Eastern Gondwana breakup: Rifting and subsidence from the Tasman Basin through Lord Howe Rise

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During the Late Cretaceous, the eastern Australian margin rifted to form the Lord Howe Rise continental ribbon. To understand the history of this region since rifting we use reflection seismic data collected in 2016 onboard R/V *Kairei*. We focus on processing and interpreting a regional ~900-km-long east-west oriented seismic reflection profile at 27.2˚S. The seismic data were processed through pre-stack depth migration and interpretation shows the structure and evolution of this margin. The profile covers the oceanic Tasman Basin through the continental Lord Howe Rise. Sediment-filled depressions are found within the Tasman Basin and likely relate to early transform faulting with later deposition. The Lord Howe Rise is largely made up of syn-rift and post-rift sedimentary sequences in multiple structurally controlled basins. Two additional features are found between these regions, the Dampier Ridge and the Middleton Basin. The Dampier Ridge has a sharp, probably transform, boundary against the eastern edge of the Tasman Basin. Within the ridge are multiple rift basins up to 3 km deep that are comparable in size and structure to those found on the Lord Howe Rise. Between the Dampier Ridge and the Tasman Basin is the Middleton Basin which contains well-stratified sediments that are up to ~3.5 km thick. Stratal relationships indicate that the Middleton Basin formed during a post-rift event with large amounts of subsidence. Deep reflections beneath this basin reveal mantle at a shallow depth. The results have important implications for the evolution of the margin from initial rifting, opening of the Tasman Basin, and subsequent deformational processes.

Is the Ontong Java Plateau thick oceanic crust?

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The Ontong Java Plateau, arguably the most massive Large Igneous Province (LIP), covers an area of 1.9 x 10^6 km^2 (Coffin and Eldholm, 1994), equivalent to five times the area of Japan. From scientific ocean drilling results on the OJP, the basement is basalt with ages of about 120 million years (e.g. Shipboard Scientific Party, 2001), suggesting that formation was geologically instantaneous. Many models for the origin of LIPs have been proposed, such as plumes from the deep mantle (e.g. Richards et al., 1989), impact-induced decompression melting (e.g. Ingle and Coffin, 2004), lithospheric delamination (e.g. Elkins-Tanton, 2005), etc. However, no models for LIP origin explain existing observations. Crustal structure studies of the OJP have not yielded consistent results: Moho depths determined by a wide-angle seismic experiment were ~42 km (Furumoto et al., 1976), whereas that of gravity modeling was 25 km (Sandwell and Renkin, 1988). To obtain robust crustal structure information, including Moho depth, that is necessary to understand the origin of OJP, a large-scale seismic experiment was conducted across the central OJP (High Plateau) involving a large volume seismic source and one hundred ocean bottom seismometers (OBS) in 2010 by the Japan Agency for Marine-Earth and Technology (Miura et al., 2011). The new data are high quality, showing first arrival traveltime signals from offset distance >300 km in OBS profiles. From inversion analysis using first arrival and Moho reflection (PmP) traveltimes, we determine the Moho depth to be about 43 km on the central OJP. The new P-wave velocity (Vp) structure of the OJP indicates an upper crust with a relatively large velocity gradient and a lower crust with a relatively small velocity gradient, which is similar to typical oceanic crust except for different thicknesses. Moreover, the S-wave velocity (Vs) structure and Vp/Vs ratio are also similar to typical oceanic crust. Density estimates derived from simple calculations of the upper and lower crusts of the OJP confirm isostatic compensation without any anomalous high density crust, consistent with the OJP’ s submarine history. The velocity model of the OJP resembles that of Iceland (Foulger et al., 2003), although crust of the former is thicker than that of the latter. Iceland’ s subaerial crust is related to the Mid-Atlantic Ridge coinciding with a hotspot. Although the tectonic settings of Iceland and OJP are different, the tectonic setting of Iceland provides clues to the origin of OJP and LIPs. In this presentation, we will consider the origin of the OJP and LIP.

Keywords: Large Igneous Province, Ontong Java Plateau, MCS, OBS, crust, Moho

Plate Boundary Reorganization of the Pacific Plate during Cretaceous

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Several major tectonic events occurred in the Pacific plate during the mid-Cretaceous. A gigantic oceanic plateau was formed around 125 Ma and immediately separated into three plateaus, Ontong Java, Manihiki, and Hikurangi plateaus (Taylor 2006). At approximately the same time, Shatsky Rise ceased to be formed and then Hess Rise started to be formed (e.g. Sager, 2006). These events were accompanied by plate boundary reorganization of the Pacific plate. There are two large troughs in the western Pacific Ocean that are scars of the plate boundary reorganizations of the Cretaceous Pacific plate. One is the Nova-Canton Trough in the western equatorial Pacific Ocean. Taylor (2006) showed that the trough was formed during the separation of Ontong Java and Manihiki plateaus around 125 Ma. The other one is the Hokkaido Trough north of Shatsky Rise. Mammerickx and Sharman (1988) concluded that the trough was the initiation site of a failed oceanic rift which rifting propagated westward along the trough. Norton (2007) proposed another model that the trough is the abandoned Pacific-Izanagi Ridge. The origin of the Hokkaido Trough is still controversial.
The Hokkaido Trough is situated between Kuril Trench and Shatsky Rise. Most of the seafloor around the Hokkaido Trough were formed during the Cretaceous Normal Polarity Superchron (125.93-83.64 Ma), implying little magnetic anomaly lineations are available to reconstruct plate boundaries. Seafloor spreading fabric as abyssal hills and topographic features can give us the information of the reorganization of the mid-Cretaceous Pacific plate. We examined the topographic features around the Hokkaido Trough using multibeam bathymetric data. Most of the multibeam bathymetric data were obtained by the research cruises by R/V *Mirai*, JAMSTEC. The multibeam bathymetric data exposed the detailed topographic expression of the trough and seafloor spreading fabric around the trough. The topographic expression indicates that the Hokkaido Trough is not an abandoned spreading ridge proposed by Norton (2007). We found several curved troughs, which topographic feature is similar to those around the propagating ridges. Our study suggests that the reorganization of the Pacific-Izanagi ridge during Cretaceous was accompanied by propagation of the Pacific-Izanagi ridge and fragmentation of the Pacific plate.

Keywords: abyssal hill fabric, fracture zone, Hokkaido Trough, Pacific Plate, Cretaceous

Direct-ascended petit-spot magma from asthenosphere with little or no assimilation

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Petit-spot is alkaline monogenetic volcano distributed at the localities of plate-flexure such as the concavely flexed zone of the outer rise prior to plate subduction and rebounding lithosphere after glacial unloading. Petit-spot volcanism is unlikely related to mantle plumes or hotspots because they are randomly distributed without making seamount tracks. Alkaline melt erupted at petit-spot volcanoes originate from asthenosphere which move upward through the oceanic lithosphere by tectonic forces associated with plate flexure. Therefore, sampling the petit-spot lavas may be the only way for us to gain the materials directly from the asthenosphere below oceanic plate.
In the case of petit-spots at the concavely flexed lithosphere, the base of the lithosphere is extended so that the least compressive principal stress (σ_3) is perpendicular to the flexural axis. Otherwise, the σ_3 changes to be parallel to the flexure axis below the upper lithosphere, where the stagnation of ascending melt is speculated at the mid-depth of lithosphere. During the stagnation, melt could experience various degrees of fractionation and/or assimilation with lithospheric mantle materials (Valentine and Hirano, 2010). Pilet et al. (2006) showed the chemical similarity between clinopyroxene observed in petit-spot mantle xenoliths and clinopyroxene from melt-metasomatized continental mantle peridotites. They argued the petit-spot melt experienced metasomatic interaction with lithospheric peridotite. Thus, it is indispensable to ignore consider the lithospheric interactions when we estimate the asthenospheric composition from petit-spot lava. We present the geochemical variation of petit-spot lavas in relation to the tectonic regime of subducting Pacific Plate.
Submersible investigation of petit-spot lava field off the Pacific coast of northeastern Japan, called Site C, was conducted in 2014 (YK14-05). In this cruise, we found a young petit-spot volcano (~ 0.1 Ma) on outer rise and collected fresh lavas. The lavas are low-SiO_2 and strongly alkaline relative to previously reported petit-spot basalts. In contrast to aphyric petit-spot basalts previously reported, strongly alkaline lavas in this study contain much olivine phenocryst, indicating more rapid magma ascending than other petit-spots caused by unique tectonic regime below the young volcanoes on the outer rise. We found that such tectonic forces of both upper and lower lithosphere below their eruptions sites are clearly correspond to geochemical variations.

Keywords: Petit-spot, Asthenosphere, Plate flexure, Alkali basalt

Ocean Bottom Gravity Measurement Using a Landing AUV

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Gravity measurement at sea is usually conducted by using a research vessel. The accuracy of this sea surface gravity data is around 1 mgal at most. Recently, gravity measurement using the cruising type AUV URASHIMA of JAMSTEC has been conducted. The accuracy of this subsea moving gravity measurement is about 0.1 mgal (Shinohara et al., 2015). On the other hand, gravity measurement at the ocean bottom was also carried out by using a ROV or using a hanging wire rope from a ship (Joshima et al., 2006, etc). The accuracy of this method is higher than those of the two moving methods mentioned above and is comparable with that of on land. The ocean bottom gravity measurement is generally conducted near the targets for exploration. Therefore, relatively large gravity anomalies can be observed. If the ocean bottom gravity measurement by using a seafloor landing AUV is implemented, it is possible to get more accurate gravity data in deep sea at low cost.

Preliminary experiments for ocean bottom gravity measurement using a hovering type AUV Tri-TON of IIS/UTokyo and an ocean bottom gravity meter OBG manufactured by KGE were successfully carried out in August 2015 and December 2016 at Numazu, Shizuoka Prefecture. To avoid use of vertical thrusters while the gravity measurement on seafloor and obtain an efficient grounding force, the buoyancy of Tri-TON attached with OBG was adjusted slightly negative in advance. Although tilt correction bias due to an ambiguity of the passive gimbal leveling system still remains, the gravity data obtained on seafloor have low SD values and its accuracy is almost comparable with those of on land.

Keywords: Ocean Bottom Gravity Measurement, Landing AUV, Tri-TON, OBG

Development of the autonomous BBOBS-NX (NX-2G) : preliminary test report

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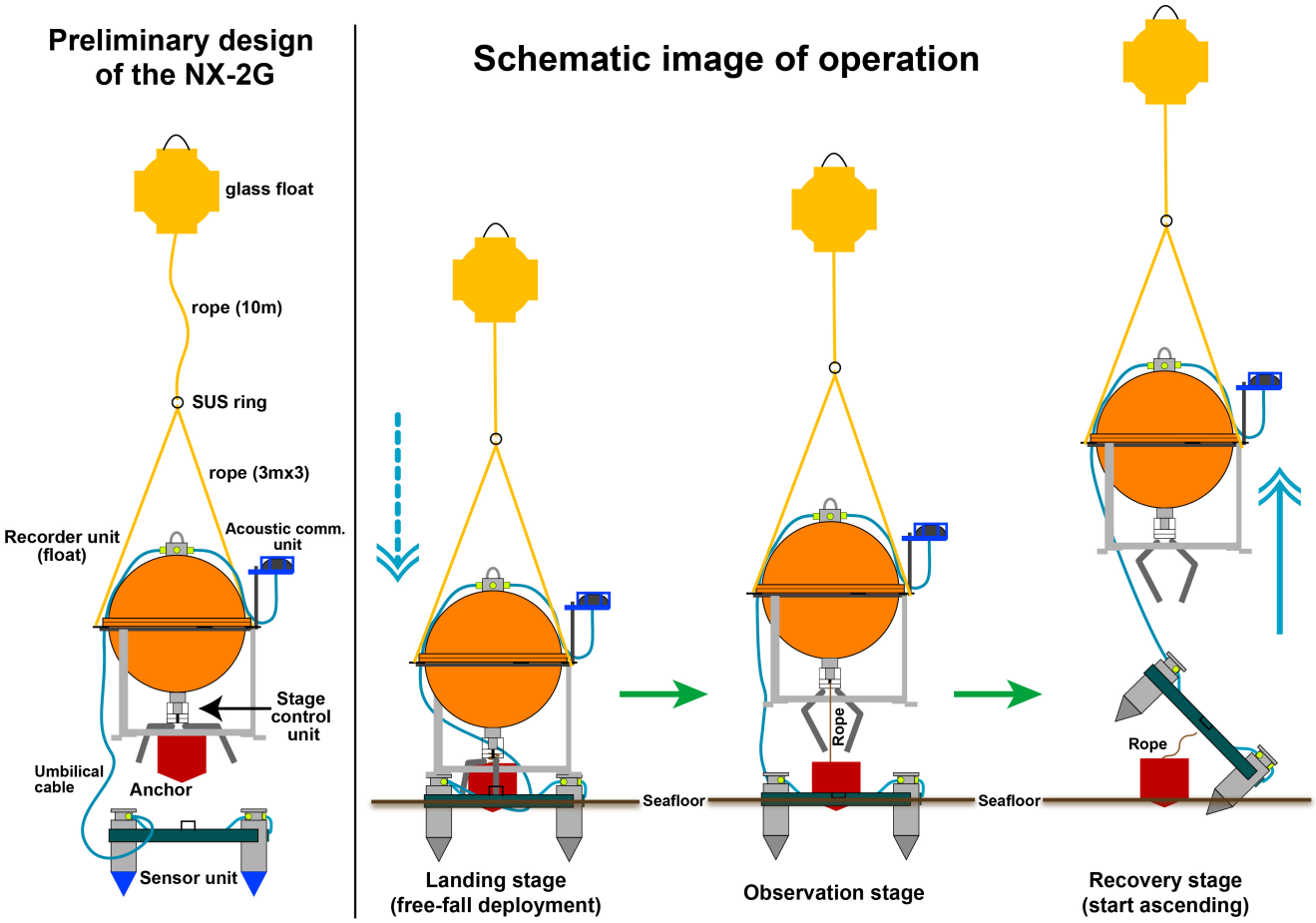
We have developed the broadband ocean bottom seismometer (BBOBS) and its new generation system (BBOBS-NX), and, with them, several practical observations have been performed to create and establish a new category of the ocean floor broadband seismology, since 1999. Now, our BBOBS and BBOBS-NX data is proved to be at acceptable level for broadband seismic analyses. Especially, the BBOBS-NX is able to obtain the low noise horizontal data comparable to the land station in periods longer than 10 s, which is adequate for modern analyses of the mantle structure. Moreover, the BBOBS(T)-NX is under practical evaluation for the mobile tilt observation at the seafloor, which will enable dense geodetic monitoring by its mobility and low cost.

