

ジルコン微量元素組成を用いたA-type花崗岩の判別法：高知県足摺岬花崗岩類の例

Trace element composition in zircons from A-type granitoids in the Cape Ashizuri, SW Japan: Implications for new source rock index using zircon

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Trace element composition in zircon is expected to be an important indicator of composition of host magma, especially of Hadean detrital zircons (e.g. Grimes et al., 2007). Some Hadean detrital zircons are suggested to be formed in continental crustal magma (e.g. Valley et al., 2005; Grimes et al., 2007), however, detail composition of host magma is still unveiled. Recent discoveries of granitic clast in meteorites in Early Solar System (lunar, HED and LL meteorite) showing anhydrous, alkali-rich A-type granitic affinities (e.g. Warren et al., 1983; Bonin et al., 2002; Terada and Bischoff, 2009) implies that A-type granitic rocks were present in the Hadean Earth (Bonin et al., 2007). Therefore, it is important to know trace element characteristics in zircons from A-type granite for exploring evidence of the ancient A-type granitic rocks.

To obtain primary features of trace element composition in zircons from A-type granite, we conducted *in-situ* LA-ICP-MS trace element analysis for 47 zircon grains from 4 samples of rapakivi granite, Qtz-syenite and melanocratic syenite in the Ashizuri complex. These alkalic granitoids in Ashizuri complex have characteristics of A-type granite (Loiselle and Wones, 1979) and within-plate granite (Pearce et al., 1984), and is suggested to be formed dominantly by crystal fractionation process from OIB-type basaltic magma (Stein et al., 1996).

Zircons from the Ashizuri A-type granitoids show oscillatory zoning, homogeneous dark core, disturbed texture and patchy texture in Cathodoluminescence images. Based on the typical igneous REE patterns (HREE enrichment, negative Eu anomaly and positive Ce anomaly) and its similarity each other in zircons from rapakivi granite and Qtz-syenite, it is suggested that the trace element composition of the zircons reflect those of the host magma. On the other hand, some zircons in melanocratic syenite show large variations of REE pattern and include obvious inherited cores, which imply contamination of surrounding rocks to host magma. To clarify characteristics of zircons crystallized from A-type granitic magma, we only use data from the rapakivi granite and the Qtz-syenite for comparison with previous data from other type (S-, I-, M-type) granitic rocks.

The magmatic zircons from the Ashizuri A-type granitoids show large Eu negative anomalies ($Eu/Eu^* = <0.004 - 0.070$), high Nb contents (2.85 -236 ppm), relatively high Y (423 -13520 ppm) and U contents (171 -7908 ppm), and relatively low Sr contents (0.08 -2.38 ppm). These trace element feature in the zircons probably reflect high HFSE, low Eu and Sr concentration in the host A-type granitic magma. The geochemical characteristics of the zircons from Ashizuri complex become more distinct in Eu/Eu^* , Nb/Sr, U/Sr, Y/Sr closs-plot diagram, showing lower Eu/Eu^* , higher Nb/Sr, U/Sr and Y/Sr ratio compared to those in zircons from other type granitic rocks. Previous trace element data in zircons from A-type granitoids in Delamerian Orogen, South Australia (Pankhurst et al. 2013) is also plotted on similar area to the Ashizuri A-type granitoids in Eu/Eu^* vs. Nb diagram. Because high HFSE, low Eu and Sr contents are common feature in the A-type granitic rocks, these diagrams are probably useful for distinguish zircons crystallized in A-type granite from those in other

granitic rocks.

キーワード：ジルコン微量元素組成、A-type花崗岩、LA-ICP-MS、足摺岬

Keywords: Zircon trace element composition, A-type granite, LA-ICP-MS, the Cape Ashizuri, SW Japan

