ON THE NATURE AND ORIGINS OF TYPE II CHONDRULES IN CR2 CHONDRITES H. C. Connolly, Jr.[1,2,3], M. K. Weisberg[1,2], G. R. Huss[4], K. Nagashima[4], 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 Institute of Geophysics and Planetology, University of Hawai'i at Manoa, Honolulu, HI 96822, USA.

Introduction: Type II chondrules within CR2 chondrites (CR) have received little research attention over the years [1,2]. In our investigation we characterize the petrographic nature and the mineral and oxygen isotopic composition of 31 type II chondrules and chondrule fragments from 6 CRs. We show that they are surprisingly diverse and we explore their relationship to other CR components and chondrite types.

Experimental Technique: We investigated one thin section from each of the following CRs; Al Rais AMNH 4168-1, EET 87770,4, EET 92011,5 (EET), El Djouf 001 AMNH 4758-1, MAC 87320,10 (MAC), Renazzo AMNH 88-2 and Renazzo USNM 1123-1. Objects were identified and initially characterized as a type II chondrule, chondrule fragment (having some arc), or igneous fragment (no arc is present to clearly characterize it as a chondrule fragment) 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. Oxygen isotopic composition of olivines was analyzed with the UH Cameca ims 1280 ion microprobe. Experimental details are provided in [3].

Overall Petrography: The characteristics of 31 type II objects are summarized in Table 1. Chondrules range in apparent diameter up to 1.4 mm. Fragments vary in size from apparent shortest axis of 100 µm to 2 mm. No apparent accretionary or layered rims are observed on any of the objects. All of the objects are olivine rich, 80% are PO. Approximately 36% of the chondrules contained > 1 apparent vol% (Fig. 1) opaque phases that include sulfides, hydrated sulfides (tochilinite), troilite, pentlandite and Fe, Ni-rich metal (~16–60 wt% Ni). A detailed investigation of the opaque phases is the focus of a companion abstract [4]. Chromites are of minor abundance within all objects. Pyroxene, when present, is in the form of small dendrites within the mesostases. Mesostases are in various states of alteration, from apparently unaltered glass to indistinguishable from matrix phyllosilicates.

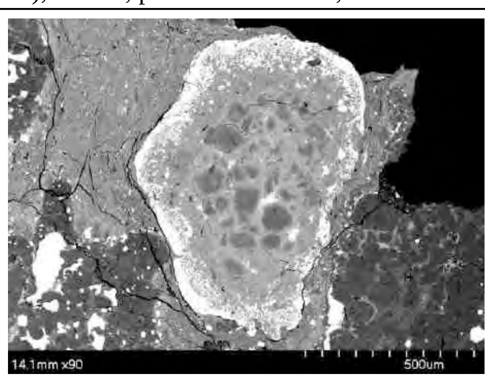

Figure 1. BSE images of atype II chondrule from Ren. Note the abundant, S-rich assemblages in the margin (bright in image).

Table 1. List of results from our investigation.

Sample #	Fa	Type	[1]Opaque	Shape
Renazzo AMNH 588-2				
Ch1	43.54	BO	< 1	Ch
Ch2	25.82	PO	< 1	Frag
Ch3	20.83	PO	< 1	Frag
Ch4	28.2	PO	< 1	Frag
Ch5	17.43	PO	< 1	Frag
Renazzo USNM 1123-1				
Ch1	15.81	PO	< 1	Ch Frag
Ch2	23.33	PO11	2	Ch Frag
Ch3	20.10	PO	3	Ch
Ch 4	25.79	PO	3	Frag
Ch 5	27.94	PO	15	Frag
Ch 6	22.24	PO	< 1	Frag
Ch 7	30.75	PO	< 1	Ch
Ch 8	52.90	PO	2	Frag
Ch 9	45.83	PO	20	Frag
Ch 10	51.54	PO	< 1	Frag
Ch 11	49.17	PO	15	Ch
Al Rais AMNH 4168-1				
Ch1	42.63	PO	20	Frag
Ch 2[1]	9.75	BO	< 1	Ch
Ch 3	36.57	PO	2	Ch Frag
El Djouf 001 AMNH 4756-1				
Ch1	27.43	PO	< 1	Frag
Ch 2	37.62	PO	< 1	
Ch 3	38.22	PO	3	Frag
EET 87770,4				
Ch1	29.8	BO	< 1	Ch
Ch 2	N/A	CC	< 1	Ch Frag
EET92011,5				
Ch1	38.8	BO[2]	< 1	Ch Frag
Ch2	46.38	PO[+]	< 1	Chon
Ch3	21.57	PO	3	Ch Frag
Ch4	28.8	PO11	< 1	Frag
Mac 87320,10				
Ch1	15.6	PO	3	Frag
Ch2	25.78	PO	< 1	Frag
Ch3	42.65	BO/RO	3	Ch Frag

Notes: [1]vol%. Fa=mean of at least 3 phenocrysts cores. Ch frag=chondrule fragment; Frag=igneous fragment. BO =Barred Olivine, PO=Porphyritic Olivine.

Mineral Compositions: All of the type II objects are olivine-rich with compositions that show no systematic variation between the CRs investigated. Mean core compositions range from $Fa_{15.6}$ to $Fa_{52.9}$ (Table 1). Most olivines are normally zoned, with values ranging up to ~Fa_{70} at crystal edges. Minor-element contents vary from grain to grain and between different chondrules, with Cr_2O_3 ~0.15-0.70 wt%; MnO ~0.11-1.0 wt%; CaO ~0.06-0.45 wt%. No correlations are apparent Fa content and minor element concentrations. Two chondrules contain obvious relict grains with the extreme represented by EET Ch4 with cores of Fa_2.

