Japan Geoscience Union Meeting 2013
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SIT05-01 Room:104 Time:May 21 09:00-09:15

Diversity of MORB genesis within the uppermost mantle: an example from the northern Oman ophiolite

Norikatsu Akizawa[1], Shoji Arai[1*], Akihiro Tamura[1], Kazuhito Ozawa[2]

[1]Earth Sciences, Kanazawa Univ., [2]Earth and Planetary Science

Dunite bands and veins in the ophiolitic mantle peridotite are interpreted as fossil melt conduits within the suboceanic mantle. In particular, concordant dunite bands are possibly important as the 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 conducted sampling of concordant dunite bands and its aureole from various "stratigraphic levels" in the mantle section from an estimated ancient-segment center and its end in the northern Oman ophiolite. They are various both in thickness (few millimeters to few meters) and in frequency of appearance. Dunite bands are almost pyroxene-free, and their orthopyroxenes, if any, are vermicular in shape.

Mineral chemistry shows systematic variations in the wall peridotites toward the dunite bands: (1) a decrease in Fo content (92 to 90.5) of olivines, (2) an increase in 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 Na2O content (almost nil to 0.2 wt%) of clinopyroxene. In ambient residual peridotites, rare earth element (REE) patterns of clinopyroxene incline from light-REE (LREE) to heavy-REE (HREE) monotonously. The REE pattern of clinopyroxene in dunites and surrounding peridotites show various shapes, depending on the position, the segment center to end: gentle slope from HREE to LREE at the segment center, and U-shaped at the segment end.

We conducted calculation for REE enrichment in clinopyroxenes by using 1-D steady state modeling, which duplicates simple fractional melting process and influx melting process. The results indicate that LREE-enriched melts (E-MORB-like) and LREE-depleted MORB melts (N-MORB-like) were involved in formation of the present-day concordant dunite bands within the Oman mantle with various ratios of LREE-enriched melt/LREE-depleted melt; LREE-enriched melt/LREE-depleted melt ratios are high at the segment center, and they are low at the segment end. The primitive MORB melts have possibly changed to MORB through interaction with peridotites en route to the uppermost mantle, however the interaction degrees between the segment center and the segment end were different. The difference was caused by variation of temperature profile through the Mid-ocean ridge.

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

SIT05-02 Room:104 Time:May 21 09:15-09:30

Paleogeodynamic setting of the Andaman ophiolite

Biswajit Ghosh[1*], Tomoaki Morishita[2]

[1]Calcutta University, [2]Kanazawa University

Dismembered bodies of Cretaceous ophiolite slices occur in the eastern part of the Andaman Island and continues further south in the Rutland Island. The mantle tectonites of this ophiolite suite are represented by a broad spectrum of variably depleted peridotitic rocks that hosts impersistently developed podiform chromite and records a systematic variation from north to south. The restitic peridotite in middle- and north-Andaman mostly belongs to less-depleted, lherzolite dominated mantle that occasionally grades to clinopyroxene bearing harzburgite with development of thin layers and lenses of olivine-rich dunitic pods showing features of melt-rock interaction and irregular margins with the harzburgite. On the contrary, the mantle sequence in Rutland Island is characterized by depleted harzburgite to clinopyroxene-bearing harzburgite.

The chemistry of the disseminated residual chrome-spinels suggests that the mantle peridotites in the Rutland Island towards south are akin to arc peridotites of suprasubduction zone whereas those of north-Andaman are akin to less depleted peridotites. The massive chromitites of Andaman Island show bimodal distribution of Cr2O3 content. The high-Cr pods (54-60 wt.% Cr2O3) are documented from north-Andaman as well as in Rutland Island whereas the low-Cr pods (39-42 wt.% Cr2O3) are restricted only to north-Andaman. The coexistence of both the types of chromitites, high- and low-Cr in the same area from north-Andaman possibly reflects the spatial and/or temporal variations of separate melt intrusions produced through specific melting stages and emplaced in different sub-arc mantle domains during the opening of a back-arc basin in a suprasubduction zone environment. In the late Mesozoic, therefore, a replica of the present day geodynamic features with an arc-back arc setting existed along the eastern periphery of the Indian subcontinent and we infer that an arc setting of that paleogeodynamic configuration occurred towards south which might have gradually shifted away from the trench towards north and gave rise the back arc setting. This behavioural change in subduction kinematics may have a direct link with the rotation of the plates in response to oblique subduction in the Andaman region. Therefore, this directional change in chrome-spinel composition may reflect the spatial and/or temporal variations linked to the melting history where the same sliver of oceanic mantle underwent different styles of melting in different tectonic settings at different points in time.

Keywords: Andaman Ophiolite, Chromitite, Mantle, Geodynamic setting

SIT05-03 Room:104 Time:May 21 09:30-09:45

Magma system along fast-spreading ridges: Evidence from the northern Oman Ophiolite

Sumio Miyashita[1*], Yoshiko Adachi[1], Yutaka Nogawa[1], Ryu Kaneko[1], TOMATSU, Takashi[1], HASHIMOYO, Teruhisa[1]

[1]Niigata University

Ocean ridges are segmented into various scales with a hierarchy, from the biggest 1st-order to the smallest 4th-order segments. These segment structures control magmatic processes beneath ocean ridges in respect to upwelling mantle, partial melting, and magma delivery system. However, systematic studies on the segment control for the magmatic processes are few at present ocean ridges due to difficulty to obtain samples from different depths. Therefore, studies of ocean ridge segmentation in ophiolites would bring significant information to understand magmatic processes beneath ocean ridges. Because, precise 3-D architectures from mantle to the uppermost extrusive layer and their lateral variations would be determined in ophiolites. We have studied northern Oman ophiolite where a complete succession from mantle peridotite to the uppermost extrusives is well exposed. Miyashita et al. (2003), Adachi and Miyashita (2003) and Umino et al. (2003) proposed a segment structure in the northern Oman ophiolite; Wadi Fizh area is regarded as northward propagating tip of ridges based on geological lines of evidence (Adachi and Miyashita. 2003). On the other hand, Wadi Thuqbah area, about 25 km south to Wadi Fizh, is regarded as a segment center based on the thickest Moho transition zone, well developed EW-trending lineations in the MTZ and layered gabbro and comparatively primitive compositions of layered gabbros. Furthermore, the southern margin of the Hilti block, about 40 km south to Wadi Thuqbah, is assumed to be the segment end, based on a regional compositional variation of sheeted dike complex (Miyashita et al., 2003).

The bulk rock compositions of sheeted dike complex show systematic variations along the ridge segment; both highly evolved and less-evolved compositions appear at northern and southern segment margins, respectively, while narrow and uniform mildly evolved compositions appear at the segment center. This is interpreted by that larger and more persistent melt lenses at the segment center but much smaller and more transient melt lenses at the segment margins due to a difference of thermal conditions. At the larger and more persistent melt lenses, multiple magma mixings suppress advance of fractional crystallization and resulted in comparatively uniform mildly evolved melts. On the contrary, at the smaller and transient melt lenses at the segment margins, more intensive fractional crystallization resulted in highly evolved melts due to cooler conditions. On the other hand, primitive melts without stagnant in the melt lenses may extrude at the segment margin because of absence of the melt lenses. Thus, both evolved and primitive melts may be produced at the segment ends.

We have also examined along axis variations of the mantle-crust transition zone (MTZ) in the northern Oman ophiolite. Systematic variations of thickness of the MTZ are apparent; very thin at the segment margin (ca. 10 m), intermediate at the intermediate locations (ca. a few tens m) and thick MTZ at the center (ca. 250-300 m). Also mode of occurrence just beneath the MTZ is variable depending the location in the segment architecture. Abundant gabbroic pods and veins are found in the harzburgites just beneath the MTZ at the segment margins, but they are very few at the segment center. These lines of evidence show that the melt extraction from the upper mantle to the crust is more efficient at the segment center. On the contrary, melt extraction is inefficient at the segment margins, resulting in stagnant and crystallization of melts in the upper mantle at the segment ends.

