

O-ISOTOPE COMPOSITION OF THE GAS PRESENT DURING CHONDRULE FORMATION AS RECORDED IN CR CHONDRITES. D. L. Schrader¹, H. C. Connolly Jr.^{1,2,3}, D. S. Lauretta¹, K. Nagashima⁴, G. R. Huss⁴, J. Davidson¹, and K. J. Domanik¹. ¹University of Arizona, Lunar and Planetary Laboratory (LPL), Tucson, AZ 85721, USA, (schrader@lpl.arizona.edu), ²Dept. Physical Sciences, Kingsborough Community College of the City University of New York, 2001 Oriental Blvd., Brooklyn N.Y. 100235, USA, and the Dept. of Earth and Environmental Sciences, The Graduate Center of CUNY, ³Dept. Earth and Planetary Sciences, AMNH, Central Park West, New York, NY 10024, USA. ⁴Hawai'i Institute of Geophysics and Planetology, School of Ocean and Earth Science and Technology, University of Hawai'i at Mānoa, Honolulu, HI 96822, USA.

Introduction: *In situ* O-isotope measurements of chondrules provide clues about their solid precursors, melting history, and exchange with a gas reservoir [1, 2]. We present observations that constrain the O-isotope composition of the gas reservoir that exchanged with ferromagnesian chondrules from CR chondrites and compare it to the suggested primordial water reservoir from the early Solar System [3]. This is part of an ongoing study to understand the formation conditions of type-II chondrules from CR2 chondrites [2,4-6] and whether there is a relationship between their formation to that of type-I chondrules from CR2 chondrites.

Analytical Procedure: We investigated chondrules from CR chondrites QUE 99177, GRA 95229, and GRA 06100. We analyzed element abundances of olivine grains in 8 type-I and 12 type-II chondrules with the Cameca SX-50 electron microprobe (EMP) at LPL. These same grains were analyzed with the UH Cameca ims 1280 ion microprobe for their O-isotope composition [2]. Additional details are in [6].

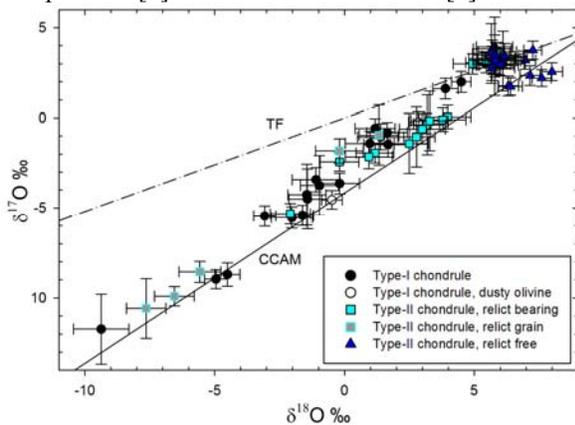


Figure 1. Summary of all olivine measurements of this study. A continuum of data exists from the type-I chondrules and relict grains from type-II chondrules, through the type-I chondrules and relict grain-bearing type-II chondrule phenocrysts, and ends at the ¹⁶O-poor cluster dominated by the relict-free type-II chondrules. Terrestrial fraction (TF) line, and Carbonaceous chondrite anhydrous mineral (CCAM) line plotted for reference.

Results: Type-II chondrules in this study fall into two groups: (1) those whose olivine apparently consists only of FeO-rich phenocrysts (melt grown crys-

tals), and (2) those that contain FeO-poor relict grains in addition to FeO-rich phenocrysts. For ease of communication these will be referred to as relict-free and relict-grain bearing type-II chondrules, respectively. The O-isotope composition of olivine from relict-free type-II chondrules ranges in $\delta^{18}\text{O}$ and $\delta^{17}\text{O}$ by only ~ 2 ‰, and in $\Delta^{17}\text{O}$ by ~ 3 ‰ (20 analyses, 8 chondrules), and plot in single ¹⁶O-poor cluster (Fig. 1) [6]. The O-isotope composition of olivine in relict-grain bearing type-II chondrules ranges in $\delta^{18}\text{O}$ and $\delta^{17}\text{O}$ by ~ 14 ‰, and in $\Delta^{17}\text{O}$ by ~ 7 ‰ (23 analyses, 4 chondrules) [6]. Similarly, the O-isotope composition of olivine from the type-I chondrules studied ranges in $\delta^{18}\text{O}$ and $\delta^{17}\text{O}$ by ~ 14 ‰, and in $\Delta^{17}\text{O}$ by ~ 7 ‰ (21 analyses, 8 chondrules) [6].

Discussion: The O-isotope composition of olivine in highly melted (i.e., relict-free compared to less melted relict-grain bearing) type-II chondrules cluster at an ¹⁶O-poor composition (Fig. 1). If type-II chondrules did undergo isotopic exchange with a gas phase while molten, this ¹⁶O-poor ‘endpoint’ is likely due to the maximum degree of O-isotope exchange they underwent with a gas reservoir. Experimental work by [7] suggested that a reasonable degree of exchange between a chondrule melt and a gas is 50%. The partial pressure of water vapor, duration, and temperature of gas-liquid interaction determine the degree of exchange. A 50% exchange takes place within 5 min at ~ 1 bar (at 1400–1450°C) and likely within 10 hrs at a more canonical nebular pressure of $\sim 10^{-3}$ bar (at $\sim 1727^\circ\text{C}$; [7]). The timescale for O exchange to reach 50% (min to hrs) at different pressures is consistent with those inferred from experimental chondrule formation [e.g., 8,9] and from experimental sulfide formation relevant to type-II chondrules in CR chondrites [10].

