Physical properties of fault fracture zones by downhole physical loggings - Case study of Atotsugawa fault, central Japan

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Drilling is an effective method to investigate the structure and physical state in and around the active fault zone. In previous studies, we did integrate investigation on active faults in central Japan by drilling into the Nojima fault and Neodani fault. Those faults are estimated to be at different stage in the earthquake cycle, i.e., Nojima fault which appeared on the surface by the 1995 Great Kobe earthquake (M=7.2), the Neodani fault which appeared by the 1891 Nobi earth-quake (M=8.0). Each faults showed characteristic features of fracture zone structure according to their geological and geophysical situations. In a present study, we report core observations and downhole physical logging at the Atotsugawa fault, central Japan, that is considered to have activated at 1858 Hida earthquake (M=7.0). The Atotsugawa fault is characterized by active seismicity along the fault. But, at the same time, the shallow region in the central segment of the fault seems to have low seismicity.
A 350m depth borehole was drilled vertically beside the surface trace of the fault in the low seismicity segment. Logging data showed that the apparent resistance was about 100 - 600 ohm-m, density was about 2.0 - 2.5g/cm3, P wave velocity was approximately 3.0 - 4.0 km/sec, neutron porosity was 20 - 40 %. Results of physical logging show features of fault fracture zone that were the same as the fault fracture zones of other active faults that we have drilled previously. In addition, Caliper logging, which measures the diameter of borehole, showed enlargement of borehole (max. 2 times of initial borehole diameter) and indicate the strength of borehole wall was lowered extremely.
Recovered cores were overall heavily fractured and altered rocks. In the cores, we observed many shear planes holding fault gouge. The observations of cores and physical logging data indicate that the borehole passed in the fracture zone down to the bottom, and that the fracture zone has complicate internal structure including foliation not parallel to the fault trace.
With the results of Nojima and Neodani fault, physical logging data show physical properties are different among different lithologies, and that the host rock zone and fault fracture zone have much different physical properties. In addition, characteristics of physical properties of fracture zones are differet from each other fault. What factors affect the different physical properties are not yet clear. They may be associated with case histories in physical and chemical processes of each fault activity in the past. We need further comparative studies on different fault drilling results.

Keywords: physical logging, fault fracture zone, Atotsugawa fault

ICDP Drilling project to probe seismogenic zones of M2.0-5.5 earthquake in deep South African gold mines - Commencement of drilling.

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The International Continental Scientific Drilling Program (ICDP) approved our proposal to drill into and around seismogenic zones where critically-stressed faults initiated ruptures at depth. The drilling targets include four ruptures equivalent to M2.0, 2.8, 3.5, and 5.5 earthquakes that dynamically and quasi-statically evolved in 2.9 Ga hard rock in the Witwatersrand basin, South Africa. A major advantage of our proposed project is the large quantity of high-quality data recorded by existing dense seismic arrays, both on surface and near-field underground, in three deep gold mines. Additionally, the great depths (1.0 to 3.3 km from surface) at which drilling starts reduces costs significantly and allows a larger number of holes to be drilled with the available budget. Flexibility in the drilling direction will also allow us to minimize damage to the borehole or the drilled cores. With ICDP funds, we will conduct full-core drilling of 16 holes at ranges of 50 to 750 m to recover both solid and fractured material in and around the seismogenic zones. This will be followed by core and borehole logging. Additional in-hole monitoring of rock deformation, ground motion, hydrology and geomicrobiology will be supported by co-mingled funds. We will also determine the 3D stress tensor near the collars of the holes using an overcoring technique that has been optimized for the highly-stressed ground and the working conditions found in deep South African mines. The measurement of the differential stress is based on the assumption that anisotropic variation in the diameter of the recovered core is caused by elastic expansion after drilling.

The M5.5 earthquake that took place near Orkney, South Africa on 5 August 2014 offers a special opportunity to compare models of the spatio-temporal evolution of both the main rupture and the aftershock activity determined by the inversion of ground motion measurements with direct observations.

Drilling will commence in early 2017.

Keywords: ICDP, Seismogenic zones, Deep South African gold mines

Data acquisition of drilling parameters on D/V Chikyu: Current status and issues on integration with borehole scientific data

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In the drilling science, integration of various data sets derived from drilled borehole is an essential work to maximize scientific results obtained in a scientific drilling operation. Scientific dataset measured on geological sample (core and drilling cuttings) and acquired by well-logging is primary important. In addition to the scientific data, engineering data is acquired in a drilling operation (drilling parameters; e.g., hook load, Top Drive speed, Top Drive torque), and the engineering data is directly influenced by formation lithology and rock strength. Therefore, the engineering data is also important for research of the drilling science.
On D/V Chikyu, drilling instruments are controlled by Drilling Control and Instrumentation System (DCIS) equipped on the Chikyu. The DCIS does not only control the drilling instruments but also acquire and monitor data derived from each drilling instrument. The DCIS is driven by the PROFIBUS (Process Field Buss) technology, and data output from the DCIS is also controlled based on regulations of the PROFIBUS system.
In order to acquire data of drilling parameters in real-time, 3rd party tool has to connect to the DCIS via DP/DP-link of the PROFIBUS system for 3rd party tool. In 2015, the DCIS was replaced and data communication interface with 3rd party tool was also changed to the DP/DP-link. The DP/DP-link is a technology to enable accurate data synchronization between the DCIS and 3rd party tools (e.g., mud logging data). It is critical to acquire the DCIS data in real-time for mud logging. Therefore, the replaced DCIS and DP/DP-link are powerful tools for integration of drilling parameter data with borehole scientific data. In this presentation, outline of the DCIS and data acquisition system including 3rd party tools will be introduced, and quality of data integration and synchronization of the DCIS data with borehole scientific data will be discussed.