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Keywords: oceanic crust, magmatism, MORB, ocean ridge segmentation, Oman ophiolite

SIT05-04 Room:104 Time:May 21 09:45-10:00

AMS fabrics and emplacement processes of sheeted dikes in IODP Hole 1256D

Ryo Anma[1]*, Eugenio E. Veloso[2], Toshitsugu Yamazaki[3]

[1]Faculty of Life and Environmental Sciences, University of Tsukuba, [2]Universidad Catolica del Norte, [3]Atmosphere and Ocean Research Institute, The University of Tokyo

IODP Hole 1256D in the equatorial East Pacific off Panama is located on the C5Br and C5Bn.2n magnetic boundary (~15.16 Ma), The crust at the site formed under a super-fast spread condition with full spread rate of 22 cm/y. The hole penetrated basalts and sheeted dike complex of an intact oceanic crust and reached to two sheets or lenticular gabbroic layers of several 10 meter-thick. Dolerite rocks around the gabbros are metamorphosed to form a granoblastic textures with opx mineralization. The hole supposedly nearly reached to the upper boundary of the third layer of the oceanic crust. Zircon separated from the gabbros yielded weighted mean U-Pb ages of 15.0~15.2 Ma. The upper volcanic and doleritic rocks have reversed magnetic polarity, whereas the lower granoblastic dikes and gabbros have normal polarity. Because the hole 1256D was inclined ~5 degree to west from the vertical, the hole may have penetrated the boundary between C5Br and C5Bn.2n crust as the hole was deepened. Otherwise, the intrusion of the gabbros at later stage may have modified the original magnetic structure.

Magnetic properties indicate that the main ferromagnetic minerals are mostly pseudo-single domain (titano)magnetite crystals and that these are responsible for both anisotropy of magnetic susceptibility (AMS) and magnetic remanence signals. Measured AMS fabrics were reoriented into a geographic reference frame using magnetic remanence data, and corrected for a counterclockwise rotation of the Cocos Plate relative to the East Pacific Rise (EPR) ca. 15 Ma. Corrected AMS fabrics were then compared with the orientations of chilled margins previously obtained from Formation MicroScanner (FMS) images of the SDC at Hole 1256D. Samples from dike margins tend to have dike-normal Kmin, horizontal Kmax parallel to the dike planes and prolate AMS ellipsoids implying that the Kmax can be used to infer melt flow directions. The horizontal Kmax direction implies that the flow potentially delivered melts to the surface far from robust melt-source regions within the EPR system. Subvertical Kmin orientations in the interior of the dikes, however, may have required settling or compaction of the magma shortly after intrusion, thus rearranging the AMS fabric.

Keywords: sheeted dike complex, fast-spread-rate crust, AMS, emplacement processes

SIT05-05 Room:104 Time:May 21 10:00-10:15

Petrology and petrogenesis of felsic rocks in the Oman ophiolite, Oman

Nobutaka Tsuchiya[1*], Kazufumi Nakamura[1], Takaaki Umetsu[1], Jun Sasaki[1], Yoshiko Adachi[2], Sumio Miyashita[2]

[1]Department of Geology, Iwate University, [2]Niigata University

The Oman ophiolite is a sliver of the Neo-Tethys oceanic lithosphere obducted onto the Arabian plate during the late Cretaceous time. Lippard et al. (1986) classified the felsic rocks in the Oman ophiolite into three stages; high-level intrusive rocks of axis stage, late stage intrusive rocks, and younger biotite granites associated with emplacement stage. Rollinson (2009) described similar classification of the felsic rocks in the Oman ophiolite, and discussed petrogenesis of these felsic rocks.

The 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 in Wadi Rajimi, Wadi Khabiyat, and eastern margin of the Lasail complex. The base of the 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). They describes disequilibrium melting models to explain relatively lower REE concentrations in axis stage felsic rocks. 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.

Lasail plutonic complex (4.7 x 3.8 km), as a typical example of late stage intrusive rocks, is located to the south of Wadi Jizi, and intrudes into the base of V1 volcanic rocks and sheeted dike complex. The Lasail plutonic complex consists of various rock types ranging from ultramafic cumulates to tonalite, and is associated with minor amounts of axis stage gabbro to quartz diorite. Petrochemical evidence suggests that the massive gabbro 2 was formed by the partial melting of residual MORB mantle which is contaminated with slab melt derived from the axis stage rocks interacted with seawater. In addition, petrogenesis of felsic rocks in the Lasail complex can be explained by the partial melting model of pre-existing layered gabbro.

Small intrusive bodies of young biotite granites and tourmaline leucogranites are intruded into harzburgite in the upper part of the mantle sequence at the west of Zaymi, upper stream of the Wadi Fizh. Chemical compositions indicate the analysed granitic rocks were largely minimum melts that crystallised at variable aH_2O and pressures around 2 to 4 kbar. Petrochemical modelling suggests that the granitoids formed largely by the dehydration melting of muscovite rich metasediments of ophiolitic metamorphic sole similar to the model of Cox et al. (1999).

U-Pb zircon ages analyzed by LA-ICPMS are 100 +/- 2 and 99 +/- 2 Ma for late stage tonalite and 100 +/- 1 Ma for axis stage quartz diorite (Tsuchiya et al., 2013). These ages are slightly older than the ages reported for felsic rocks in the Oman ophiolite (ca., 95 Ma; Tilton et al., 1981; Warren et al., 2005), and suggest that the conversion from ridge stage to detachment stage took place rapidly. If two diverging plates moved from divergent hemisphere to convergent hemisphere, divergent boundary (ridge) switches to convergent boundary (detachment or subduction) in a short time span, and very rapid change from divergent to convergent plate boundary may occur (Niitsuma, 2010). The Oman ophiolite may be a rare example of rapid conversion from divergent hemisphere to convergent hemisphere.

Keywords: Oman ophiolite, plagiogranite, axis stage, late stage, emplacement stage, petrochemistry

SIT05-06 Room:104 Time:May 21 10:15-10:30

Hess Deep Plutonic Crust, Expedition 345

Jonathan Snow[1*], Kathryn Gillis[2], Adam Klaus[3], Shipboard Scientific Party IODP Expedition 345[4]

[1]Univ. Houston, [2]Univ. Victoria, B.C., [3]Texas A&M Univ., [4]IODP Expedition 345

Since Project MOHOLE in the 1960's, drilling studies of the oceanic crust have had the objective of understanding the processes by which the ocean crust is constructed through magmatism, deformation, metamorphism and hydrothermal cooling. Currently, much attention is focused on understanding the nature and genesis of the relatively inaccessible fast spreading lower ocean crust (Hole 1256D, Hole 894G, this study). Two major end-member models for fast-spreading lower ocean crustal accretion are recognized, the gabbro glacier model (GGM) and the sheeted sill model (SSM). The GGM predicts that most crystallization occurs within a shallow melt lens and the resulting crystal mush subsides downwards and outwards by crystal sliding, followed by largely conductive cooling. The SSM predicts magmatic injection at many levels in the crust, and requires rapid cooling of the lithosphere in order to satisfy physical constraints of heat removal from the lower crust. These two models currently cannot be definitively distinguished given the available observations. What is needed is a test of the two main model predictions against igneous, metamorphic and structural observables from near in-situ lower crust.

