Olivine from spinel peridotite xenoliths: Hydroxyl incorporation and mineral composition

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Abstract

Traces of water in mantle minerals strongly influence mantle melting and viscosity that, in turn, governs large-scale processes like mantle convection, plate tectonics, and the stabilization of cratons. One way of estimating the mantle's water content is by analyzing mantle xenoliths brought to the Earth's surface. A major problem in estimating the mantle's water budget from xenoliths arises from decompression-induced water loss during uplift. Mantle-derived xenoliths from numerous occurrences worldwide have been investigated with respect to water. However, little is known about water in the mantle beneath most parts of Europe and Asia. This study presents water contents for mantle olivine from Germany, Austria, Mongolia, and Nigeria and suggests a possibility to assess water loss. It also addresses the question whether or not water contents are related to olivine composition and/or the presence of coexisting amphibole.

The highest water concentrations are present in olivine from the Eifel, Germany (up to 21 ppm H_2O), whereas the Fichtelgebirge xenoliths, Germany, reveal the lowest contents (<1 ppm). All water-bearing olivines show three dominant infrared absorption bands: bands at 3572, 3525, and 3560 cm^{-1} and weaker bands at 3485, 3542, and 3597 cm^{-1}. The peaks at 3572 and 3525 cm^{-1} are ascribed to Ti-related substitutions of H. Additional peaks, related to H substitutions involving trivalent cations, occur in the 3300–3400 cm^{-1} range. However, their intensity does not correlate with the content of trivalent cations. The olivines show a pronounced correlation of Al + Cr and Ca implying that incorporation of Al and Cr is governed by pressure and temperature and primarily attributed to Tschermak's substitution. This study confirms that a coupled substitution involving Ti is the most important mode of water storage in shallow upper mantle olivine. The Ti content and the fraction of water bound to "Ti defects" are related and support the substitution model $Ti^{4+} + 2H^+ = Mg^{2+} + Si^{4+}$. Hence, the Ti content is a useful proxy to estimate the maximum amount of water incorporated by this substitution—providing a tool to approximate the degree of water loss. Five of the investigated olivines provide evidence for no or very little water loss. Their water content of 16–21 ppm is presumably typical for the depleted uppermost mantle. Twelve samples with <1–15 ppm may have lost between 36 and >80% of their original water. Olivine from amphibole-bearing spinel peridotite has relatively low water contents as well as low amounts of Ca, Al, Cr, Ti, and V. Particularly low Ca, Al, and Cr contents suggest fluid infiltration, amphibole formation, and re-equilibration of the whole assemblage at comparably low pressure and/or temperature and may explain the low water content of olivine. Infrared spectra with dominant peaks in the 3200–3300 cm^{-1} range (spectrum type E) are confined to olivine from amphibole-bearing peridotite.

Keywords: Water content, nominally anhydrous minerals, olivine, spinel peridotite, trace elements