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Water sensitivity of the seismic properties of upper-mantle olivine

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The wave speeds and attenuation of seismic waves in the upper mantle are expected to be strongly influenced by the defect chemistry of olivine grain interiors and the associated chemical complexity of grain-boundary regions. Changes in chemical environment (oxygen fugacity and/or water fugacity) can impose different defect chemistries, including the creation and retention of hydrous defects, and therefore can directly influence anelastic relaxation involving stress-induced migration of lattice defects and/or grain-boundary sliding. Here we report the first low-frequency experimental study of the seismic properties of olivine under water-undersaturated conditions. Three synthetic sol-gel derived olivine (Fo90) specimens were fabricated by hot-pressing in welded Pt capsules with various concentrations of hydroxyl, chemically bound as doubly protonated Si vacancies, charge balanced by substitution of Ti on a neighboring M-site (i.e. the Ti-clinohumite-like defect). Hydroxyl contents, determined following the subsequent mechanical testing within Pt sleeves, increased systematically with the amount of added Ti-dopant. Added Ti concentrations ranged between 176 and 802 atom ppm Ti/Si, resulting in concentrations of bound hydrogen in the three samples ranging between 330 and 1150 atom ppm H/Si. Each hot-pressed specimen was precision ground and then sleeved in Pt for mechanical testing in forced torsional oscillation under water-undersaturated conditions. Forced-oscillation tests were conducted at seismic periods of 1 – 1000 s and 200 MPa confining pressure during slow staged cooling from 1200 to 25°C. Each Ti-doped specimen showed mechanical behavior of the high-temperature background type involving monotonically increasing dissipation and decreasing shear modulus with increasing oscillation period and increasing temperature. Comparison of the mechanical data acquired in these water-undersaturated conditions with a similarly tested, but dry, Ti-bearing specimen (enclosed within an Ni-Fe sleeve under more reducing conditions) shows a marked contrast. The OH-bearing specimens exhibit much lower shear moduli (by as much as 80%) and higher levels of dissipation (by as much as 0.5 log units in Q-1), but also limited sensitivity of the seismic properties to the total water content among the hydrated specimens in the series. These results indicate that the higher oxygen and water fugacities prevailing within Pt-sleeved specimens result in lower shear moduli and higher dissipation under water-undersaturated conditions – presumably attributable to contrasting defect populations and/or grain boundary chemistries. Clarification of the relative roles of grain-boundary sliding and any additional intragranular relaxation under increased fH_2O and fO_2 thus offers the prospect of an improved understanding of the seismological signature of more oxidized/hydrous portions of the Earth's upper mantle, such as subduction zone environments.