Japan Geoscience Union Meeting 2012
(May 20-25 2012 at Makuhari, Chiba, Japan)

MIS31-01 Room:106 Time:May 24 09:00-09:15

Relationships of crystal orientation between antigorite and olivine in serpentinite mylonite

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Serpentinite mylonite is developed penetrative foliation and consists of antigorite. Serpentinite mylonite is described from sheared ultramafic bodies (e.g., Norrell et al., 1989). Foliated antigorite serpentinite with lattice preferred orientation (LPO) causes seismic anisotropy observed in subduction zones (e.g., Katayama et al., 2009, Jung, 2011). However, formation mechanisms and conditions of antigorite LPO are unclear. To clear the formation process of antigorite LPO, we focus on the relationships of crystal orientation between antigorite and host olivine in the serpentinite mylonite.

Studied serpentinite mylonite is from Kurosegawa belt at Toba area, Kii Peninsula. The serpentinite body undergoes multiple stages of deformation and serpentinization. In outcrop, the serpentinite mylonite is cohesive and is surrounded by incohesive serpentinite which has undergone the serpentinization of later stage under lower temperature.

The serpentinite mylonite mainly consists of antigorite and olivine, and developed mylonitic textures such as shear bands and olivine porphyroclast system. The foliation and lineation is defined by array of blade shape antigorite and elongated olivine grains. Antigorite with blade shape are crystallized in the pressure shadows of olivine porphyroclast and pull-apart of olivine grain. Their occurrences indicate syntectonic growth of antigorite.

We measure the crystal orientation of olivine and antigorite by the U-stage and EBSD. In EBSD measurement of antigorite, we try automatic indexing, in addition to manual indexing. Both indexing methods bring the same fabric pattern. Comparing the antigorite patterns from the U-stage measurement and EBSD measurement, both methods also show the same fabric pattern.

The LPOs of olivine show point maximum or partial girdle distributions, and these concentrations deviate from the foliation and lineation of serpentinite mylonite. The LPOs of olivine are formed before the antigorite serpentinization. The LPOs of antigorite, from olivine free domain, show that b axes are parallel to the lineation, c axes are perpendicular to the foliation or make a partial girdle distribution normal to lineation and a axes are a point maximum or form a partial girdle distribution. The orientations of antigorite grains, growing in olivine grains, show topotactic relationship between antigorite and olivine. However, b axes tend to be parallel to the lineation.

Topotactic relationships between olivine and antigorite are attractive mechanisms for the making antigorite LPO (Boudier et al., 2010). Under the shear deformation condition, the other mechanisms, such as rotation of grains, diffusion-precipitate process and anisotropic growth of grains, also would affect the formation of antigorite LPO, in addition to topotaxial growth.

Keywords: antigorite, olivine, LPO, topotactic relationship

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MIS31-02 Room:106 Time:May 24 09:15-09:30

Topotaxic replacement of olivine by a lizardite and brucite mixture in the Higashi-akaishi ultramafic body

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Fluid-rock reactions in the ultramafic system cause a wide variety of serpentinite. Analyses of the natural occurrences of serpentinite provide important constraints on contributions of variable factors controlling the development and related fluid chemistry. We present detailed petrological observations of lizardite and brucite (Liz+Brc) serpentinite, that is a retrograde product in a subduction zone environment, in the Higashi-akaishi ultramafic body.

We identified two end members of penetrative structures consisting of a fibrous Liz+Brc mixture: topotaxic vein and non-topotaxic mesh structure. Non-topotaxic vein can be regarded as an intermediate. Topotaxic veins are characteristically developed in a coarse-grained dunite and an optical X axis of a Liz+Brc mixture is sub-parallel to a c-axis of host olivine. Mesh textures overprint porphyroclastic textures of dunite and a Lis+Brc fibers are normal to olivine grain boundaries. The topotaxic veins are localized in the central part of the body whereas non-topotaxic mesh is more dominant in the peripheral part close to the surrounding schists.

Topotaxic veins preserve mineralogical and chemical zonings, indicating a Liz formation at a reaction front and a diffusive extraction of Fe to form magnetite (Mgt) at the center of the vein. Micro-Raman mapping reveals a close relationship between stripes of Brc and Mgt at a vein center. This indicates that Fe ion released at Ol-vein interface has transported through a channel filled by Brc. The Mgt formation was controlled by a reaction: Fe-rich Brc + SiO2 -> Liz +Mgt. A topotaxic relation between Ol and Liz(+Brc) is probably due to a low mobility of Si and high confining pressure. Non-topotaxic meshs show similar mineralogical features but they are rich in Liz and have abundant Mgt at the core. The difference between topotaxic and non-topotaxic replacements can be explained by mobility of elements and a supply of SiO2 depending on activities of aqueous fluids.

A topotaxic replacement of Ol by Liz+Brc possibly take place in shallow mantle where a supply of water-rich fluid is restricted. The case of the Higashi-akaisi body indicates that it can cause a significant amount of Liz+Brc serpentinite with stress-dependent anisotropic structures.

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MIS31-03 Room:106 Time:May 24 09:30-09:45

Mass-transfer and rate-limiting process of serpentinization

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Serpentine minerals, which are produced by interaction between ultramafic rocks and fluids, contain about 13% water and are the greatest carrier of H2O into the deep interior of Earth. Therefore, the volume and distribution of hydrated oceanic mantle are of special interest for understanding the global water circulation. There are several hydrothermal experiments on serpentinization in ultramafic rocks (Ol, Opx, peridotite)-water (seawater) interaction; however, these previous studies focused only on the extent of hydration of solids (Martin & Fyfe, 1970; Wegner & Ernst, 1983) or on the evolution of solution chemistry (e.g., Seyfried and Dibble, 1980; Allen and Seyfried, 2003). Therefore, the detailed reaction mechanism is still poorly understood, including evolution of the overall reactions, rate-limiting process, and resulting textures.

In this study, we conducted hydrothermal experiments in the olivine (Ol, Fo91) - orthopyroxene (Opx, En92) - H2O system at 250 degreeC and vapor-saturated pressure (Psat) for understanding the mechanism of serpentinization at oceanic lithosphere. At this temperature, high extent of hydration is expected for both Ol-H2O and Opx-H2O systems. The low-pressure condition of this study enables us to analyze both solution chemistry and the extent of hydration of the solid samples in detail. The main cryndorical reaction vessel (inner diameter 10.5 mm, height 100 mm) contains two sub-reaction tubes (inner diameter 4.5 mm, height 100 mm), in which the mineral powders (0.025-0.125 mm in size) are packed by meshes. We conducted three types of experiments in the Ol-H2O, Opx-H2O and Ol-Opx-H2O (Opx layer is sandwiched by Ol layers) systems, respectively.

In the Ol-H2O system, the reaction is divided into three stages. The Mg and Si concentrations increases (stage 1), then decreases (stage 2) and reaches the steady state (stage 1). The mineral assemblage also changes from serpentine (Srp) + magnetite (Mgt) at stages 1 and 2 to Srp + Mgt + brucite (Brc) at stage 3, that is consistent with the solutions, that change from stability field of serpentine to serpentine + brucite by drop of silica activity. The serpentine minerals occur as aggregate of fine-grained crystals (primarily lizardite, but chrysotile appear at stage 3), and discrete brucite crystals occur at the contact with olivine. The olivine commonly contains fractures filled by the products, that is similar to the natural mesh textures. In the Opx-H2O system, the silica activity is 1 to 3 order higher than that in the O-H2O system. The products are composed only of serpentine, and do not contain brucite, talc and magnetite. In contrast to serpentinization after olivine, the reaction occurs by psuedomorphic replacement of Opx. In the Ol-Opx-H2O system, the Mg concentration in the bulk solution is similar to that of the Opx-H2O system, whereas the Si concentration shows the similar behavior to the Ol-H2O experiments. The serpentinization preferentially occurred in the Ol zone at the contact with the Opx zone.

At 250 degreeC, the hydration rate is greater in the Ol-H2O system than in the Opx-H2O system. The contrasting natures of solution chemistry and products suggest that the rate-limiting process during serpentinization in the Ol-H2O, Opx-H2O and Ol-Opx-H2O systems are dissolution of olivine, precipitation of serpentine, and dissolution of orthopyroxene, respectively. Our results also indicate that hydrogen production, that is accompanied by the formation of magnetite, does not occur in the vicinity of Opx.

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Keywords: serpentinization, hydrothermal experiments

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MIS31-04 Room:106 Time:May 24 09:45-10:00

Alteration of uppermost oceanic crust and its effect on deformations in subduction zones

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Simultaneous deformation and diagenesis characterize shallow parts (depths of $<$10 km) of subduction zones. While the relationships between diagenesis and deformation of hemipelagic and terrigeneous sediment in subduction zones have been discussed for many years, those of basaltic basement have not been evaluated well. To explore the role of diagenesis in subducting basalt, we examined mineralogy and geochemistry of ocean floor basalt at Site C0012, where oceanic crust entering the Nankai Trough, as well as on-land greenstone body within the Mugi melange in Shimanto Accretionary Complex, Japan, which subducted down to 150 - 200 degrees C and 6 - 7 km depth, metamorphosed and then exhumed.

