Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)


SIT05-01 会場:104 時間:5 月 21 日 09:00-09:15

# 最上部マントルにおける MORB 生成の多様性: 北部オマーンオフィオライトを例として
# Diversity of MORB genesis within the uppermost mantle: an example from the northern Oman ophiolite

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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

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# アンダマンオフィオライトの形成場
# Paleogeodynamic setting of the Andaman ophiolite

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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.

キーワード: Andaman Ophiolite, Chromitite, Mantle, Geodynamic setting
Keywords: Andaman Ophiolite, Chromitite, Mantle, Geodynamic setting

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# 高速拡大海嶺におけるマグマシステム：オマーンオフィオライトからの検討
# Magma system along fast-spreading ridges: Evidence from the northern Oman Ophiolite

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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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キーワード: 海洋地殻, 火成作用, MORB, 海嶺セグメント構造, オマーンオフィオライト
Keywords: oceanic crust, magmatism, MORB, ocean ridge segmentation, Oman ophiolite

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# IODP 1256D 孔のシート状岩脈の帯磁率異方性と岩脈の貫入プロセス
# AMS fabrics and emplacement processes of sheeted dikes in IODP Hole 1256D

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パナマ沖赤道太平洋に位置する 1256D 孔は、海洋地磁気 C5Br と C5Bn.2n 境界（~15.16 Ma）に位置する玄武岩層からシート状岩脈群（Sheeted Dike Complex: SDC）を掘り抜き、岩脈状あるいはレンズ状の貫入形態をもつ幅数十メートルの 2 枚の斑糲岩層に到達した。これらの斑糲岩層の周囲は、熱変成を受けて granoblastic な組織を持つ含斜方輝石ドレライトからなり、最下部は海洋地殻第 3 層の上部境界付近まで到達したと考えられる。斑糲岩層から分離されたジルコンは 15.0 ~ 15.2 Ma の加重平均を示し、上位の玄武岩層・SDC が負の磁極性を持つのに対して、下位の斑糲岩層と含斜方輝石ドレライトは正の磁極性を持つ。これは、1256D 孔は垂直から 5 度西側に傾いているため、掘り進むにつれて C5Br 海洋地殻から C5Bn.2n 海洋地殻に移行したか、斑糲岩がやや若い年度を示すことから初成的な海洋地殻磁気構造が斑糲岩の貫入とキュリー点温度を超える熱変成によって改変されたものと思われる。

C5Br 海洋地殻の SDC の貫入プロセスを推定するため、上下方向が認定できるコア試料から岩石磁気測定用のキューブ試料を系統的に採取し、帯磁率異方性（Anisotropy of Magnetic Susceptibility: AMS）の測定を行った。上下方向が認定できるコア試料でも掘削パイプの中で回転軸を中心に回転しているため、半割面を基準として測定した AMS 方位を地理学的方位に復元する必要がある。コア試料は掘削時の再磁化の影響をうけているため、残留磁化方位を交流消磁曲線（0-80 mT）の高保持力成分あるいは end point から求め、SDC は negative polarity を保持しているものと仮定して、AMS 異方性とコア中に観察された主要な構造方位の復元を行った。AMS に寄与する磁性鉱物は、主に擬単磁区構造を持つ磁鉄鉱である。

SDC から得られた帯磁率異方性楕円の長軸（Kmax）は水平で貫入面に平行する傾向にあるが、短軸（Kmin）は鉛直方向に極大値をもつ。このことは、マグマが水平方向に流動したこと、貫入後のマグマが充分に暖かかった時期に drain back あるいはテクトニックな引張の影響を受けて、短軸が貫入面にたいして直交する本来の AMS ファブリックが改変されたものと解釈できる。シート状岩脈面に発達する微細構造も貫入面に直交する引張を強く示唆する。

キーワード: シート状岩脈, 高速拡大海嶺, 帯磁率異方性, 貫入プロセス
Keywords: sheeted dike complex, fast-spread-rate crust, AMS, emplacement processes

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# オマーンオフィオライト中の珪長質岩類のバリエーションとその成因
# Petrology and petrogenesis of felsic rocks in the Oman ophiolite, Oman

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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.

キーワード: オマーンオフィオライト, 斜長花崗岩, 海嶺期, 後期火成岩類, 大陸衝上期, 岩石化学
Keywords: Oman ophiolite, plagiogranite, axis stage, late stage, emplacement stage, petrochemistry

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SIT05-06 会場:104 時間:5 月 21 日 10:15-10:30

# ヘス　ディープの火成岩地殻，345 航海成果
# Hess Deep Plutonic Crust, Expedition 345

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本発表では，平成 24 年 12 月 11 日ー平成 25 年 2 月 12 日に行われた IODP EXP. 345 の Hess Deep 掘削の速報を行う。

キーワード: 高速拡大海嶺, ヘス　ディープ, 国際海洋掘削, 海洋プレート, 下部地殻
Keywords: Fast spreading Ridge, Hess Deep, IODP, Oceanic Plate, Lower Crust

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# エチオピア巨大火成岩区ラリベラ地域の高 Ti ピクライトについて
# High-Ti picrite from the Lalibella area, Ethiopian LIP

