HIGH-PRECISION O ISOPTIC SYSTEMATICS OF OLIVINE AND PYROXENE IN CR CHONDRITE CHONDROLES: TWO ISOTOPICALLY DISTINCT CHONDROLE POPULATIONS.


Introduction: Chondrules in primitive carbonaceous chondrites (CC) show a significant range in oxygen 3-isotope ratios, represented by the primitive chondrule minerals (PCM) line; $\delta^{18}$O = (0.987 ± 0.013) × $\delta^{16}$O – (2.70 ± 0.11) [1]. The PCM line is a regression line of SIMS oxygen isotope analyses of olivine and low-Ca pyroxene in multiple chondrules from Acfer 094, one of the most primitive CC, which has been interpreted as a mixing line between two primordial O isotopic reservoirs in the solar nebula with distinct $^{18}$O-rich and $^{16}$O-poor signatures [1]. Recent SIMS studies of chondrules in CV, CO, CA, and CM chondrites, as well as remeasurements of Acfer 094 chondrules [2; reference therein], show that the majority of chondrules plot slightly below the PCM line while a few chondrules plot on/above the PCM line. This observation challenged the original interpretation of the PCM line: it could be a mixture of two trends where typical CC chondrules plot below the PCM line whereas chondrules above may be linked to an ordinary chondrite (OC)-like reservoir [2, 3]. Chondrules in CR chondrites are so far indistinguishable from the PCM line within uncertainties [e.g., 4, 5]. To determine the location of CR chondrules in relation to the PCM line and identify potential contributions from different O isotopic reservoirs, we reanalyzed 16 CR chondrules initially studied by [5] in the Queen Alexandra Range 99177 (CR2) chondrite at improved precision.

Methods: We used the WiseSIMS Cameca IMS 1280 to analyze the O isotopic ratios of chondrule olivines and low-Ca pyroxenes. The Cs+ primary ion beam was focused to a ~12 µm spot size at ~2 nA. Secondary ions ($^{16}$O, $^{17}$O, $^{18}$O) were detected simultaneously using Faraday cups in multicollection mode including $^{17}$O by using a 1012 ohm feedback resistor with low thermal noise [2, 6]. Instrumental biases were corrected using 7 olivine (Fo60-100) and 10 pyroxene (En27-100 Wa0-50) reference materials [2]. The average external reproducibility of the San Carlos olivine standard was 0.2 % in $\delta^{18}$O and 0.3 % in $\delta^{17}$O (2SD), which is better than the 0.4 % average for $\delta^{18}$O of [5]. Detailed descriptions of reference materials and analytical conditions can be found in previous studies [e.g., 2, 6]. Host chondrule compositions were determined from the average host mineral data.

Results: We analyzed the O isotopic ratios of 70 olivines and 64 low-Ca pyroxenes in 16 chondrules, previously studied by [5]. All chondrules are porphyritic, type I with Mg# ranging from 96–99. Initial measurements by [5] and new results are largely identical, although 2SD of $\delta^{18}$O and $\Delta^{17}$O was significantly improved. O isotopic ratios range from −3.9 to 3.7 ‰ in $\delta^{18}$O, −7.5 to 0.5 ‰ in $\delta^{16}$O, and −5.6 to −1.2 ‰ in $\Delta^{17}$O. Four olivines are relic grains with $\delta^{18}$O as low as −8.9 ‰. Most chondrules show O isotope homogeneity among their (non-relict) olivines and low-Ca pyroxenes. Minerals in eleven chondrules show smaller internal variabilities than those in the initial measurements, i.e., <0.5 ‰ 2SD for $\delta^{18}$O vs. −0.8 ‰ on average in [5]. Within uncertainties, all but four chondrules are indistinguishable from the PCM trend. All four exceptions fall below the PCM line by −1 ‰ and have $\Delta^{17}$O ≈ −5 ‰.

Discussion: Contrary to other major CCs [2], the majority of chondrules in CR chondrites plot on the PCM line. No chondrule plots clearly above the PCM line, indicating absence of chondrules that might have formed in the OC-like isotope reservoir. It was previously not recognized that several chondrules fall clearly below the PCM line. These chondrules plot on the $\delta^{18}$O = (0.968 ± 0.022) × $\delta^{16}$O − (3.46 ± 0.10) major CC chondrule trend described by [2] and are consistent with chondrules from other CCs. They are further characterized by striking similarities: all are highly magnesium (Mg# ≈ 99), $^{16}$O-rich chondrules with a limited range of $\Delta^{17}$O around −5 ‰ [5]. They show resolvable excess of $^{26}$Mg from the decay of $^{26}$Al with inferred Al-Mg ages similar to those of major CC chondrules at ~2.5 Ma after CAIs [7] and therefore belong to an earlier generation of chondrules that formed in the CR reservoir. In contrast, the majority of CR chondrules do not show resolvable $^{26}$Mg excess, indicating that they formed later (>3–4 Ma after CAI) under different physicochemical conditions [e.g., 5, 7, 8]. Systematic differences in chondrule sizes and textures as described by [8] were not yet observed. More measurements will be carried out to better distinguish both populations and understand the differences between the CR and other CC chondrule forming reservoirs.