This undertaking has followed two main strategies: total crustal penetration (e.g. project MOHOLE) and offset drilling, which involves drilling shallow holes in tectonic windows to produce a composite section Such tectonic windows are common in crust produced at slow spreading rates but are rare at faster spreading rates. Here we report preliminary results of the ongoing Expedition 345 of the International Ocean Drilling Program to the Hess Deep Rift in the Eastern Pacific Ocean. At the Hess Deep Rift, propagation of the Cocos Nazca Ridge (CNR) into young, fast-spreading East Pacific Rise (EPR) crust exposes a dismembered, but nearly complete lower crustal section, with extensive exposures of the plutonic crust. The drilling was carried out in ~4850 m water depth under quite challenging borehole conditions. We recovered primitive (Mg-number 75-89) plutonic lithologies including gabbro, troctolitic gabbro and olivine gabbronorite. These rocks exhibit cumulate textures similar to those found in layered basic intrusions and some ophiolite complexes. Details of their mineralogic and petrologic evolution, however, are novel on the ocean floor. Additionally, they were deformed primarily under magmatic conditions at the EPR. The abundant evidence for hypersolidus plastic deformation in a crystal mush suggests that substantial amounts of the overall deformation occurred under plastic, partially molten conditions. After that, relatively little sub-solidus crystal plastic deformation took place. Metamorphism is dominated by background sub-greenschist facies alteration (including prehnite and chlorite) associated with late stage cataclastic deformation. Widespread amphibolite facies metamorphism that might be indicative of pervasive high-temperature hydrothermal cooling of the lower crust was not observed. Tremolite-chlorite coronas around olivine represent most of the high-temperature metamorphism. These observations raise the question how, exactly, the deformation associated with plate separation is accommodated in the oceanic lower crust.

Keywords: Fast spreading Ridge, Hess Deep, IODP, Oceanic Plate, Lower Crust

SIT05-07 Room:104 Time:May 21 11:00-11:15

High-Ti picrite from the Lalibella area, Ethiopian LIP

Akira Ishiwatari[1*], Dereje Ayalew[2], Minyahl Teferi Desta[1]

[1]CNEAS, Tohoku University, [2]Addis Ababa University, Ethiopia

Through the one million years of time span around 30 Ma in Oligocene, a vast extent of flood basalt lavas erupted in the Ethiopian plateau with regional uplift. Some rhyolite lavas and pyroclastic flows erupted and large basaltic shield volcanoes formed in the later stage, and the Ethiopian LIP was completed. From Miocene to the present, the volcanism is restricted in the narrow rift zones and the Afar triangle where continental rifting is taking place. The flood basalts to the west of the rift zone are divided into two series; western (inland) low-Ti series and eastern (near rift) high-Ti series, though they are simultaneously formed. Picrite is rare in this LIP (Beccaluva et al. 2009; J. Petrol.; Rogers et al. 2010; EPSL), but is found along the Dilb Road section of the Lalibela area as some lava flows alternated with the high-Ti basalt lavas. The Lalibela Ethiopian Orthodox (Copt) Church that is registered as a world heritage site is an in-situ carving of a picrite lava. Picrite is an important target of igneous petrology as the most primitive mantle-origin magma or its olivine accumulation. We analyzed 3 picrite samples that are collected in the Lalibela area. Olivine phenocrysts are Fo77.7-88.4 and the Mg-rich crystals contain 0.3-0.4 wt% NiO. Clinopyroxene phenocrysts are Mg#72-88 and contain 0.8-2.9 wt% TiO2. Spinel inclusions and microphenocrysts are Cr#79-84, Mg#18-51, Fe3+#11-26, and contain 3.6-7.0 wt% TiO2. Plagioclase is around An60. Ilmenite also occurs. Maximum Fo value of olivine (88-89) indicates a primitive nature of the magma that can coexist with mantle peridotite. Most characteristic feature of the mineral chemistry is the high Cr# of spinel (>80). The Sorachi-Yezo picrite (Ichiyama et al. 2012; Geology) bears spinels with Cr#44-67, and the Mino-Tamba picrite/basalt (Ichiyama et al. 2006; Lithos; Koizumi and Ishiwatari, 2006; Isl. Arc) also bears spinels with Cr#58-67. These picrites are thought to be originated in oceanic LIPs. It is well known that continental layered intrusions that originated in continental LIPs bear high Cr# spinels. Although high-Ti series magmas occur in both oceanic and continental LIPs, the high Cr# spinels of the Ethiopian picrites indicate their continental signature, and give suggestions for the origin of the subcontinental mantle.

Keywords: picrite, flood basalt, high-Cr spinel, subcontinental mantle, continental rifting, oceanic crust formation

SIT05-08 Room:104 Time:May 21 11:15-11:30

Possible lateral variation of seismic anisotropies in the oceanic lithosphere due to an active mantle flow

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

[1]Department of Geosciences, Faculty of Science, Shizuoka University

Crystal-preferred orientation (CPO) is a common feature of peridotites and is developed during intense homogeneous plastic deformation of peridotitic minerals with a dominant slip system. Whereas an olivine CPO classification (A, B, C, D and E types) has been proposed by Karato and co-workers to illustrate the roles of stress and water content as controlling factors of olivine slip systems (e.g., Karato et al., 2008 Annu. Rev. Earth Planet. Sci.), an additional CPO type (AG) has also been proposed in recognition of its common occurrence in nature (Mainprice, 2007 Treatise on Geophysics). AG-type has been experimentally formed in sheared partially-molten samples, in which a-axes of olivine grains are aligned predominantly normal to the shear direction, rather than parallel to it (Kohlstedt & Holtzman, 2008 Annu. Rev. Earth Planet. Sci.). Thus, we can expect the development of AG-type olivine fabrics to be related to the occurrence of melt during deformation, most likely in the vicinity of mid-ocean ridges, where strong upflow is related to active mantle ascent (Nicolas et al., 2000 Marine Geophysical Researches; Michibayashi et al., 2000 MGR). Results from our analysis of peridotites from the Hilti mantle section of the Oman ophiolite show that olivine in that section is dominated more commonly by AG-Type than A-type CPO. This section preserves subhorizontal uppermost mantle lithosphere (Michibayashi & Mainprice, 2004 Jour. Petrology; Onoue & Michibayashi, 2013 JpGU abstract). Since olivine contains intrinsic elastic anisotropies, the development of CPO within peridotite during plastic deformation at mid-ocean ridges gives rise to seismic anisotropy in the upper mantle. Seismic properties of AG-type olivine fabrics reveal that whereas Vp velocity is maximum parallel to the flow direction (X) and minimum normal to the flow plane (Z), the intermediate direction (Y) has relatively higher Vp velocity than the median velocity. This feature of AG-type fabric is different from that of A-type, which occurs commonly under melt-free conditions, resulting in the different degrees of seismic anisotropies between AG-type and A-type. Thus, we propose, based on our results for the Oman ophiolite, that the intensity distribution of seismic anisotropy in the uppermost mantle could vary laterally depending on various strength of mantle ascent along a given segment of mid-ocean ridges in conjunction with various degree of melt impregnation.

Keywords: Olivine farics, Seismic anisotropy, melt, segment center, mid-ocean ridge

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MoHole to Mantle: Project M2M

Susumu Umino[1*], Scientific Party M2M[2]

[1]Department of Earth Sciences, Kanazawa University, [2]International MoHole Science Group

Sampling a complete section of crust and shallow mantle was the original motivation for scientific ocean drilling, since ”Project Mohole (1958-1966)”. With development of the Japanese riser-drilling vessel Chikyu, the aspirations of generations of Earth scientists to drill completely through the oceanic crust, and through the Moho into the upper mantle, have moved into the realm of technical feasibility.

