Advent of Continent: Evidence from the Nishinoshima Volcano in the Ogasawara Arc

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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. Here we report the scientific results of our endeavours to collect lavas from the currently erupting lava flows on the surface to the submarine lavas of the Nishinoshima volcano. Using olivine-bearing phenocryst-poor andesite samples, we developed a mantle-derived andesite model for the genesis of the Nishinoshima volcano. Shallow and hydrous mantle melting is necessary to produce primary andesite magmas, and thus it is only achieved beneath Nishinoshima and submarine volcanoes in the Ogasawara arc, where the crust is thin. We also show that the primary magma composition change from basalt produced at a considerable depth beneath the old thick lithosphere to andesite produced beneath the present curst corresponds to the thermal evolution of the mantle wedge in the Ogasawara arc.

Keywords: andesite, continental crust, oceanic arc


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Izu-Bonin-Mariana Arc basement from IODP Exp. 351(Amami Sankaku Basin)

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IODP (International Ocean Discovery Program) Exp.351 targeted, in particular, evidence for the earliest evolution of the Izu-Bonin-Mariana (IBM) arc system following inception. This can be obtained by identification and exploration of regions adjacent to an arc, where unequivocally pre-arc crust (basement) overlain by undisturbed arc-derived materials exists. The drill site (U1438) is located in Amami Sankaku Basin (ASB), west of the Kyushu-Palau Ridge (KPR), i.e., paleo-IBM arc. Exp.351 successfully recovered pre-Izu-Bonin-Mariana arc basement, a volcanic and geologic record spanning pre-Arc, arc initiation to remnant arc stages. In this contribution, age and geochemical characteristics of arc basement and its tectonic significance will be discussed.
At U1438, 1611m thick section in total was cored, comprising 1461m of sediment section and 150m of igneous basement. Numerous flow contacts were identified in the basement, several chilled margins could be identified but low recovery in basement rock makes their interpretation in terms of volcanic stratigraphy difficult. Paleomagnetic measurements show consistent shallow plunges of maximum anisotropy axes, and that implies these basalts were emplaced as sheet flows rather than pillow lavas.
Basalts have diverse textures that include aphyric to subophitic/ophitic. Phenocrysts are present in approximately half of the basalts and consist of plagioclase, clinopyroxene, titanomagnetite, spinel and minor olivine.
Age interpretations based on biostratigraphy (Arculus et al., Nat Geosci, 2015) determined that the basement section is between 64 and 51 Ma, and direct age determination of basement basalt by Ar/Ar dating is under way.
Whole rock geochemical analysis of the basement basalt shows that these basalts are low K tholeiitic basalts. They mostly have high-MgO (generally >8 wt%), low-TiO_2 (0.6–1.1 wt%), Ti/V, low-Zr (mostly <50 ppm). On Ti/V plot, the U1438 basalts and forearc basalt (FAB) which is supposed to be associated with subduction initiation from IBM arc are similar to each other and clearly distinct from Philippine Sea backarc basin basalts and normal MORB by having low Ti/V.
One prominent characteristic of the basalts is their depletion of immobile highly incompatible elements compared with MORB, e.g., they are strikingly light REE (LREE) depleted. But La/Nd ratio and Th/LREE increases upcore in the uppermost part of the basement, and these trace element variations with depth is accompanied by variation of major element composition such as Si and Ti.
Hf-Nd isotopes for the basement basalts show a significant range of compositions, and relatively radiogenic Hf compared to Nd indicates an Indian Ocean-type MORB source. However, the dominant signature, with e_{Hf} >16.5, is more radiogenic than most Indian MORB.
Preliminary data suggests that the basement basalts are relatively primitive melts and likely derived from Indian Ocean-type MORB sources that are more strongly depleted in terms of incompatible trace elements than typical MORB or backarc basin basalt in the Philippine Sea.
Geochemical variation in the uppermost part of the core might imply variability of slab-derived enrichment and/or fertility of mantle at the onset of subduction.
Geochemical characteristics of arc basement from Exp.351 imply that depleted MORB-like basalt (“FAB”) appears to have formed in wider area than previously thought, i.e., including “reararc”side

of ancient IBM arc. However, critical assessment of genetic relation between FAB and basement basalt of ASB requires precise age determination to constrain tectonic setting where the ASB basalts formed.

Keywords: arc basement, Izu-Bonin-Mariana arc, geochemical characteristics, Ar/Ar age

Physical properties of fore-arc basalt and boninite recovered by IODP EXP352 and its significance for the seismic velocity structure in the oceanic crust

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Physical properties of the cores recovered by IODP EXP352 were characterized through a set of measurements on whole core sections and discrete samples. Gamma ray attenuation density (GRA), magnetic susceptibility (MS) and P-wave velocity (PWL) of the cores were obtained using the Whole-Round Multisensor Logger (WRMSL). Natural gamma radiation (NGR) was measured by the Natural Gamma Radiation Logger (NGRL). Point magnetic susceptibility (PMS), reflectance spectroscopy and colorimetry (RCS) data were acquired using the SHMSL. Thermal conductivity (TCON) and moisture and density (MAD) were obtained on sections and discrete samples, respectively. All raw data were subsequently “filtered” to remove spurious points that correspond to empty intervals in the liner or broken pieces. We have mainly studied the relationships among P-wave velocity, density, prosity and magnetic suscepetibility. We show that the physical properties are useful dataset for the interpretation of the layer 2 (i.e. volcanic rocks) in the seismic velocity structure of the oceanic crust.