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エチオピア高原の広範囲において，新生代漸新世の 30 Ma 前後の約 100 万年間に，地殻の広域的な隆起を伴って体積 250,000 km3 に達する洪水玄武岩溶岩が噴出し，その末期には流紋岩の溶岩・火砕流の噴出や玄武岩楯状火山の形成があって，巨大火成岩区（LIP）が形成された．その後，中新世から現在までは地溝帯の中軸部やアファー三角地帯で火山活動が継続し，大陸分裂が進行している．地溝帯西方の洪水玄武岩は地域によって化学組成が異なり，西部（内陸側）では低 Ti，東部（地溝帯側）では高 Ti の傾向があるが，ほぼ同時に噴出した．本 LIP におけるピクライトの産出は稀であり (Beccaluva et al. 2009; J. Petrol.; Rogers et al. 2010; EPSL)，高 Ti 玄武岩と互層する溶岩として Lalibela 地域の Dilb 道路沿いに分布する．世界遺産になっているエチオピア正教（コプト教）のラリベラ教会はピクライト溶岩をくり抜いて作られている．ピクライトは最も未分化なマントル起源マグマまたはそのようなマグマからのかんらん石集積岩として火成作用の重要な研究対象である．今回はこの地域で採集したピクライト質玄武岩 3 試料を分析した．かんらん石斑晶は Fo77.7〜88.4 で Mg に富むものは 0.3〜0.4wt%の NiO を含む．単斜輝石は Mg#72〜88 で 0.8〜2.9wt%の TiO2 を含む．スピネルは Cr#79〜84, Mg#18〜51, Fe3+#11〜26，TiO2=3.6〜7.0wt%，斜長石は An60 程度で，他に不透明鉱物としてチタン鉄鉱が含まれる．かんらん石の最大 Fo 値からみてマントルかんらん岩と平衡に存在し得る未分化マグマに近い．鉱物化学組成で特徴的なのはスピネルの高い Cr#である．海洋 LIP 起源と考えられる空知エゾ帯のピクライト (Ichiyama et al. 2012; Geology) のスピネル Cr#は平均 56（44〜67）であり，美濃丹波帯のそれは 58〜67 であって，80 を超えるようなスピネルは産しない (Ichiyama et al. 2006; Lithos; Koizumi and Ishiwatari, 2006; Isl. Arc)．一方，大陸の層状貫入岩体のスピネルの Cr#が高いことはよく知られている．高 Ti 系列の LIP マグマは海洋地域にも産するが，スピネルの高 Cr#はエチオピア LIP の大陸的性格をよく示しており，大陸下マントルの起源についても示唆を与える．

キーワード: ピクライト, 洪水玄武岩, 高 Cr スピネル, 大陸下マントル, 大陸分裂, 海洋地殻形成
Keywords: picrite, flood basalt, high-Cr spinel, subcontinental mantle, continental rifting, oceanic crust formation

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# 古海洋プレートリソスフェア最上部マントルの結晶方位異方性と地震波特性
# Possible lateral variation of seismic anisotropies in the oceanic lithosphere due to an active mantle flow

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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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SIT05-09 会場:104 時間:5 月 21 日 11:30-11:45

# モホールからマントルへ：M2M 計画
# MoHole to Mantle: Project M2M

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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.

キーワード: 国際統合深海掘削計画, モホール, マントル掘削, モホ, 海洋リソスフェア, ちきゅう
Keywords: IODP, MoHole, mantle drilling, Moho, oceanic lithosphere, Chikyu

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SIT05-10 会場:104 時間:5 月 21 日 11:45-12:15

# 神話の崩壊ー海洋底かんらん岩の解読
# Paradise Lost: Interpreting peridotites from oceanic ridges

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　中央海嶺下のマグマ活動は，最も単純で理解が進んでいると思われている。しかし，中央海嶺のマグマ活動を我々は，本当に理解しているのだろうか？海洋底かんらん岩のデータから、この点について深く考え直してみよう。

キーワード: 中央海嶺, 融解, メルト移動, かんらん岩, 単斜輝石
Keywords: Mid-Ocean Ridge, Melting, Melt migration, Peridotite, Clinopyroxene

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SIT05-11 会場:104 時間:5 月 21 日 14:15-14:30

# N.Qaidam 山地・勝利口橄欖岩 と海洋底岩石に見られる塩素角閃石の比較
# Cl-rich amphibole in the Shenglikou peridotite, N.Qaidam Mountain and its comparison with Cl-amphiboles in oceanic rocks

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下部地殻や上部マントルで活動する流体の中でも、とりわけ高塩濃度流体が注目されている。その理由として、
（１）沈み込み帯深部でスラブから放出される深部流体は高塩濃度を持つこと。
（２）物理探査（magnetotelluric) により調べることができること。
（３）高塩濃度流体は流体中のトレース元素の溶解し、輸送する能力に長ける。
などの理由が挙げられる。

さらに沈み込みプレート内地震の分布が表面から 50km 以深まで及ぶことは、プレート内の上部マントル深度にも含水鉱物が形成されていることが示唆される、しかし、このようなプレート下マントルに水流体を持ち込む機構は十分に理解されていない。本発表では塩素流体に富む上部マントル物質の一例として、中国北西部の勝利口橄欖岩を紹介する。

勝利口橄欖岩は、N.Qaidam 超高圧変成帯に露出するザクロ石橄欖岩であり、大部分が輝石に富むザクロ石レールゾライトで構成され、少量のダナイト・輝岩レイヤーを含んでいる。塩素に富む含水鉱物組み合わせは、高圧のザクロ石橄欖岩共生中に包有物として観察される。ザクロ石中には、粗粒なスピネル＋角閃石（Cl-rich Ti pargasite）＋斜方輝石+sodium gedrite と細粒な緑泥石＋ Ti-poor ホルンブレンド+アパタイト、Fe-Mg 角閃石 (anthophyllite)、アパタイト、タルク、スピネル、石墨と NaCl スカポライト (marialite) の鉱物組み合わせが観察され、それぞれ超高圧変成作用以前のスピネル橄欖岩相・および緑泥石橄欖岩相で形成されたと考えられる。一方で単斜輝石中には、塩素を含む角閃石（トレモライト～ホルンブレンド）＋蛇紋石±緑泥石± Ca-rich ザクロ石（uvarovite, andradite, grossular）の鉱物組み合わせが見られ、lizardite の存在は非常に低温条件 (T<400 C) で形成したことを示唆する。