Keywords: D/V Chikyu, Drilling parameters, Borehole scientific data, Data integration, Data synchronization, DP/DP-link

Continuous depth profile of mechanical properties in the Nankai accretionary prism based on drilling performance parameters

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In-situ rock properties in/around seismogenic zone in an accretionary prism are key parameters to understand the development mechanisms of an accretionary prism, spatio-temporal variation of stress state, and so on. For the purpose of acquiring continuous-depth-profile of in-situ formation strength in an accretionary prism, here we propose the new method to evaluate the in-situ rock strength using drilling performance property, such as weight on bit (WOB), drillstring rotational torque (Tr), rate of penetration (ROP), and drillstring rotational per one minute (RPM). Drilling parameters are inevitably obtained by any drilling operation even in the non-coring intervals or at challenging environment where core recovery may be poor. The relationship between the rock properties and drilling parameters has been proposed by previous researches [e.g. Teale 1964]. We introduced the relationship theory proposed by Teale [1964] and Karasawa et al. [2002], and developed a converting method to estimate in-situ rock strength without using uncertain parameters such as WOB. Specifically, we first calculated equivalent specific toughness (EST) which represents gradient of the relationship between Torque energy and volume of penetration at arbitrary interval (in this study, five meters). Then the calculated EST values were converted into strength using the drilling parameters –rock strengths correlation obtained by Karasawa et al. [2002]. This method was applied to eight drilling holes in the Site C0002 of IODP NanTroSEIZE in order to evaluate in-situ rock strength in shallow to deep accretionary prism. In the shallower part (0 –300 mbsf), the calculated strength shows sharp increase up to 20 MPa. Then the strength has approximate constant value to 1500 mbsf without significant change even at unconformity around 1000 mbsf (boundary between forearc basin and accretionary prism). Below that depth, value of the strength gradually increases with depth up to 60 MPa at 3000 mbsf with variation between 10 and 80 MPa. Because the calculated strength is across approximately the same lithology, the increase trend can responds to the rock strength. This strength-depth curve correspond reasonably well with the strength data of core and cutting samples collected from hole C0002N and C0002P [Kitamura et al., 2016 AGU]. These results show the validity of the method evaluating in-situ strength from the drilling parameters.

Keywords: drilling parameter, formation strength, equivalent specific toughness

P-wave velocity of gabbroes from ODP and IODP cores: Implications for the origin of the P-wave velocity reduction in the lowermost oceanic crust

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Variety of gabbroic samples were taken from the Atlantic Ocean (ODP Legs 153 & 209, IODP Exps. 304&305), the Indian Ocean (the Atlantis Bank: ODP Legs 118 & 176) and the Pacific Ocean (Hess Deep: IODP Exp. 345). Those gabbroic core samples were originated from the upper part and lower part of the oceanic crust. The P-wave velocity of the samples were measured by the same machines and the methods on-board JOIDES Resolution. Here we argue a possibility of the velocity reduction where the oceanic lower crust is highly altered. A series of gabbroic cores from ICDP Oman Drilling will be expected this reveals more with detail examination of the relationship between the mineral mode, chemistry, the degree of alteration and P-wave velocity on-board D/V Chikyu.

Keywords: Oceanic Lower Crust, Gabbro, IODP, P-wave velocity, D/V Chikyu, Oman Chikyu Project

Automated microfossil classification by image recognition and machine learning to develop an AI system for age-dating

