

Chondrule olivine provenance in carbonaceous chondrites: chemical and oxygen isotope systematicsG. P. Bonning¹, T. R. Ireland¹, J. N. Ávila¹, G. Mallmann¹¹Research School of Earth Sciences, Australian National University, Canberra, ACT, 2601, Australia

Introduction: Chondrites are predominantly composed of chondrules and matrix. Bulk chondrites have specific and distinct bulk O-isotopic compositions, yet they appear to sample common populations of chondrules that exhibit wide-ranging O-isotope compositions [1, 2]. The relationship between chondrule populations and their host rock is of importance for determining the formation mechanisms and environmental conditions necessary for chondrites, the planetary building blocks, to form. In this study, we investigated chemical and oxygen isotope distinctions between Type I (forsterite-rich) and Type II (fayalite-rich) chondrules in three carbonaceous chondrites, and the distinct chondrule-forming environments they represent. We have analyzed olivine, the most dominant phase in most chondrules, in large numbers of chondrules and fragments (20-40) in each chondrite to sample the distribution of the chemical and oxygen isotope compositions in each population.

Samples and Methods: Samples of Allende (CV 3.6), Moss (CO 3.6), and Murray (CM 2.0) were investigated. Sites were selected in olivine grains within chondrules, chondrule fragments, and igneous fragments that were >25µm in diameter, and free of cracks or foreign phases. In Allende, 81 sites were analyzed in 35 chondrules and fragments, 68 sites in 42 chondrules and fragments in Moss, and 47 sites in 25 chondrules and fragments in Murray. Meteorite sections were imaged by SEM-BSE and reflected and transmitted light. Major- and minor- element compositions were determined by electron microprobe. Oxygen isotope compositions were determined *in-situ* using the SHRIMP-SI ion microprobe at the Research School of Earth Sciences, Australian National University. The SHRIMP-SI multiple collector was configured to allow simultaneous measurement of ¹⁶O⁻, ¹⁷O⁻, and ¹⁸O⁻ with ion signals collected in Faraday cups. Analyses of unknown olivines were bracketed by measurements of San Carlos olivine reference material. The analytical reproducibility of Δ¹⁷O was typically better than 0.5‰.

Results: Oxygen isotope compositions of olivine in all three chondrites plot along the PCM (Primitive Chondrule Mineral) line in oxygen three-isotope space. The Allende section hosts only Type I olivine, while Moss and Murray host both Type I and II olivine. All three samples are dominated by Type I porphyritic chondrules. The average Δ¹⁷O values in Allende olivine, excluding relict grains, range from -8 to -1‰. The average Δ¹⁷O values of Type I and Type II olivine in Moss range from -8 to 0‰ and from -3 to 2‰, respectively. The average Δ¹⁷O values of Type I and Type II olivine in Murray range from -8 to -1‰ and from 0 to 2‰, respectively. The Type I olivines in Moss and Murray are enriched in refractory elements (CaO, Al₂O₃, TiO₂) relative to Type II, which are enriched in the semi-volatile elements MnO (and Cr₂O₃ in Murray).

Discussion: In all samples, Type I chondrules and fragments show a similar range in Δ¹⁷O, while Type II are more restricted in their compositional range. This is consistent with early formation of Type I chondrules followed by homogenization before or during the formation of Type II chondrules, along with introduction of ¹⁶O-depleted oxygen, such as that expected from nebular water [3]. The introduction of Fe²⁺ to Type II olivine indicates a higher oxygen fugacity (fO₂) in the surrounding environment during melting [4], and the retention of semi-volatiles indicates higher pressures and solid densities than that during Type I chondrule formation [5-7]. The Type II chondrules, then, may be the result of recycled chondrules equilibrating with a more ¹⁶O-poor gas of higher fO₂ and higher solid densities. The Type I and Type II chondrule populations of Moss and Murray have similar O-isotope compositions that may indicate sampling from common chondrule reservoirs.

Conclusions: In three carbonaceous chondrite groups, Type I chondrule formation produces, or preserves, a larger spread of O-isotope compositions relative to Type II chondrule formation. The more restricted oxygen isotope compositions of Type II olivine may be result of high-temperature recycling of chondrules. The depletion of ¹⁶O, enrichment of semi-volatiles, and higher fO₂ during formation of Type II relative to Type I chondrules is consistent with the addition of ¹⁶O-depleted nebular water to the chondrule-forming region. Moss and Murray appear to sample common chondrule reservoirs.

References: [1] Clayton, R. N. et al. 1991 *Geochimica et Cosmochimica Acta* 55:2317-2337. [2] Clayton, R. N. and Mayeda, T. K. (1999) *Geochimica et Cosmochimica Acta* 63:13-14. [3] Tenner T. J. et al. (2015) *Geochimica et Cosmochimica Acta* 148:228–250. [4] Grossman, L. et al. 2008 *Reviews in Mineralogy & Geochemistry* 68:93-140. [5] Alexander, C. M. O'D. et al. 2008 *Science* 320:1617-1619. [6] Hewins, R. H. and Zanda, B. (2012) *Meteoritics and Planetary Science* 47:1120-1138. [7] Marrocchi, Y. and Libourel, G. (2013) *Geochimica et Cosmochimica Acta* 119:117-136.