その後、勝利口橄欖岩は超高圧変成作用を被ったと考えられ、塩素に富む含水鉱物が高圧のザクロ石橄欖岩共生へ変化したと考えられる。このザクロ石橄欖岩共生の鉱物組み合わせは、ザクロ石＋単斜輝石＋斜方輝石±かんらん石である。地質温度圧力計を適用した結果、ザクロ石橄欖岩ステージの鉱物組み合わせの平衡条件は 790 C/4.1 GPa (± 80/0.3) と推定された。

ザクロ石橄欖岩の鉱物組み合わせは、最後の減圧・冷却ステージで後退変成作用の影響を被り、ザクロ石は Cl に乏しい Ca 角閃石（pargasite, Cl<0.1 wt. %）±スピネルに置換され、単斜輝石も Cl に乏しい Ca 角閃石（tremolite˜hornblende）に置換されている。

以上の結果から、勝利口かんらん岩は超高圧変成作用以前に高塩濃度流体による汚染を受けたことが示唆される。これらのデータは地質学的背景を基に次のように解釈される。

N.Qaidam 超高圧変成岩を構成する塩基性岩（eclogite）は、約 800Ma 以前にロディニア超大陸分裂（リフト帯形成）に伴って形成された海洋リソスフェアの断片だと解釈されている。この文脈に従うと、勝利口橄欖岩はロディニア大陸下マントルが、大陸分裂に伴い海洋底に浮上したものだと考えられる。このリフト帯において、勝利口橄欖岩は海水を起源とする高塩濃度流体による海洋底変質を被ったと考えられる。その後、約 460Ma に海洋底が閉じ大陸衝突運動が起きた際に、勝利口橄欖岩は 100km 以深まで沈み込み、ザクロ石橄欖岩へ相転移したと考えられる

本研究では、さらに勝利口橄欖岩の塩素に富む角閃石と、現在の拡大軸（海嶺）やリフト帯に見られる塩基性・超塩基性岩中の角閃石組成の比較を行った。角閃石の水酸基を置換する塩素の量から、共存する流体の塩素濃度を推定することが可能である。比較結果から、勝利口橄欖岩において、初期のスピネル橄欖岩相当深度（深さ 25km 以深）で活動する流体の塩濃度は約 40 NaCl mol. %程度と非常に高かったことが示唆された。この結果は、リフト帯において海水起源の高塩濃度流体が上部マントル深度（25km 以深）まで浸入できることを示した結果である。現在のリフト帯である大地溝帯に見られる Zabargad 橄欖岩においても、高温条件で高塩濃度・流体活動が起きていることが知られている。これらの事実は、リフト帯において海水がマントル相当深度にまで入り込み、リソスフェア深部の汚染を引き起こす可能性を示唆する。この機構を理解することは、プレート深部に含水鉱物を形成するメカニズムを解明する上で非常に重要な手がかりとなる。

キーワード: 造山型橄欖岩, ロディニア超大陸, ツァイダム地塊, 海洋性橄欖岩, 熱水変質, 塩水
Keywords: orogenic peridotite, Rodinia super continent, Qaidam craton, oceanic peridotite, hydrothermal alteration, brine

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# 沈み込むプレート内で起こる熱水循環を考慮した沈み込み熱帯モデルの構築と、その日本近海の熱流量異常への応用
# Thermal subduction-zone model including hydrothermal circulation in an aquifer that thickened toward the trench axis

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南海トラフ室戸沖や日本海溝三陸沖の海溝海側で観測されている高熱流量異常の原因と、その地震発生帯温度への影響を明らかにするための数値計算を行った。沈み込み帯の地震活動は温度の影響を何らかの形で被っているため、沈み込み帯深部の温度構造は地震活動を理解するための鍵となる。

先行研究の Spinelli and Wang (2008) によると、沈み込んだプレートの最上部にある厚さ一定の透水層内で熱水循環が起こることで、高熱流量を作ることができる。沈み込んだ後の透水層内の熱水循環は沈み込み帯深部から海溝付近へと熱を汲みあげるため、沈み込み帯深部の温度は熱水循環によって最大 100 ℃程度下がる。ただし、通常考えられている厚さ 500 m 程度の透水層の内でおこる熱水循環で観測を説明するためには、海嶺軸並みの浸透率 $10^{?9}$ $m^2$ が必要になるという難点がある。

本研究では、プレート最上部にある $V_p/V_s$ が大きい領域が海溝に向かって厚くなるとの観測結果 (Fujie et al., 2012, 2013) を受け、海洋地殻の透水層の厚さが海溝に近くなるほど厚くなるモデルを考えた。典型的には、海側 150 km で 500 m 厚の透水層が、海溝に向かって 3000 m 厚となるとした。数値計算により、このモデルは 2 種類の熱水循環を引き起こすことが分かった。1 番目に、透水層直下の熱を上方に汲みあげる循環が起こる。この循環は透水層が厚くなるレートに依存するが、浸透率にはあまり依存しない。このとき、厚くなりつつある透水層の直下で温度が低下し、その代わりに透水層の直情で温度が増加する。この循環は沈み込んだ後のプレート温度にはほとんど影響がない。この循環は、透水層の浸透率が典型的なプレートの値 $10^{?12}$ $m^2$ で熱流量異常を説明できる程度に起こる。日本海溝の熱流量異常はこの循環で説明できる。2 番目に、特にプレート年代が若い場合では、Spinelli and Wang (2008) と同じく、沈み込んだ後の透水層内の熱水循環が起こる。Spinelli and Wang (2008) では高い浸透率が必要であったが、このモデルでは、透水層の浸透率が典型的なプレートの値 $10^{?12}$ $m^2$ で熱流量異常を説明でき、Spinelli and Wang (2008) モデルの難点を解消できる。この循環により、南海トラフの熱流量異常が無理なく説明できる。