For simplicity, we assume that the initial (i) composition of olivine before melting and gas-liquid exchange is the type-I chondrule average ($\delta^{18}\text{O}_i = -0.5$ ‰, $\delta^{17}\text{O}_i = -3.4$ ‰), and that the final (f) O-isotope composition of olivine after crystallization from the liquid which interacted with the gas is represented by the relict-free type-II chondrule average ($\delta^{18}\text{O}_f = 6.3$ ‰, $\delta^{17}\text{O}_f = 3.0$ ‰) (Fig. 2, Table 1). Assuming an O-isotope exchange of 50% between chondrule melt and the gas phase, applying a simple mass balance between

the initial and final O-isotope compositions above we find that the gas composition would be $\sim \delta^{18}\text{O}_g = 13\text{‰}$ and $\delta^{17}\text{O}_g = 10\text{‰}$ (Fig. 2, Table 1). This is roughly consistent with the O-isotope composition of the ‘light water’ (LW, in [11]) hypothesized to have accreted by the CR chondrite parent body. It is also near the *in situ* O-isotope values of secondary carbonates in GRO 95577 [12]. If the O-isotope exchange was extremely efficient at 75 % (unlikely to occur during the time-scale of chondrule formation), the gas composition would be $\sim \delta^{18}\text{O}_g = 9\text{‰}$ and $\delta^{17}\text{O}_g = 5\text{‰}$ (Fig. 2, Table 1). If we assume that both the gas phase and the water that accreted on the CR chondrite parent body are ^{16}O -poor relative to anhydrous materials in the CR chondrites [13, and references therein], then aqueously altered minerals in the CR chondrites would be either more ^{16}O -rich than or in isotopic equilibrium with the water with which they exchanged [e.g., 11,14,15]. Since a mineral hypothesized to be produced by aqueous alteration identified in [16] is more ^{16}O -depleted than the gas composition value at 75 %, this exchange rate is unlikely (Fig. 2, Table 1). If the level of exchange is lowered to 25 %, the gas composition would be $\sim \delta^{18}\text{O}_g = 27\text{‰}$ and $\delta^{17}\text{O}_g = 22\text{‰}$ (Fig. 2, Table 1). If the level of exchange is lowered further to 10 %, the gas composition would be $\sim \delta^{18}\text{O}_g = 67\text{‰}$ and $\delta^{17}\text{O}_g = 61\text{‰}$ (Table 1). However, this ^{16}O -poor value (10 % scenario) seems unrealistic when compared to the comparatively ^{16}O -rich features of aqueous alteration in the CR chondrites [11-13,16]. We suggest that the O reservoir was relatively uniform, and that the degree of O-isotope exchange between the gas phase and type-II chondrule liquid and was between $\sim 25\text{--}50\%$. Small variations in the degree of gas-liquid exchange, precursor and gas O-isotope composition may explain the small spread of type-II chondrule olivine measurements which make up the ^{16}O -poor cluster (Fig. 1) [6].

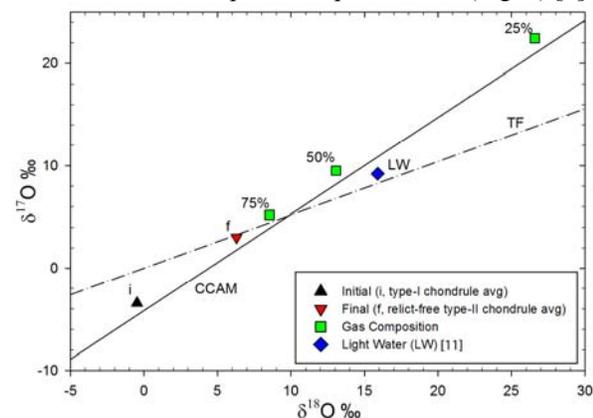


Figure 2. Estimated O-isotope composition of the gas phase that exchanged with type-II chondrules. The value for the 10% scenario plots off of graph.

Type-I chondrules exchanged with a ^{16}O -poor gas reservoir [1]. We suggest that a combination of partial melting and relatively low $\text{H}_2\text{O}/\text{H}_2$ ratios during melting led to lower gas-liquid O-isotope exchange than type-II chondrules [6].

We suggest the O reservoir that exchanged with ferromagnesian chondrules in the CR chondrites to be between $\sim \delta^{18}\text{O}_g = 13\text{--}27\text{‰}$ and $\delta^{17}\text{O}_g = 10\text{--}22\text{‰}$. Therefore, the reservoir present during the formation of type-II chondrules in the CR chondrites was ^{16}O -rich relative to the extremely ^{16}O -poor primordial water reservoir ($\delta^{17,18}\text{O} \sim 180\text{‰}$) that exchanged with material in Acfer 094 [3].

Table 1. Calculated gas phase O-isotope composition.

	$\delta^{18}\text{O}\text{‰}$	$\delta^{17}\text{O}\text{‰}$	$\Delta^{17}\text{O}\text{‰}$
Starting conditions			
Initial	-0.5	-3.4	-3.2
Final	6.3	3.0	-0.2
% Exchange with Gas			
75%	8.6	5.2	0.7
50%	13.1	9.5	2.7
25%	26.6	22.4	8.6
10%	67.2	61.2	26.3

Initial = Average type-I chondrule O-isotope composition.

Final = Average relict-free type-II chondrule O-isotope composition.

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