The BBOBS-NX system is a powerful tool for ocean bottom seismic studies, although, the current system has intrinsic limitation in opportunity of observations due to the necessary use of the submersible vehicle for the deployment and recovery. If we can use this system at almost any kind of vessels, like as the BBOBS (self pop-up system), it should lead us a true breakthrough of ocean bottom observations in geodynamics. Hereafter, we call the new autonomous BBOBS-NX as NX-2G in short. There are two main problems to be cleared to realize the NX-2G system. The first one is a tilt of the sensor unit on landing, which is larger than the acceptable limit of the sensor (±8˚) in about 50% after our 16 free-fall landings of the BBOBS-NX. As we had no evidence at which moment the tilt occurred, we tried to observe it during the BBOBS-NX landing in 2015 by attaching a video camera and an acceleration logger. This result shows that the tilt on landing would be determined by the final posture of the BBOBS-NX system just before the penetration into the sediment. The second problem is a required force to extract the sensor unit from the sticky sediment, which was about 80 kgf in maximum from several in-situ measurements. This value is not so large to realize the self pop-up recovery system. The function of the NX-2G system is based on 3 stage operations like as the current BBOBS-NX system as shown in the figure. The core mechanism to perform these operations has been developed for the ultra-deep OBS system in 2012, already. It was also examined that we can place any object close to the sensor unit as far as they were mechanically decoupled, in the sense of the seismic band noise induced by the bottom current in 2012, too. Additional glass floats are aimed not only for obtaining large buoyancy to extract of the sensor unit, but also for suppressing the rotation (oscillating tilt) of the main part of the NX-2G system in descending.

In Oct. 2016, we made the first in-situ test of the NX-2G system near the observation node (YOB3) of the new off Kamaishi ocean floor cable system by using a ROV, where the water depth is 1570 m. Same as the deployment of the BBOBS-NX in 2015, the video camera and the acceleration logger were equipped with the NX-2G system, and then, it was dropped from the sea surface. The ROV was used to watch the operation of the NX-2G system at the seafloor. The landing looked well with small tilt, and it was examined from the acceleration data in descending. The maximum tilts measured this time was about ± 2.5˚, whereas that of the BBOBS-NX in 2015 was more than ±12˚. So that, the additional glass float effectively worked to suppress the rotation of the main part of this system, which is almost same design as the BBOBS-NX. The extraction of the sensor unit, which had been penetrated well, was also succeeded with the total buoyancy of about 75 kgf, although it took more than 2 minutes to finish the extraction completely. As the final experiment, we will start one-year-long observation of this NX-2G system in this April, with the BBOBS-NX and the BBOBS, to obtain simultaneous data for comparison of the noise level.

Keywords: ocean bottom seismometer, broadband seismology, instrument development



Structural interpretation of the hydrothermal activity area by the Multi-source ACS survey method

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Seafloor Massive Sulfide (SMS) deposits have been recognized to be formed at the hydrothermal vent site in the submarine volcano. They typically show abundant chimney structures, massive sulfide mounds and highly hydrothermal altered host rock. Active seafloor hydrothermal systems, related to forming the SMS deposits, are good natural laboratories for understanding the genesis of ancient Volcanogenic Massive Sulfide (VMS) deposits. While studies on these active hydrothermal sites have been progressing, the inactive hydrothermal sites are not well studied because of few efficient methods to detect and characterize them.
Therefore, we proposed a multi-source Autonomous Cable Seismic (ACS) survey system using a deep-towed autonomous cable and multiple sound sources with different acoustic characteristics. With this high-resolution acoustic survey system, we focused on the detection of physical (e.g., density) anomaly in volcanic sediments caused by hydrothermal alteration. The main objective of this study is to identify the variations in the acoustical characteristics of volcanic sediments with respect to SMS deposits and hydrothermal alteration.
Izena Hole is one of the most studied fields of SMS deposits around Japan. We conducted the multi-source ACS survey in the Izena Hole, using the Koyo-maru, in November 2016. We used three different sound sources of air gun, sparker and Sub-Bottom Profiler (SBP) in order to demonstrate the resolution and efficiency of our technique and describe the hydrothermal alteration of different stages and their acoustic characteristics. We obtained seven profiles running through the hydrothermal active/inactive area, caldera floor and outside of caldera wall. As a result of the survey, we obtained a cross-section of the internal caldera that enabled us to study the area from the viewpoint of seismic stratigraphy, and the resulting classifications of sedimentary features on the section suggested the possibility of restricting fluid circulation. In addition, penetration of high frequency components of sound sources suggested the potential existence of low-porosity layers in the shallow part of the sub-seafloor. From these results and discussion, it was suggested that the hydrothermal alteration zone in the volcanic caldera could be identified by the seismic data.

Keywords: Seafloor Massive Sulfide (SMS) deposits, multi-source Autonomous Cable Seismic (ACS) survey, hydrothermal alteration zone

Potential of Hydrothermal activity around the northern part of Sumisu Submarine Caldera, Izu-Ogasawara Arc

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Sumisu Submarine Caldera, Izu-Ogasawara Arc is distant about 470km southerly from Tokyo. The caldera 9×8km in diameter, has steep inner walls about 550-800m high, and a floor averaging about 900m below sea level. Tokai University preformed acoustic water column research by Multi Beam Echo-Sounder and sampling in the northern part of Sumisu Submarine Caldera in 2016. We extrapolated potential of hydrothermal activities in the research area.
We detected a number of acoustic water column anomalies that indicated a pattern like rising horizontally from northen rim of Sumisu Submarine Caldera. The acoustic anomalies came into begin ambit about 4km in the east-west direction in the northern rim. We called the area ‘Bosei site’ tentatively. In addition, we obtained many reddish brown clastic rocks by sampling in the same area. Infill of reddish brown clastic rocks include volcanic rock fragment, calcareous sediment (embracing biogenic silica), crystalline calcite, reddish brown granular calcite, cristobalite and amorphous ferruginous veinlet.
Infill of the rocks had many crystalline calcite because hydrothermal behavior of hydrothermal activity was neutrality side alkalinity. Some reason of environmental transformation changed the behavior to acidity. It may be low temperature that is making reddish brown granular calcite, cristobalite and amorphous ferruginous veinlet.
So we supposed two type hydrothermal activities have occurred in the Bosei site. And it may be that unknown phenomena which cause multi-beam acoustic scattering have been occurred around the seabed by the present hydrothermal activities in the Bosei site.

Keywords: Sumisu Submarine Caldera, Acoustic water scolumn anomaly, Reddish brown clastic rock, Hydrothermal activity

Three-dimensional seismic structure of the Rainbow area, Mid-Atlantic Ridge, at 36°14’ N: Fault development, crust-mantle transition, core complex formation, and mantle alteration at slow spreading ridges

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Oceanic lithosphere formed along slow-spreading mid-ocean ridges is structurally and compositionally heterogeneous due to spatial and temporal variations in tectonic extension and magmatic accretion. While mid-ocean ridges with greater magma supply host a greater abundance of hydrothermal systems, the relative roles of magmatic input, heat advection and faulting in controlling ridge structures are still poorly understood. The MARINER (Mid-Atlantic Ridge INtegrated Experiments at Rainbow) seismic and geophysical mapping experiment was designed to examine the relationship between tectonic rifting, heat/melt supply, and oceanic core complex formation at a non-transform offset of the Mid-Atlantic Ridge, 36°14’ N, the site of the Rainbow core complex and its associated hydrothermal vent field. Using the seismic refraction data from this experiment, we constructed three-dimensional tomographic images of the crust and upper mantle around the Rainbow area. The seismic velocity images reveal clear stripe-like structures with alternating high- and low-velocity patterns aligned in the ridge-parallel direction which correlate with the locations of large normal faults and the variation in lower crustal thickness. This structure suggests that the entire crust has been rotated by semi-vertical faulting during tectonic stretching. Throughout the experiment area, there is little evidence in the wide-angle data for persistent reflected arrivals from the Moho discontinuity (PmP). This implies that the crust-mantle transition occurs gradationally in the vertical direction rather than forming a sharp seismic boundary. At the Rainbow massif, where mantle rocks have been recovered by direct sampling, seismic velocities near the seafloor (the upper 2 km of the lithosphere) are lower than expected for mantle rocks and have a sharp contact with higher-velocities below. The velocity boundaries are consistent with reflectors within the Rainbow massif revealed by MCS reflection data [Canales et al., Geology, in press] and probably represent alteration and cracking fronts of the mantle lithosphere. These results suggest that fluid circulation channeled by dense faults alter the whole massif efficiently and enhances the active hydrothermal system.

Keywords: Mid-Atlantic Ridge, Seismic refraction, Normal faults, Hydrothermal vents, Mantle alteration

Seismicity and 3D seismic velocity structure at the Kairei hydrothermal vent field near the Rodriguez Triple Junction in the Indian Ocean

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1. Introduction

In the northern part of the first segment of the central Indian Ridge from the Rodriguez triple junction, the Kairei hydrothermal vent field exists and discharges hydrothermal fluid with rich hydrogen. Serpentinized peridotite and troctolites, and gabbroic rocks were discovered on the seafloor around the Kairei hydrothermal field. These rocks (originally situated at several kilometers beneath seafloor) exposed around the Kairei field may cause the rich hydrogen fluid. At the Kairei field, hydrogen-based various hydrothermal vent fauna were found. In the ”TAIGA” Project (Trans-crustal Advection and In situ reaction of Global sub-seafloor Aquifer), this area is a representative field of ”TAIGA” of hydrogen. The areas at and around the Kairei hydrothermal vent field, the Hakuho Knoll and the Yokoniwa Rise, locate near the non-transform offset (NTO) between the first and second segments, and are regarded as an NTO massif. To investigate how the deep-seated rocks are uplifted and exposed onto seafloor, and the hydrothermal fluid circulates in subsurface, we conducted a seismic refraction/reflection survey and seismicity observation with ocean bottom seismometers (OBSs).

In JpGU 2016, we reported that a swarm of micro earthquakes exists at a location about 3-5 km northwest of the Kairei field and its depth is about 4-7 km. The focal mechanisms in the swarm are normal type. Another swarm exists at the first segment of the central Indian Ridge, and is divided into upper and lower parts, and both incline at about 60-70° toward west.

To determine more detailed 3D velocity structure and seismicity, we use TomoDD program (Zhang and Thurber, 2003). This presentation will show 3D velocity structure from artificial and natural sources and relocated hypocenter distributions.

2. Observation and methods

We conducted a seismic survey around the Kairei hydrothermal field from January 27 to March 19 in 2013 using S/V Yokosuka of Jamstec (YK13-01, YK13-03). We used 21 OBSs. We determined 3D velocity structure and hypocenter locations by TomoDD program. We obtained better resolution at deeper parts using natural sources.

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. A low velocity area locates under the ridge, and this suggests existence of magma. Seismicity shows swarms under the ridge at the northern part of the first segment and near the Kairei field. All of the swarms incline at about 60-70° toward west. This suggests that these fault system may form the NTO massif. The swarm near the Kairei vent field has very shallow events at the far side from the vent. This may imply a sea-water input area of the hydrothermal system.

Acknowledgements

We thank the captain and the crew 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, seismicity, crustal structure, NTO massif

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 off-ridge area at the CIR-S1 segment are depleted trace element compositions than typical MORB. Furthermore, depletions of 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. Newly analyzed isotope compositions suggest that MORB depleted in trace element is enriched in radiogenic Sr and Nd. Machida et al. (2014) proposed that "Radiogenic Depleted component (RD)" contributes to the genesis of basalts from CIR-15 segment at 20 degree south and CIR-18 segment at 16 degree south. We suggest that RD component widely spreads along CIR.

Keywords: Mid-ocean ridge basalt, Central Indian Ridge, Mantle heterogeneity

Unraveling the oceanic serpentinization reaction from aluminum-zoning in mesh textures

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Serpentinization (hydration of mantle peridotite) gives significant changes to both chemical and physical properties of lithosphere. Mesh texture was usually observed in serpentinized peridotite, and is a key to understand the dynamics of oceanic lithosphere. Serpentine minerals in mesh texture commonly contain subtle amounts of aluminum, but the influences of Al on kinetics of serpentinization is poorly understood.

