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

*Brian Boston[1], Yasuyuki Nakamura[1], Shuichi Kodaira[1], Seiichi Miura[1], Flora Gallais[1], Gou Fujie[1], Yuka Kaiho[1], Ron I Hackney[2], Yasuhiro Yamada[1], Saneatsu Saito[1], Kazuya Shiraishi[1], Scott Nichol[2], George Bernardel[2], Cameron Mitchell[2]

1. Japan Agency for Marine-Earth Science and Technology, 2. Geoscience Australia

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?

*Seiichi Miura[1], Gou Fujie[1], Taro Shirai[1], Naoto Noguchi[1], Shuichi Kodaira[1], Millard F Coffin[2], Simon A Kawagle[3], Ronald T Verave[4]

1. Japan Agency for Marine-Earth Science and Technology, 2. University of Tasmania, 3. University of Papua New Guinea, 4. Mineral Resource Authority, PNG

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

*Masao Nakanishi[1]

1. Geosystem and Biosystem Sciences Division Graduate School of Science Chiba University

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

*Yuki Sato[1], Naoto Hirano[2]

1. Graduate School of Science, Tohoku University, 2. Center for Northeast Asian Studies, Tohoku University

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

*Atsushi Oshida[1], Toshihiro Maki[2], Takumi Matsuda[2], Shigeo Okuma[3], Masao Komazawa[3], Toi Tachibana[1], Ryuji Kubota[1]

1. Kawasaki Geological Engineering Co., Ltd., 2. Institute of Industrial Science, The University of Tokyo, 3. Geological Survey of Japan, AIST

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

*Hajime Shiobara[1], Aki Ito[2], Hiroko Sugioka[3], Masanao Shinohara[1]

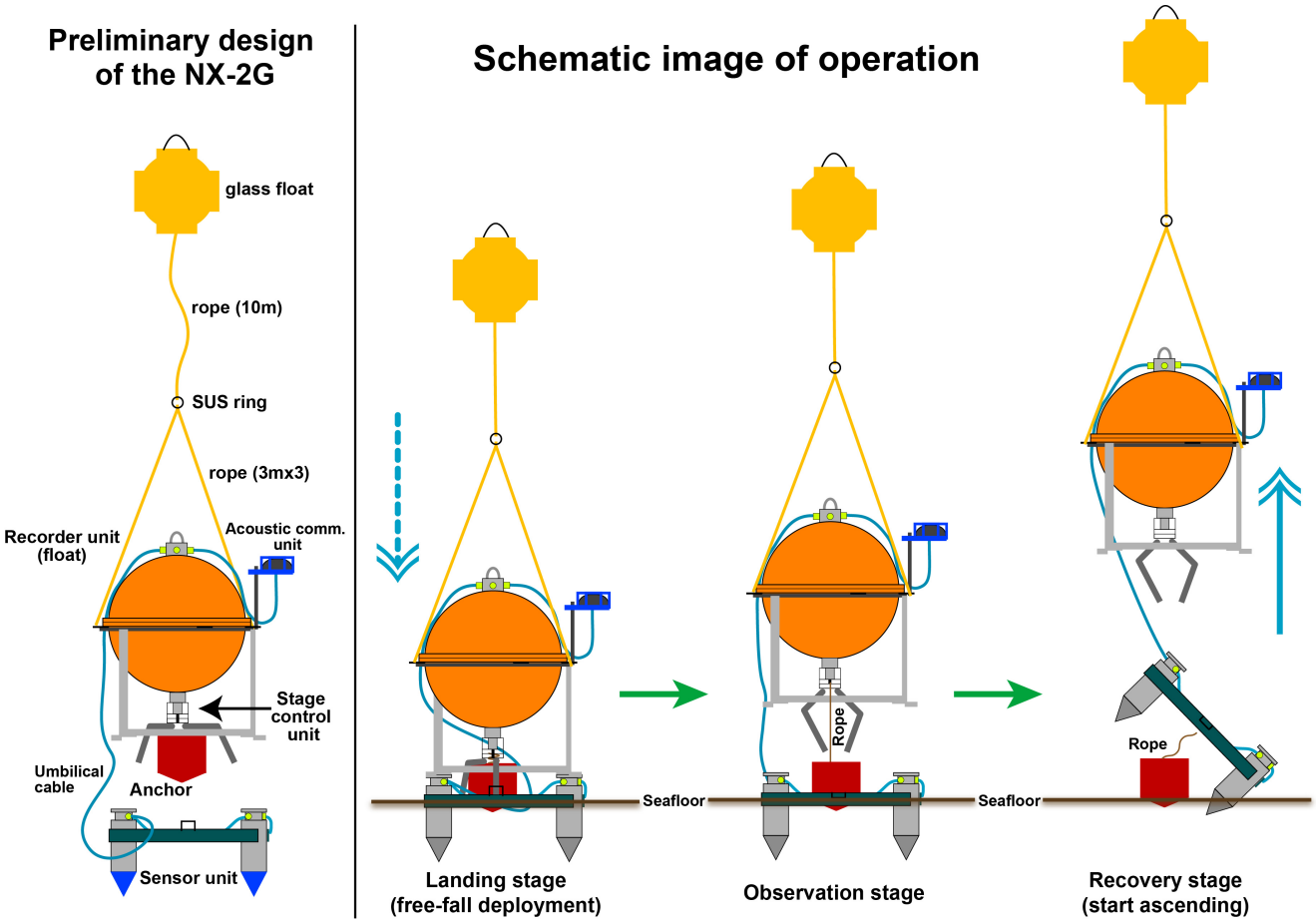
1. Earthquake Research Institute, University of Tokyo, 2. D-EARTH, Japan Agency for Marine-Earth Science and Technology, 3. Graduate School of Science, Kobe University

