SIT05-P01 Room:Convention Hall Time:May 21 18:15-19:30

# Petrology of peridotites in the southern part of the Central Indian Ridge: Implications for ocean floor formation

Tomoaki Morishita[1]*, Ryoko Senda[2], Katsuhiko Suzuki[2], Hidenori Kumagai[2], Hiroshi Sato[4], Kentaro Nakamura[2], Kyoko Okino[3]

[1]Kanazawa University, [2]JAMSTEC, [3]University of Tokyo, [4]Senshu University

A wide variety of peridotites (lherzolte, harzburgite, dunite and orthopyroxene-rich peridotite) including plagioclase dunite-troctolite was recovered from the southern part of the Central Indian Ridge by submersible dives & dredges using the SHINKAI 6500 and the R/V Hakuho-maru. We examined these peridotites and discuss their implications for the formation of ocenic lithosphere.

**Oceanic Core Complex (25S OCC):** A typical oceanic core complex (25S OCC) has been well described in this area (Kumagai et al., 2008 *Geofluids*; Sato et al., 2009 *G-cubed*). We recovered harzuburgites cut by gabbroic veins, gabbroic rocks from olivine-gabbro to oxide gabbro, granitic rocks, dolerite, basalt and their deformed rocks (Nakamura et al., 2007 *Geochem. Jour.*; Morishita et al., 2009 *Jour. Pet.*). Peridotites are residues after moderate degree (13-15 %) partial melting, then were slightly chemically modified due to infiltration of evolved melts (now gabbroic veins). Petrological and mineralogical characteristics of gabbros are basically similar to Hole 735 B gabbros in the Southwestern Indian Ridge. Deformation and alteration of these lithologies were locally concnentrated along the detachment fault, resulting in exhumation of the OCC associated with long-lived fault activities. Small serpentine bodies were also found in this area (Green Rock Hill of Hellebrand et al., 2002 *Jour. Pet.*, Yokoniwa Hills of *this study*). Petrological characteistics of these peridotites are the same as those from the OCC.

**Dunite-Troctolite small body (Uraniwa Hills):** We found small hills near the Kairei Hydrothermal Filed, which might compose of plagioclase dunite, troctolite olivine gabbro and dolerite based on the results from our submersible dives (Nakamura et al., 2009 *Earth Planet. Sci. Lett.*). These rocks can not be explained by crystal fractionation model but might be interpreted as the series of products after melt-mantle interactions (cf. Arai & Matsukage, 1996 *Lithos*).

**Peculiar Serpentine knoll (not named yet):** We recovered pyroxene-rich peridotites from a knoll along the Central Indian Ridge (Morishita et al., 2013 *AGU abst.*). Only gabbros and serpentine were recovered from the top of the seamount by dredge. Peridotite samples were classified into (1) dunite, (2) pyroxene-bearing peridotite (olivine > pyroxene) and (3) pyroxene-rich peridotite (pyroxene > olivine). It is noted that almost samples of pyroxene-bearing peridotite are nearly completely serpentinized. Spinel is usually the only relic of mantle assemblages. Spinel compositions of the pyroxene-bearing samples are 0.3-0.4, identical to those of OCCs and small peridotite bodies. Pyroxenes in both the pyroxene-bearing and the pyroxene-rich samples are orthopyroxene. We proposed that the pyroxene-rich rocks were formed by interaction with silica-rich melt/fluid in a different tectonic setting, such as subduction zone, in ancient time rather than the mid-ocean ridge setting. Our recent Os isotopic data on these rocks supports the ancient subduction-metasomatized peridotite origin.

**Implications:** We will discuss the implicatins of the existing of these peridotite in this region on the formation of oceanic plate.

This work was partly supported by the Taiga-Project.

Keywords: Peridotite, Ocean floor, Ancient event, melt-peridotite interactions, Central Indian Ridge, troctolite

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# Petrological and structural examination of the origin of foliated gabbros in the Oman ophiolite

Masahiro Oikawa[1*], Yoshiko Adachi[2], Yutaka Nogawa[3], Sumio Miyashita[4]

[1]Graduate School of Natural Science, Niigata University, [2]Center for Transdisciplinary Research, Niigata University, [3]Mitsubishi Materials Techno Corporation, [4]Department of Geology, Faculty of Science, Niigata University

The gabbro units constituting a lower part of fast-spread oceanic crust are divided into layered gabbro, foliated gabbro and upper gabbro in ascending order. Layered gabbro is generally characterized by modal layering but foliated gabbro lack conspicuous modal layering and is accompanied by a strong mineral preferred orientation. The upper gabbros show massive appearance free from layering, foliation and preferred orientation of minerals. The upper gabbro units are considered to be solidified products of thin melt lens which is root of sheeted dyke complex beneath fast-spread ocean ridges. On the other hand, genesis of the foliated gabbro units is controversial. Nicolas et al. (2009) considered that they are formed due to subsidence from the melt lens, while MacLeod and Yaouancq (2000) proposed that they are produced during buoyant up flow from underlying crystal mush where layered gabbros were formed. However, the definition between foliated gabbro and layered gabbro are not clear. Therefore, the quantitative analysis in respect to structural features of the various gabbro facies is required to understand for the genesis of foliated gabbro.

