyokawa, 2009; Kiyokawa et al., 2012; Ueshiba & kiyokawa, 2012). Reddish brown seawater sometimes flows out of Nagahama bay. However, movement of ferric hydroxide out of the bay has not been clarified. In this study, we report the results of scientific analysis of caldera bottom core samples at 10km south of Satsuma Iwo-Jima Island.

We observed reddish brown suspended particles and sediments in Nagahama bay with FE-SEM. We collected cores in two survey cruises (KT10-18 and KS14-10) in 2010 and 2014 using a research ship Tansei-maru and Shinsei-maru of JAMSTEC (Japan Agency for Marine-Earth Science and Technology) at 10km south of Satsuma Iwo-Jima Island. We observed the cores with X-ray CT scan and the thin-sectioned samples with a microscope. In addition, we conducted the chemical analysis with XRF to find out scientific behavior of sediments. Moreover, we analyzed the core at 70km south of Yakushima (TSK1PC) for comparison.

FE-SEM observation shows that the suspended particles consist of globular ferric hydroxide (about $0.2\mu\text{m}$), on the other hand, the iron-rich sediments are composed of bigger one ($>1\mu\text{m}$). This indicates the ferric hydroxide is precipitated by flocculation. X-ray CT scan observation shows that the cores don't include foreign origins, such as volcanic ash. Characteristic change was observed in the 4 elements out of 10 elements. We found a strong negative correlation between concentration of Ca and that of Si. We can confirm a negative peak of the Ca at 30cm from the surface in the core (KS14-10), which probably results from clastic particles in this depth. It is thought that the high concentration of Mn in the core (TSK1PC) can be caused by high oxidative environment. In the surface of the core (KS14-10), high concentration of Fe can result from leaching iron by burial of sediments. Furthermore, concentration of Fe in the caldera bottom cores (KT10-18 and KS14-10) is smaller than the core (TSK1PC) at 70km south of Yakushima. The former cores are shallower and include more organic matter than the latter core. This suggests that the former has deposited in the more reductive environment, which probably caused the difference of Fe. It is conceivable that redox status affects concentration of iron in sediments more strongly than concentration of iron hydroxide in seawater does.

We discovered the change in color of the caldera bottom core (KT10-18 and KS14-10). Nevertheless, We didn't find foreign origins in the cores. This appears to be the strongest proof that we couldn't find the significant material changes in thin-sections. We conclude that the change in color in the caldera bottom cores (KT10-18 and KS14-10) is due to leaching ferric hydroxide by burial of sediments.

Keywords: Kikai caldera, ferric hydroxide, redox status

Abiotic formation of methane by oxidation of sulfur species under hydrothermal conditions

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In recent years, abiotic reactions have been considered as one of the potential mechanisms for the formation of reduced carbon species (i.e., CH₄, ..) in hydrothermal systems at seafloor. Because the fluid flux through deep-sea hot-springs represents a potentially significant source of carbon and energy to support microbial activities in surface and sub-surface habitats, the possibility that abiotic processes may influence the speciation of carbon in vent fluids has direct implications for the maintenance of life in present-day hydrothermal environments. Although aqueous carbon compounds have significant role in broad spectrum of geochemical and biological processes, reactions to produce abundant aqueous hydrocarbons at seafloor hydrothermal environment are poorly understood.

Abiotic synthesis of hydrocarbons in hydrothermal environments is attributed to Fischer-Tropsch type processes, which are characterized by the reduction of CO₂ or CO by H₂ on catalytic mineral surfaces including magnetite (Anderson, 1984). These reactions are also thought to occur in association with serpentinization of mantle peridotites, which produces H₂ and Fe₃O₄. Previous experimental studies under hydrothermal conditions (e.g., Foustoukos et al. 2004) succeeded in production of H₂ and abiotic CH₄. For example, Foustoukos et al. (2004) reported the production of 208 mmol/kg of H₂ and 39 μmol/kg of CH₄ by the olivine hydration over 1000 hours; however, the concentration of CH₄ gas was quite low than those observed in natural ultramafic hosted hydrothermal vent fluid, for example, 0.13 ~2.2 mmol/kg of CH₄ from the hydrothermal vent at the Lost City.

In this study, we focused on sulfur species as reducing agent, based on Putri et al. (2011), which reported high H₂ generation rate (64.3 mmol/kg in an hour) in the system of H₂S and H₂O. We conducted a series of hydrothermal experiments with H₂S to generate H₂ by reduction of H₂O. We used Na₂S • 9H₂O for H₂S species, NaHCO₃ for CO₂ species, and Fe₃O₄ for catalyst of Fischer-Tropsch type CH₄ synthesis. The initial concentration of H₂S and CO₂ species were set to be 10 mmol/kg and 40 mmol/kg, as analogue of hydrothermal vent fluids. The experiments were conducted at 300 degree C, and initial pH was controlled at 9.9~10.0 with NaOH. After 168 hours experiment, the concentration of H₂ gas was 39.7 mmol/kg, which means almost H₂S species was consumed by the reduction of H₂O. The generated H₂ gas was used for the second reaction CH₄ gas. The CH₄ gas concentration was 30.3 μmol/kg in 168 hours, 6.3 times higher than that from serpentinization experiment (Foustoukos et al., 2004). In the same condition except for absence of Fe₃O₄, the gas concentration of H₂ were 40.14 mmol/kg and 4.91 μmol/kg, respectively. The experiment without Fe₃O₄ generated CH₄ gas and the concentration of CH₄ was quite lower than the experiment using Fe₃O₄, that indicates Fe₃O₄ takes the role of catalyst in the formation of CH₄, while other catalytic effect should be considered in the system.

References

Anderson, R.B., The Fischer-Tropsch reaction, 1984.

Foustoukos, D.I. and Seyfried, W.E., Science, 2004, 304, 1002.

Putri S., Javier V., Watanabe N., Kishita A., Tsuchiya N., International Journal of Hydrogen Energy, 2011, 36, 10674.

Keywords: hydrothermal fluid vent, abiotic methane, CO₂ reduction

Paleoshape of Antarctica and Australia

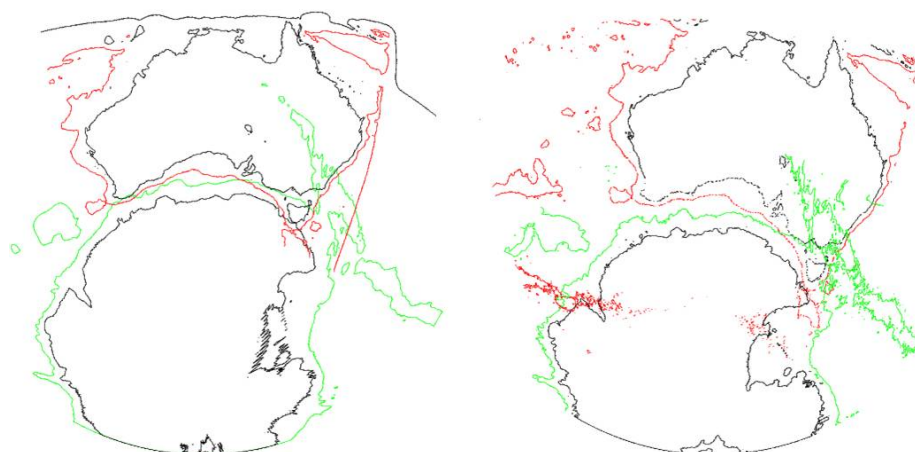
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Using 20 years GPS data, we reconstructed the paleo shapes of Antarctica and Australia continents by extrapolating smooth-surfaced vector field of the GPS data to check how far we can extrapolate the GPS data toward the past.

