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