We have studied gabbroic unit from layered gabbro to massive gabbro, of the Hilti block in the northern Oman ophiolite in term of structural and petrological aspects. Configuration and preferred orientation of plagioclase on X-Y plane and X-Z plane of samples are analyzed. Mineral compositions are also analyzed. It is noted that some foliated gabbros lack a lineation. Furthermore, the degree of intensity of foliation which is defined by alignment and aspect ratio of plagioclase is varied due to the stratigraphic position; the foliation of foliated gabbro is strongly developed just above the layered gabbro. While, the foliation just beneath the massive gabbro is week. Plagioclase compositions tend to evolve upward in the foliated gabbro unit. These lines of evidence suggest that the buoyant up flow model is appropriate for the genesis of the foliated gabbro. The zoning patterns of plagioclases are different in the foliated gabbro (normal zoning) and layered gabbro (reverse zoning). This may be interpreted by the difference in cooling rates between the foliated and layered gabbros.

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# Spatial compositional distribution in the southernmost part of the Salahi mantle section, the Oman ophiolite

Satoru Fujii[1*], TAKAZAWA, Eiichi[1]

[1]Faculty of Science, Niigata University

An ultramafic complex (8 km x 5.5 km) occurs in the southwest part of the Salahi block from the northern Oman ophiolite. It consists of highly refractory dunite with spinel Cr# >0.8 associated with minor amount of harzburgite and pyroxenite (Nomoto and Takazawa, and 2013). It is considered that an infiltration of fluid from the base caused flux melting of harzburgite and formed boninitic melt associated with highly refractory dunite. There are two other ultramafic complexes of the same scale located in the direction of south-southeast of this complex and the distributions of highly refractory peridotites are expected like the northern part of Fizh mantle section (Kanke and Takazawa, 2013). This study reports the spatial compositional distribution of the mantle section including an ultramafic complex in the southernmost part of Salahi mantle section.

Spinel Cr# of harzburgite has a narrow range of 0.46-0.67 whereas dunite's spinel Cr# varies from 0.43 to 0.80 showing a wider compositional range associated with highly refractory end member. Moreover, dunite with spinel Cr# >0.7 frequently occurs in the eastern part of the study area. On the other hand, in the central part, the dunite's spinel Cr# (0.47-0.57) is systematically lower than the spinel Cr# (0.53-0.67) of harzburgites. In terms of structure, the southernmost part of Salahi block is nearly horizontal in foliation, so that there is little variation in the depth from the Moho. Therefore, on the surface, the uppermost part of mantle section is widely observed. Moreover, as a result of examining the depth from the Moho using a cross section, the central part with the low Cr# spinel is equivalent to the shallower part compared to the area of the high Cr# spinel in the eastern side. The dunites with a low Cr# spinel were formed by a reaction between MORB melt and harzburgite beneath a spreading ridge. On the other hand, the dunites with a high Cr# spinel were located in the deeper part relative to the former and were produced by a flux melting of harzburgite due to a fluid infiltration from the base during the incipient island arc stage.

In the central part of the ultramafic complex, dunite's spinel Cr# shows relatively high value of 0.74-0.80 whereas in the border part the dunite's spinel Cr# is 0.54-0.67 lower than the central part. Moreover, in a border part, plagioclase-bearing dunite, plagioclase lherzolite and a phlogopite-bearing wehrlite occasionally occur indicating some reactions with MORB melt and/or fluid. Apparently the combination of the formation of highly refractory dunites by infiltration of fluid from the base, and a formation of the plagioclase-bearing peridotite by a reaction with a MORB melt in a single ultramafic complex needs to be resolved.

Keywords: oman ophiolite, mantle section, high refractory zone, spinel, peridotite, MORB

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# Along-axis variations of a fast-spreading mid-ocean ridge: implication from the volcanic rocks in the Oman ophiolite

Yuki Kusano[1*], Yoshiko Adachi[2], Susumu Umino[1], Sumio Miyashita[1]

[1]Kanazawa University, [2]Niigata University

Overlapping spreading centers and small offsets 'devals' mark the boundaries of the magma supply systems in fast spreading centers [Langmuir et al., 1986] and the topographic features appear as volcanic and compositional variations between each segment. For example, digitized profiles of the ridge axis show deeper depth, narrower axial summit and deeper melt lens beneath the ridge axis in the segment margin than shallower and inflated segment center [Scheirer and Macdonald, 1993]. It indicates that magmatisms are changed along a ridge segment. However, seafloor observations of the EPR suggest that effusion rates of lavas frequently change in each flows [Fundis et al., 2010] and investigating along-axis variations needs to detailed three-dimensional observation. Based on the segment structure proposed by Miyashita et al. [2003], we studied along-axis variations of upper crustal section in the Oman ophiolite and discovered systematic changes of extrusive sequence due to the segment structure.

Comparing eight geologic sections spanning 70 km, the along-axis volcanic system is reconstructed. Representative area of the segment center and margin is Bani Ghayth and Wadi Fizh, respectively. The total thickness of on-axis lava section decreases from the segment center (603 m thick) to the margin (410 m thick). Predominant appearance of pillow lavas around the segment margin indicates more ragged seafloor topography than the center where pahoehoe flows dominate. The intermediate areas are characterized by relatively thick (50-300 m thick) transition zone from sheeted dike complex to extrusive sequences than the segment center and margin areas (20-50 m thick). These differences might be derived from volcanic cycles between high and low lava supply periods on the area compared with an effusive segment center or less magmatic segment margin. Although thinner on-axis lava sequences occur at the segment margins, total thickness of lava section is relatively fixed because of off ridge volcanisms. Occurrences of the fissure vent or dikes intruding into the extrusives imply the volcanisms after on-ridge magmatism. Such vigorous off-axis volcanisms are recognized around the second- and third-order segment margins along the EPR. They might be rooted at less-evolved melts from depths avoiding the focus into the melt lens beneath the axis area.