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The occurrence and/or disappearance of planktonic microfossils in marine subsurface sediments (e.g., diatoms, foraminifera, radiolarians, and calcareous nannoplankton) is diagnostic for identifying age of sediment cores in scientific ocean drilling. For age-dating, significant experience and expertise on taxonomic identification of microfossils are required, which processes including extraction, preparation of slides, microscopic observation, and identification that need laborious onboard efforts. Because the age-dating is one of the crucial measurements for scientific ocean drilling, micropaleontologists have a significant role with huge efforts on the microscopic work onboard since DSDP in 1960’s.
To date, computers can replace human beings as the drivers of cars, because of rapid improvement of process capability. A defeat of the world’s best Go player by the Google DeepMind’s artificial-intelligence program ”AlphaGo” is still fresh in our mind. This news shocked the world because Go create much more possible scenarios than chess and Shogi which had already surrendered to computer software and thus was considered to be the last bastion of human superiority. Deep learning, which is a kind of machine learning, enabled the victory of computer. In machine learning, by giving data consisting of input objects and desired output values, an algorithm analyzes and produces an inferred function automatically, providing rapid and accurate autonomous decision-making. The machine learning technology is used for pattern recognition, allowing recognition of many types of images. For example, face authentication system has been applied to immigration control at international airports, security gate system at amusement parks and concert venues.
The aim of this study is to apply machine learning and image recognition technologies to taxonomic identification of microfossils and develop an AI system which can automatically determine the age of cored sediments. As a feasibility study, we tested the NEC’s AI software “RAPID Machine Learning” to identify two kinds of calcareous nanofossils with relatively simple structures. At first, we prepared smear slides and took images of nannofossils of *Pseudoemiliania* (P) and *Reticulofenestra* (R) by polarization microscopy. For training data, 32 images of each P and R were rotated by every 90 degrees to 270 degrees and 256 images were obtained in total. For the test, 10 images of each P and R were prepared. A statistical model was built automatically by inputting all the training images and data (i.e., correct answer of P or R) into the RAPID Machine Learning, and then the model was tested for identification of the nannofossils.
As a result, 6 out of 10 images of P, and 4 out of 10 images of R were correctly identified with a confidence of 60% or more. The correctly identified images with high degree of confidence had distinctive shape to P or R, confirming the feasibility of applying machine learning to identification of microfossils. On the other hand, ambiguous images without the distinctive shapes were not correctly identified with low degree of statistical confidence. In the future study, the accuracy of identification will be improved by preprocessing the images as sharpening by using graphics software and increasing the number of training data (about 1,000 images per a object are required generally).

Keywords: age-dating, microfossil, machine learning, image recognition, AI

IODP Expedition 370: Temperature Limit of the Deep Biosphere off Muroto

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International Ocean Discovery Program (IODP) Expedition 370 aimed to explore the limits of life in the deep subseafloor biosphere at a location where temperature increases with depth at an intermediate rate and exceeds the known temperature maximum of microbial life (~120˚C) at the sediment/basement interface ~1.2 km below the seafloor. Drilling Site C0023 is located in the vicinity of Ocean Drilling Program (ODP) Sites 808 and 1174 at the protothrust zone in the Nankai Trough off Cape Muroto at a water depth of 4776 m. ODP Leg 190 in 2000, revealed the presence of microbial cells at Site 1174 to a depth of ~600 meters below seafloor (mbsf), which corresponds to an estimated temperature of ~70˚C, and reliably identified a single zone of higher cell concentrations just above the décollement at around 800 mbsf, where temperature presumably reached 90˚C; no cell count data was reported for other sediment layers in the 70˚–120˚C range, because the limit of sensitivity in cell counting for low-biomass samples was not high enough. With the establishment of Site C0023, we aimed to detect and investigate the presence or absence of life and biological processes at the biotic–abiotic transition with unprecedented analytical sensitivity and precision. Expedition 370 was the first expedition dedicated to subseafloor microbiology that achieved time-critical processing and analyses of deep biosphere samples by simultaneous shipboard and shore-based investigations.
Our primary objectives during Expedition 370 were to study the relationship between the deep subseafloor biosphere and temperature. We aimed to comprehensively study the factors that control biomass, activity, and diversity of microbial communities in a subseafloor environment where temperatures increase from ~2˚C at the seafloor to ~120˚C at the sediment/basement interface and thus likely encompasses the biotic–abiotic transition zone. We also aimed to determine geochemical, geophysical, and hydrogeological characteristics in sediment and the underlying basaltic basement and elucidate if the supply of fluids containing thermogenic and/or geogenic nutrient and energy substrates may support subseafloor microbial communities in the Nankai accretionary complex.
To address these primary scientific objectives and questions, we penetrated 1180 m and recovered 112 cores across the sediment/basalt interface. More than 13,000 samples were collected. Ensuring minimal contamination of potentially extremely low biomass core samples was of highest priority for the research objectives of Expedition 370. Therefore, rigorous quality assurance and quality control (QA/QC) efforts and super-clean technologies were implemented, including helicopter transport of freshly taken core samples to the onshore super-clean room facility at Kochi Core Center (KCC).