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

*Kenji Tara[1], Eiichi Asakawa[1], Fumitoshi Murakami[1], Hitoshi Tsukahara[1], Shutaro Saito[1], Sangkyun Lee[1], Masashi Kato[1], Ehsan Jamali Hondori[1], Tomonori Sumi[3], Tadashi Yamakawa[2], Masami Kose[4]

1. J-MARES/JGI, 2. J-MARES/MMTEC, 3. J-MARES/NSENGI, 4. J-MARES/JAPEX

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

*Matsushita Koharu[1], Izumi Sakamoto[1], Taiki Uehara[1], Yuta Shinomiya[1], Kosuke Tutumi[1], Nagisa Nakao[1], Marin Miura[1], Masatoshi Yagi[1], Satoshi Okamura[2], Michio Tanahashi[3]

1. Tokai University, 2. Hokkaido Univ.Edu, 3. OHTI

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

*Ryuta Arai[1], Robert Dunn[2], Deborah Eason[2], Pablo Canales[3], Robert Sohn[3]

1. Japan Agency for Marine-Earth Science and Technology, 2. University of Hawaii at Manoa, 3. Woods Hole Oceanographic Institution

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

Taiyu Mori[1], *Toshinori Sato[1], Hiroyoshi Takata[1], Yuki Imai[2], Yui Noguchi[1], Akihiro Kono[1], Tomoaki Yamada[3], Masanao Shinohara[3]

1. Graduate School of Science, Chiba University, 2. Faculty of Science, Chiba University, 3. Earthquake Research Institute, the University of Tokyo

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

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Keywords: TAIGA Project, hydrothermal field, seismicity, crustal structure, NTO massif

Mantle heterogeneity across segment at southern segment of Central Indian Ridge

*Hiroshi Sato[1], Shiki Machida[2], Ryoko Senda[2]

1. School of Business Administration, Senshu University, 2. JAMSTEC

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

*Ryosuke Oyanagi[1], Atsushi Okamoto[1], Yumiko Harigane[2], Noriyoshi Tsuchiya[1]

1. Graduate School of Environmental Studies, Tohoku University, 2. Geological Survey of Japan National Institute of Advanced Industrial Science and Technology (AIST)

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

*Hidenori Kumagai[1], Jun-ichiro Ishibashi[2], Tatsuo Nozaki[1], Lena Maeda[1], Yasuhiro Yamada[1], Tomokazu Saruhashi[1], Masanori Kyo[1], CK16-05 On-board Member

1. Japan Agency for Marine-Earth Science and Technology, 2. Kyushu Univ.

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

*Shuhei Totsuka[1], Jun-ichiro Ishibashi[2], Tatsuo Nozaki[3], Kazuhiko Shimada[2], Jun-Ichi Kimura[4]

1. Department of Earth and Planetary Sciences, Graduate School of Sciences, Kyushu University, 2. Department of Earth and Planetary Sciences, Faculty of Science, Kyushu University, 3. Research and Development Center for Submarine Resources, JAMSTEC, 4. Department of Solid Earth Geochemistry, JAMSTEC

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

*Jun-ichiro Ishibashi[1], Saki Tsutsumi[1], Naoya Ebina[1], Tomohiro Toki[2]

1. Department of Earth and Planetary Sciences, Faculty of Science, Kyushu University, 2. Department of Chemistry, Biology and Marine Science, Faculty of Science, University of the Ryukyus

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

*Yusuke Ota[1], Tada-nori Goto[1], Koki Kashiwaya[1], Katsuaki Koike[1], Weiren Lin[1], Osamu Tadai[3], Takafumi Kasaya[2], Toshiya Kanamatsu[2], Hideaki Machiyama[2]

1. Graduate School of Engineering, Kyoto University, 2. Japan Agency for Marine-Earth Science and Technology, 3. Marine Works Japan

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

*Shogo Komori[1], Yuka Masaki[2], Wataru Tanikawa[2], Junji Torimoto[2], Yusuke Ota[3], Masato Makio[4], Lena Maeda[2], Jun-ichiro Ishibashi[4], Tatsuo Nozaki[2], Osamu Tadai[5], Hidenori Kumagai[2], CK16-01 on board member