In this study, we conducted hydrothermal experiments in olivine (Ol)–plagioclase (Pl)–H_2O system at 230 ° C and a vapor-saturated pressure of 2.80 MPa for understanding the effect of Al on the mechanism of olivine replacement. By using unique tube-in-tube type hydrothermal experiments vessel (e.g., Oyanagi et al., 2015), spatial and temporal data were obtained.

We found the systematic difference in olivine replacement textures between Al–metasomatic zone near the Ol–Pl contact and isochemical zone far from the contact. In the isochemical zone, lizardite + brucite + magnetite was formed and original olivine outline was not clear. In contrast, in the metasomatic zone, Al–rich serpentine + Ca-Saponite aggregate replaced olivine with forming a characteristic zoning of core, mantle, and rim parts. Microstructual observations revealed that this zoning was produced by initial formation of mantle part at Al–free solution, subsequent to simultaneous progress of pseudomorphic replacement at olivine front (core part) and overgrowth (rim part) with migration of Al metasomatic front. Similar Al zonings of olivine mesh texture were observed in partly serpentinized harzburgite and Pl-bearing wehrite, suggesting that local mass transfer plays an essential role on replacement progress and texture development with volume expansions during serpentinization of oceanic lithosphere by onset of beak down of Al–bearing minerals.

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Keywords: Serpentinization, Mesh texture, Hydrothermal experiment, Serpentine

Preliminary results of the CK16-05 Cruise: Scientific drilling in Okinawa Trough of coring, logging using geothermal tool and refit of Long-term monitoring apparatus

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The CK16-05 Cruise by D/V Chikyu was performed at the Izena Hole and Iheya Minor Ridge, in the middle Okinawa Trough from November 16th to December15th, 2016. Aiming to construct the genetic model of seafloor hydrothermal deposits, the subseafloor polymetallic sulfide ore body and relevant geology were investigated under an umbrella of Cross-ministerial Strategic Innovation Promotion Program (SIP). Throughout the cruise, systematic coring partly coupled with logging using a geothermal tool were conducted at the Hakurei Site, Izena Hole. Within the five of the eight sites, massive sulfide ore-bodies were successfully drilled and sampled. Owing to an improved sampling tool, a hydraulic piston-coring system modified to adjustable (short) penetration, the transition zones from sediments to ore bodies were continuously sampled without significant disturbances. The continuous profiles of natural gamma-ray together with borehole temperature and pressure were also obtained at the half of the holes. In the middle of the cruise, installation of a revised long-term monitoring apparatus equipped with sensors to monitor the secular variation of pressure, temperature, flow rate and precipitation weight within the apparatus on hydrothermal vents artificially made as Hole C9017A at the very vicinity of the last installation at the Hole C9017B, at Noho site, in the south of Iheya-Minor Ridge.

In this presentation, we report the preliminary results of operations conducted in the CK16-05 Cruise.

Keywords: Izena Hole, Systematic sampling of sulfide minerals, Natural gamma ray, Long term monitoring

Estimation of subseafloor environment at active hydrothermal fields in Okinawa Trough based on mineralogical and geochemical analysis

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A series of drilling campaign was conducted in Okinawa Trough under the framework of the Next-generation Technology for Ocean Resources Exploration Project. I investigated hydrothermal alteration, sulfide and sulfate minerals in drill core samples. The study fields of this investigation are the Iheya-North hydrothermal field and Noho Site in mid-Okinawa Trough. Deep sea drilling was conducted in 2014 (CK14-04 Cruise) and 2016 (CK16-01 Cruise) using the drilling vessel *Chikyu*. In total, 7 holes in the Iheya-North hydrothermal field and 3 holes in Noho Site were drilled. The deepest hole reached 208.5 mbsf (meters below seafloor). X-Ray Diffraction analysis of the core samples was performed onboard for 199 samples to identify mineral species in the cores. 67 polished sections were prepared to determine rock texture and mineral assemblage. Electron Probe Micro Analysis was applied to determine chemical composition of the sulfide minerals. Pb isotope ratios were analyzed for 26 representative sulfide samples using Laser Ablation-Inductively Coupled Plasma-Mass Spectrometry.
Site C9021 is located midway between Natsu Site and Aki Site in the Iheya-North hydrothermal field. The core sample consisted of a 70 m thick layer of fresh pumice. Sites C9016 and C9023 were drilled in the vicinity of two active hydrothermal vents. The core samples consisted of abundant anhydrite with clay minerals associated with minor sulfides (pyrite, sphalerite, galena, and chalcopyrite). K-bearing minerals such as illite and K-feldspar were also observed. The abundant anhydrite indicates rigorous mixing between the seawater and hydrothermal fluids beneath the seafloor. Sphalerite was relatively low in Fe suggesting deposition under an oxidative condition. Pb isotope composition of the sulfide minerals shows a narrow range indicating deposition from a common hydrothermal fluid. Site C9017 is located in the Noho Site. The 120 m-long core sample consisted of alternations between basaltic lava and clay-rich layers. Hydrothermal alteration was not intense but observed over the entire core sample. Ca-bearing minerals, anorthite, wairakite, and dolomite occur in ascending order of core depth. Minor pyrite, pyrrhotite, cubanite, sphalerite, and anhydrite were identified. Sphalerite was relatively high in Fe indicating deposition under a reduced condition.
In the Iheya-North hydrothermal field, hydrothermal alteration and sulfide minerals occur under oxidative condition beneath the seafloor, in the vicinity of the active hydrothermal vents. Indicative of a high seawater flux entrained through the permeable pumice layer. In contrast, the Noho Site is under a reduced condition. This may have been generated by the lava layers which act as cap rocks and prevent seawater penetration. In both fields, a high temperature condition is estimated in the deeper portions, based on occurrence of alteration minerals. Alteration minerals in the Iheya-North hydrothermal field are rich in K, whereas those in the Noho Site are Ca-rich. This difference reflects different host rock, dacite pumice for the former and basaltic lava for the latter. In summary, degree of seawater entrainment, temperature of the hydrothermal fluid, and chemical composition of the host rock are important controlling factors that determine environment beneath the active hydrothermal fields in Okinawa Trough.

Keywords: Seafloor hydrothermal deposit, Iheya-North hydrothermal field, Noho Site, CK14-04 Cruise, CK16-01 Cruise, Hydrothermal alteration

Geochemistry of pore fluids collected from active hydrothermal fields in Iheya North Knoll, Okinawa Trough

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We investigated chemical composition of pore fluids extracted from sediment samples collected by scientific drilling from Iheya North Knoll hydrothermal field in mid-Okinawa Trough. Two drilling campaigns CK14-04 and CK16-01 were conducted employing Drilling Vessel Chikyu under the framework of the Next-generation Technology for Ocean Resources Exploration Project. Sediment cores were drilled from Site C9016 within the hydrothermal field of Aki Site, from Site C9021 about 1 km apart from Aki Site, and from Site C9023 drilled on an active hydrothermal mound of Aki Site (27˚46.1' N, 126˚54.1' E; water depth = 1070 m). Prior to these campaigns, another scientific drilling in Iheya North field was conducted as IODP (Integrated Ocean Drilling Program) Expedition 331, which targeted at Original Site (27˚47.5' N, 126˚53.8' E; water depth = 1000 m). After the pore fluid study reported as the result of Expedition 331, we document geochemical signature of pore fluids, to discuss fluid interactions and migrations within the sediment layer.

Pore fluid from Site C9021 away from the active field showed approximately same chemical composition as seawater for whole range of the sampled depth, from 0 to 66 mbsf (=meters below the seafloor). The exception was recognized in slight decrease of SO_4 and increase of alkalinity at the depth from 45 to 58 mbsf. Together with detection of H_2S in the same layer, this change is attributed to sulfate reduction within the sediment. Similar seawater entrainment was recognized in shallow layer (< 11 mbsf) at Site C9016 located within the active field. Whereas pore fluid in deep layer (>30 mbsf) showed distinctive chemical composition which showed similarity in several species rather to the vent fluid emanating from the hydrothermal mound. Pore fluid at Site C9023 collected directly from the active hydrothermal mound showed complicated profiles, but likely to converge to the vent fluid composition in deep layer (> 40 mbsf).

Occupation of pore fluid in deep sediment layer by the hydrothermal component of vent fluid composition was already recognized in the Original Site by the previous study. As well as seawater entrainment into a certain depth, extensive fluid migration would be attributed to distribution of porous pumiceous sediment piled on Iheya North Knoll. Combination of the lateral migration of the ascending hydrothermal component and seawater entrainment is responsible for the drastic change in pore fluid chemistry profiles in subseafloor region of the active hydrothermal field. Given that mixing between these two components is not obvious in the chemical profiles, separation by an impermeable layer would be inevitable. Pore fluid chemistry beneath active hydrothermal field in Iheya North Knoll would be controlled by geologic structure of a stratovolcano as well as hydrothermal structure.

Keywords: submarine hydrothermal system, hydrothermal alteration, volcanic sediment, fluid migration

Relationship between Resistivity Characteristics and Mineral Species of Rock Samples in the Seafloor Hydrothermal Area

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Geophysical surveys around seafloor hydrothermal areas are conducted for the purpose of metal resources development. However, the information from geophysical survey is limited so that new technology developments are necessary for quantitative interpretation of grade and spatial distribution of mineral resources. To solve this problem, rock physics model incorporating correlations of physical properties and chemical composition of target area is helpful. This is known as concept of multidisciplinary analysis based on the rock physics (e.g., Suzuki, 2013) that estimate geological information hardly obtained only from the physical properties. In this research, we measured and analyzed both physical properties and chemical composition of the rock samples obtained from seafloor hydrothermal areas. Based on them, we suggest a rock physics model, useful for our final goal; evaluation of amount of mineral resource by combined analysis of geophysical explorations.
The rock physics model constructed in this research gives the predicted resistivity of rock based on assumption of porosity and other parameters. The reason why we focus on resistivity comes from the previous researches that resistivity structure is useful for the investigation of metal resources in the seafloor hydrothermal area (e.g. Kowalczyk, 2008). Moreover, it is known that sulfide minerals such as pyrite (abbreviated in seafloor hydrothermal area) are exerting high electrical conductivity.
In order to construct an appropriate model, it is necessary to clarify the physical and chemical characteristics of the rock sample. Therefore we first measured several physical properties and analyzed the chemical composition of rock samples obtained from the Noho-site, Izena Caldron and Iheya North Knoll known as seafloor hydrothermal area in the Okinawa Trough, Japan. The measurement properties are resistivity, porosity, grain density, natural remnant magnetization, together with metal element content. Particularly in the measurement of resistivity, in order to reveal the formation factors and electrical conduction of solid rock matrix, we conducted resistivity measurements with changing concentrations of NaCl solution in pore water (such as in Suzuki, 2003). After these measurement and analysis, we applied our new model to determine the each parameter of the model.
As a result, obvious correlation was confirmed between each parameter of our new model and the specific chemical elements of rock samples. This suggests that the model constructed in this study is useful to extract chemical information such as mineral species from physical properties such as resistivity. In the future, we will develop this detailed resistivity model, then quantitatively incorporate other physical properties and chemical composition for further discussion.

Keywords: seafloor massive sulfides, Archie’ s law, electrical conductivity, rock physics model

Electrical features of the submarine hydrothermal system around the Iheya-North Knoll area and the Noho Site, Okinawa, Japan, inferred from resistivity and IP properties of drilling samples from the Chikyu CK16-01 cruise

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The exploration and exploitation of submarine hydrothermal deposits are becoming increasingly important for the steady supply of metal resources to Japanese industry. Valuable metal elements are commonly included as sulfide minerals in these deposits. Most of the sulfide minerals generally exhibit a high electrical conductivity, and an anomalous signature of the Induced Polarization (IP) effect. Therefore, electromagnetic investigations have been considered to be effective in finding unidentified sub-seafloor deposits. Understanding the resistivity and IP properties of rock samples taken from the deposits is important for the improvement of exploration techniques and the reduction of risks during exploitation. The present study involved measurements of resistivity and IP properties of drilling samples from the research program entitled “the Chikyu CK16-01 cruise” from February to March 2016.

The drilling research was conducted in the Iheya-North Knoll and the Noho Site adjacent to the Iheya-Minor Ridge (Kumagai et al., in prep.), where an extensive high-temperature hydrothermal system was expected based on previous surveys (e.g., Takai et al., 2015). The present study included complex resistivity measurements with a wide frequency range between 0.01 Hz and 100 kHz, using non-polarizable electrodes in a four-electrode configuration. Most of the measured sulfide samples are of hydrothermal origin, including fine-grained pyrite. Some samples consist of other sulfide minerals such as chalcopyrite, galena, pyrrhotite, and sphalerite. Massive sulfide rocks were rarely sampled, and disseminated sulfide rocks dominated.

The measurements showed the following results. There is a negative correlation between resistivity and porosity. However, no significant correlation was found between resistivity and sulfide mineral fractions, and the measured resistivity values (greater than 1 Ωm) are higher than those of typical massive sulfides (less than 0.1 Ωm), suggesting that the resistivity is controlled by the connectivity of the interstitial sea water filling the pores. Regarding the IP signature, the sulfidic sediments bearing fine-grained pyrite have low phases at low frequencies, and the values increase with frequency. This feature is consistent with experiments by Revil et al (2015), which demonstrated that fine-grained sulfide causes anomalous high phases at high frequencies. According to further data analyses based on the Cole-Cole model, the estimated chargeability exhibits a positive correlation with the sulfide content.

