OXYGEN ISOTOPES AND THE NATURE AND ORIGINS OF TYPE-II CHONDRULES IN CR2 CHONDRITES H. C. Connolly, Jr.[1,2,3], G. R. Huss[4], K. Nagashima[4], M. K. Weisberg[1,2], R. D. Ash[5], D. S. Ebel[2], D. L. Schrader[3] and D. S. Lauretta[3]. [1]Dept. Physical Sciences, Kingsborough College of the City University of New York, Brooklyn NY 100235, USA (hconnolly@kbcc.cuny.edu); [2]Dept. Earth and Planetary Sciences, American Museum of Natural History (AMNH), New York, NY 110024, USA; [3] Lunar and Planetary Laboratory (LPL), University of Arizona, Tucson, AZ 85721, USA; [4]Hawai'i Inst. of Geophysics and Planetology, University of Hawai'i at Manoa, Honolulu, HI 96822, USA; [5]Dept. of Geology, University of Maryland, College Park, MD 20742, USA.

Introduction: In our continued investigation to fully characterize CR2 chondrites (CR2) using *in situ* analytical techniques, we have expanded upon the data set of [1,2]. We report new O-isotopic data for petrographically well-characterized type-II chondrules (FeO-rich) from three CR2 chondrites. Our new data imply that some CR2, type-II chondrules maybe exogenous, potentially related to ordinary chondrite (OC) type II chondrules. Our results have profound implications for the temporal relationship of CR2, type-II chondrules and mixing of chondritic materials.

Experimental: Details of our petrographic investigation and preliminary O-isotope data were reported by [1,2]. In this work, we re-analyzed and add new data for the O-isotopic compositions of type-II chondrules from Renazzo USNM 1123-1 (Ren), EET 92011,5 (EET) and MAC 87320,10 (MAC). Objects were characterized as type-II chondrules by backscattered electron imaging on the FE-SEM at the AMNH. Analyses of major and minor elements were performed at the LPL on a CAMECA SX 50 electron microprobe. O-isotopic compositions of olivines were analyzed with the UH Cameca ims 1280 ion microprobe. Experimental details are provided in [3].

Table 1. Summary of O-isotope data.

Sample #	Fa	Type	$\delta^{17}O$	$\delta^{18}O$	$\Delta^{17}O$
Renazzo USNM 1123-1					
Ch1	15.8	PO	3.9±0.9	6.3±1.9	0.6±0.2
Ch2	23.3	PO	4.7±0.6	6.9±1.4	1.1±0.7
Ch 7	30.8	PO	3.9±0.3	6.2±0.8	0.7±0.2
Ch 8	52.9	PO	-1.7±1.2	0.6±1.1	-2.0±0.7
Ch 11	49.2	PO	4.3±0.8	7.2±1.4	0.6±0.6
EET92011,5					
Ch1	38.8	BO/PO	-0.9±1.1	1.6±1.1	-1.7±0.8
Ch2	46.4	PO	3.1±0.7	4.9±0.7	0.5±0.7
Ch3	21.6	PO	3.6±0.5	5.6±0.7	0.7±0.7
Ch4	28.8	PO	4.0±1.0	5.4±1.3	1.1±0.8
Mac 87320,10					
Ch1	15.6	PO	2.4±1.1	7.1±0.9	-1.3±1.0
Ch2	25.8	PO	2.7±0.4	7.0±0.5	-1.0±0.3

Notes: Fa=mean of at least 3 phenocrysts cores. O-isotopic values are means for chondrules. BO =Barred Olivine, PO=Porphyritic Olivine.

Results: The characteristics of 31 type-II objects were summarized by [2]. We designated a sub-set of 11 chondrules (Table 1) from the data set for analysis of the O-isotopic compositions of olivines (Fig. 1).

Mac 87320: Data for two chondrules cluster together on the CCAM line, except for the inverted red triangle, which represents a petrographically characterized relict grain from Ch2.

