

O-ISOTOPE FEATURES OF CHONDRULES FROM RECENT SIMS STUDIES. T. J. Tenner¹, T. Ushikubo², D. Nakashima³, D.L. Schrader⁴, M.K. Weisberg^{5,6}, M. Kimura⁷, and N.T. Kita⁸. ¹Los Alamos National Laboratory, NM, USA (tenner@lanl.gov). ²JAMSTEC, Kochi, Japan. ³Tohoku University, Miyagi, Japan. ⁴Arizona State University, AZ, USA. ⁵Kingsborough Community College and Graduate Center, CUNY, NY, USA. ⁶American Museum of Natural History, NY, USA. ⁷Ibaraki University, Mito, Japan. ⁸University of Wisconsin-Madison, WI, USA.

Overview: Oxygen isotope ratios of chondrules are an important tool for cosmochemical research, as they reveal how early Solar System materials were processed and transferred. In particular, chondrules dominate the volume of unequilibrated meteorites (20-80%; [1]). Oxygen is prevalent in chondrules, which is expected as it is the third most abundant element in the Solar System, after hydrogen and helium [2]. Therefore, that oxygen has three isotopes, ¹⁶O, ¹⁷O, and ¹⁸O (99.757, 0.038, and 0.205 atom %, respectively; [3]), with relatively large mass differences, is useful, as they fractionate due to many processes chondrules have experienced. O-isotope ratios record primary, high-temperature signatures of chondrule formation, and are also susceptible to secondary processing that occurred on the parent asteroid by thermal metamorphism and/or aqueous alteration. Often, primary and secondary features coexist within chondrules, and decoding respective O-isotope signatures is not straightforward. To this extent, recent advances of *in situ* O-isotope analysis by secondary ion mass spectrometry (SIMS) has increased our understanding of chondrule processing. Specifically, SIMS now has the ability to interrogate O-isotope signatures of individual grains in chondrules (1-15 μm spot analyses), with sub-per-mil precision [4] in $\delta^{17,18}\text{O}$ (‰) = [(R_{sample}/R_{VSMOW}) - 1] × 1000, where R = ^{17,18}O/¹⁶O, and VSMOW: [5].

The focus of this review is to highlight recent chondrule O-isotope findings by SIMS. First, we discuss interphase O-isotope relationships within chondrules, and what they reveal with respect to internal homogeneity during chondrule formation. This includes definitions of host O-isotope ratios (i.e. the value of the final chondrule melt), and identifying relict grains that formed in a prior heating event, survived the final chondrule-forming event, and retained distinct O-isotope signatures from their initial formation. Additionally, some chondrules have heterogeneous isotope ratios, where neither host nor relict signatures can be properly determined. Furthermore, differences in O-diffusion rates of chondrule phases can be used to assess the level of disturbance a chondrule has experienced. Chondrule plagioclase and glass have fast O-diffusion rates during thermal metamorphic conditions, relative to olivine and pyroxene [6]. In turn, recent SIMS studies provide evidence that chondrule plagioclase and glass show O-isotope overlap with coexisting

olivine and pyroxene as chondrites approach petrologic type 3.00, but that plagioclase and glass deviate in their O-isotopes relative to coexisting olivine and pyroxene with increasing levels of thermal metamorphism.

In addition to interphase relationships we compare the range of host and relict O-isotope ratios of chondrules from different chondrite types, emphasizing mass-dependent versus mass-independent fractionated O-isotope signatures. We highlight the slope-1 ($\delta^{18}\text{O}$ vs. $\delta^{17}\text{O}$) primitive chondrule mineral (PCM) line defined by SIMS chondrule phenocryst data from the primitive Acfer 094 chondrite [7], and show that chondrule data from other carbonaceous chondrites fall onto this trend.

Finally, we discuss relationships between O-isotope ratios of chondrules and their major element characteristics. For example, among LL3 ordinary chondrites, FeO-poor chondrules show that host O-isotope ratios fractionate mass-dependently as a function of bulk silica, likely through open-system evaporation and condensation effects [8]. In addition, recent studies of several carbonaceous chondrites reveal that the abundance of mass-independent fractionated ¹⁶O among chondrules is linked to chondrule Mg#’s (= mol.% MgO/[MgO + FeO]). As chondrule Mg# is directly related to redox conditions when chondrules formed, by metal-silicate phase equilibria [9], inferences can be made with respect to proportions of various chondrule precursors, such as oxidizing ¹⁶O-poor H₂O ice [10] and reducing ¹⁶O-poor gas [11], which controlled O-isotope ratios of chondrules and the redox states they have recorded.

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