Keywords: IODP EXP352, Physical property

Evolution process of volcano-bounded basin revealed by mapping of seismic reflectors associated with geological boundary from drilling results in Izu rear arc

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International Ocean Discovery Program (IODP) has successfully conducted the first rear-arc drilling in the Izu-Ogasawara (Bonin) intra-oceanic arc at Site U1437 in 2014. The drilling purpose of Site U1437 is to reveal the formation of oceanic arc crust and its evolution into continental crust about the history of “the missing half” of the subduction factory. Site U1437 is located at the volcano-bounded basin between the Manji and Enpo backarc seamount chains in the Izu rear arc and ~90 km west of the arc-front volcanoes Myojinsho and Myojin Knoll, at 2117 m below sea level. Site U1437 had excellent core recovery in Holes U1437B and U1437D, and we succeeded in hanging the longest casing ever in the history of R/V *JOIDES Resolution* scientific drilling (1085.6 m) in Hole U1437E and cored to 1806.5 mbsf.
In order to evaluate the crustal structure of this proposed site before the IODP drilling, Japan Agency for Marine-Earth Science and Technology carried out many seismic reflection and refraction surveys using R/V Kaiyo and Kairei in the Izu rear arc during 2006 to 2008. Five clear seismic reflection profiles consisting of three kinds of survey environments and one seismic velocity image by seismic refraction survey are obtained across the drilling site U1437. Five sedimentary units consisting of volcaniclastics are identified from our interpretations around the drilling site in the seismic reflection profiles over the 5 km/s and 6 km/s iso-contours of P-wave velocity obtained by the velocity image of seismic refraction survey in order to evaluate structure of the drilling location before drilling. However, some unit boundary is not recognized from the drilling core. It means the difficulties for identification the geological target from only seismic images in volcanic regions. According to the drilling results, the acquired geological core is consisted of seven lithological units (I, II, III, IV, V, VI and VII). Units I to V was produced at age of 0-9 Ma. The Unit VI and VII, 1320-1806.5 mbsl, have the ages ranging from 9 to ~14 Ma. P-wave velocity calculated from obtained core samples increases downhole from ~1500 to ~4500 m/s which agree with the range of our velocity analysis. Tops of unit II, V and VII correspond to the strong reflector of seismic profiles. We interpreted and mapped using grid survey data around the drilling site. The top of unit II which corresponds to the volcaniclastics has south dipping trend. The top of unit V which corresponds to the mudstone with volcaniclastics layer has south dipping trend. The top of unit VII which corresponds to volcaniclastics estimated by near-vent deposit has southeast dipping trend. Each reflector is interrupted by igneous basement near seamount chains. We also calculate the thickness from unit VII to V and unit II to seafloor from mapped reflectors. These features suggest the different activity of various directions in the Izu rear arc. We will discuss about the evolution process in Izu rear arc deduced from our mapping results.

Keywords: site survey, volcano-bounded basin, rear arc

Preliminary reports on the Nature of the Lower Crust and Moho at Slower Spreading Ridges (SloMo)

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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 that is a 5 km local high along the eastern wall of the Atlantis II Transform of the Southwest Indian Ridge. Atlantis Bank has been interpreted as an oceanic core complex, where intact lower crust and the uppermost mantle are tectonically exposed by a long-lived detachment fault. 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.
Expedition 360 Scientific Party: Donna K. Blackman, Julie A. Bowles, Michael J. Cheadle, Kyungo Cho, Jakub Ciazela, Jeremy R. Deans, Virginia P. Edgcomb, Carlotta Ferrando, Lyderic France, Biswajit Ghosh, Benoit M. Ildefonse, Mark, A. Kendrick, Juergen H. Koepke, James A.M. Leong, Chuanzhou Liu, Qiang Ma, Antony Morris, James H. Natland, Oliver Pluemper, Jason B. Sylvan, Maurice A. Tivey, Riccardo Tribuzio, Gustavo Viegas

Keywords: Ultraslow-spreading ridge, Oceanic Core complex, Oceanic Lower Crust

Lord Howe Rise Drilling: Deep stratigraphic record for the Cretaceous eastern Gondwana margin

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The Lord Howe Rise (LHR) is an elongate ribbon of submerged and extended continental crust that separated from Australia during the Late Cretaceous. Current knowledge of the LHR is based only on widely-distributed marine and satellite geophysical data, limited dredge samples, and sparse shallow drilling into Cenozoic pelagic sediments. Building more detailed knowledge of LHR geology and the evolution of the eastern Gondwana margin requires drilling into rocks that record the tectonic and climatic history of the region.
Geoscience Australia and JAMSTEC are leading an international effort to promote an IODP project (871-CPP) to drill a deep stratigraphic hole through a LHR rift basin using D/V CHIKYU that will recover Cretaceous and older sediments and basement rocks. The objectives of 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 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.

Keywords: IODP, Lord Howe Rise, Chikyu, Cretaceous, Gondwana, Zealandia

Seismological structure of oceanic lithosphere inferred from Po/So waves

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Oceanic lithosphere, comprising oceanic crust and upper mantle, plays an important role in plate tectonics. Knowledge of the detailed structure of oceanic lithosphere is key to understanding its origin.

The propagation of Po/So waves over large distances across oceanic lithosphere provides information about lithospheric structure. Po/So waves, characterized by a high frequency, large amplitude, and long duration, were identified as early as 1935 [Linehan, 1940]. Many previous studies have attempted to quantitatively explain the generation and propagation mode of Po/So phases. Although it is generally accepted that Po/So phases are guided waves traveling very efficiently throughout the oceanic lithosphere, the generation and propagation processes of Po/So phases remain unclear.