Keywords: Fast-spreading ridge, MORB, Volcanostratigraphy, Oman ophiolite, Segment structure

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# Petrology of peridotite in the Western Mirdita Ophiolite, Albania: The origin of fertile peridotite

Masayuki Inamura[1*], Tomoaki Morishita[2]

[1]JX Nippon Mining & Metals, [2]Kanazawa university

Based on geochemistry, the volcanic sections of the Western and the Eastern Mirdita Ophiolite (Albania) are characterized by mid-ocean ridge basalt-like and arc-like signatures, respectively. The peridotite bodies in the Western Miridta Ophiolite (WMO) has never been well characterized yet. Gomsiqe and Puke massifs in the WMO are examined in this study. The Puke massif mainly consists of plagioclase- and amphibole-bearing lithologies, whereas only a few plagioclase-bearing peridotites were found in the Gomsiqe massif. Peridotites in the Gomsiqe massif and the Puke massif show different structure and petrological characteristics. The Gomsiqe massif consists of less or moderate deformed spinel lherzolite with small amounts of dunite, pyroxenite and gabbro, whereas the Puke massif consists of highly deformed plagioclase- and amphibole- bearing peridotite, troctolite, and gabbro. Major and trace element compositions of minerals in lherzolite of the Gomseque massif indicate residue of low-degree of partial melting and are similar to those of ocean floor peridotites directly recovered from mid-ocean ridges. Based on spinel compositions, dunites in the Gomsiqe massif are classified into two types: low-Cr#[=Cr/(Cr+Al) atomic ratio] spinel (0.2-0.4)-bearing dunite, and high-Cr# spinel (0.6-0.7)-bearing dunite. The former was related to mid-ocean ridge basalts whereas the latter was of arc-related magmas. Based on lithology and mineral chemistry, plagioclase- and amphibole- bearing peridotites in the Puke massif was formed by infiltration of MORB-like melts followed by and H2O and SiO2-rich fluids/melts, probably derived from subduction zone, respectively. Plagioclase peridotite may have been formed by melt impregnation because plagioclase and clinopyroxene occur as veins in plagioclase- bearing peridotite. In spite of constant Cr# of spinel, TiO2 content in spinel in plagioclase- rich peridotite is higher than that of plagioclase- poor peridotite. On the other hand, low Nb, Zr amphibole in amphibole- bearing peridotite resembles to that in metasomatized peridotite from subduction zone. In conclusion, the Gomsiqe and the Puke massif might experience a sequence of events during their evolution in response to the change in tectonic setting from oceanic lithosphere formed at mid-ocean ridges to the subduction.

Keywords: Albania, Ophiolite, Fertile peridotite

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# Comparison of the CPO of antigorite serpentinite by U-stage, EBSD and synchrotron X-rays

Yusuke Soda[1*], WENK, Rudolf[2]

[1]School of Natural System, College of Science and Engineering, Kanazawa University, [2]University of California, Berkeley

Crystallographic preferred orientation (CPO) of antigorite is the cause for seismic anisotropy observed in subduction zones. Antigorite CPO is a key to understanding deformation in subduction zone. Phyllosilicates, including antigorite, are mechanically weak minerals compared with olivine or quartz. Antigorite CPO has been measured by several methods, U-stage, EBSD and synchrotron X-rays.

We measured antigorite CPO of foliated antigorite serpentinites from Toba, Saganoseki and Nagasaki areas in Southwest Japan. A serpentinite sample from Toba contains olivine and shows mylonitic textures. Microstructures around olivine porphyroclasts indicate that antigorite grew synchronous with the shear deformation. Serpentinite mylonite from Saganoseki is serpentinized completely. Chemical composition maps of serpentinite from Saganoseki show that the Fe-content of antigorite is inhomogeneous and Fe-rich antigorite crystallized along grain-boundaries and in fractures of Fe-poor antigorite. Serpentinite schist from the Nagasaki area develops a weak foliation and lineation, defined by arrays of bastite (altered phases of pyroxenes).

In the case of U-stage (optic microscope), we could measure relatively coarse-grained antigorite with needle shape. The CPO pattern of antigorite from Saganoseki and Toba is that [010] of antigorite is parallel to the lineation, [001] of antigorite is normal to the foliation, [100] of antigorite is normal to the lineation on the foliation. EBSD measurements from Saganoseki and Toba gave the same antigorite CPO patterns as the U-stage measurements. Compared with olivine, Kikuchi patterns of antigorite are weaker. We could not get the fabric pattern from fine-grained aggregates by U-stage or EBSD. Synchrotron X-ray measurements performed at the high-energy beamline ID-11-C of APS, Argonne National Laboratory on serpentinites from Saganoseki and Nagasaki also provided the same fabric patterns, averaging also over fine-grained crystallites.