In this study area, it was shown that the presence or absence of sulfide minerals is reflected in the IP properties, rather than in the resistivity values. In general, pore water resistivity decreases with an increase of temperature, resulting in a reduction of bulk resistivity. Therefore, not only massive sulfides but also high-temperature hydrothermal fluids maintained in porous sediments could be identified as a low-resistivity body by seafloor electromagnetic surveys, meaning that more care should be taken in the

interpretation of the resistivity structure.

Acknowledgements:
This study was conducted under the program “Next-generation technology for ocean resources exploration, Cross-ministerial Strategic Innovation Promotion Program (SIP)” by the Council for Science, Technology and Innovation (managed by JAMSTEC). We would like to thank the laboratory technicians for supporting our measurements.

Keywords: submarine hydrothermal deposit, Iheya-North Knoll, Noho Site, resistivity, induced polarization, sulfide minerals

Challenge to monitor the nearby hydrological response to the drilling into hydrothermal venting area: A case for mid-Okinawa Trough Noho hydrothermal site

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Thermal and hydrological properties within a hydrothermal system are obviously key factors to constrain the size, flux and lifetime of a hydrothermal reservoir. During the Expedition 908 conducted with JAMSTEC drilling platform Chikyu , heat flow and pressure monitorin were carried out using SAHF (Stand Alone Heat Flow meter) and POODLE (Pressure and "Ondo” On Deep-seafloor for Long-term monitoring Equipment). The main purpose of these observatories is to detect, if any, a thermal and hydrological response to the nearby drilling into a hydrothermal ventins site. Such signals should provide critical information about thermal and hydrological properties in a system. We deployed SAHF and POODLE 7 hours before drilling SIP NH-01(site C9017) and recovered them in November 2016 by using the ROV.

We present here a quick-look report on the monitoring of sub-seafloor temperature and pressure data, recorded in the period of nearby drilling into the Noho hydrothermal venting area in mid-Okinawa Trough.

Keywords: heat flow, Okinawa Trough, hydrothermal circulation

Two types of upper crust seismic velocity structure in the Izu-Bonin-Mariana back-arc basin

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We focus on the seismic velocity structure in the Izu-Bonin-Mariana (IBM) back arc basin, and investigate spatial variation of P-wave velocity structure of the upper crust. The seismic velocity of oceanic crust is composed of 3-6 km/s with large velocity gradient (layer 2), and 6-7 km/s with less velocity gradient (layer 3). The thickness of the layer 2 formed at fast spreading mid-ocean ridges is about 1~2 km (e.g., Kearey *et al.*, 2009). The upper crust P-wave velocity structures of the back-arc basins are divided into two groups by the thickness and velocity gradient of layer 2 (Sato *et al.*, 2015); 1) The same structure to the crust created at fast spreading mid-ocean ridges (We call this “standard structure”), 2) The structure which has thicker (~3 km) layer 2 and lower velocity than that of “standard structure” at shallow depth because of smaller velocity gradient (We call this “lower velocity structure”). The lower velocity structure probably due to high porosities of the crust, which corresponds to rock samples and low gravity anomaly (Dunn and Martinez, 2011). They suggest that when near the volcanic arc, back-arc spreading centers preferentially advect hydrous, low-viscosity mantle, possibly augmented by dynamic buoyant upwelling, as inferred for the arc itself. The upper oceanic crust velocity structures in the Southern Mariana Trough and the Lau back arc basin shows “lower velocity structure” where subduetion influence would exist (Jacobs *et al.*, 2007; Dunn and Martinez, 2011; Sato *et al.*, 2015).
We investigate spatial variation of the upper crust velocity structure in the IBM back-arc basin using 2-D velocity structures (Takahashi *et al.*, 2015) to identify two types of structure. The 2-D velocity structures were obtained along eight survey lines across Izu-Bonin arc and one survey line across the Mariana arc. These lines lie in W-E direction and extend near old spreading center in N-S direction. We make graphs of veloscity structure against depth below sediment. The boundary point of two groups is set at 1.5 km depth and 5 km/s velocity because the difference of two groups become clear at this point based on Sato *et al.* (2015). We define the middle structure of two groups as “middle structure”.
The velocity structures of all lines vary in order of lower velocity structure, middle structure, and standard structure from east to west. The width of each structure is different from each line. We name each survey line as line 1-9 from north to south. In line 1,2 and 8, there are lower velocity structure of 15~40 km, middle structure of 30~80 km, and standard structure in the rest western area. In line 3, there is only standard structure. In line 4,5,6 and 9, there are lower velocity structure of 30~70 km and middle structure in the rest western area. In line 7, there are middle structure of 30~80 km, and standard structure in the rest western area, but no lower velocity structure. Only line 9 cross Mariana trough. There are middle structures of 40 km in the eastern end and 55 km in the western end of the trough, and standard structure of about 100 km in the rest area near the spreading center.
Our analysis reveals that lower velocity structure and middle structure exist in the IBM back-arc basin, suggesting that the upper crust influenced by subduction was formed. All areas of lower velocity structures and middle structures are influenced by subduction with older crust in these arcs. This indicates that the influenced crust was made in early stage of back arc formation when the spreading center was near the subduction zone. The subduction influences vary along the spreading center, because width of each lower velocity structure and middle structure structure is different. Especially, there is no standard structure in the middle of Shikoku basin and Parece Vela basin, suggesting the subduction influences would be significant there.

Rifting structure in the northern and middle Okinawa Trough deduced from seismic reflection and refraction data

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The Okinawa Trough is an active backarc basin as the Ryukyu (Nansei-Shoto) arc-trench system, to southwest of Kyusyu, Japan. The length and width of the trough are around 1,000 km and 100-200 km, respectively, and its rifting stage varies from north to south. Previous seismic surveys demonstrated that the crust beneath the trough has continental characteristics and the Moho depth shallows southward from about 25 km at the north to around 15 km at the south. However, the number of the seismic explorations in the Okinawa Trough was not so many to obtain detailed rifting structure considering the large dimension of the trough. We, Japan Coast Guard, have conducted extensive seismic reflection and refraction surveys in the Nansei-Shoto region since 2008 and we compiled the seismic structure in the northern and middle Okinawa Trough. We will show the results from seven seismic lines in this presentation: we carried out two lines along the trough strike and five lines perpendicular to the trough. The two of the five across-trough lines are positioned to the north of the Tokara Gap, the distinctive topographic depression between the north and middle trough. The other three lines are designed in the middle trough from the Tokara Gap to the Kerama Gap. These across-trough seismic lines intersect the along-trough lines at around the center of the trough.

The seafloor topography and multi-channel seismic (MCS) reflection records largely vary in the direction of the across-trough, in spite of a common feature that many normal faults were observed beneath all the MCS lines in the Okinawa Trough. The western part of the trough shows a flat topography and the several intrusions recorded in the MCS profiles do not reach to the seafloor. In contrast, the seafloor in the eastern part of the trough is characterized by many small-scale lineament structures. The strike of most of the lineaments is almost parallel to the volcanic front especially in the northern trough. The MCS records reveal many volcanic intrusions penetrate the seafloor.

The P-wave velocity models beneath the northern and middle Okinawa Trough generally show an extended arc crust of the Ryukyu Islands which consists of upper, middle, and lower crusts. We estimated crustal thicknesses below the trough mainly from Moho reflection (PmP) travel times. The along-trough seismic line in the middle trough demonstrates that the crustal thickness becomes thinner from north to south due to the decrease in thickness of the lower crust. However, such systematic decrease is not observed in the northern trough because of very inhomogeneous distribution of the middle and lower crusts along the seismic line. The across-trough seismic lines show that the crust below the trough is significantly thinner than the crusts beneath the Ryukyu Islands and the continental shelf of the East China Sea. The position of the shallowest Moho along the line is not necessary corresponding to the areas with the deepest water depth.

Keywords: Okinawa Trough, rifting, marine seismics

GNSS/Acoustic geodetic measurement at the west end of spreading Okinawa trough back arc basin.

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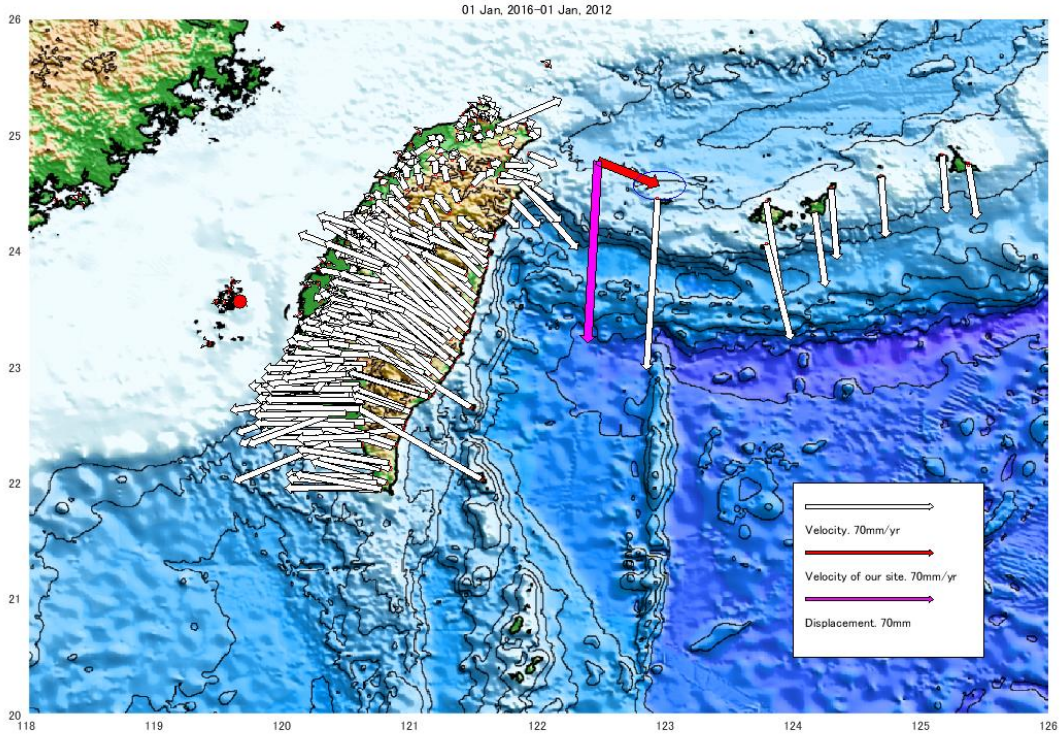
In this presentation, we show a result of seafloor crustal deformation measurement using GNSS/Acoustic technique conducted off Ilan, Taiwan, from July 2012 to May 2016.
The measurement site is located at the intermediate point between Taiwan and Yonaguni Islands in the west end of the Okinawa trough which is the back arc basin of the South-West Islands of Japan. The east adjacent area of our site, the north off the Yonaguni Island, is known as the region where the back arc spreading is especially fast in the Okinawa trough. The velocity of the GEONET station by Geospatial Information Authority of Japan (GSI) in Yonaguni Island relative to the Eurasian plate from 2010 to 2013 is about 6-7 cm/yr to the south. Institute of Earth Sciences, Academia Sinica deployed the seafloor benchmark consisting of four seafloor transponders which form a square 1,000 m on a side at the southern edge of the trough axis. Our aim is to observe the behavior of the back arc opening at the point very close to the spreading center.
The GNSS/Acoustic measurement were conducted eight times using observation vessel during four years from July 2012 to May 2016. For each measurement, we obtained 3D coordinate of the onboard GPS antenna and the vessel attitude both with interval of 0.2 sec, two way acoustic travel time and CTD. These data are combined and processed using the method proposed by Ikuta et al. (2008) to solve position of the seafloor benchmark. The 3D coordinate of GPS antenna was solved using IT (Interferometry Trajectory) which is the software suitable especially for long baseline measurement developed by NASA/GSFC. On the benchmark positioning by method of Ikuta et al. (2008), we introduced an assumption that the relative position of the four seafloor transponders does not change through all the measurements and estimated the movement of the position of their centroid.
From the result , the velocity of the centroid is 5.7 cm/yr to the southeast with reference to Eurasian plate. The horizontal time series of the centroid shows small deviation that maximum residual is about 7 cm from an approximated straight line. On the other hand, the horizontal time series seems to have an offset in between July and September 2013, so we tried to fit it with two straight lines and evaluated the goodness of fitting with AIC (Akaike’ s Information Criterion). As a result, the value of AIC was the smallest when the period was divided at the period between July and September, 2013. Fitted by two straight lines, the time series show southward movement of about 11 cm during the period between July and September, 2013. Ando et al. (2015) reported that dyke intrusion accompanying an earthquake swarm occurred at the deepest part of the trough north off Yonaguni Island in April 2013. The southward movement of the centroid off Ilan may show that this back arc spreading event propagated westward during the following 3-5 months. Spreading of the Okinawa trough with apparently constant speed by the observation based on land GNSS of the South-West Islands may occur intermittently without seismic activity near spreading center of the Okinawa trough. When fitted by a straight line, the centroid moves with velocity intermediate between GNSS stations located in Yonaguni Island and Ilan plain, Taiwan. This result suggests that although northern part of Taiwan and the west end of the South-West Islands show very different movement, they does not have significant discontinuity between them.

