Uncertainty of vertical positioning of seafloor geodetic observation

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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.

For the precise GPS-Acoustic seafloor positioning, we are developing analysis software, which combines a kinematic GPS result and an observed acoustic travel time to get a precise position of an array of seafloor stations. In this analysis, vertical coordinates of seafloor stations and the sound velocity are not completely independent. Therefore vertical coordinates are influenced by the error of sound velocity and in consequence their accuracy is more deteriorated than that of horizontal coordinates.

In this presentation, we present a new analysis strategy for precision improvement.

Keywords: Seafloor geodetic observation, GPS-Acoustic combination technique

Accuracy of GPS-Acoustic seafloor geodetic observation evaluated by numerical simulation

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Hydrographic and Oceanographic Department, Japan Coast Guard (JHOD), has been carrying out seafloor geodetic observations with the GPS-Acoustic combination technique (GPS-A), in order to detect a displacesment of a focal area of the interplate earthquake. For example, we detected coseismic displacements, long-term interseismic and postsesmic deformations [e.g., Sato et al., 2011]. However, insufficient frequency of the observation (a few times per year) prevents us from detecting the short-term deformation due to slow slip events and time-dependent postseismic effects. Therefore, it is necessary to improve the accuracy and/or frequency of the observation under the condition of limited ship-time. For the purpose of improving the frequency, we tested the alternative survey lines to optimize the accuracy and geometrical simplicity simultaneously, using pseudo GPS-A data generated by the GPS-A simulator [Yokota et al., 2016]. This simulator can generate the pseudo observation data sets with any errors and obtain the pseudo positions of seafloor transponder by inversion analysis.
In this presentation, we report the results of the accuracy of the alternative survey line, comparing the results using actual observation data.

Keywords: seafloor geodetic observation, GPS-Acoustic combination technique

Analytical method of seafloor crustal deformation corresponding to the large-scale ocean current region

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We monitor seafloor crustal deformation at two observation points (north and south of Nankai Trough (TCA and TOA)) across the Nankai Trough, Japan, from 2013 to 2015. A warm ocean current flows frequently above our points called the Kuroshio current that has temperature difference perpendicular to the flow axis down to 1000 m in depths. Sound speed in the water depends on temperature [Del Grosso, 1974]. Determination of seafloor benchmark position has a bias when the sound speed structure includes a horizontal inhomogeneity in large-scale ocean current area. This bias is caused by trade-off between estimated spatial-temporal variation of sound speed structure and seafloor benchmark position. In this study, we propose a new analytical method adopted a horizontal inhomogeneity of sound speed structure.
We use the following equation to adopt the horizontal inhomogeneity model: $S(X,x,z)=S_0(z)+dS(A(z)\times \tan(q(X,x)-R(X))$, $S(X,x,z)$ where is the spatial variation of slowness but spatial variation is the uniform during the observation period, $S_0(z)$ is the reference sound speed structure from CTD observation, dS is the rasio of slowness variation of horizontal direction, $A(z)$ is the vertical distance between seafloor benchmark and z, $q(X,x)$ is angle of incidence from each benchmark, $R(X)$ is the horizontal distance of the seafloor benchmark position from gradient axis, x is the ship position, and X is the benchmark position, z is the depth of the horizontal inhomogeneity. The gradient axis and magnitude (parameter dS) can be estimated by the travel time residual derived from Ikuta et al. [2008] analysis method (Yasuda et al., 2015 in SSJ fall meeting). The characteristic of the horizontal inhomogeneity appears as the sine curve in three benchmarks in the travel time residual. The gradient axis and magnitude can be estimated by the initial phase and amplitude of three sine curves, respectively. The gradient parameters derived from the travel time residual are low precision. Therefore, we decide gradient parameters when the residual sum of squares becomes minimum by performing a grid search in the range of an error.
We observed four times at TCA and TOA stations, respectively. Kuroshio current flowed above observation point at all epoch. We carried out this new analysis at all epoch of TCA and TOA. As a result, the direction of the fastest speed of sound is south -southeast direction all observation. This direction is consistent with flow direction of the Kuroshio current. RMS of the travel time residual decreases at most 0.027 ms at TCA station on May 2015. RMS of the seafloor benchmark position in conventional analysis and this analysis decreased 40.1 cm in NS component and increased 0.9 cm EW component at TCA station. In TOA station, RMS decreased 38.3 cm and 16.7 cm in NS and EW component, respectively. The bias was largely improved by the analysis of this study.

Keywords: Seafloor crustal deformation, Kuroshio, Nankai Trough

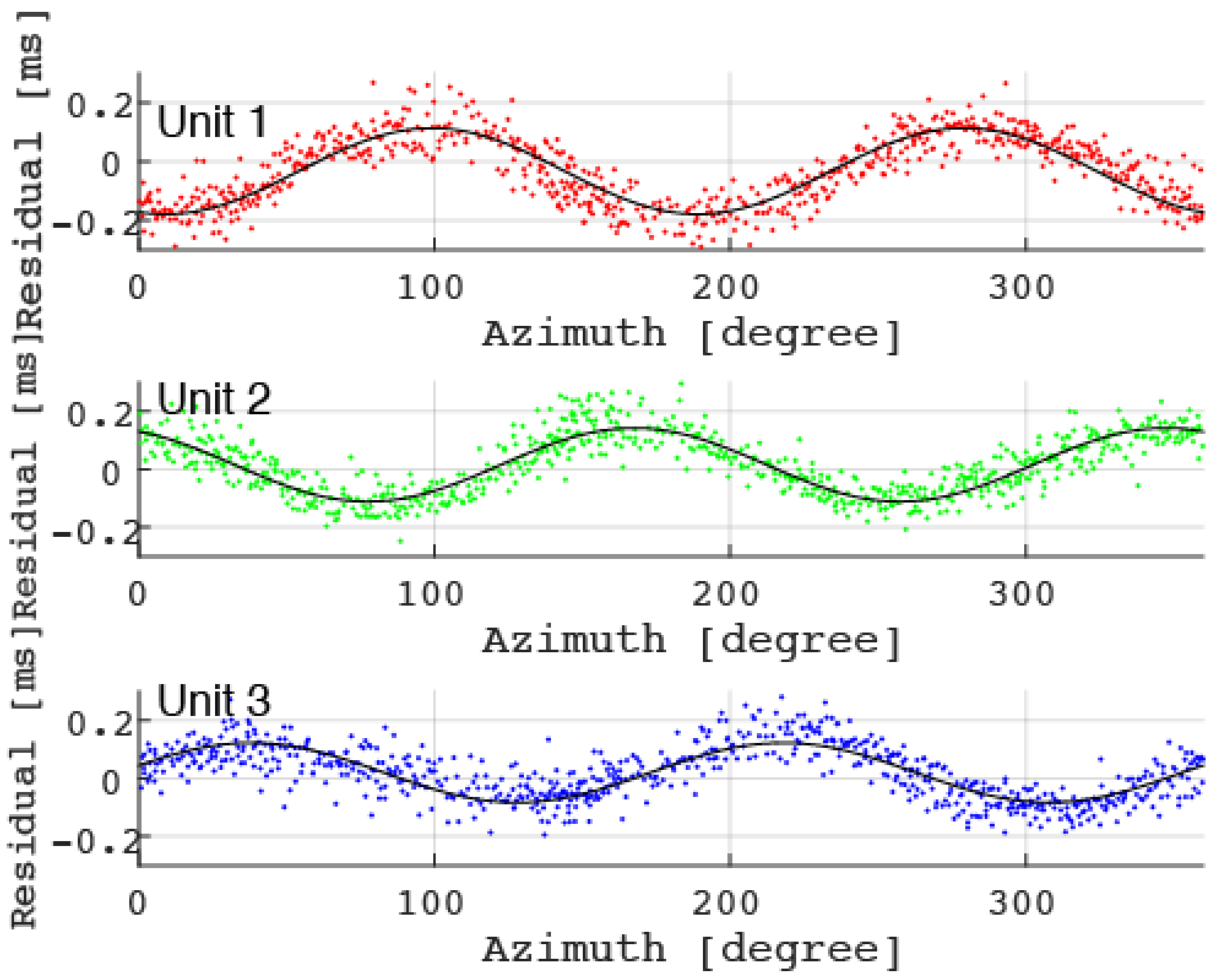

Figure 1. Travel time residual of TCA observation at May 1 2015. Solid line is the curve fitting by Yasuda et al. (2015) in SSJ fall meeting.

Seafloor Crustal Deformation Measurement at the Nanseisyoto Trench

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The occurrence potential of subduction-zone earthquakes has never been evaluated for the Nanseisyoto Trench because characteristics of earthquake occurrence remain obscure. In addition, Nakamura [2009] pointed out that the 1771 Yaeyama Tsunami, Southern Ryukyu Islands, Japan, was caused by subduction earthquake along the Nanseisyoto Trench; and it is necessary to understand the interplate coupling along the Nanseisyoto Trench. Although geodetic data are useful to grasp interplate coupling, it is difficult to deduce interplate coupling along the Nanseisyoto Trench only from the GPS network data on the Ryukyu islands because the trenchward motion of the Ryukyu Arc that is associated with the active backarc spreading along the Okinawa Trough. Nakamura [2011] measured seafloor crustal deformation at site RKA to the southeast of the Okinawa Island; and reported a full-coupling region beneath RKA with widths of about 50 km. In this study, we installed a new site RKB, in 2011. The site RKB is located about 70 km northeast of RKA and 53 km from the Nanseisyoto Trench axis. The water depth at RKB is about 2200 m. We performed seafloor crustal deformation observation four times in 2001, 2012, 2014, and 2015, using R/V Tonanmaru of Okinawa Prefectural Fisheries Research and Extension Center.
The four-years measurement revealed a site velocity at RKB, 6+/-22 mm/yr to the south and 2+/-26 mm/yr to the east with respect to GEONET Kamitsushima station on the Amurian Plate. The velocity is significantly different from that at RKA, 35+/-23 mm/yr to the north and 30+/-19 mm/yr to the west Nakamura [2011], indicating difference in interplate coupling beneath the two sites. The crustal deformation field along the Ryukyu Arc is affected by the backarc spreading along the Okinawa Trough [Nishimura et al., 2004], slow-slip events [Nishimura, 2014], and back-slip caused by the interplate coupling. The back-slip rate at RKB is calculated at 24+/-25 mm/yr in a northwest direction relative to stable Amurian Plate, resulting 0-20 % of interplate coupling rate beneath RKB from a forward modeling. The low coupling rate is consistent to an active strain release events, such as slow-slip events, very low frequency earthquakes [Tu et al., 2010], and trust-type earthquakes, around RKB. Our observation demonstrates less strain accumulation caused by plate convergence, in the hanging wall side at RKB. We plan to install a new site on the seafloor about 90 km southwest of RKA site in 2016.
Acknowledgement: This work was partly supported by Council for Science, Technology and Innovation (CSTI), Cross-ministerial Strategic Innovation Promotion Program (SIP), "Enhancement of societal resiliency against natural disasters" (Funding agency:JST).