1. National Institute of Advanced Industrial Science and Technology, 2. Japan Agency for Marine-Earth Science and Technology, 3. Kyoto Univerity, 4. Kyushu University, 5. Marine Works Japan

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

*Masataka Kinoshita[1,2], Yuka Masaki[2], Wataru Tanikawa[2], Yohei Hamada[2], Tatsuo Nozaki[2], Hidenori Kumagai[2], Hiroyuki Yamamoto[2]

1. Earthquake Research Institute, University of Tokyo, 2. JAMSTEC

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

*Yuka Furukawa[1], Nobukazu Seama[1], Narumi Takahashi[2], Yuka Kaiho[3], Shuichi Kodaira[3]

1. Kobe University, 2. National Research Institute for Earth Science and Disaster Resilience, 3. Japan Agency for Marine-Earth Science and Technology

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

*Azusa Nishizawa[1], Kentaro Kaneda[1], Mitsuhiro Oikawa[1], Daishi Horiuchi[1], Yukari Fujioka[1], Chiaki Okada[1]

1. Hydrographic and Oceanographic Department, Japan Coast Guard

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

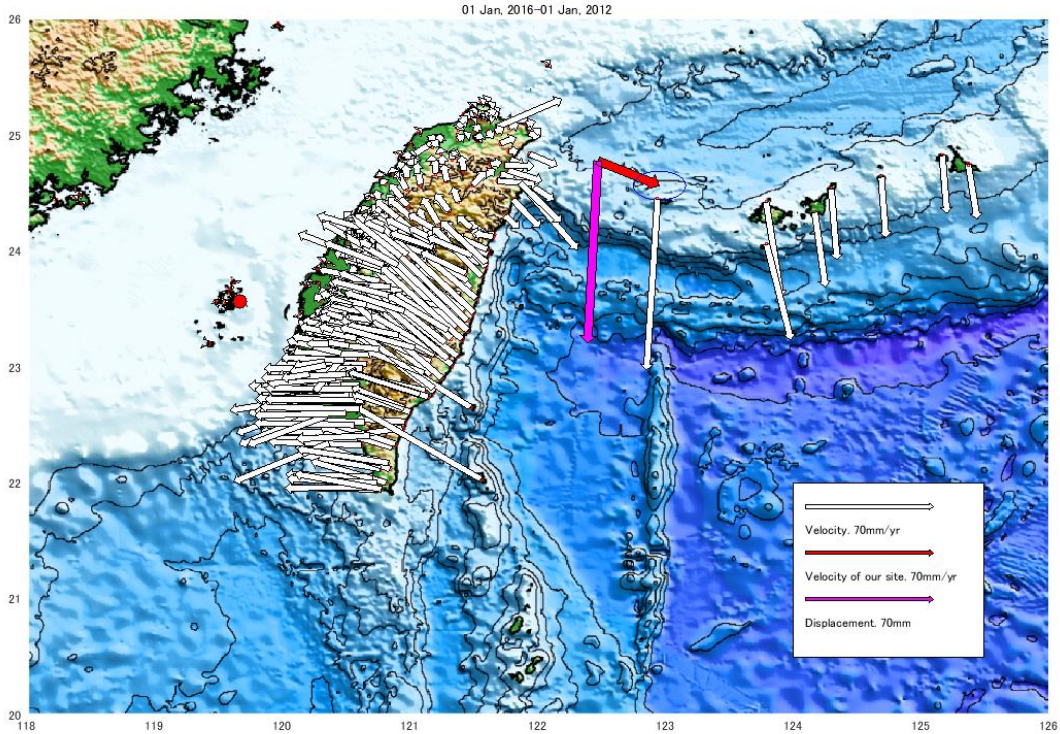
GNSS/Acoustic geodetic measurement at the west end of spreading Okinawa trough back arc basin.

*Takeru Koumi[1], Ryoya Ikuta[1], Horng-Yue Chen[3], Cheng-Horng Lin[3], Ya-Ju Hsu[3], Masataka Ando[2]

1. Faculty of Science, Shizuoka University, 2. Center for Integrated Research and Education of Natural Hazards,Shizuoka University, 3. Institute of Earth Sciences, Academia Sinica

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

*Masataka Ando[1], Ryoya Ikuta[1]

1. Center for Integrated Research and Education of Natural Hazards, Shizuoka University

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

*Fumiaki Tomita[1], Chie Honsho[2], Motoyuki Kido[2]

1. Graduate School of Science and Faculty of Science, Tohoku University, 2. International Research Institute for Disaster Science, Tohoku University

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

*Tadashi Ishikawa[1], Yusuke Yokota[1], Shun-ichi Watanabe[1]

1. Hydrographic and Oceanographic Department, Japan Coast Guard

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