Figure below shows that about 90Ma shapes of the two continents (left) fit better each other than current shapes of the continents (right). black lines are coast lines, green and red lines are 3000m depth contours of Antarctica and Australia respectively. This result implies that 20 years of GPS data include deformation of continents for the time scale of tens of million years.

Keywords: GPS, Antarctica, Australia, deformation



Seismic structure at the Kairei Hydrothermal vent field near the Rodriguez Triple Junction in the Indian Ocean

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1. Introduction

The Central Indian Ridge is located at the north of the Rodriguez Triple Junction and shows slow~intermediate spreading rate. The Kairei Hydrothermal Field (KHF) was discovered in the first segment of the Central Indian Ridge. The vent fluid has higher H₂ content compared to other hydrothermal vent fluids in the world.

Although the KHF itself exists above a basaltic rock massif named the Hakuho Knoll, gabbro and peridotites were discovered on the seafloor around the KHF. The Yokoniwa Rise is located at the north of the KHF and shows peridotites exposure on the seafloor. The Uraniwa Hills are small core complexes which exist just east of the KHF and olivine-rich gabbroic rocks are exposed on the seafloor. The serpentinization of these deep-seated rocks exposed around the KHF may contribute to the high H₂ concentration of the vent fluid. To understand the sub-seafloor of the KHF, we conducted a seismic reflection/refraction survey with ocean bottom seismometers (OBSs).

2. Observation and Analysis

We conducted a seismic reflection/refraction survey from January 27 to January 29 in 2013 and from March 5 to March 6 in 2013 using S/V Yokosuka of JAMSTEC. In the experiment, we used 19 OBSs, an air gun (G.I.gun) and a single channel steamer cable. We obtained 5 survey lines NNW-SSE direction parallel to the ridge axis, 5 lines E-W direction and 5 lines NE-SW direction. In addition to these lines, we acquired other 5 lines passing through the point above the KHF or the Yokoniwa Rise.

In analysis of refraction data, we estimated 2-D velocity model under survey lines using the progressive model development method (Sato and Kennett, 2000). Then, we constructed a 3-D initial model and conducted 3-D inversion using FAST (Zelt and Barton, 1998).

3. Results

Seismic velocities under the Yokoniwa Rise and the Hakuho Knoll exceed about 6 km/s at depth of 1-2 km below seafloor. The high velocity area extends horizontally beneath the Yokoniwa Rise, suggesting that deep-seated rocks are uplifted when the Yokoniwa Rise was formed. The high velocity area beneath the Hakuho Knoll extends vertically, indicating that the knoll is a volcanic seamount.

A 1-D velocity profile of this study area generally seems to be similar to that of mid ocean ridges such as Mid-Atlantic Ridge, East Pacific Rise until depth of 3 km below the seafloor. However, the velocity of this study area at the seafloor shows about 1 km/s faster than that of other ridges except Juan de Fuca Ridge and the Southern Ridge. The Southern Ridge is the south part of the Atlantis Massif core complex on the Mid-Atlantic Ridge, and serpentines were sampled on the seafloor. The 1-D velocity structure of this study area is similar with that of the Southern Ridge, suggesting that deep-seated rocks are uplifted and serpentinized at shallow depth in this study area.

Acknowledgment

We thank the captain and crews of S/V Yokosuka of JAMSTEC for their support. This work was supported by Grant-in-Aid for Scientific Research on Innovative Areas of the Ministry of Education, Culture, Sports, Science and Technology (Grant Number 20109002, TAIGA project).

Keywords: TAIGA Project, hydrothermal field, crustal structure, triple junction of the Indian Ocean

Distributions of mantle heterogeneity across segment at southern segment of Central Indian Ridge

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Recent petrological and geochemical investigations of MORB at the southern segments of Central Indian Ridge (CIR) reveal the heterogeneous distributions of MORB-source mantle (Sato et al., 2015). Sato et al. (2015) concluded that MORB from CIR-S2 segment and off-ridge area at the CIR-S1 segment are depleted compositions than typical MORB. Furthermore, depletions based on trace element geochemistry of off-ridge MORB from CIR-S1 segment decrease toward present spreading ridge. Because off-ridge MORB was recovered from several dredge sites parallel to the flow line, these distributions might indicate spatial distributions of mantle heterogeneity beneath CIR-S1 segment.

Keywords: mid-ocean ridge basalt, Central Indian Ridge, mantle heterogeneity, geochemistry

On the origin of seafloor flattening

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The subsidence of an aging seafloor starts to slow down at ~ 70 Ma old with respect to the prediction of simple half-space cooling, and this phenomenon has long been known as seafloor flattening. The flattening signal remains even after removing the influence of the emplacement of hotspot islands and oceanic plateaus. The combination of small-scale convection and radiogenic heating has been suggested as a mechanism to explain seafloor flattening, and this study explores a possibility of using the magnitude of seafloor flattening to constrain the amount of radiogenic heating in the convecting mantle. By comparing properly scaled geodynamic predictions with the observed age-depth relation of the normal seafloor, the mantle heat production is estimated to be $\sim 12 \pm 3$ TW, which supports geochemistry-based estimates. A widely-held notion that small-scale convection enhances cooling thus being unable to explain seafloor flattening is suggested to be incorrect. The ability to predict the age-depth relation of seafloor based on the thermal budget of Earth has an important bearing on the future theoretical study of early Earth evolution.

Keywords: seafloor flattening, mantle convection, internal heating, early Earth, surface environment

Pacific Array

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Based on our recent results on broadband ocean bottom seismometry, we propose a next generation large-scale array experiment in the ocean. Recent advances in ocean bottom broadband seismometry (e.g., Suetsugu & Shiobara, 2014, Annual Review EPS), together with advances in the seismic analysis methodology, have now enabled us to resolve the regional 1-D structure of the entire lithosphere/asthenosphere system, including seismic anisotropy (both radial and azimuthal), with deployments of ~10-15 broadband ocean bottom seismometers (BBOBSs) (namely "ocean-bottom broadband dispersion survey"; Takeo et al., 2013, JGR; Kawakatsu et al., 2013, AGU; Takeo, 2014, Ph.D. Thesis; Takeo et al., 2014, JpGU). Having ~15 BBOBSs as an array unit for 2-year deployment, and repeating such deployments in a leap-frog way (an array of arrays) for a decade or so would enable us to cover a large portion of the Pacific basin. Such efforts, not only by giving regional constraints on the 1-D structure, but also by sharing waveform data for global scale waveform tomography, would drastically increase our knowledge of how plate tectonics works on this planet, as well as how it worked for the past 150 million years. International collaborations might be essential, as if three countries/institutions participate this endeavor together, Pacific Array may be completed within five or so years.

Keywords: OBS, seismic array, lithosphere, asthenosphere

Oceanic plate structure beneath the northwestern Pacific Ocean revealed by explosion experiments

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Plate tectonics is based on a concept that a rigid lithosphere moves over a weaker asthenosphere. Understanding of the plate tectonics is important to understand the Earth's system. However, the nature of the lithosphere and asthenosphere boundary (LAB) is not yet well determined. To understand the physical condition for the LAB, we have conducted a seafloor observation called "Normal Oceanic Mantle (NOMan) Project". We focused on the oceanic plate because the nature and evolution history of the oceanic plate is simpler than the continental plate so that it is easier to investigate its nature.

To analyze the upper mantle structures around the LAB, we conducted a seismic explosion experiments as a part of NOMan project.

Seismic explosion experiments were conducted at four shot sites with ten broadband ocean bottom seismometers and the size of explosions is 400 kg at two sites, and 200 kg at other sites. The profile lengths are about 700 and 400 km, respectively.

Previous studies in this area revealed the azimuthal anisotropy in the uppermost lithosphere (Shinohara et al., 2008), a sharp LAB at a depth of ~80 km (Kawakatsu et al. 2009), and small-scale heterogeneities in the lithosphere (Shito et al., 2013).