Keywords: Okinawa trough, back arc spreading, seafloor crustal deformation, GNSS/Acoustic measurement



Mechanism of large earthquakes along the southwestern Ryukyu subduction zone and the east coast of Taiwan

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The Philippine Sea Plate subducts along the southwestern Ryukyu Trench, while it collides to the east coast of Taiwan. Tectonics of this complex region is discussed based on our recent results from studies of tsunami deposits and seafloor crustal deformation observation.

1. Large tsunamis off the coast of Miyako and Ishigaki islands.

Results of our recent survey on Ishigaki reveal that large tsunamis occurred approximately with a recurrence interval of 600 years (Ando et al. 2017). We found fissures in the soil bed beneath the 1771 tsunami layer, which were certainly created during the strong ground motions of the 1771 earthquake. Usami (2010) estimated the seismic intensity of the scale of JMA as IV for Okinawa, 400km east of Ishigaki. Thus, the strength of ground shaking of the 1771 earthquake is to be equivalent to seismic intensity V or more. We infer that the 1771 event was not as anomalous as the 1896 Sanriku-oki earthquake, and was rather an ordinary thrust earthquake at the southern Ryukyu trench. Another huge tsunami occurred on the east of the 1771 source area. On Shimo-jima (Miyakojima city), the largest tsunami boulder (Obi-ishi) in Japan has been transported to the current site by another tsunami. This tsunami is estimated to have occurred between 11th century and 1771. These observations suggest that large earthquakes and tsunamis occurred repeatedly over at least 250 km long along the Ryukyu Trench. These earthquakes are considered to be reverse fault earthquakes at the plate boundary. Based on the model of the 1771 earthquake (Nakamura, 2009), the seismic coupling ratio of the upper and lower plates is estimated to be 20%.

2. Trench retreat and strain field

According to GPS observation, the Ryukyu arc retreats south to southeastward at a velocity of 4-6 cm/y. This migration is caused by the southward retreat of the Ryukyu subduction zone, which causes Sakishima islands stretched at a strain rate of +1–3x10^{-8}/y. Accordingly, in the Okinawa trough, the back-arc basin of the Ryukyu subduction zone, magma intrudes intermittently in a passive manner. In April 2013, magma intrusion occurred in the Okinawa trough, 50 km north of Yonaguni Island. Approximately 3 months after this event, magma intrusion possibly happened 100 km west of the site of 2013 which is revealed by a seafloor crustal deformation observation (Koumi et al., 2017). In the southeastern Ryukyu subduction zone, the trench retreats, while compressional strain is still accumulated near the trench associated with the subduction, and large earthquakes are generated with a recurrence interval of 600 y. It is notable that large earthquakes can occur recurrently even in a weakly coupled subduction zone.

3. Seafloor crustal deformation observation

A survey of seafloor crustal deformation started in 2014, 60 km south of Hateruma Island. Our recent results reveal that this seafloor site moved southward relative to Hateruma, suggesting this region stretched in the trench-normal direction. However, the reliability of the observational results is still low because of its short observation period (2 years). It is necessary to continue the observation at least three more years. At the same time, off the east coast of Taiwan, seafloor observation started in 2009 at three sites to verify the interplate-coupling ratio on the east coast of Taiwan. The recent results of the northernmost site (off Ilan), for the period of 2012 to 2016, show the velocity at 4 cm/y southing and 8 cm/y easting (Koumi et al., 2017). However, the observation point is too far from the trench to estimate a coupling ratio of the subduction zone. Further observation is really required at sites closer to the trench (off Hualien and Chenggong).

4. Summary

In order to elucidate the mechanism of the large earthquakes along the southwestern Ryukyu Trench, the continual observation of crustal deformation off Hateruma Island, and sites near the trench off the east coast of Taiwan.

Keywords: Ryukyu trench, Tsunami, Plate coupling rate, Recurrence interval, Large earthquake, Extensional strain field

Detection of offshore vertical displacements after the 2011 Tohoku-oki Earthquake from GPS-A observations

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Postseismic displacements following the 2011 Tohoku-oki Earthquake (Tohoku Eq.) have been detected by on- and off-shore geodetic observations. Especially offshore GPS/Acoustic (GPS/A) observations showing an extensive postseismic displacement pattern [Watanabe et al., 2014, GRL; Tomita et al., 2016, AGU], which have strong constraints on modeling postsesimic deformation processes [e.g., Sun et al., 2014, Nature]. However, these GPS/A studies have basically detected only in horizontal components. Potseismic vertical motions are sensitive to the postseismic processes because they show different spatial pattern from horizontal motions; therefore, detecting vertical motions is quite important. Although Watanabe et al. [2014] detected vertical motions after the Tohoku Eq., an extensive pattern of the postseismic vertical motions has not still been obtained.

It has been a difficult work to detect vertical motions by GPS/A observations because a parameter of calculating vertical motions has the trade-off nature with a parameter of the sound speed in the seawater (SSS). Sato et al. [2013, J. Geod.] showed acoustic ranging data obtained from numerous and extensive sea-surface ranging points could constrain the parameters; Watanabe et al. [2014] similarly estimated the postseismic vertical motions. In contrast to their data collections, we have collected acoustic ranging data from a fixed ranging point just above the center of a seafloor transponder array (point survey data) based on the strategy of Kido et al. [2006, EPS]. In this strategy, we can obtain a horizontal seafloor motion precisely by each ping, but it is difficult to constrain vertical motions. However, we have also collected less but extensive acoustic ranging data (moving survey data) occasionally to initially configure the seafloor transponder array. In this study, we challenge to calculate extensive vertical motions after the Tohoku Eq. using moving survey data obtained from Seq. 2012 to Nov. 2016 at the 20 GPS/A sites in the Tohoku-oki region.

In our strategy, we initially calculated relative positions of seafloor transponders at each site; then we simultaneously calculated positions of arrayed transponders (array positions) in both horizontal and vertical components for each cruise and temporal changes of SSS. In order to accurately calculate vertical motions, we also have to estimate an offset between a GPS antenna and an acoustic transducer mounted on each research vessel. Since we have employed a different vessel for each cruise, the transducer offset values may cause critical biases in the calculated vertical motions. Thus, we iteratively estimated the transducer offset values and the initial relative positions of seafloor transponders and the array positions. Then, postseismic displacement rates were calculated from the obtained vertical motions.

The obtained vertical displacement rates show spatially charaterized pattern: subsidence above the coseismic rupture area and uplift near the trench, but they have 3-15 cm/yr errors in 1 σ that are much larger than the errors in the horizontal components. The worse errors in the vertical component are probably caused by the trade-off nature with SSS and the shortage of the moving survey data. Some sites show small errors with ~3cm/yr, but we cannot figure that the accurate results are actually obtained because the larger errors are obtained in the other sites by the same method. Due to the errors, it is difficult to quantitatively discuss the postseismic deformation processes at the moment. However, this study successfully showed the potential capability of our data for detecting vertical motions. In order to quantitatively discuss the vertical motions, further moving survey data in the future and detailed evaluation of the errors are required.

Keywords: Seafloor geodesy, The 2011 Tohoku-oki Earthquake, GPS/Acoustic observation, Postseismic deformation, Vertical motions

An estimation of undersea sound speed structure: a more accurate strategy of GPS-A seafloor geodesy

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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.

The primary purpose of this observation is to detect and monitor the crustal deformation caused by the subduction of the oceanic plate near the plate boundary.

For the precise GPS-Acoustic seafloor positioning, we are developing analysis software, which combines a GPS positioning result and undersea acoustic travel times to get a precise position of an array of seafloor stations.

In this analysis, undersea sound speed structure must be given to convert travel times of acoustic wave into travel ranges. In order to estimate the seafloor positions accurately, it is necessary to have a sufficiently accurate sound speed structure. However the sound speed varies with time and space. Therefore it is practically impossible to cover all these variations in detail.

For positioning at the centimeter level, we are trying to estimate the sound speed variation from the travel time residuals in the positioning analysis. The travel time residuals include the information of the temporal variation, spatial variation and systematic difference of sound speed. By taking a proper strategy, the correction of sound speed based on this estimation improves the final positioning result significantly.

We investigate the behavior of the travel time residuals using spectrum analysis to extract the various frequency of sound speed variation. Based on the result, we will examine a more accurate analysis strategy.

Keywords: GPS-Acoustic ranging combination technique, seafloor geodetic observation, undersea sound speed structure

Results of physical property measurements obtained during the CHIKYU cruise CK16-05 of hydrothermal fields at the middle Okinawa Trough.

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The middle Okinawa Trough, located along the Ryukyu-arc on the margin of the East China Sea, has several active hydrothermal fields. Cruise CK16-05 of D/V CHIKYU targeted one of the largest hydrothermal fields, the Izena hydrothermal field, and conducted coring operations. Site C9027 is located on the center part of the Northern sulfide mound. Four other sites where we can observe the subseafloor sulfide layer were drilled along an eastward transect from the Northern mound (Sites C9028, C9026, C9025 and C9032 from west to east). Two additional reference sites (C9029 and C9030) located to the north and northwest of Site C9027, where the subseafloor sulfide layer is not distributed, were also drilled. Here, we present the results of physical property measurements obtained by using CHIKYU's on-board laboratory.

Drilled core samples from the Northern mound (Site C9027) mainly consisted of sulfide-rich rocks. The total recovered core length was 5.09 m and core recovery rate was only 3.9 %, due to the difficulty of coring operations in this material. These core samples exhibited the highest thermal conductivity (18.37 W/m·K) and the highest P-wave velocity (7,613 m/sec) of all sites, which is consistent with an abundant occurrence of sulfide minerals.

The four sites along the eastward transect from the Northern mound (Sites C9028, C9026, C9025 and C9032) consisted of hemi-pelagic sediment, hydrothermal altered sediment, pumiceous gravel and sulfide layers. Conspicuous peaks in the results of physical property measurements such as a notably high grain density were observed within the cores from all four sites, suggesting that a large sub-seafloor sulfide layer is widely distributed in this area.

Core samples from the two reference sites (Sites C9029 and C9030) mainly consisted of pumiceous gravel and mud, and total recovered core lengths were 84.5 m and 61.4 m with recovery rates of 53.7% and 66.7%, respectively. Physical property data from these two sites did not exhibit the conspicuous peaks that were observed in the sites associated with the sub-seafloor sulfide layer.

Using whole physical property data, we will also present a first-order sub-seafloor physical property model for the Izena hydrothermal field in this presentation.

Keywords: seafloor hydrothermal deposit, CHIKYU, Physical Property, Izena

Chemical and isotopic compositions of interstitial water from the Izena hydrothermal field

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In the previous SIP cruises, several hydrothermal sites have been drilled in the Iheya North Knoll, and distribution of sulfide ore deposits and hydrothermal fluids have been unraveled. However, the sulfide ore deposits in the Iheya North Knoll are relatively small to understand detailed formation processes of a massive hydrothermal ore deposits, particularly factors controlling the scale and grade of the deposits, which will be useful for exploration of large and high-grade deposits. In the Izena Hole, two hydrothermal active fields have been reported, and they have been called Hakurei and JADE sites (Halbach et al. 1989). At Hakurei site, several mounds up to tens of meters in height lie in lines. A potential sulfide ore body has been also pointed out beneath the mound of sulfide by JOGMEC (http://www.jogmec.go.jp/news/release/news_06_000130.html). In this study, coring was conducted around the massive hydrothermal ore deposits at Hakurei site, and chemical compositions of interstitial water and headspace gases from sediments or volcanic rocks were investigated. The purposes of this study are (1) to investigate the influence of hydrothermal activities on the chemistry of interstitial water and headspace gas and (2) to understand how the distribution of hydrothermal fluids below the seafloor is related to the growth of massive hydrothermal ore deposits.

Keywords: Izena Hole, hydrothermal system, interstitial water, chemical and isotopic compositions

Physical Properties of massive sulfide samples at the Iheya North Knoll Hydrothermal Area, Off-Okinawa, Japan

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Seafloor massive sulphides (SMS) around seafloor hydrothermal active zone are attractive due to the general growth trend of global economical activities. Since the SMS is located below the deep seafloor, which restricts a number of boreholes for land-based mineral explorations, deep seafloor geophysical surveys (e.g., electromagnetic, magnetic, gravity and seismic surveys) are conducted to image the detailed distribution of SMS below seafloor. However, the complicated lithological structure around SMS interrupts the good interpretation of sub-seafloor structure by using sole geophysical technique. For example, low resistivity value is expected for SMS, but the evaluation of amount of metal deposits is not enough only from the resistivity structure.
In this study, we try to include the physical properties (and amount of metal deposits) obtained from laboratory experiment using rock core samples to add better constraint to the joint inversion, recently used for physical models based on the geophysical explorations. The rock samples of SMS were obtained by ROV and submersible exploration around the hydrothermal active areas in the Okinawa Trough, Japan. From 21 core samples, resistivity, density, porosity, natural remanent magnetization (NRM) are measured. The chemical components are obtained by X-ray fluorescence (XRF) analysis.
The measured result indicates a correlation between resistivity, NRM, density and concentration of metal. For example, the resistivity values measured in laboratory indicates pretty low features. The resistivity cannot be explained by the conventional Archie’ s law, and modified one (called as parallel circuit model). We newly develop a rock physics model of resistivity for massive sulphide in this study. In our model, a direct connection term between conductive solid and conductive liquid to the conventional model. As a result, our new model well explains the measured resistivity trend, especially samples including large amount of pyrite. The contribution of conductive material in rock sample indicates high correlation to the amount of Cu, Fe, Zn. We conclude that the higher conductivity of rock matrix and higher NRM are possibly relates to the high metal contents and can be a good index for mineral deposits.