Although only 20% of modern mid-ocean ridges are fast-spreading (>80 mm/yr), more than 50% of the present day seafloor (~30% of Earth’s surface), and the great majority of crust subducted into the mantle during the past 200 M.yr was produced at fast spreading ridges. As a plate moves away from the ridge, seawater entering through fractures deep into the crust and the uppermost mantle is heated to become reactive hydrothermal fluid that hydrates and exchanges materials with the rocks and returns to the ocean. While being altered by hydrothermal fluids, the crust and mantle become extensive habitats for microorganisms. Water recycled into the mantle by the subduction of hydrated plate reduces the mantle viscosity and melting temperature, allowing continuous mantle convection and plate tectonics, providing the key reason why Earth is different from the other terrestrial planets in the solar system (e.g. Venus), and is a key ingredient for the formation of arcs and continents.

Because of the relatively uniform architecture of fast-spreading plates, understanding of mantle and crust genesis and evolution at one site can be extrapolated to a significant portion of Earth’s surface with some confidence. Importantly, we have well developed theoretical models of contrasting styles of magmatic accretion at intermediate to fast-spreading ridges, which can be tested using samples recovered from cored sections of ocean basement. Therefore, the goal of the currently proposed project ”MoHole to Mantle (M2M)” is to sample, as continuously as feasible, the entire crust, Moho and shallow mantle peridotites, in oceanic crust and mantle formed at a fast-spreading rate. Drilled cores will be used to test models of crustal accretion and melt movement, to resolve the geometry and intensity of hydrothermal circulation, and to document the limits and activity of the deep microbial biosphere. After completion of drilling, coring, and logging, the MoHole will be used for experiments, including vertical seismic profiles, and long-term geophysical and microbiological monitoring. Instrumenting the MoHole will eventually be a key, last-stage goal. Hence, the sub-sea equipment and borehole should be constructed to accommodate observatory science (e.g., fluid monitoring, and microbiology incubation experiments).

Based on the scientific requirements and technological constraints, three regions have been identified as potential MoHole project areas: 1) Cocos Plate; 2) Off Southern and Baja California (including the original site of project Mohole); and, 3) North of Hawaii.

Keywords: IODP, MoHole, mantle drilling, Moho, oceanic lithosphere, Chikyu

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Paradise Lost: Interpreting peridotites from oceanic ridges

Peter Kelemen[1*]

[1]Lamont-Doherty Earth Observatory, Columbia University

Summary: In many ways, polybaric decompression melting, focused melt transport and accretion of igneous crust at oceanic spreading ridges is the simplest and best understood igneous process on Earth. However, in this presentation we focus on remaining - in some cases, increasing - uncertainties in understanding melting and melt transport beneath oceanic spreading ridges from the perspective of studies of residual mantle peridotites.

Degree of melting & potential temperature: Reaction of cooling melt with shallow peridotite can reset indicators of degree of melting and potential temperature in both melt and residual peridotite. Yb concentration and spinel Cr# in peridotite are affected by (a) small scale variations in reactive melt transport, (b) variable extents of melt extraction, and (c) *impregnation*, i.e. partial crystallization of cooling melt in pore space. Comparison of abyssal peridotite bulk compositions to residual trends indicate that roughly 3/4 of abyssal peridotites have undergone major element refertilization. Also, many peridotites at ridges may have undergone several extensive partial melting events over Earth history, while others could be residues of extensive melt extraction from mafic heterogeneities in the mantle source. For all of these reasons, estimates of the *degree of melting* based on peridotite compositions should be viewed with increasing skepticism.

Melt focusing to ridges: Dissolution channels (dunites) within residual peridotite are predicted to coalesce downstream, but so far numerical models have not produced sufficient focusing to explain why $>$ 95% of oceanic crustal accretion takes place in a zone $<$ 5 km wide. Modeled crystallization of cooling melt in the shallow mantle can create a permeability barrier guiding underlying melt diagonally toward the ridge, but field studies have not identified such barriers. Permeable *shear bands* may guide melt to the ridge, but the nature of shear bands in open systems at natural grain size and strain rates is uncertain. 2D and 3D focused solid upwelling due to melt buoyancy and weakening as a function of permeability - especially increasing permeability with decreasing pyroxene content during melting - may warrant more attention.

Crustal thickness, spreading rate & melt productivity: The following three statements are inconsistent: (1) Modelled peridotite melt productivity beyond cpx exhaustion is $>$ 0.11%/GPa. (2) Crustal thickness is independent of spreading rate. (3) Thermal models predict, and observations confirm, thick thermal boundary layers beneath slow spreading ridges. Most sampled peridotites from ridges melted beyond cpx-out. Cpx in these rocks formed via impregnation and/or exsolution during cooling. When abyssal peridotite data are filtered to remove refertilized samples, and pyroxene compositions are recalcalated at ˜ 1300 C, more than half contain no residual clinopyroxene. Thus, most or maybe all abyssal peridotites undergo cpx exhaustion during polybaric decompression melting. If (a) melt productivity is $<<$ 0.1%/GPa beyond cpx-out, and (b) cpx-out occurs $>$ 15 km below the seafloor beneath most ridges, then the independence of crustal thickness with spreading rate can be understood.

Conduit generation and geometry: Dunites, formed by pyroxene dissolution in olivine-saturated melt ascending by porous flow, are conduits for focused porous flow of melt, preserving disequilbrium between melt and pyroxene in surrounding peridotite at P $<$ 1.5 GPa. Perturbations in permeability grow into dunite conduits because incongruent dissolution increases porosity and permeability. Perturbations may arise from *shear bands* and/or heterogeneities in the mantle source. Conduits may also involve mechanical instabilities, if it is easier to open a pore than to close it. Most models and experiments do not produce the power law distribution of dunites at a given depth observed in peridotites, except for some shear band experiments.

Keywords: Mid-Ocean Ridge, Melting, Melt migration, Peridotite, Clinopyroxene

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Cl-rich amphibole in the Shenglikou peridotite, N.Qaidam Mountain and its comparison with Cl-amphiboles in oceanic rocks

Kosuke Naemura[1*], Jianjun Yang[2]

[1]Department of Earth and Planetary Science, The University of Tokyo, [2]Institute of Geology and Geophysics, Chinese Academy of Science

The saline-rich fluid (brine) activity are considered as important components in the lower crust and upper mantle due to the following reasons:

(1)dehydration reaction in the slab released brine at sub-arc depth.
(2)brine can contain and transport abundant trace-elements.
(3)saline-rich fluid can be detectable by geophysical method (magnetotelluric).

The distribution of the intraplate earthquake suggests that hydrous minerals are formed in the subducting plate to the depth up to 100 km. However it has not been reconciled how to transport water to the depth of 50-100 km in the subducting plate. As a rare example of mantle rocks hydrated by seawater derived fluid in the mantle depth, we would like to introduce an occurrence of Cl-rich hydrous minerals in the Shenglikou peridotite, N.Qaidam mountains.

The Shenglikou peridotite predominantly consists of garnet lherzolite with minor layers of dunite and garnet-pyroxenite. In all the lithotypes, Cl-enriched hydrous minerals are observed as inclusions in high-pressure minerals.In garnet, two kinds of inclusions with different sizes have been identified, (i)a coarse-grained inclusion mainly consists of Cl-enrich ed Ti-pargasite, orthopyroxene, spinel and sodium gedrite, and (ii)a fine-grained one consists of Cl-rich Ti-poor hornblende, apatite, anthophyllite, talc, graphite and rare scapolite (maliarite). The coarse and fine-grained inclusions were formed under spinel-lherzolite facies and chlorite peridotite condition respectively, prior to the high-pressure metamorphism. The clinopyroxene also includes Cl-rich hornblende-tremolite, lizardite, +-chlorite+-brucite+-Ca-garnets(uvarovite,andladite)+-brucite which were formed by a low-T (<400 C) serpentinization. Subsequently, the Shenglikou peridotite experienced ultrahigh-pressure metamorphism that transformed Cl-enriched hydrous minerals into the high-P garnet peridotite assemblage consisting of garnet+clinopyroxene+orthopyroxene+-olivine+-chromite.The application of garnet-orthopyroxene geobarometer and two pyroxene thermometer of Taylor (1998) yields at 790 C/4.1 GPa (+-80/0.3).This garnet-bearing assemblage is affected by retrogression, which transformed garnet to Cl-poor Ti-pargasite (Cl<0.1 wt.%)+-spinel and clinopyroxene to Cl-poor tremolite. Above result indicates that the Shenglikou garnet peridotite was infiltrated by a saline-rich fluid prior to the Paleozoic UHP metamorphism, which is interpreted as follows in the context of regional geological history.