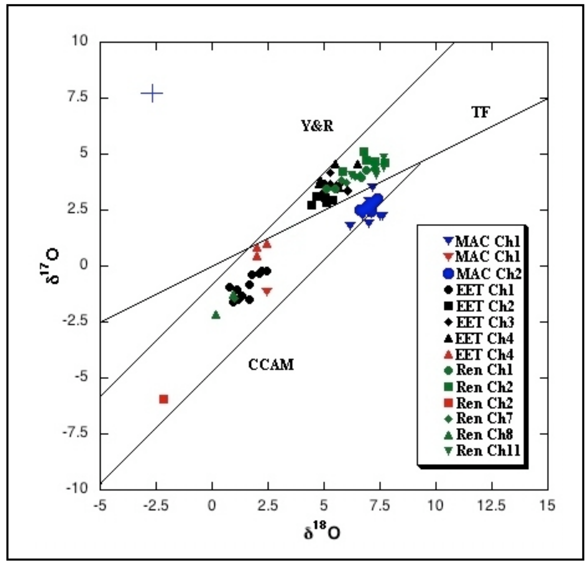

Fig. 1. Three-isotope plot for olivines analyzed within chondrules. Red symbols are petrographically characterized relict grains. Y&R = Young and Russell line [4]. Representative error bar shown in the upper left.

EET 92011: Chondrule olivines from EET define two populations on the three-isotope plot, one above the TF line (Ch 2,3 and 4), the other (Ch 1) several ‰ below TF line. Ch 4 contains several relict grains, with O-isotopic compositions plotting below the TF line.

Renazzo: Most olivines from Ren chondrules plot above the TF line, as was the case for EET. One chondrule (Ch 8) plots very near EET Ch 1, below the TF line. One grain from Ch 7, probably a relict, falls in the same region.

Discussion: The O-isotope compositions of type-II chondrules are diverse, ranging from compositions similar to ordinary chondrites (OC) down to olivines from type I chondrules from CR2 (Fig. 2). They are also diverse in that the range in $\delta^{18}O$ extends from close to the Young and Russell (Y&R) line [4] to the CCAM line. There is no apparent correlation between the degree of hydration of the whole rock and O-isotope signatures of chondrule olivines, nor with the level of alteration of chondrules studied. Ren and EET chondrule olivines form two groups, with no defining petrographic feature.

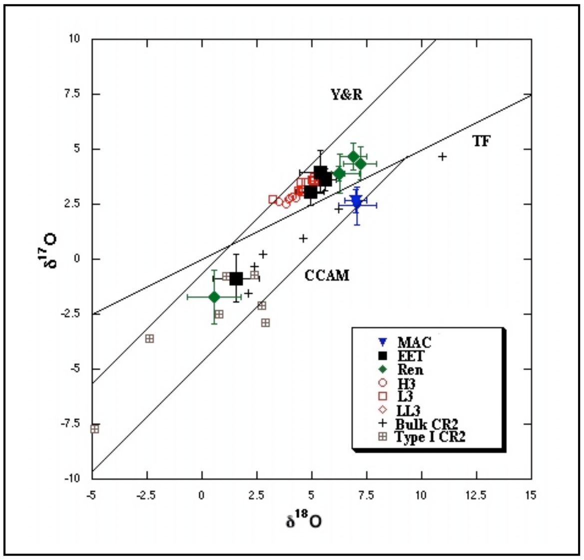

Fig. 2. Mean values for analyzed olivines from investigated chondrules along with data for bulk OCs [5], bulk CR2 [6] and olivines from CR2 type I chondrules [7,8].

An important observation is that several PO, type-II chondrules from Renazzo appear to be almost equilibrated with respect to Fe-Mg concentrations in olivine (Fig. 3). Other chondrules (Fig. 4), however, are similar to classic type-II chondrules as defined by [9], with pronounced Fe-Mg zoning in phenocryst. No correlation exists between these textural types and their olivine O-isotopic composition.