Keywords: Hydrothermal Area, Massive Sulfide, Rock Physics

Possibility of the large-scale hydrothermal alteration zone (Bosei-site) observed around the northern part of outer-rim of Sumis caldera, Izu-Ogasawara Arc

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There are some submarine calderas on the volcanic front of Northern Izu-Ogasawara Arc. Volcanic massive sulfide deposits were reported from some of these caldera. Geological and bathymetric investigations with acoustic water column anomalies survey were carried out around the Smith caldera, in 2016. Plural small mounds and spur were confirmed as a geographic characteristic on north side outer rim of a volcanic crater. And also it was confirmed a plural number acoustic water column anomalies in a range of approximately 5km.By the dredge sampling around the outer rim area where underwater acoustic water column anomalies was observed, a large quantity of volcani-clastic rocks were sampled. All of these rocks are lapilli stone and lapilli tuff samples, and these rocks were subjected to conspicuous alteration which generally caused them to turn reddish and sinter developed in a rock margin. We performed microscopy and X-ray diffraction analysis to examine the origin of the red material, but the iron related material was not detected. However, by the quantitative analysis result of these sinter matrix, Fe_2O_3 more than 60wt.% was confirmed at the maximum. Needles of cristobalit are dispersed throughout in the vesicles of lapilli stone. So, we estimate that the low-temperature hydrothermal activity happens in a northern outer rim of Smith caldera area. Judging from distribution of acoustic water column anomalies and dredge sample, the scale may happen in a wide area of approximately 5km in northern rim of Smith caldera.

Keywords: hydrothermal alteration zone, Submarine caldera

Hydrothermal activity and sub-seafloor serpentinization on the Yokoniwa Rise developed in the Central Indian Ridge: Constraints from AUV mapping and rock magnetisms

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Exposures of ultramafic mantle rocks are extensively distributed within slow spreading environments, where alteration processes significantly influence submarine ecosystems and result in high concentrations of metals. The location and spatial extent of hydrothermal activity are difficult to constrain; however, studies of near-seafloor magnetic field can highlight these features because crustal magnetic minerals can be destroyed or created by hydrothermal processes. Therefore, investigating magnetic signatures in these ultramafic-hosted hydrothermal systems is important for detecting active and inactive hydrothermal sites and their mineralization states.

High-resolution vector magnetic measurements were performed on an inactive ultramafic-hosted hydrothermal vent field, known as Yokoniwa Hydrothermal Field (YHF), using a deep-sea manned submersible *SHINKAI 6500* and an autonomous underwater vehicle (AUV) *r2D4*. The YHF has developed at a non-transform offset massif near the Rodrigues Triple Junction of the Southeast Indian Ridge, Southwest Indian Ridge, and Central Indian Ridge. Dead chimneys were widely observed around the YHF along with a very weak venting of low-temperature fluids so that hydrothermal activity of the YHF was almost finished. The rock samples collected around the YHF and in the slope of the Yokoniwa Rise were utilized for measurements of physical and rock magnetic properties, and petlogical ivestigation.

The distribution of crustal magnetization from the magnetic anomaly revealed that the YHF is associated with enhanced magnetization, as seen at the ultramafic-hosted Rainbow and Ashadze-1 hydrothermal sites of the Mid-Atlantic Ridge. The results of rock magnetic analysis on seafloor rock samples (including basalt, dolerite, gabbro, serpentinized peridotite, and hydrothermal sulfide) showed that only highly serpentinized peridotite carries high magnetic susceptibility and that the natural remanent magnetization intensity can explain the high magnetization of Yokoniwa. These observations reflect abundant and strongly magnetized magnetite grains within the highly serpentinized peridotite. The detailed magnetic hysteresis measurements demonstrated that single-domain (SD) magnetite was formed during the later stage of serpentinization, and it is assembled inside of mesh structures with strong magnetostatic interactions. Comparisons with the Rainbow and Ashadze-1 suggest that in ultramafic-hosted hydrothermal systems, strongly magnetized magnetite and pyrrhotite form during the progression of hydrothermal alteration of peridotite. After the completion of serpentinization and hydrogen production, pyrrhotites convert into pyrite or nonmagnetic iron sulfides, which considerably reduces their levels of magnetization. Our results revealed origins of the magnetic high and the development of subsurface chemical processes in ultramafic-hosted hydrothermal systems. Furthermore, the results highlight the use of near-seafloor magnetic field measurements as a powerful tool for detecting and characterizing seafloor hydrothermal system.

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Keywords: Seafloor hydrothermal system, Serpentinization, Magnetic anomaly, Rock magnetism, Slow-spreading ridge

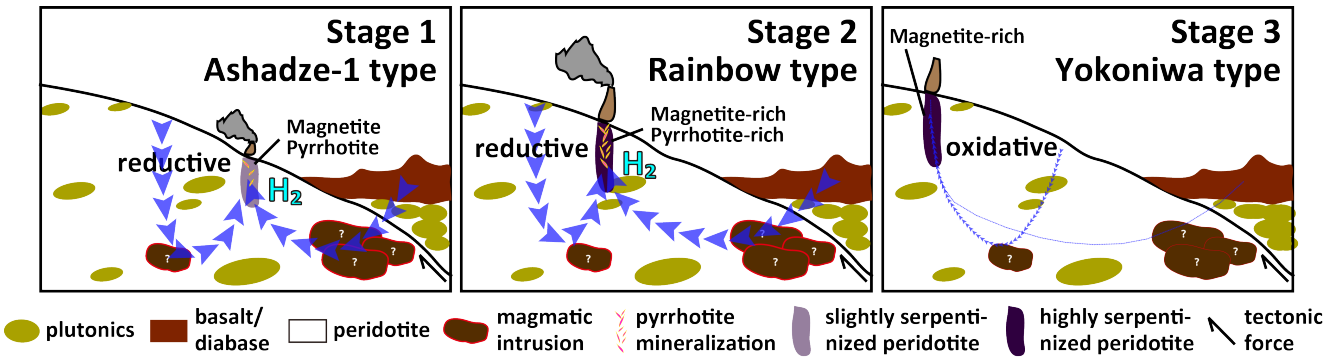

Figure. Model of magnetic mineral formation. Model showing the 3-stage formation history of magnetic minerals in ultramafic-hosted hydrothermal systems.
Stage 1: some magnetized magnetite and pyrrhotite form thorough serpentinization and sulfide mineralization under reductive conditions,
Stage 2: large quantity of magnetized magnetite and pyrrhotite are accumulated thorough serpentinization and sulfide mineralization under reductive conditions,
Stage 3: only magnetized magnetite remains as main magnetic source under oxidative condition after serpentinization of host rock.

Geomorphological features of the Southern Mariana Trough spreading center obtained from near-bottom surveys using the AUV Urashima

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We characterized field-scale geomorphological features at the sea-floor spreading center in the southern segment of the Southern Mariana Trough back-arc basin to understand its crustal formation in fine-scale. The Southern Mariana Trough is a currently active back arc basin, and it has fast spreading morphologic and geophysical characteristics (e.g. axial high), suggesting an abundant magma supply, even though the full spreading rate is categorized as slow spreading (e.g. Seama et al., 2015). Bathymetry and geomagnetic field data in the Southern Mariana Trough show highly asymmetric seafloor spreading; much faster spreading in the west side of the spreading axis compared to the east side (Seama and Okino, 2015). They estimated the spreading rate of the southern segment as 46 km/Myr with its half rate of 33 km/Myr for the west side and 13 km/Myr for the east side. We analyzed near-bottom acoustic survey data along an axial relief in the southern segment to obtain fine scale topographic map and back-scatter images. The near-bottom acoustic survey during JAMSTEC YK09-08 cruise was conducted using the AUV Urashima, in which a 120 kHz side-scan sonar and a 400 kHz multi-beam echo sounder are mounted. Seven survey lines along spreading axis cover 2.5 km by 0.9 km area along and across the spreading axis, respectively. The topographic map and the back-scatter images together with eight dive observation data acquired by the submersible Shinkai 6500 allow us to derive characteristic features at the sea-floor spreading center. The current active spreading axis is identified by six mounds with their diameters of 100-300 m; the mounds are in line parallel to the axial high in the southern segment and they are composed by pillow lavas without sediment. The mounds are divided into two groups that probably show fine scale different ridge segments; three mounds in the south are more active with their height of 10-25 m, while three mounds in the north are a few meters high, and two groups have a 100 m offset in line parallel to the axial relief. Further, we found asymmetric geomorphological features at the spreading center in small-scale (< 1 km scale). A lot of fault scarps and lineaments parallel to the axial axis exist in the topographic map and the back-scatter images, respectively, and their locations show high asymmetry; many of them locate in the northwest side of the axial axis, but few exist in the southeast side. The small scale asymmetric geomorphological features near the current spreading axis provide an important constraint on the style of the highly asymmetric seafloor spreading in the Southern Mariana Trough back-arc basin.

Keywords: Southern Mariana Trough back-arc basin, asymmetric seafloor spreading, near-bottom acoustic survey

Tectonics of long-offset oceanic transform faults along the Central Indian Ridge

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Oceanic transform faults, conservative plate boundaries in light of plate tectonics, are one of the first-order features of global seafloor. It connects offsets of mid-ocean ridge system up to 400km in length, controlling thermal structure, mantle flow, magmatism and hydrothermalism at mid-ocean ridges. Transform fault is also a good recorder of past and present plate motion and the fault wall is a tectonic window for investigating deep crust / upper mantle lithology. Although the recent numerical studies show that contribution of seawater infiltration along oceanic transform faults is not negligible in global water flux, the degree and spatial extent of serpentinization around the faults system remain poorly constrained. Oceanic transform faults (OTF), especially long-offset transforms where two extremely different age plates are juxtaposing, are thus interesting research target, however the previous field observations are very limited. We mapped the Marie Celeste OTF of 215 km offset as a part of Central Indian Ridge magmatism and hydrothermal activity studies in 2006 and discovered several characteristic features within and around the OTF. Then, we revisited the area January, 2016 and conducted detailed surveys along and across the Marie Celeste and other three OTFs in order to investigate the tectonics, evolution and fluid influence.

Among four transform faults we surveyed, three OTFs (OTF1, 2, and 3) are associated with prominent median ridges near ridge-transform intersections.Median ridges have been reported along both fast- and slow-slipping oceanic transform faults. But the origin of this shallow topography is still enigmatic. Previous studies have proposed along-transform volcanism, intrusion or diapirism of serpentinite, and transpression or localized compression resulting from change of plate boundary geometry. We collected basalt, dolerite, gabbro samples along the middle to upper slope of median ridge of OTF1. The median ridge is sheared and current principal transform deformation zone seems to extend north of the median ridge. Preliminary zircon U-Pb age dating from a recovered sample [Orihashi, personal comm.] shows 13.25+-0.24 [Ma], that is almost same age as the northern wall (=~12 Ma). These observations may suggest that the median ridge is a portion of the northern transform wall which was detached along the present deformation zone.

Previous studies have shown that slow-slipping transform faults are characterized by more positive RMBA (residual mantle gravity anomalies) than their adjacent ridge segment, due to thinning of crustal thickness towards segment ends. We calculated RMBA in our study area, assuming 6-km thick crust and three-dimensional mantle flow. OTF2, where the relative plate velocity is 38 mm/yr., is associated with RMBA of ~0 mGal that is almost same level as the adjacent ridge segment. This result is consistent with spreading rate dependence of gravity anomalies along OTFs by Gregg et al. [2007]. OTF1 (Marie Celeste) shows more negative anomaly than the adjacent ridge segment. A negative RMBA suggests mass deficit along OTF1, which could indicate serpentinization of mantle materials, increase of rock porosity, and/or relatively thick crust. It may suggest the effect of increased rock porosity and serpentinization enhanced by long-offset transform fault, that is usually hidden by effect of crustal thinning. Another possibility is more fast-spreading like crustal structure, that is suggested by off-axis large volcanoes and sheet lava flow within the axial valley at the ridge segment south of OTF1.

Keywords: oceanic transform fault, fracture zone, median ridge, gravity anomaly, Central Indian Ridge, serpentinization

Crustal structure and tectonic setting of the abyssal basin southeast of the Ontong Java Plateau, western Pacific Ocean

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Ontong Java Plateau(OJP) is located north of the Solomon Islands in thewestern Pacific Ocean. The area of OJP is about 1.9×10^6 km^2. Deep-sea drilling samples indicate that most of the OJP was formed rapidly about 120 Ma at mid-southern latitude in the Pacific Basin. Taylor (2006) proposed that the OJP was formed as a single large volcanic province together with the Manihiki and Hikurangi plateaus, called Ontong Java Nui (Chandler et al., 2012). The OJP is surrounded by the East Mariana, Pigafetta, Nauru, Ellice, Stewart, and Lyra basins. The former three basins (East Mariana, Pigafetta, and Nauru) were formed at the Pacific-Izanagi and Pacific-Phoenix ridges, respectively (Nakanishi et al., 1992). The tectonic history of the latter three basins (Ellice, Stewart, and Lyra) is, however, unknown because of lack of magnetic anomaly lineations. It is thus unclear whether OJP was formed at mid-oceanic ridges or away from active plate boundaries. To expose the tectonic history of Ellice, Stewart, and Lyra basins, we conducted the multichannel seismic reflection survey in the basins as well as OJP during the research cruise MR14-06 Leg 1 by R/V Mirai of JAMSTEC. After the regular data processing, we found several tectonic structures in the basins. The relief of the acoustic basements in the basins are not overall smooth. We found several igneous diapirs in Stewart and Ellice basins, implying that the volcanism occurred after the formation of the basins. We identified normal faults in the southern part of Stewart Basin, probably caused by the plate bending owing to the Pacific Plate subduction. We discovered the graben structures in the OJP situated at the northern and southern franks of the Stewart Basin. The graven structures were formed at the beginning of the formation of the Stewart Basin. Taylor (2006) concluded the basin was formed by NW-SE rifting during the separation of OJP and Manihiki Plateau around 120 Ma. Neal (1997) proposed another model, in which the NE-SW rifting and spreading event formed the Stewart and Ellice basins around the basin around 80 Ma. Our study prefers the model by Neal et al. (1997).