日本島弧における花崗岩質岩石中モナザイトの化学組成

Geochemistry of monazite in granitic rocks from Japanese island arc

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Monazite is a one of rare earth element (REE)-rich phosphate mineral and commonly occurs in pelitic metamorphic rocks and peraluminous igneous rocks (Williams et al., 2007). Geochemistry of metamorphic monazite has been intensively investigated using laser ablation-inductively coupled plasma-mass spectrometry (LA-ICPMS) and its REE pattern, especially Eu negative anomaly ($[Eu/Eu^*]_N$) and heavy REE (HREE) depletion ($[Gd/Lu]_N$), is linked to the crystallization condition (e.g., Rubatto et al., 2006). In contrast, the geochemical investigation of igneous monazite has been mainly carried out using electron-microprobe analysis (EMP) (e.g., Kelts et al., 2008). Hoshino et al. (2012) analyzed the monazites in granites and pegmatites from Japan by EMP. They found that the ratios of light REE (LREE) to middle REE (MREE) on the monazites are different between ilmenite- and magnetite- series granitic rocks, which was interpreted to reflect the different degree of differentiation. Yet, the determination of Eu and HREE abundances have not been carried out due to the interference and low-concentrations during EMP analysis. In this study, we have used LA-ICP-MS to measure Eu and HREE abundances in the monazites and examined whether Eu anomaly and HREE depletion exhibit consistent variations with LREE or not. The results of monazite REE analysis using LA-ICPMS shows distinct REE patterns between the monazites from ilmenite-series and magnetite-series granitic pegmatites. The Eu negative anomalies of the igneous monazites were significantly large ($[Eu/Eu^*]_N < 10^{-3}$) relative to those of metamorphic monazites. This feature may be used as indicator to distinguish between a monazite in pegmatite and a one in metamorphic rock. Among the monazites of the two series, the $[Eu/Eu^*]_N$ values of ilmenite-series monazites are larger by one or two orders of magnitude than those of magnetite-series monazites. The REE patterns of monazites in ilmenite-series rocks display moderate decrease from La to Gd relative to those of monazites in magnetite-series rocks; in contrast, the monazite REE patterns of ilmenite-series rocks show prominent decrease from Gd to Lu relative to those of magnetite-series rocks. These different features in REE patterns between monazites from ilmenite-series and magnetite-series would reflect the degree of differentiation and imply that the formation of ilmenite-series rocks is attributed to not only assimilation of sediments but also crystal fractionation, especially the fractionation of minerals incorporating HREEs relative to MREEs. The relatively enriched MREE and depleted HREE abundances in ilmenite-series monazite cannot be explained simply by assimilation of subducted sediments, which are enriched in both MREE and HREE (Plank and Langmuir, 1998). This inference is consistent with the differences of O, Sr and Nd isotopic features between two-series granitic rocks (Takagi, 2004). We consider that fractional crystallization of the minerals enriched in HREE relative to MREE (e.g., garnet) subsequent to sedimentary assimilation defines the characteristic monazite REE patterns of the magnetite-series and ilmenite-series granitic rocks in Japanese island arc.

キーワード：希土類元素、微量元素、レーザーアブレーション誘導結合プラズマ質量分析

Keywords: REE, trace element, LA-ICP-MS

オントンジャワ海台玄武岩の強親鉄性元素多様性

Highly siderophile element variations in the Ontong Java Plateau basalts

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The Early Cretaceous Ontong Java Plateau is widely recognized as a product of the largest igneous activity on the Earth, and its formation and evolution has been investigated by multidisciplinary approaches in order to understand large igneous provinces (LIPs) in general. Recent geochemical studies suggest that the Ontong Java Plateau has sampled a near-primitive, less degassed deep mantle reservoir that has remained isolated from convecting upper mantle shortly after the formation of the Earth. Since such primitive reservoir is possibly only available at the base of lower mantle in the modern Earth, the plateau-forming lavas may have characteristic compositions of highly siderophile elements reflecting the deep-plume source likely influenced by core formation or core-mantle interaction. Here we report comprehensive dataset of Re-Os isotopes and highly siderophile element (HSE: Os, Ir, Ru, Pt, Pd and Re) concentrations for all three distinct geochemical types of the Ontong Java Plateau basalts. They are comprised of 11 samples of the less evolved Kroenke-type lavas (>8 wt.% MgO) from two deep sea drill sites (ODP Sites 1185 and 1187), 22 samples of the more dominant Kwaimbaita-type basalts (<8 wt.% MgO) from three drill sites (ODP Sites 1183, 1185 and 1186) and on-land exposure in Malaita, Solomon Islands and 22 samples of less voluminous Singgalo-type basalts (<8 wt.% MgO with a few exceptions) forming younger cover on the Kwaimbaita-types lavas at an ODP Site 807 and Malaita. All of Kroenke- and most of Kwaimbaita-type basalt data yield a linear array on the Re-Os isochron diagram corresponding to an age of 121.5 ± 3.1 Ma and initial $^{187}\text{Os}/^{188}\text{Os}$ ratio of 0.1304 ± 0.0049 , almost identical to those reported in previous studies. Singgalo-type basalts tend to show variably radiogenic initial $^{187}\text{Os}/^{188}\text{Os}$ ratios, indicating contributions of enriched components either derived from surficial environments or from radiogenic pyroxenitic source. Significant contributions of pyroxenitic source is inferred from the observation that Singgalo-type lavas have distinctively lower platinum-group element (PGE) abundances when compared with similarly evolved Kwaimbaita-type basalts, although sulfide-fractionation may have played a role on their depletions. The chondrite-normalized HSE patterns of Kroenke- and Kwaimbaita-type basalts show broadly similar IPGE-depleted and PPGE-enriched patterns typical of sulfur-undersaturated tholeiitic basalts. However, the two types can be distinguished by contrasting Os and Ru abundances (Kroenke: high, Kwaimbaita: low) probably reflecting the different degrees of olivine/spinel fractionation. Since the observed HSE fractionation trend (particularly Ir variation) is significantly different from those identified for Hawaiian picrites or Archean komatiites, further constraints on HSE behavior during magma evolution are clearly required for estimating HSE compositions of primitive magma and source mantle.