Keywords: IODP, Deep Biosphere

Lateral variation in structural characteristics of the décollement zone and underthrust sediments in the Nankai accretionary prism: Preliminary results from IODP Expedition 370

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Integrated Ocean Discovery Program (IODP) Expedition 370 penetrated the toe of the Nankai accretionary prism and plate-boundary décollement zone, and touched the oceanic basement at Site C0023, off Muroto Peninsula, SW Japan. The drilling site is located at ~4 km NE from legacy two sites (Sites 808 and 1174), and therefore gives us great opportunity to examine lateral variations in structural geology, physical properties, fluid flow. Lithological and structural key observations made on cores recovered from Site C00023 are:
a) Sediments recovered from the Site C0023 are composed of the same 5 lithologic units encountered at legacy sites.
b) Typical early-stage diagenetic minerals found between 200-700 mbsf are carbonate and pyrite with a clay mineralization-stage beginning at 700-1000 mbsf. Hydrothermal strata-bound mineralization in the form of anhydrite, barite and rhodochrosite is focused between ~700 and 1100 mbsf. The Apparent temperature limits for co-occurrence of anhydrite, veins of barite and rhodochrosite may represent in the 150-200 ºC, slightly higher than present in-situ temperature.
c) Most of the core-scaled reverse faults are located above and within the décollement zone (~758-796 mbsf), whereas dense populations of normal fault were identified beneath the décollement zone (underthrust sediment). This variation apparently reflects stress decoupling between the décollement zone.
d) Mineral veins composed of calcite, barite, and anhydrite occur beneath the décollement zone and most of these are located within or closely associated with faults and the strata-bound mineralization.
Variations in bedding dip and healed fault distribution in Site C0023 are broadly similar to Site 1174. On the other hand, the thicknesses of fault zones within the décollement zone and the nature and distribution of deformation structures in the underthrust sediments at Site C0023 is totally different from sites 808 and 1174. At site C0023, the décollement zone is characterized by a thinner fault zone sandwiched between intact mud-rock intervals, apparently a weaker deformation compared with the pervasive pulverization in the décollement zone in legacy sites. A dense population of faults and mineral veins in the underthrust interval is also unique point in Site C0023. Additional paleomagnetic studies are necessary to consider the deformation mechanisms. In addition, physical properties variations (i.e. porosity/density, P-wave velocity) above and below the décollement zone at the Site C0023 were lesser than those in the legacy sites.
Seismic cross sections indicate Site C0023 is located towards the center of a low amplitude syncline where the seismic décollement zone is faint and intermittent. On the other hand, previously-drilled legacy sites are located above the strong amplitude décollement zone. These lateral variations in deformation and physical properties correspond with predictions made from seismic images.

Keywords: décollement zone, IODP, Exp. 370, T-limit, Chikyu

Thermal/hydrological prediction in the toe region of Nankai Trough off Muroto - Are "T-Limits" the temperature limits?

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One of the essential objectives of IODP Expedition 370 is to know insitu temperature along the borehole. The temperature observatory (TTO) is developed in order to provide essential constraint to ‘Limits of Life’, including determination of insitu temperature from seafloor through decollement and down to the basement, and detection of any possible transient signals.
It is essential to predict downhole temperatures (down to the basement) for the design of TTO system. Currently available temperature sensors are rated to 50 degC, which is obviously lower than expected near the bottom.
The formation temperature profile is primarily controlled by the basal heat flow but is also affected by the rapid sedimentation, spatial variation of thermal conductivity, radioactive heat generation, and advective heat transfer. Since we have not information about the fluid flow the advection effect is not considered here. Rapid sedimentation apparently reduce the temperature gradient, and its effect is calculated by assuming the sedimentation rate similar to that at Site 1174. Temperature profiles are calculated for three basal heat flow values. Most likely temperature at the top of decollement is predicted as 93 –111 degC.
The designed total length of TTO was set at 1200m, beneath the sediment/basement interface (1180m below sea floor). The primary target depth is set around the decollement, which was interpreted in the seismic profile at 800 mbsf but was revised at 760 mbsf later.
Array of 55 temperature sensors, outside and inside the 4-1/2” steel pipe (called the tubing), deployed from Chikyu into Hole C0023A. They keep measuring temperatures at each position (from zero=seafloor to ~1000mbsf, spanning every 10 to 100 meters interval.) at every 10 minutes or every 1 hour, for one year. The maximum temperature expected at the bottom-hole exceeds 120 degC. Temperature data is recorded in the memory inside each temperature sensor. The data is recovered wither by recovering the sensor array itself, or by connecting the connector when we revisit the site by ROV.
In order to achieve the overall goal of expedition, we deployed two independent arrays of temperature sensors; one is the thermistor array attached outside the tubing and the other the independent sensors attached to rope and lowered inside the tubing. They are successfully deployed during the expedition. The data will be recovered using the ROV in the spring of 2018.

Keywords: IODP, Nankai Trough off Muroto, heat flow

The Chicxulub impact crater cores recovered by IODP-ICDP Expedition 364: Status Report

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The Chicxulub impact structure in the northern Yucatan Peninsula, Mexico, formed at the Cretaceous-Paleogene boundary (66.0 Ma), was drilled by the joint IODP-ICDP Expedition 364 in April-May 2016. This is the first attempt to obtain materials from the topographic peak ring within the crater previously identified by seismological observations. Major objectives of Exp. 364 are to understand (1) the nature and formation mechanism of peak rings, (2) how rocks are weakened during large impacts, (3) the nature and extent of post-impact hydrothermal circulation, (4) the deep biosphere and habitability of the peak ring, and (5) the recovery of life in a sterile zone.