キーワード: 熱流量, 温度構造, 沈み込み帯, 海洋プレート, 地震発生帯, 熱水循環
Keywords: heat flow, temperature structure, subduction zone, oceanic plate, seismogenic zone, hydrothermal circulation

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# 海嶺側面でおきるプロセス：大西洋 North Pond 研究から
# Ridge flank processes at North Pond, Mid-Atlantic Ridge

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海洋プレート最上部は、岩石ー水の通過道として、海洋プレートおよび海水組成の変化に大きな影響を与えているにもかかわらず、理解が進んでいない。さらにこれに加えて，微生物活動は，この海洋底の水循環にどのように関与しているのか？
本発表では，これらのことに関して，North Pond で進めている研究成果をもとに話題を提供する。

キーワード: 地球化学と岩石学, 地殻の形成, 海洋底水門学, 微生物
Keywords: Geochemistry-Petrology, Crustal accretion, Hydrology, Microbiology.

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# 日本海溝海側の高熱流量異常と沈み込む太平洋プレートの変形
# High heat flow anomaly seaward of the Japan Trench associated with deformation of the subducting Pacific plate

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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.

キーワード: 熱流量, 日本海溝, 太平洋プレート, 温度構造, 沈み込み帯, 間隙流体循環
Keywords: heat flow, Japan Trench, Pacific plate, thermal structure, subduction zone, pore fluid circulation

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

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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.

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

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SIT05-16 会場:104 時間:5 月 21 日 16:15-16:45

# Anisotropy preservation/alteration in young subducted oceanic mantle
Anisotropy preservation/alteration in young subducted oceanic mantle

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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.

キーワード: anisotropy, subduction
Keywords: anisotropy, subduction

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SIT05-17 会場:104 時間:5 月 21 日 16:45-17:00

# 日本海背弧海盆玄武岩再検討
# Sea floor basalts of the Japan Sea back-arc basin revisited: Upwelling and melting of hydrous mantle and slab sediment d

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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.

キーワード: 日本海, 玄武岩, 断熱融解, 背弧マントル
Keywords: Japan Sea, basalt, adiabatic melting, back-arc mantle

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SIT05-18 会場:104 時間:5 月 21 日 17:00-17:15

# Os Isotopic Signature of Backarc Abyssal Peridotites from the Godzilla Megamullion
Os Isotopic Signature of Backarc Abyssal Peridotites from the Godzilla Megamullion

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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.

キーワード: oceanic core complex, abyssal peridotite, osmium, Godzilla Megamullion
Keywords: oceanic core complex, abyssal peridotite, osmium, Godzilla Megamullion

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SIT05-19 会場:104 時間:5 月 21 日 17:15-17:30

# ボニナイト質岩脈群とその深成岩相からみる初期島弧形成プロセス：オマーンオフィオライト北部地域を例として
# Incipient island arc magmatism: petrogeneisis of boninitic dike swarms and related cumulates in the Oman ophiolite

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オマーンオフィオライトの北部 Fizh 岩体北部地域では、MORB 質の斑れい岩質下部地殻に、MORB よりも不適合元素濃度に枯渇した含水マグマを起源とする超塩基性集積岩類（ダナイト-単斜輝岩）・ガブロノーライト類（かんらん石斑れい岩-含 Fe?Ti 酸化物ガブロノーライト）・斜長花崗岩類（閃緑岩-トロニエム岩）から構成される複合深成岩岩体が後期貫入し、地殻部の厚さを 8-9 km へと厚化させた。そこに最後期の貫入岩として、地殻下部から上部にかけて数百のボニナイト質岩脈が平行貫入し、2-5km 幅を持つ４帯の岩脈群を形成している。オフィオライト北部の溶岩層には、MORB (V1 or Geotimes unit) → IAT (V2 or Lasail & Alley unit) への火成活動の変遷が認められ、Alley unit 中にボニナイト溶岩が伴われることから（Ishikawa et al., 2002）、岩脈群は Alley 溶岩層の供給岩脈群の一部であった考えられる。

ボニナイト質岩脈は両輝石・かんらん石斑晶に富む多斑晶質のものが多く、全岩化学組成によりコマチアイト、高 Ca ボニナイト、高 Mg 玄武岩?安山岩に分類される。この幅広い組成傾向は、下部地殻内における MgO 12~14wt%の初生的な高 Ca ボニナイトメルトからの斑晶の沈積・分別に由来すると考えられる。また、単斜輝石斑晶の累帯構造解析からは、その形成プロセスに分化程度および微量元素組成の特徴（LREE/MREE など）が異なるボニナイト質マグマの混合が存在したことを示唆している。

一方、岩脈群の根付近に存在する後期貫入超塩基性岩類の一部から、不適合元素濃度がより強度に枯渇したボニナイト的なクロムスピネル (Cr# >70) を伴う単斜輝岩?ダナイトが見つかった。岩脈中の単斜輝石斑晶と、枯渇的な超塩基性岩類中の単斜輝石は、Y, REE など不適合微量元素濃度、REE パターンが共通の特徴示すことから、これらは初生的なボニナイトマグマを起源とする超塩基性集積岩であると結論づけられる。また、推定された初生的なメルト組成は、M~HREE に対して Th および LREE に富む特徴的な微量元素パターンを示す。これは、ボニナイト質岩脈群の起源となる枯渇マントルに、沈み込むスラブから供給された堆積岩メルトが付加した痕跡として解釈される。