Severe low-temperature alteration is encountered throughout the core samples from Site C0012. Matrix glass is mostly replaced by saponite/celadonite/Fe-hydroxide, olivine is completely replaced by saponite, and plagioclase is partly replaced by saponite and zeolites. Alteration is classified into two stages: broad oxidizing alteration accompanying Fe-hydroxide, and limited reducing alteration accompanying pyrite and intense saponitization, which is concentrated in the topmost ~20 m-thick part of basaltic rocks. These two alterations would correspond to open- and closed-system hydrothermal circulation (i.e. circulation before and after deposition of overlying sediment), respectively (Lister, 1982). On the other hand, corrensite, saponite-chlorite mixed layer clay is the dominant clay mineral phase of basaltic rocks in the Mugi melange (Kameda et al., 2011). Whole-rock geochemistry data shows smaller LOI and K2O number in the Mugi melange in comparison to Site C0012.

Saponite releases water in response to temperature rise, and is progressively converted to chlorite at temperatures of 150?250 degrees C (Kameda et al., 2011). This diagenetic reaction would build up excess fluid pressure especially within highly saponitized part of ocean floor basalt where off-axis reducing alteration encountered, and enhances underplating of oceanic crust and fluxing of fluid-mobile elements along subductuion thrust. Deformation and mass flux of subducting basalt could be controlled by alteration pattern formed prior to subduction.

MIS31-05 Room:106 Time:May 24 10:00-10:15

”Rock -Fluid-Ecosystem” linkage in oceanic crust

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In this presentation, I will talk about ”Rock -Fluid-Ecosystem” linkage in oceanic crust and its implication for the exploration of unseen deep biosphere.

Keywords: oceanic crust, Rock -Fluid-Ecosystem linkage, deep-biosphere

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MIS31-06 Room:106 Time:May 24 10:45-11:00

Along-axis variations of magmatism: implication from the V1 volcanic rocks in the northern Oman ophiolite

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Overlapping spreading centers and small offsets, devals, mark the boundaries of the magma supply systems in spreading centers [Langmuir et al., 1986] and it appears as compositional variations between each segment. For example, MORBs recovered from the EPR (11 20 N and 9 30 N) have relatively a small geochemical variation whereas lavas from 10 30 N have a great range in composition, including evolved and less-evolved [Batiza et al., 1996]. On the other hand, 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. 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. Their lava compositions are also varied systematically. Homogenized mildly-evolved lavas characterize the segment center. The larger melt lens and the higher ability of melt concentration below the segment center would produce the thick and comparatively homogenized lava sequence. On the other hand, both evolved and less-evolved lavas showing lower degrees of partial melting occur in the segment margin. Smaller melt lenses would promote highly evolved and less-evolved lavas. 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: MORB, Segment structure, Volcanology, Bulk rock composition, Oman ophiolite

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MIS31-07 Room:106 Time:May 24 11:00-11:15

Occurrence and petrology of the axis stage felsic rocks in the northern Oman ophiolite

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At mid-ocean ridges, a critical interface for heat and mass exchange between the lithosphere and hydrosphere is the magma–hydrothermal transition (Gillis and Coogan, 2002). A distinctive feature of ophiolitic upper gabbros is the presence of leucocratic rocks in vein networks and/or discrete bodies that commonly contain partially resorbed xenoliths of basaltic material. These presence of felsic rocks in ohiolite suites has been reported by numerous authors, and are called plagiogranite (Coleman and Peterman, 1975). These lithologies are attributed to partial melting of basaltic material, extreme fractional crystallization of basaltic melt, or a combination of these two end-members (Pedersen and Malpas, 1984).

Lippard et al. (1986) classified the felsic rocks in the Oman ophiolite into three stages; high-level intrusives (axis stage), late intrusives, and younger granites associated with emplacement. Rollinson (2009) described similar classification of the felsic rocks in the Oman ophiolite, and discussed petrogenesis of these felsic rocks. This paper describes field occurrences, petrography, and petrochemistry of the felsic rocks in early (axis stage) intrusive rocks.

The early (axis stage) felsic rocks characteristically intrude into the boundary between lowermost sheeted dike complex and upper gabbro. We investigate felsic rocks intrude into the boundary between lowermost sheeted dike complex and upper gabbro, which includes sheeted dikes as large blocks less than 10 m from the main stream of the Wadi Rajimi (Rollinson, 2009). Felsic rocks associated with the sheeted dikes from eastern margin of the Lasail complex and the Wadi Barghah are also investigated, which are intruded by upper gabbroic rocks and quartz diorites. We also investigate felsic rocks intrude into the sheeted dike complex near the quartz dioritic to tonalitic intrusion in the Wadi Khabiyat. These sheeted dikes are infiltrated by quartz dioritic vein networks, which sometimes occurs as pockets and patches. In some places, sheeted dikes are composed of hornblende and pyroxene hornfels cut by quarts dioritic vein networks. These occurrences resemble to the anatectic migmatites of axial magma chamber roof exposed in the Troodos ophiolite, Cyprus, described by Gillis and Coogan (2002).

Gillis and Coogan (2009) describes disequilibrium melting models to explain relatively lower REE concentrations in early felsic rocks. Disequilibrium melting models assume that the concentration of an element in a melt is simply controlled by its concentration in the constituent minerals and the relative proportions in which they dissolve into the melt (e.g., Bea, 1996). Incompatible element concentrations sometimes lower in the quartz dioritic vein compared with the values predicted by equilibrium melting of sheeted dikes, this discrepancy can be explained by disequilibrium melting model. Disequilibrium melting may play a significant role on the petrogenesis of axis stage felsic rocks.

Keywords: Oman ophiolite, plagiogranite, axis stage, oceanic crust, petrochemistry

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MIS31-08 Room:106 Time:May 24 11:15-11:30

Petrogenesis of MORB: a implication from concordant dunite bands of the northern Oman ophiolite

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Dunite bands and veins in the ophiolitic mantle peridotite are interpreted as melt conduits within the suboceanic mantle. In particular, concordant dunite bands are possibly important as melt conduits, through which parental melts of MORB (mid-ocean ridge basalts) were transported to shallower mantle beneath the ridge axis. However, no detailed petrological data of concordant dunite bands and surrounding peridotites have been published. We found concordant dunite bands from various "stratigraphic levels" in the mantle section of the northern Oman ophiolite. They are various in thickness (few millimeters ~ few tens of centimeters) and frequency of appearence. Dunite bands are almost pyroxene-free, and orthopyroxenes, if any, are vermicular in shape. Modal clinopyroxenes in wall peridotites increase toward the dunite band.

Mineral chemistry shows systematic variations in the wall peridotites toward the dunite bands: (1) a decrease in the Fo content (92 to 90.5) of olivines, (2) an increase in the Cr/(Cr + Al) atomic ratio (0.5 to 0.6) and TiO2 content (nil to 0.25 wt %) in spinels, and (3) an increase in the Na2O content (almost nil to 0.2 wt%) of clinopyroxene. In residual peridotites, rare earth element (REE) patterns of clinopyroxene incline from light-REE (LREE) to heavy-REE (HREE) monotonously. REE patterns of clinopyroxene in peridotites near dunite bands are U-shaped or flat. REE characteristics of clinopyroxene in dunite bands within the mantle away from the layered gabbro/peridotite boundary suggest an involvement of "slightly depleted MORB melts", which are slightly more enriched in LREE than the melts in equilibrium with residual peridotites.

We conducted simplified modeling for REE enrichment in clinopyroxenes by using chromatographic approach. The results indicate that MORB melts and "slightly depleted MORB melts" were transported through the present-day concordant dunite bands within the Oman mantle; MORB melts were migrated around the layered gabbro/peridotite boundary. The primitive MORB melts might have changed to MORB through "slightly depleted MORB melts" by interaction with peridotites en route to the uppermost mantle.

Keywords: Oman ophiolite, concordant dunite band, MORB, melt/rock interaction

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MIS31-09 Room:106 Time:May 24 11:30-11:45

Distribution of ultramafic layers in the mantle section of the Oman ophiolite: early magma genesis at spreading centre

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Ultramafic dykes concordant to their host foliation (layerings) are frequently observed at various level of the mantle section of the Oman ophiolite. They generally crop out as series of 3 to about ten parallel veins, a few mm (one crystal) to a ten of cm wide, a few cm spaced out. Their host is usually harzburgite showing, in one third of the cases, increasing Opx content when approaching the layer and, in the two other third of the cases, no variation of the Opx content. Locally concordant dunite may appear in association with pyroxene-rich layerings as thin (a few mm to a few cm) parallel vein in contact with the layer or not. We present here a compilation of the data obtained on about 240 samples taken all over the mantle section of the Oman ophiolite. Their modal composition cover a wide part of the ultramafic domain with rare clinopyroxenite, dunite or wehrlite, abundant orthopyroxenite and websterite, and scarcer clinopyroxene-bearing harzburgite and lherzolite. The distribution map shows that layerings appear at any level in the mantle section, close to the basis as well as a few tens of meters below the Moho. Layerings are abundant only in the northernmost part of the ophiolite, from the Wuqbah to the Fizh blocks with exceptionally low abundance in the Hilti block. They are rare or even non-existent in the south-eastern massifs (Maqsad, Wadi Tayin, etc.) suggesting that condition for their genesis or preservation were reunited only in some specific places in the mantle before obduction. Their major elements chemistry is generally in equilibrium with their host peridotite and their pyroxenes and olivines compositions stay within the peridotite chemical domain with no specific rim-core evolution. However, Cpx trace elements content shows compositions richer in REE than the classical Oman harzburgite with chondrite normalised profiles slightly dipping in the HREE suggesting a magmatic origin with possible magma generation in the garnet peridotites field. Two-pyroxenes geothermometer show equilibrium temperatures between 950 and 1100^{o}C, suggesting high temperature transposition and equilibration. The high abundance of layerings observed close to the Moho transition zone in the Fizh and Wuqbah blocks show that these features and their transposition are not related to the obduction but to early magmatic process below the Omanese spreading centre followed by mantle flow at high temperature.