Keywords: Ontong java plateau, multichannel seismic reflection survey, large igneous provinces

Deep structure offshore eastern Australia from wide-angle refraction seismic data: from the Tasman Sea to the Lord Howe Rise

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The eastern Australian margin was shaped during the fragmentation of eastern Gondwana in the Late Cretaceous. This led to the opening of the oceanic Tasman Basin and to the formation of sub-parallel ridges and basins, including the Lord Howe Rise. The deep structure of the area is still unknown. In March-May 2016 onboard the R/V *Kairei*, the first large-scale crustal experiment in this region was conducted by JAMSTEC and Geoscience Australia with the deployment of 100 ocean-bottom seismometers (OBS) along a 680 km profile at 27.2˚S. The OBSs registered clear refracted arrivals from the crust and the mantle that are recorded at very large offsets of up to 300 km. The variation in the offset of the triplication point between these two refracted arrivals suggests strong crustal thickness variation along the profile. Both pre- and post-critical reflected phases from the Moho (PmP) are also very clearly recorded by the OBSs. We performed first-arrival tomographic inversion to analyze the data The initial layered P-wave velocity model was built using the basement reflection interpreted from coincident multi-channel reflection seismic data andthe PmP arrivals were used during the inversion to constrain the thickness of the crust. The final tomographic Vp model confirms the strong variations in crustal thickness and allows the identification of distinct crustal domains along the profile: Below the Tasman Basin is an oceanic domain with 7 km thick crust; further east, thicker crust (14 km) is present below the Dampier Ridge where granitic rocks have been dredged; directly east of the Dampier Ridge, the crust thins to 8 km below the Middleton Basin; the northern Lord Howe Rise has ~20 km thick crust. Below the northern Lord Howe Rise, lateral variations in upper crustal velocities are associated with Moho relief. Some areas show higher velocities (Capel Basin) compared to surrounding areas (Faust Basin). We propose that these lateral variations are related to weakly-expressed SW-NE oriented lineaments through the northern Lord Howe Rise that link to the Barcoo-Elisabeth-Fairway fracture zone in the oceanic Tasman Basin. Similar variations in crustal velocities are observed in the west below the Dampier Ridge. These variations are also associated with Moho topography. We suggest that the SW-NE trending lineaments linked to major fracture zones active during the opening of the Tasman Basin may have strongly controlled the latitudinal segmentation of the Lord Howe Rise, the Dampier Ridge and adjacent areas. The nature of the crust within the different crustal domains will be inferred using gravity modelling and by comparing the modeled P-wave velocities with previously published results from the western Pacific region. This comparison will help to better understand the processes that led to the fragmentation of eastern Gondwana.

Continuous formation processes of the shallow plate boundary fault in the Japan Trench reproduced by analog modeling experiments

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Large earthquakes and tsunamis have repeatedly occurred along the Japan Trench. In the 2011 Tohoku-Oki earthquake (Mw 9.0), the fault rupture extended to the shallow portion of the Japan Trench. These large slips on shallow decollement resulted in the huge tsunami that devastated much of the east coast of Japan. Therefore, it is key to understand the history of fault formation near the trench for the disaster prevention. At the 2011 earthquake, the slip of the plate boundary fault reached to the trench, and the seafloor of the outermost part of the landward trench slope horizontally moved approximately 50 m toward the trench, and uplifted approximately 7 to 10 m (Fujiwara et al., 2011, Science). The large fault rupture and propagation might be due to the essentially weak fault material and dynamic weakening, suggested by high-velocity frictional experiment on fault zone material (Ujiie et al., 2013, Nature Geoscience) and borehole temperature measurement (Fulton et al., 2013, Nature Geoscience) during the IODP JFAST study.

Our previous study (Koge et al., 2014, EPS) applied the theory of critically tapered Coulomb wedge to 12 transects of Japan Trench before the 2011 earthquake, in order to obtain along-trench variations of frictional properties (especially, effective frictional coefficient of the plate boundary megathrust). The results show that the area of high effective frictional coefficient has characteristic topographies (e.g. seamount or well-developed horst-and-graben structure) on subducting plate, and effective frictional coefficient closely correlates with the near-trench slip distribution during the 2011 earthquake. However, it has not been sufficiently considered how the topography affects the processes of wedge formation and internal deformation. This is because the seismic profiles represent snapshots at certain times. The kinematic history should be reconstructed using structural geological principals and techniques or can be forward modeled through analog modeling.

Therefore, in order to understand the formation history of the shallow plate boundary faults which was related to the 2011 earthquake, we conducted analog model experiments reproducing that the half-graben structure subducts the frontal wedge. In the experiments, deformation of the sand layer was photographed at intervals of 5 seconds, and then these snapshots were analyzed with digital image correlation (DIC) to show the temporal transition of the fault activity inside the wedge. Our experiments show that the fault activity changes at the following four stages when the frontal part of the wedge reaches half-graben structure. Stage 1: The front of the wedge stacks when the wedge enters the graven. Stage 2: The wedge starts to grow (uplift) by forming a branch fault. Stage 3: A new frontal thrust is formed, and the activity of the branch fault is stopped. Stage 4: The frontal thrust continues the activity with that a decollement is torn and eventually step down to half-graven as a new thrust.

For future work, by comparing these experimental results with the seismic structure, it would lead to an understanding of the fault formation and development processes at the toe of the trench landward slope.

Keywords: Japan Trench, Analog model, sandbox

A high-resolution seismic image of possible fluid migration pathway associated with the 2011 Tohoku earthquake

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Large megathrust earthquakes along subduction zones pose a seismic and tsunami threat to densely populated coastal cities. The 2011 Tohoku earthquake (M9.0) ruptured the interface between the subducting Pacific plate and the overlying Okhotsk plate, yielding massive tsunamis. Pore fluid along the plate interface might play an important role in the occurrence of large megathrust earthquake. Helium isotopes are useful in identifying the origin of fluids and may provide the key information about the source of interplate fluids. Geochemical evidences demonstrated a sharp increase in mantle-derived helium in bottom seawater near the rupture zone one month after the 2011 Tohoku earthquake. The timing and location indicate that fluids were released from the mantle on the seafloor along the plate interface. The movement of the fluids was rapid with a velocity of ~4 km per day, suggesting that over-pressurized fluid is discharged along the plate interface. Considering the location of helium isotope anomalies at the forearc seafloor, there must be fluid migrations along out-of-sequence thrust (OOST) fault planes from the plate interface up to the forearc seafloor. However, the fluid migration pathway, i.e., OOST fault plane, has never been identified so far, probably because of low-resolution seismic image.
In order to elucidate the fluid behavior along the OOST fault plane, we have carried out geophysical and geochemical investigations in the Tohoku forearc using R/V Shinsei-maru (KS16-17 cruise) in November 2016. During the cruise, we have done: (1) high-resolution seismic imaging by parametric sub-bottom profiler (SBP), (2) seafloor mapping by multi-beam echo-sounder, (3) bottom seawater sampling by CTD sampler, (4) seafloor sediment sampling by multiple corer, and (5) onboard magnetic and gravity observations. We observe a clear seismic reflection image of fault scarp on a high-resolution SBP line near the Site N3 at which the helium isotope anomaly was observed one month after the 2011 Tohoku earthquake. A possible OOST fault is likely to produce tilting structure of the topmost sedimentary layer. Despite low continuity of the reflector, deep crustal multi-channel seismic reflection data exhibit a possible OOST fault plane with reverse polarity reflection upward from deep plate-interface, suggesting the fluid migration along the fault associated with the 2011 Tohoku earthquake. In this paper we will show preliminary results of the cruise KS16-17.

Keywords: high-resolution seismic image, fluid migration pathway, Tohoku earthquake

Plate boundary temperature at the prism slope estimated from topographically corrected BSR-derived heat flow in the Nankai Trough

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Seismogenic zones have been investigated in numerous studies to understand the occurrence mechanisms of earthquakes and tsunamis at subduction zones. Temperature on the plate interface is considered to bound the upper and lower limits on the seismogenic zone, whose temperatures are estimated to be around 100–150˚C and 350–450˚C, respectively [*Hyndman and Wang*, 1993, JGR]. Thus, temperature along the plate boundary fault should be a significant player governing the seismogenesis of plate boundary faults. Subseafloor temperature is known to be affected by various phenomena. For example, undulation of seafloor relief is one of the major factors disturbing thermal regime especially in shallow part of subseafloor. However, few studies have considered the topographic effect to estimate the plate boundary temperature, while studies taking into account the effect might be required for the precise estimation. This study focuses on the temperature at the upper limit of the seismogenic zone around 100˚C at the prism slope off southwest of Kii peninsula where the number of studies is restricted. First, we mapped the distribution of BSRs in the Nankai subduction zone. Second, we modeled a two-dimensional thermal structure to topographically correct BSR-derived heat flow in areas of undulating seafloor. Third, we estimated the plate boundary temperature one-dimensionally using topographically uncorrected and corrected BSR-derived heat flow by assuming uniform thermal conductivity with depth.
Distance from the trench axis of plate boundary temperature of 100˚C is approximately 25 km calculated from the uncorrected BSR-derived heat flow off southwest of Kii peninsula. On the other hand, the distance is approximately 22 km calculated from the corrected BSR-derived heat flow there. This suggests the depth of upper limit of the seismogenic zone on the plate interface shifts 450 m associated with the topographically corrected thermal structure.

Shallow crustal structure at the northern Okinawa Trough based on seismic reflection survey

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The Okinawa Trough, a backarc basin of the Ryukyu (Nansei-Shoto) island arc-trench system to the southwest of Kyushu, Japan, is considered to be in the stage of continental rifting caused by the subduction of the Philippine Sea plate. The crustal extension beneath the trough is in progress and its degree varies from north to south. We, Japan Coast Guard (JCG), conducted several geological and geophysical investigations including seismic refraction surveys with ocean bottom seismographs (OBSs) and seismic reflection surveys to obtain fine seismic structural images related to the rifting process in the Okinawa Trough.

In this report, we will show a multi-channel seismic reflection (MCS) profile in the northern Okinawa Trough. The seismic line is N-S trending along the trough strike and its length is 563 km: the line starts from the continental shelf to the east of Goto Islands at the northernmost, through the Danjo Basin, to the west of Yokogan-Sone bank, intersects the volcanic front to the north of Io-Torishima Island, and ends to the northwest of Okinoerabu Island at the southernmost line. Except for about 200 m depth at the northern end of the survey line, the water depth gradually becomes deeper from 700 m at the north to 1,200 m at the south. We employed a trigun cluster with a total capacity of 1,050 (350×3) $inch^3$ and 3,000 m multi-channel hydrophone streamer with 240 channels to record the seismic signals from airgun shots. Totally 11,363 shots were fired at every 50 m on the survey line. The acquired MCS data were processed through a band-pass filter, deconvolution, normal move out correction and CMP stacking.

We divided the seismic line into three parts based on the characteristics of the seafloor topography and the MCS records, and described them from north to south. The northern part corresponds to the area from the continental shelf to the Danjo Basin. The water depth abruptly changes from 200 m at the shelf to 800 m at the center of the basin. The MCS profile shows a thick sedimentary layer with the maximum thickness of around 4,000 m beneath the Danjo Basin. We interpreted the structure as a “syn-rift” accumulating sediments while the ongoing crustal extension.

In the middle part, from the south of the Danjo Basin to 90 km west of the volcanic front, the water depth varies from 700 to 1,000 m southwardly. There are some NE-SW trending bathymetric highs with heights of 200-300 m on the seismic line. The seafloor topography between the knolls is rather flat and the MCS records show there are sedimentary layers below the flat seafloor. However, we can see lots of normal faults in the sedimentary layer and these faults don’t reach up to the seafloor.

The southern part of the line is characterized by lineaments of the seafloor topography with strikes of NE-SW or ENE-WSW. The NE-SW orientation is parallel to the volcanic front in this region. There are many seafloor undulations and knolls with heights of 300-500 m. The MCS records reveal a number of igneous intrusions and normal faults which deform the sedimentary layer and the seafloor.