In the past two decades, there have been great technological advances in computer simulations of high-frequency seismic waves in heterogeneous structures and in broadband seismic observations on the seafloor. These gains motivated us to further investigate the processes relating to guided waves in oceanic lithosphere and the generation of Po/So waves, using broadband seismic data and the numerical Finite Difference Method (FDM) to simulate high-frequency seismic waves. In this presentation, we outline recent progress in the study of Po/So waves.

Shito et al. [2013] reported that Po/So waves are generated by multiple forward scattering of P- and S-waves due to small-scale heterogeneities in oceanic lithosphere. The laterally elongated heterogeneities are described by a von Karman distribution function with a correlation length of 10 km in the horizontal and 0.5 km in thickness, with a velocity perturbation of 2%.

Kennett and Furumura [2013; 2014] and Shito et al. [2015] found that the propagation efficiency of Po/So waves depends on the age of oceanic lithosphere, and that this relationship can be qualitatively explained by thickening of oceanic lithosphere that contains small-scale heterogeneities and a reduction in intrinsic attenuation. Recently, Kennett and Furumura [2015] proposed a new model that the amplitude of such heterogeneities increases with depth to the bottom of the lithosphere. These results suggest that small-scale heterogeneities may form continuously in oceanic lithosphere, from the time of its formation at a spreading ridge, via the solidification of melts in the asthenosphere.

The petrological and mineralogical processes that cause the small-scale heterogeneities remain poorly known. Future studies that combine seismological observations with petrological analyses will yield a greater understanding of the origin of oceanic lithosphere.

Keywords: Po/So waves, oceanic lithosphere, small-scale heterogeneities

The effect of melt density, assimilation, and eruption location on volatile and halogen contents in MORB glasses: an example from IODP Site 1256

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A continuous section of ~700 m-thick lava pile at Integrated Ocean Drilling Program Site 1256 provides important depth variation of volatile (H_2O, CO_2, S) and halogen (Cl) contents in fresh glasses to understand style of eruption, condition of magma storage, and degree of hydrothermal assimilation. The lava pile is divided into two groups based on eruption location: off-axis basalts of upper portion (250–534 m beneath seafloor, mbsf) and on-axis basalts of lower portion (534–941 mbsf). Majority of the lava pile is composed of pillow, sheet, and massive lavas, but both groups have short (1–2 m) intervals of hyaloclastite layers (e.g., Wilson et al., 2006, Science).
H_2O contents of hyaloclastite samples are distinctly higher than those of lavas, suggesting that the high H_2O would induce explosive eruption to produce the hyaloclastite materials. CO_2/Nb and S/Dy in most fresh glasses are smaller than degassed ratios (e.g., Saal et al., 2002, Nature), and these facts indicate shallow degassing and CO_2 and S losses during transport to the seafloor. Saturation pressures calculated by dissolved H_2O and CO_2 contents are wide range from pressure of seafloor (~25 MPa) to pressure of magma chamber (~60 MPa). The saturation pressure positively correlates with melt density, but obvious differences between off-axis and on-axis samples are not identified. These observations may imply that the melt density is important factor to estimate degassed pressure. When the melt density is low, the melt can ascent from melt lens (top of magma chamber) to shallow place within oceanic crust and highly degassed before reach to seafloor. Conversely, dense melt would not ascent to the shallow place and less degassed at deep level near the melt lens.
The most distinctive character for the Site 1256 glasses is higher Cl/Nb and Cl/K than any other MORB glasses. The strong Cl enrichment is explained by assimilation of highly hydrothermally influenced crust (e.g., Sano et al., 2008, 2011, G-cubed). Beneath the Site 1256, melt lens was very shallow (<1.5 km) and hydrothermal circulation of high-salinity brines would easily reach to roof crust of the melt lens.

Keywords: IODP, volatile, melt density

A seamount on top of Ontong Java Plateau was created by remelting of plateau lithosphere by plate flexure

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The Ontong Java Plateau (OJP) was formed by a main volcanism occurred at ca. 120 Ma, followed by several pulses of the late-stage volcanism on and along the margins of the plateau. The origin of the late-stage volcanism is poorly understood because of limited rock sampling. We present the age and geochemical composition of basalts dredged from Nuugurigia Atoll that stands on the plateau basement, possibly erupted in the late-stage volcanism. The $^{40}Ar/^{39}Ar$ age of dredged basalts is ca. 20 Ma, younger than any other known late-stage volcanism on OJP (down to 34 Ma), and is coincided with the collision of the plateau with the proto-Solomon arc. These basalts have enriched isotopic signatures pointing towards EM1 distinct from any other rocks thus far collected from OJP. Moreover, they show unusual trace element composition with Sr enrichment and Zr-Hf depletion relative to the elements with similar incompatibility. Such isotopic and trace elemental feature are shared with quartz-bearing garnet pyroxenite xenoliths rarely found from Solomon Islands (Ishikawa et al., 2007). Ishikawa et al. inferred that such pyroxenite was derived from delaminated granulitic lower crust and was part of the OJP lithosphere underplated beneath the plateau lithosphere via the mantle upwelling responsible for the main plateau-forming volcanism. We suggest that the basalts in the late-stage volcanism at Nuugurigia were products of rejuvenated melting of such pyroxenite. Melt transport through the lithosphere may have been facilitated by plate flexure occurred just south of the atoll when the plateau collided with the proto-Solomon arc around 20 Ma.