キーワード：巨大火成岩岩石区、玄武岩、白金族元素

Keywords: Large Igneous Provinces, basalt, Platinum-group elements

Os同位体比と白金族元素から見たEM-1成分の由来

Os isotope ratios and PGE abundances of the Pitcairn basalts: Implication for the EM-1 source

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It is widely known that subduction recycled materials are involved in producing the chemical and isotopic heterogeneities observed in oceanic island basalts (OIB). The type of recycled material present in the Enriched Mantle 1 (EM-1) source, which have radiogenic Sr, unradiogenic Nd, and unradiogenic Pb isotope compositions compared to those of depleted mantle source, has been widely debated. Oceanic crust with pelagic sediment (e.g., Chauvel et al., 1992), delaminated subcontinental lithospheric mantle (SCLM) (e.g., Hauri and Hart, 1993), subducted oceanic plateaus (Gasperini et al., 2000) and just single melting process involving pristine mantle (Collerson et al., 2010) have all been invoked as the EM-1 source. The rocks from Pitcairn hotspot are well known to have a strong EM-1 flavor. Recently, Garapic et al. (2015) suggested that the high Ti abundances in the Pitcairn basalts are possibly related to recycled pyroxenites in the Pitcairn mantle source. We have measured Os isotope ratios and major and trace element abundances including the platinum group elements (PGE) in the basalts from Pitcairn Island to elucidate the origin of the EM-1 signature of these basalts.

The Os isotope ratios for the samples with Os > 20 pg/g range from 0.135 to 0.152 and are similar to those measured in previous studies on EM-1-type basalts (~0.150 for samples with Os > 50 pg/g and ~0.180 with Os > 20 pg/g from Reisberg et al., 1993; Eisele et al., 2002; Garapic et al., 2015). The Os, Ir and Ru concentrations of the Pitcairn basalts are roughly correlated with MgO and Ni contents and tend to be lower than those of other OIB such as Hawaii and Canary Islands. Whereas Pd and Re concentration are similar to those for other OIBs. The chondrite-normalized PGE patterns of studied samples show systematic variation with or against the degree of the EM-1 flavor (e.g., decreasing of the $^{206}\text{Pb}/^{204}\text{Pb}$ and $^{143}\text{Nd}/^{144}\text{Nd}$ isotope ratios). Since crustal materials normally show large fractionation between I-PGE and P-PGE and the crustal materials have higher Os isotope ratios than mantle, the simple assimilation of crustal materials cannot explain our data. We carefully try to make an assumption of the source magma components to explain the genesis of Pitcairn Island basalts based on our data combined with previous studies.

