Reports of IODP Exp. 359: Sea Level, Currents, and Monsoon Evolution in the Indian Ocean

*Mayuri Inoue[1], Santi Dwi Pratiwi[2], Masatoshi Nakakuni[3], Kaoru Niino[4], Christian Betzler[5], Gregor P Eberli[6], Carlos A Alvarez-Zarikian[7], IODP Expedition 359 Scientists[7]

1.Graduate School of Natural Science and Technology, Okayama University, 2.Graduate School of Engineering and Resource Science, Akita University, 3.Graduate School of Engineering, Soka University, 4.Graduate School of Science and Engineering, Yamagata University, 5.Institute of Geology, CEN, University of Hamburg, 6.Department of Marine Geosciences, University of Miami, 7.International Ocean Discovery Program, Texas A&M University

IODP Expedition 359 was conducted from October to November in 2015 in the Maldives Archipelago in the Indian Ocean to study changes of sea level, currents and monsoon evolution in the Indian Ocean during the Neogene. The monsoon is one of the most dramatic recurring weather phenomena on Earth and affects over a billion people every year. However, little is known about when the monsoon started and how it changed over time. The monsoon brings rainfall to the continents, which is critical for agriculture, and increased river discharge to the oceans. It is known for its winds that change direction with the winter and summer monsoon. Many studies have tried to reconstruct the monsoon history from the rain-induced weathering and discharge into the ocean. In Expedition 359 a novel approach was taken to extract the history of the monsoon from wind-related features. The winds of the monsoon drive the ocean currents across the Maldives. These currents, like rivers in the ocean, carry sediment. In the Inner Sea of the Maldives the currents slow down and release the sediment to build large drift deposits. The sediments in these drifts hold the record of climate change and monsoon activity for the last 12 million years. The sediments, however, also buried ancient reef buildups that flourished in the Inner Sea before the monsoon started. These reefs hold the history of sea level changes before the onset of the monsoon. In this way, IODP Expedition 359 was able to reconstruct environmental changes in the Indian Ocean since the late Oligocene to the present.

Keywords: Maldives, Monsoon, Carbonate, Sea Level Change

IODP Expedition 357: Atlantis Massif Serpentinization and Life

Gretchen Früh-Green[1], Beth Orcutt[2], *Yuki Morono[3,4], IODP Exp. 357 Scientists

1.ETH Zurich, 2.Bigelow Laboratory for Ocean Sciences, 3.Kochi Institute for Core Sample Research, JAMSTEC, 4.R&D Center for Submarine Resources, JAMSTEC

Serpentinization is a fundamental process that controls rheology and geophysical properties of the oceanic lithosphere and has major consequences for heat flux, geochemical cycles and microbial activity in a wide variety of oceanic and terrestrial environments. International Ocean Discovery Program (IODP) Expedition 357: Atlantis Massif Serpentinization and Life was conducted by the *James Cook* (Natural Environment Research Council, UK) at the Atlantis Massif on the slow-spreading Mid-Atlantic Ridge, where the Lost City vent field stands near the summit of the ridge, to better understand the role of serpentinization in driving hydrothermal systems, in sustaining microbiological communities, and in the sequestration of carbon in ultramafic rock.
Expedition 357 was the first IODP Expedition to utilize seabed rock drills as a method for acquiring sub-surface core material. During Expedition 357, two seabed rock drills were deployed: the MeBo 70 rock drill from MARUM (Bremen, Germany) and the RD2 rock drill from the British Geological Survey. Although drilling conditions proved challenging, the drills recovered a wide range of lower crustal and upper mantle lithologies with varying degrees of alteration and deformation in the Atlantis Massif. The total length of cores recovered by two seabed drills during Expedition 357 was 57 m after 109 m of total penetration, and with an average core recovery of 53% at nine different sites. We present an overview of the scientific objective, operational performance, and some preliminary information from onboard activities of Expedition 357 including microbiological studies to study the links between serpentinization processes and life that can be supported in low temperature ultramafic hydrothermal systems.

Deployment of logging while drilling at hydrothermal fields in Okinawa Trough: Preliminary results of CK16-01 Cruise

*Saneatsu Saito[1], Yohei Hamada[1], Takeshi Tsuji[2], Kazuya Shiraishi[1], Kan-Hsi Hsiung[1], Chandoeun Eng[2], Keita Yoshimoto[3], Yukari Kido[1], Yoshinori Sanada[1], Hidenori Kumagai[1], Tatsuo Nozaki[1], Jun-ichiro Ishibashi[2], Lena Maeda[1], CK16-01 Shipboard Party

1.Japan Agency for Marine-Earth Science and Technology, 2.Kyushu University, 3.Yamaguchi University

A scientific drilling cruise CK16-01 was conducted by D/V Chikyu at the active hydrothermal fields on Iheya-North Knoll and Iheya Minor Ridge in the Okinawa Trough in February-March of 2016, as a part of the Cross-ministerial Strategic Innovation Promotion Program (SIP). During the former half of the cruise logging while drilling (LWD) was deployed to investigate subseafloor stratigraphy and hydrogeology. The long-term monitoring apparatus, "Kuroko-ore cultivation apparatus", was also installed, that is equipped with sensors to monitor the secular variation of pressure, temperature, flow rate, and precipitation weight within the apparatus on artificial hydrothermal vents. In succession to the operations, coring were conducted in the later half of the cruise.
The LWD tools acquire natural gamma ray, resistivity, borehole images, and annular pressure and temperature data. Based on the results from the CK14-04 cruise in 2014 at the Iheya-North Knoll, LWD was useful to identify and characterize the submarine hydrothermal deposits and the LWD survey enhanced the successful recovery of sulfide samples. In this presentation, we report the preliminary results of LWD deployed during the CK16-01 Cruise.

