

OXYGEN-ISOTOPIC COMPOSITIONS OF R-CHONDRITE CHONDRULES. Junko Isa¹, Alan E. Rubin¹, Johanna Marin-Carbonne², Kevin D. McKeegan² and John T. Wasson^{1,2}, ¹Institute of Geophysics and Planetary Physics, ²Department of Earth and Space Sciences, University of California, Los Angeles, CA 90095-1567, USA (jisa@ucla.edu).

Introduction: The Rumuruti (R) chondrites are one of the two most oxidized chondrite groups. Their high bulk $\Delta^{17}\text{O}$ values and their proportions of chondrule textural types are similar to the properties of ordinary chondrites (OC); in contrast, their high matrix abundance resembles that of carbonaceous chondrites (CC).

R chondrites are characterized by a low chondrule/matrix abundance ratio, moderately sized chondrules ($\sim 400\ \mu\text{m}$), abundant sulfide (typically 6-10 wt.% pyrrhotite and pentlandite), and rare refractory inclusions (e. g., $\sim 0.04\ \text{vol.}\%$ [1-6]). The high state of oxidation of R chondrites is reflected by the absence (or very low modal abundance) of metallic Fe-Ni, the high Ni contents of those metal grains (mainly awaruite) that are present, the abundance of NiO-bearing ferroan olivine (typically Fa37-40), the presence of Fe^{3+} -bearing, TiO_2 -rich chromian spinel, the occurrence of magnetite in a few specimens, and in the case of R6 LAP 04840, abundant hornblende and minor biotite [3-10]. R chondrites range in petrologic type from 3.6 (e. g., ALH 85151 and PRE 95404) to 6 (e.g., Y 980702). Most R chondrites are brecciated: some are fragmental breccias; others are regolith breccias that contain solar-wind-implanted rare gases and a few R5 and R6 clasts [11]. Magnesium- and CI-normalized refractory lithophile abundances in R chondrites (~ 0.97) are similar to those in OC; refractory and common siderophile abundances are at CI levels; volatiles (especially Se and Zn) are significantly enriched relative to OC [5].

Previous R-chondrite oxygen-isotopic studies: The mean bulk R-chondrite $\Delta^{17}\text{O}$ value of $\sim 3\text{‰}$ is the highest among chondrite groups. Most R whole rocks have similar $\Delta^{17}\text{O}$ values [2-5,12,13]. The O-isotopic compositions of separated chondrules scatter around a mass-fractionation line with $\Delta^{17}\text{O} = \sim 2.7\text{‰}$; however, chondrules from Carlisle Lakes and PCA 91241 plot close to the OC region ($\Delta^{17}\text{O} = 0.68\text{‰}$ [2] and -0.4 to 0.7‰ [12], respectively). Most individual olivine and pyroxene grains in R chondrites plot near an R-chondrite mass-fractionation-line (RFL), defining the intercept ($\Delta^{17}\text{O} = \sim 3\text{‰}$), or in the region of unequilibrated ordinary chondrites (UOC) [12]. In PCA 91241, the $\Delta^{17}\text{O}$ value in grains of nearly pure magnetite is slightly higher than in the whole rock. Whereas the O-isotopic composition of magnetite in Semarkona (LL3.0) has $\Delta^{17}\text{O}$ elevated by $\sim 2\text{‰}$ compared to mafic silicates, R-chondrite magnetite has much lower $\delta^{18}\text{O}$ and is similar in $\Delta^{17}\text{O}$ to R-chondrite whole rocks [12]. A few refractory forsterite grains in DAG 013 have low $\Delta^{17}\text{O}$ values of $\sim -3\text{‰}$ [13]. Most individual minerals in most R-chondrite CAIs plot along a slope-1 line and are lower $\Delta^{17}\text{O}$ values, ~ -23 to -26‰ [14].

To increase the R-chondrite O-isotope database and to understand R-chondrite components and the relationship between R chondrites and other chondrite groups, we studied the O-isotopic compositions of chondrules from the primitive R3.6 chondrite, PRE 95404.

Sample: PRE 95404 (R3.6). This is the one of the least-altered R chondrites. The weathering category is wi-3 based on the weathering index developed by Rubin and Huber (2005). The rock contains (in vol.%): 90.5% silicate, 8.8%

troilite and 0.4% pentlandite ($n = 2549$ points). Chondrules occur in a variety of textural types and most have unequilibrated mineral compositions [15].