Keywords: Concordant dykes, Pyroxenites, Oman ophiolite, Mantle, Magatism

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MIS31-10 Room:106 Time:May 24 11:45-12:00

Spatial compositional variability and origin of incipient subarc mantle inferred from the northern Oman ophiolite

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The Oman ophiolite is a remnant of Neo-Tethyan oceanic lithosphere that has been modified by arc-related magmatism during oceanic thrusting prior to the obduction to the Arabian continent. To understand the formation of oceanic mantle lithosphere at spreading ridge and subsequent modification at incipient subduction zone we conducted a Km-scale mineral chemical mapping of the mantle section in the Fizh and Salahi blocks in the northern Oman ophiolite.

In the Fizh mantle section the range of spinel Cr# (=100xCr/[Cr+Al] molar%) in harzburgites becomes wider from the south (Cr# 43-67) toward the north (Cr# 22-78). In the south, where paleo-ridge segment center has been inferred, relatively homogeneous harzburgites with spinel Cr# around 60 are widely distributed indicating that the degree of melting was equivalent to the upper limit of abyssal peridotites (spinel Cr#˜60). On the other hand, in the northern part, where a paleo-ridge segment end was inferred, refractory harzburgites with spinel Cr# greater than 70 are abundant and are linearly distributed from the basal thrust to the Moho. Such highly refractory harzburgites are associated with thick dunite bands in which spinel Cr# is also high (greater than 70). Such region with abundant refractory peridotites is called highly refractory zone (HRZ, hereafter). Away from the HRZ the harzburgites are less refractory and often contain spinels with low Cr# (smaller than 50). Thus, except for the peridotites in the HRZ the harzburgites in the northern Fizh mantle section is less refractory relative to those in the southern Fizh mantle section. Dunites in the Fizh mantle sections have spinel with Cr# ranging from 45 to 80 and tend to have higher spinel Cr# than the harzburgites. Moreover, the dunites with high Cr# spinel (greater than 70) are abundant in the HRZ and in the basal part of the Fizh mantle section.

In the Salahi mantle section the spinel Cr# of harzburgites ranges from 42 to 70 and is most frequent in the range of 55-60. The harzburgites in the southern Fizh mantle section also have similar variation. On the other hand, the Cr# of spinel in dunites in the Salahi mantle section shows a bimodal distribution: frequency peak occurs both at 55-60 and at 68-75. The peak in the 55-60 is also observed in the harzburgites while the peak in the 68-75 occurs only in the dunites. The dunites in the lower level of the Salahi mantle section above the basal thrust often contain high Cr# spinels greater than 70 while the dunites in the upper level of the Salahi mantle section have spinel with Cr# smaller than 65. We consider that the dunites with such low Cr# spinel were formed at MOR stage while those with the high Cr# spinel formed by a reaction with boninitic melt during oceanic thrusting stage.

The distribution of refractory harzburgite and dunite in the northern Oman ophiolite can be modeled as follows. During oceanic thrusting the Oman ophiolite was forced to be located above an incipient subduction zone. The fluid released from metamorphic sole due to thermal metamorphism of altered oceanic crust infiltrated into the mantle section. Dunite channels may have been responsible for fluid infiltration from the base of the ophiolite. The fluid infiltration through dunite channel caused the flux melting of wallrock harzburgite. The presence of the HRZ in the northern Fizh mantle section implies that the infiltration of fluid from the base of ophiolite was abundant in the ridge segment boundary region. The orientation of the HRZ may imply that shear deformation in the segment boundary region enhanced the fluid infiltration. Alternatively, flux melting of less-refractory harzburgites (spinel Cr# smaller than 50) in the ridge segment boundary region produced relatively large amount of boninitic melt. Large porosity may have enhanced further infiltration of fluid from the base resulted in the formation of the HRZ in the segment boundary region.

Keywords: Oman ophiolite, mantle, peridotite, spinel Cr#, flux melting, fluid migration

MIS31-11 Room:106 Time:May 24 13:45-14:00

A study of the structure and evolution of the oceanic lithosphere inferred from mantle xenoliths and drilling samples

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Deep-seated rock xenoliths often included in oceanic island basalts and abyssal peridotite sampled by oceanic drilling and dredges provide us a lot of information about the deep structure and evolution of the oceanic lithosphere. Here a review of recent studies on such peridotite and the deep crustal materials from the oceanic lithosphere will be presented.

Keywords: oceanic lithosphere, mantle xenoliths, ocean drilling, abyssal peridotite

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MIS31-12 Room:106 Time:May 24 14:00-14:15

Fabric and petrological characteristics of mafic and ultramafic rocks in the Tonga Trench

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The Tonga trench is one of the deepest oceanic regions in the world (10,866 m), so it may likely to be the closest location to the mantle. In the Tonga trench, various types of rocks have been dredged and drilled at several localities on the landward slopes of the trench. In particular, very pristine peridotites occur at the most deep landward trench slope. 100 samples of mafic and ultramafic rocks collected from several locations were analyzed in order to understand the characteristics and whole picture of the Tonga trench. Mineral composition of olivine and spinel in peridotites suggests that there are two types of regions: central region and northern region. The peridotites in the central regions have high-Cr# (0.46-0.83) which were typical of forearc peridotites. In contrast, the peridotites in the northern region have evidences of the reaction with magma during partial melting. Moreover, on the basis of H2O content (over 100 ppm) of olivine and TiO2 content (from 0.06 to 0.79 at northern region) of spinel, they remarkably reacted with melt and/or fluid. In addition to peridotites composition, mineral composition of plagioclase, clinopyroxene and amphibole in gabbroic rocks also suggest that there have been affected by water infiltration. Olivine fabrics are characterized by E-type and D-type. Although E-type and D-type are no clear relationship of mineral composition, grain size and equilibrium temperature, the only difference between E-type and D-type were fabric intensities. This difference suggests that pristine and serpentinized peridotites in the Tonga trench are deformed in the region where high strain field occurred due to the dragged flow. Eventually, they expose in a very neat condition (i.e. active tectonic erosion and fast ascent rate) resulting from an unique tectonic setting including fast subducting plate (24 cm/yr), fast spreading plate (15 cm/yr) and slab rollback.

Keywords: Tonga trench, mantle wedge, peridotite, serpentinite, gabbro

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MIS31-13 Room:106 Time:May 24 14:15-14:30

Reactive Melt Flow as the Origin of Residual Mantle Lithologies and Basalt Chemistries in Mid-Ocean Ridges

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A reactive flow geochemical model using pMELTS thermodynamic calculations explains the observed modal, major, and trace element variations in the Red Hills peridotite, New Zealand. The model also reproduces the major and trace element chemical variation in the mid-ocean ridge basalts (MORBs) observed in the present day spreading ridges. The Red Hills peridotite is thought to originate in paleo-MOR magmatic processes in the mantle-MOHO transition zone. The peridotite body consists of a harzburgite matrix and dunite channels. The harzburgite forms the Lower Unit and the harzburgite is intruded by the replacive dunite channels in the Upper Unit. This lithology gradually turns into a massive dunite zone in which disseminated to lenticular clinopyroxene aggregates are present. The rare earth element (REE) compositions of peridotite samples vary greatly depending on their lithologies. In the Lower Unit, REEs are extremely depleted, whereas in the Upper Unit they are relatively fertile, in contradiction to their depleted lithologies. Our model consists of two-stages. The first-stage assumes melting of a depleted MORB source mantle in the garnet stability field, and the second assumes reactions between residual solids and the melts from the first-stage in the spinel stability field in an open system. The model explains the formation of depleted harzburgite and the formation of dunite channels in the harzburgite matrix well. The major and trace element compositions of the melts calculated by the model vary from ultra-depleted MOR melts in harzburgite to normal MORBs in dunite, suggesting that these lithologies are residues of a paleo-MOR. The model also explains the origins of the local and global geochemical trends found in MORBs and the geochemical variation in the abyssal peridotite samples. Our model confirms the important role of reactive flow in the mantle-MOHO transition zone beneath MORs.

Keywords: Ocean ridges, Mantle, MORB, Ophiolite, Melt

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Diversity in PT history of exhumed mantle peridotites and its implication in lithosphere-asthenosphere interaction

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Pressure and temperature history of exhumed mantle peridotites shows significant diversities, which may be attributed to several factors such as: (1) lithospheric thermal gradient before exhumation, (2) rate of tectonic motion and thermal and mechanical conditions during exhumation, (3) thermal perturbation shortly before or during exhumation of lithosphere such as episodic asthenospheric thermal convection with lithosphere erosion and related magma generation, and transportation, (4) lithosphere formation or growth from asthenosphere through melting and melt separation and subsequent exhumation. These factors may, conversely, be estimated from the mantle peridotites if each effect can be isolated from the others by considering tectonic environment where the mantle peridotite resided and exhumed. The first factor is recorded as the initial condition of exhumation potentially providing information on steady-state mantle heat flow. The second is recorded as compositional zoning of minerals in terms of elements sensitive to PT change. Among these factors, (3) and (4) represent direct thermal and mechanical interactions between lithosphere and asthenosphere and are examined by whole-rock compositions and its heterogeneity constraining thermal condition of melting and melt segregation processes if they were involved (e.g., abyssal peridotite exposed along mid-ocean ridges). The following cooling and thermal relaxation are recorded as compositional zoning in minerals and chemical heterogeneity in a composite lithology over the scale of more than a few centimeters.