Three measurement methods fundamentally give the same antigorite CPO pattern. However, the strength of the fabric patterns decreases in following order: U-stage>EBSD>X-rays. This is due to the selection of well-crystallized antigorite by the former two methods. Calculated elastic velocity anisotropy from X-rays results are lower (anisotropy of P-wave (AVp); 11-15%, anisotropy of S-wave (AVs); 10-15%) than from EBSD results (AVp; 12-19%, AVs; 18-21%). EBSD measurement and U-stage thus over-estimate elastic velocity anisotropy, since both methods only measure relatively coarse-grained and well crystalized antigorite.

Keywords: antigorite, CPO, elastic velocity anisotropy, synchrotron X-ray

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# Mantle evolution beneath back-arc basin inferred from peridotite xenoliths form the Japan Sea

Yuji Ichiyama[1*], Tomoaki MORISHITA[2], Akihiro TAMURA[2], Shoji ARAI[2]

[1]JAMSTEC, [2]Kanazawa University

Peridotite xenoliths are found in basaltic to andesitic lavas from the Shiribeshi Seamount in the Sea of Japan, a Miocene back-arc basin of the Western Pacific Region. These peridotites are divided into two-pyroxene peridotites, dunite and wehrlite. Two-pyroxene peridotites have retained their original mantle geochemical signatures, although partly suffered from chemical modifications from the host magma. The dunites and wehrlite were, on the other hand, formed from the two-pyroxene peridotites by extensive interaction with magma active before the host one. Clinopyroxenes in the two-pyroxene peridotites display various REE patterns. Some peridotites are similar in LREE-fractionated (LREE-depleted) character of clinopyroxene to abyssal peridotites directly recovered from mid-ocean ridges and back-arc basins, which are usually interpreted as simple residue after partial melting. Other samples with LREE-enriched patterns of clinopyroxenes are residues after flux melting due to infiltration of slab-derived fluids. Orthopyroxene veins cutting olivine in the two-pyroxene peridotites were a product of reaction with aqueous fluid released from subducted slab. The geochemical variations of the peridotite xenoliths from the Sea of Japan (the Seifu Seamount, the Oshima-?shima Island and the studied samples) are likely to be related to evolution of the mantle beneath the Sea of Japan from hydrous to near-dry with a progress of the back-arc rifting. The mantle evolution beneath the Sea of Japan inferred from the peridotite xenoliths is well consistent with the geochemical and isotopic results from the Miocene basaltic rocks formed during opening of the Sea of Japan. Our mantle process model beneath the Sea of Japan also reconciles with recent models for the melting regime and evolution of the mantle beneath global back-arc basins, and gives constraints on formation and evolution of the back-arc basins.

Keywords: Back-arc basin, Sea of Japan, Mantle, Peridotite xenolith

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# Effects of pH and silica on the progress of serpentinization deduced from hydrothermal experiments.

Ryosuke Oyanagi[1*], Atsushi Okamoto[1], Noriyoshi Tsuchiya[1]

[1]Tohoku Univ., Japan

Hydration of ultramafic rocks (serpentinization) commonly proceeds in seafloor hydrothermal systems at mid-ocean ridges along the bending faults, and at the boundary of wedge mantle and subducting plate. The extent and distribution of hydrated mantle plays an important role on the global circulation of H2O. Silica activity and pH conditions are key factors in controlling reaction paths and the rate of serpentinization. (Frost and Beard, 2007; Lafay et al., 2012) In this study, we conduced hydrothermal experiments to investigate the reaction mechanism of serpentinization at oceanic seafloor at which circulating across crust and mantle, especially focusing on the effects of solution pH and silica.

We conducted two types of batch-type hydrothermal experiments at 250, 300 and 350 degreeC at vapor-saturated pressure: (1) olivine (Fo91)-H2O system with varying initial solution pH from under conditions of 250degreeC, 300degreeC and 350degreeC, and (2) olivine-quartz-H2O system as the analogue of boundary between mantle and crustal rocks. In the latter experiments, we used the tube-in-tube vessel with inner alumina tube containing the powder of olivine/quartz/olivine and quartz were set in tube-in-tube vessels under conditions of 250degreeC, 350degreeC and vapor-saturated pressure to examine the temporal evolution of solution chemistry and products in runs of up to 1180h in duration. The extent of the serpentinization was measured by thermogravimetry, and occurrences of the products was observed by using SEM with EDS.

The products of the Ol-H2O experiments after 1812 h are serpentine + brucite. The morphology and extent of serpentinization are nearly constant at pH $<$ 11; serpentine crystals show cone-in-cone and the extent of the serpentinization were ˜40 % at 300 ?C. In contrast, at pH $>$ 11, serpentine crystals become fibrous crystals (chrysotile), and the reaction rate increased significantly (˜ 90 % of olivine was serpentinized at pH =13.5 under conditions of 250degreeC and 300degreeC). Fibrous crysotile veins are commonly observed in serpentinized peridotites which contained mainly mesh-textures of lizardite; therefore, our results may indicate such fibrous crysotile veins is a trace of the high-alkaline solutions. In the experiment at 250 and 300 ?C, the solution pH increased with time, implying acceleration of serpentinization reactions.