A continuous core was successfully recovered from the peak ring in the depths between 505.7 and 1334.7 mbsf. After the initial observation on a Mission Specific Platform, the up to 1.5 m-cores were transported to MARUM, University of Bremen, for further analysis at the onshore science party (OSP) held in September-October 2016, where visual core description as well as biostratigraphic (foraminifera and calcareous nannofossil assemblages), geophysical (density, P-wave velocity, paleomagnetism), geochemical (major and minor elements, carbon contents), and petrological analyses (optical microcopy and XRD) of the cores were performed.

The uppermost part of the core (505.7–617.3 mbsf) is post-impact sediments, including PETM, that are mainly composed of carbonate with intercalation of siliciclastic materials that are occasionally rich in organic carbon. Below is a transitional zone that shows a drastic change into impactites (suevite and impact melt rock) with lithologically diverse clasts composed of sedimentary and basement rocks (617.3–747.0 mbsf). We found uplifted, fractured, and shocked granitic basement rocks forming the peak ring below the impactite unit (747.0–1334.7 mbsf). The granitic basement is intruded by mafic and felsic subvolcanic dikes as well as impact melt-breccia dikes. The lithological and physical properties of the Chicxulub cores confirmed the dynamic collapse of an overheightened central uplift of the crater as a favored model for the peak-ring formation [1].

Four Japanese OSP participants have been working on sedimentological, geochemical and mineralogical aspects of the allocated samples to understand various impact and post-impact events: resurge process and tsunami generation, search for projectile component using platinum group elements, elemental and isotopic evolution in the Eocene and Paleocene seawater, shock metamorphism of impactites and basement rocks, hydrothermal alteration of the basement rocks, and the deep biosphere and habitability of the peak ring.

The IODP-ICDP Expedition 364 Science Party is composed of S. Gulick (US), J. V. Morgan (UK), E. Chenot (France), G. Christeson (US), Ph. Claeys (Belgium), C. Cockell (UK), M. J. L. Coolen (Australia), L. Ferrière (Austria), C. Gebhardt (Germany), K. Goto (Japan), H. Jones (US), D. A. Kring (US), J. Lofi (France), C.

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Keywords: Chicxulub crater, shock metamorphism, K-Pg boundary, tsunami, PETM

Drilling proposal of 3.2 Ga Moodies Group in Barberton Greenstone Belt: high resolution reconstruction of surface envirnment and biosphere of middle Archean Earth

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Chritoph Huebeck and international collaborators are now proposing new ICDP drilling of Moodies Group in Barberton, South Africa. Scientific objectives for this drilling proposal are introduced in this presentation. Sedimentary rocks of the Moodies Group are about 3.22 Ga old and represent some of the world’s oldest, well-preserved, shallow-water strata. The metamorphic grade is lower greenschist facies. They thus represent a very clear window of Archean surface conditions and processes. Their coastal and fluvial-alluvial facies is ideal to investigate shallow surface environments of the early Earth, and Moodies Group may be the only group to investigate “surface” environmental processes of middle Archean Earth.
For instance, the oxidation state of 3.2 Ga surface environments has been vigorously debated in past literatures. Banded iron formations in Moodies Group are unique among other Archean BIFs, because of their shallow water deposition features. U and Cr enrichments are found in those shallow BIFs by our research group. This suggests that appreciable amounts of U and Cr were dissolved in 3.2 Ga Moodies shallow ocean, indirectly suggesting surface ocean water was oxygenic. However, those enrichments were found in surface rocks and it is highly desired to confirm the same enrichment in un-weathered drilled rocks. Microbial mat-like layers are also recognized in Moodies sedimentary rocks. But it is still uncertain if such microbial mats are ubiquitous in Moodies rocks and if they represent some consortia (mixture of photoautotrophs and heterotrophs, etc.) of different microorganisms, etc. Drilled samples from fresh Moodies rocks may give us a chance to answer those top-ranked scientific questions.

Keywords: Archean, Barberton, Moodies Group

Comparison of improved 3D seismic image with borehole information around IODP C0002 site in Nankai Trough off Kumano

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We introduce a preliminary investigation of geological structures around the IODP C0002 site by integration analysis of new 3D seismic image with existing borehole information obtained in scientific drilling expeditions. The 3D seismic survey data was acquired in 2006 as a site survey of IODP NanTroSEIZE project in Nankai Trough off Kumano. The 3D seismic data was reprocessed by applying new technologies advanced in a decade after the initial processing, such as broadband processing, multiple and noise attenuation, and pre-stack depth migration with TTI anisotropy. The improved depth image shows clearer three-dimensional structures than the previous depth image in the old accretionary sediments beneath the Kumano basin, such as folds, dipping reflectors, and discontinuities of reflectors. In the deeper part after multiple reflections were better attenuated, some dipping reflectors can be clearly observed just above the megasplay faults. The mega-splay fault is imaged at the depth about 5,200 –5,400 mbsf, and a high velocity zone was estimated above the mega splay fault with 1.5 - 2.0 km thickness and the maximum value more than 5,000 m/s. On the other hand, a lot of geological information are available obtained from downhole logging, core samples, and drill cuttings down to 3,059 mbsf of drilled holes in the C0002 site. The data integration of different scale information between seismic and borehole is necessary for better understanding of geology and geophysics in the complex structures. We can observe well correspondence between regional deformation structures estimated from seismic image and structural information from the borehole measurement. From the viewpoint of seismic data analysis for further investigation, quantitative investigation through attribute analysis or seismic inversion will be useful to understand the dynamic deformation in the seismogenic zone with some physical properties by regional estimation from the seismic data and the local measurement along the boreholes.