These approaches are similarly applicable to any types of mantle peridotites such as orogenic peridotites, mantle section of ophiolites, and mantle xenoliths in alkali basalt and kimberlite. Xenoliths can provide instantaneous thermal states of the mantle up to the depth as deep as a few hundreds km, and is superior in examination of (1) and (3). Contrary to this, intrusive peridotites always underwent slow exhumation process more or less obscuring lithospheric information, and is superior in examination of (2) and (4).

Following the above strategy, thermal histories of three peridotite bodies from world orogenic belts are compared. These are the Horoman peridotite in the Hidaka belt, peridotite bodies in the Pyrenees, and Ronda in the Betic Cordillera. The common feature of these peridotites is that they were initially resided in the garnet stability field before decompression. There are, however, several distinctions: (1) garnet in any rock types is completely transformed into low pressure mineral assemblage (symplectite) in Horoman, garnet in pyroxenites remains but that in peridotites is completely transformed into symplectites in Pyrenees, and garnet remains in peridotites as well as in pyroxenites in Ronda, (2) orthopyroxene in garnet- or symplectite-bearing rocks shows remarkable M-shaped Al zoning in Horoman, weaker but distinct M-shaped in Pyrenees, and very weakly developed in Ronda, (3), orthopyroxene in peridotite and pyroxenites has a Ca-rich margin in Horoman, but such features are not common in Pyrenees and Ronda, and (4) topotaxy is always established in two-pyroxene spinel symplectite in Horoman (Odashima et al., 2008) but not so in Ronda (R. Nagashima, personal communication). These systematic relationships suggest that dP/dT was very small or even negative in Horoman (˜adiabatic or heating during exhumation), moderate in Pyrenees (˜adiabatic), and large in Ronda (effective cooling with decompression). It is inferred that exhumation accompanying active asthenospheric thermal perturbation took place in Horoman, passive exhumation in Pyrenees, and transportation towards the cooler region probably in a subduction environment in Ronda, in spite of the suggested asthenospheric thermal perturbation in the spinel and plagioclase facies in Ronda (Garrido et al., 2010).

Keywords: lithosphere-asenosphere interaction, mantle pressure temperature history, mantle thermal structure

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Three-dimensional shear wave structures of the upper mantle beneath the Philippine Sea and the French Polynesia region

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We have operated many seafloor observations by using newly developed long-term broadband ocean bottom seismometers (BBOBSs) to reveal the mantle dynamics beneath the oceanic region in the Pacific Ocean. We have conducted array observations by BBOBS in and around the Philippine sea plate to analyze the structure of the subduction zone and in the French Polynesian region characterized by a topographic high of 700 m (called Pacific superswell), a concentration of hotspot chains, and large scale low-velocity anomalies in the lower mantle to analyze the whole mantle structures in this region.

We have analyzed the three-dimensional shear wave structures of the upper mantle beneath these regions by using surface wave tomography technique.

In the Philippine sea region, we analyzed the isotropic and anisotropic shear wave velocity structure by using Rayleigh and Love waves recorded by land and seafloor broadband seismometers. We obtained high spatial resolution (about 300km) shear wave structure model in the Philippine Sea region. Along the Izu-Bonin(Ogasawara)-Mariana arc, we have detected three separate slow anomalies in the mantle wedge at depths shallower than 100 km beneath the rear arc. Each anomaly has a width of about 500 km. We suggest that each of the anomalies is a site of large scale flow of deep mantle into the mantle wedge, and that each already contains a component from the adjacent subducting slab.

Our anisotropic structure model suggests that the fast directions of azimuthal anisotropy are parallel to the directions of ancient seafloor spreading in the lithosphere of the Shikoku and West Philippine Basins and Pacific Ocean, whereas they are parallel to the direction of the present-day absolute plate motion (APM) in the asthenosphere of the Shikoku Basin, and oblique to the direction of the APM in the Pacific Ocean (by about 30 degree) and in the northern part of the West Philippine Basin (by about 55 degree). In the subduction zones around the Philippine Sea plate, the fast direction of azimuthal anisotropy is trench-parallel in the Ryukyu arc, and oriented NW-SE in the Izu-Ogasawara island arc. The Philippine Sea plate, which is a single plate, shows very large lateral variations in azimuthal and radial anisotropies compared with the Pacific plate.

Beneath the superswell in the French Polynesian region, we determined three-dimensional shear wave speed model down to a depth of 200 km by using fundamental mode of Rayleigh waves. The temporary observation by seafloor and islands enables us to study the upper mantle structure beneath the superswell with an unprecedented high resolution. Resolution analyses indicate that these temporary observations locally improve the lateral resolution to about 400 km. We observe superficial slow anomalies associated to the spreading ridges such as the Lau Basin and two kinds of hotspot signatures: We found pronounced and continuous slow anomalies down to at least 200 km depth near the Society, McDonald, Marquesas, and Pitcairn hotspots whereas the slow anomalies beneath the Samoa, Rarotonga and Arago hotspots are only present at depths shallower than 80 km.

Keywords: seafloor observation, upper mantle structure, surface wave analysis

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The nature of mantle xenoliths from three frontal volcanoes of the Kamchatka arc: toward a general view of the sub-front

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We have a large amount of data about petrological and geochemical features of upper mantle peridotites, but the nature of sub-arc mantle, especially beneath a volcanic front, has not been fully understood due to the scarcity of occurrences of mantle-derived materials there. Mantle-wedge peridotites are opened to the impact of fluids or melts released from downgoing slab. They induce magma production and modify the petrological and geochemical features of the mantle wedge. To identify the nature of sub-arc mantle and the metasomatic agents, peridotite xenoliths trapped in arc magma is one of the most useful tools. Kamchatka Peninsula is one of the active volcanic arcs, and peridotite xenoliths derived from the upper mantle beneath the volcanic front are obtained from 9 of its volcanoes (Erlich et al., 1979). Avachinsky (Avacha) volcano is the most famous of them because of its easy accessibility and high xenolith production. Peridotite xenoliths from Avacha record high degree of melting and multiple stages of metasomatism (e.g., Ishimaru et al., 2007; Ionov, 2010). Formation of secondary orthopyroxenes replacing olivine is one of characteristics of arc-derived peridotite xenoliths (e.g., Arai & Kida, 2000; McInnes et al., 2001). In addition, we found peculiar metasomatisms, e.g., Ni enrichment (e.g., Ishimaru and Arai, 2008), in the Avacha peridotite xenolith suite. We examined additional peridotite xenoliths suite from other two volcanoes of the volcanic front of Kamchatka arc, Shiveluch and Bezymyanny volcano, to obtain a more generalized view of the mantle-wedge process there.

We examined 2 harzburgite xenoliths from Bezymyanny and 13 xenoliths of pyroxenites with/without olivine and 3 xenoliths of peridotites (2 dunites and 1 metasomatized harzburgite) from Shiveluch. Both of them are brought up to the surface by calc-alkaline series andesite to dacite. To clarify the residual features of the mantle peridotites, we only dealt with 3 peridotites from Shiveluch, because most of Shiveluch pyroxenites show textures of cumulate and/or extensively modification by interaction with the host andesite. The mantle peridotites from both Bezymyanny and Shiveluch are composed of fine-grained minerals (cf. Arai and Kida, 2000), and occasionally contain hornblende and/or phlogopite. Almost all orthopyroxenes show irregular shapes and replace olivine, indicating a secondary origin. At the boundary between the harzburgite and host andesite, we observed hornblende and secondary orthopyroxenes. At the interior of the xenoliths, the Fo content of olivine in Bezymyanny and Shiveluch samples is 91-92 and 94, respectively, and the Cr# (= Cr/(Cr + Al) atomic ratio) of chromian spinel is high, 0.43-0.69 and 0.63-0.72, respectively, and the former decreases to 76 at the boundary with the host andesite although the Cr# is almost constant. These petrographical and geochemical features are shared with Avacha peridotite xenoliths (e.g., Ishimaru et al., 2007). Orthopyroxenes in the both peridotite suites do not show simple residual feature in REE pattern, but instead are LREE-enriched and MREE-depleted. These REE concentrations of orthopyroxene indicate the metasomatic agents, which formed olivine replacing orthopyroxene, for Bezymyanny and Shiveluch were strongly enriched in LREE and SiO_2-oversaturated melts or fluids (= evolved magma?).

We will make discussion about the nature of sub-frontal mantle peridotite and metasomatic events with additional geochemical data.