In the olivine-quartz-H2O experiments, talc was formed as well as serpentine. At the Qtz/Ol boundary, only talc (Mg/Si = ˜0.8) was formed, whereas talc-serpentine mixture (Mg/Si=1.0-1.2). The total amount of H2O in the products increased with time toward TG loss of ˜ 5 wt%, and then slightly decreased. Especially, the amount of serpentine increased then decreased, whereas the amount of talc increased monotonicly, indicating two step of reactions; initial formation of serpentine minerals followed by talc formation at the boundary between mantle and crustal rocks.

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Keywords: ultrabasic rock, serpentine

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# Evolution of permeability and fluid pathway in the oceanic crust inferred from experimental studies on basalt cores

Kenta Kawaguchi[1*], Ikuo Katayama[1]

[1]Department of Earth and Planetary Systems Science, Graduate School of Science, Hiroshima University

Ocean crust is formed at mid-ocean ridge and transported to the trench, which takes about hundred million years. At the trench, ocean crust is subducted under continental crust or other ocean crust. The ocean crust is suffered various chemical and physical alternation at seafloor. Hydrothermal system is very active owing to volcanic activity near ridge axis. Low-temperature hydrothermal system is continued to several hundred km far from the ridge axis have been investigated from the gap between observation and simulation of heat flow. Hydrothermal systems are closely related to the permeability in the ocean crust. Bore-hole measurement indicate that permeability are different with depth and age, which probably reflect the rock type and structure.

The uppermost ocean crust is composed of pillow basalt and hyaloclastite. Such basalt layer has a large fracture, so the permeability is relatively high, and the range is $10^{-10}$ m$^2$ to $10^{-12}$ m$^2$. Below this layer, massive basalt, sheeted dyke and gabbro is located, which layer has a low permeability, of less than $10^{-16}$ m$^2$. After the ocean crust is formed, pelagic sediment is gradually increased at the top of the ocean crust. It permeability is significantly low ranging $10^{-14}$ m$^2$ to $10^{-18}$ m$^2$. Consequently, the uppermost basalt layer is the most permeable layer in the ocean crust. Thus the hydrothermal systems far from the ridge axis is occurred beneath the seafloor.

In-situ measurements of permeability of the uppermost basalt layer reveal a systematic decrease with increasing crustal age, in which permeability reduces by four orders of magnitude from crustal ages of 1 to 7 Ma. In this study, We measured the permeability of basalt core sample from Ocean Drilling Program. The confining pressure at the uppermost basalt layer is increase with crustal age. So, in the laboratory measurement of permeability, we focused on the effect of confining pressure to test whether mechanical compaction is able to explain the age evolution of permeability of the uppermost basalt layer of oceanic crust. However, the pressure effects found in the laboratory experiment are insufficient to fully explain the result of in-situ measurement of permeability through the oceanic crust. This result indicate that mechanical compaction alone cannot explain the observed evolution of permeability in the uppermost oceanic crust.

Based on these experiments, factors in addition to mechanical compaction are required to explain the decrease in permeability with age in young oceanic crust within the uppermost basaltic layer. Carbonate veins are ubiquitous in oceanic crust accreted in ophiolite sections and are precipitated within a few million years of formation of the crust. This carbonate precipitation likely result in the reduction in porosity, consequently permeability also decreased with crustal age. I calculated the potential inorganic precipitation of $CaCO_3$, in which the total amount of $CaCO_3$ in the oceanic crust is represented by the fluid flux (m/s) and the concentration of $CaCO_3$ (mM) in aqueous fluid. Even though these carbonates are fully precipitated in the oceanic basement, the calculated volume of precipitation is insufficient to fill the available porosity in the basalt layers. Staudigel and Furnes (2004) reported that about 50% of alternation in the upper oceanic crust is caused by the biotic activity. These data implies that $CaCO_3$ precipitation might be associated with biotic activity.

Futhermore, I discuss the effect of these fluid flow structure on the accreted oceanic crust as a green rocks or green schist. To investigate such rocks, we need to investigate the structure of ocean crust in terms of fluid flow properties.

Keywords: Oceanic crust, Hydrothermal system, Permeability, Porosity, Carbonate precipitation

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# Olivine crystal fabric variations in the Hilti mantle section, Oman ophiolite

Ayaka ONOUE[1*], Katsuyoshi Michibayashi[1]

[1]Department of Geosciences, Shizuoka University

The purpose of this study is to investigate macroscopic structure of ocean lithospheric mantle by structural analyses of the Hilti mantle section in Oman ophiolite that is the largest ophiolite in the world located in the easternmost end of Arabian Peninsula. Coarse granular harzburgites were measured crystal-preferred orientations (CPO) and chemical compositions of their constituent minerals. Olivine grain sizes within the harzburgites range from coarser grains (>3mm) to medium grains (~1mm) and show undulose extinctions as well as kink bands. Orthopyroxene grains have exsolution lamellae. Olivine CPOs of all samples are a-axis girdle type (i.e. AG type) that are characterized by intense [010] maxima normal to the foliation with both [100] and [001] forming weak girdle distributions sub-parallel to the foliation. Chemical compositions of spinel, olivine and orthopyroxene were measured in the three samples (99OK163, 99OK164, 99OK165), which were located at the different distances from the mantle-crust boundary. The Cr/(Cr+Al) number (Cr#) of spinel is 0.5~0.6. The Mg/(Mg+Fe) number (Mg#) of olivine is 0.91~0.92. The chemical compositions show that they are residual peridotites of the mantle origin. Furthermore, spinel Cr# shows that they are abyssal peridotite. It is suggested that the peridotite samples in this study have been derived from the ocean lithosphere formed in the mid-ocean ridge. The olivine CPOs in the Hilti mantle section are dominated by AG type, whereas A type is rather minor. These results may indicate that the olivine CPO could be dominantly AG type rather than A type in the ocean lithosphere. It was shown by an experimental study that olivine CPO appears to change from A type to AG type where olivine grains are influenced by melt. Consequently, the development of AG type observed in this study could be related to the occurrence of melt beneath the mid-ocean ridge.

