

Unravelling metamorphic-fluid events in Gondwana collision: U-Pb-REE constraints from Sor Rondane Mountains, Antarctica

Unravelling metamorphic-fluid events in Gondwana collision: U-Pb-REE constraints from Sor Rondane Mountains, Antarctica

外田 智千^{1*}, 堀江 憲路¹, 足立 達朗², 小山内 康人², 中野 伸彦², 馬場 壮太郎³, 豊島 剛志⁴
HOKADA, Tomokazu^{1*}, HORIE, Kenji¹, ADACHI, Tatsuro², OSANAI, Yasuhito², NAKANO, Nobuhiko², BABA, Sotaro³, TOYOSHIMA, Tsuyoshi⁴

¹ 国立極地研究所, ² 九州大学, ³ 琉球大学, ⁴ 新潟大学

¹National Institute of Polar Research, ²Kyushu University, ³University of Ryukyus, ⁴Niigata University

Assembly of Gondwana supercontinent has been argued in numerous studies. Generally the reported ages of Gondwana collision zones are in the range of 750-500 Ma, and two main age groups of 750-620 Ma and 570-530 Ma are estimated (e.g., Meert, 2003). The first episode (~620Ma) is mainly reported from eastern Africa to East Antarctica, and the second episode (~530Ma) is dominated in southern Africa through East Antarctica-Sri Lanka-southern India to eastern Australia. It is, however, not yet fully understood the superimposition of these two events in the crossing region.

Sor Rondane Mountains in East Antarctica is one such area where 640-630 Ma and 550-520 Ma metamorphic-fluid events are recorded (e.g., Shiraishi et al., 2008. Adachi, 2010). Greenschist-facies through amphibolite-facies to granulite-facies metamorphic rocks occupy the area, and the granulite-facies rocks are dominated in the northeastern-central part of the area (e.g., Shiraishi et al., 1992; Osanai et al., 1992). Multiple leucocratic veins and granitic intrusives are also developed. We present zircon and monazite U-Th-Pb and REE analyses by using ion microprobe and electron microprobe applying to garnet-biotite-sillimanite gneiss and associated leucoveins in the central part of Sor Rondane Mountains. Zircon in garnet-sillimanite-biotite gneiss yields c.640-630 Ma with minor >700 Ma and 550-520 Ma ages, and gives clear age-chemistry relation that HREE/MREE ratios drop in c.640-630 Ma zircon crystals compared with older and younger grains that are presumably controlled by REE partitioning with the coexisting garnet. Zircon and monazite in multiple generations of leucoveins also yield >700 Ma, 640-630 Ma and 550-520 Ma ages. Combined rare earth elements (REE) chemistry with the U-Th-Pb age domains in syn- and post-metamorphic leucoveins suggests contrasting isotopic and chemical signatures, and could provide constraints for decoding Neoproterozoic-Cambrian metamorphic-fluid regimes in the Gondwana collision zone.

キーワード: ゴンドワナ, 東南極, セールロンダーネ山地, 変成作用, ジルコン, モナザイト

Keywords: Gondwana, East Antarctica, Sor Rondane Mountains, metamorphism, zircon, monazite

東南極セール・ロンダーネ山地におけるリソスフェアの進化 Evolution of continental lithosphere in the Sor Rondane Mountains, East Antarctica

大和田 正明^{1*}, 亀井淳志², 堀江憲路³, 馬場壮太郎⁴, 小山内康人⁵

OWADA, Masaaki^{1*}, KAMEI, Atsushi², HORIE, Kenji³, BABA, Sotaro⁴, OSANAI, Yasuhito⁵

¹ 山口大学大学院理工学研究科, ² 島根大学総合理工学部, ³ 国立極地研究所, ⁴ 琉球大学教育学部, ⁵ 九州大学比較文化研究院

¹ Yamaguchi University, ² Shimane University, ³ National Institute of Polar Research, ⁴ University of Ryukyus, ⁵ Kyushu University

The Sor Rondane Mountains is situated within the collision zone between the West and East Gondwana and the time of collision is regarded as the late Proterozoic (650-600 Ma). The mountains consist of greenschist- to granulite-facies metamorphic rocks and various kinds of intrusive rocks. The tonalite complex is exposed in the southern part of the mountains and its magmatic age is considered to be at the middle Proterozoic (990-920 Ma). This tonalite would originally be formed at the subduction related tectonic setting prior to the collision event. Large amounts of microgabbro occur as mafic magmatic enclaves (MMEs; 990 Ma) and dikes (950 Ma) in the tonalite complex. Unmetamorphosed lamprophyre dikes intrude the tonalite complex and gneisses during the late- to post-collisional stages. The intrusive age of the lamprophyre is of 560 Ma. The magma processes of the tonalite complex together with the late- to post collisional lamprophyre dikes, therefore, provide us useful information of the evolution of continental lithosphere during the formation of Gondwana supercontinent.