Keywords: Nanseisyoto Trench, Seafloor Crustal Deformation, Interplate Coupling

GNSS/Acoustic measurement conducted on “Source region” of the 1771 Yaeyama Tsunami -Is huge inter-plate earthquake being prepared there?-

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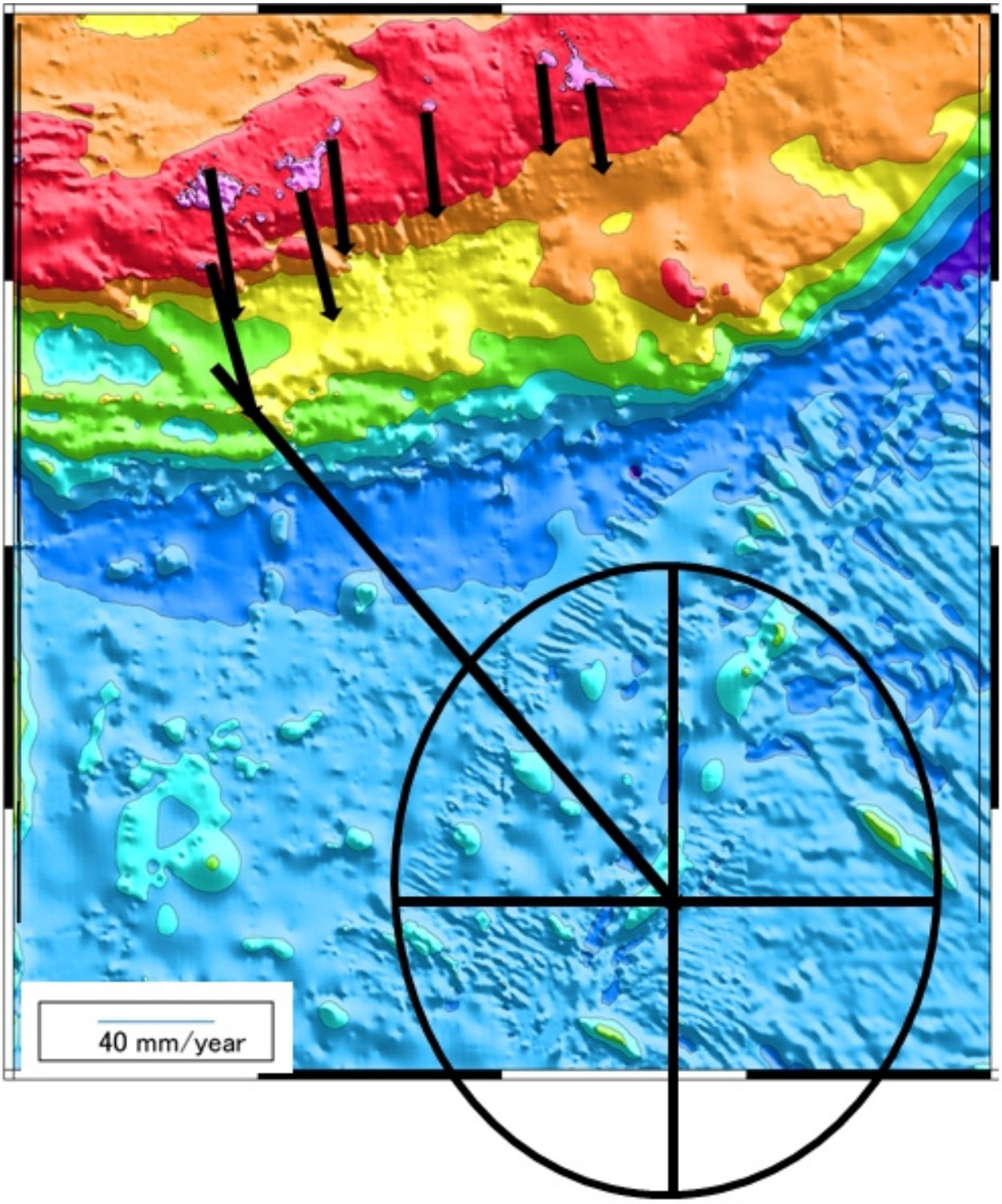
We have conducted GPS/Acoustic measurement at 60 km south to the Hateruma Island. In there, a huge Tsunami struck Yaeyama Islands along west Ryukyu trench in 1771. A huge inter-plate earthquake beneath Ryukyu trench is proposed as the source mechanism of the Tsunami (Nakamura, 2009). If this is the case, the proposed focal area should be coupled in the inter-seismic period. Therefore, we installed a GPS/Acoustic benchmark unit on the proposed focal area in October 2014 and conducted measurement twice with 9 months interval. We obtained about 3,000 and 4,000 available acoustic shots during 24 hours and 30 hours measurements in 2014 and 2015, respectively. As a result, the benchmark showed southeastward displacement of 12±8 cm/yr during the 9 month interval with respect to the GEONET station on Hateruma Island, which suggests trench-normal extension of the Hateruma forearc basin.
Although the result is preliminary because we have conducted measurement only twice, the result suggests that the area is not accumulating compressional strain which causes huge inter-plate earthquake. Additional measurements may also reveal offshore motion of the trench and the mechanism of back arc spreading.
Nakamura, M. 2009a, Fault model of the 1771 Yaeyama earthquake along the Ryukyu Trench estimated from the devastating tsunami. *Geophysical Research Letter*., 36, L19307, doi:10.1029/2009GL039730.

Keywords: Yaeyama Tsunami, GPS/Acoustic geodesy, Ocean bottom crustal deformation



Seismic characteristics around the Kerama Gap in the Nansei-Shoto (Ryukyu) Island arc

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The Nansei-Shoto (Ryukyu) Island arc is generally divided into three parts based on topography, geology, biology and other characteristics. The most significant boundaries are the Tokara Gap between the Tokara and Amami Islands in the northern arc, and the Kerama Gap between the Okinawa and Miyako Islands in the southern arc. Other than the two gaps, some large topographical saddles along the island arc characterize the Nansei-Shoto Island arc. We carried out seismic refraction and reflection surveys to investigate seismic structure around the Kerama Gap, which gives us key information to consider the tectonic evolution of the Nansei-Shoto Island arc-backarc system. Two seismic profiles, ECr25 and ECr31, are designed to cross the Kerama Gap and Miyako Saddle in the southern arc and forearc regions.

Line ECr25 along the forearc has a length of 415 km from the Nansei-Shoto (Ryukyu) Trench at the southwestern end, through the Miyako Saddle, to the Kerama Gap at the northeastern end. Multi-channel seismic (MCS) profile reveals many normal faults in the shallow sedimentary layer below the Kerama Gap and some faults reach to the seafloor, which suggests the deformation is in progress at the present time. The MCS record also shows clear reflection signals from the top of the subducting Philippine Sea plate. The depth of the plate boundary was estimated to be around 15 km below the forearc region from the reflection and refraction measurements. The ECr25 P-wave velocity (Vp) model reveals the top of 4-5 km/s layer is much shallower in the forearc regions to the southwest of the Kerama Gap, where higher free-air gravity anomaly and lower seismicity are different from other region.

Another line ECr31 with a length of 228 km was planned to be located along the Nansei-Shoto Island arc and cross the Miyako Saddle at the southwestern end and the Kerama Gap at the northeastern end. The MCS record for ECr31 show many normal faults beneath the Miyako Saddle and Kerama Gap, which indicates extensional regime along the island arc. Several conspicuous and almost continuous reflectors with small normal faults are detected at 1-2 s below the seafloor of the Miyako Saddle. On the other hand, some reflectors beneath the Kerama Gap are rather discontinuous due to large offsets of the normal faults, which indicates larger deformation in this region.

Vp model of ECr31 reveals a typical island arc structure. Although the thickness of the middle crust with Vp of 6.1-6.5 km/s varies along the seismic line, the variation seems to be independent of the positions of the Kerama Gap and Miyako Saddle. Therefore, the topographical deformation may not reach to the depth of the middle crust. We estimated the Moho depth of around 30 km from PmP arrivals. Some reflection signals from deeper than the Moho are also observed and they may reflect at the top of the subducting Philippine Sea plate or at its oceanic Moho. Traveltime mapping of these signals results in many scattering reflectors and it is difficult to determine the depths of deeper reflectors precisely.

Keywords: Nansei-Shoto (Ryukyu) Island arc, Kerama Gap, marine seismics

Creep rate measurement and fault modeling at the North Anatolian Fault, beneath the Sea of Marmara, Turkey, by means of acoustic ranging

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The North Anatolian Fault (NAF) is the strike-slip fault that passes 1200 km length through the Northern Turkey having about 20 mm/yr of right-lateral motion in average. In the past 100 years, the fault sequentially ruptured from east to west. In 1999, two earthquakes occurred at Izmit (M7.4) and Duzce (M7.2) adjacent to the Sea of Marmara, the south of Istanbul, where it remains unruptured. Because NAF is under the sea, we cannot directly observe its motion by using GNSS or other space geodetic tools. To reveal the strain rate and fault structure of NAF in the Sea of Marmara, we use “direct path acoustic ranging” in this study.
The acoustic ranging can detect relative motion across the fault with millimeter-level precision for 1 km baseline. We installed five instruments at so-called the Western High across the NAF. Round trip time is recorded every 6-hours. At the same time, in-situ temperature, pressure (for sound speed), and tilt (for attitudes) were also recorded. These data can be recovered on-demand through acoustic modem from a ship.
In this talk, we present the ranging data from September 2014 to July 2015. At first, we evaluate sound velocity. Observed temperature variation was quite small (~0.007℃) close to the instrumental resolution, so we applied a polynomial fitting to get smooth variation. Pressure correction was applied only during the first half period, because it was not available due to instrumental failure in the second half. Without pressure correction, small scatter remains in the apparent range, which does not much affect the creep rate determination, though. After correcting instrumental attitude and baseline angle to the fault line, we obtained 4-8 mm/yr of right-lateral motion. Because such extremely large strain rate is unlikely, we consider the observed 4-8 mm/yr movement at the Western High along the NAF is “creep” in the shallow crust out of 20 mm/yr of regional block motion. We will also talk about the fault structure modeled using additional onshore GNSS data.

Acknowledgement: This observation is carried out in the MarDiM, SATREPS promoted by JICA/JST

Keywords: direct path acoustic ranging, the North Anatolian Fault, GNSS, fault modeling, seafloor geodesy

Detailed spatial distribution of microearthquakes beneath the Sea of Marmara, Turkey, deduced from long-term ocean bottom observation

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The North Anatolian Fault (NAF) crosses the Sea of Marmara in E-W direction, accommodating about 25 mm/yr of right-lateral motion between Anatolia and the Eurasian plate. There are many large earthquakes along the 1500 km long NAF repeatedly occurred and interacted each other. The recent large northern Aegean earthquake with Mw=6.9 filled one of the last two seismic gaps along NAF that experienced extraordinary seismic moment release cycle during the last century and confirmed a remained blank zone in the Sea of Marmara. However, this segment keeps its mystery due to its underwater location. Earthquake hazard and disaster mitigation studies in Marmara region are sensitive to detailed information on fault geometry and its stick-slip behavior beneath the western Sea of Marmara. We have started ocean bottom seismographic observations to obtain the detailed information about fault geometry and its stick-slip behavior beneath the western Sea of Marmara, as a part of the SATREPS collaborative project between Japan and Turkey namely MarDiM project “Earthquake and Tsunami Disaster Mitigation in the Marmara Region and Disaster Education in Turkey”. The target area spans from western Sea of Marmara to offshore Istanbul along the NAF. In the beginning of the project, we deployed ten short period Ocean Bottom Seismographs (OBSs) between the Tekirdag Basin and the Central Basin (CB) in September 2014. Then, we added five short period OBSs and deployed them in the western end of the Sea of Marmara and in the eastern CB to extend the observed area in March 2015. We retrieved all 15 OBSs in July 2015 and deployed them again in the same locations after data retrieve and battery maintenance.
From continuous OBS records, we could detect more than 700 events near the seafloor trace of NAF during 10 months observation period whereas land-seismic network could detect less than 200 events. We estimated the micro-earthquake locations using manual-picking arrival times incorporating station corrections. The tentative results show heterogeneous seismicity. The Western High (WH) and CB have relative high seismicity and the seismogenic zone was found to be thicker than the previous estimations done by other researchers. Our result clearly shows that the maximum depth of seismogenic zone is about 24 km beneath the WH and the western half of CB, and this depth suddenly decreases to about 15 km in the eastern half of CB. Our results also suggested that the dip angle of NAF is almost vertical or northward beneath WH, whereas it is about 80 degrees southward beneath the eastern CB and perhaps further decreases to 60 degrees towards the Kumburgaz Basin. These results suggest that some structural or frictional segment boundary is located around 28°E in the middle of CB.

Keywords: Ocean bottom seismographic observation, Sea of Marmara, Seismicity distribution

Along-trough variations and characteristics in the shallow crustal structure of the incoming Philippine Sea Plate at the Nankai Trough

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The Shikoku Basin which produced during 30-15 Ma by backarc spreading of Philippine Sea Plate is subducting to Nankai Trough at the northern margin. It is important to reveal the characteristics of crustal structure of incoming Phippine Sea Plate for understanding the mechanism of large earthquake in Nankai seismogenic zone, the great tsunami event is also known for occuring along the Nankai Trough. In order to reduce a great deal of damage to coastal area from both strong ground motion and tsunami generation, it is necessary to understand rupture synchronization and segmentation of the great Nankai earthquake. We focus on the recent deformation structure in and around the axis of Nankai Trough. However, there are few seismic lines of legacy surveys across the Nankai trough axis. High-resolution seismic reflection surveys have been conducted around Nankai Trough by Japan Agency for Marine-Earth Science and Technology after 2011 in order to image the detailed structure near tough axis. Obtained seismic profiles indicate the many reflectors and faults in the sediments of the Shikoku Basin. We mapped the horizons identified from seismic profiles such as the top of oceanic crust, lower Shikoku Basin facies, upper Shikoku Basin facies, trough-fill sediments in the Shikoku Basin. The well-stratified turbidite deposits are recognized off Kii Peninsula. We will present the incoming crustal characteristics about the western Shikoku Basin, middle Shikoku Basin and eastern Shikoku Basin from our mapping results.
This study is part of ‘Research project for compound disaster mitigation on the great earthquakes and tsunamis around the Nankai Trough region’ funded by MEXT, Japan.

Keywords: MCS Survey, Shikoku Basin, Philippine Sea Plate

The crustal structure of the Ojin-Rise Seamounts, North Pacific.