Keywords: arc mantle, peridotite xeloliths, volcanic front, metasomatism

MIS31-P02 Room:Convention Hall Time:May 24 17:15-18:30

Petrological nature and origin of ultramafic complex in the basal part of the Salahi mantle section, the Oman ophiolite

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The Salahi (Hilti) mantle section located in the northern Oman ophiolite is mainly composed of harzburgite and dunite, but the ultramafic complex in the southwestern part of the Salahi mantle section is mainly composed of dunite and pyroxenite. This study clarifies petrological nature of the ultramafic complex and examines the origin of this complex using their rock textures and mineral compositions.

Peridotites in the ultramafic complex in the basal part of the Salahi mantle section have the equigranular texture with coarse-grained to very coarse-grained (grain diameter greater than 1cm), and the grain boundary is intricate like a labyrinth.

The spinel Cr# of harzburgites in the basal part of the mantle section ranges from 55 to 72, and is most frequent in the range of 64-66, and then the second peak in the 70-72. Harzburgites with high Cr# spinel (Cr# greater than 70) are abundant in this area, so we speculate the presence of highly refractory zone (HRZ, hereafter) that has been reported from the northern Fizh block (Kanke and Takazawa, 2006). Also the spinel Cr# of dunites in this area ranges from 61 to 84, and is most frequent in the range of 76-82, so highly refractory dunites are also abundant as well as the harzburgites. This indicates that during oceanic thrusting stage a large volume of fluid infiltrated into the mantle section from the base, and then voluminous dunites were made by flux melting of residual harzburgite. Dunites with very coarse-grained texture also support this hypothesis.

Moreover, two types of dunites can be classified on the basis of compositional relationship between harzburgite and dunite that are nearby each other in the field, that is increase or decrease in Fo of olivine with the increase of spinel Cr# from harzburgite to dunite. The distribution of these two types is separated clearly in the field. The former is found in the central part of the ultramafic complex, while the latter occurs in the periphery of the ultramafic complex. This indicates that a large amount of fluid infiltrated into the central part of the ultramafic complex, so flux melting caused dissolution of not only orthopyroxene but also a small amount of olivine forming dunites with high Fo olivine. On the other hand, dunites with low Fo olivine associated with pyroxenite may have formed by fractional crystallization of olivine and pyroxene from a partial melt in the periphery of the ultramafic complex.

The HRZ has been detected in the northern part of the Fizh mantle section, indicating a large volume of melt/fluid infiltrated into paleo-ridge segment end region during oceanic thrusting stage (Kanke and Takazawa, 2006). We consider that the ultramafic complex in the southwestern part of the Salahi mantle section is also a kind of HRZ. Moreover, the southern part of the Salahi block has been considered as a paleo-ridge segment end similar to the northern part of the Fizh block (Miyashita et al., 2003; Monnier et al., 2006). Our study suspects that highly refractory harzburgites was closely related to the segment end region during oceanic thrusting. Previous study showed that clinopyroxene-rich harzburgites or lherzolite tend to occur at the basal part of paleo-ridge segment end region (Takazawa et al., 2003; Monnier et al., 2006). Flux melting of such fertile peridotite produces relatively larger amount of partial melt resulted in a large porosity in residual peridotite. Large porosity can enhance further infiltration of fluid into residual peridotite. This positive feedback system may explain the formation of HRZ at a paleo-ridge segment end region.

Keywords: Oman ophiolite, mantle section, highly refractory zone, spinel, peridotite, pyroxenite

MIS31-P03 Room:Convention Hall Time:May 24 17:15-18:30

Along-axis variations of ultramafic-mafic intrusions in the northern Oman ophiolite

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The Oman ophiolite contains ubiquitous ultramafic-mafic intrusions (called as "wehrlite" intrusions). There are three different ideas for the genesis of these intrusions; 1) off-axis magmatism (Jousselin and Nicolas, 2000), 2) oceanic thrusting during V2 volcanism (Koepke et al., 2009), 3) mantle remelting due to mantle diapir in the sub-ocean ridge (Clenet et al., 2009). Although Jousselin and Nicolas (2000) claimed genesis of ocean ridge, Koepke et al. (2009) insisted island arc setting for the genesis of "wehrlite" intrusions. On the other hand, Adachi and Miyashita (2003) showed that there are two different types of ultramafic-mafic intrusions, common ubiquitous intrusions (genesis of ocean ridge; Geotimes unit) and plutonic equivalents of island arc magmatism (Alley unit). Ridge segment structure in the northern Oman ophiolite is shown by Miyashita et al. (2003) and Umino et al. (2003): Wadi Fizh area is northern margin, Wadi Thuqbah area is center, Wadi Hilti area is intermediate and Wadi Ahin area is southern margin of the second order ridge segment. We describe petrological features of the ultramafic-mafic intrusions and discuss with along-axis variations and these genesis.

Recently we have found a huge ultramafic-mafic intrusion (Barghah complex ; 10x2km) from the northern part of Salahi (Hilti) block (Wadi Barghah). The layering and foliation of the host layered gabbro are dragged by this intrusion to result an apparent anticline structure around the Barghah complex. This complex is mainly composed of Cpx (clinopyroxene) dunite, Cpx-Pl (plagioclase) dunite, wehrlite, Pl wehrlite and Cpx mela troctolite. The Moho transition zone of Wadi Barghah area is mainly composed of dunite, Pl dunite, Cpx-Pl dunite and Ol mela gabbro, and attains about 200m thick, indicating that this area corresponds to the ridge segment center.

"Wehrlite" intrusions at the Wadi Fizh area (segment margin) about a few tens to hundred m width, are mainly composed of Hbl (hornblende) mela Ol gabbro, Hbl mela troctolite and Hbl mela Ol gabbronorite. These rocks are characterized by abundant brown Hbl and Opx (orthopyroxene).

Fo contents of olivine and Cpx Mg# from Barghah complex ranges from 85 to 91, and 0.89 to 0.94. These compositions are primitive as similar to those of the Moho transition zone (Ol Fo=86˜92,Cpx Mg#=0.88˜0.93) in this area. Ti and Na contents of Cpx show wide compositional ranges, though the Cpx Mg# ranges are narrow, suggesting a melt-mantle reaction. These compositional features of Cpx are different from the differentiation trend of MORB. Cr# and TiO2 contents of Cr spinels ranges from 0.45 to 0.62, and 0.19 to 2.41 wt%, respectively, similar to MORB spinels and distinct from those of island arc magmatism (Alley unit).

Fo contents of olivine and Cpx Mg# from Wadi Fizh area ranges from 80 to 86, and 0.85 to 0.88. Apparently these compositions are considerably evolved than those of the Barghah complex. Cr# and TiO2 contents of Cr spinels ranges from 0.51 to 0.69, and 0.48 to 2.90 wt%, respectively, similar to MORB spinels and distinct from those of island arc magmatism (Alley unit).

Abundant appearance of Hbl and Opx indicates that the melts of Fizh "wehrlite" are rich in H2O. The origin of H2O may be ascribed to the penetration of sea water along the fracture at the ridge segment margin. On the other hand, ultramafic-mafic intrusions of Wadi Barghah are free from igneous amphiboles and have less evolved features, similar to the Moho transition zone in terms of lithology and mineral composition. This complex is rooted the Moho transition zone and intruded diapirically. Thus, ultramafic-mafic intrusions show signficant variations due to the location in the ridge segment.

Keywords: Oman ophiolite, wehrlite intrusion, ridge segmentation

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Petrology of Ol-Cpx layered units in the Higashi-Akaishi ultramafic body, SW Japan: Close affinity to high Ca boninite

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The Higashi-akaishi ultramafic body (HA) in the Sanbagawa belt, SW Japan, is composed of dunite, wehrlite, olivine-clinopyroxenite and garnet-bearing rocks. The body is regarded as a piece of hanging wall mantle at the deeper part of oceanic-type subduction zone. Understanding of the petrological signature is important to gain insights into the formation of the mantle wedge. We present field and microtextural observations and mineral chemistry of a 250 m-thick section of compositional layering in the central part of the body and link them to the magmatic process and composition related to the formation of the HA body.

The layering in the section form a trend of compositional variation in centimeter to 10m-scales: dunite - wehrlite - olivine-clinopyroxenite. Fo and NiO in olivine and Cr/(Cr+Al) in spinel decrease in accord with this trend. These changes can be explained by fractional crystallization of Cpx following olivine and spinel. So, the dunite in the section can be regarded as a member of Ol-Cpx cumulate.

Olivine shows high Fo (up to 94) and high NiO content (- 0.33 wt%), and Cr-spinel is rich in Cr (Cr/(Cr+Al)=0.65-0.90) and poor in TiO2. Coarse porphyroclasts of Cpx in wehrlite and olivine-clinopyroxenite show highly depleted REE patterns (C1 normalized values of Ce and Yb are 0.1-0.8 and 0.3-2, respectively). The Cpx includes abundant Cr-spinel exsolutions and is most likely to preserve a primary composition crystallized from magma. Later alterations are identified by distinctive REE patterns of Cpx with microtextural features of recrystallization.

The primary chemical compositions of minerals and estimated melts in equilibrium with the Cpx overlap the ranges of high-Ca boninite (HCB); they are less depleted than low-Ca boninite and are more depleted than the Setouchi high Mg andesite. The crystallization of Ol and Cpx is also consistent with a HCB magma. Highly depleted but Ca-rich nature of HCB requires a cumulative partial melting of fertile lherzolite forming harzburgite. Experimental and natural evidence shows that it takes place in hot (close to 1300 oC) and moderately hydrous conditions. Therefore, the HA body can be regarded as a record of a high temperature phase in the Sanbagawa arc evolution.

