Mg-rich Staurolite + Sapphirine + Quartz Association as an Evidence of High-pressure and Ultrahigh-temperature Metamorphism in Collisional Orogens

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Introduction

Ultrahigh-temperature (UHT) crustal metamorphism is often characterized by the occurrence of diagnostic mineral assemblages (e.g., sapphirine + quartz, spinel + quartz, orthopyroxene + sillimanite + quartz) that were probably stabilized at T >900°C or even >1000°C (e.g., Kelsey, 2008; Harley, 2008). Among them, a direct contact of sapphirine and quartz, which as been reported from several UHT terranes in the world (e.g., Napier Complex of East Antarctica and Eastern Ghats Belt of India), is regarded as a robust evidence of such extreme metamorphism.

Schreyer et al. (1984) first reported sapphirine + quartz with Mg-rich staurolite, which are all included in poikiloblastic pyrope-rich garnet from the Central Zone of the Limpopo Complex, South Africa. Such an occurrence of Mg-rich staurolite + sapphirine + quartz association is extremely rare and has been obtained only from two UHT regions; the Neoproterozoic Palghat-Cauvery Suture Zone in southern India (Nishimiya et al., 2010) and the Neoarchean Limpopo Complex in southern Africa (Schreyer et al., 1984; Tsunogae and van Reenen, 2010). In this study we introduce reaction microstructure of this unique mineral assemblage based on our recent studies in these terranes and evaluate the potential of the rare Mg-rich staurolite + sapphirine + quartz association as a possible evidence of high-pressure and ultrahigh-temperature metamorphism in collisional orogens.

Neoproterozoic Palghat-Cauvery Suture Zone in southern India

The Palghat-Cauvery Suture Zone, an E-W trending network defining Late Neoproterozoic Gondwana collisional suture, marks the boundary between the Neoproterozoic to Cambrian granulite blocks to the south and the Archean Dharwar Craton to the north in southern India. Sapphirine-, corundum-, and gedrite-bearing Mg-Al-rich rocks occur in various localities within the Palghat-Cauvery Suture Zone (Tsunogae and Santosh, 2003; Santosh et al., 2004; Shimpo et al., 2006). The Mg-Al-rich rock discussed in this study from Panangad is composed of garnet, sodic-gedrite, sapphirine, corundum, and spinel, with accessory staurolite and rutile. It is characterized by coarse-grained (~26 mm in diameter) poikiloblastic garnet with numerous inclusions of sapphirine, staurolite, phlogopite, and rutile. The inclusion staurolite is fine-grained (<0.7 mm in length) and yellowish in color. It is compositionally Mg-rich (X_{Mg} ~0.58) if compared to other Barrovian type staurolites, and commonly surrounded by sapphirine or sapphirine + quartz corona, suggesting the formation of sapphirine + quartz after staurolite. As the host garnet displays irregular grain boundary with sapphirine, we regard that garnet also reacted to form sapphirine + quartz from staurolite through the progress of the following FMASH continuous reaction: Grt + St $\rightarrow$ Spr + Qtz +H_2O (1) (Nishimiya et al., 2010).

Neoarchean Limpopo Complex in southern Africa

The Limpopo Complex in southern Africa is known for its classic exposures of regionally metamorphosed granulite-facies rocks formed by collision of two Mesoarchean to Neoarchean cratons; the Zimbabwe Craton to the north and the Kaapvaal Craton to the south during the Neoarchean (e.g., van Reenen et al., 1987). An Mg-Al-rich rock from the Central Zone of the Limpopo Complex in Zimbabwe contains poikiloblastic garnet with fine-grained (~0.7 mm) inclusions of kyanite, sapphirine, rutile, orthopyroxene, and Mg-rich (X_{Mg} = 0.44-0.58) staurolite. The staurolite is often mantled by sapphirine or sapphirine + quartz corona, similar to the texture observed from southern India. It is rarely completely replaced by sapphirine + quartz symplectite, and fine-grained relict staurolite grains are included in the sapphirine and quartz. The textures also suggest the formation of sapphirine + quartz from staurolite by reaction (1) (Tsunogae and van Reenen, 2010). The host garnet is mantled by orthopyroxene + plagioclase corona probably formed by post-peak decompression.

Discussion

Sapphirine + quartz corona around Mg-rich (X_{Mg} ~0.58) staurolite were found from two UHT metamorphic terranes. Recently Sato et al. (2010) performed high-*P*-*T* experiments of staurolite with moderate X_{Mg} (= 0.7-0.5) and demonstrated that at 950°C and pressures between 14-16 kbar staurolite with X_{Mg} = 0.7 decomposed to orthopyroxene + corundum + melt, while staurolite with X_{Mg} = 0.5-0.6 decomposed with orthopyroxene to sapphirine + melt. Based on these results, the Mg-rich staurolite with X_{Mg} ~0.58 is stable at *P* >14 kbar. Previous reports of magnesiostaurolite from UHP rocks (e.g., Simon et al., 1997) and eclogites (e.g., Enami and Zang, 1988) are consistent with the formation of our staurolites at high pressure. The occurrence of relict kyanite from several localities in the Palghat-Cauvery Suture Zone (e.g., Shimpo et al., 2006) and the Limpopo Complex (Tsunogae and van Reenen, 2010) is also supports the proposed prograde high-pressure event.

This high-pressure event was probably followed by rapid decompression to ~ 9 kbar toward the peak UHT metamorphism of *T* ~1000°C as inferred from the presence of sapphirine + quartz coronas developed around the staurolite. The inferred rapid decompression event is supported by the symplectic nature of the sapphirine and quartz. The peak UHT event might have been followed by isobaric cooling towards the stability field of orthopyroxene + sillimanite + quartz, which is present in garnet-orthopyroxene-gedrite rock in the Palghat-Cauvery Suture Zone (Shimizu et al., 2009) and pelitic granulites from the Limpopo Belt (Tsunogae and van Reenen, 2010). Our petrologic data are therefore consistent with a clockwise *P*-*T* evolution of the two regions.

Prograde high-pressure (*P* >14 kbar) metamorphism and subsequent decompression and peak UHT (*T* ~1000 °C) metamorphism were inferred from sapphirine + quartz + staurolite association from the Palghat-Cauvery Suture Zone and the Limpopo Complex. Although the two UHT terranes have no genetic relations, both of them are regarded as collisional orogens formed by continent-continent collision (e.g., van Reenen et al., 1987; Santosh et al., 2009). We therefore infer that HP-UHT metamorphic evolution obtained from Mg-rich staurolite + sapphirine + quartz association is an evidence of extreme crustal metamorphism during collisional orogeny.

Acknowledgements

Partial funding for this project was produced by a Grant-in-Aid for Scientific Research (B) from the Japanese Ministry of Education, Culture, Sports, Science, and Technology (MEXT) to Tsunogae (No. 20340148) and JSPS-INSA Joint Research Program.

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