Water sensitivity of the rheology and seismic properties of upper-mantle olivine

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Hydrous, but water-undersaturated, conditions for the fabrication and mechanical testing of synthetic olivine polycrystals have been achieved within internally heated gas-medium high-pressure apparatus. Enclosure of specimens within a Pt capsule rather than the usual Ni-Fe sleeve results in significantly more oxidising conditions and a relatively high water fugacity. Exposure of Ti-doped olivine to these conditions results in the creation and preservation of an extended defect involving Ti/Mg substitution, charge balanced by double protonation of a neighbouring Si vacancy. Fully synthetic solution-gelation derived Fo_{90} olivine, doped with 660-1940 atom ppm Ti/Si, was hot-pressed and then deformed in Pt capsules at 300 MPa confining pressure and temperatures of 1200–1350°C. Due to the enhanced grain growth under hydrous conditions, the samples were at least three times more coarse-grained than their dry counterparts and deformed by power-law creep at differential stresses as low as a few tens of MPa. The data define an essentially linear relationship between strain rate and the concentration of chemically bound hydroxyl, inferred from the intensity of infrared absorption bands at 3572 and 3525 cm^{-1} diagnostic of the Ti-hydroxyl defect. The observed rheology is broadly consistent with the hydrous rheology previously determined for olivine under water-buffered, and therefore saturated conditions. However, in contrast with previous interpretations, we conclude that extrinsic defects (involving the Ti impurity) in olivine play the dominant role in water weakening of the Earth’s upper mantle (Faul et al., *EPSL*, 2016). Concerning seismic properties, similarly prepared Ti-doped olivine polycrystals, have been sleeved in Pt for mechanical testing in torsional forced oscillation under water-undersaturated conditions. The observed mechanical behavior is of the high-temperature background type involving monotonically decreasing shear modulus and increasing dissipation with increasing oscillation period and increasing temperature. The modulus dispersion and dissipation, thus measured under water-undersaturated conditions, are markedly stronger than for a similarly prepared specimen, tested dry within an Ni-Fe sleeve under more reducing conditions. The contrasting seismic properties of the hydrous and dry specimens suggest an important role for the chemical environment (changes of f_{O2} and f_{H2O}) in the viscoelastic relaxation responsible for reduced seismic wave speeds and attenuation in the Earth’s asthenosphere (Cline et al., *Nature Geoscience*, submitted).

Keywords: olivine rheology, water weakening, seismic wave dispersion and attenuation