本調査地域の火成史は、海洋地殻層序の形成後、含水枯渇マグマによる後期貫入深成岩類の貫入による地殻の厚化を経て、ボニナイトマグマの貫入が生じたと解釈される。この火成活動の変遷は、伊豆マリアナ前弧域に代表される海洋性島弧の発生過程、特に海洋底内での沈み込み帯形成直後からボニナイト火成活動以前の短い期間に相当する最初期の地殻発達プロセスとして解釈される（Ishizuka et al., 2011）。従って、オマーンオフィオライト北部 Fizh 岩体北部地域は、沈み込み帯の形成直後に~10km 厚へと急激に厚化した海洋性島弧地殻断面の好例であると考える。

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

キーワード: オフィオライト, 初期島弧火成活動, ボニナイト, 岩脈群, 地球化学, 火成岩岩石学
Keywords: ophiolite, boninite, island arc magmatism, dike swarm, geochemistry, petrology

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SIT05-20 会場:104 時間:5 月 21 日 17:30-17:45

# 沈み込み開始と連続的海嶺沈み込みによるトルードス SSZ オフィオライトの形成、その溶岩層序、化学組成、Ar-Ar 年代の新資料
# Geochemistry and geochronology of the Troodos ophiolite: An SSZ ophiolite by an extended episode of ridge subduction

遅沢 壮一 [1*], 新城竜一 [2], 羅清華 [3], 江博明 [3], Nguyen Hoang[4], 佐々木実 [5], 石川賢一 [6], 鹿納晴尚 [7], 星博幸 [8], Costas Xenophontos[9], John Wakabayashi[10]
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]

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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.

キーワード: トルードスオフィオライト, 島弧ソレアイト, 2 種のボニナイト, Ar-Ar 年代と放散虫, 沈み込み開始, 海嶺沈み込み
Keywords: Troodos ophiolite, island arc tholeiite, boninite, geochronology and biostratigraphy, subduction initiation, ridge subduction

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SIT05-21 会場:104 時間:5 月 21 日 17:45-18:00

# オマーンオフィオライトマントルセクションからみた沈み込み帯のマントルウェッジにおける酸化還元状態
# Redox state of mantle wedge above subduction zone as inferred from the Oman mantle section

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本研究は，オマーンオフィオライトのマントルセクションから，マントルウェッジの酸化還元状態を知ることを試みた。オマーンオフィオライト北部のフィズマントルセクションは，モホ面から深度約 14 km までが地表に露出している。同岩体からこれまでに採取したかんらん岩を用いて，Ballhause et al. (1991) の方法にしたがい，カンラン石とスピネルの鉱物組成から酸素フガシティーを予察的に計算した。そして，Log fO2 の FMQ バッファーからの偏差をフィズ岩体マントルセクションにプロットしたところ，オフィオライト基底部はモホ面付近より酸素フガシティーがかなり低く，すなわちより還元的なことが明らかになった。とくに，基底スラスト付近では，Δ log fO2 が FMQ?３に達するところもある。従来，島弧玄武岩やマントル捕獲岩は MORB や深海底かんらん岩よりも酸素フガシティーが高く，島弧のマントルは海嶺より酸化的とされている。今回の結果は，沈み込むスラブと接するマントルウェッジ基底部は従来の通説とは逆に，より還元的である可能性を示唆している。

オマーンオフィオライトのマントルセクションは海洋プレート内衝上運動で沈み込み帯の初期の過程を経ており，その際に，下位のメタモルフィックソールから H2O を主体とする流体がマントルセクションに流入し，フラックス溶融を起こしたことが知られる (Arai et al., 2006; 高澤, 2012)。このことはスピネルの Cr#の高い高枯渇なかんらん岩が多数存在することから支持される。すなわち，オマーンオフィオライトでは形成まもないマントルウェッジ（オフィオライト）と沈み込むスラブの上面（メタモルフィックソール）が直接接していることになる。従来，島弧のマントルは酸化的であるとされており，今回オマーンのスピネルから得たデータが正しければ，沈み込み帯のスラブ上面のマントルウェッジは還元的で，地殻に向かうにつれてより酸化的になることを示すことになる。これらの結果を酸素フガシティーのプロキシとされる化学組成（V/Sc 比, Zn/Fe 比）や堆積物由来のメルトの指標 (Th/Ce 比など) と比較し，沈み込みスラブ物質の寄与の度合いを検討する。それによって，沈み込むスラブ上面の堆積物に由来する還元的なメルトによってマントルウェッジが下方から還元された可能性と，もともと還元的な海洋性マントルが熱水循環によって上方から酸化された可能性について検証する。

キーワード: オマーンオフィオライト, かんらん岩, 酸素フガシティー, マントルウェッジ, 沈み込み帯, 酸化還元状態
Keywords: Oman ophiolite, peridotite, oxigen fugacity, mantle wedge, subduction zone, redox state

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SIT05-P01 会場:コンベンションホール 時間:5 月 21 日 18:15-19:30

# 中央インド洋海嶺南部のかんらん岩岩石学：海洋底形成への提言
# Petrology of peridotites in the southern part of the Central Indian Ridge: Implications for ocean floor formation

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中央インド洋海嶺南部からはかんらん岩類がたくさん露出していることがわかってきた。この岩石学的特徴を明らかにし，海洋底形成モデルについて言及したい。