We have detected first arrivals from all data whose epicentral distance is between 100 and 670 km. At these distant ranges, first arrival is passing through the mantle, that is, Pn wave is first arrival. The apparent velocities of longer shots are about 8.0 km/s. However, at a shorter shot, first arrival times with nearly same distance is apart about 3 seconds. It suggests that the uppermost mantle structure in this region is very heterogeneous or has azimuthal anisotropy. After analyzing, we found the azimuthal anisotropy in the uppermost mantle whose amplitude is about 4% and whose fast axis is nearly perpendicular to the magnetic lineations, which is consistent with Shinohara et al. (2008).

We also found that some Pn waveforms at ~300 km is complicated although some others are simple, which may suggest the existence of the heterogeneities in the lithosphere.

Keywords: oceanic plate, explosion experiment, northwestern Pacific Ocean

Geographical distribution of shear wave anisotropy within marine sediments in the north-western Pacific

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Elastic properties of marine sediments, including P and S wave velocities, have been recently investigated well by active seismic surveys. However, information on S anisotropy associated with alignments of fractures and fabric remains elusive. To obtain such information, we used ambient noise records observed by ocean bottom seismometers at ~250 sites in the northwestern Pacific to calculate auto-correlation functions for retrieving S reflections coming from a sedimentary basement. We measured differential travel times and polarized directions of these S reflections to see, if any, geographical systematic distribution of S anisotropy. Consequently, the observed differential times were at most 0.05 s. The fast polarization axes tend to align in trench-parallel direction in the outer rise region. In particular, their directions systematically change in accordance with the direction of trench axis that changes sharply across the junction of the Kuril and Japan Trenches. We suggest two contributors for the obtained S anisotropy within marine sediments in the outer rise region, cracks induced by stresses due to bending of the plate and fractures associated with the basement deformation below the sediments. Which effect is dominant depends on the degree of plate bending. In the northwestern Pacific, both stress-induced cracks and fractures due to the basement deformation cause S anisotropy in a region where a large bending of the plate is observed, while fractures due to the basement deformation only create S anisotropy in other region of small bending of the plate. Moreover, we carried out numerical simulations with three-dimensional finite difference method taking into account anisotropy to simple, two-layered structure. Our results indicate that successful extraction of S anisotropy from the retrieved S reflection attributes near-vertically propagating S reverberations associated with extremely low Vs within marine sediments. Another numerical simulation with a realistic velocity model underneath the seafloor was conducted on the Earth Simulator in order to confirm whether S reflections from interfaces below the basement could be extracted or not. As a result, it is considered that such S reflections would be hindered by S reverberations with large amplitudes within marine sediments.

Keywords: marine sediment, S anisotropy, ambient noise, northwestern Pacific

Crustal thickness of the Ontong Java Plateau revealed from traveltimes inversion analysis

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The Ontong Java Plateau (OJP) is the largest oceanic plateau on Earth, located in the western equatorial Pacific and delineated by the 4000-m bathymetric contour. It is five times as large as the Japanese islands. From the results of sampling and drilling, the OJP is a representative example of large igneous provinces (LIPs) (e.g. Coffin and Eldholm, 1994), which do not fit plate tectonic theory, and no formation model explains all existing observations from the OJP. Environmental impacts of OJP formation had the potential to be large scale as suggested by a geologically short interval of emplacement and the feature's large area and volume. To understand its formation and environmental impacts, investigation of the crustal structure of the OJP is important. Structural studies of the OJP began in the 1960s. Since then, the few studies have determined the Moho depth beneath the OJP, which have varied according to survey method. For example, the Moho depths of seismic (Furumoto et al., 1976) and gravity (Sandwell and Renkin, 1988) studies are 35-42 km and 25 km, respectively. The Moho depth beneath the southernmost OJP is 35 km, as determined by a forward modeling approach (Miura et al., 2004), and an inversion analysis shows similar results (Korenaga, 2011). However, until recently the Moho depth at the center of the OJP has not been clearly determined and modern survey techniques were required. A seismic survey with 100 ocean bottom seismometers (OBS) across the center of the OJP was conducted in 2010 (Miura et al., 2011). First arrival traveltimes tomography and forward modeling have been applied to the OBS data (Miura et al., 2013). Recently we have initiated traveltimes inversion analysis of the OBS data using first arrivals and the largest amplitude later reflection phases (PmP), following noise reduction processing of reverberations from previous shots (Miura et al., 2014). Our analyses with initial models using various Moho depths show crustal thicknesses greater than those resulting from previous studies. Uncertainty analysis (Korenaga, 2011) will be applied to verify reliability of Moho depths.

Keywords: LIPs, OJP, MCS, OBS, traveltimes, inversion

New insights into the oceanic lithosphere from petit-spot around the Marcus Island

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Petit-spot volcanoes on the subducting NW Pacific Plate off the Japan Trench formed from melt that originated in the asthenosphere and ascended within a zone of concave flexure in the outer rise. Such tiny volcanoes are likely to be ubiquitous in such zones of plate flexure and have recently been reported from the oceanward slope of the Tonga, Chile, and Java trenches. They may also commonly occur in other settings, as similar volcanoes have been reported from the extensional Basin and Range province in North America, and from south of Greenland. It is therefore important to search for other examples of petit-spot volcanoes because they help us to address some important first-order questions about zones of lithospheric flexure.

Clusters of small conical volcanoes occur in the area southeast of Marcus Island, as inferred from precise bathymetric data acquired by the Japan Coast Guard. Most of the cones in the clusters are ~100 m high and <10 km across. Their morphologies are similar to those of petit-spot volcanoes. A search for petit-spot volcanoes around Marcus Island was conducted in May 2010 by the R/V *Yokosuka* of JAMSTEC (cruise YK10-05), carrying the submersible *Shinkai6500*. A young volcano was observed southeast of Marcus Island, contradicting the assumption that Cretaceous seamounts only occur on the Jurassic Pacific plate. The occurrence of highly vesicular alkaline lavas indicates that petit-spot volcanic activity is ubiquitous on the oldest oceanic plate as well. The morphologies of the lava flows in the area southeast of Marcus Island are different to those of flows in the NW Pacific, indicating a low-viscosity magma. The eruption setting in the area southeast of Marcus Island is unusual because the site is located far from any trench. An as-yet unknown origin of petit-spot melt ascending through the lithosphere might be identified via studies of the oldest oceanic crust in the world's oceans.

Keywords: alkali-basalt, petit-spot, Pacific, lithosphere, Marcus Island

Experimental constraint on magma genesis for petit-spot in the northwestern Pacific: the second step

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Plate deformation owing to the outer-rise induces eruption of magma forming diminutive volcanoes compared to hotspots and large igneous provinces, so called petit-spot volcanism. Even if unique geochemistry of alkaline basalts suggest that they are originated from partial melts in the heterogeneous asthenosphere, detailed melt production process for petit-spot volcanism is still not constrained. We thus conduct melting experiments to define phase relations for the petit-spot primary magmas. Our first experiment (Machida et al., 2013, JpGU) for the youngest knoll situated in flexed region of the northwestern Pacific plate (sample KR04-08 D08-002) showed that the primary magma is saturated with olivine and orthopyroxene or clinopyroxene at about 2.1 GPa and about 1280 °C. Therefore, when we consider that the depth of the lithosphere-asthenosphere boundary (LAB) for the northwest Pacific (WP2) is 82 km (Kawakatsu et al., 2009, Science), equilibrated pressure corresponds to the lower lithosphere. This result looks like resisting a conventional hypothesis that the petit-spot volcano was formed by exuding of magma existing in the upper asthenosphere, place deeper than approximately 90 km, through the lithosphere (Hirano et al., 2006, Science). To verify the universality of the result, we further select two samples as the second targets. Sample 6K 879-R3A was collected from a knoll in flexed region of the northwestern Pacific plate (approximately 2 km north of youngest knoll for the first experiment) during cruise YK05-06 of *R/V Yokosuka*. Sample 10K 56-R001 was collected from a knoll distributed at the Japan Trench ocean-ward slope during cruise KR97-09 of *R/V Kairei*. Based on the ⁴⁰Ar/³⁹Ar age of sample 10K 56-R001 and the present absolute plate motion, the erupting location corresponds to flexed region of the northwestern Pacific plate, same as the other two samples.