Keywords: Okinawa Trough, Cross-ministerial Strategic Innovation Promotion Program (SIP), Logging While Drilling, Seafloor hydrothermal Deposit, Iheya-North Knoll, Iheya Minor Ridge

Estimation of under-seafloor fluid on temperature and volume from the logging-while-drilling data in an active hydrothermal field

*Yohei Hamada[1], Saneatsu Saito[2], Yoshinori Sanada[2], Yuka Masaki[2], KYAW MOE[2], Yukari Kido[2], Hidenori Kumagai[2], Tatsuo Nozaki[2], Katsuhiko Suzuki[2], Maeda Lena[2], CK14-04 Cruise member[2], CK16-01 Cruise member[2]

1.Japan Agency for Marine-Earth Science and Technology Kochi Institute for Core Sample Research, 2.Japan Agency for Marine-Earth Science and Technology

In Jul. of 2014 and in Feb. -Mar. of 2016, offshore drillings on Iheya-North Knoll and Iheya minor ridge, Okinawa Trough, were executed as part of Next-generation technology for ocean resources survey, which is a research program in Cross-ministerial Strategic Innovation Promotion Program (SIP). In these expeditions, logging-while- drilling (LWD) and measuring-while-drilling (MWD) were conducted around Iheya area, including Iheya-North (original) site (C9011 -C9015) and in Iheya-North Aki site (C9016), to investigate spatial distribution of hydrothermal deposit and geothermal fluid reservoir. LWD tools are supplemented by a measurement-while-drilling tool that is located above the LWD tools in the bottom-hole-assembly. In this expedition, arcVISION and TeleScope were integrated as LWD and MWD respectively. The arcVISION obtained physical properties along borehole (resistivity, natural gamma-ray), and the TeleScope collected drilling mechanics data and transferred them to the surface by mud pulse telemetry. Both of these tools included annular pressure-while-drilling (APWD). Annular pressure and temperature were monitored by the APWD to detect possible exceedingly-high-temperature geofluid. In addition, drilling fluid was continuously circulated at sufficient flow rate to protect LWD tools against high temperature (non-stop driller system).
At C9012 and C9016, the arcVISION clearly detected temperature anomaly at 234 meter below the seafloor (mbsf) and 80 mbsf, respectively. Temperature quickly increases at that depth and it would reflect the existence of high-temperature heat source. During the drilling, however, drilling water was continuously circulated at high flow-rate (2600L/min) as stated above. Thus the measured temperature is not exactly in-situ temperature, but the profile of the temperature reflects the temperature variation of each stratigraphic layer of the bore hole.
To investigate the detail of the heat source, such as in-situ temperature and quantity of heat, we performed numerical analyses of thermal fluid and energy-balance assuming injection of high-temperature fluid. We combined pressure loss theory of double cylinders and temperature equation to replicate the fluid flow and its temperature between borehole wall and drilling pipe during the thermofluid injection. As the result, we estimated the temperature and the volume of injected fluid to be 115oC~ and 17.3 m3, respectively (at C9012) from the calculation. This temperature is lower than that of a hydrothermal vent which had been found near the hole (300oC). We will present preliminary results of the calculation for the newest cruise (CK16-01).

Keywords: Okinawa Trough, Seafloor hydrothermal Deposit, Cross-ministerial Strategic Innovation Promotion Program (SIP), Logging-while-drilling

Current status of the Japan Beyond-Brittle Project (JBBP)

*Hiroshi Asanuma[1], Noriyoshi Tsuchiya[2]

1.AIST, 2.Tohoku Univ.

A team of Japanese geothermal researchers have initiated a Japan Beyond-Brittle Project (JBBP) which aims to realize commercial geothermal power generation using the engineered geothermal systems (EGS) technologies in the brittle-ductile transition (BDT) in 2011. Because the geothermal energy has advantages in environmental burden, energy security and stability, the government of Japan expects drastic increase of geothermal power generation as an output of the JBBP and funded for drawing of a roadmap up to 2050 to generate several GW of power from the BDT. The authors made a one year investigation to identify scientific and technological key breakthroughs and planned a series of national project to achieve goal as described in the presentation

Keywords: JBBP, Geothermal power generation

Relationship between the length of drilled core and the depth of drilled hole -Examples from IODP Exp. 346 U1425 and U1427

*Tomohisa Irino[1], Johanna Lofi[2], Akinori Karasuda[3], Takuya Sagawa[4], Ken Ikehara[5], Shunsuke Kurokawa[3], Ryuji Tada[3]

1.Faculty of Environmental Earth Science, Hokkaido University, 2.Universite de Montpellier, 3.Department of Earth and Planetary Science, University of Tokyo, 4.Institute of Science and Engineering, Kanazawa University, 5.Institute of Geology and Geoinformation, National Institute of Advanced Industrial Science and Technology

Core-log-seismic integration is an ultimate goal of all the efforts to understand and predict the physical properties and composition of geological formations at various scales (mm-km). Downhole logs are continuous with depth, and measure formation properties on a scale that is intermediate between those obtained from laboratory measurements on core samples and geophysical surveys. Where core recovery is good, log and core data complement one another and may be interpreted together. Where core recovery is poor, downhole logs provide continuous stratigraphic data to fill gaps in core recovery. Establishing accurate correlation between sediment cores and logging data is thus a crucial step to reposition cores in correct depth and check that no major gaps are present in the spliced core data.

