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Mineral equilibrium modeling of incipient charnockite and adjacent garnet-biotite gneiss from southern India

Mineral equilibrium modeling of incipient charnockite and adjacent garnet-biotite gneiss from southern India

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The Southern Granulite Terrane (SGT) in India is known for its classic exposures of regionally metamorphosed granulite-facies rocks formed during the collisional orogeny related to the amalgamation of Gondwana supercontinent. The SGT is composed of a collage of Proterozoic crustal blocks dissected by large Late Neoproterozoic shear/suture zones. The Trivandrum Granulite Block (TGB) is comprises dominantly metasedimentary sequence with khondalites, leptynites and charnockites with subordinate quartzite, mafic granulite, calc-silicate rocks, and meta-ultramafic rocks. The TGB is known as one of the classic examples for the spectacular development of ‘ incipient charnockites ’ within orthopyroxene-free felsic gneisses as exposed in several quarry sections in the states of Kerala and Tamil Nadu. The charnockite-forming process in the TGB is considered to have been triggered by the infiltration of CO2-rich anhydrous fluids along structural pathways within upper amphibolite facies gneisses, resulting in the lowering of water activity and stabilization of orthopyroxene through the breakdown of biotite. However, no quantitative study on the stability of charnockitic mineral assemblage using mineral equilibrium modeling approach has been done so far. In this study, we report a new occurrence of incipient charnockite from Mavadi in the TGB and discuss the petrogenesis of granulite formation in an arrested stage on the basis of petrography, geothermobarometry, and mineral equilibrium modeling. In Mavadi, patches and lenses of charnockite (Kfs + Qtz + Pl + Bt + Grt + Opx + Ilm + Mag) of about 30 to 120 cm in length occur within Opx-free Grt-Bt gneiss (Kfs + Qtz + Pl + Bt + Grt + Ilm) host rocks. The application of mineral equilibrium modeling on charnockite assemblage in NCKFMASHTO system to constrain the conditions of charnockitization defines a P-T range of 800 °C at 4.5 kbar to 850 °C at 8.5 kbar, which is broadly consistent with the results from the conventional geothermobarometry (810-880 °C at 7.7-8.0 kbar) on these rocks. The P-T conditions are lower than the inferred peak metamorphic conditions from the ultrahigh-temperature granulites of the study area (T $>$900 °C), which might suggest heterogeneity in peak P-T conditions within this crustal block in relation to local buffering of metamorphic temperature by Opx-Bt-Kfs-Qtz assemblage. The result of T versus mole H2O (M(H2O)) modeling demonstrated that Opx-free assemblage in Grt-Bt gneiss is stable at M(H2O) = 0.3 to 1.5 mol.%, and orthopyroxene occurs as a stable mineral at M(H2O) $<$0.3 mol.%, which is consistent with the petrogenetic model of incipient charnockite related to the lowering of water activity and stabilization of orthopyroxene through breakdown of biotite by dehydration caused by the infiltration of CO2-rich fluid from external sources. We also propose a possible alternative process to form charnockite from Grt-Bt gneiss through slight variations in bulk-rock chemistry (particularly K- and Fe-rich portion of Grt-Bt gneiss) that can enhance the stability of orthopyroxene rather than that of biotite.

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変成条件が局所的に異なる岩石間の変成反応の推定
Metamorphic reaction to describe local-scale difference in mineral assemblage stable under different conditions

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変成岩の鉱物組み合わせは主に温度、圧力、流体組成によって決まる。同じ鉱物組み合わせをもつ岩石が数十 km スケールで産する場合、その違いは主に変成時の温度や圧力の違いであることがわかっている。一方で鉱物組み合わせが局所的 (数十 cm スケール) に異なる変成岩の産状も報告されている。このようなスケールでの温度と圧力の違いは現実的でないが、その代わりに流体組成は狭いスケールで変化することが可能である。局所的な流体組成の違いは鉱物組み合わせの変化をもたらし、そのような鉱物組み合わせの違いは、脱水反応で表現されることが必要である。しかし、このような反応を隣接する岩石間の鉱物の化学組成や産状の違いによって見積もった例はほとんどない。本研究では、局所的に鉱物組み合わせが変化する一例として、スリランカに産するチャーノッカイトと周囲の岩石の構成鉱物の化学組成を比較し、二つの岩石間の変成反応を推定した。

チャーノッカイト中の黒雲母は片麻岩中のものと比べて、Fe+Mg に富み、Ti に乏しい。

この組成の違いを空席 [ ] として以下の置換で表現する。

[ ]Ti = $(Fe+Mg)_2$

チャーノカイトに含まれている普通角閃石は片麻岩中の普通角閃石と比べて K、Fe+Mg、Si に富み、Na、Ti、Al に乏しい。それは次のような置換で表される。

$[\ ]_{0.5}Na^{M4}Ti^{M1-3}Al_{0.5} = K_{0.5}(Fe+Mg)^{M4}(Fe+Mg)^{M1-3}Si_{0.5}$

上記の置換から求められる斜方輝石生成反応は、次のように書くことができる。

Ti-rich biotite + quartz = Ti-poor biotite + orthopyroxene + ilmenite + alkali feldspar + H_2O (1)