The northern Qaidam terrane was originally formed at the margin of Rodinia supercontinent, and the oceanic basin was formed as a result of continental breakup of the Rodinia at 800 Ma. Emplacement of the subcontinental peridotites onto the ocean floor, and the alteration by saline-rich fluid activity should have occurred during the rifting episode. Subsequently, ocean basin closed and continental collision occurred at early Paleozoic (460Ma), which brought the northern Qaidam rocks to >100 km depth during the UHP metamorphism. The Shenglikou rocks were transformed to garnet peridotite at this episode.

To constrain the origin of Cl-rich amphibole in the Shenglikou rocks, we compare it with amphibole data reported from oceanic gabbro/peridotite in the mid-ocean ridge/rift. It is possible to estimate the salinity by use of Cl contents in amphibole. It is shown that Cl contents in the Shenglikou Cl-rich pargasite and hornblende included in garnet are similar to those in pargasite from gabbros in the fast spreading ridges. It is well known that the high saline fluid activity (40 NaCl mol.%) occurred in the lower crust of fast spreading ridge, and the similar saline-rich fluid should have occurred in the mantle depth in the Shenglikou rocks.

These result suggests that the seawater derived brine could have penetrated into the mantle in some rift system, which offer a possible mechanism to transport water and to form hydrous minerals in the interior of the lithosphere.

Keywords: orogenic peridotite, Rodinia super continent, Qaidam craton, oceanic peridotite, hydrothermal alteration, brine

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SIT05-12 Room:104 Time:May 21 14:30-14:45

Thermal subduction-zone model including hydrothermal circulation in an aquifer that thickened toward the trench axis

Yoshifumi Kawada[1*], Makoto Yamano[1], Nobukazu Seama[2]

[1]ERI, Univ of Tokyo, [2]Kobe University

To clarify the mechanism of high-heat-flow anomalies observed at the Nankai Trough offshore of Muroto, Japan and the Japan Trench, we construct a thermal subduction-zone model including parameterized hydrothermal circulation within an aquifer, the uppermost part of subducting oceanic plates. We aim to obtain the relationship between the observed heat flow and the intra-plate temperature structure within subduction zones.

In the model of Spinelli and Wang (2008), parameterized hydrothermal circulation within a constant-thickness aquifer in a subducted plate produces high-heat-flow anomaly near trench axes. Heat is pumped up along the aquifer from deeper part of the subducted plate to the location around the trench axis, thereby it significantly lowers the temperature at depth, 100^{o}C at most. However, in order to explain the observed magnitude of high-heat-flow anomalies with a 500 m thick aquifer, which is typically observed in bore holes (Fisher, 1998), the aquifer permeability should be as high as that near the spreading axis, 10^{-9} m^2.

Alternatively, we model an aquifer that is thickened toward the trench axis, based on a detailed mapping of seismic velocity near the Japan and Kuril trenches, in which a high V_p/V_s zone in the uppermost part of the oceanic plate is thickened toward the trench axis (Fujie et al., 2012, 2013). We assume a 500 m thick aquifer 150 km seaward of the trench axis is linearly thickened to 3000 m at the trench axis. Calculations show that this thickened aquifer induces two kinds of hydrothermal circulation. First, upward vertical hydrothermal heat transport occurs in the aquifer being thickened, which pumps up heat vertically below the aquifer. The magnitude of high-heat-flow resulted by this hydrothermal circulation depends on the rate of aquifer thickening, but not on the permeability. The temperature is decreased below the aquifer being thickened and increased above it, but not influenced within the subducted plate. More importantly, this circulation can account for the observed high-heat-flow even if the aquifer permeability is as low as a typical value for the oceanic plate, 10^{-12} m^2. This type of hydrothermal heat transport can account for the high-heat-flow anomaly observed at the Japan Trench (Yamano et al., 2008). Second, in especially with young plates, along-aquifer hydrothermal heat transport of Spinelli and Wang (2008) occurs at a low permeability around 10^{-12} m^2, because the subducted aquifer is thick. This type of heat transport can explain the high-heat-flow observed at the Nankai Trough (Yamano et al., 2003). This model overcomes the deficit of Spinelli and Wang's (2008) model, which requires extremely high permeability.

Keywords: heat flow, temperature structure, subduction zone, oceanic plate, seismogenic zone, hydrothermal circulation

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SIT05-13 Room:104 Time:May 21 14:45-15:15

Ridge flank processes at North Pond, Mid-Atlantic Ridge

Wolfgang Bach[1*], Katritna Edward[2], Janis Thal[1], Lotta Ternieten[1]

[1]University of Bremen, [2]The University of the Southern California

The uppermost part of the permeable ocean crust harbors the largest hydrologically active aquifer on Earth. It is well known that the geochemical changes associated with basalt alteration in the uppermost oceanic crust play an important role in setting ocean chemistry. It is unknown what role microorganisms play in mediating this seawater?ocean crust exchange. Worse still, the extent to which microbes colonize, alter, and evolve in subsurface rock is not known. Several lines of observation suggest that oxidative ocean crust alteration takes place primarily during the first 10 m.y. of ocean crust evolution. We hypothesize that hydrologically active, young ridge-flank crust releases energy associated with the oxidation of ferrous iron in the basalt, and a sizeable microbial biomass may be supported by these oxidative alteration reactions.

The North Pond study site,is a sediment pond on the western flank of the Mid-Atlantic Ridge, which is underlain by hydrologically active upper oceanic crust. Basement was drilled during DSDP Leg 45/46 (Hole 395A), and the uppermost 500m consist of depleted plagioclase-olivine phyric and aphyric basalt as well as a sedimentary breccia unit with gabbroic rocks and serpentinized peridotites. Previous heat flow and borehole logging work at North Pond showed that the basement is highly permeable and conducive to rapid lateral flow of cold seawater. Based on these results North Pond was selected as site for long-term observatory science, using state-of-the art CORK instrumentation. The principal aim of Integrated Ocean Drilling Program Expedition 336 was to install subseafloor observatories in the young ridge flank at North Pond to examine the extent and the consequences of microbial life within the basaltic ocean crust. The CORK observatories installed comprise packer seals and a string of osmotic pressure driven sampling and incubation devises, as well as temperature and oxygen sensors, all protected by perforated fiber glass casing. Additionally, pressure sensors and additional osmo samplers were installed in the CORK head, where they connect to the subseafloor through umbilical lines. Two observatories were sucessfully installed, a single-zone CORK in upper basement between 90 and 210 mbsf, and a multiple-zone CORK monitoring and sampling three zones to 331.5 mbsf (meters below sea floor). The North Pond microbial observatory is in place and collects unique data and samples for several years. A first follow-up ROV expedition to the area was conducted to install additional experiments and begin time series measurements. A third CORK was installed by ROV during this expedition. Seafloor mapping and sampling of basement outcrops surrounding North Pond yielded insights into the geological setting of the area. A prominent dome-shaped rift mountain south of North Pond turned out to be composed of serpentinized harzburgite and troctolite. In contrast, the two north-south trending ridges NE and NW of North Pond are volcanic.

