

TRACE ELEMENT PARTITIONING BETWEEN OLIVINE, ORTHOPYROXENE, SILICATE MELT, METAL AND SULFIDE IN EXPERIMENTAL CHONDRULES EQUILIBRATED WITH NEBULAR GAS

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Introduction: Chondrules, one of the major components of primitive meteorites consisting of olivine, pyroxene, glassy mesostasis, metal beads and sulfides, are the results of fusion-crystallization of solid precursors in interaction with nebular gases [1,2,3]. Due to their chemical and textural diversity, establishing a general formation model is challenging. Indeed, despite numerous geochemical and experimental studies, there is no consensus about the nature of the solid precursors, the physical (pressure, temperature, thermal history) and chemical (redox, gas composition) conditions that controlled the formation of these complex objects. Trace element partitioning between olivine, orthopyroxene, silicate melt, metal and sulfide have been measured in a variety of chondrules [4-7]. Experimental studies produced partition coefficients in chondrule-like systems [8] that have been useful for inferring chondrule cooling rates [7]. However, these experiments did not include an equilibrium with a gaseous phase, even though it is supposed to have played a major role in the formation of chondrules. In this study, we experimentally reproduced chondrules, at equilibrium with a gaseous phase, and at various oxygen fugacities (fO_2). We obtained partition coefficients in order to interpret chondrule data, and ultimately better understand the processes (condensation versus magmatic processes) and conditions (temperature, fO_2) of their formation.

Materials and method: We performed 25 experiments in evacuated silica tubes at temperatures ranging from 1150°C to 1450°C, with two different starting compositions: the carbonaceous chondrite NWA11345 (CM2) and the ordinary chondrite Tamdakht (H5). The [volume of starting powder]/[volume of the tube] ratio was minimized to favor evaporation at high temperature. Experiment duration was between 2 and 72 hours to ensure vapor/sample equilibration. The samples were weighed before and after experiment to calculate the evaporated masses, which range between 1 and 67%. The redox conditions were mostly buffered by the graphite-CO equilibrium, resulting in fO_2 ranging from IW-6.1 to IW-3, in agreement with fO_2 measured in type I chondrules [9]. High-resolution images and multi-elemental X-ray maps were acquired using SEM on the experimental samples to characterize their mineral phases. Major and minor element concentrations of the various phases were measured by EPMA, and trace elements were acquired in-situ by laser ablation ICP-MS. Partition coefficients were then calculated.

Results and discussion: The experimental samples are composed of silicate glass, forsterite, enstatite, kamacite and sulfides (troilite and sometimes keilite, alabandite) in variable proportions and compositions according to fO_2 and temperature. One sample contains anorthite. These mineralogies are equivalent to the reduced mineral assemblages of type I chondrules in carbonaceous, ordinary and enstatite chondrites. Whisker crystals, condensed from the vapor phase during the quench, were also observed in most tubes. We therefore obtained enstatite/melt, forsterite/melt, enstatite/melt, sulfide/melt and metal/melt trace element partition coefficients (D_s) and most of them are strongly correlated with fO_2 (e.g. $D_{Cr}^{metal/melt}$, $D_{Ti}^{opx/melt}$, $D_Y^{sulfide/melt}$, $D_{Er}^{sulfide/melt}$). The D_s of redox-sensitive elements can therefore be used as oxybarometers in type I chondrules. Enstatite/melt and forsterite/melt D_s plotted in Onuma diagrams prove crystal-melt chemical equilibrium in the experiments, but some elements, in particular V, display anomalously high D_s , similar to natural chondrule data [4]. As D_s obtained in similar systems and redox conditions, but without an interaction with gas, do not display these anomalies [10], we hypothesize that extremely high V D_s result from the interaction between the melt and the gas phase. The data obtained in this study will allow us to infer the conditions of formation of type I chondrules and discuss the influence of magmatic and nebular processes on their geochemistry.

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