

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

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

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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 weak. 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、ポ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、含金雲母ウエールライトの一部が認められ、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, spinel, peridotite, MORB

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变化: 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 ではオフアキ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、オフアキ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

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 Mirdita 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#[$=\text{Cr}/(\text{Cr}+\text{Al})$ 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

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 serpentinitized 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 (AV_p); 11-15%, anisotropy of S-wave (AV_s); 10-15%) than from EBSD results (AV_p; 12-19%, AV_s; 18-21%). EBSD measurement and U-stage thus over-estimate elastic velocity anisotropy, since both methods only measure relatively coarse-grained and well-crystallized antigorite.

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

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 from 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

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 conducted 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 chrysotile veins are commonly observed in serpentinized peridotites which contained mainly mesh-textures of lizardite; therefore, our results may indicate such fibrous chrysotile 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 monotonically, 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

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碎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、付加体や高压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

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ッ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

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, gabbro 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 °C. These conditions lie on a conductive geotherm with heat flow of 60-80 mW/m² 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

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 gabbros are not simple cumulate from basaltic melt, but they require ultrabasic melt that is rich in Mg and Cr. Lithostratigraphy of the olivine-bearing gabbros also show that those rocks are related to the more mafic, sometimes ultramafic rocks. This new model must be 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 gabbros

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

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 McDonough, 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

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 clinopyroxenes 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 chondrite-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

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 ($f_{max}=5$ 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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