Keywords: Oman, harzburgite, Crystallographic fabric, ocean lithosphere

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# Fragments of deep oceanic lithosphere from the Yukawa knoll in NW Pacific

Tomoyuki Mizukami[1*], Keigo Nakamura[1], Tomoaki Morishita[1], Akihiro Tamura[1], Shoji Arai[1], Natsue Abe[2], Naoto Hirano[3]

[1]Earth Science Course, School of Natural System, College of Science and Engineering, Kanazawa Univers, [2]Institute for Research on Earth Evolution Independent Administrative Institution Japan Agency for, [3]Center for Northeast Asian Studies, Tohoku University

Chemical and physical structures of oceanic lithosphere have been generally inferred based on comparative examinations using the seismic profiles, dredged or drilled samples of young rocks at mid-oceanic ridges and exposed sections of ophiolites. However, direct observations of the constituent materials are limited to the shallowest part (up to 20 km depth) and, therefore, a large part of old oceanic lithosphere, especially of its deeper part, is petrologically still unknown. It is known that the NW Pacific plate is accompanied with young monogenetic volcanoes originating at depths just below the bottom of the lithosphere. Lithospheric fragments entrapped by the alkaline magmas are able to shed light on the whole structure across the plate. In this study, we examined dredged samples (D07&8 during Kairei KR04-08 Cruise) from the youngest volcano (0-1 Ma), Yukawa knoll, at the eastern slope of the outer rise in the NW Pacific plate. They include mm-scale xenocrysts and xenoliths of crustal and mantle origins. Here we report the petrological nature of these valuable pieces that test models of oceanic plate.

We found hundreds of xenocrysts: olivine, Cpx, Opx, plagioclase and xenoliths (consisting of more than 2 grains) of spinel-bearing lherzolite, harzburgite, pyroxenite, troctolite, olivine-bearing anorthosite, gabbronorite and non-alkaline basalt with medium- and fine-grained plagioclase. Mineral chemistry of the crustal fragments is plotted in the range of seafloor samples and ophiolites. However, mafic minerals forming xenocrysts and those in spinel-bearing lherzolite have distinctive compositions. Olivine, Opx and Cpx imply a Fe-rich nature of lithospheric mantle compared to residual peridotite in ophiolite. Cr# of spinel in the lherzolite is 0.16. Cpx has an extremely high Na2O content up to 2.3 wt% whereas the Al2O3 content (3-7 wt%) is comparable to the oceanic samples. The Cpx is enriched in REE (C1 normalized value of Sm = 10) but relatively low in HREE implying it has coexisted with garnet.

Geothermobarometry for the pyroxenes with the garnet signatures gives results consistent with their origins at pressures of 1.5-2.3 GPa (45-70km depth) and temperatures of 750-1000 oC. These conditions lie on a conductive geotherm with heat flow of 60-80 mWm and are expected for the 130 Myr old Pacific plate. The REE patterns of the pyroxenes in the spinel lherzolite from the Yukawa knoll are very similar to those in cratonic garnet peridotite. Na2O in the Cpx and the spinel Cr# are close to Na-rich source mantle, partial melting of which can explain a large part of residual abyssal peridotite. Our finding of the Na-rich pieces from the NW Pacific implies that deeper parts of the oceanic mantle are occupied by such fertile peridotite that is comparable to sub-cratonic mantle.

Keywords: oceanic lithosphere, xenolith, mantle

SIT05-P12 Room:Convention Hall Time:May 21 18:15-19:30

# Review of petrological studies on olivine-bearing gabbro and troctolite: Implications for formation of the oceanic lower

Natsue Abe[1]*

[1]IFREE, JAMSTEC

Recent study on the oceanic lower crust implies that the hybridization of peridotite and basaltic melt is one possibility for the origin of the lower crust, especially for the olivine-bearing lithologies. Their texture, mineral and bulk rock chemistry suggest that some of the olivine-bearing gabbroes are not simple cumulate from basaltic melt, but they require ultrabasic melt that is rich in Mg and Cr. Lithostratigraphy of the olivine-bearing gabbroes also show that those rocks are related to the more mafic, sometimes ultramafic rocks. This new model must the important constraint of the formation of the oceanic lower crust. In this presentation, recent studies of the olivine-bearing gabbroic lithologies in ophiolites and ocean floor samples will be reviewed.

