

AN EXPERIMENTAL STUDY OF DISSOLUTION, FE-MG EXCHANGE AND ZONING BETWEEN RELICT FORSTERITE AND CHONDRULE MELT: IMPLICATIONS FOR THERMAL HISTORIES OF CHONDRULES G. Ustunisik^{1,2}, D. S. Ebel^{2,3}, D. Walker^{3,2} ¹Department of Geology and Geological Engineering, South Dakota School of Mines and Technology (SDSM&T), Rapid City, SD, 57701 ²Department of Earth and Planetary Sciences, American Museum of Natural History (AMNH), New York, NY, 10024 ³Department of Earth and Environmental Sciences, Lamont Doherty Earth Observatory of Columbia University (LDEO), Palisades, NY, 10964.

Introduction: One of the most revisited problems in cosmochemistry is the timescales of the heating that produced tiny melt droplets, chondrules, during the early stages of Solar System evolution. Many researchers constrain the thermal histories of chondrules (cooling rates and timescales of exposure to peak temperatures) from volatile abundances (e.g. Na, K) and/or matching experimental and natural textures [1].

However, the chemical and textural characteristics of different generations of precursor grains in chondrules can also record the processes that affected solids in the evolving nebula. Strong evidence that chondrules were affected by re-melting is provided by the relatively common occurrence of relict (exotic) grains in chondrules, primarily olivine. These refractory (FeO-poor) olivines are commonly found within high-FeO, porphyritic chondrules in Type II ordinary and Type III carbonaceous chondrites [2, 3]. Typically, they have sharp transitional boundaries between core and zoned rim. Their zoning is inconsistent with in-situ crystallization from their host chondrule melt. These characteristics indicate that relict grains underwent a significant incomplete melting and dissolution episode at temperatures above the glass transition temperature, when reaction between the relict and its surroundings occurred. The extent of melting and dissolution of each chondrule is clearly a function of temperature, liquid and mineral composition, and grain size. Mineral dissolution, Fe-Mg exchange, and zoning within relict crystals can help to constrain the temperature-time aspects of this re-melting process and therefore provide insights into the host chondrule thermal history.

Previous experimental studies on olivine dissolution focused on melts of terrestrial compositions ranging from basalts to rhyolites [4-7]. For planetary materials, experiments were more limited and focused on constraining the relationship between different types of chondrules [8, 9] or understanding oxygen isotope signature [10] along with some modeling work [11].

Here, we designed isothermal and controlled cooling experiments to 1) quantify temperature-time effect on dissolution and expected Fe-Mg exchange and zoning in relict forsterite, 2) determine the relative roles of dissolution and Fe-Mg exchange (diffusion) on erasing the relict signature, and 3) observe the volumetric evolution of the crystal shapes and textures and correlate them with the chemical changes by imaging initial and

the partially resorbed olivines via X-ray computed tomography (X-ray CT).

Experimental Design: Both isothermal and controlled cooling experiments were run at Lamont Doherty Earth Observatory (LDEO) in a vertical Deltech furnace where CO-CO₂ gas mixtures kept the fO₂ ~IW-1. Starting compositions (Table 1) were prepared from high purity oxides and silicates by homogenizing the mixtures in ethanol in an agate mortar for >1 hr and drying at 125°C under vacuum to remove any adsorbed water. Gem quality Mogok forsterite (Mfo, Fo₉₉) from the AMNH mineral collection was cut into ~equant 1 mm² cubes. Slices were examined under the optical microscope to select inclusion- and crack-free crystals. For each run a cubic Mfo crystal of known size (by X-ray CT) was placed in a synthetic Type IIA chondrule composition (C11 mesostasis [12] with 4.92 wt% FeO (T_{Liquidus} ~1315°C). Pressed pellets of this mixture were hung on Pt-wire loops and inserted into the hot spot. For isothermal experiments, each charge was heated to 1428°C, 1350°C, 1250°C, and 1150°C and was held there from 20 mins to several days (>3 days) before drop-quenching into cold water. The controlled cooling experiments were held at 1428°C for 20 mins, cooled at rates of 75°C, 722°C, and 1444°C/hr to 1000°C and then water quenched.

Table 1. Target and modified compositions of Type IIA C11 Semarkona mesostasis [12] and Mfo.

	Target Type IIA C11	Type IIA C11 with FeO	Mogok Forsterite
SiO ₂	53.35	51.42	42.78
TiO ₂	1.19	1.15	0
Al ₂ O ₃	24.52	23.63	0
FeO	0.49	4.92	1.02
MgO	2.76	2.84	57.05
CaO	17.69	16.04	0.03
Total	100	100	100

Analytical Procedures: The charges were scanned by X-ray CT at AMNH to obtain non-destructive three dimensional (3D) images of partially resorbed olivines, including thickness of dissolution rims and zoning characteristics. This allowed a high resolution view of the dissolution process, especially at the edges of the crystals for determining the changes in the volume of the specific crystal scanned before and after the experiment. Due to the strong correlation of x-ray attenuation with olivine FeO content, the contrast between olivine crystals and surrounding glass allowed measurements of dimensions of olivine grains. After reconstruction, full 3D information of the charges was recovered (Fig. 1).