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Ojin-Rise Seamounts is located between Shatsky Rise and Emperor Seamount Chain. The main portion of Shatsky Rise was formed by impact of the mantle plume head after 148 Ma (Nakanishi et al., 1999). Shatsky Rise consists of three plateau, TAMU, ORI, and Shirshov massifs. The radiometric ages of drilling samples of the three massifs are about 144 Ma for TAMU, 134 Ma for ORI, and about 128 Ma for Shirshov, respectively (Geldmacher et al., 2014; Heaton and Koppers, 2014). The seafloor age around Orin Rise Seamounts is estimated to be 134-125 Ma (Nakanishi et al., 1999). The geophysical measurements (bathymetry, gravity and geomagnetism) and rock sample sampling were conducted in 2014 summer (R/V KAIREI cruise, KR14-07). We therefore present the crustal structure of the Ojin-Rise Seamounts based on the analysis of bathymetric and gravity data.
We use multibeam bathymetric data obtained in KR14-07 and bathymetric grid data reported by Sager et al. (1999) and free-air gravity anomaly data by Sandwell and Smith (2009). We have estimated the oceanic crustal thickness using the method by Kuo and Forsyth (1988) and the state of isostasy and effective elastic thickness using the admittance analysis by McKenzie and Bowin (1976).
Our result shows that the crustal thickness beneath the Ojin-Rise Seamounts is about 12 km, which is two-times thicker than the normal oceanic crustal (e.g., 6 km). The effective elastic thickness is calculated to be about 2.6 km. The state of isostasy is Airy type. We conclude that the Ojin-Rise Seamounts was formed near the spreading ridige about 134-125 Ma. The timing of the formation is close to that of Shirshov Massif, impling that the same volcanic activity might form both Shirshov Massif and Ojin-Rise Seamounts.

Keywords: Ojin-Rise Seamounts, Shatsky Rise, admittance analysis, gravity, bathymetry feature

Estimation of thick crustal distribution of the Ontong Java Plateau

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The Ontong Java Plateau (OJP), which is the largest oceanic plateau on Earth, has an area of 1.86 x 10^6 km^2 (Coffin and Eldholm, 1994), five times Japan's area. Scientific drilling on the OJP has shown that ages of basement basalts below sediments are approximately 120 million years (Ma) (e.g. Shipboard Scientific Party, 2001), suggesting that formation of the OJP was geologically brief. No formation mechanism yet proposed explains all observations. Crustal structure is important for understanding the formation mechanism of oceanic plateaus, and geophysical experiments have been conducted on the OJP since the 1960s. However, only a few experiments addressed the whole crust, i.e., everything above the Moho (e.g. Furumoto et al., 1976, Gladczenko et al., 1997). The Moho depth of the southernmost OJP colliding with the Solomon Islands is about 35 km (Miura et al., 2004). However, the Moho depth of the central OJP has not been determined confidently because of discrepancies in results among different survey methods. In 2010, we conducted a seismic experiment on the central OJP using a large volume airgun array, 100 ocean bottom seismometers (OBS), and a 6 km multi-channel seismic (MCS) streamer cable (Miura et al., 2011). We analyzed the OBS data using a forward modelling approach (Miura et al., 2013), a traveltime inversion approach (Fujie et al., 2013) using first arrival and Moho reflection phases (PmP) with the uncertainty outlined by Korenaga (2011), and a finite-difference amplitude method (Larsen and Grieger, 1998) for reflection phases (Miura et al., 2014, 2015). From these analyses, the Moho depth of the central OJP exceeds 40-km below sea level. To estimate the distribution of the Moho depth or crustal thickness of the OJP outside of the 2010 survey area, we will analyze wide-angle data collected in 1998 by scientists aboard RV *Hakuho-maru* (Araki et al., 1998) and previous results (e.g. Furumoto et al., 1976, Gladczenko et al., 1997) to calculate crustal volume and formation rate. These will contribute to resolving the mechanism(s) by which OJP formed and to assessing the environmental impact of formation.

Keywords: LIPs, OJP, MCS, OBS, crust, Moho

Electrical conductivity structure suggests no plume beneath the Tristan da Cunha hotspot in the southern Atlantic Ocean

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Tristan da Cunha Island is one of the classical hot spots in the Atlantic Ocean, situated at the western end of the aseismic Walvis Ridge which forms a connection to the Cretaceous Etendeka flood basalt province in northwestern Namibia. The discussion about its source (in shallow asthenosphere or deeper mantle) have not reached consensus yet because of lack of the geophysical observations in the area. A marine magnetotelluric (MT) experiment was conducted together with seismological observations in the area in 2012–2013 through a German-Japanese collaboration with the goal to constrain the physical state of the mantle beneath the area. A total of 26 MT seafloor stations were deployed around the Tristan da Cunha Islands and available data were retrieved and processed from 24 stations. We applied iterative topographic effect correction and one-dimensional (1-D) conductivity structure inversion to the data. Then, we conducted three-dimensional (3-D) inversion analysis incorporating the topographic effect, using the 1-D model as the initial model. The local small-scale topography and the far continental coast effects are incorporated as the distortion term in the 3-D inversion. The preliminary result of our analysis shows no evidence of a significant conductive anomaly arising from the mantle transition zone, suggesting that the current magmatic source (major place of melting) of the hotspot activity is in the shallow upper mantle. This is in contrast to results from geochemical analysis, in which samples along the Tristan track exhibit an ocean-island-basalt-type incompatible element pattern pointing to a deep mantle source of the melt. Our findings therefore might indicate that the deep mantle up-welling underneath Tristan da Cunha Islands may be almost dead. A conductive anomaly at about 100 km depth in our derived conductivity model to the southwest of Tristan da Cunha Islands may be as the result of an interaction between the mid-ocean ridge and/or up-welling further south, e.g., beneath the Gough Island, which is the other termination of the Walvis Ridge and shows clearer geochemical evidence for a plume source. This conductor bulges upward beneath a fracture zone just south of the Tristan da Cunha islands. It may suggest that the fracture zone can be a path that melt can transport from the asthenosphere to the seafloor (maybe the islands nearby) although the anomaly was not clearly imaged in upper 20 km depths.

Keywords: marine magnetotellurics, electrical conductivity, upper mantle, hotspot, fracture zone, Atlantic Ocean

Red relief image map and integration of topographic data in and around the Japan Sea

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In recent years, we conducted marine seismic surveys in the Japan Sea with the research vessels of the Japan Agency for Marine-Earth Science and Technology (JAMSTEC). In these surveys, high quality bathymetric data by the multi-narrow beam echo sounder have been obtained simultaneously with navigation of vessels. In this report, we describe about red relief image map and DEM (Digital Elevation Model) data which are created by the integration of topographic data in and around the Japan Sea.
We used various accuracy and/or scale data, such as J-EGG 500m gridded data, digital bathymetric contour data (M7000), and GEBCO 2014 30arc second grid data, in addition to multi-narrow beam data. To remove noises from enormous point cloud data, we applied ground filtering algorithms of aerial Lidar processing system. And to check for errors, like artificial irregular peak pits, visualized data by red relief image map. Corrected bathymetric data and land elevation data are gridded by spline interpolation, and jointed to a sheet of DEM dataset compilation at 0.0005 degree resolution.
Created red relief image map from corrected DEM dataset are easily understandable sea floor feature, such as fold structure, volcano, and submerged valley. This bathymetric data and visualizing are beneficial to understand active faults and folds, seismicity, and crustal structure in the Japan Sea.

Keywords: Japan Sea, Bathymetric data, Data integration, Red relief image map, DEM

Huge deep-sea landslide in the Southern Mariana Trench: a preliminary report of 6K-1429 dive

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We have identified a huge deep-sea landslide structure in the Southern Mariana Trench. DSV Shinkai 6500 dive 1429 investigated this structure during YK15-11 cruise of R/V Yokosuka. In this contribution, we will have a preliminary report of the dive and discuss the origin of this structure.

Keywords: Southern Mariana Trench, deep-sea landslide, serpentinized mantle peridotite

Sedimentary structure of muddy turbidites recorded in a terminal basin

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Paleoseismic records of subduction zone are very important to mitigate great earthquake disaster. Terrestrial and marine archive analyses are necessary in order to gain long-term paleoseismic records in contrast to historical documents and ruins. Especially, marine sediments contain high quality pinpoint paleoseismic records because we can locate sampling sites close to epicenters. In order to obtain paleoseismic records from turbidite deposits, the samples should be carefully taken from the site without direct input of terrestrial sediments since turbidity currents are also derived from floods. Because such samples are dominant in fine-grained materials, we have to distinguish fine-grained turbidites from hemipelagic mud. The primary focus of this study is to understand the characteristic of sedimentary structure of seismogenic muddy turbidites already identified by the previous study. The second focus is to carry out detailed analytical and observational analysis of a longer sediment core collected at the same location and discuss the possible scenarios for the seismogenic turbidite distribution.
The samples used in this study include a 46 cm-long multiple core and a 6.7 m-long piston core which were collected from the sedimentary basin southeast off Kii Peninsula during the KS-14-8 R/V “Shinsei Maru” cruise. The sampling site is located at the ENE-WSW elongated basin between the accretionary prism and the Kumano forearc basin without terrestrial sediment supply. The basin exhibits “a terminal basin” that captures all sediments supplied from outside. From the multiple core sample, the Cs^{137} and Pb^{210} concentration indicate that the muddy sediment layer in the upper 17 cm was formed by the 2004 off the Kii Peninsula earthquake. We conducted visual observation, X-ray CT images, anisotropy of magnetic susceptibility (AMS), paleomagnetism, rock magnetism, electrical resistivity measurements and grain size analysis on both the cores.
Muddy seismogenic turbidite observed at the upper 17 cm of the multiple core have thick homogeneous clay layer above the silty lamination. The sequence beneath the muddy seismogenic turbidite shows various orientations oblique to the bedding plane suggesting shaking deformations during the 2004 earthquake. The magnetic susceptibility decreases upwards in the laminated zone. This specific feature suggested that the muddy turbidity current slowly decelerated and settled down the slope. Paleocurrent estimated from the paleomagnetic and AMS measurements is consistent with the slope orientation of the terminal basin. These characteristic features are also recognized in the piston core. From tephra chronology and radiocarbon dating of foraminifera, the interval of the probable seismic event layers almost matches the recurrence time of the known past earthquakes of the Nankai Trough area. In conclusion, the terminal basin is likely to hold most records of past seismic events in this region. Further age determination is required for understanding of the earthquake event history off Kii Peninsula.

Keywords: turbidity current, anisotropy of magnetic susceptibility, X-ray CT, event deposit

Late Neogene to Quaternary turbidite deposition in the northern Japan Basin and its relation to regional tectonics

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Many fine-grained turbidite beds occurred in core at Site U1422 of IODP Expedition 346 on the northeastern Japan Basin. Turbidite sediments contain much feldspar, suggesting grain supply of volcanic materials from the Japanese island arc. Muddy turbidite disappears at around 1.7 Ma. Stepwise decreasing of sedimentation rate at around 1 and 0.6 Ma also reflects the change of uplift mode of the Okushiri Ridge. Both change of turbidite deposition and of sedimentation rate in the northeastern Japan Basin margin might reflect the regional tectonics along the eastern margin of the Japan Sea.

Keywords: turbidite, Eastern margin of Japan Sea, tectonics

Sedimentation of iron deposits in Nagahama Bay, Satsuma Iwo-jima Island:Precipitation behavior of colloid

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Satsuma Iwo-Jima Island, with volcanic activities, is located about 40km south of Kyushu Island, Japan. This island is one of the best places to observe a shallow water hydrothermal system. Nagahama Bay, in the south of Satsuma Iwo-Jima Island, is partly separated from open sea. The seawater appears dark reddish brown color due to colloidal iron hydroxide by the mixing of volcanic fluids (pH=5.5, 50-60 degree Celsius) and oceanic water (Ninomiya & kiyokawa, 2009; Kiyokawa et al., 2012; Ueshiba & kiyokawa, 2012). Very high deposition rate (33 cm per year) of iron-rich sediments was observed in the bay (Kiyokawa et al., 2012). However, precipitation behavior of colloidal iron hydroxide has not been clarified. In this study, I report the results of analysis of deposition experiments of the colloidal particles at the Nagahama bay.

Since the size of the colloidal particles is 1nm~1μm, single particle cannot be precipitated. This arise from precipitation of the particles in the viscous fluid is according to the Stokes' law. Colloidal iron hydroxide has the property of having the electric charges on the surface. The charge on the colloids is affected by pH of its surrounding seawater and can become more positively or negatively charged due to the gain or loss, respectively, of protons (H+) in the seawater. This property affects the stability of the colloidal dispersion.