キーワード：白金族元素存在度、Os同位体比、EM-1

Keywords: PGE abundances, Os isotope ratio, EM-1

南太平洋ピトケアン島におけるメルト包有物の地球化学的研究

Geochemical study of melt inclusions in Pitcairn basalts, South Pacific

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水や揮発性元素の存在は、マントルダイナミクスを考える上で重要であるが、マントル由来の火山岩からマントル中の揮発性元素量や分布を制約するような研究はまだ少ない。そこで、揮発性元素を保持していると考えられるオリビンメルト包有物に対して、揮発性元素と同時に主要元素、微量元素、鉛同位体比を局所分析することを試みた。南太平洋のピトケアン島に産するメルト包有物について予察的な結果を得たので報告する。ピトケアン島の火山岩の同位体組成はDMからEM1の範囲を示すが、本研究ではEM1的な岩石試料からPC-41とPC-87Aの2つの玄武岩選択し、複数の分析装置により局所分析するために50 μm 以上の比較的大きいメルト包有物を用意した。それぞれのメルト包有物は特徴が異なり、PC-41のメルト包有物には自形の単斜輝石を晶出するもの、角閃石とイルメナイトを晶出するものの2種類があった。一方PC-87Aのメルト包有物は、均質なガラスもしくは樹枝状の単斜輝石を均等に含む。分析領域は晶出した鉱物から最大限離れたガラスあるいは石基領域に設定した。始めに揮発性元素(H₂O, CO₂, F, P, S, Cl)を15 μm 径で、続いて鉛同位体を30 μm 径でSIMS(IMS 1280-HR)を用いて測定した。次にFE-EPMAにより10 μm 径で主要元素の測定を行った。最後に、LA-ICP-MSを用いて20 μm 又は30 μm 径で主要元素と微量元素について測定を行った。PC-41とPC-87AはPb同位体比に関して差はなく、全岩の同位体比と同じ範囲に入った。一方、元素組成に関しては両者に差があることが示された。MgOと他の主要元素について比較してみると、PC-87Aは全岩組成のトレンドに一致するが、PC-41は明らかにこれから外れた2つのトレンドを示す。この2つのトレンドは包有鉱物種の違いと相関していることから、メルト包有後に結晶晶出により分別したものだと考えられる。また、PC-41がPC-87Aに比べてMgOが低いことも、PC-41で分別がより進んでいることと調和的である。微量元素については、PC-87Aが全岩の組成に一致する一方、PC-41ではPC-87Aと同様の組成を持つものとそれとは異なる組成を持つものが見つかった。これは晶出鉱物や主要元素の違いとは相関を持っていなかった。そして、後者は特徴的に重希土類元素が低い値を持ち、これは高圧下でガーネットと共存していたメルトがマグマだまりに流入し、マグマだまりで組成の不均質を生じている可能性を示唆している。揮発性元素に関しては、PC-41とPC-87AでH₂O量に顕著な差が見られた。PC-87Aは0.370.81 wt.%であるのに対して、PC-41は、0.030.10 wt.%と低い値を示す。CO₂は共に脱ガスや気相への濃集の影響により元の値を保持していないと考えられる。しかし、比較的脱ガスしにくいハロゲンについては、例えばClが570-1700 ppmと高濃度であり、H₂Oや微量元素との相関も見られることからマグマの組成を反映していると考えられる。今回の分析により、PC-87Aのような急冷され均質なメルト包有物は、比較的深部の情報を保持している可能性があり、メルト包有物からマントルソースでのH₂Oや揮発性成分組成を見積もる上で有用ということが分かった。しかし、PC-41のような晶出結晶を多く含むメルト包有物は、そのH₂Oの量が脱ガスや拡散の過程で大きく減少し、メルト包有物組成から初生マグマの組成を推定することは難しいことに留意する必要がある。

マントルリザボアの成因：沈み込み帯フィルターとマントル熱進化の役割

Origin of geochemical mantle reservoirs: Roles of subduction filter and thermal evolution of mantle

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Upwelling mantle melts at Mid-Ocean Ridges (MOR) to form basaltic igneous oceanic crust (IOC). IOC and overlying sediment (SED) descend into the mantle at subduction zones (SZ). The IOC, SED, and overriding mantle melt to form stable continental crust (CC) after crustal-level processing, whereas the residual slab is recycled into the lower mantle. We quantitatively explore the element re-distributions at MOR and SZ using numerical mass balance models, and we evaluate their roles in the Earth's geochemical cycle. Our models of slab residues differ from previous ones by being internally consistent with geodynamic models of modern arcs and successful explanations of modern arc magma genesis, and by including element fluxes from the dehydration or melting of each underlying slab component. We find that the upper mantle potential temperature (T_p) was 1400-1650 °C from 3.5 to 1.7 Gyr before decreasing gradually to ~1300 °C today. Hot SZs with T_p ~1600 °C have a thermal structure like modern SW Japan where high-Mg andesite is formed that is like CC. Isotopically, residual IOC from hot SZ evolves to the HIMU OIB reservoir, residual SED to EMII, the residual base of the mantle wedge to EMI, and the residual top of the mantle wedge to the subcontinental lithosphere (SCLM) reservoir, after 1.7-2.5 Gyr of storage in the lower mantle. The Common (C) or Focal Zone (FOZO) reservoir is a stable mixture of the first three residues. Older recycled residues (~2.5 Gyr) form the DUPAL anomaly in the southern hemisphere, whereas younger ones (~1.7 Gyr) are in the northern hemisphere. These ages correspond to major CC forming events. We attribute the E-W heterogeneity of the depleted upper mantle (DMM) to involvement of sub-Gondwana SCLM except in the Pacific.

キーワード：マントルリザボア、沈み込み帯フィルター、マントル熱史

Keywords: Mantle reservoir, Subduction zone filter, Thermal evolution of mantle