The microgabbro represents the low-K and tholeiitic series, and is geochemically classified into Low-Ti and High-Ti microgabbros. The MMEs and dikes of microgabbros are equivalent to the Low-Ti and the High-Ti microgabbros, respectively. The Low-Ti and High-Ti microgabbros show geochemical signature similar to the Oceanic Arc Basalts and the Back-Arc Basin Basalts, respectively. The middle Proterozoic magma processes would, therefore, proceed at a subduction zone with back arc spreading in an oceanic arc environment. The lamprophyre corresponds to alkaline rocks in the TAS diagram, and are characterized by high abundances of LILE elements and REE, especially Rb, Ba, Sr and LREE. The trace element abundances normalized to primitive mantle display enrichment of LILE and depression of HFSE with Nb and Ta negative anomalies. The lamprophyre is plotted in the within-plate field and a part of the island arc field that is close to the within-plate field on some discrimination diagrams. Considering the geochemical features, the lamprophyre was formed in a within-plate tectonic setting by the mixing of subduction-related materials. The initial Sr isotopic ratios (SrI) range from 0.7022 to 0.7040 (epsilon SrI = -14 to 12) for the Low-Ti microgabbro and from 0.7024 to 0.7030 (epsilon SrI = -14 to 1) for the High-Ti microgabbro. The initial epsilon Nd values for the Low- and High-Ti microgabbros are calculated within the same range (epsilon NdI = -0.1 to +0.5). On the other hand, the isotopic compositions of the lamprophyre show SrI = 0.7043 - 0.7044 (epsilon SrI = +7.6 to +9.2) and epsilon NdI = -0.62 to -0.34.

The geochemical studies including Sr-Nd compositions reveal that the microgabbros have been originated from a depleted source, whereas chemical compositions of the lamprophyre is more enrichment rather than those of the microgabbros. Consequently, the magma processes in the Sor Rondane Mountains reflect the evolution of lithosphere from the middle Proterozoic to the early Paleozoic; the depleted mantle at the initial subduction stage then changing to the enriched mantle at the continental collision stage. This lithospheric evolution can be explained by interaction between the depleted mantle and the enriched materials (e.g., slab-derived fluids, melting product of subducted crustal rocks, or reaction with fossil wedge mantle) during closure of the Mozambique Ocean.

キーワード: ゴンドワナ超大陸, 南極, セール・ロンダーネ山地, トーナル岩, 細粒斑れい岩, ランプロファイアー

Keywords: Gondwana supercontinent, Antarctica, Sor Rondane Mountains, tonalite, microgabbro, lamprophyre

東南極 Lutzow-Holm 岩体に産するアルカリ ~ 高カリウム貫入岩の産状と化学組成 Occurrence of alkali ~ highly potassic dykes intruded into metamorphic rocks on Lutzow-Holm Complex, East Antarctica

