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Effect of minor elements (Al^{3+} and H^{+}) on the elastic properties of mantle minerals

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Over the past decades, the improvement on the seismic techniques have provided a more detailed picture of the structure of the mantle and revealed complexities in the seismic velocity profiles. In particular, high-resolution seismic tomography studies provide evidence for strong lateral velocity variations in the lower mantle that may be partially associated to chemical heterogeneities. The sound velocities, elasticity, and crystal chemistry of silicate and oxide minerals in Earth's mantle are therefore essential for the interpretation of seismic observations, as well as for the modeling of the geochemical and geodynamical evolution of the mantle. However, while the elastic properties of end-member mineral phases have received much attention over the past years, the influence of minor element substitutions on the elastic properties of mantle minerals is not yet well constrained.

In this talk we review recent investigations of the effect of minor elements, namely Al^{3+} and H^{+}, on the high pressure elastic properties of major minerals in the upper and lower mantle. In particular, we will present recent Brillouin spectroscopy measurements to determine the acoustic velocities and elasticity of single-crystal hydrous aluminous-bearing orthopyroxene (AlOpx) containing 6.3wt% Al_2O_3 and 1500 ppm H_2O. The results confirm that the stiffening of the bulk modulus reported in natural Opx relative to Mg-end-members and Mg-Fe solid solutions is related to the substitution of Al^{3+} for smaller Si^{4+} in tetrahedral sites. AlOpx is also characterized by compressional (VP) and shear (VS) wave velocities that are 7% and 4% higher than those of the magnesium end-member. These observations indicate that Al^{3+} has the strongest effect on the seismic velocities of Opx of all minor elements and may be taken into account to refine compositional and mineralogical models of the upper mantle. The evolution with pressure of the elastic properties, their relation to crystal structure and the effect of Al^{3+} on phase transformations will be discussed. In addition, investigations of the effect of Al^{3+} on the high-pressure elastic properties of ferropericlase to lower mantle conditions will be presented. Ferropericlase (Mg,Fe)O is the second most abundant phase in the lower mantle and therefore small variations of its elastic properties may have strong influence in the dynamic and structure of this area. The results of the elasticity studies show that 1) although Al^{3+} does not affect the bulk modulus of (Mg,Fe)O, it decreases the shear modulus by about 4%; 2) 1mol% Al^{3+} may have a comparable effect to 1mol% Fe on the elastic properties of MgO; and 3) most importantly, increases the anisotropy of Ferropericlase by about 8%. The implications of theses observations for the anisotropy and the chemical composition of the lower mantle will be discussed.