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

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SIT05-P02 会場:コンベンションホール 時間:5 月 21 日 18:15-19:30

# オマーンオフィオライトフォリエイテッド斑レイ岩の成因の岩石学的・構造岩石学的検討
# Petrological and structural examination of the origin of foliated gabbros in the Oman ophiolite

及川 真宏 [1*], 足立 佳子 [2], 野川 裕 [3], 宮下 純夫 [4]
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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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# オマーンオフィオライト・サラヒ岩体最南部地域のマントルセクションにおける広域的空間組成変化
# Spatial compositional distribution in the southernmost part of the Salahi mantle section, the Oman ophiolite

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オマーンオフィオライト北部のサラヒ岩体南西部には，スピネルの Cr#が 0.8 以上と非常に枯渇した特徴を示すダナイトと，少量のハルツバージャイトとパイロクシナイトから構成される超苦鉄質複合岩体（8 km × 5.5 km）が存在する (野本・高澤, 2013)。この岩体は，基底部から浸透した流体によるフラックス溶融が大規模に生じ，ボニナイトメルトの形成場と考えられている。この岩体の南南東方向に同様な規模の超苦鉄質複合岩体が 2 ヶ所点在しており，フィズ岩体北部 (Kanke and Takazawa, 2013) と同様に，高枯渇かんらん岩の帯状配列が予想される。そこで本研究は，サラヒ岩体最南部を対象に，超苦鉄質複合岩体を含むマントルセクションの空間的組成変化を検討したので報告する．

鉱物化学組成の分析の結果，ハルツバージャイトのスピネル Cr#は 0.46-0.67 と組成範囲が限られ，0.7 以上の高枯渇なものは認められない。一方，ダナイトのスピネル Cr#は 0.43-0.80 と組成範囲が広く，高枯渇なものも存在する。また，空間分布を見ると，ダナイトのスピネル Cr#は 0.7 以上のものが東部に集中して出現し，中央部から基底部にかけてはダナイトのスピネル Cr#（0.47-0.57）がハルツバージャイトのスピネル Cr# (0.53-0.67) よりも系統的に低い傾向を示す。サラヒ岩体最南部は面構造が水平に近く，深度方向の変化が少ない。そのため，地表では最上部マントルを水平方向に観察していることになる。また，断面図を用いてモホ面からの深さを検討した結果，中央部から基底部にかけての低 Cr#スピネルの地域は，東部の高 Cr#スピネルの地域よりもより浅所に相当することが明らかになった。スピネルの Cr#の分布と合わせると，低 Cr#スピネルのダナイトは海嶺下で MORB メルトとハルツバージャイトの反応によって形成され，高 Cr#スピネルのダナイトは前者よりも深部で，初期島弧ステージで基底部から浸透した流体との反応したハルツバージャイトのフラックス溶融によって生じたと考えられる。

一方，超苦鉄質複合岩体中心部では，ダナイトのスピネル Cr#が 0.74-0.80 と高い値を示すが，岩体縁辺部では，0.54-0.67 と中心部より低い値を示す。また，縁辺部では，斜長石ダナイトや，斜長石レルゾライト脈，含金雲母ウェールライトが一部で認められ，MORB メルトや流体との反応が示唆される。基底部からの流体の浸透による高枯渇ダナイトの形成と， MORB メルトとの反応による斜長石を含むかんらん岩類の形成の相互関係について今後検討を進める。

キーワード: オマーンオフィオライト, マントルセクション, スピネル, カンラン岩, 高枯渇帯, MORB
Keywords: oman ophiolite, mantle section, high refractory zone, spinel, peridotite, MORB

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# 高速拡大海嶺におけるセグメント構造に規制されたマグマシステムの系統的変化: オマーンオフィオライト V1 溶岩層からの検討
# Along-axis variations of a fast-spreading mid-ocean ridge: implication from the volcanic rocks in the Oman ophiolite

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海嶺は 1〜4 次のセグメントから構成され、この構造によって地形のみならずマグマの供給やマントルプロセスが支配されていると考えられている。海嶺セグメント内の地形は、セグメント中心部で膨らみ、境界部へ向かって低くなっていく地形を示している [Scheirer and Macdonald, 1993]。この地形変化に沿って、海嶺下の地震波低速度帯もセグメント境界部で大きく下降する。したがって、海嶺セグメントに沿ってセグメント中心部では比較的安定なメルトレンズを有し、境界部へ向かってメルトレンズが縮小・消滅するという系統的な変化していることが推定される。本研究では、これらの変化をオマーンオフィオライト北部地域に分布する溶岩層から検討した。

本研究では南北 70 km にわたる 8 つの地域で溶岩層の火山学的検討を行い、古海嶺軸方向の火成活動システムを復元した。海嶺軸上で形成された溶岩層の厚さはセグメント中心部の Bani Ghayth において厚さ 603 m、境界部では Wadi Fizh で厚さ 410 m であった。つまり、海嶺軸上火成活動で形成される溶岩の厚さはセグメント中心部から境界部へと薄くなる傾向がある。岩相は、全体にパホイホイ溶岩が卓越して観察されるセグメント中心部に対して、境界部では枕状溶岩が卓越しており、境界部における起伏に富んだ海底地形が推測される。海嶺セグメント中間部では厚さ 50-300 m のシート状岩脈群―溶岩層遷移帯が観察され、これは中心部や境界部（厚さ 20-50 m）と比べて厚い。この違いはセグメント中心部から境界部にかけて、溶岩噴出が頻繁に起こる―溶岩がやや間欠的に噴火する―溶岩の噴出よりも岩脈貫入が優位に起こる、というマグマシステムの変化を反映している可能性がある。しかし海洋底溶岩層全体の厚さはこれらの各地域を通じて大きな変化はない。2 次および 3 次のセグメント境界に相当する Wadi Fizh, Suhayli, Hilti ではオフアクシス火成活動の痕跡である割れ目噴火口や溶岩層へ貫入した「岩脈群」が認められ、オフアクシス火成活動によって生成された溶岩が海洋底溶岩層全体の厚さに寄与していることが明らかとなった。

