

LOW-TEMPERATURE EXPERIMENTAL ALTERATION OF AMORPHOUS MATERIALS: INSIGHTS INTO EARLY FLUID-ASSISTED HYDRATION PROCESSES ON CHONDRITE PARENT-BODIES. E. Dobrică¹, J. A. Nuth² and A. J. Brearley¹, ¹Department of Earth and Planetary Sciences, MSC03-2040, 1 University of New Mexico, Albuquerque, NM 87131-0001, USA (edobrica@unm.edu); ²Solar System Exploration Division, Code 690, NASA Goddard Space Flight center, Greenbelt MD 20771 USA.

Introduction: For decades, the study of chondritic meteorites has been driven by a perpetual quest to identify and understand the most pristine materials formed in the early solar system. The goal of these studies is to constrain the physico-chemical conditions of these materials and their evolution, within the protoplanetary disk and later on the chondrite parent-bodies. Following asteroidal accretion, multiple secondary processes come into play such as thermal- and shock-induced metamorphism, metasomatism, and aqueous alteration and modify these pristine components of chondrites [1]. These processes begin to occur even at very low degrees of secondary alteration [2]. Therefore, we need to understand these secondary processes to retrace the characteristics of the earliest solar system materials. In this study, we investigate the formation conditions of FeO-rich olivines, which remains a key problem to understanding the effects of secondary alteration through hydrothermal processes on chondrite matrices. Iron-rich olivine is one of the major minerals in the matrices of unequilibrated ordinary (UOCs) and carbonaceous (CV, CK, CO) chondrites whose petrologic type is >3.1 [3-5]. Additionally, FeO-rich olivine has been detected in cometary dust particles [6]. Our first experiments provide clear evidence that hydrothermal growth of elongated, FeO-rich olivine can occur during thermal metamorphism in the presence of a fluid (220°C, 0.4 W/R mass ratio, 6 days, [7]), as described previously in meteorites and supported by thermodynamic calculations [8-10]. So far, hydrothermal alteration experiments have been successful at forming FeO-rich olivines with the compositions and textures observed in the matrices of chondrites only at 220°C [7]. Therefore, understanding the formation conditions of FeO-rich olivines at lower temperatures, durations, and water-to-rock (W/R) mass ratios remains a key problem to understanding the effects of hydrothermal alteration on chondrite matrices.

Methods and results: We performed five hydrothermal alteration experiments in an attempt to synthesize FeO-rich olivines at low-temperatures (50°C, 100°C, and 150°C). We used three different reactants for these experiments: (1) amorphous silicates (~3.5 mg to 9.5 mg, depending of the experiment), (2) iron metal powder (~4.5 mg to 25 mg), and (3) different amounts of deionized water (18 megohms) to simulate W/R mass ratios of 0.2, 0.5, and 1.2. We chose amorphous silicates as the precursor material since they are ubiquitous fine-grained materials in

almost all primitive solar system materials (chondritic meteorites and interplanetary dust particles) and in most astrophysical environments [11-13]. The amorphous silicate grains were synthesized experimentally by disequilibrium condensation [12]. The composition of the silicate grains, which condense from the SiO-H₂-Fe vapor, is FeSiO [13]. Additionally, we added iron metal powder (spherical particles, $<10\ \mu\text{m}$) to the experiments, because previous studies [14] showed that fayalite forms from a FeO-rich fluid that is SiO₂-poor and very reduced ($\log f(\text{O}_2)$ less than QFM conditions of -35.7 at 300°C). According to thermodynamic calculations fayalite could form at W/R ratios lower than 0.2 W/R [10]. However, the estimated W/R mass ratio for chondritic parent bodies range from <0.1 to 0.6 (or possibly higher for CI chondrites), which is significantly lower than the solar value of 1.2 W/R mass ratio [15].

We loaded the reactants in gold (Au) capsules, which were welded using a carbon arc welder. We tested whether the experiments were successful or not (e.g. leaks) by weighing the capsules before and after the experiments. The capsules were placed in Parr bombs (reactor vessels) and heated in a low-temperature furnace (Fisher Scientific, Isotemp 500 Series). Based on previous studies, we carried out experiments for periods of 2 and 14 days at three different temperatures 50°C, 100°C, and 150°C.

Scanning electron microscope (SEM) studies of the products of the five experiments show that the distribution of reactants and products is heterogeneous. Figure 1a shows the presence of regions where the reactants were not extensively modified during the experiments; however, in each experiment, we identified scarce regions where new phases were formed (Fig. 1b). This suggests that the distribution of water in the experiment was heterogeneous and that locally the W/R mass ratio could have been higher than the one intended for each experiment. No new phases were formed in the dry regions. Figure 1a shows that in these regions only the iron metal powder was embedded in the amorphous material during the experiment (Fig. 1a). However, in the presence of water, Fe and silica were mobile, forming new, platy, and fibrous FeO-rich minerals (Fig. 1b).

