FIB-TEM analysis of an ultrahigh-temperature sapphirine + quartz granulite: Implications for P-T path

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Ultrahigh-temperature (UHT) metamorphism is known as an extreme crustal metamorphism formed at >900°C or even >1,000°C at pressures in the range of 7-13 kbar. Such very high-temperature processes in middle to lower crust often form unique minerals or mineral assemblages, among which equilibrium sapphirine + quartz has been regarded as one of the robust evidences of UHT metamorphism at ~1000°C. The assemblage is also useful for the construction of post-peak *P-T* paths because of various reaction textures associated with the assemblage. For example, sapphirine associated with quartz in UHT granulites from Tonagh Island in the Napier Complex (East Antarctica) is mantled by garnet + sillimanite + orthopyroxene corona, suggesting near-isobaric cooling from ~1,000°C (Shimizu et al., 2013). Therefore, detailed investigations of reaction textures involving sapphirine and quartz are useful for unraveling exhumation history of UHT granulite terranes. However, some sapphirine + quartz assemblages lack reaction texture particularly if the minerals occur as inclusions in garnet. For example, sapphirine and quartz within garnet in pelitic granulites from Rajapalaiyam in the Madurai Block (southern India) show direct contact relations, and there is apparently no reaction texture between them (Tateishi et al., 2004). Therefore, it is difficult to infer post-peak *P-T* path for the assemblage, although the difficulty could be because the reaction rim around sapphirine might be too thin to examine by BSE images. In this study, we thus attempted to identify reaction microstructures between sapphirine and quartz, which are texturally in equilibrium, in a pelitic granulite from Rajapalaiyam by using FIB (Focused Ion Beam) and TEM (Transmission Electron Microscopy) to identify nanoscale minerals along grain boundaries, and to infer post-peak *P-T* path.

The pelitic granulite sample examined in this study is composed dominantly of garnet, mesoperthite, orthopyroxene, sillimanite, quartz, and retrograde cordierite. Garnet is poikiloblastic and contains numerous inclusions such as sapphirine, quartz, spinel, orthopyroxene, plagioclase, and K-feldspar. In this study, the boundary between sapphirine and quartz within garnet was sliced using a JEOL JIB-4000 FIB to prepare electron transparent cross-sectional samples for TEM observation. The transmission electron microscopy of the samples was obtained with a JEOL JEM-2100F TEM operated at 200 kV and equipped with energy dispersive X-ray spectroscopy (EDS) at TEM Station in NIMS. Our TEM observations and EDS analyses identified open grain boundaries of about 20 nm between sapphirine and quartz, although parts of them are filled with carbon, sillimanite, and unknown nanosized minerals that comprises Fe, Mg, Al, Si, and O with/without Ca (possibly garnet). The results of this study thus suggest that the garnet and sillimanite could have been formed from sapphirine and quartz, suggesting the progress of the following continuous reaction in FMAS system related to near-isobaric cooling:

sapphirine + quartz => garnet + sillimanite

The reaction could have taken place at low-H_2O activity condition due to the occurrence of CO_2, which was subsequently reduced and crystalized graphite along the grain boundary. This is the first report of nanoscale reaction textures between sapphirine and quartz obtained by FIB-TEM analysis, and we found this technique is useful for the evaluation of post-peak *P-T* evolution of UHT granulite terranes.

References

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