FE-SEM observation shows that the suspended particles consist of colloidal iron hydroxide (about 0.2μm), on the other hand, the iron-rich sediments are composed of bigger one (>1 μm). This indicates the colloidal iron hydroxide is precipitated by flocculation. We examined the precipitation amount of colloidal iron hydroxide under the various pH environments. The precipitation amount of pH=7.8 seawater 10% higher than that of pH=7.2. This result is roughly follows the theoretical value.

Keywords: Kikai Caldera, Colloid, iron hydroxide

Preliminary results of the CK16-01 Cruise: Scientific drilling operations of coring, in-situ thermometer and geothermal logging tool

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The CK16-01 Cruise by D/V Chikyu was performed at the Iheya-North Knoll and Noho Site, middile Okinawa Trough from 11th, February to 17th, March 2016 in order to investigate the subseafloor hydraulic structure and geology, aiming to construct the genetic model of seafloor hydrothermal deposits. In the first half of the CK16-01 Cruise, logging while drilling (LWD) was mainly done to obtain physical parameter beneath the Iheya-North Knoll and Noho Site, as well as install of the “Kuroko-ore cultivation apparatus” equipped with sensor loggers to monitor the secular changes of pressure, temperature, flow rate and precipitation weight within the Kuroko-ore cultivation apparatus on artificial hydrothermal vents. This Kuroko-ore cultivation apparatus will be recovered after one year by ROV Kaiko Mk-IV. In the latter half of the CK16-01 Cruise, the main operation was coring to obtain drilled core sample together with temperature measurement by in-situ thermometer and borehole logging after coring operation using a geothermal tool bearing pressure, temperature, flow rate and gamma-ray sensors. In this presentation, we report the preliminary results of operations during the latter half of the CK16-01 Cruise.

Keywords: Okinawa Trough, Iheya-North Knoll, Noho Site, seafloor hydrothermal deposit, Kuroko deposit, CK16-01 Cruise

Preliminary results of the CK16-01 Cruise: Scientific drilling in Okinawa Trough using Logging While Drilling tools and installation of long-term monitoring apparatus

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In the period of February to March of 2016, the CK16-01 Cruise by D/V Chikyu was performed at the Iheya-North Knoll and Iheya Minor Ridge in middle Okinawa Trough, in order to investigate the subseafloor hydraulic structure and geology, aiming to construct the genetic model of seafloor hydrothermal deposits under an umbrella of Cross-ministerial Strategic Innovation Promotion Program (SIP). In the former half of the cruise, logging while drilling (LWD) operation was mainly performed to obtain physical parameters beneath both the area, as well as to install of the Long-term monitoring apparatus, "Kuroko-ore cultivation 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. The precipitation volume of the apparatus will be recovered later to by ROV. In the latter half of the cruise, the main operation was coring to obtain drilled core sample together with temperature measurement by in-situ thermometer and borehole logging after coring operation using a geothermal tool bearing pressure, temperature, flow rate and gamma-ray sensors. In this presentation, we report the preliminary results of operations during the former half of the CK16-01 Cruise.

Keywords: Okinawa Trough, Iheya-North Knoll, Iheya Minor Ridge, Seafloor hydrothermal Deposit, CK16-01 Cruise, Cross-ministerial Strategic Innovation Promotion Program (SIP)

Acoustic and magnetic surveys using AUV Urashima around the hydrothermal sites off Kumejima island in the Mid-Okinawa Trough

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Recently, polymetallic sulfides deposited in seafloor hydrothermal vents have attracted interest as a potential mineral resources for e.g., Cu, Zn, Pb, In, Ga, Ge, Au, and Ag (Schrope, 2007). Development of effective methods for exploring seafloor hydrothermal activity is an important key for future exploitation of this type of deep-sea mineral resource and thus, more efficient methods for exploration of seafloor hydrothermal vents are expected.
Recent progress in near-bottom geophysical and geochemical surveys using autonomous underwater vehicles (AUV) allows us to perform high-resolution surveys in which the signatures of seafloor hydrothermal activity can be detected (German et al., 2008; Kumagai et al., 2010; Nakamura et al., 2013). Moreover, in the last decade, water column observations using multi-beam echo sounder (MBES) systems equipped on a surface ship have also become successfully applied to exploration of seafloor hydrothermal vents (Tanahashi et al., 2014; Kasaya et al., 2015; Nakamura et al., 2015).
During the YK15-14 cruise in 2015, we conducted the shipboard MBES survey by R/V “Yokosuka” and the near-bottom acoustic and magnetic surveys using AUV “Urashima” around the hydrothermal sites in order to reveal the distribution and characteristics of seafloor hydrothermal vent sites off Kumejima island in the mid-Okinawa Trough. The presence and amplitude of hydrothermal plume signals were first detected by acoustic water column imaging with a shipboard MBES system. A total of four AUV “Urashima” dives (Dives #217-220) were completed around the sites. During these dives, we have successfully obtained high-resolution bathymetric data, side scan sonar image, sub-bottom profile, vector magnetic field and chemical sensor data (ORP, turbidity and temperature). The vector magnetic field were measured by three fluxgate magnetometers mounted in the payload space of AUV “Urashima” to investigate the seafloor magnetic features related to hydrothermal alteration processes. The distribution of crustal magnetization are estimated using the magnetic anomalies by the inversion method. Here we report the overview of the YK15-14 cruise and show new results from AUV “Urashima” dives. Then, the characteristics of the hydrothermal sites in the mid-Okinawa Trough will be discussed by comparing with the results from the ROV surveys during the KR15-16 cruise.

Keywords: seafloor hydrothermal exploration, mid-Okinawa Trough, AUV, detailed bathymetry, magnetic anomaly

High-resolution Magnetic Signatures of Irabu Hydrothermal Fields, Okinawa Trough

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Near-seafloor magnetic fields near the active Irabu Hydrothermal fields (IHFs) were obtained by using the AUV *URASHIMA* during the R/V *Yokosuka* cruise YK14-16. The Irabu knolls are located on the axial area of a back-arc rift of the Okinawa Trough and consist of basalt to andesite. The seafloor rock samples from the same region were used for rock magnetic measurements and petrological observations. The integrated analysis of the magnetic anomaly and rock magnetic properties led to the following conclusions:

(i) The IHFs are associated with reduced magnetization reflecting the hydrothermal alteration of magnetic minerals present in the extrusive lavas and the deposits of non-magnetic hydrothermal material.

(ii) The basaltic rocks show high natural remanent magnetization (NRM) intensity ranging from 7 A/m to 214 A/m. The extremely strong NRM was caused by less oxidation, abundant single-domain-titanomagnetite grains formed under proper crystal growth rates, and low Ti content for titanomagnetites. These strongly magnetized host rocks produce large variations of magnetic anomalies in the Irabu knoll, resulting in a clear magnetic contrast between the IHFs and their surroundings areas.

(iii) The low magnetization zones (LMZs) related to the IHFs are located at the rim of the caldera floor in an elongated direction parallel to the local strike of the caldera, and extend into the caldera wall. These observations suggest that the hydrothermal fluids ascended through the caldera fault and caused accumulation of hydrothermal deposits and the occurrence of hydrothermally altered zones in both the caldera floor rim and wall.

(iv) The LMZ extends across several hundred meters along the caldera rim. Compared with similar hydrothermal fields of the Hakurei and Brothers situated in other arc-back-arc volcanoes with summit calderas, it is clarified that hydrothermal systems controlled by caldera faults have horizontal spatial scale equal to or larger than those of detachment-controlled large hydrothermal fields at slow-spreading ridges such as the TAG. It is implied that the permeability structure and style of hydrothermal circulation may play important roles in the formation of the larger demagnetized hydrothermal fluid pathways at caldera-controlled systems.

Keywords: Seafloor hydrothermal system, Marine magnetic anomaly, Rock magnetics, Okinawa Trough

Spatio-temporal scale of seafloor hydrothermal systems: Constraints from borehole and seafloor observations in the Mid-Okinawa Trough

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Drilling, submersible, and surface data suggest that an enormous hydrothermal reservoir with a horizontal extent of ~1500 m lies beneath the Iheya-North hydrothermal field. Heat flow exceeds 10 W/m2 within ~500 m of the Active Site, where active chimneys vent high-temperature fluid. At the Active Site, drilling encountered high-density (hard) layers 1–2 m thick and up to 90 m below seafloor (mbsf), and drilling through these layers led to hydrothermal fluid emission. Measurements of thermal and chemical discontinuities strongly suggest that a hydrological barrier confined the hydrothermal fluid below.
Eastward in the Western Basin, heat flow was up to 0.5–1 W/m2, substantially higher than the regional average (0.1 W/m2), although the surface morphology showed no sign of hydrothermal activity. Farther east, where the seafloor was flat but rough, surface heat flow values, including at IODP Site C0017, were much lower than in the surrounding area. Subbottom temperatures above 40 mbsf at Site C0017 indicated that the heat flow was consistently as low as the surface values (0.03 W/m2), but temperatures increased to 80 °C below 60 mbsf.
We used a 2-D time-dependent hydrothermal circulation model and performed simulations with and without the assumption of a hydrological barrier below the area from the Active Site to Site C0017. Simulations with a hydrological barrier with permeable windows below the Active Site and Site C0017 reproduced the observed hydrothermal conditions between 30 and 300 years after reservoir emplacement. Simulations assuming pure conduction or a continuous barrier could not reproduce the observed conditions.

Keywords: heat flow, Okinawa Trough, IODP, hydrothermal circulation

Post-caldera volcanism and hydrothermal activity revealed by AUV surveys in Myojin Knoll caldera, Izu-Ogasawara Arc, Japan

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Myojin Knoll caldera is one of submarine silicic calderas lying on the volcanic front of the northern Izu-Ogasawara arc and has attracted increasing attention since the discovery of a large hydrothermal field called the Sunrise deposit. Although many detailed surveys using a manned submersible have been conducted in Myojin Knoll caldera, they have explored too limited areas to draw a complete picture of the caldera and the Sunrise deposit. We carried out deep-sea surveys using an autonomous underwater vehicle (AUV) and obtained high-resolution bathymetric and magnetic data and sonar images covering ~70 % of the caldera. Besides post-caldera volcanism in the central cone, it was revealed that volcanic eruptions have commonly occurred in the caldera wall. Regular or irregular mottled patterns are ubiquitous in sonar images from the caldera floor, and those in the northwestern floor correspond to areas Mn precipitation was confirmed by a submersible survey. The Sunrise deposit lies in the foot of the caldera wall and is mainly composed of three ridges growing straight in the sloping direction. Only slight reduction in magnetization is observed in the deposit area, suggesting a dipping alteration zone beneath the Sunrise deposit. Preferential magma intrusion along a NW-SE direction was inferred from the distribution of high magnetization in the central cone and may play a major role in the occurrence and evolution of the Sunrise deposit in the southeastern caldera wall.

Enhanced and asymmetric melting beneath the southern Mariana back-arc spreading ridge, influenced by the subduction of the Pacific plate

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The southern Mariana Trough has distinct features from the remain of the Trough, such as slow seafloor spreading but axial high topography, gravitationally low anomaly and thick crust, slow crustal seismic velocity under the ridge influenced by slab-derived water, lack of currently active subaerial arc volcanoes but signatures of slab-derived or arc components in rocks sampled on and off the ridge axis. These features suggest enhanced melting beneath the ridge and the influence on the back-arc spreading process from water dehydrated from the subducted Pacific slab, which lies beneath the ridge. To reveal the distribution of melt and water in the upper mantle and the upper mantle dynamics in the southern Mariana Trough from electrical resistivity, we conducted a marine magnetotelluric experiment along a ~120 km transect across the ridge at ~13°N. Electromagnetic field data obtained at 9 sites were analyzed to image a 2-D electrical resistivity structure by inversion, after processing the data and striping seafloor topographic distortion from magnetotelluric responses. The obtained 2-D model shows 1) low resistivity at ~10-20 km depth beneath the ridge center but slightly offset to the trench side, 2) moderately low resistivity expanding asymmetrically to the remnant arc side and deeply under the conductor of 1), 3) high resistivity having a constant thickness of ~150 km under seafloor on the trench side, and 4) high resistivity under seafloor thickening from the ridge center up to ~50 km on the remnant arc side. These model features suggest 1) the presence of melt beneath the ridge center, possibly including slab-derived water 2) melt/water-retained mantle produced by asymmetric passive decompression melting of hydrous back-arc mantle, 3) cold and depleted mantle wedge and Pacific slab, and 4) cold and residual lithospheric mantle off the ridge axis. The electrical resistivity structure of the southern Mariana Trough, which clearly contrasts with the structure of the central Mariana Trough at 18°N that is absence of conductor beneath the ridge center, provides insights on the mantle dynamics and its relation to a characteristic tectonics and many observations in the southern Mariana Trough.