Keywords: Nankai Trough seismogenic zone, 3D seismic survey, Core-Log-Seismic integration

The Lord Howe Rise Drilling Project: Tectonics, paleoclimate and deep life on the Cretaceous eastern Gondwana margin

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Ribbons of continental crust rifted from continental margins are a product of plate tectonics that can influence the Earth system. Yet we have been unable to fully resolve the tectonic setting and evolution of huge, thinned, submerged continental ribbons like the Lord Howe Rise (LHR), which formed during the final fragmentation of eastern Gondwana. IODP proposal 871-CPP was initially submitted in October 2014 to drill a deep stratigraphic hole through a LHR rift basin up to 3.5 km below the seafloor using *D/V Chikyu*. The objectives of the drilling proposal are to: 1) define the role and importance of continental crustal ribbons in plate tectonic cycles and continental evolution; 2) recover new 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. The proposal was rated “excellent” in January 2017 and has now progressed to planning stage. A geophysical site survey was undertaken from March to May 2016 in order to characterize the proposed IODP deep drilling sites and to better constrain the crustal-scale geological and tectonic framework of the LHR. The survey obtained deep-crustal seismic reflection and wide-angle refraction profiles across the Tasman Sea oceanic crust and the LHR continental crust. High-resolution 2D seismic reflection profiles at each of the two candidate deep drill sites show possible massive continental basement, layered pre-rift basement, syn-rift Cretaceous sediments, and Paleogene to Neogene post-rift sedimentary sequences.

Keywords: IODP, Lord Howe Rise, Continental ribbon, Gondwana, Chikyu

A reassessment of the stratigraphy of the Cretaceous-Paleogene (K-Pg) transition interval at the Lord Howe Rise, southern Pacific

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The Lord Howe Rise is an elongate ribbon of submerged and extended continental crust that was separated from Australia during the Late Cretaceous. Deep Sea Drilling Project (DSDP) Leg 21 drilled on the Lord Howe Rise, and recovered Cenozoic and latest Cretaceous pelagic sediments at Sites 207 and 208. In this study we provide new geochemical, biostratigraphic and magnetostratigraphic data for the latest Cretaceous and the Paleocene sediments of the DSDP Site 208 (cores from 21-208-30R to 21-208-34R), to reassess the stratigraphy around the boundary between Cretaceous and Paleogene (K-Pg). The sediments are mainly composed of calcareous nannofossil chalk with an interval of siliceous mudstone and marlstone in the top 83 cm of the Core 21-208-33R, which was previously identified as the K-Pg transition zone. Both paleomagnetic data and calcareous nannofossil assemblages show that the sediment deposited nearly continuously from 550 to 590 meter below seafloor (mbsf), corresponding to ca. 62 through 68 Ma, respectively, with an average sedimentation rate of ~7 m/m.y. However, the sedimentation rate significantly dropped in the K-Pg transition zone, which was attributed to several hiatuses. Because radiogenic isotopic composition of osmium ($^{187}Os/^{188}Os$) of ocean water draws a unique and globally synchronous variation across the K-Pg boundary, it can be used as a stratigraphic correlation tool. Simply, the K-Pg boundary marks a very low $^{187}Os/^{188}Os$ value of <0.2 compared to the Maastrichtian (~0.5-0.6) and Danian (~0.4). Our $^{187}Os/^{188}Os$ data of sediment show a similar variation with the typical pattern of ocean water $^{187}Os/^{188}Os$ values from the Maastrichtian through Danian. More importantly, we found a siliceous mudstone sample with a low $^{187}Os/^{188}Os$ value of ~0.16. We propose that this sample represents the K-Pg boundary. However, paleomagnetic data suggest that this sample belongs to the chron C29N, substantially younger than the K-Pg boundary. In the presentation we will discuss the controversy, and further assess the stratigraphy around the K-Pg boundary.