宮本 知治^{1*}, 角替 敏昭², Dunkley Daniel Joseph³

MIYAMOTO, Tomoharu^{1*}, TSUNOGAE, Toshiaki², DUNKLEY, Daniel Joseph³

¹九州大学, ²筑波大学, ³Geoscience Australia

¹Kyushu University, ²University of Tsukuba, ³Geoscience Australia

東南極 Dronning Maud Land の Lutzow-Holm Complex (LHC) は、Rayner Complex の西方・Yamato-Belgica Complex の東に位置する、東南極楕状地の高温変成岩体の一つである。これまでの日本隊による南極観測 (JARE) における地質調査では東経 45 度?37 度に分布する沿岸露岩において変成岩の詳細な調査が行われている。また、非変成の火成岩の貫入も認められている。JARE-52 における野外調査では、LHC の数カ所の露岩にてアルカリ?超カリウム岩岩脈の存在が新たに認められた。そのうち、Skallevikshalsen と Rundvagshetta にて見いだされた苦鉄質岩脈は、ほぼ南北方向 (わずかに NNE-SSW 方向) の走向で東に急傾斜し、厚さは数センチメートルから 0.5 メートルまで変化する。一方、Prince Orav Coast の二番岩では走向 N70 °W で東北東に傾く厚さ 20-30 センチメートルの苦鉄質岩脈が見いだされた。Rundvagshetta の苦鉄質岩脈の一部は苦鉄質岩貫入後に活動したペグマタイトの影響で粗粒角閃石を伴う角閃岩に変化している。貫入岩は完晶質で粒径は 0.1-2 ミリメートルにおよび、斑晶鉱物が認められない。主にカリ長石からなり、黒雲母、角閃石、チタン石、燐灰石を伴う: これらの鉱物の量比は、その有無も含めて産地ごとに変化する。少量の石英と希に斜長石が含まれる。黒雲母・角閃石は貫入方向に並列する。岩脈の化学組成は、今回調査時に観察された 5 カ所の露岩毎に異なる: SiO₂ 含有量は 46.3-60.2wt.% で、MgO 含有量は 9.48-0.69wt.% まで変化する。K₂O 含有量は 3.42-10.83wt.% におよび、一般的な火成岩より高い K₂O/Al₂O₃・K₂O/Na₂O 値を示す。全アルカリ-SiO₂ 含有量の関係では、テフライト・粗面安山岩・粗面岩に相当する。この岩脈の中で、Skallevikshalsen に産する超カリウム苦鉄質岩脈 (MgO = 7.92 - 9.48wt. %, K₂O = 8.10 - 8.72wt. %) は高い微量元素含有量を示し、ランプロアイトに似ている。Rundvagshetta の苦鉄質岩脈の一部母岩は加水変質反応を被り、その影響で母岩中のザクロ石が分解して黒雲母に変化する。この変化は苦鉄質岩岩脈との境界付近で最も強く見られ、境界から離れると変化の程度が低い。岩脈が交代作用のための流体を供給したと考えられる。

キーワード: アルカリ岩, 超カリウム火成岩, 岩脈

Keywords: alkali rock, ultrapotassic rock, dyke

The stability of sapphirine + quartz in high/low oxygen fugacity rocks: a case study of Southern India/East Antarctica

The stability of sapphirine + quartz in high/low oxygen fugacity rocks: a case study of Southern India/East Antarctica

清水 恒子^{1*}, 角替 敏昭¹, M. Santosh²
SHIMIZU, Hisako^{1*}, TSUNOGAE, Toshiaki¹, M. Santosh²

¹ 筑波大学大学院生命環境科学研究科地球進化科学専攻, ² 高知大学理学部

¹Earth Evolution Sciences, Graduate School of Life and Environmental Sciences, University of Tsukuba, ²Faculty of Science, Kochi University

Sapphirine has been the focus of many petrological investigations for the last two decades as the mineral often occurs in Mg-Al rich and pelitic rocks formed at high temperature to ultrahigh temperature (UHT). Particularly, sapphirine coexisting with quartz is considered as one of the most diagnostic mineral assemblages of UHT metamorphism. It is also known that sapphirine often occurs in magnetite-bearing high oxygen fugacity rocks, and, in such cases, the mineral can incorporate considerable quantity of ferric iron as well as Fe²⁺. It is therefore important to evaluate the effect of Fe³⁺ content on the stability of sapphirine-bearing assemblages for estimating peak conditions as well as constructing *P-T* paths. In this study, we compared the stability of sapphirine + quartz in magnetite-bearing high-oxygen fugacity rocks from India (Madurai Block in the southern granulite terrane) with that in magnetite-absent low-oxygen fugacity rocks from Antarctica (Bunt Island in the Napier Complex) using mineral equilibrium modeling technique. The calculations have been done in NCKFMASHTO system using THERMOCALC 3.33 with an updated version of the internally consistent data set.

The Madurai Block is the largest granulite block in the Southern Granulite Terrane, India, which was formed by collisional orogeny related to the assembly of the Gondwana Supercontinent. The block contains granulites with various UHT mineral assemblages including sapphirine + quartz, orthopyroxene + sillimanite + quartz, and Al-rich orthopyroxene. Magnetite-bearing quartzo-feldspathic garnet-sillimanite granulites from Rajapalayam area in the southern part of the block, for example, contain sapphirine + quartz inclusion in garnet as a stable mineral assemblage at the peak of metamorphism. The calculated *T-X* pseudosections suggest that the stability temperature of sapphirine + quartz is lowered from 1000°C at reduced condition ($X_{Fe_2O_3} = 0.02$) to 910°C at oxidized condition ($X_{Fe_2O_3} = 1.0$).