Deep-sea geomagnetic surveys across fracture zones and transform faults

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Water exists in the solid earth and affects solid earth dynamics through its circulation. Oceanic lithosphere would work as a carrier of water into the deep mantle. Our approach is the first attempt to understand the role for fracture zone and transform faults through where the water could be transported from the ocean into the oceanic lithosphere. Our targets are Nosappu fracture zone, Marie Celeste transform fault, and Argo transform fault. Nosappu fracture zone locates in the old Pacific lithosphere just before subducting into the deep mantle at the Kuril trench. Marie Celeste transform fault and Argo transform fault are boundaries of two oceanic lithospheres in Indian ocean with a large age offset. We conducted deep-sea geomagnetic field measurements together with surface geophysical surveys across the fracture zone and the transform faults during YK14-09 Yokosuka and KH-15-5 Hakuho-maru cruises. During YK14-09 cruise, we successfully conducted AUV Urashima geomagnetic surveys and surface geophysical surveys at the Nosappu fracture zone between 38°40'N and 40°40'N. We had four AUV Urashima dives across the fracture zone to obtain geomagnetic data. The length of each survey line is about 17 miles, which contain about 13 miles at the AUV depth of 3300m. The exception is one dive, which was forced to end at the middle of the survey line due to an emergency uplift of the AUV. The surface geophysical surveys allow us to collect multi-narrow beam bathymetry and geomagnetic field data, which cover total 1,200 miles in the AUV Urashima dive area. The surface geophysical surveys contain 17 survey lines across the fracture zone with their length of 40 miles for most, and survey lines along the fracture zone cover 110 miles at each side of the fracture zone. During KH-15-5 cruise, we successfully conducted two deep-tow magnetic surveys together with surface geophysical surveys across Marie Celeste transform fault at 65°15'E and Argo transform fault at 66°07'E. We used our deep-sea geomagnetic field measurement system which consists of a depth meter, a proton precession magnetometer, and flux-gate type magnetometers. The length of each survey line is about 25 miles. The intensity of the geomagnetic field at sea surface and at deep-sea with even height from the seafloor (2500 - 4000 m depth) were obtained. The geomagnetic anomaly field at deep-sea shows 2 - 3 times bigger amplitude and also has shorter wave length anomaly than those at sea surface. Our results from Nosappu fracture zone provide magnetization signature beneath the fracture zone. The magnetic boundary in the fracture zone is not a single boundary as predicted by a simple plate boundary model, but two magnetic boundaries parallel to Nosappu fracture zone are identified by the deep-sea vector geomagnetic anomaly field and by seafloor magnetization solution calculated from the surface geomagnetic anomaly field. We will discuss on magnetic property beneath fracture zones and transform faults as a result of reaction with water.

Keywords: fracture zone, transform fault, Deep-sea geomagnetic survey

High-temperature hydrothermal activities around Moho: diopsidites and anorthosites in Wadi Fizh, northern Oman ophiolite

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Reaction products between hydrothermal fluids and uppermost mantle harzburgite-lowermost crustal gabbro have been reported along Wadi Fizh, northern Oman ophiolite. They are named mantle diopsidite or crustal diopsidite. They construct network-like dike crosscutting structures of surrounding harzburgite or gabbro. The mantle diopsidite is mainly composed of diopsidic clinopyroxene, whereas the crustal diopsidite is of diopsidic clinopyroxene and anorthitic plagioclase. Here, we report new reaction product, crustal anorthosite, collected in the lowermost crustal section. It is always placed in the center of the crustal diopsidite network. It mainly consists of anorthitic plagioclase with minor titanite and chromian minerals as chromite and uvarovitic garnet.
Aqueous fluid inclusions trapped in negative crystal are evenly distributed in the crustal anorthosite. Some of them include angular-shaped or rounded daughter minerals as calcite or calcite-anhydrite composite, which were identified by Raman spectroscopic analyses. We estimated their captured temperature at 530ºC at least by conducting microthermometric analyses of the fluid inclusions by Heating-cooling stage. Furthermore, we examined their chemical characteristics by direct laser-shot sampling method operated by laser ablation-inductively coupled plasma-mass spectrometer (LA-ICP-MS). The results indicate that the trapped aqueous fluids contain an appreciable amount of Na, but no K.
Hydrothermal fluids involved in the crustal anorthosite formation transported hydrothermally immobile Cr, which was probably provided from chromite seam in the uppermost mantle section to precipitate chromites and uvarovitic garnet in the lowermost crustal section. Cr got soluble by forming complexes with anions as SO_4^{2-}, CO_3^{2-} and Cl^-. In addition, these hydrothermal fluids transported Fe, Mg, Ti and rare-earth elements. Our temperature estimation for the crustal anorthosite formation requires rather lower temperatures (530–600ºC) with considering microthermometric results and mineral equilibria, thus later circumstance than the mantle diopsidite and crustal diopsidite formation. Therefore, a series of high-temperature hydrothermal events had been significantly contributing to the chemical flux occurring around the boundary between the mantle and crustal sections.

Keywords: Hydrothermal circulation, Mid-ocean ridge, Chemical flux

Two types of basalts erupted in Active rift, Izu-Bonin arc, Japan

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We observed that two types of basalts have erupted in Sumisu rift, Izu-Bonin arc, Japan. High-Zr type basalts have higher concentration of K_2O, Na_2O, Y, Zr, Ni than Low-Zr basalts at similar FeO*/MgO ratio. High-Zr type basalts have higher Nb/Yb, Ce/Yb, Zr,Yb ratio and lower Ba/Th ratio than Low-Zr type basalts. The Sr isotope composition tends to be higher in direction from High-Zr type to Low-Zr type, although the Nd isotope composition of both types are similar. The Hf isotope composition ($^{176}Hf/^{177}Hf$) tends to be lower in direction from High-Zr type to Low-Zr type. The Hf isotope composition of Low-Zr type basalts similar to basalts from Sumisu Caldera in the volcanic front.
Olivines in High-Zr type basalts have higher wt. % NiO than those in Low-Zr type basalts at given Fo contents. Estimated primary olivine compositions are more magnesian (Fo = 92.3) in Low-Zr type basalts compared with those in High-Zr type basalts (Fo = 89.6).
Major element compositions of the calculated primary magmas indicate that the primary High-Zr type magmas segregated from source mantle at deeper than those of Low-Zr basalts (High-Zr: 1-2 GPa; Low-Zr: 2-3.5 GPa).
From the petrological and geochemical factors mentioned above, it is difficult to explain the differences of two types of basalts from different degrees of partial melting of the same source mantle and addition from slab-derived components (for example, sediment melt). Thus, we concluded that the two types of basalts are derived from different source mantle. This may indicate that the mantle beneath Sumisu rift have heterogeneities in the vertical direction (High-Zr type sources are in the shallow part of the mantle and Low-Zr type sources are in the deep part of the mantle). Moreover, Low- and High-Zr type basalts similar to West Philippine Basin MORBs and Shikoku basin basalts, respectively. The mantle heterogeneities beneath the Sumisu rift might have been related to the development of Izu-Bonin arc.
In this presentation, we also discuss the basalts from Myojin and Aogashima rift near the Sumisu rift.

Keywords: Izu-Bonin arc, Active rift, Back-arc basin basalts, Mantle heterogeneity

Researching of alkali-element enrichment using the SEM-EDS mapping analyses of BABB at the site C0012, IODP EXP 333 in the northern Shikoku Basin

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The Shikoku Basin is a back arc basin located westside of the Izu-Ogasawara (Bonin) arc, spreading was from 25 to 15 Ma. The backarc basin basalts (BABB) of the Shikoku Basin were recovered by drilling of DSDP, ODP and IODP researches. The BABB of the Site C0012, south of the Kii Peninsula, operated during the IODP Exp 333, show prominent enrichment of alkali elements. Haraguchi et al. (2015) reported that the identification of host-phase of alkali element by XRD method, and considered alteration environments. In this study, we consider secondary mineralization using mapping analyses by SEM-EDS method, and system of alkali element enrichments.
SiO_2 and MgO contents of these basalts are 47-55 and 5-8 wt%. These basalts show wide variation of enrichment of alkali elements, 2.3-7.5 and 0.4-4.2 wt% of Na_2O and K_2O. Na_2O+K_2O contents show 2 wt% higher trends than other BABBs in the Shikoku Basin at the same SiO_2 contents. The XRD results indicate that the analcime is found from the extremely Na-enriched, more than 4 wt% samples, and thomsonite is also found from many samples. The host phases of K are mainly identified into K-feldspar.
The one of weak point of the XRF analyses is the identification of feldspar. That is, identification of end-member, Ca, Na and K, is difficult because of the peak pattern among these end-member show similar characteristics. Especially, discriminate between anorthite and albite is difficult. Therefore, we attend the mapping analyzed of SEM-EDS method for discrimination of feldspar.
The results of SEM-EDS analyses, feldspar show high Na and K intensity, and the remarkable point is very low intensity of Ca. Therefore, feldspar is considered to completely replacing into alkali feldspar. In the high-Na samples, most feldspars are replaced into albite, on the other hand, high-K samples show K-enriched layer on the rim and clack of feldspar crystals. This K-enriched layer is considered to K-feldspar, equal to the result of XRF method. These observation indicate that the main alkali element-enriched process is albitization. The albitization occur under more than 100°C (e.g. Alt et al., 1986), and albite and K-feldspar occur under higher and lower temperature. The zeolite and clay mineral assemblages support this temperature (e.g. Miyashiro & Shido 1970).
Compared to the lithostratigraphy, the Na and K enrichments are prominent in the layer of low- and high-recovery ratios. And precipitation of zeolite is prominent in the High-Na, equal to low-recovery layers. Therefore, we consider that the Na enrichment occurred under high water/rock ratio with active hydrothermal circulation because of high water permeability of pillow lava. We also assume that the temperature at the path of hydrothermal fluids was high and that at the basement far from the path was low. Under this environment, basement was altered under zeolite facies alteration plagioclase was replace into alkali feldspar and result to enrichment of bulk alkali element enrichments.

Keywords: backarc basin basalts, hydrothermal activity, albitization, mapping analyses

Initial break-up process of Gondwana around the Natal Valley and the Mozambique Ridge, off South Africa.

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The Natal Valley and the Mozambique Ridge are considered to be formed during the initial break-up stage of Gondwana, however the detailed opening process is not well defined because of the poor geophysical survey data set in this region. To understand the crustal nature and history of the Natal Valley and the Mozambique Ridge, vector magnetic data are obtained during R/V Pelagia cruise 2009. Vector magnetic anomalies and magnetic boundary strikes are calculated from vector magnetic data. The total magnetic anomalies around this region are compiled by using those calculated by vector magnetic anomalies and marine magnetic anomalies from National Geophysical Data Center (NGDC) as well as the EMAG2 digital magnetic anomaly data set. Intensity of the crustal magnetization is deduced from the total magnetic anomalies incorporated with ETOPO1 topography data and offshore global sedimentation model. 2D magnetic block models are also estimated along some of the magnetic anomaly profiles. Moreover, crustal thickness is estimated from satellite derived gravity anomalies using with ETOPO1 topography and offshore global sedimentation model.

It is unlikely that the total magnetic anomalies in the northern Natal Valley (NNV) indicate the magnetic lineations proposed by previous studies. Low intensity of crustal magnetization similar to that of adjacent African continental area is observed on the area of the thick crust (about 14km) that is predominant in the NNV. The thick crust (about 14km) with the low intensity of magnetization most likely shows stretched continental crust. Areas of high intensity of crustal magnetization (more than +3A/m) with thin crust (about 12km) would represent the basaltic crust, and account for about 30% in the NNV. Magnetic boundary strikes obtained in the NNV most likely indicate the boundaries between basaltic intrusion and the stretched continental crust. The basaltic intrusion might be related to Karoo volcanism. In the southern part of the southern Natal Valley (S-SNV), NW-SE magnetic boundary strikes along the total magnetic anomaly profiles show the magnetic isochrones M10-M0 proposed by previous studies. Several fracture zones are suggested from the magnetic boundary strikes and intensity of crustal magnetization along observation lines. In the northern part of the southern Natal Valley (N-SNV), low intensity of crustal magnetization with the 9~11km crustal thickness are observed and these imply the stretched continental crust similar to the stretched continental crust area of the NNV. The N-SNV most likely shows the edge of the stretched continental crust, and seafloor spreading in the S-SNV started at the time of M10. In the northern part of the Mozambique Ridge (N-MOZR), features of intensity of crustal magnetization and crustal thickness are also similar to those in the NNV, suggesting the same formation process of the NNV. In contrast, high intensity of crustal magnetization is dominated in the southern part of the Mozambique Ridge (S-MOZR). The magnetic boundary strikes show the clear NW-SE trend however the magnetic anomaly pattern is not clear and crustal thickness is thicker more than 11km. High intensity of crustal magnetization and thick crust probably indicates that the S-MOZR was formed with excessive volcanism such as hotspot. NW-SE trend of magnetic boundary strikes may represent the trend of the spreading ridge. These results suggest that there is continental ocean boundary between the N-MOZR and the S-MOZR.