Following CT imaging, run products were mounted in epoxy, then sectioned and polished for optical examination and quantitative analysis. Backscattered electron (BSE) images were obtained and major oxide abundances were analyzed using the Cameca SX100 electron microprobe (EMP) at AMNH with 20nA beam current and 1 μ m beam for both melt and crystals.

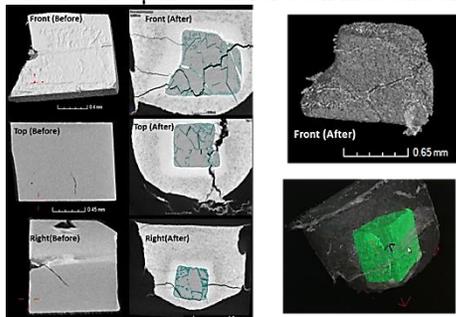


Fig. 1. Before and after run 3D images (front, top, and right view) of forsterite crystals obtained by X-ray CT along with an example of a reconstructed crystal.

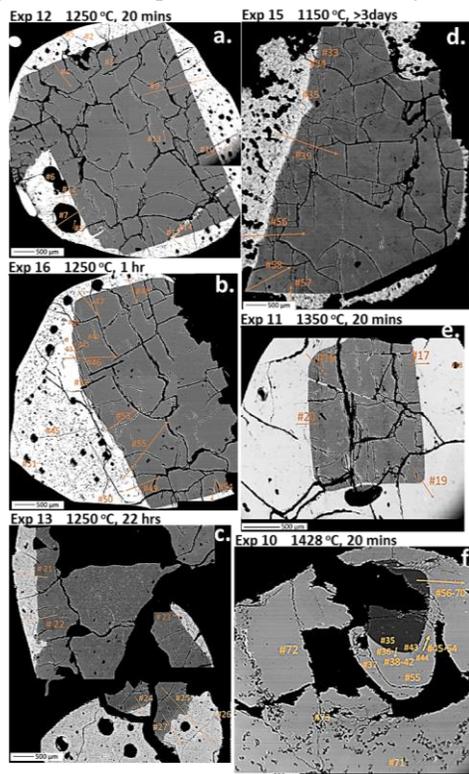


Fig. 2. BSE images of run products (#12, 16, 13, 15, 11, 10) for isothermal cooling experiments at IW-1.

Results and Discussion: The isothermal experiments at 1150 and 1250°C for 20 mins, produced no bulk FeO diffusion into the Mogok forsterite (Mfo, Fig. 2a). Very minor Fe-Mg exchange at the crystal rims gives slight MgO zoning within the nearby melt (Fig. 3a). With increasing duration (1 hr and 22 hrs), at 1250°C, embayments of melt form into the rims of the crystal (amplified at 22 hrs) with significant FeMg

exchange (Fig. 2b and 2c). FeO content of Mfo increased with major MgO zonation within nearby melt (Fig. 3b and 3c). At 1150°C, the same increase in FeO in Mfo and zonation in nearby glass could only be achieved in a >3 days experiment (Fig. 2d).

At high temperatures (1428°C) in 20 min run, ~75 volume % of Mfo has been dissolved into the melt (Fig. 2f). Resorption erased the Fe-Mg exchange at the rims of the crystal (Fig. 3e and 3f). In longer duration experiments (1250°C, 22 hrs and 1150°C, >3days) quench olivine crystals and silica (cristobalite) have been observed within the melt along with low-Ca pyroxene along the edges of the Mfo (Fig. 2c and 2d) and the Fe-Mg exchange was amplified at certain edges (Fig. 3c and 3d). The metastable pyroxene acted as a protective cover thwarting Fe-Mg exchange between Mfo and Fe-bearing melt. The cristobalite occurred as a result of melt fractionation. Here we only report on the results of isothermal experiments; the data from controlled cooling ones will be shown in the conference.

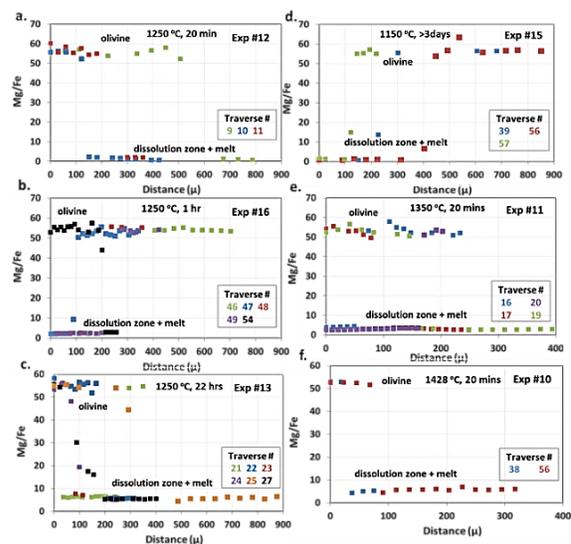


Fig. 3. Distance versus Mg/Fe diagram showing changes in olivine and dissolution+melt zone for various traverses from Figure 2.

Acknowledgments: This research was supported by NASA Cosmochemistry grant NNX10AI42G (DSE) and the Kathryn Davis Scholarship of the AMNH MAT program (GU).

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