Differences in trace element systematics of these basalts and the drill core samples indicate that the mantle source was heterogeneous on the scale of few kilometers. Alteration of the basalts is variably oxic to suboxic. Suboxic alteration results in the formation of celadonite and associated enrichment of alkalis in the altered basalt. Oxic alteration and palagonitization of basaltic glass leads to strong enrichment of phosphorous and uranium, which are tied to the formation of ferric oxyhydroxides. The distribution of the two alteration types varies on a meter scale within individual boreholes and on a kilometer scale within the North Pond area.

Keywords: Geochemistry-Petrology, Crustal accretion, Hydrology, Microbiology.

SIT05-14 Room:104 Time:May 21 15:15-15:30

High heat flow anomaly seaward of the Japan Trench associated with deformation of the subducting Pacific plate

Makoto Yamano[1*], Yoshifumi Kawada[1], Hideki Hamamoto[2], Shusaku Goto[3]

[1]Earthq. Res. Inst., Univ. Tokyo, [2]Center Environ. Sci. Saitama, [3]Geol. Surv. Japan, AIST

The Pacific plate subducting along the Japan Trench is very old, over 130 m.y., and thus supposed to be cold. Heat flow values measured on the seaward slope of the Japan Trench along a parallel of 38^{o}45'N were, however, significantly higher than that expected from the seafloor age (Yamano et al., 2008). It indicates that the temperature structure of the incoming Pacific plate may be anomalous, which has an influence on the temperature distribution along the subduction plate interface. Aiming to investigate the extent and cause of the high heat flow anomaly, we conducted heat flow measurements along three E-W lines across the Japan Trench at latitudes of about 38 to 40^{o}N. We obtained 136 new heat flow data mainly on the trench seaward slope and outer rise.

Combined with the existing data, our new results revealed the following features of heat flow distribution on the seaward side of the Japan Trench.

1) Heat flow distributions along the three lines are similar to each other. Heat flow is variable and anomalously high, higher than 70 mW/m^2, at many stations, while values normal for the seafloor age (about 50 mW/m^2) are observed at some stations. No anomalously low values were obtained. It suggests high heat flow anomaly seaward of the trench is not a local phenomenon but extends at least over the northern half of the trench.

2) Significantly high heat flow (over 70 mW/m^2) was observed within 150 km of the trench axis, though we need more data to examine if there is a distinct boundary. The limited extent indicates that the anomaly is closely related to deformation of the Pacific plate associated with subduction.

3) Closely-spaced measurements on the trench outer rise at around 40^{o}15'N and 145^{o}40'E revealed that rather uniform high heat flow spreads over 2 km in the N-S direction, parallel to the trench. In the E-N direction, a steep variation (50 % decrease in 2 km) was observed in the same area.

These results confirmed the existence of thermal anomaly in the uppermost part of the subducting Pacific plate and provide important information on the temperature distribution along the plate interface, including the rupture area of the 2011 Tohoku-Oki earthquake. High average heat flow within 150 km of the trench axis probably results from pore fluid circulation in the upper part of the oceanic crust, which has been highly fractured by deformation of the Pacific plate. Plausible heat transfer mechanism by pore fluid circulation is discussed in another paper in this session (Kawada et al.). Magma intrusion due to petit-spot volcanism in the last several million years cannot be a major source of the observed extensive heat flow anomaly because petit-spot volcanoes are rather sparsely distributed and the amount of melt produced in the mantle is also thought to be small. Local, kilometer-scale variations in the observed heat flow may be attributed to localized fluid flow along faults or high permeability zones developed in the surface part of the Pacific plate.

Keywords: heat flow, Japan Trench, Pacific plate, thermal structure, subduction zone, pore fluid circulation

SIT05-15 Room:104 Time:May 21 15:30-16:00

Structural evolution of the incoming oceanic plate and its along-trench variation

Gou Fujie[1*], Shuichi Kodaira[1], Yuka Kaiho[1], Takeshi Sato[1], Tsutomu Takahashi[1], Yojiro Yamamoto[1]

[1]IFREE/JAMSTEC

The dehydration process and the expelled water from the subducting oceanic plate are expected to affect various subduction zone processes, including the arc volcanism, generation of the intermediate-depth earthquakes and the seismic coupling of plate interface. To better understand these subduction zone dynamics, it is essential to clarify the amount of water that is being subducted within the incoming oceanic plate into the subduction zone.

Recent seismic and thermal structure studies have suggested that most water percolation and oceanic plate hydration are associated with the plate bending-related faulting in the trench-outer rise region. To confirm the structural evolution and its along-trench variation prior to subduction in the northwestern Pacific margin, where extremely old (more than 120Ma) oceanic plate is subducting, we have conducted extensive wide-angle seismic reflection and refraction surveys since 2009. Obtained seismic data of vertical and horizontal components were of good quality and we successfully revealed the progressive changes in Vp, Vs, and Vp/Vs ratio within the incoming plate just before subduction. These seismic velocity models indicate the water content within the incoming oceanic plate increases toward the trench accompanied with the development of the bending-related fractures at the top of the oceanic crust, suggesting the seawater percolation into the incoming plate near the trench.

In addition, we observed a remarkable along-trench structural variation within the incoming Pacific plate in the northern Japan trench region. In this region, it has been suggested that the along-trench variation in the distribution of large interplate earthquakes are well correlated with the along-trench variation in the outer trench seafloor roughness (the degree of horst and graben development). As expected, our seismic velocity models within the incoming plate clearly show that seismic velocities are low and Vp/Vs ratio is high in the region where the seafloor bathymetry is rough, suggesting that water percolation and/or hydration within the incoming oceanic plate is high in the region where the seafloor is rough.

In this presentation, we will show the regional variation of the seismic structure within the incoming plate, and discuss its origin and the impact on the subduction zone dynamics.

Keywords: outer rise, structural evolution, along-trench structural variation, wide-angle seismic survey, water contents, hydration

SIT05-16 Room:104 Time:May 21 16:15-16:45

Anisotropy preservation/alteration in young subducted oceanic mantle

Teh-Ru Alex Song[1*]

[1]IFREE, JAMSTEC

Knowledge of the rate of plate-spreading at mid ocean ridges is critical for estimating plate motions and the outward flux of heat from the interior of the Earth. Strong seismic anisotropy in the oceanic plates can be demonstrated by observations of azimuthal variations in refracted Pn velocity, Rayleigh wave phase velocity and splitting of teleseismic core phases such as SKS waves. In particular, Pn azimuthal anisotropy up to several per cent in the topmost oceanic mantle is strongly linked to a mantle ophiolite section containing anisotropic dunite and harzburgite. However, it is not clear if the seismic anisotropy is radially homogeneous within the oceanic plate or there are intrinsic layering that are relevant to the formation of oceanic lithosphere. In addition, if such a strong anisotropy can be preserved through subduction and if a relationship between spreading rates and Pn azimuthal anisotropy can be established, it is possible to access paleo spreading rates. Here I will attempt to highlight recent progress on localized seismic anisotropy in the uppermost mantle of subducted plates in several young subduction zones and discuss potential implications on the evolution of oceanic lithosphere.