We conducted melting experiments using 1/2-in.-diameter piston cylinder type high-temperature and high-pressure apparatus at Kyoto university. Starting materials were prepared from mixture of pre-dried reagents of oxide, hydroxide, and carbonate representing major element compositions of primary magmas equilibrated with Fo=90 olivine (obtained by the olivine maximum fractionation model), and including 10% CO₂ and 1% H₂O (Okumura and Hirano, 2013, Geology). The other experimental procedures are same as those of Machida et al. (2013, JpGU). As results of our experiments, sample 6K 879-R3A is multiply saturated with olivine, orthopyroxene, and clinopyroxene at about 1.8 GPa and about 1280 °C, and sample 10K 56-R001 is multiply saturated with olivine and orthopyroxene at about 1.4 GPa and about 1275 °C. Therefore, it is a common condition, regardless of the difference of eruption position and age, that petit-spot magmas were equilibrated with depleted peridotite at the lower part of lithosphere.

Keywords: petit-spot, multiple saturation experiment

Dense heat flow measurements on the outer rise of the Japan Trench: Fracturing and pore fluid flow in the oceanic crust

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Anomalous heat flow values, higher than that expected for the seafloor age, are observed on the seaward side of the Japan Trench. Previous surveys revealed that the high heat flow is widely distributed on the seaward trench slope and outer rise along the northern half of the Japan Trench but does not extend beyond about 150 km from the trench axis (Yamano et al., 2014), indicating that the anomaly is related to deformation of the incoming Pacific plate associated with subduction. The seismic velocity structure of the oceanic crust also shows anomaly on the seaward side of the trench, attributable to fracturing and seawater percolation (Fujie et al., 2013). Based on these observations, Kawada et al. (2014) proposed that thickening of the permeable layer in the oceanic crust due to fracturing leads to development of pore fluid circulation, which efficiently pumps up heat from the underlying impermeable basement. They showed through numerical modeling that this process may yield a broad high heat flow anomaly at a scale of 100 km, as observed on the seaward side of the Japan Trench.

Overlapping the broad high anomaly, large local variations at a scale of a few kilometers were found at some sites where concentrated measurements were made. Such local anomalies may arise from heterogeneity of the oceanic crust, e.g., topography of the permeable basement in which fluid circulation occurs and high-permeability faults produced by plate bending. The existing heat flow data are, however, not dense enough to be compared with the detailed crustal structure.

For investigation of the origin of the local anomalies, we conducted closely-spaced heat flow measurements on the outer rise of the Japan Trench around 39°N on KS-14-17 cruise of the R/V Shinsei-maru in 2014. Measurements were made at intervals of several hundred meters along an E-W pre-existing multi-channel seismic survey line (JAMSTEC SR101), in an area 60 to 80 km from the trench axis, where immature horst and graben structures are observed. The obtained 20-km detailed heat flow profile perpendicular to the trench shows prominent sawtooth-like variations (60 to 110 mW/m²) at a scale of 3 to 5 km. This characteristic heat flow distribution has no apparent correlation with the basement topography and faults and might result from heterogeneity in deeper part of the oceanic crust. Possible causes of the observed small-scale anomalies, including local variations in the permeability structure, are discussed in another paper in this session (Kawada and Yamano). We should conduct measurements along lines parallel to the trench as well for further investigation of the relation between the heat flow distribution and the crustal structure.

Keywords: Japan Trench, Pacific plate, heat flow, oceanic crust, subduction zone, pore fluid

Fluid flow in a partially-thickening aquifer: A model for km-scale high heat flow on the outer rise of the Japan Trench

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Anomalous high heat flow is observed broadly on the seaward side of the Japan Trench offshore of Sanriku (*Yamano et al.*, 2008, 2014). Average heat flow within 150 km seaward of the trench axis is ca. 70 mW/m², which is substantially higher than that predicted by thermal models with the plate age 135 Ma, 50 mW/m². Individual heat flow values scatter between 50 and 120 mW/m². Dense measurements (at intervals of several 100 meters) conducted along 39°N have revealed that the scatter has a spatial scale of 3-5 km (*Yamano et al.*, JPGU2015). The origin of such fine scale anomaly must be just below the seafloor; however, seismic surveys cannot detect any structure within the sediment below the heat flow anomaly.

A high V_p/V_s layer is imaged at the uppermost part of the subducting oceanic plate where the heat flow anomaly is observed (*Fujie et al.*, 2013a, 2013b). The layer is imaged to be thickened toward the trench axis. The uppermost part of the oceanic plate is porous and works as an aquifer, and the observation could be interpreted as thickening of the aquifer toward the trench axis.

Previously, we constructed a model to explain the high average heat flow (*Kawada et al.*, 2014). Being inspired from the observation of the high V_p/V_s layer, we modeled a 500-m-thick aquifer 150 km seaward the trench axis that is linearly thickened to 3000 m toward the trench axis. Numerical modeling of heat and fluid transport results in anomalous high heat flow that is comparable to the observation, +20 mW/m². According to this model, the origin of the observed anomalous high heat flow is vertical heat mining from the underlying plate below the thickening aquifer.

In this presentation, we investigate the role of partial thickening of the aquifer on the resulting heat flow anomaly, in order to explain the observed fine-scale heat flow anomaly. Although *Kawada et al.* (2014) assumed that the aquifer is thickened smoothly, thickening of the aquifer should occur as discrete events because it is physically propagation of fissures. We consider two situations:

1. A part (1-2 km width) of an aquifer is abruptly thickened to 3000 m. In this case, we conducted numerical calculations of heat and fluid transport across the trench axis.
2. A permeable fault of ~100 m width, 3000 m deep, and infinite length along the strike is abruptly formed. In this case, we conducted calculations of conductive heat transport with enhanced thermal conductivity that mimics hydrothermal circulation.

In both cases, high heat flow peaks are formed above the permeable zone (thickened aquifer or fault) immediately after the calculation begins. High heat flow anomaly that is comparable to the observation ~100 mW/m² persists over several hundreds of thousand years. Heat is transported from the surrounding areas of the permeable zone, where no hydrothermal convection occurs. That is, heat in the surrounding area is mainly transported horizontally toward the permeable zone by thermal conduction and then is transported vertically due to hydrothermal circulation within the permeable zone. Because the area of the surrounding area is larger than the permeable zone, high heat flow anomaly can continue for a long time.

Keywords: heat flow, hydrothermal circulation, Japan Trench, subduction zone

Large tsunamis along a weakly coupled interface in the western Ryukyu trench

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A large tsunami struck the coasts of Ishigaki and surrounding islands along the western Ryukyu Trench on 24 April 1771. Several different earthquake phenomena were recently found along the western Ryukyu Trench: slow slips on the plate interface, very low frequency earthquakes, a tsunami earthquake and splay faults near the trench, which were similarly found in the Nankai trough. Moreover, it is pointed out based on GPS data on Taiwan that the westernmost Ryukyu subduction zone is fully coupled (Hsu et al., 2012). For all of these reasons, we purpose to investigate a plate coupling condition along the western Ryukyu subduction zone, based on tsunami deposits and GPS velocity data.