For this purpose, physical property data acquired from both core and logs are compared both in terms of value and data pattern, and natural gamma-ray radiation (NGR), density, and resistivity are commonly used. Generally speaking, higher the vertical resolution of data acquisition is, more precise the quality of correlation is. In the case of IODP Exp. 346, resolutions of shipboard data collection from cores were 0.5 cm for RGB of digital image, 1-5 cm for reflectance spectrum, 2.5-5 cm for gamma-ray attenuation (GRA) density, and 20 cm for NGR, while data acquisition intervals for logging were 0.25 cm for formation micro-scanner (FMS) and 4-15 cm for NGR and density.

Popular correlation method using NGR could enable us the meter-scale pattern matching between the profiles obtained from core onboard and from borehole by logging. Therefore, once we aim to realize higher resolution correlation and integration of core and logging data, we need to utilize FMS data, which vertical resolution is about 5 mm in soft sediments. Because FMS gives a high-resolution relative resistivity profile of the formation, these data should be ideally compared to resistivity measured on whole-round cores at cm-scale interval. However, such data have not been acquired during IODP Exp. 346. In this particular presentation, we will seek for another possibility to implement centimeter-scale correlation between core and logging data.

Keywords: core-log integration, sediment physical property, IODP Expedition 346

Outline of a scientific drilling project offshore SW Taiwan

*Yasuhiro Yamada[1], Andrew Tien-Shun Lin[2], Char-Shine Liu[3]

1.Japan Agency for Marine-Earth Science and Technology (JAMSTEC), R&D Center for Ocean Drilling Science (ODS), 2.Dept of Earth Sciences/Institute of Geophysics, National Central University, Taiwan, 3.Institute of Oceanography, National Taiwan University, Taiwan

Offshore SW Taiwan is situated in a unique tectonic setting where two plates transitions from subduction/accretion (south) to collision (north), that generates its characteristics on structural style, fluid flow/material circulation, deep biosphere, seismic activity/tsunami hazard, submarine slides, and energy resources. We are preparing an IODP scientific drilling proposal and introduce the outline of the project in this presentation.

Keywords: IODP, plate subduction, continental collision

An Experiment to Trigger a Moderate Earthquake on a Mid Ocean Transform Fault

*James Mori[1]

1.Earthquake Hazards Division, Disaster Prevention Research Institute, Kyoto University

Increasing fluid pressure in the vicinity of faults has often be observed to induce small earthquakes. Recently, there have been many examples in the US and Europe of earthquakes associated with underground fluid pumping. Also, filling of water reservoirs often produces small earthquakes, and was apparently responsible for causing the larger 1967 Koyna, India (M6.5) and 1975 Oroville, California (M5.7) earthquakes. Induced seismicity is becoming an important science topic with broad societal impacts.
We are proposing an experiment to understand the initiation of earthquakes by inducing seismic events on a shallow fault with water injection. Increasing the fluid pressure near an active fault will reduce normal pressure on a fault and bring it closer to failure, according to the classic Coulomb failure criterion. A study to monitor the water pressure and subsequent triggered earthquakes can help answer some fundamental questions in seismology about the stress levels that cause earthquakes and the physical conditions that are necessary for a large earthquake to occur. By triggering a moderate earthquake we hope to investigate questions related to earthquake initiation and scaling.
1) What is the strength of faults during earthquakes?
2) Is there an observable earthquake precursory signal? Does it scale with the size of the earthquake?
3) What is the size of the stress perturbation needed to trigger seismicity relative to the strength of the fault?
4) Does the size of the pore pressure or fluid volume perturbation correlate with the size of the triggered earthquake?
Appropriate sites for such an experiment would be transform faults near mid-ocean ridges, such as Blanco on the Juan de Fuca Ridge and Quebrada, Gofar, or Discovery on the East Pacific Rise. In such settings, shallow moderate (M5 to M6) earthquakes occur at repeating intervals of 5 to 15 years. The hypocenters of strike-slip earthquakes on these faults are shallower than for onshore faults because of the high thermal gradient, and thus are more easily accessible by drilling to depths of a few kilometers. We would like to conduct a water injection experiment at one of these sites a few years before the expected earthquakes recurrence, to try to trigger an early occurrence of a moderate-sized event. In addition, earthquakes in this region are often preceded by foreshock sequences.
A 2 to 3 km deep borehole could be drilled into the hypocentral region of a moderate earthquake. Earthquakes along the transforms occur at shallow depth above the 600 ^{o}C isotherm at depths of about 2 to 5 km. Using riser drilling capabilities, water pressurized at various pressures from about 0.001 MPa (about 0.1 psi) to higher values, (possibly 1 MPa, 140 psi) would be pumped into the borehole in order to raise pore pressure in the region of the hypocenter. The upper value for the pumping pressure approaches the values of the static stress drops of the earthquakes.

