Observation of 3D shapes of olivine negative crystals in equilibrated chondrites:Estimation of equilibrium form and relative ages of healed cracks.

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Olivine is one of the most common minerals both in the solar system and circumstellar environments. It is important to understand its crystal shape because anisotropy of the crystal faces affects various physicochemical processes. For example, the IR spectral features of olivine in circumstellar regions depend on the crystal shape, which was controlled by its formation process (e.g., [1]) and the origin of water of the Earth might be affected by anisotropic adsorption of water molecules on olivine surfaces [2]. There are two kinds of crystal forms; growth and equilibrium forms. Growth forms of olivine have been obtained from natural crystals. Recently, its equilibrium form was obtained by *ab initio* calculation [3]. In order to confirm this from natural crystals, we examined the shapes of negative olivine crystals along a healed crack in an equilibrated chondrite [4]. We obtained a shape, which seems to be nearly equilibrium from but is different from the calculated equilibrium form. However, the result was obtained only for one sample. In this study, more number of samples was examined with more detailed crystallographic analysis to discuss equilibrium form. It is also expected that we can estimate relative formation ages of healed cracks if the degree of annealing of negative crystals are different among the healed cracks.
We observed three, two and two samples of the Tuxtuac (LL5), Kilabo (LL6) and Y793214 (LL5) meteorites, respectively. A cube-shaped sample (20-30 um in size) with inclusions was extracted from a polished thin section by using FIB (FEI Quanta 200 3DS). Then, the sample was imaged to obtain three-dimensional structures of negative crystals along a healed crack using imaging microtomography system at beamline BL47XU, SPring-8, Japan with the effective spatial resolution is approximately 150 nm. The crystallographic orientations of host olivine crystals were determined with an FE-SEM/EBSD (JEOL 7001F/HKL CHANNEL5). Then, the lengths along the crystal axes and crystal planes of negative crystals were determined from the CT images together with the EBSD results. Voids with facets, or negative crystals, 0.5–8.0 um in size were present along a plane, suggesting their forms a healed crack. Sometimes two healed cracks were recognized in one sample. The axial length ratios of negative crystals along a healed crack in the Tuxtuac meteorite are almost similar irrespective of their size. This indicates that the negative crystals in this healed crack were most annealed and their shapes changed to near-equilibrium form. The annealing might be caused by thermal metamorphism and/or post shock heating in a parent body. The near-equilibrium form has {100}, {010}and {021} planes with rounded edges. The development of {100} planes is different from the equilibrium form obtained by *ab initio* calculation [3], where (100) plane with a high surface free energy do not appear. Possible causes for this discrepancy are Fe-rich surface composition or adsorption of molecules onto the surface of the negative crystals. Degrees of annealing of healed cracks can be evaluated from deviation of the axial length ratios of negative crystals. More than one healed cracks with different degrees of annealing is present in a single rock fragment, indicating relative ages of healed cracks can be evaluated.

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