Oxygen Isotope Compositions: The oxygen isotopic composition of olivines from two objects from MAC 87320, four from EET 92011 and one from Renazzo USNM 1123-1 were analyzed. Although some of these grains were analyzed previously [1], the new data have a higher precision than was previously achieved. The overall spread in oxygen isotopic data for type II chondrules in CR2 chondrites ranges from that of bulk OC to slightly lower than -5‰, 0‰, on the CCAM line. EET Ch1 is the most ^{16}O-rich, ~2.5‰ lighter than the Fo-rich relict grain in EET Ch4. Some of the olivines from MAC Ch1 and Ch2 plot on the CCAM line, with the most restricted range.

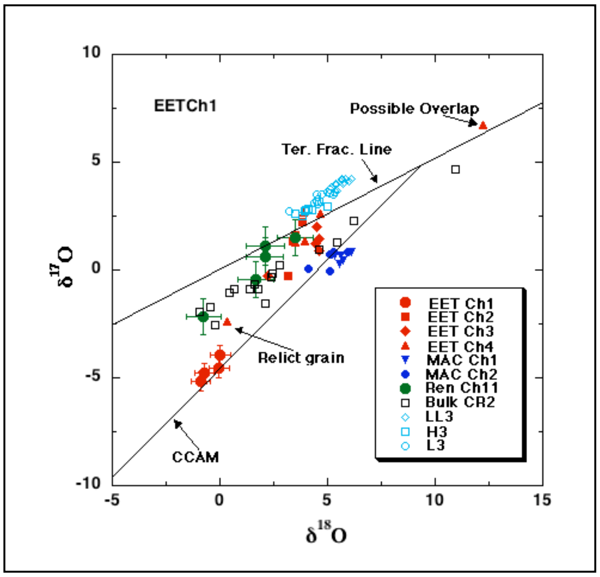

Fig. 2. Oxygen isotope data for type II chondrules from this investigation, other data from [6].

Discussion: Clearly, type II chondrules are more abundant in CRs than previously thought (<1 vol% [5]). Their apparent size is similar to type I chondrules from CRs and type II chondrules from OCs and CV3s. Type I chondrules from CRs often have layered rims, however, no rims are observed on type II chondrules. This suggests that both the pre and post-formation environments for CR type II chondrules were not rich in mineral dust, unlike that of CR type I chondrules (although this may also reflect different times of processing). Most CR type II chondrules have broken or abraded surfaces and ~ 50% are type II fragments and retain no arc, whereas CR2 type I chondrules are typically whole, suggesting that CR type II chondrules were either more easily broken or experienced a more destructive (higher energy) collisional environment than CR type I chondrules.

The range of Fa contents (15.6-52.9) for CR type II chondrules is greater than that observed in OCs ($Fa_{18.11-25.65}$) or COs (Fa_{22-39}) [7,8]. This observation suggests that CR type II chondrules either had precursors that were more FeO-rich that type II chondrules from OC and CO, and/or that the environment and gas in which they formed was more oxidizing. Curiously enough, the abundance of S-rich phases in CR2 type II chondrules, especially if they are primary (part of the precursors) may indicate that sulfur was either enriched in the precursors and/or the gas phase during and after melting relative to that experienced by CR type I chondrules or type II chondrules from OCs and COs. Alternatively, this observation may reflect a difference in their thermal histories. Additional implications are discussed by [4]. Regardless, this finding presents an interesting issue. Sulfide abundance suggests a reducing environment for their formation and post-formation environments. But the high Fa values are in apparent conflict with this hypothesis.

Relict grains were found in two chondrules whereas no obvious relict grains have been identified in type I chondrules in CRs. This suggests that CR type II chondrules experienced recycling but type I did not, or least they retained no obvious petrographic evidence of recycling (texture, major, minor element abundances).

The range of oxygen isotope data for CR type II chondrules overlap with bulk OCs and extend to the CCAM line. This range basically overlaps the entire range of bulk CR values. However, type I chondrules from CRs show a much wider range in oxygen isotope composition, overlapping with that of type II chondrules and extending down to -46‰, -48‰ [9]. Although the range of CR type II oxygen isotopic data is more restricted than CR type I, the larger implication may lie in exploring the potential relationship, at least with respect to oxygen isotopes, between OCs and CR type II chondrules.

References: [1] Connolly et al., (2003) *LPSC* #1770. [2] Krot et al., (2006) *GCA* 70, 767. [3] Huss et al, (2007) this conference. [4] Schrader et al., (2007) this conference. [5] Weisberg et al., (1993) *GCA* 57, 1567. [6] Weisberg et al., (2006) in *Meteorites and the Early Solar System II.* [7] Jones R. H. (1992) *GCA*, 54. [8] Wasson and Rubin (2003), *GCA* 67, 2239. [9] Varley et al., (2003) *LPSC* #1988. This research funded by NASA grant NNG05GF39G-HCCJr, NNG05GG48G-GRH, NANG06GD89G-DSE, NNG04GF65G-DSL. Thanks to K. Domanik for EMP; MWG and the Smithsonian for samples.