ON THE NATURE AND ORIGINS OF FEO-RICH CHONDRULES IN CR2 CHONDRITES: A PRELIMINARY REPORT.

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Introduction: In recent years considerable research has been devoted to understanding the components in CR2 chondrites [1,2,3,4]. In particular, constraints have been placed on the nature and petrogenesis of FeO-poor (type I) chondrules, Fe-Ni metal associated with FeO-poor chondrules and matrix, and refractory inclusions. One group of objects, the FeO-rich chondrules, has yet to be investigated in detail. Herein we present our preliminary results on the petrography, geochemistry, and O-isotope composition of FeO-rich (type II) chondrules from CR2 chondrites. Our goal is to determine the origin of FeO-rich chondrules and their relationship to other objects within the CR2's and, in the long term, to similar chondrules in other chondrite groups.

Experimental Technique: We studied one thin section from each of the following CR2 meteorites, MAC87320,10; Renazzo AMNH588-2; EET87770,4; EET92011,5; Al Rais, AMNH4168-1; El Djouf 001 AMNH4758-1. Objects were identified and initially characterized as FeO-rich chondrule, chondrule fragment, or igneous fragment by backscattered electron imaging. Imaging and analyses of major and minor elements were performed at Rutgers University Microanalysis (RUMrunner) using the JEOL 8600 Superprobe and the CAMECA SX100 located at the AMNH.

Oxygen isotopic composition of olivines and mesostases were analyzed with the ASU CAMECA ims-6f ion microprobe. The Cs^+ primary ion beam was focused in aperture-illumination mode to a ~20 μm spot. The secondary column was operated at 9 Kv with a mass resolving power of 5500 and a 75 eV energy window. Oxygen-16 was measured on the faraday cup and $^{17,18}O$ were measured on the electron multiplier. The normal-incidence electron flood gun was used for charge compensation. Iron produces a significant matrix effect in O analysis of olivine. Several olivine standards with different Fa values were measured to generate a calibration curve with which to adjust the instrumental mass fractionation for the primary standard (Eagle Station Olivine, Fa_{20}) to the appropriate Fa value for the sample olivines. We do not have a suitable standard for chondrule glass, so the position along the mass fractionation line is uncalibrated. The $\Delta^{17}O$ values are unaffected by this.

Overall Petrography: The characteristics of 15 FeO-rich chondrules, chondrule fragments, or igneous fragments are summarized in Table 1. Chondrules range in apparent diameter up to 1.4mm. Fragments vary in size from apparent shortest axis of 200μm to 2mm. No accretionary or layered rims were observed on any of the objects.

Table 1. List of results from survey.

Sample #	Mean Fa*	Type	Shape	$\Delta^{17}O$
Renazzo AMNH 588-2				
Ch1	43.5	BO	Ch	
Ch2	25.8	PO	Fragt	
Ch3	20.8	PO	Fragt	
Ch4	28.2	PO	Fragt	
Ch5	17.4	PO	Fragt	
Al Rais AMNH 4168-1				
Ch1	42.6	PO	Fragt	
El Djouf 001 AMNH 4756-1				
Ch1	27.4	PO	Fragt	
EET 87770,4				
Ch1	29.8	BO	Ch	
EET92011,5				
Ch1	38.8	BO*	Ch Fragt	-1.8
Ch2	46.4	PO	Ch	1.0
Ch3	21.6	PO**	Ch Fragt	0.8***
Ch4	28.8	PO**	Fragt	0.5***
Mac 87320,10				
Ch1	15.6	PO	Fragt	-0.3
Ch2	25.8	PO	Fragt	-0.9
Ch3	42.7	BO/RO	Ch Fragt	-3.2

Notes: Fa*=mean of at least 3 grains. BO*=barred olivine and compound. PO = porphyritic olivine with relicts grains. Ch= chondrule; Ch fragt= chondrule fragment; Fragt = igneous fragment; ***calculated without relict grain.**

Phase Compositions: All of the FeO-rich objects are olivine-rich with compositions that show systematic variations between meteorites. Mean core compositions range from $Fa_{15.6}$ to $Fa_{46.4}$ (Table 1). Most olivines are normally zoned, with values ranging up to ~Fa_{70} on crystal edges. Minor-element contents vary from grain to grain and between different chondrules, with Cr_2O_3 ~0.15-0.70wt%; MnO ~0.11-1.0wt%; CaO ~0.06-0.45wt%. Pyroxene is absent from these objects with the possible exception of small dendritic microcrystallites within the mesostases that are too small for accurate analyses. Two chondrules contain relict olivine grains with the extreme represented by EET Ch4 that contains olivine grains with cores of Fa_2 with overgrowths of significantly more Fa-rich olivine.

Mesostases are in various states of alteration. Some objects retain apparently unaltered glass and others are completely altered, showing no textural or chemical distinction between mesostasis and matrix.