Keywords: oceanic plateau, lithosphere, recylced material

Understanding continental crust emplacement: A continental scientific drilling perspective

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Scientific drilling is a critical tool for Earth science to understand crustal evolution and processes. In the recent past, the International Continental Scientific Drilling Program, ICDP, supported several drilling operations in hard rock addressing the formation and emplacement of continental crust from Archean volcanism (Peering into the Cradle of Life, Barberton, South Africa), Paleoproterozoic volcanism (FAR-DEEP, Baltic Shield, Russia), rift volcanism (Krafla, Iceland), hot spot volcanism (Hawaii, USA, Snake River Plain, Idaho, USA) and Himalyan-style thrust sheet emplacement (COSC, Sweden). The results of these studies have significantly improved our understanding in past and present formation of continental crust.
ICDP supports scientific drilling operations that facilitate outstanding science at globally important sites. ICDP brings together scientists and stakeholders from 24 nations to work together at the highest scientific and technical level. Since its founding in 1996, more than 40 drilling projects and 75 planning workshops have been supported by ICDP worldwide. The outcomes of scientific drilling operations supported by ICDP cover the full range of the Earth sciences from climate change, natural hazards and earth resources to the origins and evolution of life on Earth, effectively addressing the needs of our growing population for energy, sustenance, and quality of life.
Forthcoming ICDP drilling into the Samail ophiolite complex in Oman will provide key data on melt extraction processes from the mantle, igneous accretion of oceanic crust, and hydrothermal modification of that crust. Drilling will also investigate present day alteration processes of mantle peridotites and their relationship to the deep biosphere.
The Surtsey volcano drilling in fall 2016 aims to investigating processes of rift zone volcanism, hydrothermal alteration and biological colonization of basaltic tephra. It will refine our understanding of seawater- interactions with magma and rock that influence diagenetic and microbial alteration of tephra to produce lithified tuff and shed new light on how rift zone volcanic islands form, lithify, and are ultimately destroyed.
ICDP is also funding drilling for Reservoir Triggered Seismicity near the Koyna dam located close to the west coast of India. The basement rocks of the Koyna-Warna region consists of Precambrian basement overlain by a more than 1 km thick Deccan Trap cover that erupted about 65 Ma ago. Two pilot boreholes will provide critical information on the in-situ stress regime, pore fluid pressure, fluid/gas properties and hydrological parameters of basement rocks, and the geothermal regime. These 3 km deep wells will lay the ground for two deep main boreholes for penetrating into the source of induced seismicity at more than 5 km depth.

Keywords: ICDP, Scientific Drilling, Continental Crust emplacement

From Birth to Death: Fate of The Extremely High-T Subduction Zone of The Oman Ophiolite

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The Oman Ophiolite preserves the entire geological records of intra-oceanic subduction zone formation and arc evolution, where 98-96 Ma MORB-like basalt magmatism (V1) was followed by 96-94 Ma arc tholeiitic and low-silica boninitic volcanism (V2) [1,2,3,4]. The remanents of the subducted slab are now preserved as the high-grade metamorphic soles beneath the ophiolite sheets [5]. After a quiescence period, alkali basalt flows (V3) were extruded at about 90 Ma, which has an intermediate geochemical characteristics between OIB and EMORB [6]. The V3 trace element compositions can be reproduced by pooled partial melts in the stability field of garnet and spinel lherzolite.Through the V2 magmatism, the source mantle shows progressive depletion by stepwise melt extraction, as shown by the lower Nb/Ta ratios for the younger volcanic rocks (V2 boninite < V2 tholeiite < V1) [2] with identical εHf(t) values. V2 glasses have higher B, Pb, and LILEs with age, indicating an increasing contribution of slab fluids from earlier arc tholeiite to later boninite. Boninite magma was generated with the supply of high-T hydrous fluid and sedimentary melt liberated from the metamorphic sole as demonstrated by the Sr-Nd isotopic compositions of the amphibolite and metachert in the sole and clinopyroxene separates from boninites [1,2,7]. Therefore, the metamorphic sole beneath the ophiolite sheets are responsible for the generation of V2 arc magmas. Melt inclusions in Cr spinel derived from boninite comprise homogeneous glass of mostly low-Si boninitic [3,4] and slightly differentiated composition, with SiO_2 ranging in 52-62 wt% and MgO up to 16 wt%. The primary boninite magma assumed as the most magnesian melt inclusion can coexist with mantle olivine and orthopyroxene [9] at 0.4-0.6 GPa and 1350°C. This T-P conditions indicate a segregation depth of ~17 km from the mantle with a potential T of 1400°C. Meanwhile, the peak metamorphic conditions for the subducted slab that liberated high-T fluids to form boninite and arc tholeiite magmas are 770–900°C and 1.1-1.3 GPa [1,6,7].

The keys of the Oman subduction zone are 1) the preservation of diapiric structures in the mantle [10], 2) short time interval of the V1 and V2 magmatism <2 m.y., 3) T-P conditions for a primary low-Si boninite (Umino et al., 2014); and 4) extremely high T & low-P metamorphic conditions for the sole that liberated the fluids generating the V2 magmas [1,5]. These lines of evidence are most readily explained by intraoceanic thrusting initiated near the ridge axis that developed into a shallow and hot subduction zone [1,2,8,10].

Forced subduction of such an extremely high-T, buoyant slab suppressed convection in the mantle wedge, resulted in the progressive depletion of the source mantle through the V2 arc magmatism. Numerical modeling suggests that melting of the slab and mantle wedge occurrs only in the early stage and ceases as the mantle wedge cools because of the absence of convection [10]. Consequently, the Oman arc volcanism terminated in only a few million years. After several million years, parts of the subducted slab delaminated and induced upwelling and adiabatic melting of DMM asthenosphere, resulted in the generation of alkalic magmas of V3 extruded onto thick pelagic sediments before colliding onto the Arabian Peninsula.

