OXYGEN ISOTOPE SYSTEMATICS OF CHONDRULE MINERALS FROM THE REDUCED CV3 CHONDRITE NWA 8613.

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Introduction: Recent SIMS oxygen three-isotope studies of chondrules from various groups of carbonaceous chondrites (CC), including CR [1], CO [2], $CV_{OxA,B}$ [3, 4], CM [5], and ungrouped CC [6, 7], have demonstrated that most chondrules are internally homogeneous in terms of oxygen isotope ratios and that, with a few exceptions, analyses plot close to the PCM line. In addition, it has been shown for CR chondrites that there exists a systematic relationship between the average $\Delta^{17}O$ (= $\delta^{17}O - 0.52 \times \delta^{18}O$) values of chondrules and the Mg# (molar Mg/(Mg+Fe)%) of olivine and pyroxenes [1]. Based on this relationship, [1] developed an oxygen isotope mixing model that would test the environment of chondrule formation such as different oxygen isotope reservoirs and the extent of dust enrichment.

The reduced CV chondrites constitute an important lithology within the CV chondrite group [e.g., 8], yet systematic SIMS oxygen isotope studies are sparse [9]. In part, complications arise from the high degree of shock [e.g., S4, Efremovka, 10] experienced by prominent members of this subgroup. Recently, [11] presented the newly classified reduced CV3 chondrite NWA 8613. The petrologic subtype of NWA 8613 was found to be 3.1-3.2, based on, e.g., the grain size of olivine in the matrix and the inspection of olivine rims of AOAs. Almost no nepheline is present in chondrules and CAIs. Further, in addition to an only mild thermal alteration, NWA 8613 was not affected by shock metamorphism [S1, 11], hence, making the reduced CV3 NWA 8613 a primary target for SIMS analysis.

In this study, we performed oxygen three-isotope analyses of chondrules from NWA 8613 to (i) test the degree of internal homogeneity of chondrules, (ii) compare oxygen isotope systematics of NWA 8613 to other CV chondrites, and (iii) use average $\Delta^{17}O$ values and Mg#s of chondrules to infer possible dust enhancement factors and water ice contents of precursor material.

Methods: High-precision oxygen three-isotope analyses were performed using a Cameca IMS 1280 at the WiscSIMS laboratory. Analysis were carried out using multi-collection Faraday cups and instrumental bias corrections were applied similar to [1, 12]. The primary Cs^+ beam was set to ~3.5 nA with a diameter of 12 µm. We used a newer FC amplifier with lower noise level for ^{17}O and reduced the analysis time from 8 min to 5 min as described in detail by [13], which led to slight improvements in external reproducibility on the running standard especially for $\delta^{18}O$ measurements (mean 2SD of standard brackets; $\delta^{18}O$: 0.16‰, $\delta^{17}O$: 0.3‰, $\Delta^{17}O$: 0.3‰). In most cases, 8 analyses per chondrule were performed to test for isotopic homogeneity. Chemical composition of olivine and pyroxene were determined prior to SIMS analysis by using a Cameca SXFive FE electron microprobe hosted at the UW Madison.

Results: 28 porphyritic chondrules (24 POP, 2 PP, 2 PO), 2 barred olivine chondrules (BO), and one chondrule fragment were analyzed for mineral chemistry and oxygen isotope ratios of olivine and pyroxenes. Except for the chondrule fragment, chondrules in NWA 8613 are Fe-poor (Mg#≥90 for olivine and pyroxene). Mg#s of olivine in these chondrules scatter between 99 and 89, while those of pyroxenes show considerably smaller ranges. The average pyroxene Mg#s of individual chondrules range from 99.2 to 98.2, except for one BO with Mg# of 91. In conjunction with low-Ca pyroxenes (Lpx), some chondrules contain an additional population of Ca-poor pyroxenes with Wo contents of 3 to 9, which are called here "intermediate pyroxenes" (IntPx, see also [1]). The chondrule fragment consists of FeO-rich olivine (Mg#: 76 - 50) containing a forsteritic core (Mg#: ~87); a small forsterite grain (Mg#: ~ 93) is adjacent and probably a part of the chondrule fragment.

SIMS analyses of olivine and pyroxene plot on the PCM [6] line or in between the PCM and CCAM [14] lines (Fig. 1). Notable exceptions are analyses of the BO with Mg# of 91 that plot above the PCM and on the TF line ($\Delta^{17}O$ ~ 0 ‰). Excluding analyses of this chondrule, olivine $\Delta^{17}O$ values range from –9‰ to –1‰ with one exceptionally ^{16}O-rich grain (~ –17 ‰); pyroxene analyses show $\Delta^{17}O$ values from –7‰ to –4 ‰ (Fig. 2). Forsteritic cores in the the FeO-rich chondrule fragment are ^{16}O-rich ($\Delta^{17}O$ ~ –5‰) relative to the host olivine grains (~ –2‰).