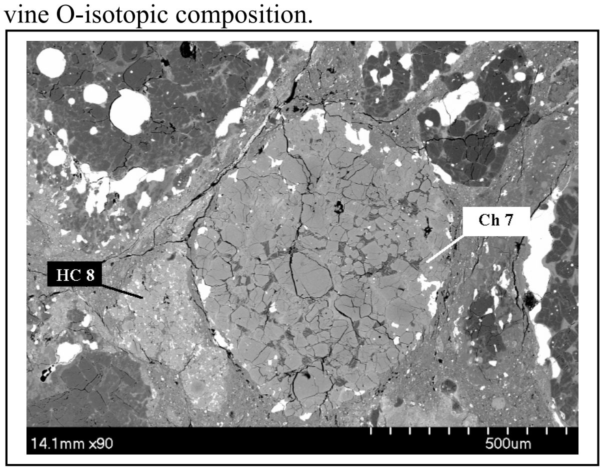

Fig. 3. BEI of two, type-II chondrules from Renazzo that are essentially equilibrated, which may contain relicts.

Implications: It appears that the O-isotopic composition of CR2, type-II chondrules form three groups. The isotopic composition does not correlate with any petrographic feature. We hypothesize that the chondrules plotting above the TF line are either (1) OC type-II chondrules that were scattered into the CR2 region before accretion, (2) derived from a source region similar to but independent of the OC source region, or (3) formed in the same O reservoir (e.g., gas) as OC chondrules, but at a different time. Low-Fa relict olivine grains within this first groups of CR2 type-II chondrules have O-isotopic compositions similar to some CR2, type-I chondrule olivines. The implication for this population is that the type-I chondrules formed first and that type-II chondrules derived part of their precursors from these chondrules [2,10]. However, the bulk of the precursors were OC or OC-like. If hypothesis (1) is correct, then OC chondrules formed before the CR2 parent body accreted.

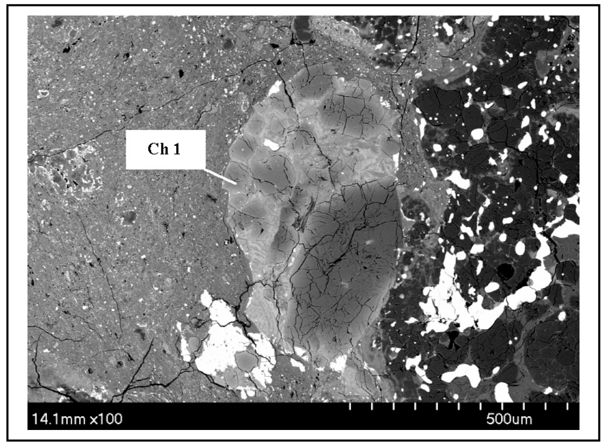

Fig. 4. BEI of a classic type-II chondrule fragment from Renazzo.

The second population of type-II chondrules plots with CR2, type-I chondrules. We hypothesize that these chondrules derive their O isotopic composition from the same or similar reservoir as CR2, type-I chondrules. But when type-II chondrules formed, the reservoir was in a more oxidized state. As speculation, the oxidation state of the chondrules may represent a time sequence in the formation region, with type-I chondrules forming first and type-II chondrules produced later from more oxidized precursors or a mixture of reduced and oxidized materials [10].

The third population of chondrules plots on the CCAM line, which is very different from the bulk-rock composition (δ^{17}O = -0.87; δ^{18}O = 1.79 [6]). This population is not yet observed in the other CR2 we investigated. Clearly, CR2, type-II chondrules record a multitude of source regions and potential formation times.

References: [1] Connolly et al., (2003) *LPSC* #1770. [2] Connolly et al, (2007) *LPSC* #1571. [3] Huss et al. (2007 *LPSC* #2128. [4] Young E. D. and Russell S.S. (1998) *Science*, **282**, 452. [5] Weisberg et al., (2006) in *Meteorites and the Early Solar System II*. [6] Weisberg et al., (1993) *GCA* **57**, 1567. [7] Krot et al., (2006) *GCA* **70**, 767. [8] Varley et al., (2003) *LPSC* #1988. [9] Jones R. H. (1990) *GCA,* **54**, 1785. [10] Connolly et al. (2001) *MAPS* **36**, A44. This research funded by NASA grant NNG05GF39G-HCCJr and NNG05GG48G-GRH. Thanks to MWG and the Smithsonian for samples.