キーワード: 高速拡大海嶺, MORB, 火山岩層序学, オマーンオフィオライト, 海嶺セグメント構造
Keywords: Fast-spreading ridge, MORB, Volcanostratigraphy, Oman ophiolite, Segment structure

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# アルバニア，ミルディータオフィオライト西帯かんらん岩の岩石学的特徴：メルト成分に富むかんらん岩の成因
# Petrology of peridotite in the Western Mirdita Ophiolite, Albania: The origin of fertile peridotite

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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.

キーワード: アルバニア, オフィオライト, 肥沃なかんらん岩
Keywords: Albania, Ophiolite, Fertile peridotite

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# U-stage, EBSD, シンクロトロンX線によるアンチゴライトCPOの測定
# Comparison of the CPO of antigorite serpentinite by U-stage, EBSD and synchrotron X-rays

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

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

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

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

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

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# 日本海に産するかんらん岩捕獲岩から推測される背弧海盆下のマントル進化
# Mantle evolution beneath back-arc basin inferred from peridotite xenoliths form the Japan Sea

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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.

キーワード: 背弧海盆, 日本海, マントル, かんらん岩捕獲岩
Keywords: Back-arc basin, Sea of Japan, Mantle, Peridotite xenolith

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# 水熱実験による蛇紋岩化作用における pH とシリカの影響についての検討
# Effects of pH and silica on the progress of serpentinization deduced from hydrothermal experiments.

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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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キーワード: 超塩基性岩, 蛇紋岩
Keywords: ultrabasic rock, serpentine

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# 玄武岩掘削試料の透水実験に基づく海洋地殻の浸透率変化と海洋底での流体移動
# Evolution of permeability and fluid pathway in the oceanic crust inferred from experimental studies on basalt cores

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海洋地殻は中央海嶺で形成された後、最長で 1 億数千万年という年月をかけて海溝へと水平に移動し、大陸プレート、あるいは別の海洋プレートの下に沈み込んでその一生を終える。この間、海洋地殻は様々な物理的、化学的変化を受ける。中央海嶺近傍では、300 ℃から 400 ℃の高温のブラックスモーカーや、多様な生物の存在から、火成活動に起因する活発な熱水循環系が発達しているとされる。さらに、中央海嶺から離れた後も、数から数十℃の低温の熱水循環が引き続いて起こっていることが、モデル計算と熱流量の観測との相違から推察されている。こうした熱水活動は浸透率というパラメータと密接に関連している。海洋地殻の浸透率は海洋底掘削の際の掘削孔を用いたその場観測により、深さごとの値や、年代による変化が詳細に知られるようになった。浸透率の深さによる違いは、海洋地殻を構成する岩石種や、その構造が大きな要因となっていると考えられる。

中央海嶺において玄武岩質マグマが海底に直接噴出し、海洋地殻最上部には枕状溶岩や、それが海水により急冷されて破砕された破片の集合体であるハイアロクラスタイトが形成される。その浸透率は間隙や割れ目の存在から $10^{-10}$ $m^2$ から $10^{-12}$ $m^2$ という高い値を示す。その下部には、塊状玄武岩、平行岩脈群、ハンレイ岩の順に存在するが、それらの浸透率は間隙や割れ目がほとんど存在しないことから $10^{-16}$ $m^2$ 以下と低い値を示す。さらに、海洋プレートの移動に伴って、海洋地殻最上部には遠洋性堆積物がしだいに厚くなっていく。この遠洋性堆積物の浸透率は低くその値は $10^{-14}$ $m^2$ から $10^{-18}$ $m^2$ である。したがって、枕状溶岩やハイアロクラスタイトからなる浸透率の高い最上部玄武岩層は、その上下に浸透率の低い層に挟まれた格好になる。そのため、中央海嶺から離れた非軸部の低温の熱水循環系は最上部玄武岩層内に存在し、海底とは遮断され、熱水循環は海底下で静かに起こっていると推定される。

さて、浸透率の年代による変化であるが、高い浸透率を示す最上部玄武岩層においては、プレートの年代とともに系統的に低下することが分かっている。その変化は、年代が 1 Ma の地点では約 $10^{-10}$ $m^2$ であったものが、7 Ma の地点では $10^{-14}$ $m^2$ とおよそ 600 万年の間に 4 桁低下するというものである。本研究はこのような浸透率の系統的な低下がなぜ生じるかということに着眼して実験を行った。

海洋プレートは年代とともに深さが増し、その最上部の遠洋性堆積物の厚さも増加することから、最上部玄武岩層にかかる封圧も年代とともに増加していく。こうした封圧の増加に起因する圧密により、最上部玄武岩層の浸透率が低下するかどうかを、海洋底掘削試料の玄武岩を用いて、広島大学設置の容器内変形透水試験機を用いて実験した。実際に海底下で推定される封圧変化を再現して、浸透率の測定実験を行ったが、その場観測から期待される 4 桁もの浸透率の低下は認められなかった。このことから、浸透率の低下には、圧密以外のプロセスが主に働いていると結論づけた。