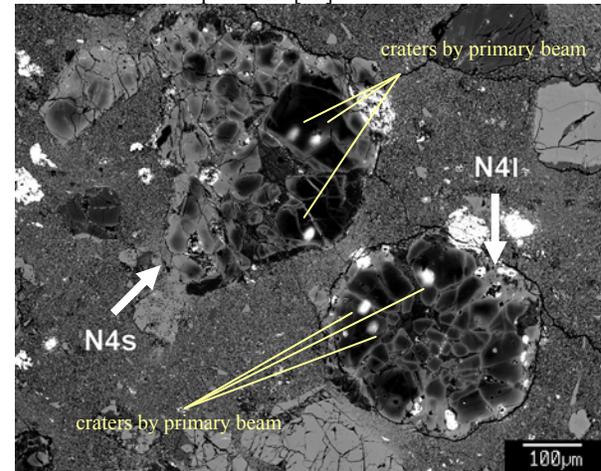


Fig. 1: BSE image of chondrules N4l and N4s.

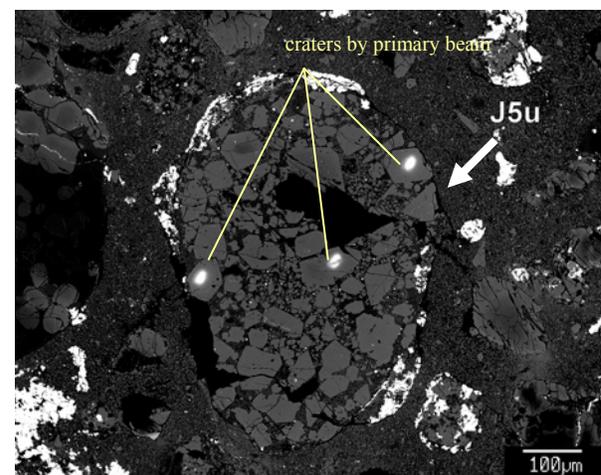


Fig. 2: BSE image of chondrule J5u.

Analytical techniques: Oxygen isotopes were measured on the UCLA 1270 ion microprobe using a primary Cs^+ beam and negative secondary ions. Samples were sputtered with a primary beam of about 10 nA intensity and a 10 kV acceleration voltage focused to a $30\text{-}\mu\text{m}$ spot. A normal incident electron gun was used to compensate for possible sample charging. Oxygen isotopes were simultaneously measured on a multicollector using a Faraday cup (FC, ^{16}O) and an electron multiplier (EM, ^{17}O , ^{18}O) at a mass resolving power >5000 to resolve interference of ^{16}OH at mass 17. Instrumental mass fractionation was determined from Eagle Station, Esquel and San Carlos olivines. With these conditions, the precision on an individual measurement was better than 0.2-0.5‰ and the reproducibility on $\delta^{18}\text{O}$ and $\delta^{17}\text{O}$ was around 0.6‰ and 1.2‰ (at 1 σ), respectively.

Results: We obtained preliminary O-isotope data from three porphyritic-olivine (PO) chondrules in PRE 95404 that contain olivine with different mean Fa contents (Fig. 1,2). The olivine compositions near the SIMS analysis spots in chondrules J5u, N4l and N4s are Fa 38, Fa 1.0, and Fa 0.4-0.7, respectively. The craters made by the SIMS analysis are shown in the BSE image (Fig. 1,2). Our O-isotope data, R-chondrite literature values, and UOC values are plotted on a three-isotope diagram (Fig. 3). The data for each chondrule show uniform compositions. The most magnesian PO chondrule, N4s, is ^{16}O rich ($\delta^{18}\text{O} = -8.59\text{‰}$; $\delta^{17}\text{O} = -8.52\text{‰}$; $\Delta^{17}\text{O} = -4.05\text{‰}$). The most ferroan PO chondrule, J5u, plots near the terrestrial fractionation line (TFL) ($\delta^{18}\text{O} = 0.19\text{‰}$; $\delta^{17}\text{O} = 0.78\text{‰}$; $\Delta^{17}\text{O} = 0.68\text{‰}$). N4l data plot near the RMF ($\delta^{18}\text{O} = -1.29\text{‰}$; $\delta^{17}\text{O} = 2.08\text{‰}$; $\Delta^{17}\text{O} = 2.75\text{‰}$).

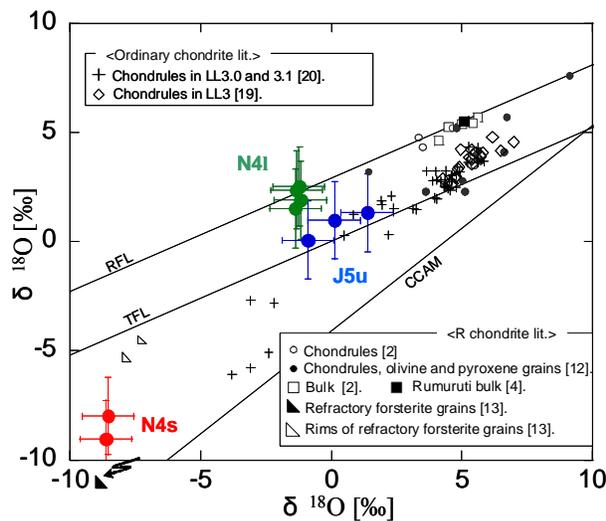


Fig. 3: Oxygen-isotopic compositions of R chondrites and ordinary chondrites. Our chondrule data for J5u, N4l and N4s are plotted as filled circles. “RMF” is the R-chondrite slope-0.52 mass fractionation line at $\Delta^{17}\text{O} \approx +3\text{‰}$