Present activities of HCB lavas are found in oceanic arc systems (Bonin and Tonga) and in a site of arc-plume interaction (northern edge of Tonga arc). Considering that the HA body is located in the middle of the E-W elongation of the Sanbagawa metamorphic belt, it is likely that the HCB activity produced the cumulate occurred in an island arc system behind which hot asthenospheric mantle was upwelling. This can be related to the Mesozoic high temperature episode in the east Eurasian margin due to a replacement of continental lithosphere by fertile asthenospheric mantle.

MIS31-P05 Room:Convention Hall Time:May 24 17:15-18:30

Petrological evidence of ancient mantle components beneath the Mid-Ocean Ridge? Results from a serpentine seamount along

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We examined abyssal peridotites recovered from a small seamount along the Central Indian Ridge. 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). We will show you our interpretation that some of these samples were formed in a diffent tectonic setting at ancient age.

Keywords: mid-ocean ridge, mantle

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Geology of ophiolite and serpentinite melange around Mitsuishi Horai-san, Kamuikotan Zone, Hokkaido

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Serpentinites containing high-P/T metamorphic rocks are expected to provide information on structure, physical properties, and dynamics inside subduction zone of upper mantle depths. Comparing with structural evolution of concurrent accretionary and subduction complexes and forearc basin, it could be a key to comprehensively understand the entire subduction zone dynamics. Based on this aspect of view, we have thus surveyed geology of serpentinite melange and related rocks exposed around Mitsuishi Horai-san in the Kamuikotan high-P/T zone in Hokkaido. This area is known to yield blocks of the most high-grade metamorphic rocks (garnet- and/or epidote amphibolite) in the Kamuikotan zone. However, isolated occurrence of serpentinite melange among Neogene deposits and poor exposure has obstructed to evaluate its significance on subduction zone evolution. To date, we have made a geological map of eastern half of the area, and obtained two new insights (A and B below) on geological components and structures, which will be here presented.

A: Constituent rock units

A geological body that has been wholly regarded as a ”serpentinite melange” is composed of at least three components.

The first is a dismembered ophiolite (here named as ”the Gunkan-yama ophiolite”) as a pile of tectonic slices of ultramafic and mafic rocks without any signs of high-P/T metamorphism. The ultramafic rocks comprise a partly serpentinized harzburgite body and extensively serpentinized cumulate bodies (clinopyroxenite-wehrlite and dunite with trace gabbro). Mafic rocks are composites of gabbro (-diorite) and diabase, whose grain sizes considerably vary in each single body. Based on occasional intrusive boundaries, they probably comprise dike complexes intruded into cumulates.

The second component is a serpentinite melange (here named as ”the Horai-san serpentinite melange”) with severely sheared matrices of foliated serpentinite. It lies on the southwest of the Gunkan-yama ophiolite, and contain blocks of amphibolites, antigorite serpentinite, minor metapelites, and of rocks common with the ophiolite such as massive serpentinite, ultramafic cumulate, gabbro and diabase.

The third component is a low-grade (blueschist facies) metabasite occurring on the northeast of the ophiolite. Based on lithological similarity, it is inferably an extension of a coherent metabasites in the main exposure of the Kamuikotan Zone to the northeast of the study area.

Rocks of the study area are therefore regarded as a full set of the fundamental elements of the Kamuikotan zone: an ophiolite, a serpentinite melange, and a low-grade metamorphic body. They seem to be arranged more regularly than previous view of entire mixed-up structure.

B: Relationships with surrounding sediments

It has been considered that the ”basement rocks” now consisting of ophiolite, serpentinite melange, and metabasites were emplaced along with a fault crosscutting the surrounding Neogene deposits. However, our mapping revealed that they are unconformably overlain by the basal conglomerate of the Neogene deposits both on their NE and SW margins, with several observations of the contact on outcrops. The basement exposure is thus regarded as an inlier at the core of an anticline. This suggests that the basement rocks had been emplaced before the timing of the unconformity. Clasts of epidote-amphibolite and chromian spinel are contained in the Cretaceous forearc basin deposits to the northeast of the study area, and therefore, the emplacement might have basically completed until late Early Cretaceous (Albian).

Keywords: ophiolite, serpentinite melange, high-P/T metamorphic rocks, subduction zone

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Hydration processes in the mantle wedge peridotite; an example from the Ust-Belaya ophiolite, Far East Russia

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The Ust'-Belaya ophiolite is exposed in the 80 km x 40 km area on the south of Ust'-Belaya (N65 30', E173 17'), Far East Russia (Sokolov et al., 2003 Geol. Soc. London, Spec. Publ. 218, 619-664). The associated limestone suggests Devonian or older age of this ophiolite. The ultramafic rocks of the Ust'-Belaya ophiolite are mainly composed of fertile lherzolite, lherzolite/harzburgite with small amount of dunite, pyroxenite and chromitite. Those are characterized by significant hydration, which caused formation of secondary minerals. Here we describe hydration process of the mantle peridotite.

Mantle peridotite of the Ust'-Belaya ophiolite is divided into hydrated peridotite and antigorite-bearing serpentinite based on mineral assemblage. In both types, primary spinel is often rimed by chlorite. In some cases, primary spinel completely breaks down to aggregate of chlorite and magnetite/ferritchromite. Hydrated peridotite is composed of olivine, amphibole, chlorite and/or talc and/or secondary clinopyroxene. Amphibole and talc occur as pseudomorph after primary pyroxenes. Antigorite-bearing serpentinite is composed of olivine, amphibole, and/or talc and/or secondary clinopyroxene. Olivine often shows apparent partings similar to cleavage, i.e., the so-called "cleavable olivine". Primary pyroxenes are basically replaced by aggregate of secondary olivine, amphibole and serpentine.

Olivine compositions in both mineral assemblages are often heterogeneous even in a single mineral grain and/or within sample because of chemical modification related to hydration events. Olivine along with amphibole shows low Fo (= 100 x Mg/[Mg+Fe] = 85~89) and poor in NiO (= 0.15~0.40 wt.%) if compared with primary olivine (Fo=90~92; NiO = 0.35~0.45 wt.%). Meanwhile olivine which is along with antigorite in antigorite-serpentinite also show low Fo contents (= ~90) but resemble to primary olivine in NiO content. This compositional modification suggests introduction of Fe during hydration.

Amphiboles show different compositional trend corresponding to the mineral assemblage. Amphiboles in hydrated peridotite are calcic amphiboles, showing a pargasite/edenite-tremolite trend, on the other hand amphiboles in antigorite-bearing serpentinite show a richterite-tremolite trend with some pargasite. Several amphiboles in antigorite-bearing serpentinite show zoning composed of pargasitic core, tremolitic mantle and richiteritic rim. This zoning indicates multiple stage addition of Na2O with Fluid. Trace element patterns of edenitic/pargasitic amphibole are similar to those of primary clinopyroxene. On the other hand, those of Na-rich tremolite and richteritic amphibole show low abundance with pronounced positive anomaly of Sr. These chemical data indicate introduction of Na and Sr during serpentinization. The reports of Na-rich tremolite and richterite in ultramafic rock are relatively rare and most of them are associated with antigorite. This may mean that formation of such amphibole requires a specific condition during antigorite formation.

The unsystematic spatial distribution of hydrated peridotite and antigorite-bearing serpentinite may mean that they represent effectively cooled part by hydrous fluids in the mantle wedge.

Keywords: mantle wedge, hydration, metasomatism, serpentinization, antigorite, Ust'-Belaya ophiolite

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Preliminary results of geophysical survey in the middle Okinawa trough during GH11 cruise

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Back-arc basins are extensional basins formed behind subduction zones by seafloor rifting or seafloor spreading. Back-arc seafloor spreading process is considered as similar to those of mid-ocean ridges. Likewise, back-arc rifting process is considered as similar to mid-ocean rifting but is not clear because there are few examples of the back-arc rifting in the present. The Okinawa Trough is a back-arc rifting basin of the Ryukyu arc, extending between the southwest Kyushu and north Taiwan. Several evidences of magmatic activity such as dike intrusions and/or oceanic crust, and hydrothermal activities were found in the trough, but it is still not clear when these magmatic activities were initiated and how they proceed during seafloor rifting.

We carried out marine geophysical survey in the Middle Okinawa Trough during GH11 cruise by R/V Hakurei maru No.2 from July 14 to August 15. Sea surface geophysical mapping (bathymetry, magnetics and gravity) was conducted during the survey. The survey area is largely divided into four area; northern area around Tokara Islands, continental shelf area around 27N. We present the preliminary results of the morphological and geophysical characteristics of the survey area and its implications as bellows;

1) In the Northern area around Tokara Islands, the present volcanic front, is located in the survey area. Several seamounts, sea knolls and lineaments trending N60E are vastly distributed west to the Tokara Islands. Positive magnetic anomalies up to 600nT are observed along Tokara Island and the northern part of the middle Okinawa trough where the seafloor is consisted of volcanic structures, suggesting the recent island-arc volcanism and back-arc volcanism by dike intrusions or initial emplacement of oceanic crust, respectively.