また、今回は約 1 から 2 Ma の年代を持つ玄武岩と 140 Ma の年代を持つ玄武岩の掘削試料を用いて実験を行ったが、古い 140 Ma の年代を持つ玄武岩には多量のカルサイト脈が見られた。こうした脈は 1 から 2 Ma の若い年代の玄武岩には見られなかったため、こうしたカルサイトの沈殿が熱水の流路を遮断し、浸透率が低下していると予想した。また、熱水の流量や炭酸カルシウムの溶解度などを用いた計算の結果、海洋底の熱水中に溶解している炭酸カルシウムだけでは、高浸透率領域の間隙や割れ目を全て充填するには不十分な可能性が高いと分かった。そして、非軸部の海洋底において、低温の熱水活動に起因する多様な生物圏が広がっていることが近年示唆されている。これらをまとめて、最上部玄武岩層の、年代による浸透率の低下は、生物活動による沈殿が大きな要因であると推定した。

陸上に顔を出した緑色岩や緑色片岩の多くは中央海嶺で形成された海洋底玄武岩を起源に持つが、付加体や高圧変成帯に海洋底玄武岩が取り込まれるか否かは海洋底の玄武岩の浸透率や間隙率の構造が鍵を握っていると言われている。このように大陸や島弧に取り込まれた海洋地殻物質中には、海洋底で形成された沈殿物や鉱物脈が存在している可能性が高い。このような沈殿物や鉱物脈の産状、量比を元あった海洋底での深さごとに調査すれば、海洋地殻の構造を知ることができるかもしれないという考えを提案する。

キーワード: 海洋地殻, 熱水循環, 浸透率, 間隙率, 炭酸塩鉱物沈殿
Keywords: Oceanic crust, Hydrothermal system, Permeability, Porosity, Carbonate precipitation

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# オマーンオフィオライトヒルチかんらん岩体のかんらん石結晶方位ファブリック
# Olivine crystal fabric variations in the Hilti mantle section, Oman ophiolite

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オマーンオフィオライトは，アラビア半島東端に位置する世界最大のオフィオライトである．本研究では，オマーンオフィオライト北部ヒルチかんらん岩体の構造解析から海洋プレートマントルリソスフェアの大構造について考察することを目的とした．試料は粗粒なハルツバージャイトを用い，SEM-EBSD システムを用いた構成鉱物の結晶方位測定，EPMA を用いた鉱物の主要元素化学組成の測定を行った．かんらん石の粒径は，粗粒（>3mm）から比較的細粒（～1mm）であり，かんらん石粒内に波動消光やキンクバンドが観察された．斜方輝石と少量の単斜輝石内部に離溶ラメラが観察された．結晶方位測定の結果，全試料が [010] の Z 軸集中が最も強く，[100] と [001] が XY 面に帯状に分布する AG タイプを示した．主要元素化学組成はモホ面からの距離が異なる 3 試料のスピネル，かんらん石，斜方輝石を測定した．スピネルの Cr#(=Cr/(Cr+Al)) は 0.5～0.6 であった．かんらん石の Mg#(=Mg/(Mg+Fe)) は 0.91～0.92 であった．鉱物の主要元素化学組成の結果，測定した試料のすべてがマントル起源のかんらん岩組成をもつことがわかった．さらにスピネルの Cr#は，海洋底かんらん岩組成を示したことから，本研究試料は中央海嶺で形成された海洋リソスフェアの状態を保存していると考えられる．また，結晶方位ファブリックについては，今回の結果と先行研究を合わせるとヒルチかんらん岩体は AG タイプが支配的と考えられる．このことは，海洋リソスフェアが A タイプではなく AG タイプを主体とした構造をもつことを示唆する．実験結果からメルトを含むと結晶方位ファブリックが A タイプから AG タイプに変化することが示されており，本研究で得られた AG タイプは中央海嶺直下のメルトの影響を受けて形成された可能性が考えられる．

Keywords: Oman, harzburgite, Crystallographic fabric, ocean lithosphere

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# 北西太平洋湯川海丘から見つかった深部海洋リソスフェアの欠片
# Fragments of deep oceanic lithosphere from the Yukawa knoll in NW Pacific

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

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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.

キーワード: 海洋地殻, 下部地殻, ガブロ, かんらん石含有ガブロ類
Keywords: oceanic crust, lower crust, gabbro, olivine-bearing gabbroes

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# Fe-K 端 XANES 分析によるプチスポットマグマの酸化還元状態の検討
# Oxygen fugacity of basaltic magma from petit spot: a preliminary result from Fe-K edge XANES study

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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.

キーワード: 酸素フュガシティ, プチスポット, 玄武岩, XANES, ガラス, マントル
Keywords: oxygen fugacity, petit spot, basalt, XANES, glass, mantle

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# オマーンオフィオライト・サラヒマントルセクション超苦鉄質複合岩体における単斜輝石の REE 組成とボニナイト質メルトの形成過程
# Evidence for the formation of boninitic melt in the ultramafic complex from the Salahi mantle section,the Oman ophiolite

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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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# 北部オマーンオフィオライト，Wadi Thuqbah におけるモホ遷移帯ダナイト‐ウェールライトの地球化学的不均質性
# Geochemical heterogeneity of Moho transition zone dunites-wehrlites from Wadi Thuqbah, the northern Oman ophiolite

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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.

キーワード: 単斜輝石, 希土類元素, ダナイト, ウェールライト, モホ遷移帯, オマーンオフィオライト
Keywords: clinopyroxene, REE, dunite, wehrlite, Moho transition zone, Oman ophiolite

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# フィリピン海プレートの短波長不均質とガイド波
# Small-scale heterogeneities in the Philippine Sea plate and the guided waves

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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.

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