The Napier Complex of Enderby Land, East Antarctica, underwent regional UHT metamorphism at ca. 2.5 Ga. Bunt Island in the Napier Complex, located in the highest-grade region of the complex, contains various kinds of UHT granulites including sapphirine-bearing rocks. Sapphirine + quartz assemblage, probably formed at the peak UHT condition, occur in sapphirine- and osumilite-bearing layers of the granulite. The absence of magnetite in the rocks indicates the sapphirine granulite was formed at reduced condition. *T-X* pseudosection of the rock suggests that the stability field of sapphirine + quartz is $T > 1050^\circ\text{C}$ at $X_{Fe_2O_3} = 0.04$, while it will be lowered in more oxidized condition ($T > 800^\circ\text{C}$ at $X_{Fe_2O_3} = 0.24$).

The results of this study demonstrated that the occurrence of sapphirine + quartz in UHT rocks is highly controlled by the oxidation state of the host rocks, particularly low oxygen fugacity rock is especially strongly influenced. In the case of Bunt Island, if $X_{Fe_2O_3}$ increases by 0.04, the stability temperature of sapphirine + quartz will be lowered by 50°C. It is therefore important to evaluate the effect of Fe³⁺ content of the stability of sapphirine-bearing granulites for estimating peak conditions as well as constructing *P-T* paths even if granulites were formed at reduced condition.

キーワード: サフィリン + 石英共生, 南インド, 東南極, シュードセクション, THERMOCALC, 酸素フガシティー
Keywords: sapphirine + quartz, Southern India, East Antarctica, pseudosection, THERMOCALC, oxygen fugacity

Petrology of garnet-clinopyroxene rocks from the Gondwana suture zone in southern India

角替 敏昭^{1*}

TSUNOGAE, Toshiaki^{1*}

¹ 筑波大・地球

¹Univ. Tsukuba

The Palghat-Cauvery Suture Zone (PCSZ) in the southern granulite terrane, India, which separates Pan-African granulite blocks (e.g., Madurai and Trivandrum Blocks) to the south and Archean terrane (e.g., Salem Block and Dharwar Craton) to the north is regarded as a major suture zone in the Gondwana collisional orogeny. It probably continues westwards to the Betsimisaraka suture in Madagascar, and eastwards into Sri Lanka and possibly into Antarctica. The available geochronological data including U-Pb zircon and EPMA monazite ages indicate that the rocks along the PCSZ underwent an episode of high-grade metamorphism at ca. 530 Ma that broadly coincides with the time of final assembly of the Gondwana supercontinent. Recent investigations on high-grade metamorphic rocks in this region have identified several new occurrences of garnet-clinopyroxene rocks and associated meta-gabbros from Perundurai, Paramati, Aniyapuram, Vadugappatti, and Mahadevi areas in Namakkal region within the central domain of the PCSZ. They occur as elongated boudins of 1 m to 1 km in length within hornblende-biotite orthogneiss. The garnet-clinopyroxene mafic granulites contain coarse-grained (up to several cm) garnet (Alm₃₀₋₅₀ Pyr₃₀₋₄₀ Grs₁₀₋₂₀) and clinopyroxene (XMg = 0.70-0.85) with minor pargasite, plagioclase (An₃₀₋₄₀), orthopyroxene (hypersthene), and rutile. Garnet and clinopyroxene are both subidioblastic and contain few inclusions of clinopyroxene (in garnet) and plagioclase. Orthopyroxene occur only as Opx + Pl symplectite between garnet and clinopyroxene in almost all the localities, suggesting the progress of decompressional reaction: $Grt + Cpx + Qtz \Rightarrow Opx + Pl$, which is a dominant texture in the PCSZ. The prograde mineral assemblage of the rocks is therefore inferred to be $Grt + Cpx + Qtz$, although quartz was probably totally consumed by the progress of the reaction. The metamorphic P-T calculations using Grt-Cpx-Pl-Qtz geothermobarometers yield $T = 850-900$ °C and $P > 13$ kbar, which is consistent with the occurrence of high-pressure Mg-rich staurolite in Mg-Al-rich rocks from this region. Fluid inclusion study of some garnet-clinopyroxene rock samples identified CO₂-rich fluid inclusions trapped as primary phases within garnet, suggesting that prograde high-pressure metamorphism was dominated by CO₂-rich fluids. The results therefore confirmed that the PCSZ underwent regional dry high-pressure metamorphism followed by the peak ultrahigh-temperature event probably associated with the continent-continent collisional and suturing history along the PCSZ.