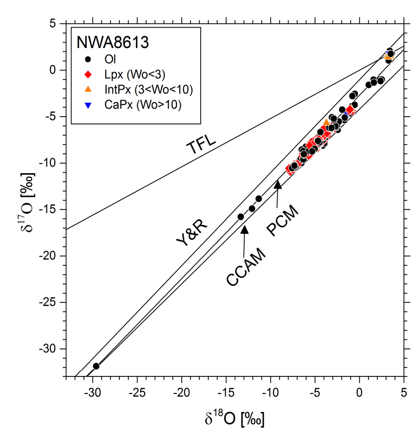

Fig. 1. Oxygen isotope ratios of individual olivine and pyroxene (n=251). Y&R, CCAM, and PCM lines are shown as reference [6, 14, 15].

Internal Homogeneity of Chondrules and Host Δ^{17}O Values: Roughly one third of the chondrules contain olivine that differs from the other minerals of the same chondrule by more than ±0.45‰ in Δ^{17}O (3SD) and are interpreted to represent relicts. Despite those isotopic relicts, most chondrules contain multiple pyroxene *and* olivine analyses that are indistinguishable from each other within analytical uncertainties (Fig. 2). This finding agrees with most previous oxygen isotope studies of chondrules from CC [16] but contrasts with conclusions drawn by [9] for the reduced CV Efremovka and the Vigarano CV breccia. The average values (e.g., isotope ratios or Mg#s) of isotopically homogeneous chondrules (host chondrule values; e.g., [6]) probably approximate properties reflecting the final chondrule-forming melt [1, 2, 6, 12].

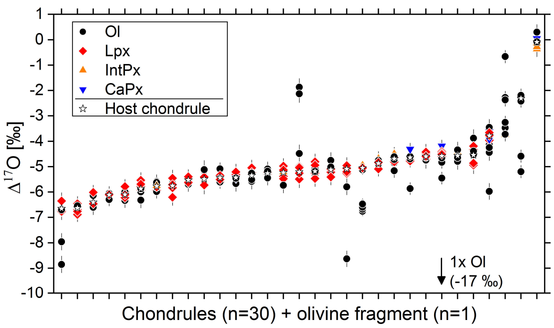

Fig. 2. Δ^{17}O values of olivine and pyroxene from individual chondrules in NWA 8613.

Comparison of host Δ^{17}O values with other CCs: Most host Δ^{17}O values in NWA 8613 range from –4‰ to –7‰ with a main mode at ~ –5‰ which is generally consistent with the distribution of host Δ^{17}O values in the oxidized CV chondrites Kaba [4] and Allende [3] as well as in Y 82094 [7]. Chondrules (or mineral fragments) with host Δ^{17}O values of ~ –2‰ are not abundant in NWA 8613; hence, there is no clear bimodal distribution of Δ^{17}O values in NWA 8613 like observed in Acfer 094, CO, and CM [2, 5, 6]. Like those in Kaba, Allende, Acfer 094, and Yamato 82094 [4, 6, 7, 17], NWA 8613 contains a chondrule with a host Δ^{17}O value of ~ 0‰ (BO with Mg# 91) and plot above the PCM line on oxygen three-isotope diagram, which would be related to OC-like isotope reservoirs [7, 17].

Mg#-Δ^{17}O relationship and chondrule formation environments: Based on the Mg#-Δ^{17}O relationship in CR, [1] suggested precursors of chondrules in CC comprised anhydrous dust and ice with distinct Δ^{17}O values of ~ –6‰ and +5‰, respectively, under dust-enrichment factors of 100-200. Unlike in type ~3.0 chondrites [1, 2, 4, 6], Mg#s of olivine in individual FeO-poor chondrules of NWA 8613 are variable and systematically lower than those of co-existing pyroxene, likely due to Fe-Mg diffusional exchange during mild thermal metamorphism. In contrast, the Mg# of pyroxene and oxygen isotope ratios in both olivine and pyroxene would be preserved due to slower Fe-Mg diffusion in pyroxenes than olivine [18], as well as slow diffusion of oxygen in these minerals [19]. Thus, the host Δ^{17}O values are plotted against the average Mg# of pyroxenes for each chondrule as shown in Fig. 3. These data are indistinguishable from those reported in Kaba CV_{OxA} [4] and near the highest Mg# end of data from CR chondrules [1]. Using the model and parameters of [1], we suggest that Fe-poor chondrules in NWA 8613 probably formed under relatively dry conditions with dust enrichment factors of 100-200 (Fig. 3). The FeO-rich chondrule fragment would have formed under higher dust enrichments of 2000-3000 and moderate ice enhancement. Given that chondrules in CV are dominated by Δ^{17}O ~ –5‰ and highest Mg# (98-99), CV chondrite-forming regions would have been depleted in water-ice and had moderate dust-enrichment factors.

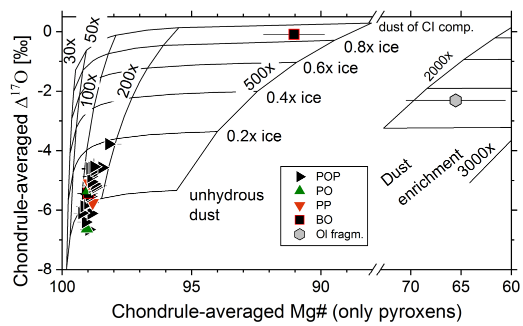

Fig. 3. Relationship between host Δ^{17}O values and Mg# of chondrules. Isolines of dust enrichment and ice enhancement are from [1].

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