Seven transmission electron microscopy (TEM) sections of the experimental run products were prepared using the focused ion beam (FIB) technique with a FEI Quanta 3D Dualbeam® FIB instrument. Bright and dark-field TEM images, quantitative EDS

X-ray analyses, and selected area electron diffraction were carried out at 200 kV on a JEOL 2010F FEG TEM/Scanning TEM (STEM).

New minerals were formed in all the experiments analyzed in this study, including those performed at very low-temperature, W/R mass ratio, and duration (50°C, 0.2 W/R mass ratio, 2 days). Iron oxides (magnetite and ferrihydrite) and phyllosilicates (greenalite, Figs. 1-2) were identified by quantitative EDS analysis and/or electron diffraction analysis. Greenalite, the iron member of the serpentine group was only identified in the experiments performed at 150°C and >0.5 W/R mass ratio. These crystals are platy, radiating rose-like aggregates (Fig. 2). They vary in length from a few hundreds of nanometer up to 4 µm and in width from 20 nm to 80 nm. The iron metal powder was not completely consumed in the experiments; however, these grains show numerous embayments along significant portions of the powder edges (Fig. 2b), which is expected if the powder was in contact with an aqueous fluid. Additionally, they are locally transformed into magnetite.

Two of the experiments analyzed in this study were performed at similar temperatures (150°C) and durations (14 days); however, the W/R mass ratios were different (0.5 – Exp. 18, Fig. 1 and 1.2 – Exp. 16, Fig. 2). Our TEM observations show that identical phases were formed in both experiments; however, at higher W/R mass ratios the abundance of these phases is clearly much higher. This indicates that the W/R mass ratio controls the abundance of phases; however, the temperature and the duration have an important role in the type of phases formed during the experiment.

Conclusion: Our study indicates that no FeO-rich olivine was formed at the low-temperature (<150°C) of these experiments. Therefore, the presence of FeO-rich olivines in the matrix of chondrites could suggest that these fine-grained materials were modified at higher temperatures than 150°C and/or for longer durations during fluid-assisted metamorphic processes.

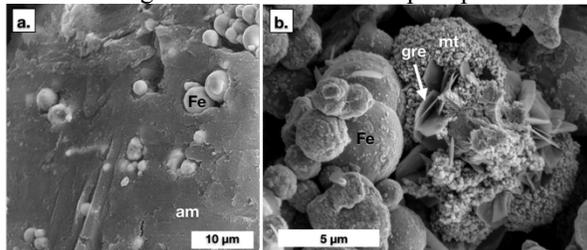


Figure 1. Secondary electron images showing the products of the experiment #18 (150°C, 14 days, 0.5 W/R mass ratio) indicating the heterogeneous distribution of reactants and products: (a) the reactants (am – amorphous material, Fe – iron metal powder) are not extensively modified during the experiments, and (b) new-formed phases (gre – greenalite and mt – magnetite).

Acknowledgments: This work was funded by NASA grant NNH18ZDA001N-EW to E. Dobrica (PI).

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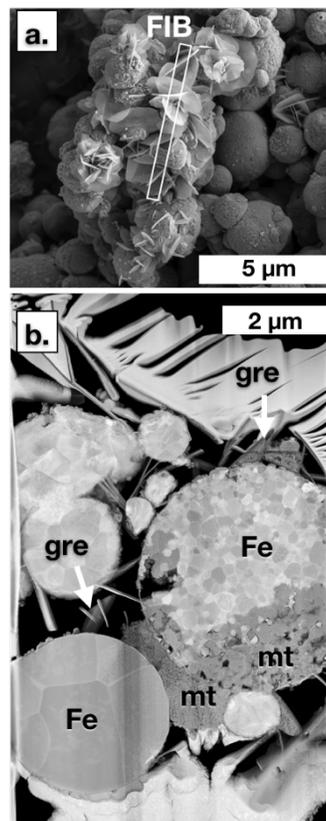


Figure 2. a) Secondary electron image showing the texture of the new phases formed in the experiment (Exp. #16) performed at 150°C, for 14 days, and 1.2 W/R mass ratio. b) Dark-field STEM image of the FIB section made in the experiment #16 (white rectangle, Fig. 2a) showing the mineralogy and the textural relationships between the reactant iron metal powder (Fe) and the new phases (gre – greenalite and mt – magnetite) formed during the hydrothermal alteration.