

CONSTRAINTS IN THE FORMATION CONDITIONS OF FEO-RICH OLIVINES. E. Dobrică¹, J. A. Nuth², and A. J. Brearley³, ¹Hawai'i Institute of Geophysics and Planetology, School of Ocean, Earth Science, and Technology, University of Hawai'i at Mānoa, Honolulu, HI (dobrica@hawaii.edu), ²Solar System Exploration Division, Code 690, NASA Goddard Space Flight center, Greenbelt MD 20771 USA. ³Department of Earth and Planetary Sciences, MSC03-2040, 1University of New Mexico, Albuquerque, NM.

Introduction: Chondrite matrices contain FeO-rich olivine (Fa₅₀₋₁₀₀) formed during fluid-assisted metamorphism [1-5]. However, the growth of FeO-rich olivines from hydrothermal fluids has not been demonstrated experimentally, except for pure fayalite [4]. In order to constrain the formation mechanism and conditions of FeO-rich olivine, we performed eight hydrothermal experiments. Additionally, we investigated the fine-grained matrix of Kaba (CV3.1), which contains both fine-grained ferroan olivine ((Fe,Mg)₂SiO₄, Fa₋₅₀) associated with nearly pure, euhedral, coarse-grained fayalite (Fe₂SiO₄, Fa₉₀₋₁₀₀) [6]. In this study, we describe the results of hydrothermal experiments and observations of the fine-grained matrix of Kaba to understand the chemical reactions and the role of fluids in the fluid-assisted metamorphism that affected the matrices of ordinary and carbonaceous chondrites.

Methods and results: We performed eight hydrothermal alteration experiments in an attempt to synthesize FeO-rich olivines at low temperatures. All experiments were carried out at a temperature of 230°C for 6 days. We used four different reactants for these experiments: (1) Fe-bearing amorphous silicates, (2) Mg-bearing amorphous silicates, (3) iron metal powder, and (4) deionized water (Table 1). We chose both Mg-, and Fe-bearing amorphous silicates as the precursor materials to understand the role of Fe and Mg in the formation of FeO-rich olivines since primitive chondrites contain only rare pure fayalite crystals. Both Mg- and Fe-rich amorphous silicates were synthesized experimentally by disequilibrium condensation [7]. The compositions of the silicate grains are shown in Figure 1. Additionally, we added iron metal powder to the experiments because previous studies [8] showed that fayalite forms from a FeO-rich fluid that is SiO₂-poor and very reduced (log *f*(O₂) less than QFM conditions of -35.7 at 300°C). We used a similar experimental procedure as the one described in [4].

The reactants and products of the hydrothermal experiments were studied using the FEI Helios 660 dual-beam focused ion beam scanning electron microscope (FIB-SEM) instrument at the Advanced Electron Microscopy Center (AEMC) at the University of Hawai'i at Mānoa. Three transmission electron microscopy (TEM) sections of selected regions containing the new phases formed in the experiment (101122_E2 and _E6) and the fine-grained FeO-rich

olivines from Kaba were prepared using the FIB technique.

Table 1. Reactants used in each hydrothermal experiment. Am. React – amorphous silicates, reactants, W/R – water/rock.

Exp #	Am. React	Am. React (mg)	Fe metal (mg)	H ₂ O (μl)	W/R mass ratio
101122 E1	MgO-SiO ₂	13.2	10.5	12	0.5
101122 E2	MgO-SiO ₂	8.2	6.8	15	1
101122 E3	FeO-SiO ₂	3.0	11.3	6	0.4
101122 E4	MgO-SiO ₂	4.9	11.9	6	0.4
121222 E5	MgO-SiO ₂	12.7	10.2	45	2.0
121222 E6	MgO-SiO ₂	4.0	10.7	30	2.0
121222 E7	FeO-SiO ₂	3.0	12.9	30	1.9
121222 E8	MgO-SiO ₂	3.8	11.3	15	1

Fe-bearing experiments: Fayalite was formed in the experiment performed at 0.4 W/R mass ratio (experiment 101122_E3, Fig. 2). However, no fayalite or any other mineral phases were identified during the experiment performed at high W/R mass ratio (2 W/R, experiment 1121222_E7).

Mg-bearing experiments: No FeO-rich olivine was identified in the experiment performed using the Mg-bearing amorphous silicates. New minerals were formed in these experiments, including those performed at a low W/R mass ratio (0.4). Ferrous-iron-rich hydroxides, [brucite, (Mg,Fe)(OH)₂] with different morphologies were identified by quantitative EDS analysis and electron diffraction (Figs. 1-2). The composition of the amorphous silicates associated with the Mg,Fe oxides is enriched in iron (avg. 10.5 wt.% FeO, Fig. 1, am. product—purple circles) compared to the original amorphous silicates used as reactants.