Keywords: induced earthquakes, earthquake triggering, earthquakes

Scientific drilling into seismogenic zones of M2.0 –M5.5 earthquakes in deep South African gold mines (DSeis)

*Hiroshi Ogasawara[1,2], Yasuo Yabe[1,3], Takatoshi Ito[3], Gerrie van Aswegen[1,4], Artur Cichowicz[1,5], Raymond J Durrheim[1,6,7], James J Mori[8], Tullis C Onstott[9], Thomas L Kieft[10], Margaret Boettcher[11], Wiemer Stefan[12], Ziegler Martin[12], Christoph Janssen[13], Shapiro Serge[14], Harsh Gupta[15], Phil Dight[16], ICDP DSeis team

1.JST-JICA SATREPS, 2.Ritsumeikan Univ., 3.Tohoku Univ., 4.Inst. Mine Seismol., South Africa, 5.Council Geosci., South Africa, 6.Council Sci. Ind. Res., South Africa, 7.Univ. Witwatersrand, South Africa, 8.Kyoto Univ., 9.Princeton Univ., USA, 10.New Mexico Inst. Min. Tech., USA, 11.Univ. New Hampshire, USA , 12.ETH Zurich, Switzerland, 13.GFZ Potsdam, Germany, 14.Freie Univ. Berlin, Germany, 15.Nat. Geophys. Res. Inst., India, 16.Univ. W. Australia, Australia

Several times a year, small (M2) mining-induced earthquakes occur only a few tens of meters from active workings in South African gold mines at depths of up to 3.4 km. The source regions of these events are accessible with short boreholes from the deep mines, and provide a very cost-effective method to directly study the earthquake sources. Recently, the largest event (M5.5) recorded in a mining region, took place near Orkney, South Africa on 5 August 2014, with the upper edge of the activated fault being several hundred meters below the nearest mine workings (3.0 km depth). This event has rare detailed seismological data available both from surface and underground seismometers and strainmeters, allowing for a detailed seismological analysis. Drilling into the source area of this earthquake while aftershocks are still occurring will enable important near-field seismological observations as well as a rare opportunity to study possible presence of H2 that is important for microbiological activity.
We intend to drill several tens of holes into and around seismogenic zones to study the rupture details and scaling of both small (M2.0) and larger (M5.5) earthquakes. An advantage of the relatively low cost of drilling is that multiple holes can be drilled. Past fault zone drilling projects have been limited to 1 or 2 boreholes, severely limiting the ability to resolve spatial variability. The value of the project will be maximized if we combine results from a number of boreholes drilled into the source area of the M5.5 seismogenic zone, and also compare with boreholes in source regions of small earthquakes in other mining horizons. Additionally, the combination of logging, fault sampling, and earthquake monitoring, will be enhanced in some cases by the direct visual observations of exhumed faults, leading to a unique complete picture of the earthquake source.
In seismogenic zones in a critical state of stress, it is difficult to delineate reliably local spatial variations in both the directions and magnitudes of principal stresses (3D full stress tensor). We have overcome this problem and can numerically model stress better, enabling orientations of boreholes that minimize stress-induced damage during drilling and overcoring. We can also reliably measure the stress tensor even when stresses are as large as those expected in seismogenic zones. Better recovery of cores with less stress-induced damage is also feasible. These studies will allow us to address key scientific questions in earthquake science and deep biosphere activities.

Keywords: South African gold mines, Seismogenic zones, Scientific drilling

JTRACK: Tracking Tsunamigenic Slips Across and Along the Japan Trench

*Shuichi Kodaira[1], James C. Sample[2], Michael Strasser[3], Kohtaro Ujiie[4], James David Kirkpatrick[5], Patrick M. Fulton[6], James J. Mori[7]

1.R&D Center for Earthquake and Tsunami Japan Agency for Marine-Earth Science and Technology, 2.Northern Arizona University, 3.University of Innsbruck, 4.University of Tsukuba, 5.McGill University, 6.Texas A&M University, 7.Kyoto University

Understanding the huge slip and associated devastating tsunami of the 2011 Tohoku-oki earthquake is a high priority challenge for IODP with important societal impacts. A primal objective of JTRACK is to define spatially-varying physical and chemical properties and conditions of the sediments and fluids of the near-trench megathrust that contribute to huge fault displacements and very large tsunamis. Following recommendations from the IODP Science Evaluation Panel and community input at the JTRACK Workshop (May 17-19, 2014, Tokyo), JTRACK focuses on the 2011 Tohoku-oki rupture zone by drilling two transects across the Japan Trench in regions of large and small coseismic slip. We will investigate the detailed geologic structures and rock properties of the fault zone, especially frictional and strength characteristics. Permeability and chemical studies will be used to infer the local hydrological structure and its effect on the earthquake rupture. Combining these observations and using comparisons of similar measurements for areas of high and low slip during the 2011 earthquake, we will try to infer key factors that control the amount of displacement during large earthquakes. In addition, time-dependent observations will be carried out to study fault healing after a large earthquake. These will focus on how the local hydrological and stress conditions change during the few years following the large fault displacement during the earthquake. Based on seismic images as well as associated geophysical data, the two 2-hole transects across the Japan Trench are selected in an area of large slip (>50 m) and smaller slip (1/3~1/2 of the large slip). Each transect has an ‘inner trench slope’ site mainly targeting the plate boundary fault zone, and an ‘input’ site seaward of the trench as a reference site.