Keywords: Okinawa Trough, crustal structure, seismic reflection survey

The 1st Sea Trial of 2-D Seismic Reflection and Refraction Surveys in Suruga Bay, Central Japan, by TUMSAT (1st Report)

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Tokyo University of Marine Science and Technology (TUMSAT) establish a new school for Marine Resource and Environment from April 2017. We adopt a new portable 2-D seismic reflection survey system in order to educate our students to the observation technology and methodology in an oceanic area and under sea floor and also to research the features under sea floor such as plate boundary area, etc. In this report, we show the outline of the first sea trial of seismic reflection and refraction surveys in Suruga Bay, Central Japan, conducted by TUMSAT, and its prelimary results.

Our portable seismic system consists of three 10-ft containers for the seismic air-gun sources, an air compressor system, and streamer-cable system, together with some controllors and recording systems in a dry laboratory. The air-gun source system consists of two pairs of Bolt Twin-Gun (a pair of 1900LL, 260 cu.in x 2) and can be towed at both gunwales. Hydrophone receivers array consists of Hydroscience digital streamer cable which has 96 channels with a sensor interval of 6.25 m inside a cable of 600 m long, and SEAMAP Tailbouy to measure the location at the tail of the cable. Research vessel ‘Shinyomaru’ was renewed on 2016. Its principle specifications: length, beam, and gross tonnage are 65 m, 12.5m, and 986 tons, respectively.

We conducted the 2-D seismic reflection survey and refraction survey with 21 ocean bottom seismometer in Suruga Bay, from Nov. 13 to 19, 2016, in order to test the system specification in a ocean area. Suruga Bay (i.e., Suruga trough) is located at the plate boundary between the Philippine sea plate and Eurasia plate. We therefore tried to clarify a shallow structure in this important area by means of both seismic reflection and refraction surveys. Four surrey lines (i.e., A to D line) were located at the eastern, northern and western area of Suruga Bay with a total measurement distance of about 74 km. Air gun was shot at an interval of 50 m under a ship speed of about 3.5 knot.

Preliminary results of seismic section shows variable bathymetric features and structure under the sea water. For example, beneath A-Line we can find a sedimentary layer with a thickness of ~100 m under the sea floor and it lays above the layer boundary with a strong reflection which may be related with the topography around the coast. The details of our result will be shown in a poster presentation.

Acknowledgements:
We appreciate the big cooperations by Shizuoka prefucture Federation of Fisheries Cooperative Associations and many Fishery Cooperatives around Suruga Bay to understand our study. We thank Tokai University for helping us in an ocean by a vessel ‘Hokuto’. We have a collaborative project with JGI, Inc. and Geosys Inc. and also thank their cooperations. Finally, we greatly thank Shinyomaru's crews and many staffs of our university for their encouragement and kindness.

Keywords: Suruga Bay, seismic reflection and refraction survey

Continuous 3-component geomagnetic observation in Yona, Okinawa Prefecture at the research and education facility of University of the Ryukyus

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University of the Ryukyus and National Institute of Information and Communication Technology (NICT) are implementing an on-land continuous 3-component geomagnetic measurement as the joint project "Study and development on the geomagnetic-variation measurement in the subtropical area" at Yona, Kunigami Village, Okinawa Prefecture, one of the research and education facilities of the university. The location is 26.76 degrees north and 128.22 degrees east, 12m altitude. The purpose of this study of NICT is to detect the geomagnetic effect due to the space-environment variation such as the solar activity, whereas University of the Ryukyus is aiming at establishing the method of calibration of offshore geomagnetic survey data around the Ryukyu Islands. Geomagnetic horizontal component, declination and vertical component are observed and recorded at this station every one minute. Data from April 1996 up to October 2011 are available as of now although there are several periods of lack of observation. After that, the magnetometer was updated in 2016 and the observation was re-started.

The authors are showing some results of a trial analysis of the on-land geomagnetic observation in 2011. The geomagnetic total force intensity shows a variation of daily variation with 30nT in amplitude, although more than 100nT change takes place corresponding the solar activity due to the occurrence of sunspots (based on the National Astronomical Observatory observation). The result of the spectrum analysis of the data in 2011 shows the peaks of at, 15, 5, 2, 1.3, and 1 day periods.

Geographic Survey Institute of Japan (GSI) is also collecting 3-component geomagnetic data in Okinawa Prefecture, at 26.630 degrees north, 128.127 degrees east, 140m altitude in Higashi Village. Both NICT and GSI data shows positive correlation approximately. However, the NICT values are about 120nT smaller and the change rate shows by about 1.3 times larger compared with GSI values.

Keywords: on-land continuous geomagnetic measurement, calibration of surface-ship geomagnetic data

Feasibility study on long-term monitoring of seafloor deformation with ocean bottom pressure recorders of pop-up type

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Precise pressure observation at the seafloor is an effective mean to detect vertical crustal deformation in offshore areas. A small sensor of high precision and low power consumption enables to build an ocean bottom observation system to make continuous observations for one to two years. The ocean bottom pressure observation networks deployed to monitor tsunami are expected to allow monitor vertical deformation of the seafloor in the seismogenic regions. Several studies have demonstrated that the bottom pressure data can detect transient signals associated with activities of submarine faults or volcanos. Time constants of the detected events were mostly shorter than a month but it would be difficult to detect tectonic events of much slower deformation rates by the seafloor pressure motoring. Since many plate boundary zones on the earth are located beneath oceans, observations of longterm deformation at the seafloor are invaluable to understand dynamics of plate interaction, formation and development. The most significant reason of the difficulties in detecting slow crustal deformations by the pressure observation is lack of the knowledges about longterm fluctuations appearing in the pressure records obtained at the seafloor. In this paper, we discuss about characteristics of ocean bottom pressure records in long, more than a couple of months, period based on the actual data obtained by the repeating deployment of free-fall/pop-up type bottom pressure recording systems in the Japan Trench area for about 10 years and also by recent laboratory experiments. Most of the obtained pressure time series show evident longterm temporal variations irrelevant to the actual motion of the seafloor but could be attributed to the instrumental instabilities. The pattern of the temporal variation on the record seems similar to one another when we compare the records obtained by the identical pressure sensor, suggesting that the observed pressure records contain a characteristic response specific to the sensor. Previous laboratory experiments on the response of pressure sensors of the same kind showed a transient behavior after applying high pressure has several similarity to those we see on the seafloor observation records. This suggest that the sensor specific characteristics can be known through laboratory tests and can be removed from the records of the seafloor monitoring to extract pressure changes associated with actual seafloor motions. Motivated by this idea, we are carrying out a long-term laboratory experiment in which the pressure sensor previously used in the field observations are exposed to well-controlled high pressure to know longterm behavior of the sensor under the pressure equivalent to the deep sea. We are making another experiment to know longterm stability of a clock install in our pressure recorders. Since the clock supplies a time base to measure oscillation frequency of the pressure sensor, its stability can also account for longterm drift in the pressure data obtained by the instruments.

Keywords: Seafloor geodesy, Pressure monitoring, Longterm deformation

Evaluation of drift characteristics of pressure sensors for improving long-term pressure monitoring at seafloor

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This study focuses on the drift characteristics of pressure sensors used for seafloor pressure monitoring, on the basis of the experimental results obtained at calibration laboratory for years. Pressure sensors with high resolution and short-time stability have been used for detecting transient tectonic movements. To use these pressure sensors for long-term pressure monitoring at seafloor, and to quantitatively evaluate the vertical tectonic deformation from the pressure data, the drift characteristics of the sensors need to be precisely evaluated. In usual case, the drift behavior of a pressure sensor can be evaluated and estimated by repeating calibrations at a regular interval. Regarding seafloor pressure monitoring, however, it would be difficult to periodically collect and calibrate the pressure sensors installed at seafloor. Furthermore, the drift characteristics of pressure sensors depend on the conditions of use; the drift of the sensor used under constant high pressure application may be different from that measured with a typical calibration procedure. Thus, the drift characteristics of the sensors should be evaluated in the similar pressure condition as the actual use.
In this study, the drift characteristics of pressure sensors have been evaluated at the pressure calibration laboratory in National Metrology Institute of Japan to improve the accuracy of the seafloor pressure measurements for a long time period. The devices under test are quartz Bourdon-tube pressure sensors whose maximum allowable pressure is 103 MPa (15,000 psi). The pressure of 100 MPa has been applied to the test pressure sensors for a long period of time. During the pressure application, the sensors were calibrated at 100 MPa using a pressure balance as the standard. The calibration results, the deviation of the sensor's output from the standard value, at 100 MPa rapidly changed immediately after the pressure application. As time proceeded, the change rate became small and almost constant. After 140 days from the pressure application, one sensor was depressurized to atmospheric pressure. The calibration results at 100 MPa changed in the opposite direction and returned to the initial value after 90 days from the pressure release. In contrast, the other sensor, which has been kept at 100 MPa for more than two years, showed a constant drift. In addition, during the pressure application of 100 MPa, the pressure was intermittently released to atmospheric pressure for a short time, and the outputs at atmospheric pressure were also obtained. The results at 100 MPa and atmospheric pressure showed a similar trend, showing that the zero drift of the sensor is the main cause of the observed drift. From the experimental results, we discuss measures to appropriately evaluate and compensate the drift characteristics of pressure sensors used for pressure monitoring at seafloor.

Keywords: Pressure monitoring, Long-term drift, Pressure calibration

Estimating bottom current velocities from ocean-bottom-seismometer records

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Current velocities in the lowermost meters of the ocean are poorly understood and not often measured. At the same time, they strongly affect the stability of benthic ecosystems.
Ocean-bottom-seismometers (OBS) are long-term installations of seismic sensors on the sea floor, which typically last for months and which have covered various parts of the global oceans in the last decades. The German OBS type LOBSTER has a peculiar design choice in the form of a ten-meter long head buoy cable that is very susceptible to current strumming. While this signal may be a nuisance for seismological observations, it does contain information: We present a method to estimate the current velocity in the lowermost ten meters from the noise created by that cable and compare noise-estimated current velocities with measurements of a colocated acoustic profiler.
Since this seismometer type has been widely used in different settings and depths worldwide in the last decade, this data may be a valuable and completely novel observable for physical oceanography and biology.

Keywords: Ocean bottom seismology, Benthic zone, Currents

Extraction and visualization of submarine geo-information in Mid-Okinawa Trough using underwater video records

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In recent years, many exploration data such as seabed topography images, biological, geochemical and geophysical data, and drilling survey data have been acquired for marine mineral resources exploration. For more effective use of these data in practical applications to exploration and exploitation, we have started to extract and compile geo-information using video image data obtained by diving surveys with the Shinkai 6500, the Hyper Dolphin and the Deep-Toe in and around Mid-Okinawa Trough. The extracted data from the video records includes geo-information on the location of the survey vessel (latitude, longitude, depth, altitude, submarine heading), seabed geological features (rock/ lava, sulfide zone, sand/ mud, ripple mark, gravel), seabed structural features (faults/ cracking, chimney, hot water/ spring water), and biological features (biomat, biological communities). These data are summarized in the event log along the vessel route for each dive. The compiled data are imported into the GIS software so as to easily search and visualize seabed geo-information for making future survey and research plans. By adding drilling data and geophysical survey data obtained by many other research institutes to the database, the GIS database newly created is expected to be used to extract detailed three-dimensional geo-information of the exploration target sea area in future.

Unite the Power! DARWIN, GANSEKI & COEDO Get Integrated!

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Japan Agency for Marine-Earth Science and Technology (JAMSTEC) archives data and samples obtained by JAMSTEC research vessels and submersibles as common properties of the human society, and publishes them for further uses with scientific/educational purposes [1]. The NUUNKUI data sites, which consist of several data sites for various data and sample types, perform the central role of JAMSTEC data publication [2].
JAMSTEC applies occasional updates to NUUNKUI data sites for improved usability, emerging datasets, and advanced informatics technologies. In 2016, JAMSTEC decided to reorganize these data sites for effective data publication. Three data sites named DARWIN [3], GANSEKI [4], and COEDO [5], which stand for online databases of cruise/dive information, rock sample information and sediment core sample information, respectively, will be integrated into a single system in the spring 2017.
DARWIN disseminates metadata and observation data of JAMSTEC cruises and submersible dives. Previously, sampling activities and submersible video/photo archives were registered on DARWIN as URLs to different data sites designated for particular data/sample types, and these data sites also provided URLs to DARWIN cruise/dive information as mutual references. Through the data site update described here, geological sample information and browsing functions of GANSEKI and COEDO are incorporated into the new DARWIN and they become seamlessly available on a single interface. In the new DARWIN, users can search geological samples by thumbnail browsing, map area, keyword filtering, and metadata constraints, and handling of associated data become more flexible in respect to the applicable data format and capacity. For rock samples, onboard sample photo and microphotographs of surface texture will be newly publicized, whereas for sediment core samples, searchability of photo images is improved and geochemical data entry becomes newly available.
This data site update also includes implementation of interactive map functions that are similar to those of previous “JAMSTEC Data Site Portal [6]”. Using these functions, users can browse JAMSTEC observation activities plotted on a map and search data and samples on an interactive map and obtain URL list for their data sites. However, the previous system has become obsolete after years of services, and security and usability problems have become obvious. This data site update improves usability of map search and visualization of search results, and users can effectively search data and sample information without concerns for particular cruise and dive.

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[5] "COEDO: Sediment Core Sample Database" http://www.godac.jamstec.go.jp/coedo/e (preexisted URL)
[6] "JAMSTEC Data Search Portal" http://www.godac.jamstec.go.jp/dataportal/index_eng.html (preexisted URL)

Keywords: Marine Geology, Database, Curation, Geological Sample