We will present the crustal features deduced from magnetic anomalies and gravity anomalies in the Natal Valley and the Mozambique Ridge, and discuss about the initial break-up process of Gondwana in this region.

Keywords: vector magnetic anomalies, break-up of Gondwana, Natal Valley, Mozambique Ridge

Seismicity at the Kairei Hydrothermal Vent Field Near the Rodriguez Triple Junction in the Indian Ocean: Part 2

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1. Introduction

In 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. 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 2015, we reported that we found more than 5000 micro earthquakes in this area during the 50 days seismicity observation. A swarm of micro earthquakes exists at a location about 1-3 km northwest of the Kairei field. The depth of the swarm is up to about 8km. The focal mechanisms in the swarm are normal type. An another swarm exists at the first segment of the central Indian Ridge. The depth of the swarm is deeper than that near the Kairei field.

This presentation will show relocated hypocenter distributions by HypoDD program (Waldhauser, 2001) which can estimate relative location of earthquakes.

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 redetermined hypocenter locations by HypoDD program (Waldhauser, 2001). We used an averaged 1D velocity structure at the swarm areas from the 3D structure estimated by Takata et al. (2015).

3. Results

The depth of the swarm at the Kairei field is about 4-7km. The focal mechanisms in the swarm are normal type. The depth of the swarm at the first segment of the central Indian Ridge is about 6-8km. This swarm is divided into upper and lower parts, and both incline at about 60-70°toward west. The focal mechanisms in the swarm are normal type.

To determine more detailed 3D velocity structure, we will determine hypocenter distribution and velocity structure by TomoDD(Zhang and Thurber, 2003).

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 area, seismicity

Preliminary report of KH-15-5 R/V Hakuho-maru cruise: Long-offset transform and ridge processes along the Central Indian Ridge 13-18°S

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KH-15-5 R/V Hakuho-maru cruise was conducted from 17th to 26th, January, 2016 along the Central Indain Ridge 13°-18°S. The objective of this cruise is to elucidate the contribution of long oceanic transform faults to global water flux and to explore the magmatic and hydrothermal activities along the ridge north of 18°45'S. During the cruise, we conducted geophysical mapping, deep-tow magnetic survey, rock samplings and CTD hydrocasts along the Marie Celeste transform fault, Argo transform fault and northern part of Seg-18 of the Central Indian Ridge under the collaboration with Mauritius Oceanographic Institute and Korean Institute of Ocean Science and Technology. The principal results of the cruise are summarized as follows.
1. Two deep-tow magnetic profiles across two active transform faults are done. A proton magnetometer and two three-component magnetometers were attached to the system. We succeeded to recover the variation of total magnetic filed intensity along ~45km profiles.
2. Along the Marie Celeste transform fault, we conducted 3 dredge hauls and 3 CTD hydrocasts. We recovered various kinds of rocks constituting oceanic crust, gabbroic lower crust to basaltic lava. CTD profiles and water sampling were successfully done from 5000m water depth, mainly for deep-sea microbiological studies. A turbidity meter attached to the dredge wire detected anomaly near the bottom on the median ridge.
3. Along the northern part of the CIR-Seg18, we conducted 6 dredge hauls. Two sites are located at the neo-volcanic zone within ridge axial valley, where we recovered very fresh lava. Three sites are designed to collect samples from off-axis area and slightly altered basalt samples are recovered. Last dredge haul was done at the lower part of an oceanic core complex, where an altered gabbro was recovered.
4. Four CTD hydrocasts were done along the ridge axis of Seg-18. We detected turbidity and transmissiometer anomalies, indicating the hydrothermal activity.

Keywords: mid-ocean ridge process, transform fault, hydrothermal activity, oceanic crust

Re-estimation of the evolution history of the West Philippine Basin

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The evolution and spreading history of the northernmost area of the West Phillipine Basin (east of the Luzon Okinawa Fracture Zone, north of Benham Rise and Urdaneta Plateau) in the Philippine Sea Plate was re-tested through the recent marine geophysical (direct magnetic total force observation and that estimated by the observation by the 3-component geomagnetic measurement) data by JAMSTEC fleets cruises and the hydrographic survey expeditions by the Japan Coast Guard. The result suggests that the area was constructed by the seafloor spreading during 23-30Ma just after around 33Ma, the cessation of the spreading at the Central Basin Spreading Centre (CBSC) and the Huatung Basin (the northwesternmost area of the WPB, between Gagua Ridge and Taiwan Island). The result is consistent with the dating from the collected rock samples by the JAMSTEC's ROV cruises in this area.

Keywords: West Philippine Basin, Geomagnetic anomaly

Seismic structure of continental rift and off-axis volcanism in the Okinawa trough back-arc basin

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Back-arc basins are a primary target to understand lithospheric evolution in extension associated with plate subduction. Most of the currently active back-arc basins host well-developed spreading centers where active seafloor spreading and creation of the oceanic crust have already occurred. However, rift structure at its initial stage, a key to understand how the continental lithosphere starts to break in a back-arc setting, is poorly documented. The Nansei-Shoto subduction zone forms a trench-arc-back-arc system from Kyushu, SW Japan, to Taiwan and provides a superb site for studying the interaction between the plate subduction and the rifting process in a continental back-arc basin. Behind this ~1,200-km-long subduction zone, the Okinawa trough forms an active continental rift zone along the southeastern end of the Eurasian plate. Although the total length of extension is estimated no more than 80 km (Sibuet et al., 1995), its rifting style is significantly variable along the trough: The northern and middle Okinawa trough is characterized by shallow bathymetry (< 1000 m) and has a wide (up to 230 km) basin structure. In the southern Okinawa trough, on the other hand, the maximum seafloor depth exceeds 2,000 m and a relatively narrow (60-100 km wide) topographic depression is formed along left-stepping en echelon rift axes. Early seismic studies suggest that crustal separation and active seafloor spreading has occurred in the central and southern Okinawa trough, whereas recent studies reveal that there exists over-15-km-thick crust beneath the rift axes even in the southern part where the deepest seafloor occurs, indicating that the whole part of the Okinawa trough is still at a stage of continental rifting (Hirata et al., 1990; Sibuet et al., 1998). Yet the fault system accommodating the crustal extension and its along-trough variation are little documented. The Okinawa trough is also known for active hydrothermal system discharging high temperature fluids, implying that the crustal rifting enhances the transfer of high-temperature magmatic bodies from the deep mantle up to near the seafloor. However, the relative roles of magmatic input and tectonic stretching in controlling the whole rifting system remain poorly understood.

Toward understanding the tectonic and volcanic processes associated with the continental back-arc rifting, JAMSTEC has been carrying out active-source seismic experiments in the Okinawa Trough. Multichannel seismic (MCS) reflection data and OBS refraction data were collected in the southern Okinawa trough (24-26ºN) in 2013 and in the northern Okinawa trough (29-30ºN) in 2015. Based on the data set, we present structural models of the Okinawa trough The MCS reflection data in the southern part show an almost symmetric rift system across the rift axis: Within the basin the sedimentary layers are highly cut by inward-dipping normal faults. Just beneath the rift axis a narrow intrusive structure is imaged, but a stable magma chamber is not observed on axis. Instead, a possible melt lens is found ~10 km horizontally away from the rift axis towards the arc. The rift structure over the possible magmatic body is disturbed, suggesting the off-axis volcanism is young or probably still active. Associated with the rifting process, the crust thins significantly from the original thickness of ~25 km and the thinnest crust of ~10 km occurs just beneath the rift axis. We interpret that the southern part of the Okinawa trough is at a transitional stage from continental rifting to seafloor spreading. The northern part of the Okinawa Trough, on the other hand, exhibits much wider deformed zone. This structural variation may be influenced by the southward increase in rifting rate along the Okinawa trough from ~2 cm/yr to ~5 cm/yr (Argus et al., 2011).

Keywords: Continental rift, back-arc, active-source study

Bathymetry and crustal structure of Taisho Bank and its vicinity in the southern Okinawa Trough

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Japan Coast Guard has conducted detailed bathymetric and multi-channel seismic reflection surveys in the southern Okinawa Trough. In this contribution, we will report detailed bathymetric feature and crustal structure of the Taisho Bank and its vicinity, thereby discussing the formation process of the bank.

Keywords: Okinawa Trough, Rifting, Bathymetric survey, Multi-channel seismic reflection survey

Spatial distribution of faults and their features in the middle Okinawa Trough on the western offshore region of Amami Oshima island.

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A numerous normal faults locate on the seafloor of the middle Okinawa Trough from the recent bathymetric surveys and the multichannel reflection seismic surveys by Hydrographic and Oceanographic Department, JCG. The predominant direction of them is N60E on the western offshore area of Amami Oshima island. The central axis of graven is shifted to the northwest side from the central axis of the depression of the middle Okinawa Trough, and arranged the left-stepping en echelon.

Keywords: Okinawa Trough, fault topography, normal fault

Occurrence and formation process of kaolin minerals in seafloor hydrothermal fields in the Okinawa Trough

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Abundant and diverse occurrence of hydrothermal clay minerals has been documented for seafloor hydrothermal fields in the Okinawa Trough, where the fluid discharge zone develops within thick sediment layer. Previous studies on clay minerals in sediments collected during IODP Expedition 331 conducted in 2010 revealed zonal distribution of alteration minerals, which was characterized by dominant occurrence of smectite - chlorite - illite along the depth beneath the seafloor of Iheya North Knoll. Another noteworthy was identification of kaolinite in shallow layer (shallower than 15 mbsf: meters below seafloor), because it suggests acidic alteration as well as high temperature alteration has occurred in the hydrothermal environment. We found occurrence of kaolin minerals in drilling sediment cores recently obtained from other sites in Iheya North Knoll. We studied their detailed occurrence and characteristics using XRD analysis and SEM-EDS observation, with a view to understanding their formation process.

The one sediment core was obtained from Site 9016B (27º46.6' N, 126º54.6' E, depth = 1124 m) during CK14-02 cruise conducted in 2014 using *D/V CHIKYU*. Site 9016B is located ~1 km apart from the activity center of Aki Site. Among the drilling core of 140 m total length, kaolin minerals were identified mainly recognized as at a depth from 8.5 to 11.0 mbsf, where alteration was visually observed as white colored. Within this range, dominant kaolin minerals changed along the depth; halloysite of fine spherules (~1 μm) at 8.7 mbsf, halloysite of tubular shape and kaolinite of hexagonal plates at 9.1 mbsf, dickite of block morphology (~15 μm) at 10.8 mbsf. Kaolin minerals were minor in the sediment from 11.0 mbsf and not identified in 11.4 mbsf, where illite and anhydrite appeared as dominant altered minerals. Together with recognition of unaltered volcanic material even in 9.1 mbsf, this change would reflect steep gradient of physical and/or chemical condition below the seafloor according to expected formation temperature of each kaolin mineral.

The other sediment core was obtained from Site BMSI-4 (27º47.4' N, 126º53.9' E, depth = 1048 m) by shallow drilling during BMS11 cruise conducted in 2011 using *R/V Hakurei No.2* . Site BMSI-4 is located about 300 m apart from the activity center of Original Site. Over most part of the obtained core of ~4.0 m length, occurrence of kaolinite was identified in sediment intensely altered as white gray colored. Within the 4 m range, amount of kaolinite increased along the depth, likely replacing smectite that was dominant in the layer shallower than 1.9 mbsf. Whereas neither halloysite nor dickite were identified. With recognition of sandy sediment without alteration in the surface (<0.05 mbsf) and induration of altered sediment including dolomite at 3.6 mbsf, abundance of kaolinite may reflect steep gradient physical and/or chemical condition below the seafloor.

Alteration zones of kaolin minerals recognized in these two sediments are commonly characterized by limited thickness of a few meters, and by subadjacent indurated sediment layer (anhydrite at Site 9016B and dolomite at BMSI-4) probably formed by high temperature alteration. Formation of kaolin minerals in these vertical profiles is difficult to be attributed to hydrothermal interaction related to mixing between upflow of the hydrothermal fluid component and seawater-like porewater. Rather, focused lateral flow of acidic fluid is more likely to explain well steep gradient in the

divergence or abundance of kaolin minerals. It is notable that occurrence of sulfide minerals such as sphalerite was recognized in both the upper and lower boundaries of the kaolin minerals alteration zone. The lateral flow of acidic fluid may play an important role in transportation of metal elements in subseafloor sediment layers.

