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# Metamorphic evolution of ultrahigh-pressure rock revealed by residual pressure of $SiO_2$ inclusion in garnet

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Residual pressures are generated in metamorphic host minerals and sealed inclusions due to the difference of their physical properties. If the residual pressure recorded in a host mineral or inclusion could be quantitatively analyzed, it would provide useful data for the estimating the crystallization conditions of the host phase and the metamorphic pressure-temperature (P-T) history. Enami *et al*. (2007, AM, 1303-1315) proposed a method to estimate the residual pressure recorded in quartz inclusions in garnet using a frequency shift in the Raman spectrum of quartz (quartz-Raman barometry). Kouketsu *et al*. (2014, AM, 433-442) calculated the relationship between the residual pressure of quartz inclusions in garnet and the P-T conditions of the garnet crystallization stage under $\alpha$-quartz stable conditions and proposed a novel method to constrain the metamorphic P-T conditions. As quartz-Raman barometry is independent of the thermodynamic model, this technique could be a powerful tool to determine the evolution of progressive metamorphism. However, the quartz-Raman barometry cannot be applied to ultrahigh-pressure (UHP) metamorphic rocks formed under coesite-stable conditions, at least in principal. That said, quartz inclusions trapped by garnet under quartz-stable conditions may preserve the information preserve the effects produced during the early stages of prograde metamorphism. In this study, we examine the metamorphic evolution of a UHP metamorphic rock can deduced from the residual pressure of quartz inclusions in garnet.

The samples studied were collected from the Yangzhuang region of the Sulu UHP metamorphic belt, eastern China. Although coesite has not been reported from in Yangzhuang samples, quartz-pseudomorph after coesite has been reported, and coesite stability conditions of 2.7-3.5 GPa/660-830 ℃ are estimated for the peak metamorphic stage (Enami and Nagasaki, 1999, IAR, 459-474). These results suggest that the Yangzhuang samples might record the prograde P-T path from quartz to coesite stability.

Garnet grains in the Yangzhuang samples were divided into inner ($Alm_{49-54}Prp_{16-28}Grs_{21-29}Sps_1$, $X_{Mg}$ = 0.22-0.36) and outer ($Alm_{45-52}Prp_{18-31}Grs_{23-29}Sps_1$, $X_{Mg}$ = 0.29-0.41) segments, the boundary between the two defined by discontinuous changes in grossular content. In the inner segment, the $SiO_2$ phases are all $\alpha$-quartz, and quartz-pseudomorphs after coesite and any radial cracks around the quartz inclusion are not observed. Residual pressures retained by the quartz inclusions systematically increased with decreasing grossular content from the crystal center to the margin in the inner segment and indicated a value of 0.9 GPa. Metamorphic pressure, estimated by an inverse calculation based on the measured residual pressure, implies that the quartz inclusions were trapped at pressure conditions just below the quartz/coesite transition. In the outer segment, quartz-pseudomorphs after coesite with radial cracks in the surrounding host garnet were observed. Coesite was identified for the first time in this region as an inclusion in a kyanite grain from the outer segment. The occurrence of coesite in the Yangzhuang sample supports the P-T conditions previously estimated by conventional geothermobarometry. These results suggest that (1) quartz inclusions in the inner segment were trapped by garnet under quartz-stable conditions, avoided phase transition to coesite at the peak metamorphic stage, and still preserved P-T information gained during the early stage of prograde metamorphism and (2) $SiO_2$ inclusions in the outer segment were included as coesite; and most of these translated into quartz and released their residual pressure during exhumation. These results suggest that the quartz-Raman barometry is a useful tool for determining P-T conditions at an early prograde stage even in the case of UHP metamorphism.

Keywords: quartz, residual pressure, quartz-Raman barometry, ultrahigh-pressure rock, Sulu belt