Semi-brittle behavior of olivine single crystals under the conditions of Earth’s mantle transition zone

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The origin of deep-focus earthquakes, which occur at depths of 300-700km in the subducting slabs, fundamentally differs from that of other earthquakes and has been attributed to the pressure-induced phase transition in olivine. Previous studies on Mg_2GeO_4 olivine have shown that grain size reduction induced by the phase transition in olivine causes shear localization (e.g., Burnley et al., 1991; Schubnel et al., 2013). Schubnel et al. (2013) reported intense acoustic emissions around the timing of a faulting which would be induced by shear localization in polycrystalline Mg_2GeO_4 olivine. In order to understand the relationship between fracturing and the phase transition in olivine, we conducted deformation experiments on single crystals of San Carlos olivine (Fo_{91}) at pressure of 10-15 GPa and temperatures of 1000-1100 degC using a deformation-DIA apparatus. Single crystal of olivine was chosen to exclude the effect of grain boundaries on nucleation of high-pressure phases of olivine (i.e., wadsleyite and ringwoodite).

Array of microcrack parallel to either (100), (010) or (110) plane was developed at an ~50 degree to the direction of uniaxial compression. Rotation of olivine axes associating the formation of subgrain boundaries was observed around the microcrack arrays, showing that plastic deformation of the olivine single crystal inevitably associated formation of the microcracks. In most samples, microcracks coalesced and then a few throughgoing fractures were developed. Particles of wadsleyite /ringwoodite having a diameter of a few micrometer or less were preferentially nucleated on the microcrack surfaces. Ultrafine-grained domains, which consist of the wadsleyite /ringwoodite particles, were formed along the throughgoing fractures. Development of a banded ultrafine-grained domain was also observed along a throughgoing fracture, implying that shear localization could occur as a result of semi-brittle flow of olivine and a transition from dislocation creep to grain-size-sensitive creep in subducting slabs at depths > 410 km.

Keywords: olivine, phase transition, semi-brittle flow, microcrack, deep-focus earthquake