Keywords: Cretaceous-Paleogene boundary, Os isotope, Lord Howe Rise

Tracking past earthquakes in the sediment record along the Japan Trench using giant piston coring: IODP proposal 866

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After the 2011 Tohoku-oki earthquake and its destructive tsunami, it is very important to understand the recurrence pattern of large earthquakes along the particular subduction area. Although onshore tsunami deposits provide a good recurrence record of huge tsunamis, the tsunami deposits might also reflect large far-field earthquakes and/or submarine landslides, and are useful only for the past few thousand years due to paleogeographic changes. Deep-sea event deposits (turbidites) deposited by earthquake-induced turbidity currents are a potential tool in the study of subaqueous paleoseismology. Previous studies in the central Japan Trench using conventional piston coring covering the last ~1500 years reveal good correlation between the deep-sea turbidite and onshore tsunami deposit record and historical documents. Furthermore, these studies also clarified the importance of surface sediment remobilization to generate earthquake-induced turbidity currents. Because sedimentary sequences in deep-sea environments are deposited in more stable conditions, intercalated event-deposits have a potential for understanding the recurrence pattern over long time-scale. The stratigraphic record of small trench-fill and graben-fill basins in the Japan Trench has great potential to record the past earthquake-related events. IODP proposal 866 proposes to obtain the long-term and complete record of large earthquakes along the Japan Trench, and to understand the impact of large earthquakes to sediment and carbon flux to the deep-sea environments.

Keywords: giant piston coring, Japan Trench, IODP

Oman Drilling project to reveal dynamics and petrophysical properties in the crust-mantle boundary

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The Samail Ophiolite, in Oman and the United Arab Emirates, is the largest, best-exposed section of oceanic lithosphere in the World. As for other ophiolites, the presence of continuous layers of pelagic and metalliferous sediments, submarine lavas, sheeted dikes, and cumulate gabbros overlying residual mantle peridotite is similar to crust formed at intermediate- to fast-spreading, mid-ocean ridges. The ophiolite has long been a testing ground for hypotheses about processes at spreading centers. The ICDP Oman Drilling Project is a comprehensive drilling program that will sample the whole ophiolite sequence, from crust through to upper mantle, in a series of diamond- and rotary-drilled boreholes. Data collection will include analysis of rock core, geophysical logging, fluid sampling, hydrological measurements and microbiological sampling. The Oman Drilling Project in Phase I has already been achieved in early December 2016, through April 2017. Three 400 m long cores have been obtained at the three sites from Wadi Gideah in the Wadi Tayin massif. These sites represent an intact crustal section, including Site GT1 (lower crust), GT2 (mid-crust) and GT3 (dike/gabbro transition). Fourth drill site in Phase I (Site BT1) is located just above the basal thrust of the ophiolite on the north end of Sumail massif at Wadi Mansah. In mid-July to mid-September 2017, drilling cores in Phase I will be sent to the IODP research drilling vessel *Chikyu* in Japan for core description by its dedicated core logging facilities. Following Phase I, Phase II drilling program is scheduled for autumn/winter 2017/2018. Drilling of crust-mantle boundary (namely "Moho") by two 400 m long cores is planned in the Maqsad diapir region of Samail massif. Rotary drilling is also scheduled in some sites for fluid sampling, monitoring and hydrological experiment. Moreover we plan to conduct wire-line logging of rotary-drilled borehole at crust-mantle boundary using the most advanced equipment. We will attempt core-log integration by directly comparing physical properties with the core lithology across crust-mantle boundary. These studies must advance our knowledge about dynamics and physical properties at oceanic Moho. In this presentation, we report the current status of the Oman drilling project and discuss how we can study drilling cores in order to understand the physico-chemical processes in the vicinity of the crust-mantle boundary.

Keywords: Oman Drilling Project, Moho, ophiolite, crust-mantle boundary, ICDP

Fore arc mantle fabrics: a petrophysical study of peridotites obtained from serpentinite mud volcanoes in Mariana convergent margin