Keywords: Japan Trench, Subduction, earthquake

Integration of seismic survey data for deep-sea drilling in Nankai Trough seismogenic zone

*Kazuya Shiraishi[1], Masataka Kinoshita[2], Yoshinori Sanada[1], KYAW MOE[1], Yasuhiro Yamada[1]

1.Japan Agency for Marine-Earth Science and Technology, 2.Earthquake Research Institute,The University of Tokyo

In Nankai trough region, various kinds of seismic surveys have been conducted in order to reveal detail subsurface structures of the seismogenic zone. In this study, we focus on the seismic surveys related to the NanTroSEIZE deep drilling, and discuss the integration studies of those seismic survey data.

Wide-angle reflection survey with ocean bottom seismographs (OBS) and airgun shooting is useful for exploration of regional deep structures by analyzing the refraction wave and wide-angle reflections. However, reflection imaging has not bee applied to the OBS data because of low illumination from the sparse receiver deployment. The recent progress of the seismic interferometry and the full waveform inversion contribute to the reflection imaging from the OBS data analysis. The seismic interferometry is useful to obtain the continuous reflection image by utilizing the multiple reflections of the OBS data. The OBS data is suitable for the FWI to estimate the fine-scale velocity structures, and the velocity model is used to improve the reflection imaging and to estimate of physical property distribution.

Vertical seismic profile (VSP) survey with vertical seismometer array in a borehole is carried out to investigate the detail structures and geophysical properties around the borehole. In walkaway and walkaround VSP data acquired at C0009 in 2009, information about structural features and geophysical properties such as attenuation and anisotropy are obtained. At C0002 site, new data will be acquired for imaging around the borehole and deep fault zone, and look-ahead for the safe deep drilling. We are doing feasibility studies by numerical simulation for optimum VSP survey design. The VSP survey with longer vertical receiver array is favorable, but we usually have some restrictions on the receiver deployment in the borehole. In such a situation, integrated analysis with simultaneous observation data of seismographs at sea floor or other seismic observatories in the borehole to expand the analysis area and improve the analysis accuracy. We have an opportunity not only to optimize the data acquisition but also to develop the new method for integration analysis.

Multi-channel seismic (MCS) survey with hydrophone streamers and airgun shooting is the most useful method to obtain subsurface information around the drilling site. Dense 2D MCS survey was conducted in 2003, and 3D MCS survey was also conducted in 2006. The 3D geometry of megasplay fault system and detail structures in the frontal accretionary prism were revealed in the Nankai trough subduction zone. However, any detail structures are not clarified in old accretionary prism between Kumano forearc basin and the megasplay fault, which are essential information for the successful deep drilling. For the success of the deep drilling in Nankai trough seismogenic zone, it is essential to know the detail of three-dimensional structures in the Nankai trough. It is expected that the quality of the 3D reflection image and velocity model are improved by applying the advanced technology. The updated results will contribute to the improvement of other data analysis and optimization of the new VSP data acquisition and processing.

In addition to the seismic data with OBS, MCS, and VSP, various kinds of scientific drilling data sets are available. Development of the integrated imaging and analyzing method is required to reveal new geophysical and geological aspect in the Nankai trough seismogenic zone.

Keywords: seismic survey, NanTroSEIZE drilling

IODP T-Limit Project: Constraining the Temperature Limit of Subseafloor Life in the Nankai Subduction Zone

Kai-Uwe Hinrichs[1], *Fumio Inagaki[2], Verena Heuer[1], Yuki Morono[2], Masataka Kinoshita[3], Yusuke Kubo[4], The IODP T-Limit Project Team

1.MARUM and Department of Geosciences, University of Bremen, Germany, 2.Kochi Institute for Core Sample Research, Japan Agency for Marine-Earth Science and Technology, 3.Earthquake Research Institute, The University of Tokyo, 4.Center for Deep Earth Exploration, Japan Agency for Marine-Earth Science and Technology

Determining factors that limit the biomass, diversity and activity of subseafloor microbial communities is one of the major scientific goals to be addressed by scientific ocean drilling. In the International Ocean Discovery Program (IODP) T-Limit Project, we will drill and core at new boreholes using the drilling vessel *Chikyu* in the immediate vicinity of the Ocean Drilling Program (ODP) Sites 1173 and 1174 off Cape Muroto in the central Nankai Trough, Japan, where anomalously high heat flow regimes observed at both sites result in *in-situ* temperatures up to 110 to 140°C at the sediment-basement interface. While the upper temperature limit of cultured microbes appears well constrained at relatively energy-rich hydrothermal vent systems at around 120°C, it remains unknown in energy-starved sedimentary subseafloor settings but is generally presumed to be lower, and thus expected to be covered by the target sites. Due to their location in the trench outer margin (Site 1173) and landward protothrust zone of the Nankai Trough accretionary prism (Site 1174), the selected sites have different geotectonic and thermal histories that resulted in contrasting biogeochemical modes of hydrocarbon gas production and consumption. During the T-Limit Project, we aim to comprehensively study (1) the factors that control biomass, activity and diversity of sedimentary microbial life in a temperature window that likely encompasses the biotic-abiotic transition, the so-called “biotic fringe”, (2) the relationship between geogenic release of water and potential substrates that support microbial activities, and (3) to determine the chemical and physical characteristics of sediments that define habitable conditions for deep subseafloor life.

