Temperature dependence of Fe,Mg partitioning in Acapulco olivine

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ABSTRACT

The temperature dependence of the intracrystalline Fe,Mg partitioning ($K_D$) in two olivine crystals (Fa$_{11}$) separated from the Acapulco meteorite was determined by single-crystal X-ray structure analysis. The independent atom model (IAM) was compared with a “bond model” which accounts for bond-induced charge accumulations on the Si-O bonds. Outliers in the set of structure amplitudes observed when using the IAM disappeared upon introducing the bond model. The crystals were equilibrated at 750, 650, and 500 °C. The refined site occupancies yield the relation ln($K_D$) = 0.345(60) – 204(53)/$T$, where $T$ is in K, which is in qualitative agreement with earlier work. Comparison of these data with the higher temperature data of Artioli et al. (1995) suggests an unusual temperature variation of the Fe,Mg distribution within two temperature regimes. Below 880 °C, Fe tends to order onto the M1 site with increasing temperature whereas it concentrates on the M2 site above 880 °C. In principle, olivine may serve as a geospeedometer similar to orthopyroxene. However, at present its usefulness is restricted because (1) the relatively weak dependence of ln($K_D$) on temperature needs to be even more tightly constrained than presented here and (2) low-temperature extrapolation of the rate constants for the Fe,Mg site exchange, derived from interdiffusion coefficients, is uncertain.

INTRODUCTION

The temperature dependent distribution of Fe and Mg on the non-equivalent M1 and M2 sites of olivines, (Mg,Fe)$_2$SiO$_4$, is characterized by a weak tendency of Fe to order onto the M1 site with increasing temperature (e.g., Aikawa et al. 1985; Ottonello et al. 1990; Princivalle 1990). Because it is difficult to quench equilibrium states from above 800–900 °C, Artioli et al. (1995) and Rinaldi et al. (1997) performed in situ neutron diffraction experiments from which they infer that at high temperatures Fe no longer prefers M1, but concentrates in M2.

Kirfel (1996) performed a round robin in which various laboratories were asked to refine Fe,Mg distributions in orthopyroxenes and olivines from X-ray intensity data provided by that author. The large spread of the obtained results was disconcerting. The same olivine, for example, was reported with Fe preferring M1 or M2, respectively, depending on the laboratory.

In the following, we report on Fe,Mg ordering states derived from refinement techniques which are considered to reduce the inadequacy of the conventional independent atom model (IAM) with respect to modeling bond-induced charge redistributions. Two olivine crystals from the Acapulco meteorite (Fa$_{11}$) were equilibrated at 750, 650, and 500 °C, then quenched to room temperature, and their site occupancies refined from X-ray intensities.

EXPERIMENTAL METHODS

Microprobe analysis

Several olivine crystals were kindly provided by J. Zipfel, Mainz. Two of them were selected for X-ray single crystal work. They were optically clear and exhibited sharp optical extinctions and sharp singular spots in Laue photographs. Two other crystals less suitable for X-ray single crystal studies but free of inclusions were analyzed with a JEOL Superprobe (JXA-8600 MX). The data were reduced by a ZAF correction. The crystals proved to be homogeneous and compositionally identical within error limits. Mean values of 203 point analyses with weight percentages between 98.5 and 101.5% are given in Table 1 along with the results of Zipfel et al. (1995) demonstrating excellent agreement.

Heat treatment

After collecting their X-ray intensity data the two selected crystals were heat-treated. Each crystal was placed in a SiO$_2$-glass capillary. Then, both capillaries were loaded side by side into a SiO$_2$-glass capsule together with Fe powder separated from the capillaries. The capsule was repeatedly evacuated, filled with purified Ne, and finally sealed. The crystals were annealed at 750 °C for 4 days, and then, after rapid quenching into water, analyzed by X-ray diffraction. This procedure of heating, quenching, and subsequent X-ray analysis was repeated for temperatures of 650 and 500 °C, allowing equilibration times of 6 and 26 days, respectively.