Revealing the Early Cooling Histories of Type 1A Chondrules using Diffusion Chronometry

W.S. Nelson[1], G. Libourel[2], J. Hammer[1], T. Shea[1], [1]SOEST, University of Hawaii at Manoa, Hawaii, USA (wnelson@hawaii.edu), [2]Université Côte d'Azur, Nice, France

Introduction: Chondrules, ancient sub-millimeter spherules of ferromagnesian silicates, Fe metals, and sulfides formed in the protoplanetary disk are one of the primary composents of most chondrite meteorites. Chemically, the most abundant chondrules are Mg-rich (Type 1). Olivine-rich (Type 1A) chondrules are further subdivided by the morphology of the olivine grains into barred olivine chondrules (BO), which have parallel lath-shaped crystals as viewed in section, and porphyritic olivine chondrules (PO), which have compact polyhedral crystals. Here we investigate the cause of this morphological difference in pursuit of a broader understanding of chondrule formation conditions.

A first hypothesis holds that morphological differences are attributed to variable extents of melting of precursor dustballs. Incomplete melting would leave crystalline seeds on which olivine could regrow as polyhedral crystals at relatively low thermodynamic undercooling. In contrast, dustballs that underwent higher degrees of melting would lose all substrates and unaided homogeneous nucleation and rapid growth would produce barred olivine [2,3]. This explanation posits a dramatically different thermal history for the BO and PO chondrule types. A second hypothesis involves differences in nucleation and growth rates, but no difference in thermal history. Rather it is the availability (or lack) of metal blebs acting as olivine nucleation sites, that controls the growth regime [4]. In this view, PO forms in melt droplets that happen to contain metal blebs; BO forms in droplets without.

A key difference between these two proposed formation scenarios is the inferred thermal history. We thus frame a testable null hypothesis: *BO and PO chondrules have indistinguishable thermal histories.* Rejection of this hypothesis, i.e., by finding resolvable differences in the thermal histories of BO and PO samples, specifically such that BO cooled faster than PO, would be evidence in support of the "partially molten dustball" idea. In constrast, indistinguishable thermal histories of the BO and PO types would be consistent with the "metal bleb" idea.

The cathodoluminescence (CL) signatures in these olivine grains were previously shown to correlate with Al content [4]. This correlation provides a means to finding chemical heterogeneities suitable for diffusion chronometry, a technique to determine diffusive timescales from assumed initial conditions through numerical solutions to Fick's second law. Electron microprobe analyses of BO and PO chondrules in two CO chondrites (Yamato 81020 and Acfer 094) reveal heterogeneities of Al, Ti, Mn, Cr, and Ca that are all in different states of diffusive relaxation. These systems provide multiple independent measures of diffusive timescales that we leverage to obtain the cooling histories of these two classes of chondrules. The result of these models permit us to address the null hypothesis, and better understand type 1A chondrule formation.

References:

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