Keywords: IODP, Deep Subseafloor Biosphere, Nankai Trough, Limits of Life and the Biosphere, Chikyu

The Lord Howe Rise (LHR) Drilling Project: tectonics, paleoclimate and deep life on the LHR high-latitude continental ribbon

Ron Hackney[1], Yasuhiro Yamada[2], Kliti Grice[3], *Junichiro Kuroda[2], Jessica H. Whiteside[4], Marco J.L. Coolen[3], Fumio Inagaki[2], Richard Arculus[5], Dietmar R. Müller[6], Saneatsu Saito[2], Hiroshi Nishi[7]

1.Geoscience Australia, 2.Japan Agency for Marine-Earth Science and Technology, 3.Curtin University, 4.University of Southampton, 5.Australian National University, 6.University of Sydney, 7.Tohoku University

The Lord Howe Rise (LHR) is an elongate ribbon of submerged and extended continental crust that separated from Australia during the Late Cretaceous. Because the LHR is concealed beneath the Tasman Sea in water depths of 1000–3000 m, current knowledge of LHR geology based only on sparse geophysical data, few dredge samples, and sparse shallow (<600 m below-seafloor) drilling into Cenozoic and latest Cretaceous pelagic sediments (Deep Sea Drilling Project DSDP Leg 21 Sites 207 and 208).
Existing data provide a broad understanding of the LHR's crustal structure, sedimentary basin architecture and resource potential. However, building more detailed knowledge of LHR geology, and understanding the geological evolution of the southwest Pacific more broadly, requires drilling into rocks that record the >100-million-year geological, tectonic and climatic history of the region. To this end, Geoscience Australia (GA) and the Japan Agency for Marine Earth Science and Technology (JAMSTEC) are leading an international effort to drill a deep (up to 3500 m below the seafloor) stratigraphic hole through a LHR basin that will recover Mesozoic sediments and potentially basement rocks.
A proposal for the drilling using the JAMSTEC drilling vessel CHIKYU was submitted to the International Ocean Discovery Program (IODP) in October 2015 (Proposal 871-CPP). The objectives outlined in this proposal are to: 1) define the role and importance of "continental crustal ribbons", like the LHR, in plate tectonic cycles and continental evolution; 2) recover new southern high-latitude data in the southwest Pacific to better constrain Cretaceous paleoclimate, and linked changes in ocean biogeochemistry; and 3) test fundamental evolutionary concepts for sub-seafloor microbial life over a 100-million-year timeframe. Drilling vessel Chikyu is the only platform that is capable to drill through the great depth at LHR, to accomplish this project.

Keywords: Cretaceous climate, continental crustal ribbons, Lord Howe Rise

Deap sea drilling at the Amami Sankaku Basin revealed wide distribution of fore-arc basalts across the Izu-Bonin-Mariana Arc: Evidence for spontaneous subduction initiation 52 million years ago

*Morihisa Hamada[1], Philipp A. Brandl[2], Kyoko Kanayama[3], Yuki Kusano[4], Osamu Ishizuka[4], IODP Exp.351 Scientists

1.Department of Solid Earth Geochemistry, Japan Agency for Marine-Earth Science and Technology, 2.GEOMAR Helmholtz Centre for Ocean Research Kiel, Germany, 3.San'in Kaigan Global Geopark Promotion Office, Tottori Prefectural Government, 4.Research Institute of Earthquake and Volcano Geology, Geological Survey of Japan, AIST

In 2014, a triplet of IODP expeditions (Exp. 350-352) focused on the Izu-Bonin-Mariana (IBM) arc were conducted with the aim of comprehensively understanding the evolution of oceanic island arc and the origin of the continental crust. Exp.351 drilled at Site U1438 in the Amami Sankaku Basin (ASB), about 100 km west of the Kyushu-Palau Ridge, a remnant of the IBM arc.
A Cretaceous age (ca. 120 Ma) island arc system now preserved around the ASB (Amami Plateau, Daito Ridge and Oki-Daito Ridge) suggests that the oceanic crust beneath the ASB had existed before subduction initiation ca. 52 Ma. The primary objectives of Exp.351 were to constrain the geochemical nature of the mantle when the oceanic crust was formed, to identify and model the processes of subduction initiation, and to reconstruct the evolution of the IBM arc during the Paleogene.
Exp.351 cored a 1611-m-long cores composed of 1461-m of sediments and 150-m of igneous basement rocks from the seafloor at a depth of 4711 m. The age for the bottom of the sedimentary layers is estimated to be ca. 50 Ma, based on biostratigraphic and paleomagnetic studies; therefore, igneous basement below the sedimentary layers should be equivalent or only slightly older than 50 Ma. The measured heat flow at Site U1438 is 73.7 mW/m^2, implying that the thermal age for the underlying lithosphere is 40-60 Ma. This age range is consistent with that constrained based on biostratigraphic and paleomagnetic studies (50 Ma or older), which is much younger than the Cretaceous age (ca.120 Ma), as estimated before the expedition.
We then analyzed the chemical composition of the uppermost igneous basement rocks on board. We found that they are not mid-ocean ridge basalts, but are very similar to fore-arc basalts (FABs) commonly found in the adjacent IBM fore-arc region that erupted ca. 52 Ma when subduction of the Pacific plate beneath the Philippine Sea plate was initiated. The igneous basement beneath the ASB should be FAB itself formed at the onset of subduction ca. 52 Ma. FABs are distributed not only in the IBM fore-arc region but also in the ASB, which is at the rear-arc side of the IBM arc. This unexpected widespread distribution of FABs suggests that the subduction zone was under an extensional environment across the arc, and that the igneous basement of the IBM arc was formed over a much wider area during the subduction inception in a mode consistent with “spontaneous” subduction. The results of our analysis will provide significant insights into the process of subduction initiation in this area, as well as into the subsequent evolution of the IBM arc.
After Exp.351, we analyzed major and volatile elements (S and Cl) of melt inclusions collected from the top to the bottom of sedimentary Unit III (30-40 Ma based on onboard biostratigraphy) using electron probe micro-analyzers. Most of the host minerals of the melt inclusions are clinopyroxene and plagioclase. The compositions of the melt inclusions are diverse, ranging from basalt through rhyolite, and also ranging from low-K through medium-K series. In terms of major elements, low-K melt inclusions are consistent with the melt compositions reported from the volcanic front of the IBM arc. Major element composition of medium-K melt inclusions overlaps with the melt composition