Keywords: acid hydrothermal alteration, scientific ocean floor drilling, seafloor hydrothermal system, kaolinite, Okinawa Trough

Bathymetric survey and indicators of hydrothermal activity in the Amami Calderas using autonomous underwater vehicle

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1. Introduction

Amami Calderas are located on the volcanic front in the central Ryukyu Arc. Fe-Mn crusts of hydrothermal origin (Yokose et al., 2010, Gekkan Chikyu) and A Kuroko-type polymetallic sulfide ore enriched in Sb and Ag (Kumamoto University, 2012, Press Release) were dredged in the Amami Calderas. Although these dredged samples indicate the presence of hydrothermal activity, no direct evidence has not been obtained yet.

2. Method

Japan Coast Guard conducted high-resolution geophysical surveys with S/V *Takuyo* and AUV *Gondou* from 2013 to 2015 in the Amami Calderas. Large-scale bathymetry and water column data was acquired with hull-mounted EM710 and EM122 multibeam echo sounder (MBES) on S/V *Takuyo.* High-resolution bathymetry, sidescan sonar (SSS) imagery, and temperature data were obtained with Sonic2022 (400 kHz) MBES, EdgeTech2200M SSS (120 kHz) and SBE49 FastCAT CTD sensor on AUV *Gondou*, respectively. AUV was set to maintain a constant altitude of 50-70 m above the bottom.

3. Result

Plumes were detected as water column anomalies with MBES EM710 and EM122 at 4 sites in the Calderas at depths between 350 and 700 m. AUV survey were conducted at 3 sites and small depressions with width of several meters to dozens of meters were confirmed. Acoustic water column anomalies were also detected on SSS imagery in the 3 sites. Some plumes rises steeply from seafloor and others rises in smoke-shaped. Positive temperature anomalies were observed at plume-detected areas. Lineaments trending E-W or ENE-WSW are well-developed around these four sites and these north-facing and south-facing lineaments form graben structure.

4. Discussion

Plumes detected with ship MBES are considered to be bubble plumes associated with volcanic or hydrothermal activity, but some plumes in combination with positive temperature anomalies detected by AUV surveys can be interpreted as hydrothermal plumes. These hydrothermal systems in the Amami Calderas may be constrained by E-W or ENE-WSW trending faults which were probably formed by the rifting activity in the central Okinawa Trough, backarc basin of the Ryukyu Arc.

Keywords: high-resolution bathymetry, hydrothermal activity, autonomous underwater vehicle, Amami Calderas, central Ryukyu Arc

Magmatic activity around Iotori-shima Island in the Central Ryukyu, based on geophysical characteristics

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The Ryukyu Arc extends approximately 1,200 km between the islands of Kyushu and Taiwan, where the Philippine Sea Plate subducts northwestward under the Eurasian Plate. From east to west, the arc consists of the Ryukyu Trench, the Ryukyu Islands, the volcanic front (Tokara Islands), and the Okinawa Trough. Volcanic front and the Okinawa Trough are the main volcanic active area in the Ryukyu arc. It is widely considered that these two magmatic activities are separated in the North Ryukyu, but toward to the Central Ryukyu, these convergent with Okinawa Trough [e.g., Geshi and Ishizuka, 2007]. We conducted marine geophysical surveys around Iotori-shima Bank in the Central Ryukyu. The Iotori-shima Bank is a huge volcanic construction located west of Iotori-shima Island [Ishizuka et al., 2014], but the detail is still unclear. Based on the seafloor morphology, magnetic anomaly, and gravity anomaly, we will describe magmatic and tectonic activities of the Central Ryukyu around Iotori-shima Bank.

Many submarine volcanoes are identified in the southwest of Iotori-shima Island. The extension of volcanic front southwest of Iotori-shima Island is already pointed out [Sato et al., 2014] and this implies that the two kinds of magmatic activities in the volcanic front and Okinawa Trough do not necessarily converge at the Central Okinawa Trough. In addition, submarine volcanoes which would belong to the ancient volcanic front [Sato et al., 2014] are also observed just north of Igyo-Sone Bank. This suggests that the ancient volcanic front is limited in the southern part of Central Ryukyu.

West of the volcanic front, many submarine volcanoes including Iotori-shima Bank are identified. Southwest of Iotori-shima Bank, ENE-SSW trending many seafloor lineaments are observed. These would be normal faults caused by back arc tectonic activity, but are not observed in the Iotori-shima Bank. Higher Bouguer anomaly is observed at where lineaments are observed; therefore, this gravity anomaly would imply crustal thinning caused by back arc rifting, although the main back-arc rifting is centered far west of the survey area. Iotori-shima Bank is characterized by a caldera structure and many submarine volcanic knolls. Dipole magnetic anomalies are observed on relatively-small submarine knolls, on the other hand, the largest submarine knoll located southwestern part of the caldera is not accompanied by dipole magnetic anomaly. The relatively low magnetization intensity inside the caldera suggests that collapse of volcanic knoll, destruction of magnetic minerals, and/or originally low magnetization. Upward-continued Bouguer anomaly shows NE facing transition over the Iotori-shima Bank. This suggests that the Bank is under the influence of back-arc rifting, however, seafloor lineaments are not observed on its surface.

Keywords: Seafloor morphology, Magnetic anomaly, Gravity anomaly, Ryukyu arc

Discussion on the relationship between the shallow geological condition around the northern Okinawa trough area and a magnitude (M) 7.1 earthquake offshore west of Satsuma peninsula on November 14 2015

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On November 14, there was a magnitude (M) 7.1 earthquake offshore west of Satsuma peninsula. JMA reported the CMT mechanism of the earthquake was a strike-slip fault type with NW-SE direction of its tension axis. But before the earthquake, no earthquake over M7 has been reported in the area. Japan Coast Guard conducted multi-channel seismic reflection and wide-angle refraction seismic surveys around the area before the earthquake. The time migration image shows several normal faults accompany with topographic gaps of the top of the sediment layers. The direction of the faults is NE-SW which corresponds to the tension axis of the earthquake. The general trend of the Okinawa trough, NNE-SSW, is different to the normal faults direction, but it looks similar to the general direction of topographic highs that are scattered in the northern Okinawa trough. We are going to discuss the shallow geological condition and the tectonics around the area using the result of our surveys.

Keywords: culstal strucuture, MCS

Active shallow structures of the Nankai forearc region off Hyuga

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Active deformation structures have been well investigated by swath bathymetry survey, submersible dive, MCS survey and deepsea drilling in the Nankai subduction zone. However, few studies have focused on the structure off Hyuga, the western tip of the Nankai Trough, due to limited research activity. The general trend of the Nankai accretionary prism is NE-SW to ENE-WSW from off Tokai to off Ashizuri. In contrast, the trend of the forearc basin and the prism slope off Hyuga is NNE-SSW, which is the same trend as the Ryukyu trench. The Hyuga basin located between the Ashizuri spur and the Kyushu-Palau Ridge apparently shows no distinct trenchward limit such as the outer ridges observed at the other regions of the Nankai margin. Our objective of this study is to obtain high resolution subsurface structures of the Hyuga forearc region and to evaluate recent tectonic activity.

We carried out deep-towed subbottom profiler (SBP) survey by ROV NSS (Navigable Sampling System) during R/V Hakuho-maru KH-15-2 cruise. High resolution profiling was successfully conducted by a chirp system of EdgeTech DW-106. The first target is the NNE-SSW trending Oyodo Knoll developed eastward of the Hyuga basin. The SBP shows the almost symmetrical ridge morphology cut by active flexures on both sides suggesting compressional deformation. Although faults are not detected at the surface sequence at least down to 60 meter except for two minor reverse faults, sediment thickness changes across the flexures indicate continuous deformation to the present. The second target is the western margin of the Hyuga basin where steep slopes suggestive of fault control are distributed from north to south. Two transects of SBP surveys are conducted at the southern and central regions of the western margin. SBP records of both transects show active flexures with relative landward uplift. The southern site is characterized by a V-shaped depression landward of the flexure and its sediment fill indicative of transtensional deformation. The central site also shows undulation of basin sedimentary layers landward of the flexure suggesting strike slip deformation. Our high-resolution subbottom profiles of the Hyuga forearc region revealed that the topographic framework have been formed by ongoing active deformations under high sedimentation rate.

Keywords: subbottom profiler, active flexure, active fault

Crustal structure from the Wakasa Bay to the western Yamato Basin, Japan Sea, deduced from marine seismic survey

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We participated in the “Integrated Research Project on Seismic and Tsunami Hazards Around the Sea of Japan” conducted by the MEXT of Japan; in particular, we performed seismic surveys from the R/V KAIREI in the Japan Sea beginning in 2014. In August 2015, we conducted a marine seismic survey to study the crustal structure around the area from the Wakasa Bay to the western Yamato Basin. This survey area is located in a region where the focal mechanism transitions from a reverse fault to a strike-slip fault (e.g., Mikumo, 1990; Terakawa and Matsuura, 2010) and where several earthquakes with a magnitude of 6.5 or larger have occurred in the past 100 years. Furthermore, the primary active faults in this study area have been estimated to exist in the margin of the Oki trough and the marginal terrace (e.g., Okamura, 2013; the Committee for Technical Investigation on Large-scale Earthquake in Sea of Japan, 2014).
The formation of source faults in the Japan Sea is divided into at least two types. One type is formed when reverse faults have been reactivated by inversion tectonics (e.g., Okamura et al., 1995). The other type is formed by a reverse fault occurring in the boundary of the crustal structure (e.g., No et al., 2014). Therefore, revealing the relationship between the crustal structure and tectonic history is one of an important key in the research of the source faults in the Japan Sea. In particular, because the Yamato Basin is the only large basin in the Japan Sea that is capable of being fully investigated (as a result of the exclusive economic zone), research on the crustal structure of the Yamato Basin contributes to the discussion of the source faults that formed in the land-side margin of the Yamato Basin.
We conducted multichannel seismic reflection (MCS) surveys along nine lines. Some seismic lines were crooked to avoid the many fishing operations and equipment located in the survey area. To obtain high-quality MCS data, we shot an air gun array with 50 m spacing. The tuned air gun array had a maximum capacity of 7,800 cu in (approximately 130 L) and consisted of 32 air guns. The standard air pressure was 2,000 psi (approximately 14 MPa). The air gun array was kept 10 m below the sea surface throughout the experiment. During the air gun shooting, we towed a 444-channel hydrophone streamer cable. The group interval was 12.5 m, and the cable was approximately 6 km long. The towing depth of the streamer cable was maintained at 12 m below the sea surface by depth controllers. The sampling rate and record length were 2 ms and 16 s, respectively. Moreover, the air gun array with a shot spacing of 200 m in the seismic refraction/reflection survey conducted using 54 ocean bottom seismographs (OBSs). Moreover, the airgun array with a shot spacing of 200 m in the seismic refraction/reflection survey by 54 OBSs used almost the same configuration as the MCS survey. In addition, because onshore-offshore seismic profiles in the south extension were conducted by Ito et al. (2006), Nakanishi et al. (2008), and Earthquake Research Institute (2016), we are able to obtain the crustal structure imaging of the central Japan, ranging from the Nankai Trough to the Japan Sea.
We present an outline of the crustal structure obtained from preliminary results of MCS imaging and the P-wave velocity structure of the study area.

Keywords: Japan Sea, Yamato Basin, Crustal structure, MCS, OBS

13 year continuous observation of ambient gamma ray at cold seepage site on deep seafloor with a multidisciplinary cabled observatory off Hatsushima Island in Sagami Bay

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At cold seepage site on deep seafloor off Hatsushima Island in Sagami Bay at a depth of 1175 m, multidisciplinary observation of deep-sea environment has been carried out since 1993 with a cabled observatory. The present observatory, to which a gamma ray sensor with 3 inch NaI(Tl) scintillation detector was attached, was deployed in March 2000 about 40 m north of the present location, recovered in March 2002, and re-deployed at the present location in November 2002. After the re-deployment, the observation at the same location continued up to date for more than 13 years. The specifications and preliminary observational results before the 2011 off the Pacific Coast of Tohoku Earthquake (hereafter "off Tohoku Earthquake") occurred are described in Refs. 1 and 2. In this presentation, the result of the long-term gamma ray observation to date will be reported.
Major events observed were as follows;
After the off Tohoku earthquake occurred, rapid signal level increase of Bi-214 and K-40 was observed. This would not be associated with the off Tohoku Earthquake itself, but would be associated with the mudflow caused by the Eastern Shizuoka Prefecture Earthquake (M6.4) which occurred on March 15, 2011; 4 days after the off Tohoku Earthquake.
After this event, significant event was not recognized except the abrupt signal level fluctuation associated with the underwater work with remotely operated vehicle (ROV) near the observatory.
Since December in 2014, gradual signal level decrease of Bi-214 was observed, while the signal level decrease of K-40 started gradually shortly after the off Tohoku Earthquake, roughly in October 2011. The effect of Cs-137 associated with atomic plant accident on the signal level of Bi-214 should be considered.
Throughout the observation period, predominant event is the significant signal level increase of Bi-214 in October 2006, whose fluctuation pattern was different from the other fluctuations associated with the disturbance on seafloor caused by the sedimentation or the underwater work with the ROV. It would reflect the sub-bottom incident associated with tectonic deformation.
References
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2) Iwase and Takahashi, JpGU meeting 2011, SCG059-P19 (2011).