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Keywords: Oman Ophiolite, boninite, high-T subduction zone, metamorphic sole, subduction initiation, obduction

The redox state in the Fizh mantle section, the northern Oman ophiolite as an analog of mantle wedge in subduction zone

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The redox state of the upper mantle is important because it controls phase equilibrium and partitioning of some trace elements. Previous studies of mantle peridotites show mantle xenoliths in arc lavas are more oxidized than abyssal peridotites on the ocean floor because subducting slab is dehydrated to supply ‘oxidized fluid’ such as water and carbon dioxide to the mantle wedge in hanging wall (e.g., Parkinson and Pearce, 1998).

The mantle section of the Oman ophiolite is a good analog for a mantle wedge because it experienced supra-subduction zone setting during oceanic thrusting prior to the obduction. In this study, we focus on the Fizh mantle section in the north Oman ophiolite as a proxy of mantle wedge in a subduction zone and evaluate the redox state recoded in the peridotites. We calculated delta $logfO_2$ (FMQ) using equation of Ballhaus et al. 1991, chemical composition of olivine and spinel with ferric and ferrous iron ratio assuming stoichiometory. The spatial distribution of delta log fO_2 (FMQ) in the Fizh mantle section indicates that the basal part of the mantle section is more reduced whereas the upper part of the mantle section beneath the Moho is more oxidized. This may indicate that the basal part of mantle wedge above the contact to subducting slab is most reduced.

We compared ferric and ferrous iron ratio calculated from spinel composition assuming perfect stoichiometory to those directly obtained by Mössbauer spectrometry. The reslts show that the difference is minor and does not significantly affect the tendency mentioned above. As independent approach, we used abundance ratio of vanadium against scandium in whole rock peridotites. Vanadium partitioning between peridotite and melt is sensitive to the change in oxygen fugacity whereas scandium doesn’t. Thus the ratio of vanadium against scandium is a good proxy for estimating oxygen fugacity. As a result, delta log fO_2 (FMQ) shows negative correlation with the ratios of vanadium against scandium for whole rock peridotites. This result confirms that the basal part of the Fizh mantle section is more reduced than the upper part of the mantle section.

One possible factor for the reduced signature in the basal part of Fizh mantle section is a reaction of peridotite with a reduced melt produced by melting of sediment with reduced carbon subducted beneath the Fizh mantle section. This hypothesis is supported by high Th/Ce ratio in whole rock peridotites and clinopyroxenes with low delta log fO_2 (FMQ). The high Th/Ce ratio is one of the features which indicate contribution of oceanic sediments and suggests those influence. The Raman peak of methane has also been detected in the fluid inclusions in the peridotite from the basal part. On the other hand, a peak of methane has not been detected from the fluid inclusion in the peridotites beneath the Moho Transition Zone. The presence of methane in the fluid inclusions from the basal part of mantle section also supports reduced condition at the base. We consider that the methane was derived from reduced carbon in the subducted oceanic sediment during oceanic thrusting of the ophiolite.

Keywords: Oman ophiolite, Redox state, mantle peridotite, mantle wedge, oxygen fugacity, subduction zone

Mud gas monitoring for hard rock drilling

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Mud logging in a riser drilling operation has been powerful tool in the scientific drilling. Since fast and safe drilling are minimum requirements in the deep drilling operation, it is generally difficult that continuous coring is carried out to obtain geological sample (rocks and fluid). Therefore, cuttings survey and mud gas monitoring in mud logging are essentially important in the riser drilling for scientific research. Some hard rock drilling operations by using the Chikyu have been planned (e.g., IBM, MoHole). Since continuous coring in the hard rock drilling is technically more difficult as compared with the drilling for sedimentary rocks and slow rate of penetration results in consuming much of operation time, the cuttings survey is a unique approach for lithological characterization in the hard rock drilling. In addition, fluid sampling from hard rock core is also difficult, even if core sample is obtained. Thus, the mud logging is especially important for the hard rock drilling, not only minimizing operation time but also maximizing scientific result. In this presentation, we will introduce current technology of advanced mud gas monitoring and discuss on potential of the mud gas monitoring for the hard rock drilling.

Keywords: Mud logging, Hard rock drilling, Mud gas monitoring, Formation fluid

Preliminary result of the physical properties and downhole measurements during IODP Exp. 360 Indian Ridge Lower Crust and Moho

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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 conducted drilling into the lower crustal gabbroic rocks at Atlantis Bank, and penetrated from the top of ocean floor to 798.7 mbsf. The cored interval is 742.7m and total recovered core length 469.65 m (63.2% recovery). Olivine gabbro is the dominant lithology of the recovered core samples, followed in gabbro, oxide gabbro, and oxide-bearing gabbro. Lithological variation is small in the core samples. In order to understand the petrophysics of the site, we measured physical properties on the whole round and splitted half sections and, discrete samples and also took three runs of wire-line logging; Triple-combo, FMS and UBI.
Phase II of the SloMo has proposed to drill 6 km through MOHO by the CHIKYU. In the meeting, we would like to present the preliminary results, especially of the petrophysical measurements, of IODP Expedition 360 and the future perspective leading to Phase II of the SloMo, a mantle drilling into ultraslow-spreading ridges.