2) In spite of the depth deeper than 1000m, high amplitude magnetic anomalies of +-400nT are observed in the area of southern part of Iheya knolls and Izana knolls, also suggesting back-arc magmatic activity.

In combination with the previous geological and geophysical researches, these magmatic activities discovered are not related to so-called seafloor spreading. However, it is still not clear that how these magmatic activities can be interpreted as a whole picture of the magmatic activity in the Okinawa trough. In the presentation, we will integrate the new data with the previous geophysical data to reveal the magmatic activities of the whole Okinawa trough.

Keywords: Seafloor morphology, magnetics, gravity, Okinawa trough

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Calculated phase diagrams for oceanic basalt compositions: insight into dehydration behavior of subducting oceanic crust

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The uppermost part of the oceanic lithosphere is variably hydrated by various processes such as high-T hydrothermal circulation at the mid-ocean ridge, low-T alteration on the seafloor, and seawater infiltration along fractures associated with normal faulting at the outer rise. Moreover, hydration due to fluid influx from sediments during incipient subduction stages can also be important. Heterogeneously hydrated oceanic crust and lithospheric mantle transport H_2O to great depths in subduction zones and can be released during prograde metamorphism. The flux of H_2O fluid through the slab-wedge mantle interface depends primarily on the thermal structure of the subduction zone, initial water budget of the slab, reaction kinetics, and compositions and volumes of slab constituent rocks. The complex nature of the initial water distribution and the large chemical system required to adequately describe crustal rocks are two of the major difficulties when trying to model the water release process. Nevertheless, calculation of H_2O-saturated phase assemblage diagrams (pseudosections) for given rock compositions can be used to predict the change of mineral assemblage and the amount of structurally-bound H_2O along a specific P-T path. Recent significant advances in calibrating mixing properties of complex solid-solution minerals (e.g. amphibole and clinopyroxene) allow us to calculate pseudosections for mafic rocks with some precision and accuracy. In this study, we present calculated pseudosections in the chemical system K_2O-Na_2O-CaO-FeO-Fe_2O_3-MgO-Al_2O_3-SiO_2-H_2O for normal mid-ocean ridge basalt (N-MORB) compositions. To account for the variation in the input MORB compositions in modern subduction zones of SW- and NE-Japan, pseudosections were calculated for four representative MORB compositions taken from samples from the Shikoku Basin (DSDP Leg 58 Site 442; Wood et al. 1980), Nankai Trough basement (ODP Leg 131 Site 808; Siena et al. 1993), and the Cretaceous (133-130 Ma) northwestern Pacific Ocean floor (DSDP Leg 32 Sites 303 and 304; Janney and Castillo 1997). Among many hydrous minerals predicted in these rock compositions, important dehydration reactions at forearc mantle levels involve stilpnomelane, lawsonite and chlorite. Stilpnomelane and related hydrous sheet silicates may be important H_2O carriers in cold subduction zones but reliable thermodynamic models for these minerals are not yet available. High water content (~6 wt. %) is required to form H_2O-saturated equilibrium phase assemblages in MORB compositions at very low-T conditions ($<$450 deg.C at 2.0 GPa). Accordingly, cold subduction zones are not associated with the release of significant amounts of water in the forearc region. However, recent subduction-zone thermal models that incorporate a stress- and temperature-dependent mantle rheology predict a substantial temperature rise at the depth where the slab-mantle interface becomes mechanically strongly coupled. A review of worldwide subduction zones suggests this depth is ~80 km irrespective of the subduction zone (Wada and Wang, 2009). Modelling suggests that below this strong coupling depth there is a steep temperature gradient between the top and base of the slab crust at depth. Our modeling predicts that the presence of such a steep temperature gradient in cold subduction zones such as NE Japan results in the release of substantial amounts of H_2O fluid from the uppermost part of oceanic crust at the depth where strong coupling begins. In the case of warm and hot subduction zones such as SW Japan and Cascadia, substantial dehydration of the slab is expected even at the uppermost mantle levels mainly due to breakdown of lawsonite (~370 deg.C at 1.0 GPa) and chlorite (~470 deg.C at 1.0 GPa). The predicted P-T conditions and substantial fluid release are compatible with the high fluid pressure regions inferred from high Vp/Vs ratios observed in the plate interface of warm subduction zones such as SW Japan and Cascadia.

Keywords: dehydration, MORB, pseudosection, subduction zone

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A New Geothermometer Using Crystal Size Variations of the Sheeted Dikes: Insight Into the Thermal Structure of The Upper

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Elucidation of hydrothermal system beneath the mid-ocean ridges is critical to understand cooling of lithosphere and physico-chemical evolution of the earth's surface and interior, and migration of deep bioshpere. Hydrothermal fluids are driven by thermal gradient which plays a fundamental role in hydrothermal circulation and thermo-chemical evolution of the oceanic crust.

Thermal structure of the upper oceanic crust has been estimated by numerical modeling and metamorphic temperatures based on equilibrium mineral assemblages and homogenization temperatures of fluid inclusions. However, metamorphic temperatures may not always represent the ambient temperatures of the host rocks as they are in equilibrium with the fluids that supply or remove heat from the host [1].

We present a new method of estimating the thermal structure of the ancient upper crust formed at the Oman paleospreading axis on the basis of the crystal size variations of the sheeted dike complex. A numerical simulation of crystallization in a dike (Rc) shows that the ambient wall rock temperature (Twall) is correlated with logarithm of crystal size in the center of a dike [2]. This enables us to estimate the wall rock temperatures at the time of the dike intrusion using the crystal size variations in the dike:

Twall =Tm [logRc - logRc(0)]/0.44 + Twall(0)

Tm is the liquidus temperature. A variable with (0) means a reference value.

Because dike intrusion is limited to a narrow volcanically active zone (less than 1 km in width) beneath the fast-spreading ridge axes, the groundmass crystal sizes of the sheeted dikes represent the thermal structure of the upper crust at the ridge axis. A well exposed and preserved paleoridge segment in the Oman Ophiolite [3, 4] provides ideal sites for the crystal-size geothermometry.

Application of the crystal-size geothermometry demonstrates that the estimated geotherm through the dikes at a paleoridge segment end along Wadi Fizh shows constantly low-temperatures in the upper dikes and remarkable high gradient 1.1degC/m in the lower dikes toward the gabbros. In contrast, the estimated geotherm along Wadi Hayl is consistently higher than that along Wadi Fizh and does not show any stratigraphic variation but remains in a limited range from 540 to 790degC, which is higher than any observed fluid temperatures on the present ridge axes. The thermal structure along Wadi Fizh indicates advective heat transfer by hydrothermal circulation of cold seawater in the upper dikes and conductive heat transfer in the lower dikes. However, the high geotherm in the segment center cannot be reconciled with heating by hydrothermal fluids but requires high heat supply by repeated dike intrusions.

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Keywords: Mid-ocean ridges, Oceanic crust, Oman Ophiolite, Sheeted dikes, Crystal size, Thermal structure

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Chromite-hosted sulfide inclusions in the Southwest Indian Ridge (SWIR) podiform chromitites

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Small pods of chromitites occur within dunites in Dredge 62 of the Knorr Cruise 162 Leg 9 from the Southwest Indian Ridge. The size of the pods varies from a few mm to 2 cm in width. Dunites hosting the chromitite pods are chromite-poor and dominantly composed of olivine which had been severely serpentinized. Small relics of olivine are very rare within dunites. These olivines are forsteritic (Fo content=90-91) with NiO wt%=0.31-0.35. The chromitite pods are composed solely of large chromite grains usually rimmed by chlorite. Chromites have very low Cr# (=0.22-0.23) and TiO2 content is 0.13-0.17 wt%. Except for a few sulfide inclusions, the chromites are totally free of hydrous and silicate inclusions which are reportedly common in podiform chromitites. The euhedral sulfide inclusions (<10 um in size) occur away from cracks or lamella within the chromites and are believed to be primary in occurrence. Hydrous and silicate phases and rutile have been noted as mineral inclusions within the chromites in the East Pacific Rise and Mid-Atlantic Ridge podiform chromitites (Arai and Matsukage, 1998; Abe, 2011). This work reports for the first time the occurrence of sulfide inclusions within chromites in podiform chromitites in the abyssal setting. These sulfide inclusions possibly represent the melt responsible for chromite crystallization and may provide important information on the mechanisms for the formation of podiform chromitites in the current oceanic floor.

Keywords: sulfide, inclusion, chromite, podiform chromitites, abyssal

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A plagioclase fabric database: Characterization of CPO and seismic properties in the oceanic lower crust

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This study presents a unique database of almost 200 plagioclase Crystallographic Preferred Orientations (CPOs) of variously deformed gabbroic rocks. Plagioclase is the dominant mineral phase in most of the studied samples. The CPOs characteristics as a function of deformation regime (magmatic and crystal-plastic) are outlined and discussed. CPOs of principal mineral phases are also used to calculate the seismic properties of variously deformed gabbroic rocks from the oceanic lithosphere. The studied samples are from slow- and fast-spread present-day ocean crust, as well as ophiolites. Plagioclase CPO is grouped in three main categories: type B is a strong alignment of (010) with a girdle distribution of [100], type A is a strong point maximum concentration of [100] with parallel girdle distributions of (010) and (001), and type P is point maxima of [100], (010), and (001). A majority of CPO patterns are type B as well as type P, in which both magmatic and crystal-plastic deformation textures occur. Type A CPOs are less common; they represent 24 % of the samples deformed by crystal-plastic flow. Calculated seismic properties (P-wave and S-wave velocities and anisotropies) show that anisotropy (up to 10% for P-wave and 15% for S-wave) tends to increase as a function of fabric strength. Despite of a large variation of fabric patterns and geodynamic setting, seismic properties of plagioclase-rich rocks have similar anisotropies in magnitude. The J-index does not show any consistent variation as a function of the CPO patterns. However, the [100] concentration has an influence on the seismic anisotropies in crystal-plastic deformed samples, whereas the (010) plane alignment has a strong influence on seismic anisotropies in samples deformed by magmatic flow.