We analyze the data from the baseline of Iriomote and hateruma islands from 1997 to 2015. We exclude the data between Dec. 2001 and Mar. 2002 when Mw6.8 and Mw7.1 earthquakes occurred near the baseline during the time interval. This baseline is aligned perpendicular to the general trend of the western Ryukyu trench. The baseline length of 40 km between the two islands shows an extension of 1 mm/yr and strain rate (+2.5 10E-8) over the period. The absolute strain rate along the western Ryukyu trench is smaller by one order of magnitude than those along the Nankai trough and Japan trench. As a matter of fact, the strain rate along the Nankai trough and Japan trench is negative (shortening). The long-term and constant rate extension of the baseline suggests that rifting of the Okinawa trough is caused by the retreat of the Ryukyu trench. This retreat is produced by a rollback of the Philippine Sea plate in the western Ryukyu trench.

Keywords: large earthquakes, Ryukyu trench, Interplate coupling, 1771 Yaeyama tsunami, tsunami deposits, GPS velocity

Digital terrain analysis of sea-land combined data on the Outer Zone of Southwest Japan

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Geomorphological studies have been done in predominantly land areas, and usually have been treated separately: divided into either land or seafloor. The authors have been studying land topography, however, many parts of the Japanese archipelago were formed by lifting of the seafloor associated with plate sinking in trenches. The Outer Zone of Southwest Japan, which is the object of this study, is on plate boundaries.

Recently spatial resolutions of seafloor DEMs have become enlarged, and a few subsurface structure data have been published. Therefore the authors thought that we should visualize and analyze the sea-land combined data.

In this study, we analyzed drainage networks, profiles, and terrain types of Southwest Japan using a 500-m DEM which was a mosaic of land elevation by GSI and seafloor elevation by the Japan Coast Guard. Moreover, we visualized land topography and other data, i. e., seismic tomography data (Matsubara and Obara, 2011), distribution of seismic intensity, and plate boundary data that were published on the Internet. The visualization shows inhomogeneous structure of velocity below Japanese islands and a clear hot section leading out from deep underground to Osaka Bay.

Land and shelf edges are quantitatively similar to each other in topography. However, there are almost no steep slopes with high valley density on the seafloor in contrast to land surfaces. Instead of high valley density slopes, long large steep slopes as in Quaternary volcanos, such as Mt. Fuji, are widely distributed on the deeper seafloor. In addition, steeper parts of long large slopes are distributed around active faults in land, inner trench areas and outer ridges on the seafloor, in addition to tops of volcanos.

This study was carried out within a framework of "Mapping of large landslides based on the sea-land combined terrain classification: case study of the overall Outer Zone of Southwest Japan including the Nankai Trough" which was a theme in '2014 Collaborative Research with the Disaster Prevention Research Institute, Kyoto University'. We would also like to thank the Japan Coast Guard who provided the 150-m and 450-m Geographical Feature Meshes Data of Southwest Japan.

References

Matsubara, M. and Obara, K. (2011): The 2011 Off the Pacific Coast of Tohoku earthquake related to a strong velocity gradient with the Pacific plate, *Earth Planets Space*, 63, 663-667.

Keywords: Fundamental Geospatial Data, seafloor topography, DEM, digital terrain analysis

Seismic velocity structure beneath the Philippine Sea plate descending under the Kumano basin

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In order to monitor seismic activity in the Kumano basin, the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) developed the Dense Oceanfloor Network System for Earthquakes and Tsunami (DONET) above the Tonankai earthquake source region off the Kii Peninsula (Kaneda et al., 2009, Kawaguchi et al., 2010). DONET ocean-bottom seismic and water-pressure observation stations are connected with an optical fiber cable, and data from the sensors are transferred in real time to our laboratory at JAMSTEC. The seismic and water-pressure observations made by the DONET stations immediately above the source region of megathrust earthquakes improve our ability to detect earthquakes and tsunamis.

Kamiya et al.(2012) selected seismic events occurred in and around the Kumano basin and the Kii peninsula in the period from January 2011 to June 2012 and estimated seismic P and S velocity structures in this region using arrival time data picked from the seismic waveform recorded by the DONET system and the JMA catalog. Owing to adopting DONET data, the resolution of seismic tomography was improved beneath the Kumano basin off the Kii peninsula and the low velocity region beneath the Kumano basin above the descending Philippine Sea plate and the upper boundary of the plate beneath the DONET network were depicted clearly.

In the present study, we adopt data in the period from January 2011 to December 2014. We pick arrival times from the events occurred not only in this region but also outside of this region. We use these data and estimate seismic P and S velocity structures by the use of seismic tomography technique. For the model space, we take the latitude range of 30N-37.5N, the longitude range of 129E-141E. We use a grid interval of 0.2 degree x 0.2 degree. The new data improve the resolution of seismic tomography, in particular, the data from the events occurred outside of this region make it better in and below the lower boundary of the descending Philippine Sea plate. We are able to estimate the thickness of the descending plate and the seismic velocity structure beneath the plate in this region.

Deformation structure obtained by high resolution multi-channel seismic reflection survey around Nankai Trough axis

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The big disaster earthquakes had often occurred in the Nankai Trough with a great Tsunami event. In order to reduce a great deal of damage to coastal area from both strong ground motion and tsunami generation, it is necessary to understand rupture synchronization and segmentation of the Nankai megathrust earthquake. We focus on the deformation structure around the Nankai Trough. However, there are few seismic survey lines in the trough axis in the Nankai Trough. Therefore, we planned new survey around the trough axis in the Nankai Trough in order to obtain the high resolution structure.

Japan Agency for Marine-Earth Science and Technology (JAMSTEC) carried out new high resolution multi-channel seismic reflection (MCS) surveys using portable system over 1,500 km of line length from off Kochi to Kii Peninsula during 2013-2014. The seismic source used was an G-gun cluster array of 4 air guns with total volume of 380 cubic inches (5.24 L). The hydrophone cable is ca. 1200 m long, having 192 channels at an interval of 6.25 m. The MCS data were processed through a standard seismic processing flow, which consists of noisy-trace editing, 20-200 Hz band-pass filtering, velocity analysis with every ca.313 m intervals picking, normal moveout, Common Depth Point (CDP) stacking, and poststack time migration.

We obtained 23 MCS profiles around the Nankai Trough. Clear frontal thrusts are imaged in the margin of Nankai Trough axis. We recognized distinct proto thrust zone in the south part of the frontal thrust. This results yield the possibility of extended rupture area in the Nankai Trough.

This study is part of "Research project for compound disaster mitigation on the great earthquakes and tsunamis around the Nankai Trough region" funded by MEXT, Japan.

Keywords: MCS survey, Nankai Trough, proto thrust

Improvement of gas hydrate response in marine controlled-source electromagnetic exploration using fictitious wave domain

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While most of gas hydrate deposits is found clearly on seismic sections as cross-bedding events of the Bottom Simulating Reflector (BSR), the detailed structure of gas hydrate concentrated zones is not well estimated. We focus on marine controlled-source electromagnetic (CSEM) exploration considered as a technique in practice for the exploration of hydrocarbon reservoirs including resistive gas hydrate.

Recently, transforming the Maxwell equation from the diffusive domain to the fictitious wave domain has been developed to reduce computational time (Mittet, 2010). Although the diffusive Maxwell equations require a large number of time steps in finite-difference time-domain (FDTD) method to satisfy the stability condition, the number of iterations could be greatly reduced in the fictitious wave domain. However, the characteristic of the propagation in the fictitious wave domain has not been well exploited, and has potential for a new imaging technology of subsurface structures. In this study, we suggest a new data analysis approach to transform the data from the diffusive domain to the fictitious wave domain. Since the application of the transformation has a potential for improving the response of gas hydrate in the subsurface, we conduct some numerical experiments and discuss the applicability of our approach to the gas hydrate detection and evaluation.