Ti-rich holnblende + quartz = Ti-poor hornblende + orthopyroxene + ilmenite + anorthite + albite + alkali feldspar + H_2O (2)

以上より黒雲母と普通角閃石は、それぞれ独立の反応で斜方輝石を生成することがわかった。反応式から得られる斜方輝石の生成量は、実際のチャーノッカイト中の斜方輝石の存在量とよく一致した。本研究で推定した二つの反応式は脱水反応であるため、チャーノッカイト中の鉱物組み合わせは、CO_2 に富む流体の条件下で安定となる。従ってチャーノッカイトと片麻岩の違いは、局所的な流体組成の違いで理解できることが確かめられた。

キーワード: チャーノッカイト, 普通角閃石-黒雲母片麻岩, スリランカ, 変成反応
Keywords: charnockite, hornblende-biotite gneiss, Sri Lanka, metamorphic reaction

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マダガスカル東部における太古代中期ー後期ＴＴＧ火成活動：全岩化学組成およびウランー鉛年代による考察
Mid to late Archean TTG magmatism in the eastern Madagascar; a view from whole rock geochemistry and U-Pb geochronology

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Madagascar occupies a key position in the East African Orogen for understanding the continental growth and the tectonics of collision between East Gondwanaland and West Gondwanaland. Especially in the eastern Madagascar is composed of mid Archean domain (Masora) in the east and late Archean domain (Antananarivo) in the west.

The magma genesis and timing of magmatism were studied by whole-rock chemical analysis and LA-ICP-MS U-Pb zircon age dating of granitoids in these domains.

Masora domain is divided into two parts, north and south region, defined by metamorphic grade. The rocks from the north region are only weakly deformed. The north region mainly consists of trondhjemites with subordinate amounts of metapelities including meta-BIFs, and late granitoids with mafic-ultramafic rocks. Trondhjemites in the northern Masora domain are characterized by high SiO2 (67.80-70.98 wt.%), high Al2O3 (15.86-18.44 wt.%), and high Na2O (5.35-5.98 wt.%), low TiO2 (0.27-0.40 wt.%), Mg# (31-35), CaO (1.90-2.24 wt.%), K2O (1.64-2.65 wt.%). Antananarivo domain is divided into two parts, north and south region, defined by lithology. The south region mainly consists of Hbl-Bt gneisses with subordinate amounts of Grt-Opx granuilites, amphibolites, quartzites and metapsammites including meta-BIFs. Whole rock chemical analyses for the major and trace elements demonstrate that Hbl-Bt gneisses in the southern Antananarivo domain are of igneous origin and chemically comparable with CIPW normative tonalities. Hbl-Bt gneisses are characterized by high SiO2 (71.00-73.16 wt.%), high Al2O3 (15.89-16.33 wt.%), and high Na2O (4.41-4.67 wt.%), low TiO2 (0.18-0.23 wt.%), Mg# (38-43), CaO (3.40-3.82 wt.%), low K2O (1.04-1.71 wt.%). All of these granitoids (trondhjemites and Hbl-Bt gneiesses) show pronounced negative Nb, Ti, P anomalies on the primitive mantle-normalized spidergram. These characteristics are comparable to Archean TTG (tonalite-trondhjemite-granodiorite) (e.g. Martin et al., 2005).

A xenocrystic zircon in a trondhjemite sample collected from the northern part of the Masora domain gives a single grain concordat age of mid Archean (ca. 3.2 Ga). Hbl-Bt gneiss sample in the southern part of the Antananarivo domain shows slightly scattered and discordant late Archean age (ca. 2.7 Ga). This new age is slightly older than reported oldest ages of Antananarivo domain (ca. 2.5 Ga; Kroner et al., 2000).

These results show that the area between mid Archean (Masora) and late Archean (Antananarivo) domains is underlain by ca. 2.7Ga tonalitic rocks. Similar magmatic age is reported from the southern India. Late Archean magmatic age of the charnockite and meta-granite (ca. 2.65-2.53) were reported from the Salem Block in the southern India (Clark et al., 2009; Sato et al., 2011), where located between the mid to late Archean Dharwar Craton (e.g. Peucat et al., 1993) to the north and late Archean Madurai Block (Plavsa et al., 2012) to the south. Hence we speculate that Madagascar and India records progressive outward continental growth by accretion of mid-to-late Archean (ca. 2.7-2.6 Ga) crust and the late Archean (ca. 2.5 Ga) crust to ca. 3.2Ga Dharwar nuclei crust. Although Tucker et al. (2011) suggested the 'Greater Dharwar Craton' model to explain the juxtaposition of Madagascar with India from the late Archean (ca. 2.5 Ga), we suggest more stepwise crustal growth in the Archean era.

Keywords: Madagascar, Achean TTG, geochronology, geochemistry