Keywords: IODP, Moho, SW Indian Ridge, Slow spreading ridge

Peridotites outcroppted in the southern Mariana Trench

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The Izu-Bonin-Mariana(IBM) arc, which is a typical oceanic arc, has 3000 km in length from the north to the south. The IBM forearc is non-accretionary convergent plate margin, where lithologies outcropped on the land-side slope is similar to those found in many ophiolites. The Mariana trench axis forms an arc-like shape due to collision of Ogasawara plateau and Caroline ridge [1]. Thereby, the southern Marianas from the south of Guam to Yap Trench junction shows characteristic morphology where the trench axis runs across both Mariana volcanic arc and backarc basin (Mariana trough). Geological expeditions in the southern Mariana Trench on the eastern side of the Challenger Deep have found trench peridotites as shallow as 5800 m below the sea surface [2]. The petrological compositions of these peridotites have both forearc-like depleted compositions and fertile compositions similar to those reported in the northern Mariana trough [3]. In this study, we report the geochemistry and fabric data for peridotites on the western side of Challenger Deep for the first time since Hawkins and Batiza (1977) and attempt to present the full picture of mantle domain outcropped in the southern Mariana trench.

We have selected about 140 samples from MARA20, MARA27 (dredged by R/V Thomas Washington during MARIANA Expedition in 1978), KH98-1-D1, KH98-1-D2, KH98-1-D3 (dredged by R/V Hakuho during cruise KH98-1 in 1998), KH03-3-D7, KH03-3-D8 (dredged by R/V Hakuho during cruise KH03-3 in 2003), 6K-1094, 6K-1095 (collected by R/V Yokosuka during cruise YK08-08 in 2008), 6K-1232, 6K1233, 6K1234 (collected by R/V Yokosuka during cruise YK10-12 in 2010), 6K-1397,6K-1398 (collected by R/V Yokosuka during cruise YK14-13 in 2014) and 6K-1429 (collected by R/V Yokosuka during cruise YK15-11 in 2015).

Petrological compositions of peridotites from the western side of the Challenger Deep show different characteristics between survey sites. Peridotites from the southwesternmost Mariana forearc near the Yap Trench junction area (Site1:11°2’N139°3’E) have fertile compositions (Cr#=0.25-0.6) similar to those from the Parece Vela backarc basin [4], whereas peridotites from the other site close to Challenger Deep (Site2:11°1’N140°3’E) have depleted compositions (Cr#=0.6-0.9) similar to those from the northern Mariana forearc [5]. In our presentation, We will show all chemical compositions of peridotites derived from the southern Mariana Trench in addition to the data from the western side of the Challenger Deep obtained by this study.

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Keywords: Trench Peridotite, Southern Mariana Trench, Geochemistry, Olivine Fabric

Geochemical characteristics of Izu rear arc magmatism after the cessation of the Shikoku Basin opening: Results from IODP Exp. 350

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International Ocean Discovery Program Expedition 350 Site U1437 drilled, for the first time, into the rear arc volcaniclastic sediment in the Izu arc. The drilling reached 1806.5 m below seafloor (mbsf) and in-situ lava clasts were recovered in the deepest part of the hole (stratigraphic Unit VII, below ~1460 m) (Tamura et al., 2015).
The U-Pb zircon ages obtained from an intrusive rhyolite sheet of the Unit VI at the depth of ~1390 mbsf showed 13.6+1.6/-1.7 Ma (Tamura et al., 2015) and 13.71±0.25 Ma, thus Unit VII lava clasts suggest magmas erupted after the cessation of the Shikoku Basin opening (~15 Ma) and before onset of the rear arc seamount chain magmatisms (hot fingers).
We have analyzed the major and trace element compositions, and Sr, Nd, Pb and Hf isotope ratios of selected >2 cm lava clasts collected from Unit VII. These show neither rear arc nor Quaternary volcanic front signatures in terms of trace elements and isotopes. The Nd and Hf isotope compositions are similar to those in the Quaternary volcanic front magmas. However, most samples have Sr and Pb isotope compositions similar with those in the rear arc magmas. The isotopes of Unit VII are also similar to samples collected from the active rifts. Most of samples show low Ba/La and La/Sm, and chondritic Sm/Hf ratios, suggesting that the addition of slab derived fluids/melts is small despite the horizontal trend of Nd-Hf isotopes.
Above results show that Izu rear arc magmatism at Site U1437 differed from that in the rear arc seamount chains after cessation of the Shikoku Basin opening. Contribution of the slab flux was small and the source mantle was highly depleted in terms of isotopes.

Zircon U-Pb age and geochemistry of plutonic rocks in the Mineoka-Setogawa Belts: Fragments of middle to lower crust of the IBM Arc?

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The Mineoka-Setogawa Belts are Paleogene accretionary complexes distributed around the Izu Peninsula. These belts contain the various sizes of detrital and tectonic fragments of serpentinized mantle peridotites, plutonic rocks (gabbro, diorite and tonalite), metamorphic rocks and volcanic rocks (e.g., Arai 1994), which likely show ophiolitic constituents. Although Middle Eocene microfossils were reported from sedimentary rocks in these belts (e.g., Saito, 1992; Sugiyama and Shimokawa, 1990), reliable data of the isotopic age have not been obtained yet. In this study, we determined the precise age of the plutonic rocks in the Mineoka-Setogawa Belts using the zircon U-Pb method, and compared with the current age models proposed for the Philippine Sea and IBM Arc.

The U-Pb age was measured from zircon grains collected from 10 samples of gabbros, diorites and tonalites using LA-ICP-MS (Thermo Fisher Scientific ELEMENT XR). The zircon U-Pb ages obtained from all samples concentrate at approximately 35 Ma, regardless of the rock types. These ages are coeval with the Eocene to Oligocene arc magmatism in the IBM Arc.