We assumed a 3D resistivity model as a sub-seafloor structure including anisotropic resistive gas hydrate for simulating the inline CSEM exploration. By employing the singular value decomposition (SVD) method, we transformed the received data from the diffusive domain to the fictitious wave domain. Since the stability and accuracy of the transformation depend on the threshold of singular value, we adopt the appropriate value with considering the noise floor. Finally, our results indicate that the separated gas hydrate response becomes about twice as much than the case in diffusive domain.

Keywords: marine CSEM exploration, fictitious wave domain, gas hydrate, anisotropy

Pie-shaped and dome-shaped submarine mud volcanoes

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Mud volcanoes can be viewed as natural tectonic conduits that bring up deep substances and fluids motivated by overpressuring at deep depths. Thus, mud volcanoes are useful tools to explore processes in fluid migration and material cycling. Large number of studies of the mud volcanism on Earth has been conducted, and about 300 offshore mud volcanoes had been confirmed and the double had been inferred around a decade ago. Nevertheless, so far, quantitative and statistical studies of mud volcano morphology have been mostly restricted to onshore mud volcanoes on Earth and mud volcano-like structure imaged on Mars. Herein we globally compile heights and radii of offshore mud volcanoes using bathymetric data and literatures. The compilation is forwarded to estimate a mean volume of episodic mud eruptions from the mud volcano based on authoritative studies into granular flows. The volumes are estimated in the function of the ratio of height over basal radius of mud volcano's body. Nearly all found offshore mud volcanoes are definitely proved to be polygenic. Moreover, an individual erupted volume from the pie-shaped mud volcano has a couple of orders of magnitude larger than the one from the dome-shaped one. A frequent occurrence of pie-shaped mud volcanoes, discovered in the accretionary margins characterized by high sediment influxes, is likely resulted from being efficient players for escaping large amount of fluidized sediments to reach the seafloor.

Keywords: Submarine mud volcanoes, catalog, granular flows, aspect ratio, subduction zones, material cycling

Distribution of boron in slope sediment of Nankai accretionary prism off Kumano using B isotope as a tracer

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1. Introduction

In oceanic mass balance, boron is taken up into clay minerals, thus seafloor sediment plays a role as an important sink of boron (Spivack et al., 1987). But a mechanism of the uptake has not been clarified yet in a detail. Isotopic fractionation has a specific value for each reaction, thus to investigate isotopic fractionation enables to infer in-situ reaction mechanisms. But the isotopic fractionation in the previous study through laboratory experiments cannot exactly explain reaction mechanisms in natural environments, especially at a low-temperature condition. In this study, isotopic fractionation of boron in surface sediment at a lower temperature than 25 °C was investigated to discuss a behavior of boron in natural environments at a low-temperature condition.

2. Materials and analytical methods

Samples of pore water were extracted from surface sediment recovered from Nankai accretionary prism off Kumano during IODP Expedition 338. The boron concentrations in the pore waters were measured on board by the inductively coupled plasma atomic emission spectroscopy (Strasser et al., 2014). The precision was within $\pm 2.5\%$. The boron isotope ratios in the pore waters were measured by the multi-collector inductively coupled plasma mass spectrometry after its isolation (Wang et al., 2010). The analytical results were normalized by the standard material, NBS SRM 951, and denoted as a $\delta^{11}\text{B}$ value. The precision was within $\pm 0.7\text{‰}$.

3. Results and discussion

The boron concentration in the pore water was higher than that of seawater at the surface, and decreased with increasing a depth. The $\delta^{11}\text{B}$ value in the pore water was lower than that of seawater at the surface, and higher with an increasing depth. Isotopic fractionation, α , between solid and aqueous phases for each layer ranged from 0.950 to 0.970, lower than the reported values through a laboratory experiment between 0.975 and 0.980 (Palmer et al., 1987). In a laboratory experiment, there would be factors that could not imitate enough to natural environments; in-situ pressure, porosity, mineral compositions, ion strength of aqueous phases, and so on.

The relationship was verified between isotopic fractionation and several factors; in-situ temperature, pH, plagioclase abundance, and total organic carbon content. The relationship with pH showed a slightly negative, and the similar relationship was observed in surface sediment all around the world (You et al., 1993; Kopf et al., 2000; Teichert et al., 2005). This relationship would present uptake of $\text{B}(\text{OH})_4^-$ enriched in ^{10}B , because $\text{B}(\text{OH})_4^-$ is dominant in a solution when pH is higher.

4. Conclusions

Isotopic fractionation of boron in surface sediment of Nankai accretionary prism would be moderately controlled by pH, suggesting a reaction mechanism at a low-temperature condition has never been precisely imitated in laboratory experiments.

Keywords: Nankai Trough, Accretionary prism, slope sediment, Boron isotope

Development of a stand-alone gamma-ray measuring system for long-term change at the sea floor, and first measurement

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In the Japanese Islands, the Tokai, Tonankai and Nankai earthquakes are expected within a few decades. It is a very important scientific issue to understand the physicochemical process occurring in the earthquake occurrence zone and the mechanism of earthquakes near the subduction zone for mitigation of casualties and social infrastructures. Increases of the radon concentration in atmosphere and in groundwater before earthquake are reported in the Southern Hyogo Prefecture Earthquake in 1995. The correlation between micro earthquakes and concentrations of radionuclides is expected to contribute the fundamental research on the response of the fluid in the crust corresponding to change of the crustal stress. Then this time, environmental gamma ray measurement derived from natural radionuclides at the deep-sea floor in the Kumano-basin, where the epicenter of the coming Tonankai earthquake has been inferred.

To date, submarine environmental radiometry around Japan has been mainly performed by diving of a manned submersible "Shinkai 6500/2000" or a remotely operated vehicles, e.g. "hyper-dolphin". At such measurement, the NaI gamma-ray instrument was connected by cable to power supply and data transfer (cable-tethered NaI). Thus, the spatial distribution of environmental radioactivity has limitedly been measured around diving points. On the other hand, it was impossible to measure radiation at a fixed point for a long period. Subsequently, an automatic recording gamma-ray measurement system (GRAMS [Gamma RAY Monitoring System]) was developed, and it made possible to measure submarine gamma-ray at a fixed point. But gamma ray measurement has been performed only for short period of 12 days so far.

This time we developed a new stand-alone NaI gamma-ray measuring system (stand-alone NaI) for long-term monitoring of radiation at the deep-sea floor. This system has following features; 1. It has intermittent operation mode to save power consumption. 2. An automatic shut-down function to suspend the measurement when a battery voltage falls below the threshold (for example, 6V). 3. Low power consumption: the requirement of cable-tethered NaI is 12V 170mA (2W) regardless of that of stand-alone NaI is 6V 110mA (0.66W). Thus, the power consumption decreases in 1/3 even in measurement. It enables gamma-ray measurement for long-term temporal change of submarine environmental radiation at a fixed point. Its power is supplied by 180 AA alkaline batteries, then running cost becomes dramatically inexpensive.

As first measurement, we measured secular fluctuation of radiation from 24th April to 3rd August (about 3.5 months) at a cold seepage on Kumano-Basin. Respective U, Th and K contents was calculated as almost constant of 0.19±0.07 ppm, 0.07±0.07 ppm and 0.05±0.01wt.% in surrounding seawater. There was no large fluctuation. However, after Fourier analysis, a feeble peak of 25 hours, which corresponded to tidal fluctuation, has come out.