Keywords: NaI(Tl) scintillation detector, mudflow, multidisciplinary cabled observatory

Observation of sea floor vertical motion at the Boso slow slip region

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1. Introduction

To mitigate earthquake hazards, it is important to understand earthquake generation processes and forecast earthquakes through numerical simulation using earthquake generation models. To assess the models, we make a forecast of the next step by the models, then check this through observations, and make correction in the models. We should continue this revising process in several times. Since earthquakes have long recurrence time, we need usually hundreds or thousands years to assess the models. The Boso slow slip events (SSE) have short recurrence time as a few years, and locate in a depth where earthquakes occur (about 10-20 km). Hence, we can obtain data for two or three SSE cycles and assess the models within 10-15 years, if we may be able to treat earthquakes and slow events as events of the same category. The present observation is the first step of this assessment process. From vertical movement on the sea floor using ocean bottom pressure gauges (OBPs), we investigate the slip area of the Boso SSE.

2. Observation and analyses

We conducted an ocean bottom pressure survey at the southeast area of the Boso SSE from September 2013 to July 2015 using R/V Hakuho-maru and R/V Natsushima of JAMSTEC. In this survey period, the Boso SSE occurred from December 2013 to January 2014. We used three OBPs made by ERI, University of Tokyo, with a pressure gauge, 8B2000-2 or 8B7000-2 by Paroscientific Inc., and recorders equipped an atomic clock, SA.45s CSAC by Microsemi Co.

In analyses, we conduct transformation from pressure data to depth data, at first. Then, resampling, removal of tide components, estimation of correlation component with temperature, estimation of oceanic fluctuation from correlation between observation stations, smoothing, and removal of long-term trend due to instrumental aging are performed on the data. From these analyses, we try to estimate vertical movement on the sea floor.

3. Results

The estimated movement before and after the 2013-2014 Boso SSE shows no significant movement larger than the standard deviation of the estimated vertical movement.

Acknowledgement

We thank the captains and crew of R/V Hakuho-maru and R/V Natsushima of JAMSTEC for their support. This work was supported by JSPS (25287109).

Keywords: Boso slow slip, pressure gauge, ocean bottom observation, vertical motion

Development of on-demand buoy observation system for crustal displacement

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We have developed an on-demand buoy observation system for crustal displacement and tsunami since 2012 in collaboration with Japan Agency for Marine Earth Science and Technology, Tohoku University and Japan Aerospace Exploration Agency. This system has some characteristics, which are use of pressure sensor on the sea bottom and precise point positioning system on the buoy to detect vertical crustal displacement, acoustic measurement between the buoy and seafloor transponders, slack mooring for realtime observation in high speed sea current with the velocity of over five knots. In addition, we adopted double pulse for acoustic data transmission of the pressure sensor data from sea bottom. Collected data from the sea bottom and through the acoustic measurement is sent to the land station using iridium satellite. We succeeded observation of micro tsunami propagated from the Iqique tsunami, Chile, in the Nankai Trough area. We collect pressure sensor data on the seafloor pressure unit with a sampling of 15 seconds in tsunami mode via a wire-end station below 1000 meters from the sea surface, and carry out above acoustic measurement with the sampling of one week. A buoy station on the buoy controls all actions related to the collection of the data for the observation and navigation, saving data, and data transmission to the land station. However, we need to revise to realize long term observation of one or two years and improvement of the reliability for the observation. We have issues on a rate of the data recovery, due to inhomogeneous of the acoustic characteristic of the seafloor pressure unit, contamination of reflection signals from the sea surface into the data transmission signals from the seafloor pressure unit to the wire-end station, troubles on the wire line between the wire-end station and the buoy by buoy rotation, and so on. Therefore, we revised the observation buoy system, which includes change of the flame of the seafloor pressure unit to improve acoustic characteristic, installation of the precise point positioning systems using MADOCA system and MB-ONE to derive vertical crustal displacement from seafloor pressure data, improvement of the control system on the buoy station to enable to start observation according to orders from the land station, and attachment of a fin to control the buoy rotation. And we tuned action flow to decrease electrical consumption and adopted solar panels as the batteries of the entire of the system. To improve accuracy of the acoustic measurement, we need to decrease the slack ratio. We succeeded it from 1.6 to 1.58 at this moment. We try to decrease the slack ratio more to realize accurate acoustic measurement. In this presentation, we report the current sea trials, which started in January, 2016.

Keywords: crustal displacement, real-time observation, buoy

4-D active monitoring of time-variant ocean bottom structure including a gas chimney type deposit methane hydrate by using seismic wave simulations

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Recently the studies of methane hydrate (*ie.*, MH) have been developed and a lot of MH reservoir areas were found around Japan. They are characterized by following two types of origin/deposit (1) thermal decomposition origin (*ie.*, gas chimney type deposit) and (2) biodegradation origin (*ie.*, sand filling type deposit) (Matsumoto *et al.*, 2009). Some 3-D seismic surveys were conducted in the Sea of Japan to clarify the feature of an ocean bottom structures with a gas chimney type deposit of MH (*e.g.*, Saeki *et al.*, 2009). To avoid any environmental pollution accompanying to MH developments in future, it is necessary to actively and continuously monitor the changes of geophysical and geochemical properties of the ocean bottom structure including MH deposit. We therefore have developed a 4-D active monitoring methodology and technology to observe a time-variant reservoir such as MH or oil-gas reservoir under the water (*e.g.*, Tsuruga *et al.*, 2013).

In this study we show the preliminary results of characteristic wave phases of reflected wave from MH reservoirs and some effective seismic source- receivers array designs through simulating the seismic wave filed by means of a finite difference method (Larsen, 2000). We calculated seismic waveform records on three types of underground seismic structure models as follows: (Model-1) a horizontal multilayered structure model, (Model-2) a horizontal multilayered structure model including a thin MH layer and (Model-3) a horizontal multilayered structure with a chimney type MH deposit in a sand stone layer. The horizontal multilayered structure model consists of four layers with a sea water, a MH or sand stone, mud stone, over an igneous basement rock.

As the results, Model-1 is the horizontal multilayer structure, so no characteristic wave phase is observed. Then the reflect wave from the MH deposit travels faster than that from sea water in the Model-2. It is because MH deposit has higher velocity. Finally, the MH deposit in Model-3 is in the sand stone layer, so the wave that is not reflected from the horizontal layer is observed. Also, we found some effective seismic phase to monitor the time-variant MH reservoir and then tried to optimize an effective source-receivers array design, the preliminary result showed that two types of receivers arrays are effective to monitor the changes of seismic velocity in a MH reservoir by using some particular seismic phases reflected at the boundary of a surface-type MH layer. One of the arrays is constructed my both a horizontal array and a vertical one with seismic active sources located at the sea bottom as we call it, ‘T-type array’. Also the other is called ‘H-type array’ which consists of a horizontal array and two vertical arrays with the seismic source at the sea bottom.

Keywords: Methane hydrate, Monitoring, Time-lapse

High quiality 4-D active monittoring of an ocean bottom strucuture by inovative active seismic systems

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We have been developing new method and technology to monitor the geophysical and/or geochemical changes in time and space of an ocean bottom structure including some reservoirs such as methane hydrate, oil-gas and seabed resources by using an autonomous underwater vehicle (AUV) as an innovative observation platform.
The ocean system is a total system which consists of a physical, chemical, biological and earth's processes. Tokyo University of Marine Science and Technology is encouraging to develop the effective ocean survey technology and to educate students in order to contribute to an environmental assessment during an ocean development. A real time high-quality monitoring of the various environmental perturbations accompanying to underwater developments is very difficult but we know that the measurements of high-density high-quality accurate data in both 3-D space and 1-D time will be very effective and useful particularly by means of the resource such as AUV and ships. We assumed our survey target area including a reservoir is a relatively narrow squared area with several 100s meters to a few kilometers in length and about 2000 m in deoth. The steps in the study are: (1) to develop an active seismic monitoring system with active sources and receiver arrays by using AUV effectively combining with both a mobile observation system towing in water and a self-controlled observation system installed at the sea floor, and (2) to do test of both observation systems in water simultaneously in a target area. Then it is (3) to evaluate the data quality and quantity for detecting the geophysical changes of underground structure to establish the basic active monitoring method and technology in an oceanic area. Recently we have three major objectives of our study as follows: (A) to understand the seismological feature quantitatively from the wave field simulation with a reservoir of ocean bottom resources such as methane hydrate and submarine hydrothermal deposits as a target (*e.g.*, Tsuruga *et al.*, 2010; Tachibana and Tsuruga, 2015; Mogi and Tsuruga, in this meeting) and (B) to investigate a ACROSS field test to detect the changes of wave fields by an air-injection on a land area (*e.g.*, , Kasahara *et al.*, 2012; Tsuruga *et al.*, 2012) as well as (C) to develop observation system (*e.g.*,, Tsuruga *et al.*, 2013). In this report we show the preliminary results of the developments of portable seismic source system which is towed in water. We show that our active seismic source system and receiver array system have small IC tips of atomic clock and GPS system as an accurate clock in water. We could thus solve a big problem of clock precision in water.
In future after the observation system will be complete, we will do some field tests in oceanic area at the above mentioned step-(2) and finally we will progress to a new observation integrated strategy to monitor any other time-variant items of geochemical and biological observation as well as the geophysical ocean bottom structure.

Keywords: ocean bottom , 4D monitoring of understructure, development of ocean bottom resources, AUV

Development of database system for integrating various models of seismic velocity structure and geometry of the subducting plate around Japan

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To estimate strong motions caused by earthquakes that could occur in Japan in future and predict seismic hazards, it is necessary to create an accurate model of geometry of the subducting plate and seismic velocity structure, particularly obtained by offshore seismic survey and observations. Most of various kinds of seismic velocity structure models including plate boundary around Japan are presented. However, they are managed individually by each organization constructing the model. To create a new and accurate model of geometry of the subducting plate and seismic velocity structure model, first we need to integrate existing models and clarify the spatial distribution of models regardless of their kinds. Here we have developed database system to store the data of various kinds of velocity structure and plate geometry around Japan. In this database system, various seismic structure models are stored as data, which are three-dimensional (3D) seismic velocity models obtained by seismic tomography, plate geometry, 2D seismic velocity structure models, 2D plate geometry obtained by offshore seismic survey, and hypocenter distribution determined by offshore observation and JMA. Using this database system, users can obtain several structure models at once. This database system can provide not only original data of models but also equal interval grid data, and KML data. The equal interval grid data is output as the text file and have the same scale for all kinds of models, which are produced by bicubic-interpolation of original data. On GUI of the database system, users can know what kind of models and hypocenter distribution exist around the Japanese Islands graphically, and obtain the data of different kinds of models existing in the rectangle region specified by users. The region is specified by setting a profile and the distance from the profile in the map on GUI. The equal interval grid data of 3D seismic velocity model is prepared for the vertical cross section cut by the profile specified by user, which show the distribution of seismic velocity or velocity perturbation. The equal interval grid data of plate geometry are created for the region specified by user. The equal interval grid data of 2D seismic velocity structure model and 2D plate geometry model are created from all data of the models crossing the region and selected by user. Using KML files provided by the database, the data of different kinds of models are visualized in Google Earth at once. Therefore this database system with Google Earth will enable us to create a new accurate model of geometry of the subducting plate and seismic velocity structure around Japan. Acknowledgement: This study is carried out as ‘Research project for Development of seismological information database for modeling seismic velocity structure offshore around Japan’ funded by MEXT, Japan. We are grateful to all who have kindly agreed to the incorporation of their model and data into our system. The earthquake catalog used in this study is produced by the Japan Meteorological Agency, in cooperation with the Ministry of Education, Culture, Sports, Science and Technology. The catalog is based on seismic data provided by the National Research Institute for Earth Science and Disaster Prevention, the Japan Meteorological Agency, Hokkaido University, Hirosaki University, Tohoku University, the University of Tokyo, Nagoya University, Kyoto University, Kochi University, Kyushu University, Kagoshima University, the National Institute of Advanced Industrial Science and Technology, the Geographical Survey Institute, Tokyo Metropolis, Shizuoka Prefecture, Hot Springs Research Institute of Kanagawa Prefecture, Yokohama City, and Japan Agency for Marine-Earth Science and Technology. We are grateful to Zhu Riming, Co. Ltd. VisCore, for his skill to develop this database system and data conversion system from the original data to KML.