reported from the IBM rear-arc, such as volcanoes on the KPR and/or near the ASB. These observations suggest that the turbidites accumulated at the ASB originate not only from the IBM rear arc, but also from the IBM frontal arc. We will further investigate the temporal evolution of arc volcanism by analyzing the trace elements and isotopes in the melt inclusions.

Keywords: International Ocean Discovery Program, Izu-Bonin-Mariana arc, Amami Sankaku Basin

Tairiku Project: from Nishinoshima to the ultra-deep drilling (IBM-4)

*Yoshihiko Tamura[1]

1.R & D Center for Ocean Drilling Science, Japan Agency for Maine-Earth Science and Technology

What is raw and juvenile continental crust? Furthermore, how does it form and evolve into mature continental crust? The continental crust we observe on the surface of the earth has been deformed, metamorphosed, and otherwise processed perhaps several times from its creation in subduction zones to the present. Although there are many examples of accreted arc crust on the margins of continents, during- and/or post-collision geochemical changes are widespread. However, we may have the ability to observe active crust-forming processes in modern arcs through what we can infer from eruptions at the surface.
Nishinoshima, one of the submarine volcanoes in the Ogasawara Arc, ~1,000 km south of Tokyo, Japan, suddenly erupted in November 2013, after 40 years of dormancy. The Nishinoshima volcano might represent the missing link between the mantle and the continental crust because (1) Nishinoshima, whose underlying crust is only 21 km thick, is one of the world's closest volcanoes to the mantle, and (2) the lavas have been andesites and were similar in composition to the continental crust. Nishinoshima was visited twice in 2015. Firstly knolls on the submarine flanks were sampled during cruise NT15-E02 of JAMSTEC's R/V. *Natsushima* in June using a DEEP TOW deep ocean floor towed survey system equipped with a camera and dredger. Dredges were conducted along the tracks on the seafloor. Then on July 3rd the current eruption was sampled by an unmanned helicopter operated from the R/V *Daisan Kaiyomaru*. Olivine-bearing phenocryst-poor andesites have been recovered from the Nishinoshima volcano. We suggest that the Nishinoshima andesites are mantle-derived and that their origin is strongly influenced by its thin overlying crust. Specifically, continental crust-like magmas (andesitic magmas) are readily produced in the mantle wedge at sites where the overlying crust is thin.
I'd like to discuss the relationship between our study in Nishinoshima and the proposed "ULTRA-DEEP DRILLING INTO ARC CRUST (IBM-4)", which is still the best way to sample unprocessed juvenile continental-type crust, to observe these active processes that produce the nuclei of new continental crust, and to examine the nature of juvenile continental crust as first generated at intra-oceanic arcs.

Keywords: Nishinoshima, continental crust, IBM-4, Tairiku Project

IODP Exp. 360 Preliminary reports: Indian Ridge Lower Crust and Moho at Slower Spreading Ridges (SloMo)

Henry J.B. Dick[1], Christopher MacLeod[2], Peter Blum[3], *Natsue Abe[4], Tomoaki Morishita[5], Toshio Nozaka[6], Alessio Sanfilippo[5,7], Scientific Party IODP Exp. 360[3]

1.Woods Hole Oceanographic Institut, 2.Cardiff University, 3.Texas A & M University, 4.R&D Center for Ocean Drilling Science Japan Agency for Marine-Earth Science and Technology, 5.Kanazawa University, 6.Okayama University, 7.Univ. Pavia

IODP Expedition 360, Phase I of the Nature of the Lower Crust and Moho at Slower Spreading Ridges (SloMo) project of a Multi-Leg Drilling Project, was carried out from 1 Dec., 2015 to 31 Jan, 2016, at Atlantis Bank, an oceanic core complex, along the eastern wall of the Atlantis II Transform of the Southwest Indian Ridge. We conducted all drilling operations at a single site in a single Hole U1473A and drilled 789.7 m though gabbros. This is the deepest single-leg hard-rock drilling hole in ocean crust. Expedition 360 Hole U1473 is located at 2.2 km Northeast of 1.5 km deep Hole 735B and at 1.4 km north of 158 m deep Hole 1105A. This provides us, for the first time, a unique opportunity to explore three dimensional lower crustal characteristics beneath the slow-spreading ridges. Phase II of the SloMo has proposed to drill 6 km through MOHO by the CHIKYU. In the meeting, we will introduce preliminary results of IODP Expedition 360 and the future perspective leading to Phase II of the SloMo, a mantle drilling into ultraslow-spreading ridges.