Keywords: plagioclase, fabric, seismic anisotropy, oceanic crust, lower crust, gabbro

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Differentiation processes of Shatsky Rise magmas, NE Pacific plate: constraints from clinopyroxene chemistry

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Shatsky Rise is the large igneous provinces on the northwestern Pacific Plate. Previous geophysical and geochemical studies suggest two hypotheses about Shatsky Rise formation. One is mantle plume head model, the other is decompression melting model. Shatsky Rise formed at the Pacific-Izanagi-Farallon triple junction during the latest Jurassic to Early Cretaceous. Although some geological studies of lavas have attempted to explain the origin of Shatsky Rise (e.g. Mahoney et. al., 2005), we do not still have the answer about this question because the lavas are obtained from limited sampling sites, and are covered with thick pelagic sediments.

IODP Expedition 324 cruise was carried out by the research vessel, JOIDES Resolution in 2009, at Tamu , Ori and Shirshov massifs of Shatsky Rise. In this study, clinopyroxene phenocrysts of obtained massive, pillow and subaerial lavas are analyzed by electron microprobe analysis. It would be possible to discuss about the origin of Shatsky Rise based on the trend of magma differentiation in clinopyroxene phenocrysts.

Phenocryst compositions of clinopyroxene from Tamu Massif show the data along the MORB trend. The compositions from Ori Massif, on the other hands, plot the data along the trend of OIB-tholeiite. The magma source of Shatsky Rise, therefore, changed from MORB-like to OIB-like materials during the passage of a mantle plume and the Pacific Plate beneath Shatsky Rise. Thus, it is difficult to explain that Shatsky Rise occurs from single origin in the mantle.

This research was supported by IODP After Cruise Research Program, JAMSTEC.

Keywords: Shatsky Rise, LIPs, Pacific Plate, clinopyroxene, tholeiite

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Microstructural analysis of peridotites obtained from the Izu-Ogasawara forearc region

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Forearc locates a frontal side of volcanic front in an island arc, where provides a key information for the initiation of magmatic and subduction process in island arc formation. However, there are a few studies discussed geological interpretations of the upper mantle structure in the forearc region, although there are many studies for understanding the evolution of crustal structures of the island arc. Here, we report microstructural results of five harzburgites sampled from the landward slope of the Izu-Ogasawara Trench (dredge site KH07-02-D31 and dive site KR08-07-7K417). Morishita et al. (2011) have already reported a major and trace element compositions of the harzburgite samples in this study; they show high forsterite (91.7-92.1) and NiO (0.4 wt%) contents of olivine, high Cr# [Cr/(Cr + Al) atomic ratio; 0.65-0.73] of spinel and low Al2O3 ($<$1.5 wt%), Na2O ($<$0.04 wt%) contents of pyroxene, suggesting a refractory origin. The harzburgites are characterized by coarse granular textures consisting of coarse olivine grains and elongated orthopyroxene grains. The olivine and orthopyroxene grains show intracrystalline deformations such as wavy extinction. Crystallographic preferred orientations (CPOs) of olivine show mainly a [100](001) pattern, which has a strong alignment of [100] axis to the lineation and [001]-axis concentration perpendicular to the foliation. All olivine CPOs studied have much higher intensities than those of Mariana forearc region (e.g. Michibayashi et al., 2007). The CPOs of orthopyroxene shows a [001](100) pattern with [001] parallel to the lineation and (100) normal to foliation. Since these harzburgite samples are refractory origin associated with boninitic melting during initiation of subduction (e.g. Morishita et al., 2011), their deformation characteristics could be possibly related to the initiation of subduction in the Izu-Ogaswara forearc region.

Keywords: harzburgite, olivine, orthopyroxene, crystallographic preferred orientation, Izu-Ogasawara forearc region

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Fabric and petrological characteristics of peridotiites derived from Mariana serpentinite seamounts

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Serpentinite seamounts are unique seamounts that have only been in the Izu-Bonin-Mariana arc. The Pan-lid seamount is located at the northernmost Mariana arc, whereas the Deep Blue seamount is located at southernmost part. This study envestigated serpentinized peridotites derived from the eight seamounts (Pan-lid, Conical, Packman, Twin peaks, Big Blue, Celestial, South Chamorro, Deep Blue seamounts). Samples from these seamounts are mantle-derived peridotite. These samples were analyzed by EBSD and EPMA. As a result, olivine crystal preferred orientations (CPOs) were divided into three types: A-type AG-type and D-type. The northern seamounts are characterized by A-type and/or AG-type, whereas the southern seamounts consist dominantly of D-type. Only South Chamorro seamount has both AG-type and D-type. The compositions (Cr#-Mg#) of spinel vary among the seamounts. Only Cr# of spinel in South Chamorro and Deep Blue Seamounts exceeded value of 0.6. But no clear relationship between partial melting process and CPO development has been found. These suggest that the northern Mariana arc have a complex and heterogeneous structure.

Keywords: peridotite, Mariana Trench, Serpentinite seamount

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Fluid migration and boninite formation in incipient subarc mantle inferred from dunites in the Oman ophiolite

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The Oman ophiolite has experienced a flux melting of residual peridotites during oceanic thrusting subsequent to the formation at Neo-Tethys mid-ocean ridge. We studied spatial variability of spinel Cr# (=Cr/[Cr+Al]x100 mol%) and REE abundances of clinopyroxene in dunites from the Fizh mantle section, the northern Oman ophiolite. These data are used to understand fluid infiltration from the base of ophiolite and flux melting of residual harzburgite during oceanic thrusting.

Rock texture of dunite in the Fizh block is classified into six subgroup such as very-coarse granular, coarse granular, fine granular, planer, porphyroclastic and mylonitic textures. Rock texture of dunite is similar to the wallrock harzburgite in the upper half of Fizh mantle section. However, in the lower half of Fizh mantle section dunite becomes very coarse granular with olivine grain size greater than 1 cm although porphyroclastic or mylonitic textures is common in wallrock harzburgite.

Spinel Cr# in dunites from the Fizh mantle section varies from 45 to 80 and is the most frequent in 65-70 while spinel Cr# in harzburgites is the most frequent in 55-60 that is lower than that for dunite. Moreover, harzburgites with spinel Cr# greater than 70 is limited in the highly refractory zone located in the nothern Fizh mantle section while dunites with Cr# greater than 70 distribute over much wider area. In the area where dunite has low Cr# spinel less than 60 wallrock harzburgite tends to have spinel Cr# lower than 40.

Chondrite-normalized REE patterns of clinopyroxene in dunites are variable especially in LREE. Chondrite-normalized patterns of hypothetical melts in equilibrium with clinopyroxenes in dunites from the basal part show spoon-like shape with depletion in MREE relative to HREE and enrichment in LREE relative to MREE. Chondrite-normalized patterns of such melts are similar to those of boninites from the Fizh crustal section although some melts are more depleted in LREE to MREE relative to the boninite.

Spinel Cr# within a thick dunite layer (5 m thick) is the highest in the center (Cr# 71). Fluid flow and reaction may have been enhanced in the center by higher porosity resulted in the high Cr# spinel and formation of thick dunite. Because abundance of REE in clinopyroxene is uniform over dunite and wallrock harzburgite the migration of fluid and melt was comprehensive along with focused flow in the center of dunite layer.

High Cr# spinel frequently occur in harzburgite and dunite in the northern Fizh mantle section indicating that large volume of fluid flew through dunite and caused flux melting of wallrock harzburgite. Dunites with low Cr# spinel also occur in the northern Fizh mantle section indicating that fluid flux was limited in this region. In the southern Fizh mantle section dunite tends to have high Cr# spinel while harzburgite has spinel Cr# around 60 indicating fluid flux was low so that the extent of flux melting of wallrock harzburgite was limited.

The basal part of the Fizh mantle section is characterized by high Cr# spinel greater than 60 that is similar to subarc mantle, by dunites with very coarse granular texture, by dunite clinopyroxenes enriched in LREE. We consider that the dunites in the Fizh mantle section was reacted with boninitic melt formed by flux melting of harzburgites with addition of fluid from the base due to thermal metamorphism of altered oceanic crust during oceanic thrusting of the ophiolite. Variability in REE patterns for dunite clinopyroxene requires addition of fluid as much as 8% and as low as 0.1% being variable depending on the region. These results indicate that the fluid infiltration from the base of ophiolite and migration of boninitic melt after flux melting of harzburgite was not uniform over the Fizh mantle section. Reactive infiltration instability may have developed regional variability in porosity in the Fizh mantle section forming finger-like shape of fluid and melt migration.

Keywords: Oman ophioilte, mantle section, dunite, mid-ocean ridge, subduction zone, spinel