Keywords: radiation, sea floor, long-term temporal change, NaI, gamma-ray

The changes of past sea-bottom environment deduced from the recent benthic foraminifera Southern off Costa Rica

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IODP Exp.344 (Costa Rica Seismogenesis Project: CRISP 2) is designed to understand the processes that control nucleation and seismic rupture of large earthquakes at erosional subduction zones and drilled five sites off the western coast of Costa Rica around the southern end of the Middle America Trench, where the oceanic Cocos Plate is subsiding beneath the Caribbean Plate. In this cruise, the benthic foraminiferal data were strongly needed because the distribution of recent living benthic foraminifera is essential tool to estimate the past bottom-ocean environment and paleobathymetry. However, there are few data about the distribution of the recent foraminifera southern off Middle America.

In this study, we have recognized six assemblages out of samples of southern off Costa Rica.

And we identified the the shallower-water environment assemblages of U1413 using these recent data.

Keywords: the recent benthic foraminifera, Paleobathymetry, the erosional subduction zone, southern off Costa Rica

GPS-Acoustic seafloor geodetic observation by Japan Coast Guard - results and future plan -

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The Hydrographic and Oceanographic Department of Japan Coast Guard has been developing a system for precise seafloor geodetic positioning with the GPS-Acoustic combination technique and deploying seafloor observation sites on the landward slope of the major trenches around Japan, such as the Japan Trench and the Nankai Trough.

In this presentation, we summarize seafloor geodetic observation results and future observation plans.

Summary of the observation results:

(1) Seafloor sites along the Japan Trench

We have been carried out seafloor geodetic observations along the Japan Trench in order to detect post-seismic deformation of the Tohoku-oki earthquake. The results of the observations show that the displacements vary with the sites even in the directions. MYGI and KAMS had moved toward west-northwest at constant rate. MYGW had moved toward south-southeast. KAMN had moved toward northwest. FUKU and CHOS had moved toward east-southeast. In addition, the displacements at FUKU and CHOS decay with time.

(2) Seafloor sites along Nankai Trough

Along the Nankai Trough, we deployed six seafloor reference points in the sea area from off-Omae-zaki through off-Muroto in early 2000s and had been carrying out campaign observations. From the observation data obtained before the 2011 Tohoku-oki earthquake, we detected the intraplate velocities of 2-5 cm/year toward WNW, which were generally consistent with those detected by on-land GPS measurements.

Furthermore, to monitor seafloor movement spatially in the whole expected focal regions along the Nankai Trough, we deployed nine new seafloor reference points mainly off Shikoku in January 2012. It's been 3 years since we installed new sites, we obtain provisional results which suggests the velocities are different among some regions. It is expected that a spatial variation of interplate coupling will be revealed in the sea area along the Nankai Trough.

Keywords: GPS-Acoustic combination technique, seafloor geodetic observation, Japan Trench, Nankai Trough

Postseismic deformation following the 2011 Tohoku-oki earthquake measured by seafloor geodetic observation

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Using GPS/Acoustic seafloor geodetic observation (GPS/A observation), we can directly measure seafloor movements, which cannot be obtained from on-shore geodetic observation. Watanabe *et al.* (2014, GRL) indicate significant contribution of viscoelastic relaxation to the postseismic deformation based on the fact that off-shore GPS/A sites just above the source region of the 2011 Tohoku-oki earthquake show significant landward movement while on-shore GPS sites show trenchward movement. Furthermore, Sun *et al.* (2014, Nature) show the viscoelastic relaxation is a dominant postseismic mechanism based on their numerical simulation explaining both off-shore and on-shore geodetic data. However, since GPS/A sites used in these studies are limited in the Miyagi-oki region and not above the shallow portion of the plate interface which caused large coseismic slip, it is not sufficient to reveal the spatial extent of the postseismic deformation. Hence, we aim to constrain the spatial extent and distribution of postseismic deformation using 23 GPS/A sites deployed along the Japan trench from Aomori-oki to Ibaraki-oki. Twenty out of these sites were newly deployed in Sep. 2012 in order to observe postseismic deformation following the Tohoku-oki earthquake.

So far, we conducted six campaign surveys from Sept. 2012 to Sept. 2014 (9-10/2012, 11/2012, 7-8/2013, 10-11/2013, 2-3/2014, 9/2014) completing three surveys at most of the sites. Based on the method derived by Kido *et al.* (2006, EPS), we estimate the seafloor transponder array positions for each survey and calculate the postseismic displacement rate at each site by applying linear regression to the time-series of the array positions.

Since errors in the postseismic displacement rates are estimated to be about 5-10 cm/yr, it is difficult to discuss the postseismic deformation at individual sites. However, sites above the heavily ruptured area in Miyagi-oki show a tendency of landward movement as previous studies indicate, and sites to the north and south of the heavily ruptured area show slight northward and southward movements, respectively. Moreover, these observed postseismic deformation patterns are consistent with the result of the viscoelastic model constructed by Sun *et al.* (2014). Consequently, the viscoelastic relaxation is likely a dominant postseismic deformation process during the observation period.

Next campaign survey is planned in Feb. – Mar. 2015 and will expand the time-series of seafloor array positions improving the estimation accuracy of postseismic displacement rates at individual sites. In this talk, we report these observation results including the data to be obtained in the next campaign survey and discuss detailed postseismic deformation following the Tohoku-oki earthquake.

Keywords: Tohoku-oki Earthquake, postseismic deformation, GPS/Acoustic observation, seafloor geodesy

Seafloor movements on the northern part of the Philippine Sea plate detected by GPS-acoustic observation

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Along the Sagami Trough, where the Philippine Sea plate subducts beneath the North American plate, the megathrust earthquakes such as the 1923 Taisho Kanto earthquake (M7.9) and the 1703 Genroku earthquake (M7.9-8.2) had occurred repeatedly. On the west side, the west edge of Sagami Bay is considered as a boundary of the Izu Micro plate (IM) and the Philippine Sea plate [e.g. Sagiya, 1999]. Moreover, Taylor et al. [1991] suggested the back-arc rift zone along Izu-Ogasawara trench where the Pacific plate subducts beneath the Philippine Sea plate. Nishimura [2011] quantitatively estimated the motion of the Philippine Sea plate as the rigid rotations of several blocks and the slip deficits on the boundary faults. Because the most part of the Philippine Sea plate is covered with the ocean, however, few geodetic observations have been performed near the boundary faults. Thus, we, the group of Japan Coast Guard, have repeatedly performed seafloor geodetic observation with the GPS-acoustic technique (GPS-A) in order to detect the motion of the northern part of the Philippine Sea plate, especially near the boundaries.

We installed the GPS-A sites BOSS and SAGA on the seafloor southeastern off the Boso Peninsula and in the west part of the Sagami Bay, respectively. We set BOSS on the Izu-Arc block (IA) near the Sagami Trough, to detect the speed of the subducting Philippine Sea plate. On the other hand, we set SAGA on the IA near the northern part of the IM-IA boundary, where the Izu-Hanto-Toho-Oki earthquake (M6.7) had occurred in 1980. SAGA should be affected by the coupling of the IM-IA boundary faults.

We obtained the displacements relative to the rigid IA [Nishimura, 2011] on which the sites are located. Before the 2011 Tohoku-Oki earthquake (M9.0), no significant displacement was detected at BOSS (Sep. 2007 - Oct. 2010), which suggests that the seafloor around BOSS was considered to be rigid. Displacements detected at BOSS after the Tohoku-Oki earthquake (Apr. 2011 - Nov. 2013) were not significant either, though eastward coseismic displacement of 4-5 cm was detected. On the other hand, displacements at a rate of 1-2 cm/y toward south-southeast were detected at SAGA before the Tohoku-Oki earthquake (Jan. 2003 - Mar. 2011). We also detected eastward coseismic displacement of about 10 cm due to the Tohoku-Oki earthquake at SAGA. After the earthquake, eastward component of the displacement rate at SAGA was increased (May 2011 - Jun. 2014), which is considered to be caused by the postseismic deformation. Our results at SAGA obtained before the Tohoku-Oki earthquake are consistent with the quantitative model estimated by Nishimura [2011], which indicated the coupling on the IM-IA boundary faults. Therefore, the results at both BOSS and SAGA support the validity of the block-motion model by Nishimura [2011] on the seafloor near the boundary.

