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Partitioning of Water between Magnesium Silicate Perovskite and Other High-Pressure Phases

Nathalie Bolfan-Casanova (nathalie.bolfan-casanova@uni-bayreuth.de), **Hans Keppler** (hans.keppler@uni-bayreuth.de) & **Dave C. Rubie** (dave.rubie@uni-bayreuth.de)

Bayerisches Geoinstitut, Universitat Bayreuth, Bayreuth, D-95440, Germany.

Water can have a dramatic effect on the physical and chemical properties of rocks, such as melting, diffusion, deformation, and electrical conduction, which play a dominant role in the evolution of our planet. It is therefore very important to assess the distribution of water within the Earth. Magnesium silicate perovskite constitutes about 80% by volume of the Earth's lower mantle, and thus small amounts of hydrogen dissolved in its structure could greatly affect the physical and chemical properties of the deep Earth. Also, since $(Mg,Fe)(Si,Al)O_3$-perovskite is the most abundant mineral in the Earth, small amounts of hydrogen dissolved in its structure could correspond to a non negligible fraction of the Earth's hydrosphere. Therefore, magnesium silicate perovskite could have a substantial influence on the global cycle of water. Nevertheless, despite its importance, studies of the incorporation of hydrogen in silicate perovskite are scarce, probably because it is an experimental challenge in many aspects: pressures in excess of 24 GPa are needed to synthesise the samples. Moreover, large single crystals, free of inclusions, are required for the spectroscopic analysis.

In this study, we investigated the partitioning of water between perovskite and coexisting phases in the following systems: $MgO-SiO_2-H_2O$, $MgO-Al_2O_3-SiO_2-H_2O$, $MgO-FeO-SiO_2-H_2O$ and $MgO-FeO-Al_2O_3-SiO_2-H_2O$. Water was added as brucite. Two types of bulk compositions were used, one with Mg:Si=1 and one with Mg:Si>1. The experiments were performed in a multi-anvil apparatus at 24 GPa and 1400 to 1750 C. The recovered samples were analysed with electron microprobe (EPMA) for the chemical composition and by Raman spectroscopy for phase characterisation. The water contents were measured in the near infrared (NIR) region using a Fourier Transform Infrared spectrometer.

In experiments performed in the $MgSiO_3-H_2O$ system, at 1600ºC akimotoite ($MgSiO_3$- ilmenite type structure) coexisting with magnesium silicate perovskite and a melt dissolved ~425ppm wt H_2O whereas no water was detected in the perovskite phase. When silicate perovskite coexisted with periclase and a melt in the $MgSiO_3-MgO-H_2O$ system, at 1500ºC, ~2.5 ppm wt H_2O were found in periclase whereas the perovskite was still dry.

In low temperature experiments (1400 C) magnesium silicate perovskite coexisted with a hydrous phase, either ringwoodite or superhydrous phase B, and sometimes a melt. In the $MgO-FeO-SiO_2-H_2O$ system, the EPMA analysis of ringwoodite yield an (Mg+Fe)/Si ratio of 1.95±0.01, with analysis weight totals of 98.07±0.45. The IR spectra of ringwoodite are very similar to those previously observed with bands at 3700, 3120 and 2550 cm^{-1}. The IR analysis yields a water content of 2100 ppm wt H_2O. The NIR spectra of perovskite displays only one peak at 3388 cm^{-1}, corresponding to 2 wt ppm H_2O. This gives a partitioning coefficient for water between ringwoodite and perovskite of 1050.

The NIR spectra of superhydrous B are all saturated due to its very high water content (around 6 wt% H_2O). The NIR spectra of perovskite coexisting with superhydrous B contain two peaks at 3406 and 3345 cm^{-1}, which are characteristic of superhydrous B. No band could be assigned unambiguously to structurally bound H in the perovskite structure. This was the case in both Al-, and (Al,Fe)-bearing systems.

At 24 GPa and 1500ºC, magnesiowüstite, coexisting with $(Mg,Fe)(Si,Al)O_3$ perovskite, displayed its typical band in the NIR region at 3320 cm^{-1}, which is consistent with 40 ppm wt H_2O. No band could be detected in the perovskite phase. Thus, the partitioning coefficient for water between magnesiowüstite and $(Mg,Fe)(Si,Al)O_3$ perovskite is >>1.

Our results show that the amount of hydroxyl that partitions into magnesium silicate perovskite is very small, even in the presence of trivalent cations such as Al^{3+} and Fe^{3+}. Instead, water partitions preferentially into coexisting superhydrous B, ringwoodite, or even magnesiowüstite. These partition coefficients indicate that the amount of water that can be recycled into the lower mantle via subduction processes is far lower than what can be recycled into the transition zone. Thus, the water released by the breakdown of dense hydrous phases in the downgoing slab is likely to induce melting in the lower mantle.