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Back transformation kinetics of majoritic garnet and implication for ascending diamond

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Depth of diamond formation can be estimated by phase relations of their silicate inclusions. For example, majoritic garnet in diamonds indicates that the diamonds have been formed at the deep upper mantle or the transition zone (e.g., Moore and Gurney, 1985; Stachel, 2001; Tappert et al., 2005; Banas et. al., 2007). Some majoritic garnet in diamond coexists with low-pressure phases of pyropic garnet and clinopyroxene, which are considered to have been decomposed from majoritic garnet during transportation to the Earth's surface (Gillet et. al., 2002; Harte and Cayzer, 2007). The kinetics of the back transformation of majoritic garnet would be a clue to elucidate the issue of diamond transportation from the deep mantle. Here we report new experimental results on the back transformation kinetics of majoritic garnet into pyropic garnet + clinopyroxene by time-resolved in-situ X-ray diffraction measurements.
High-pressure in-situ X-ray diffraction experiments were conducted using a Kawai-type high-pressure apparatus SPEED-1500 at SPring-8, Japan. The truncated edge length of the second-stage anvil is 3.0 mm. Pressure was calculated from the unit cell volume of gold (Tsuchiya, 2003), and temperature was monitored by W3%Re-W25%Re thermocouple. Synthesized polycrystals of majoritic garnet (10um) with eclogitic compositions were used as a starting material for the transformation experiments. The samples were pressurized to around 7.0 GPa at room temperature. Then the temperature was raised to the target values and maintained for 20 to 180 minutes and the back transformation was observed by time-resolved X-ray diffraction measurements every 300-1500 seconds. The chemical compositions of majoritic garnet, pyropic garnet, and clinopyroxene were analyzed by Scanning Electron Microscope (SEM, JEOL JSM-5800) equipped with an Energy Dispersive X-ray Spectrometry (EDS) at Kyushu University.
We observed that the back transformation occurred by grain-boundary nucleation and diffusion-controlled growth at 6.5-7.5 GPa and 1020-1300C. The temperature dependence of diffusion-controlled growth rates (k^2) were determined to be $k^2 = 9.8 * 10^{-8}[m^2/s]\exp(-238[kJ/mol]/RT)$, which was used to constrain the survival time of majoritic garnet in diamond. If we consider the grain size of 100 um for the parental majoritic garnet as typically observed in diamond, the back transformation completes in 2000 hours and 190 hours at 1200C and 1400C, respectively. We found that the ascending velocity in the normal mantle convection is far too slow to satisfy the time limitation for the survival of majoritic garnet, indicating that such diamonds have been transported directly from the deep mantle by the rapid kimberlite magma.

Keywords: majorite, transformation kinetics, diamond, kimberlite