Keywords: anisotropy, subduction

SIT05-17 Room:104 Time:May 21 16:45-17:00

Sea floor basalts of the Japan Sea back-arc basin revisited: Upwelling and melting of hydrous mantle and slab sediment d

Jun-Ichi Kimura[1*], Yuka Hirahara[1], Toshiro Takahashi[1], Takashi Miyazaki[1], Ryoko Senda[1], Qing Chang[1]

[1]IFREE/JAMSTEC

Middle Miocene seafloor basalts recovered by ODP drilling from the Japan Sea floor (Cousens & Allan, 1992), were re-examined. Sr-Nd-Hf-Pb isotopic and incompatible trace element compositions reconfirmed two basalt types from enriched (E) and depleted (D) mantle sources. D-type basalt is unradiogenic in Sr and Pb, radiogenic in Nd and Hf, and has lower incompatible element abundances than in N-MORB. LREEs are strongly and HREEs are slightly depleted than in MREEs with positive spikes in Ba, Pb, and Sr. E-type basalt is radiogenic in Sr and Pb, unradiogenic in Nd-Hf, with LREE enriched and Nb-Ta depleted trace element compositions. E-type basalt has similar trace element compositions with those in the rear-arc Quaternary basalts in the adjacent NE-Japan arc overall; however, differ greatly in elevated Zr-Hf and in isotopic enrichment.

Forward model adiabatic melting calculations of hydrous metasomatized mantle were examined with varying parameters of (1) mantle potential temperature (Tp/C), (2) initial H2O content (H2O(i)/wt%), melting termination depth (Dmt/GPa), and terrigeneous sediment flux fraction (Fsed/wt%) mixed with the source peridotite. The calculation results suggest that conditions Fsed = 1.2 wt%, with H2O(i) = 0.01-0.12 wt%, Tp = 1200-1290 (C), final melting degree of F = 0.07 at depth of Dmt = 0.8-1.4 GPa explain the trace element abundances in E-type basalt. In contrast, D-type basalt can form at the conditions of Fsed = 0.0 wt%, H2O(i) = 0.00-0.08 wt%, Tp = 1340-1410 (C), F = 0.12-0.15 at depth of Dmt = 1.4-1.7 GPa. The melting conditions for D-type basalt are deeper and hotter than for primary N-MORB (H2O(i) = 0.01-0.10 wt%, Tp = 1230-1330 (C), Dmt = 0.7-1.4 GPa, F = 0.10-0.12) calculated by the same method consistent with the depleted nature in total REEs and HREEs with higher MgO in D-type basalt. E-type basalt has different source and can form at shallower depth and lower Tp and F suggesting heterogeneous source mantle in terms of the chemistry and the melting regime.

Mixing calculations using Nd-Hf-Pb isotopes between the depleted mantle and terrigeneous sediment suggest that the bulk sediment addition rather than sediment melt/fluid accounts for the source enrichment in E-type basalt. However, depletions in Rb, U, and K should have occurred perhaps by suduction modification before the bulk sediment is involved in the adiabatic melting regime beneath the back-arc basin. D-type basalt is from depleted mantle in DM-EM1 transition similar to those in the deep rear-arc OIBs in N-China. If elevated Ba, Pb, and Sr in D-type basalt is the inherent from the source mantle likewise in N-China, then their isotopic characteristics could be from ancient slab fluids stored in the mantle transition zone (e.g., Kuritani et al., 2011). The back-arc basin basalt in the Japan Sea would thus have formed by melting of both deep-sheeted hydrous mantle and subduction-modified slab sediment during ascent of the back-arc mantle while opening of the Japan Sea.

Keywords: Japan Sea, basalt, adiabatic melting, back-arc mantle

SIT05-18 Room:104 Time:May 21 17:00-17:15

Os Isotopic Signature of Backarc Abyssal Peridotites from the Godzilla Megamullion

Wendy Nelson[1*], Jonathan Snow[1], Alan D. Brandon[1], Yasuhiko Ohara[2]

[1]Department of Earth & Atmospheric Sciences, University of Houston, Houston. USA, [2]Hydrographic and Oceanographic Department of Japan, Tokyo. Japan

Backarc seafloor spreading is a unique form of extension intimately tied to subduction zone dynamics. Unlike volcanism at mid-ocean ridges, backarc volcanism evolves from arc-like to MORB-like compositions over the short lifespan (~15 Ma) of the backarc. Our understanding of the evolution of oceanic mantle during backarc extension is limited to exposures of abyssal peridotite and ophiolites. While some ophiolites are thought to have formed in a backarc environment, few direct comparisons of ophiolite and backarc peridotite have been made due to the small number of documented exposures and limited in situ samples from backarc settings. As a consequence, isotopic investigations have thus far been limited to ophiolite and mid-ocean ridge settings, limiting our understanding of the backarc oceanic mantle.

Here we report Re-Os isotopic data for backarc abyssal peridotites from the Godzilla Megamullion, a massive ~9000 km^2 oceanic core complex located in the Parece Vela Basin (Philippine Sea). In this region, Izu-Bonin-Mariana subduction zone is responsible for creating the Parece Vella and Shikoku backarc basins as well as the Mariana Trough. In the last decade, five expeditions have collectively sampled the length of the Godzilla Megamullion. The distal end records early, magmatically productive extension marked by moderately depleted spinel peridotites. This transitions into a less melt-productive medial region characterized by more fertile peridotite. The proximal region represents the most recently exhumed portion of the megamullion and was the focus of the latest (October 2011) mapping and sampling expedition. Ultramafic samples from the proximal region are dominantly spinel lherzolite +/- plagioclase. Whole rock $^{187}Os/^{188}Os$ (0.1208-0.1301) ranges from mildly subchondritic to primitive mantle values, consistent with abyssal peridotites from mid-ocean ridge settings. Samples from distal, medial, and proximal regions are isotopically indistinguishable. Spinel grains in proximal samples record high TiO_2 and Cr# produced by melt stagnating and interacting with the mantle. Re concentrations are positively correlated with TiO_2 abundances in spinel, suggesting that Re is also influenced by melt-rock interaction. However, $^{187}Os/^{188}Os$ ratios are not correlated with Re concentration, demonstrating that modest Re addition occurred recently. A few samples record mildly radiogenic values (0.1321-0.1414), the most radiogenic of which has experienced approximately 5 wt. % MgO loss. Therefore, the radiogenic $^{187}Os/^{188}Os$ signature may be the result of seafloor weathering. As a whole, the $^{187}Os/^{188}Os$ data suggest that the backarc oceanic mantle in this region did not experience significant ancient melt depletion, and radiogenic $^{187}Os/^{188}Os$ ratios were likely generated during secondary processes.

Keywords: oceanic core complex, abyssal peridotite, osmium, Godzilla Megamullion

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SIT05-19 Room:104 Time:May 21 17:15-17:30

Incipient island arc magmatism: petrogeneisis of boninitic dike swarms and related cumulates in the Oman ophiolite

Shusaku Yamazaki[1]*

[1]Graduate School of Science and Technology, Niigata University

In the northern part of Fizh block in the northern Oman ophiolite, the crustal sequence contains large amount of late intrusive plutonics and dikes. The late intrusive plutonics formed "late intrusive complex" in the early crystalized MORB-type gabbroic crust. The complex is consisting of ultramafic cumulates of dunite to clinopyroxenite, gabbronorites of ol-gabbro to oxide gabbronorite and plagiogranites of diorite to trondhjemite. Their parental melts show hydrated and depleted characteristics than those of MORBs (e.g. early crystallization of cpx than pl and lower Ti contents in pyroxenes). In this area, the large amount of the late intrusion thickened the crust to ~8-9 km thick. As the latest intrusions in the lower crust, hundreds of parallel boninitic dikes are intruding into the early gabbros and the late plutonics and form four bands of dike swarm with 2-5 km width. The lava sequence of the northern area represents transition of magmatism from MORB (V1 or Geotimes unit) to IAT (V2 or Lasail & Alley unit) and contains boninite lavas within the Alley unit (Ishikawa et al., 2002). The boninitic dike swarms are considered to be feeders of the Alley boninites.