The whole-rock chemistry of the plutonic rocks from the Mineoka-Setogawa Belts shows calc-alkali affinity and distinct negative anomalies of Nb and Ta in their trace element patterns, which indicates that these plutonic rocks were formed by arc magmatism. Comparing the plutonic rocks with the possible analogues of the IBM middle crust, the Tanzawa Plutonic Complex and the Komahashi-Daini Seamount (Tamura et al., 2009), the major and trace elements of the plutonic rocks from the Mineoka-Setogawa Belts are very similar to those of the Tanzawa Plutonic Complex and the Komahashi-Daini Seamount.

The zircon U-Pb ages and geochemistry of the plutonic rocks in the Mineoka-Setogawa Belts probably indicate that the ophiolitic fragments in the Mineoka-Setogawa Belts are derived from the crust and upper mantle of the IBM Arc. More thorough investigations of the ophiolitic fragments in the Mineoka-Setogawa Belts will help us to understand the petrological evolution of the crust and upper mantle beneath the IBM Arc.

Keywords: Mineoka-Setogawa Belts, Zircon U-Pb age, Plutonic rocks

Estimate of the serpentinization process in the northern Fizh block, the Oman ophiolite

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The mantle section of the Oman ophiolite is composed of partially-serpentinized harzburgite, dunite and lherzolite. These peridotites are likely to have been suffered from hydrothermal circulation on ocean floor because Oman ophiolite formed at mid-ocean ridge with fast spreading axis. In addition, peridotites above the basal thrust may have reacted with a fluid liverated from metamorphic sole during oceanic thrusting. Thus the study of serpentinization of the Oman peridotites is important to understand fluid-peridotite reactions in the upper mantle. In this study, we examine serpentinization processes in the Oman ophiolite on the basis of microscopic observation and chemical composition of serpentines in the northern Fizh mantle section. Lizardite is ubiquitously present in the Fizh mantle section and develops typical mesh texture associated with lizardite veins. Some clinopyroxenes are partially replaced by tremolite indicating possible fluid supply. Because no antigolite has been found in the Fizh mantle section the reaction of clinopyroxene with hydrothermal fluid must have occurred at temperature between 600 and 900 degreeC. It suggests that seawater can infiltrate the upper mantle at such high temperature beneath fast spreading mid-ocean ridge.

One of the important observations in our study is that the peridotites in the basal part of the mantle section contain abundant magnetites within the meshes and veins of serpentine. Moreover, some talc replaces the rim of orthopyroxenes. Previous studies proposed two-stage processes for serpentinization where magnetite formed at later stage. In addition, talc and forstelite can be produced from enstatite and flluid at 650-750 degreeC (>6kbar). We consider that the fluid was liberated from metamorphic sole and infiltrated the basal part of the mantle section during oceanic thrusting.

On the other hand, in the peridotites inside the mantle section and near the Moho Transition Zone no magnetite occur in meshed serpentine and only small amounts of magnetite occur in some veins that cut earlier meshed serpentine. The compositions of veined serpentines with magnetite are higher in Si+Al and lower in Fe+Mg relative to meshed and veined serpentines without magnetite. It is consistent with the model in which serpentine and magnetite formed from brucite under high silica activity [Bach et al., 2006]. The Mg# [=Mg/[Mg+Fe] atomic ratio] of serpentines associated with magnetite in the basal peridotite are slightly lower than those of veined serpentines associated with magnetite inside of the mantle section. This may indicate that Fe difussivity was faster due to higher temperature during magnetite formation in the basal part of the mantle section. Because the amount of serpentine is uniform inside the mantle section and has no correlation with the distance from the Moho Transition Zone lizardite formed at relatively low temperature, probably less than 300 °C, by infiltration of surface water since obduction of the ophiolite.

Keywords: Oman ophiolite, serpentinization, serpentine, lizardite, magnetite

Geochemical evaluation of Haybi volcanic rocks as a protolith of amphibolites in the metamorphic sole of Oman ophiolite

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We conducted geochemical analysis of the Haybi volcanics and amphibolites of metamorphic sole from the Sumeini Window in the northern Oman ophiolite to understand the protolith of amphibolites and their genetic relationship to the Haybi volcanics.

In the Sumeini Window the metamorphic sole consists of amphibolite, greenshist and quartzite. They have been thermally metamorphosed during thrusting of ophiolite mantle section. The metamorphic sole occurs tectonically above the Haybi Complex that includes metachart, limestone and volcanic rocks so that the protolith of metamorphic sole is considered as Haybi Complex. Haybi volcanics are alternations of pillow lava and lava sheet. Some pillow lavas occur as blocks enclosed in metachart.

By examination of whole rock compositions using discrimination diagrams and C1 chondrite-normalized patterns of rare earth elements (REE) Haybi volcanics can be divided into either OIB or E-MORB type. OIB-type basalts are pillow lava and lava sheet of alkali basalt to bsasanite and is stratifically located beneath E-MORB type that is blocks of trachyandesite to dacite enclosed in metachart. On the other hand, amphibolites can be divided into N-MORB to E-MORB type. Amphibolites with E-MORB affinity are geochemically similar to E-MORB type volcanic rocks. There is no systematic distribution of N- and E-MORB types along a wadi in the Sumaini Window. Both N- and E-MORB types occur near the contact between metamorphic sole and mantle section.