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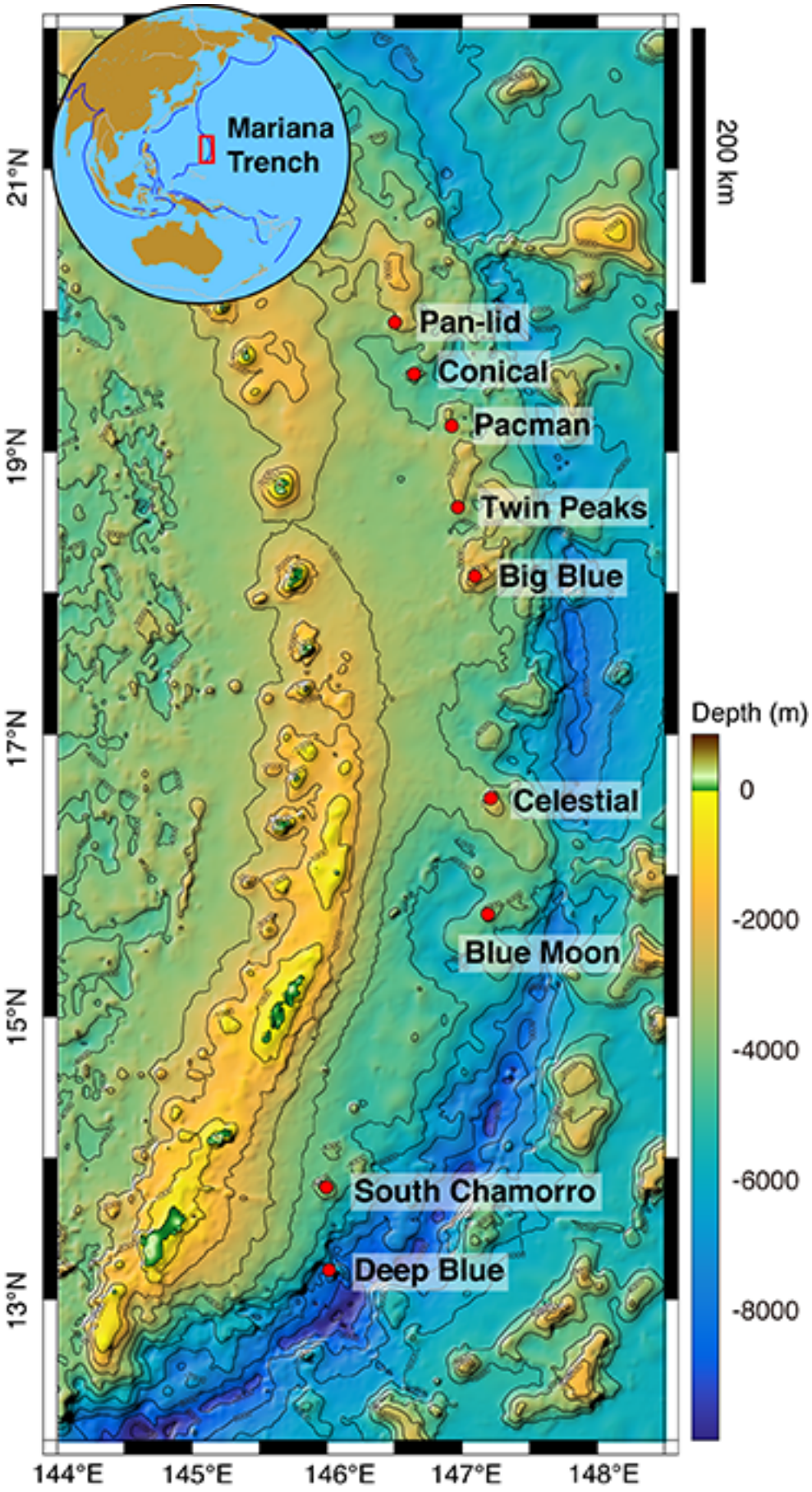
Large serpentinite mud volcanoes form on the overriding plate of the Mariana subduction zone. Fluids from the descending plate serpentinize the forearc mantle and enable serpentine muds to rise along faults to the seafloor, so that the seamounts are direct windows into subduction processes at depths far too deep to be accessed by any known technology (Fryer, 2012 Ann. Rev. Marine. Sci.). In this study, we focused on serpentinized peridotites obtained from nine serpentinite mud volcanoes in the Mariana convergent region.

The peridotite samples consist mainly of harzburgites with a few dunite samples. We analyzed olivine crystallographic fabrics as well as chemical compositions of olivine and spinel grains. Three types of olivine crystal fabrics were obtained: [010]-fiber type (AG-type), [100](010) type (A-type) and [100]{0kl} type (D-type). The chemical compositions show that Cr# ($Cr^{3+}/Al^{3+}+Cr^{3+}$) of spinel is 0.4 to 0.8 and Mg# ($Mg^{2+}/Mg^{2+}+Fe^{2+}$) of olivine is 89 to 92, which are in the range of Olivine-Spinel Mantle Array (OSMA) of Arai (1994 Chem. Geol.). The equilibrium temperatures induced by olivine and spinel compositions are 700 ˚C for D-type peridotites and 800 to 850 ˚C for AG-type peridotites.

We argue that AG-type peridotites may be derived from the older lithospheric mantle before the formation of the Mariana arc system, whereas D-type peridotites could be related to the supra-subduction tectonics during the relative plate motion between Philippine Sea Plate and Pacific Plate.

Keywords: fore arc mantle, Mariana, olivine fabrics



Progress in Bend-Fault Hydrology in the Old Incoming Plate (H-ODIN) project

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Hydration due to plate bending-induced normal faults (bend-faults) in the region between the trench axis and outer rise (outer rise) has recently drawn considerable attention (e.g., Grevemeyer et al., 2007; Fujie et al., 2013). In order to deepen our understanding of bend-fault hydration, we have submitted an IODP pre-proposal: Bending fault hydrology of the Old Incoming Plate (H-ODIN). We also organized an IODP workshop, Bend-Fault Serpentinization, in London, 2016, sponsored by CHIKYU IODP Board, the UK-IODP, and ECORD. We refined drilling purpose, drilling site and drilling strategy for Northwest Pacific region (Old-Cold subduction) and Middle Amercia region (Young-Hot subduction) in the workshop, because it is ideal to compare subduction zones in several contrasting geodynamic states (e.g. Old plate vs Young plate, Horst-and-graben bend-fault structures are well developed in the northwestern Pacific subduction system. We will present our progress in the proposals.

Keywords: Drilling project into plate bending-induced normal faults, Northwest Pacific region