Keywords: oceanic crust, lower crust, gabbro, olivine-bearing gabbroes

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# Oxygen fugacity of basaltic magma from petit spot: a preliminary result from Fe-K edge XANES study

Hidemi Ishibashi[1*], Hiroyuki Kagi[2], Natsue Abe[3], Naoto Hirano[4]

[1]Faculty of Science, Shizuoka University, [2]Graduate School of Science, The University of Tokyo, [3]IFREE, JAMSTEC, [4]Center for Northeast Asian Studies, Tohoku University

Petit-spot is a newly-discovered site of intraplate magmatism (e.g., Hirano et al., 2006); a swarm of small knolls is formed by ascent of magmas along brittle fractures that develop where plate flexes due to subduction and/or loading by seamounts. A geochemical study suggested that alkaline basaltic lavas from petit-spot volcanoes on the northwestern Pacific Plate were generated by partial melting of asthenosphere (Machida et al., 2009). In addition, basaltic glass matrix and peridotite xenoliths found in the lava indicate that the magma rapidly ascended through lithosphere and was quenched right after eruption. Therefore, the lava can be expected to retain information about physicochemical conditions of asthenosphere beneath the old oceanic plate. Oxygen fugacity ($fO_2$) is an important parameter because it influences on chemical and mechanical properties of minerals and melt. MORB glasses from all over the world revealed almost constant $fO_2$ condition near the quartz-magnetite-fayalite (QMF) buffer, indicating that the $fO_2$ of MORB source mantle is near the QMF buffer condition (Cottrell et al., 2011). However, it is unobvious whether asthenospheric mantle far from the mid ocean ridge is also under similar $fO_2$ condition or not. Petit-spot magma may provide a chance to examine it; the present study aims to quantify $fO_2$ of basaltic magma from petit-spot and to examine its source mantle condition.

Valence state of Fe in silicate glass is a sensitive indicator of magmatic $fO_2$ condition. Recent advance in Fe-K edge micro-XANES (X-ray Absorption Near Edge Structure) study enables us to determine valence state of Fe in silicate glass with several microns order of spatial resolution. In this study, Fe-K edge XANES spectra were acquired for quenched basaltic glasses using the micro-XANES analyzing system at Beam Line 4A in Photon Factory, KEK. The obtained spectra were analyzed using the method of Cottrell et al. (2009) to determine mole ratios of ferric to total iron, $Fe^{3+}/Fe_{total}$. Oxygen fugacity of the basaltic melt was calculated from its $Fe^{3+}/Fe_{total}$ ratio and major element compositions using the method of Kress and Carmichael (1991). Basaltic standard glasses synthesized at controlled $fO_2$ conditions were also measured; the results confirm the reliability of our analyses within ca. 0.4 log unit in $fO_2$.

Six basaltic samples dredged from youngest petit-spot volcanoes (site B of Hirano et al., 2006) were analyzed. They were erupted at 0.05-1Ma, include several tens vol. % of bubbles and small amount of olivine crystals within fresh basaltic glass. We measured more than three points in glass for each samples. The spectra obtained from the six glasses are very similar each other, indicating that valence states of Fe in glasses are homogeneous in the six samples. $Fe^{3+}/Fe_{total}$ ratios calculated from the obtained spectra were ca. 0.3, which is significantly higher than the mean ratio for MORB glasses (ca. 0.17; Cottrell et al., 2011). $fO_2$ estimated from the $Fe^{3+}/Fe_{total}$ ratio is ca. 2 log unit higher than the QMF buffer; the $fO_2$ value is comparable to that of arc magma and significantly higher than those of MORB and hot spot magmas. Our result suggests that the source mantle region of petit-spot magma beneath old oceanic plate was more oxidized than MORB mantle even allowing for the effects of olivine crystallization and volatile degassing. We will discuss why the source mantle of petit-spot magma is oxidized.

Keywords: oxygen fugacity, petit spot, basalt, XANES, glass, mantle

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# Evidence for the formation of boninitic melt in the ultramafic complex from the Salahi mantle section,the Oman ophiolite

Yuki Nomoto[1*], Eiichi TAKAZAWA[2]

[1]Grad School Sci and Tech, Niigata Univ, [2]Dept Geol, Facul Sci, Niigata University

An ultramafic complex in a scale of 8 km x 5.5 km is distributed in the southwestern part of the Salahi mantle section in the northern Oman ophiolite. Based on the study by Nomoto and Takazawa (2013) the complex consists mainly of massive dunite associated with minor amounts of harzburgite, pyroxenites and wehrlite. The spinels in the dunites from the complex have Cr# (=Cr/(Cr+Al) atomic ratio) greater than 0.7 indicating highly refractory signature. The range of spinel Cr# is similar to those of spinels in boninites reported worldwide (Umino, 1986; van der Laan et al., 1992; Sobolev and Danyushevsky, 1994; Ishikawa et al., 2002). The complex might be a section of dunite channel that formed by flux melting of harzburgites as a result of infiltration of a voluminous fluid from the basal thrust. We determined the abundances of rare earth elements (REE) in the peridotite clinopyroxenes (cpxs) by LA-ICP-MS to estimate the compositions of the melts in equilibrium with these clinopyroxenes.

The chondrite-normalized patterns for clinopyroxenes in the dunites are characterized by enrichments in light REE (LREE) relative to those of the harzburgite clinopyroxenes. The chondrite-normalized REE patterns for the calculated melts in equilibrium with clinopyroxenes in the dunites do not resemble to the pattern of N-MORB (Sun and McDonought, 1989) but fit very well to the patterns of the boninites (Cameron et al., 1983; Cameron, 1985; Taylor et al., 1994; Ishikawa et al., 2005). In the diagram of clinopyroxene REE contents versus spinel Cr#, with increasing the spinel Cr# from harzburgite to dunite, the Yb content of clinopyroxenes decreases whereas the Ce content increases. Chondrite-normalized REE patterns of clinopyroxenes in dunites indicate that the dunites are not a residue of closed system melting but a product of open system melting with addition of a LREE-enriched fluid. Our results supports a hypothesis that the dunites formed as residue after flux melting of harzburgite accompanied with LREE-enriched fluid infiltrated from the base of the ophiolite.