In this presentation, we report and discuss the results at BOSS and SAGA as well as other sites on and around the northern part of the Philippine Sea plate.

Keywords: GPS-acoustic seafloor geodetic observation, Philippine Sea plate, Sagami Trough, Block motion

Numerical simulation of GPS-Acoustic seafloor geodetic observation for accuracy evaluation

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Hydrographic and Oceanographic Department of Japan, Japan Coast Guard (JHOD), has been performing a seafloor geodetic observation with the GPS-Acoustic combination technique. In this observation, we first measure the absolute position of the acoustic transducer set at the bottom of the vessel using the GPS measurement. In addition, we measure the relative position of the seafloor acoustic transponder from the on-board transducer using the acoustic ranging and finally determine the absolute seafloor position. In the present system, the movements of the seafloor positions are measured with 2 - 3 centimeters precision ($1-\sigma$). We have determined the seafloor positions from seafloor geodetic observations 3 times a year for 4 - 5 years.

However, we should estimate the seafloor position with a high precision using a short-term data for determining a variable crustal movement due to the postseismic effect after the 2011 Tohoku-oki earthquake and the slow event along the Nankai Trough. This observation is also expected to be broadened to the Kuril Trench and Ryukyu subduction zones. Therefore, the improvement of observation and analytical approaches is required through the quantitative accuracy evaluation.

JHOD has discussed and estimated the accuracy of this technique by means of empirical approach using the practical data [e.g., Sato et al., 2013]. Because the final solution involves the effects from all error causes, we cannot discuss individual error causes quantitatively. This constitutes a barrier to develop for accuracy improvements. The past simulation studies from other research groups [e.g., Yamada et al., 2002] were not used for our system due to difference observation setting.

In this presentation, we numerically simulated the GPS-acoustic seafloor geodetic observation and evaluated the error causes in the observation and analytical processes. First, the error effects from the GPS positioning and the graded sound speed structure were derived in and investigated. The error effect from the GPS positioning was estimated smaller than the graded sound speed structure. The graded structure emerges the distortion of the array positioning of seafloor transponders and can be estimated on some level. We have plan to evaluate the error effects from the number of data, the coverage of observation lines, and time changes of sound speed structure, and so on, and compare with the practical observation data.

Keywords: seafloor geodetic observation, GPS-Acoustic combination technique, numerical simulation

Development of a new method for GPS/Acoustic seafloor positioning using multi-buoy system

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We are developing a new method for GPS/Acoustic seafloor positioning using multi-buoy system. In this system, we combined GPS positioning and acoustic ranging to locate seafloor benchmarks. We usually use a vessel for this observation. In the single vessel measurement, we need to assume that seawater sound speed structure is horizontally layered and changes only in time because the measurement geometry by single vessel has a resolution for sound speed variation in space or time, not both. However, this assumption causes systematic error in the locations of seafloor benchmarks when sound speed structure has some lateral heterogeneity. Using the multi-buoy system, we can estimate both the spatial and temporal variation of sound speed structure because the system can obtain travel times for cross-passing ray paths at each moment. In November 2013, we conducted multi-buoy observation in Suruga Bay. In the analysis, we introduced an obliquely layered sound speed structure model (Ikuta et al., 2010). In this model, sound speed changes depending on positions of buoys and seafloor benchmarks as $S(t, X, x) = S(t) + dS(X + ax)$, in which X and x are position of the buoys and benchmarks, respectively, $S(t)$ and dS are the temporally- and spatially-varying slowness, respectively, and dSx is contribution of the sloping structure. The coefficient (a) is implicated as the thickness of the laterally changing layer relative to the total depth, which is usually limited in the uppermost part of the seawater. Although the measurement time of about 2 hours was very short comparing to usual measurement time c.a. 10 hours, the benchmark was located within 19 cm from the expected position by previous study. The solution was improved 14 cm comparing to the same time-length single vessel measurement.

Keywords: Oceanbottom geodesy, GPS/Acoustic seafloor measurement, Buoy, Sound speed structure, Suruga Bay

Development of on-demand buoy system for crustal displacement observation and future plan

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Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Tohoku University and Japan Aerospace Exploration Agency (JAXA) has developed real-time observation system for tsunami and crustal movement using a buoy through twice sea trials since 2011. We already succeeded in mooring under the high speed sea current with over 5 knots, observation using a pressure gauge with tsunami mode, acoustic data transmission using double pulses, and data transmission from the buoy to a land station using satellite. We entered in new stage of the buoy system development for on-demand crustal displacement observation since 2014 as a part of strategy innovation program using accumulated know-how. This system measures the vertical and horizontal crustal displacements using above pressure gauge and six acoustic transponders in realtime and also make possible to measure via satellite transmission in on-demand. At this moment, we have some issues to be improved to implement this system. One is acoustic data transmission using double pulse between the seafloor unit and the wire-end station. There are error cases for identification of the double pulse due to reflection signals from the sea surface and sea bottom. And we have an issue about the accuracy for the acoustic transmission, and faced accuracy of the double pulse detection with over 1 msec. We try to reduce the accuracy to keep broad dynamic range, too. Second is data transmission between the wire-end station and the buoy station. We experienced stop of the data transmission there. As a result, we concluded that the reason is torsion of the wire rope there based on profile of the buoy position data. Considering damages by fishery activities, we decided to keep redundancy for data transmission by two methods using an electric line and pairs of electromagnetic modem. In addition, we also prepare precise point positioning systems for real-time calculation of the crustal displacement on the buoy station, which are MADOCA system developed by JAXA and starfire of commercial base. In this presentation, we introduce current stage of the development and the future view.

Keywords: Crustal displacement observation, Buoy, On-demand, real-time, Nankai Trough

Launching seafloor geodetic monitoring for the North Anatolian Fault in the Marmara Sea, Turkey

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The North Anatolian Fault (NAF) is known to be activated sequentially from east to west in the last century. NAF passes through entire Anatolian peninsula, Turkey, including the most populous city, Istanbul, where no significant earthquake has been occurred for long time. Unfortunately, NAF is submerged beneath the Marmara Sea near Istanbul, which prevent us to monitor the coupling state of the fault by land-based geodetic means, such as GNSS or triangulation. Under the SATREPS project between Japan and Turkey promoted by JICA, we have started seafloor geodetic monitoring of NAF in the Marmara Sea since 2014. We employed acoustic transponders, called extensometer, which can precisely measure ranges among instruments for short-baseline. Relative horizontal motion of the fault can be monitored as variation in baseline length across the fault. The system is designed as permanently installed for more than five years until their batteries run out. The recorded data can be obtained through acoustic modem communication without pop-up recovering of the instrument. In September 2014, we deployed four extensometers along the NAF at the Western High in the Marmara Sea, where no prominent branching faults are observed and the strain should be concentrated along the main fault. The beginning of the monitoring, we put high-frequent measurement (5 min) for 24 hours to check the accuracy of the ranging and recovered the data. Then measurement frequency has been turned into low-frequency (12 hours) for long-term monitoring. Examining the initial data, we confirmed the repeatability of the ranging is less than 5mm, which encouraged us to continue the monitoring to detect any signal in the next couple of years. In the presentation, we also show the first long-term data (6 months), which is to be recovered in the research cruise scheduled on March 2015.

Keywords: Marmara Sea, North Anatolian Fault, Turkey, earthquake, extensometer, seafloor geodesy