Discussion: We observed different O-isotopic compositions in the three PO chondrules in PRE 95404: relatively low $\Delta^{17}\text{O}$ (similar to refractory forsterite grains [13]), higher $\Delta^{17}\text{O}$ (similar to R whole-rocks), and $\Delta^{17}\text{O}$ slightly above the TFL (similar to the UOC mean value and to most chondrules in UOC). The relatively low $\Delta^{17}\text{O}$ value in chondrule N4s has not been previously observed in R chondrites; the other two chondrules have $\Delta^{17}\text{O}$ values similar to those from prior studies [2,12].

Relatively low $\Delta^{17}\text{O}$ values also occur in UOC and CC. This O-isotopic composition plots roughly between R whole-rocks and some of the refractory forsterite grains in DaG 013 [13]. Chondrule N4s may have inherited its low $\Delta^{17}\text{O}$ value from relict olivine grains in its precursor dustball that mixed with more-normal R-chondrite material during chondrule formation. The R-chondrite CAIs have O-isotopic compositions generally similar to those in other chondrite groups; most of the CAIs plot on the CCAM line with low $\Delta^{17}\text{O}$ [14]. We suggest that low- $\Delta^{17}\text{O}$ precursor materials in R chondrites experienced nebular processes similar to those in other

chondrite groups and that the high $\Delta^{17}\text{O}$ values in R whole rocks are caused by secondary processes, interaction with high- $\Delta^{17}\text{O}$ water on the parent body.

Olivine Fa and $\Delta^{17}\text{O}$ are not simply correlated among R chondrules. Our preliminary data show that low-Fa PO L4n plots in the R whole-rock region, whereas high-Fa PO J5u plots in the UOC region (Fig. 3). Most of the chondrules in R3.6 PRE 95404 had their chemical and O-isotopic compositions established in the nebula with only minor overprinting by metamorphic effects on the parent body; note that O diffuses slower than Mg and Fe cations [16,17]. Because chondrule N4l with $\Delta^{17}\text{O} \sim 3\text{‰}$, has low Fa (indicating that thermal metamorphism has been minor and has not led to mineralogical equilibrium), its O-isotopic composition may only minimally be affected by secondary alteration processes. Therefore, this chondrule seems to have formed with R-chondrite-like $\Delta^{17}\text{O}$. On the other hand, chondrule J5u may have formed with high Fa, possibly in the same nebular region as UOC.

Conclusion: On the basis of these chondrule studies, we suggest that the relationship between R chondrites and OC is much stronger than that between R chondrites and CC.

References: [1] Rubin A. E. and Kallemeyn G. W. (1989) *Geochim. Cosmochim. Acta* **53**, 3035-3044. [2] Weisberg M. K. et al. (1991) *Geochim. Cosmochim. Acta* **55**, 2657-2669. [3] Bischoff A. et al. (1994) *Meteoritics* **29**, 264-274. [4] Schulze H. et al. (1994) *Meteoritics* **29**, 275-286. [5] Kallemeyn G. W. et al. (1996) *Geochim. Cosmochim. Acta* **60**, 2243-2256. [6] Rout and Bischoff, (2008) *Meteorit. Planet. Sci.*, **43**, 1439-1464. [7] McCanta et al., (2008) *Geochim. Cosmochim. Acta* **72**, 5757-5780 [8] Ota et al., (2009) *J. Mineral. Petrol. Sci.*, **104**, pp. 215-225. [9] Righter K. and Neff K. E. (2007) *Polar Sci.* **1**, 25-44. [10] Rubin A. E. and Kallemeyn G. W. (1994) *Meteoritics* **29**, 255-264. [11] Bischoff et al. (2006) *Meteorites and the Early Solar System II*. University of Arizona Press, Tucson, pp. 679-712. [12] Greenwood et al., (2000) *Geochim. Cosmochim. Acta*, **64**, pp. 3897-3911. [13] Pack et al., 2004 *Geochim. Cosmochim. Acta*, **68** 1135-1157. [14] Rout S. S. et al. (2009) *Geochim. Cosmochim. Acta* **73**, 4264-4287. [15] Isa et al. (2010), unpublished data. [16] Jaoul et al., (1980) *Earth Planet. Sci. Lett.* **47**, 391-397. [17] Chakraborty, (1997) *J. Geophys. Res.* **102**, 12317-12331. [18] Connolly and Huss, (2010) *Geochim. Cosmochim. Acta* **74**, 2473-2483. [19] Clayton et al., (1991) *Geochim. Cosmochim. Acta* **55**, 2317-2337. [20] Kita et al., (2010) *Geochim. Cosmochim. Acta* **74**, 6610-6635.