Discussion: Previous and current hydrothermal experiments [4, 9] show that only pure fayalite can form during rapid hydrothermal processes at low-temperature (<230°C) and low W/R mass ratios (0.4 W/R). However, most FeO-rich olivines in chondrites are FeO-rich (Fa₅₄ - OC [5] and Fa₅₂ - Kaba). The lack of FeO-rich olivines in these experiments could reflect (1) a high silica and water activity in these experiments or (2) that diffusion processes may have played an important role in the formation of FeO-rich olivines in chondrites. Recent studies have shown that MgO-rich pseudomorphic olivine can precipitate at low temperatures (200-300°C) in association with brucite

during progressive hydration of olivine in dunites [11]. Though the actual factor(s) controlling the formation of these MgO-rich olivines remains unknown, this study suggests that a decrease in the silica and water activity of the reacting solution during the hydrothermal reactions could be a relevant parameter.

Previous studies show that Mg-Fe diffusion processes had an important role in the formation of FeO-rich olivines and affected the fine-grained matrix crystals in CV (e.g. Kaba) and CO chondrites [12]. However, Mg-Fe diffusional exchange is extremely limited at low temperatures and short timescales of feasible experiments [10] compared to the diffusion processes in chondrites. Therefore, the results of this study suggest that to form MgO-bearing olivine, FeO-rich olivines probably have to form first during rapid hydrothermal processes and then undergo diffusional exchange with time.

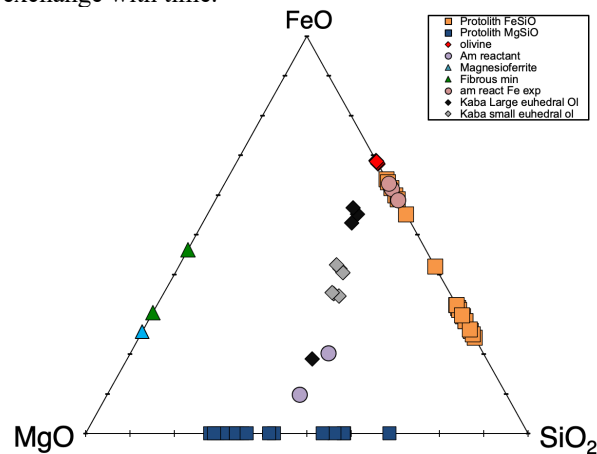
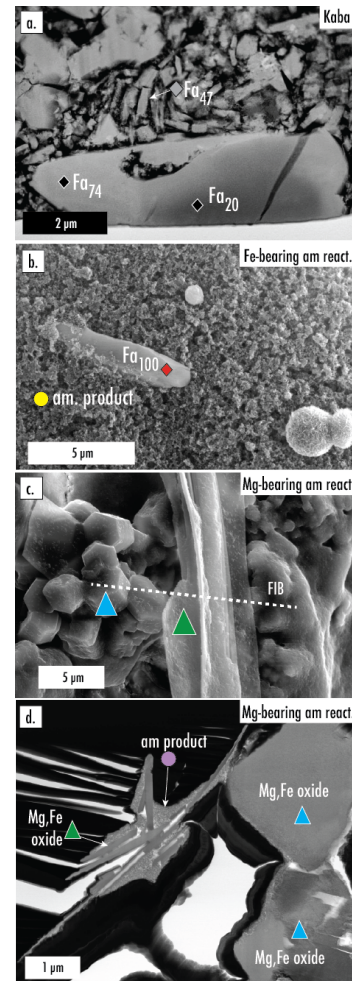


Figure 1. Ternary diagram (FeO-MgO-SiO₂, in wt.%) of FeO-rich olivines (ol.) from Kaba (black–large ol. and grey–small ol. diamonds, Fig. 2) and MET 00526 (*data from [5]); and the reactants and products of the hydrothermal experiments using Fe-bearing amorphous silicates (fayalite–red diamonds, am. reactants–orange squares, and am. products–pink circles;) and Mg-bearing amorphous silicates (Mg,Fe oxide with different morphologies–green and blue triangles, am. products–yellow circles, and am. reactants, blue squares).

Figure 2. STEM and SEM images of Kaba meteorite (a) and low temperature hydrothermal alteration experiments (b-d). a) Backscattered electron micrograph showing the presence of small, euhedral (Fa₄₇, grey diamonds, Fig. 1) and nearly pure fayalite, zoned olivine (Fa₂₀₋₇₄, black diamonds Fig. 1) from Kaba meteorite. b) Secondary electron image of fayalite (red diamonds, Fig. 1) and amorphous reactants (yellow circles, Fig. 1) produced at 0.4 W/R mass ratio during the hydrothermal experiment when using Fe-bearing amorphous silicate. c) FIB section prepared in the reactant products of the experiment 121222_E6 using

Mg-bearing amorphous silicate. d) TEM micrograph of the association of Mg,Fe hydroxides with different morphologies (blue and green triangles) and amorphous products (purple circles, Fig. 1) identified in the FIB section.



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