Keywords: boninite, dunite, flux melting, REE, open system melting, fluid

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# Geochemical heterogeneity of Moho transition zone dunites-wehrlites from Wadi Thuqbah, the northern Oman ophiolite

Ritsuko Muroi[1*], Hironori Negishi[1], Shoji Arai[2]

[1]Dept. Earth Sci., Kanazawa Univ., [2]Nat. Sci. Tec., Kanazawa Univ.

The thick Moho transition zone (MTZ) exposed along Wadi Thuqba, northern Oman ophiolite, comprises dunites, wehrlites and gabbroic rocks (Negishi et al., 2013 Lithos). As well known, the Oman ophiolite is a slice of a sort of oceanic lithosphere (cf. Nicolas, 1989). Gabbroic rocks occur either as blocks with layered structure enclosed by wehrlites or as sills or dikes cutting wehrlites or dunites. A deformed dunite-troctolite-gabbro complex is exposed near the base of the Thuqbah MTZ. Discordant dunite is observed to cut the basal layered complex, giving rise to wehrlites only close to troctolite-gabbro layers. The discordant dunite apparently grows upward to be a huge dunite-wehrlite body with sparse bands of clinopyroxenites and gabbros. Some of the MTZ dunites and wehrlites contain sulfide (pentlandite-pyrrhotite) (up to 2 volume %). The sulfide-bearing dunite shows high Fo contents (90-92) but low NiO contents (0.1 to 0.4 wt% depending on the amount of sulfide).

Clinopyroxenes in dunites and wehrlites with or without sulfides are characterized by variation in REE contents. They show LREE-depleted chondrite-normalized patterns, and their condrite-normalize (Yb/La) ratio varies from 2 to 15 even in samples from the same outcrop. The steepest slope of REE patterns is similar to that for ultra-depleted MORB melt (e.g., Sobolev and Shimizu, 1993 Nature), and the gentlest one, to that for ordinary MORB (e.g., Johnson et al., 1990 JGR). These features indicate a strong geochemical heterogeneity in melts involved in formation of the Thuqbah dunites and wehrlites. They may give us a clue to our understanding of evolution of ordinary MORB from the ultra-depleted primary MORB melt.

Keywords: clinopyroxene, REE, dunite, wehrlite, Moho transition zone, Oman ophiolite

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# Small-scale heterogeneities in the Philippine Sea plate and the guided waves

Azusa Shito[1*], Takashi Furumura[2], Daisuke Suetsugu[1]

[1]IFREE, JAMSTEC, [2]ERI, University of Tokyo

The oceanic lithosphere is an extremely efficient waveguide for high-frequency seismic wave. The guided wave, Po/So phases propagate within the oceanic lithosphere and are commonly observed on ocean bottom seismometer records in the distance range of from 5 to 30 degrees.

The Philippine Sea is one of the marginal seas of the Pacific Ocean and contains very complicated tectonic settings. It is fundamentally divided into two regions bounded by the Kyushu-Palau Ridge. It is thought that these two regions were formed in different episodes of back-arc spreading and that western part is older than eastern part (e.g. Seno and Maruyama, 1984). Such complicated tectonic settings are expected to affect the structure of the oceanic lithosphere and propagation of the guided waves.

Seismological observations using Broad-Band Ocean Bottom Seismometers (BBOBSs) was conducted in the Philippine Sea from 2005 to 2008. In the BBOBS data, high-quality Po and So waveforms from earthquakes in subducting Philippine Sea plate were recorded. Prominent features of Po and So phases are summarized as follows. (1) The frequency content of Po and So waves is up to 20 Hz, which is much higher than that of direct P and S waves. The frequency content of So waves is slightly higher than that of Po waves. (2) The travel time interval between the direct P and Po phases varies with the event depth (and the epicentral distance). (3) The Po and So phases gradually build up and decay with extremely long durations (1-2 mins). The durations of the Po phase are longer than that of the So phase, and extend into the onset of the So phase. These features indicate that the Po and So phases propagate as guided waves in the oceanic lithosphere with intense scattering, whereas the P and S waves travel directly from the sources. (4) The Po/So phase propagate much effectively in western part than eastern part of the Philippine Sea.

In order to investigate the nature of the structure of the oceanic lithosphere and the guided waves, we performed numerical FDM simulations of two-dimensional (2-D) seismic wave propagation in a realistic oceanic lithosphere model. Applying the method described by Furumura and Kennett [2005; 2008], we conducted parallel FDM modeling of high-frequency (fmax=5 Hz) seismic wave propagation in heterogeneous structure in order to explain observed feature of Po/So phases. We will demonstrate that the low-frequency direct P and S waves propagate in the asthenosphere and that the following large-amplitude, high-frequency, and long-duration Po and So waves are developed by multiple forward scattering of P and S waves due to laterally elongated heterogeneities in both the subducting and horizontal parts of the oceanic lithosphere.

Keywords: oceanic lithosphere, guided wave, Philippine Sea plate