The boninitic dikes are pyroxene and olivine phenocryst phyric and classified into komatiite, high-Ca boninite, high-Mg basalt to andesite based on whole rock composition. This wide range of composition is explained by phenocryst accumulation and fractionation from primitive boninite melts with MgO 12-14 wt% in the lower crustal level. The zoning patterns of clinopyroxene phenocrysts represents that the parental melts experienced magma mixing with different boninite melts, which were fractionated various degree and some have slightly different trace element characteristics.

On the other hand, we found boninitic clinopyroxenite to dunite with depleted chrome spinels (Cr# >70) in the late intrusive ultramafic cumulates, which distribute around the root zone of the dike swarms. We concluded that these cumulates formed by mineral accumulation from less evolved boninite melts because the clinopyroxenes of the boninitic ultramafic cumulates have consistent trace element concentrations and patterns with the phenocrysts of the dikes. In addition, the estimated primitive boninite melts compositions from the dikes represents Th and LREE enrichment relative to M- to HREE in chondrite normalized pattern, which is interpreted as the result of slab derived sediment melt influx into depleted source mantle of boninite melts.

The magmatic history in the crustal section is summarized as follows. After the accretion of early crustal gabbros from MORB, the crustal thickening occurred by hydrated and depleted magmatism. Boninite magmatism subsequently occurred by partial melting of highly depleted mantle with influx of sediment melts and formed dike swarms. This crustal evolution is comparable to the nascent stage of crustal formation of oceanic island arc such as Izu-Mariana fore arc region, which contains depleted and hydrated magmatism as pre-boninite magmatism (fore arc basalts; Ishizuka et al., 2011). Thus, the northern part of Fizh block of the Oman ophiolite is a good example for oceanic island arc crustal section, which rapidly developed to ~10 km thick immediately after subduction initiation event.

Reference:
Ishikawa et al. (2003) Geology, vol. 30, no. 10, p. 899-902.
Ishizuka et al. (2011) Earth and Planetary Science Letters, 306, 229-240.

Keywords: ophiolite, boninite, island arc magmatism, dike swarm, geochemistry, petrology

SIT05-20 Room:104 Time:May 21 17:30-17:45

Geochemistry and geochronology of the Troodos ophiolite: An SSZ ophiolite by an extended episode of ridge subduction

Soichi Osozawa[1*], Ryuichi Shinjo[2], Ching-Hua Lo[3], Bor-ming Jahn[3], Nguyen Hoang[4], Minoru Sasaki[5], Ken'ichi Ishikawa[6], Harumasa Kano[7], Hiroyuki Hoshi[8], Costas Xenophontos[9], John Wakabayashi[10]

[1]Department of Earth Sciences, Graduate School of Science, Tohoku University, [2]Department of Physics and Earth Sciences, University of the Ryukyu, [3]Department of Geosciences, National Taiwan University, Taiwan, [4]Geological Survey of Japan, AIST, [5]Department of Earth and Environmental Sciences, Graduate School Science and Tecnology, Hirosaki Univ, [6]Center for the Advancement of Higher Education, Tohoku University, [7]Tohoku University Museum, [8]Department of Earth Sciences, Graduate School of Education, Aichi University of Education, [9]Cyprus Geological Survey, [10]Department of Earth and Environmental Sciences, California State University, Fresno,USA

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New trace-element, radiogenic isotopic, and geochronologic data from the Troodos ophiolite, considered in concert with the large body of previously published data, give new insight into the tectonic history of this storied ophiolite, as well as demonstrating the variability of suprasubduction-zone ophiolites, and differences between them and commonly used modern analogs. Similar to earlier studies, we find that island-arc tholeiite of the lower pillow lava sequence erupted first, followed by boninite. We further divide boninitic rocks into boninite making up the upper pillow lava sequence, and depleted boninites that we consider late infill lavas. We obtained an Ar-Ar age from arc tholeiite of 90.6+-1.2 Ma, comparable to U-Pb ages from ophiolite plagiogranites. New biostratigraphic data indicate that most of the basal pelagic sedimentary rocks that conformably overlie the boninitic rocks are ca. 75 Ma. This suggests that voluminous eruption of boninitic rocks persisted until ca. 75 Ma. Limited eruption of boninitic lavas may have continued until 55.5+-0.9 Ma, based on the Ar-Ar age we obtained.The duration of arc magmatism at Troodos (at least 16 m.y., with some activity perhaps extending 35 m.y.) without the development of a mature arc edifice greatly exceeds that of other well-studied suprasubduction-zone ophiolites. We propose that Troodos was formed over a newly formed subduction zone, similar to many proposed models, but that the extended period of magmatism (boninitic) resulted from a prolonged period of ridge subduction.

Keywords: Troodos ophiolite, island arc tholeiite, boninite, geochronology and biostratigraphy, subduction initiation, ridge subduction

SIT05-21 Room:104 Time:May 21 17:45-18:00

Redox state of mantle wedge above subduction zone as inferred from the Oman mantle section

Eiichi TAKAZAWA[1*], Nami KANKE[2]

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

This research aims to understand the redox status of a mantle wedge as a case study of the mantle section of the Oman ophiolite. The Fizh mantle section of the northern part of the Oman ophiolite exposes about 14-km-stratigraphic height of the uppermost mantle from the Moho to the basal thrust. In accordance with the method of Ballhause et al. (1991), oxygen fugacity was calculated from the mineral compositions of olivine and a spinel using the peridotites collected from the mantle section. When the deviation from the FMQ buffer of Log fO2 was plotted on the topographic map of the Fizh mantle section, it became clear that the basal part of the ophiolite has quite low oxygen fugacity and is reduced than the peridotites near the Moho. In particular, near the basal thrust, there is also a place where deltalog fO2 reaches to FMQ-3. In general, island arc basalts and mantle xenolithes have oxygen fugacity higher than both MORB and abyssal peridotites, so that the mantle wedge is more oxidized than a MORB source mantle. Our results show that the mantle wedge just above the subducting slab is more reduced than those previously expected.

The mantle section of the Oman ophiolite records an incipient stage of subduction zone that formed by the intra-oceanic thrusting of an oceanic lithosphere. This is supported by the presence of highly refractory peridotites with high-Cr# ($>$ 0.7) spinels. A H2O-rich fluid was liberated from the metamorphic sole during thermal metamorphism by obducting oceanic lithosphere (Ishikawa et al., 2005). The infiltration of the fluid from the basal thrust triggered a flux melting of residual harzburgites forming highly refractory peridotites in the mantle section (Arai etal., 2006; Takazawa, 2012; Kanke and Takazawa, 2013). This configuration indicates that the upper surface (metamorphic sole) of the sinking slab is directly in contact with the lowermost part of the mantle wedge (ophiolite) in the Oman ophiolite. Our results indicate that the mantle wedge on the upper surface of subducting slab is the most reductive and it becomes more oxidative toward the mantle-crust boundary. The degree of contribution of a slab component is examined using the indices (Th/Ce ratio etc.) of a sediment-derived melt and the proxy of oxygen fugacity (the V/Sc ratio and the Zn/Fe ratio). It verifies either possibility that the mantle wedge was reduced by a reductive melt which originates in the sediment on the sinking slab, or that the reductive oceanic mantle was oxidized from the upper part by a hydrothermal circulation.

Keywords: Oman ophiolite, peridotite, oxigen fugacity, mantle wedge, subduction zone, redox state

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

SIT05-P02 Room:Convention Hall Time:May 21 18:15-19:30

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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SIT05-P03 Room:Convention Hall Time:May 21 18:15-19:30

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

SIT05-P06 Room:Convention Hall Time:May 21 18:15-19:30

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

SIT05-P07 Room:Convention Hall Time:May 21 18:15-19:30

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

SIT05-P09 Room:Convention Hall Time:May 21 18:15-19:30

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

SIT05-P10 Room:Convention Hall Time:May 21 18:15-19:30

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

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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