Keywords: IODP Exp. 360, Atlantis Bank, SloMo, Moho, D/V Chikyu

Oman ophiolite ICDP: outline and expected outcome

*Eiichi TAKAZAWA[1,2], Yoshihiko Tamura[2], Katsuyoshi Michibayashi[3], Tomoaki Morishita[4], Natsue Abe[2], Takashi Miyazaki[5], Ryoko Senda[5], Moe Kyawthu[2]

1.Department of Geology, Faculty of Science, Niigata University, 2.R & D Center for Ocean Drilling Science, Japan Agency for Maine-Earth Science and Technology, 3.Institute of Geosciences, Shizuoka University, 4.School of Natural System, Colleage of Science and Technology, Kanazawa University, 5.Department of Solid Earth Geochemistry, Japan Agency for Maine-Earth Science and Technology

The proposal for drilling at the southern Oman ophiolite (lead proponent: Dr. P.B. Kelemen of Columbia University, USA) has been approved by International Continental Scientific Drilling Program (ICDP). The 1st phase of drilling is scheduled for August 2016 and the 2nd phase for January-March from August 2017 (http://www.omandrilling.ac.uk). In the context of the Oman ICDP we propose drilling of a new hole through a crust-mantle boundary with a matching fund from Japanese side. In addition, advanced techniques will be introduced for borehole logging and core description to clarify lithology and physical properties at the crust-mantle boundary.
The main targets of Oman ICDP are drillings of gabbroic layers in the typical crust section, the crust-mantle boundary around a mantle diapir and altered peridotites (serpentinite and carbonate) at the basal part of mantle section. We're planning to drill a crust-mantle boundary away from the ridge axis and intensively describe the successive cores using advanced analytical facilities on the drilling vessel "Chikyu". We will systematically analyze major and trace element contents in whole rocks and minerals, Sr-Nd-Pb-Hf isotopes, Re-Os isotopes, compositions of melt inclusions in core samples. These data will be used to achieve next five objectives. (1) To clarify the characteristics of Moho discontinuity by examining fresh core samples. (2) To clarify both high temperature igneous processes and low temperature alteration processes around the Moho. (3) To identify strength and shear sense of the mantle flow and inspect the gradient of mantle flow velocity beneath Moho. (4) To conduct borehole logging to understand physical properties around the crust-mantle boundary. (5) To understand how continental crust generated from oceanic crust.
The Oman ICDP is the biggest chance to obtain fresh core samples from Oman ophiolite. At the same time, it offers a preliminary test for future drilling through oceanic Moho. In the Oman ophiolite ICDP, low temperature processes such as serpentinization, groundwater and a microorganism are given priority. Our new drilling hole will be specialized in igneous process and mantle deformation to contribute to understand "high temperature process" which lacks in the current Oman ICDP. This attempt will advance our knowledge of the reality of the Moho that is one of unsolved problems in Earth science. By organically uniting the spatial information obtained by field survey of the Oman ophiolite with the successive information obtained from drilling cores, we will reach overall understanding of the crust-mantle boundary including low and high temperature processes, mantle flow and physical nature of the Moho. The Oman ophiolite ICDP also contributes to improvement of drilling technology and the researcher development for young scientists. We will introduce the most advanced logging tools such as NeoScan. Students analyze the core intensively under researcher's guidance using latest facilities of a deep earth research vessel "Chikyu". The expected outcome is that students being superior to core description and borehole logging grow up through the Oman ICDP.

Keywords: Oman ophiolite, ICDP, crust-mantle boundary, Moho, borehole logging

Hydration in incoming plates prior to subduction: contents, perspective and road to Mantle drilling

*Tomoaki Morishita[1]

1.School of Natural System, Colleage of Science and Technology, Kanazawa University

Crustal hydration at the mid-ocean ridge by hydrothermal circulation has been considered to be the first-order control on the degree of the oceanic plate hydration. Previous ocean drilling projects have revealed hydration processes and their extent of oceanic crust at spreading centers. Recently, hydration due to plate bending-induced normal faults (bend-fault hereafter) in incoming plate just prior to subduction has drawn considerable attention (e.g., Ranero et al., 2003 *Nature*). Geophysical data indicate that the hydration has reached to the mantle depth and causes serpentinization of peridotites (e.g., Fujie et al., 2013 *Geophys. Res. Lett.*). However, we really do not know what is the bending-induced fault zone. Two new IODP proposals on hydration in incoming plate of middle America site (Morgan et al., 2014, *Pre-876: Bend-Fault Serpentinization (BFS): Oceanic Crust and Mantle Evolution from Ridge through Trench*) and northwest pacific site (Morishita et al., 2015 *Pre-886: Bend-Fault Hydrology in the Old Incoming Plate*) have been submitted. In the presentation, I introduce the contents and perspective of the proposals. In order to comprehends understand life cycle of oceanic plate, I will also suggest future plan including mantle drilling project.

Keywords: Bending-induced normal fault in incoming plate, Subduction Zone

