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Study of negative residual pressure of quartz in garnet: Quartz Raman spectra of high-temperature metamorphic rocks

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The volume of quartz inclusions in garnet porphyroblasts changes with temperature and pressure until the rock reaches the surface of the earth. Positive residual pressure is preserved by the compressional stress when the volume of the included quartz becomes larger than that of the surrounding garnet, whereas negative residual pressure is preserved by the elongational stress when the volume of quartz becomes smaller than that of the garnet. The peak position of quartz Raman spectrum shifts to toward high wavenumbers with increasing compressional stress and toward low wavenumbers with increasing elongational stress. Enami et al. (2007) measured the peak shift of quartz Raman spectra of several samples and estimated the residual pressure. They showed that there is a positive correlation between the residual pressure and metamorphic pressure. They also showed that there is almost no dependence of the residual pressure on temperature or on the chemical composition of garnet, and proposed that this technique can be applied to a quartz Raman barometer. Since quartz Raman barometry is independent of the thermodynamic model, this barometer is applied as one of the indices of pressure estimation of high-pressure metamorphic rocks in several studies (e.g., Kouketsu et al., 2010).

Recently, the quartz inclusions that preserve the negative residual pressure in the Higo metamorphic rocks were reported (Nishiyama and Aikawa, 2011). The simple elastic model used by Enami et al. (2007) shows almost no *P-T* range wheer the quartz inclusion acquires negative residual pressure (Van der Molen, 1981). Hence, Nishiyama and Aikawa (2011) interpreted that the negative residual pressure was acquired by the transition of the included quartz from beta- to alpha-phase.

In this study, we analyzed the rocks formed under high-temperature conditions to investigate in detail about the negative residual pressure that is not evaluated by the conventional quartz Raman barometer. We analyzed samples from Yanai Ryoke, collected from 5 different metamorphic zones and from East Antarctica. The metamorphic *P-T* conditions of Yanai Ryoke were estimated in detail by Ikeda (2004); Chl-Bt, Ms-Crd, and Kfs-Crd zones are stable in alpha-quartz, and Grt-Crd zone is stable in beta-quartz. The Sill-Kfs zone is near the alpha-beta transition line. The samples from East Antarctica are estimated to have formed at ultra-high temperatures.

The results of the analysis showed that the quartz included in the garnets of every sample from Yanai Ryoke have comparable values of negative residual pressure. In the sample from East Antarctica, quartz with very low residual pressure was commonly observed. This result implies that negative residual pressure is acquired when the metamorphic condition of the quartz included in the garnet is stable whether in alpha or beta phases. This result implies that the explanation provided by Nishiyama and Aikawa (2011) is insufficient. Hence, we reexamined the conventional elastic model; it became clear that the model of Van der Molen (1981) is not suitable for estimating the relation between the residual pressure and metamorphic pressure, and that the model of Zhang (1998) is more appropriate for the quartz Raman barometer. We improved the model to estimate the residual pressure by taking into consideration the pressure dependency of the bulk modulus and the temperature dependency of the thermal expansion.

The new model can explain the negative range of the quartz Raman barometer qualitatively. It was shown that the quartz acquires negative residual pressure even if it had been included in the garnet under the metamorphic conditions in a stable alpha-phase. In addition, it was also shown that the quartz included under the ultra-high temperature conditions, as in the case of the sample from Eastern Antarctica, acquires much lower values of residual pressure than that observed in the case of samples from Yanai Ryoke.

Keywords: negative residual pressure, quarz Raman barometer, high temperature metamorphism, inclusion-host system, elastic model