Whole rock Nd isotope ratio and La/Yb ratio show a broadly negative correlation that are similar to those of volcanic rocks from Kerguelen islands. These variations can be explained by mixing between MORB source mantle and isotopically enriched mantle associated with various degrees of melting. Our results show that N-MORB, E-MORB and OIB type volcanic rocks were distributed on the oceanic crust prior to the thrusting of Oman ophiolite. Then, N-MORB and E-MORB were subducted beneath ophiolite so that they were metamorphosed to amphibolite by thermal metamorphism and accreted to the base of the ophiolite. On the other hand, OIB-type volcanic rocks that are free from thermal metamorphism accreted beneath metamorphic sole after N-MORB and E-MORB at relatively lower temperature and formed Haybi Complex.

Keywords: Oman ophiolite, metamorphic sole, Haybi volcanics, OIB, N-MORB, E-MORB

Petrology and geochemistry of LREE-enriched fresh peridotite boulders from the basal part of the Fizh block, the northern Oman ophiolite

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Oman ophiolite, showing a great exposure (~ 500 km long), is one of the most famous ophiolites in the world. Whole ophiolite sequence is well preserved and the emplacement age has been determined as Cretaceous, based on the K/Ar dating on hornblendes from underlying metamorphic-sole amphibolite (e.g., Searle & Cox, 2002). There have been reported island-arc related volcanic rocks mainly in the northern part of Oman ophiolite, and in the meanwhile, volcanic rocks comparable to typical N-MORB are dominant in the southern part of the Oman ophiolite (e.g., Alabaster et al., 1982). It is still debated that the Oman ophiolite is of mid-ocean ridge origin or of ridge axis on supra-subduction zone origin. Recently, highly depleted harzburgites have been reported in the northern Oman ophiolite (Kanke & Takazawa, 2004); they were interpreted as products of the secondary partial melting of residual harzburgites beneath the mid-ocean ridge, induced by H_2O-induced flux during detachment and intra-oceanic thrusting.
We found quite hard and fresh (LOI < 1.0) peridotite boulders at the southern basal zone of the Fizh block (e.g., Wadi Hayl). The texture is variable (mylonitic, porphyroclastic, equigranular, and coarse protogranular) and some porphyroclastic samples contain highly deformed fine-grained zones. It is difficult to determine the modal proportion of minerals due to the presence of fine-grained zone, but we can judge that they are mostly harzburgites and subordinately lherzolites, based on petrography of coarse-grained part of the samples and their whole-rock major-element compositions (SiO_2 = 43.5-46.4 wt.%, Al_2O_3 = 0.38-1.10 wt.%, and CaO = 0.49-1.68 wt.%). Chondrite-normalized (the values showing with subscript CN hereafter) whole-rock REE concentrations show LREE-enriched U-shaped patterns, and the $(La/Sm)_{CN}$ and $(La/Yb)_{CN}$ are variable: 3.5-10.3 and 2.0-11.0, respectively. These values are quite high relative to the reported harzburgites (0.02-0.11 and 0.44-0.70; Godard et al., 2000) and fertile lherzolite (0.09-0.11 and 0.04-0.06; Takazawa et al., 2001: 0.28-1.15 and 0.09-0.53; Khedr et al., 2014) from other localities of the Oman ophiolite. The U-shaped REE pattern of ophiolitic peridotites has been interpreted as a result of secondary processes, such as serpentinization, ocean-floor alteration, or contamination of crustal materials during ophiolite obduction (Gruau et al., 1998). Low LOI value (< 1.0) of our samples denies the contribution of serpentinization and alteration to their enrichment of LREE, and indicates possible metasomatic addition of LREE to the mantle tectonite during/before ophiolite obduction (at high-temperature stage).

Keywords: fresh peridotite, incompatible trace elements, mantle metasomatism, Oman ophiolite

Evolutionary processes of submarine volcano in an incipient arc reference from the Oman Ophiolite

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The Oman ophiolite belonging to the Tethys ophiolite zone is one of the best places to investigate magmatic and volcanic developing processes of an infant arc. The Ophiolite had formed on a spreading axis and followed by subduction stage magmatism at approximately 100 Ma. The volcanostratigraphy is similar to that of the Izu-Bonin-Mariana Arc (e.g. Starn, 2004). However, the latest U-Pb age of zircon in plutonic bodies shows that there is only 0.5 m.y. time gap between the spreading and subduction stages (Riuox et al., 2014), therefore, it seems to record short-spanned island arc magmatism. Progressive geochemical change from island arc tholeiite (LV2) to boninite (UV2) in this period showed us the evolutionary process of the high-T and ephemeral subduction zone (Kusano et al., 2015). To reveal the stress history during the subduction stage, we reconstructed accretionary process of the arc magmas at the northern Oman ophiolite.
The subduction stage volcanic rocks (V2) extend >350 km along the Oman Ophiolite. In Wadi Salahi area, the V2 consist of the 600-970 m thick lower LV2 and 0-140 m thick upper UV2. Pahoehoe and sheet flows are dominate in the LV2, while 50 m thick pyroclastic rocks are partly distributed upward. Plural flow units and sporadically distributed plugs and dikes at 1-3 km spaces are recognized in the LV2. These plugs are 1.5-3 m in diameter with cylindrical layering of fine-grained and coarse-grained parts. The distribution of plugs and dikes look unbiased in the stratigraphic horizon. Because the LV2 was erupted through cone sheets (Alabaster et al., 1982), these plugs might be distributed along the “ring conduit”. Similar bulk rock compositions of the LV2 including lava flows and pyroclastic rocks suggest the share in the magma chamber. However, E-W concentration of strike of plugs and dikes would be resulted from the regional E-W compression (Umino et al., 1990).

Keywords: Subduction initiation, high-T subduction zone, Boninite, Oman Ophiolite, submarine volcano geology