Apparent glass compositions are, SiO_2 ~49-55 wt%; Al_2O_3 ~2-5wt%; CaO ~7-10wt%; FeO ~15-20wt%; and MgO 1-2wt%. Many totals are low, which likely reflect the presence of fine alteration phases, water, and/or pore spaces not easily detected with EMP. Analyses of apparent melt inclusions within olivines yield very different results, although here too total are low; SiO_2 ~58-61wt%; TiO_2 ~0.34wt%; FeO ~11wt%, MnO ~0.25wt%; MgO ~3 wt%; CaO ~1wt%; Na_2O ~1.7-2.2wt%; and K_2O ~2wt%. Much of the altered mesostasis appears to be phyllosilicate, as reported by [1]. Finally, most objects contain minor amounts of chromite, FeS, and in two cases, Fe-Ni metal.

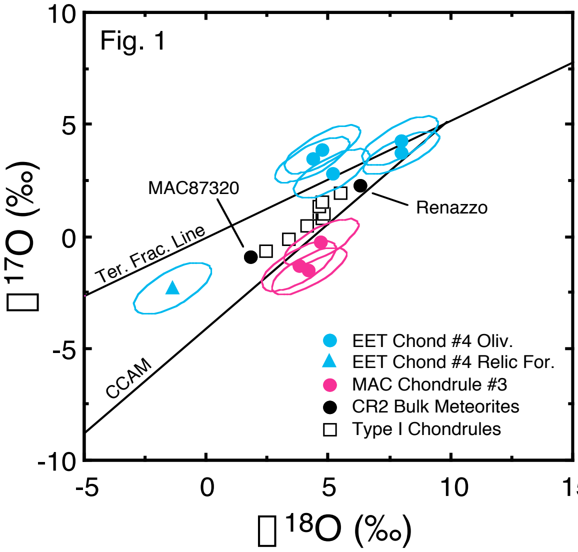

Figure 1: Oxygen isotope data for EET Chondrule #4 and MAC Chondrule #3. Compositions for bulk CR2 chondrites and CR2 type 1 chondrules from [1].

Oxygen-Isotope Compositions: Oxygen isotopes were measured for 3 chondrules from MAC87320 and 4 chondrules from EET92011. Results are shown in Table 1 and Figs. 1 and 2. The □^{17}O values for the 7chondrules show a spread of ~4‰ around the terrestrial fractionation line. Porphyritic FeO-rich chondrules tend to have more ^{16}O-depleted compositions than most FeO-poor type 1 chondrules (Figs. 1 and 2). The two BO chondrules (EET Ch1 and MAC Ch3) are more ^{16}O-rich than the porphyritic chondrules. The relict forsterite grain in EET Ch4 has a □^{17}O of -1.6‰ compared to an average value of 0.5‰ for the bulk chondrule. Some small Fa-rich olivine grains in EET Ch3 are more ^{16}O-rich than the larger grains. Chondrule mesostasis has the same □^{17}O value as the chondrule olivines. Lack of standards for mesostasis precludes any statements about the relative degree of mass fractionation between olivines and mesostasis.

Discussion and Comparisons Between CR2 Components: The apparent size of type II chondrules is similar to type I chondrules. Unlike type I chondrules that often have layered rims, no rims suggestive of interactions with dust grains post-solidification are observed on any FeO-rich object. Most type II chondrules have broken or abraded surfaces, whereas type I chondrules are typically whole. This suggests that type II chondrules were either more easily broken and abraded or experienced a more destructive environment than type I chondrules.

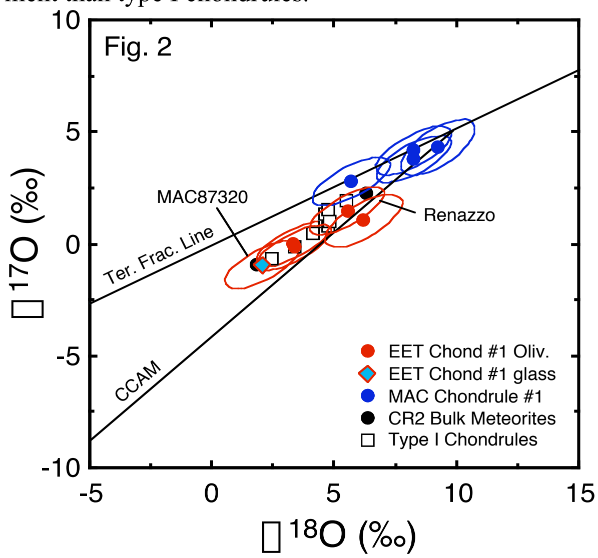

Figure 2. Oxygen isotope data for EET Chondrule #1 and MAC Chondrule #1. Compositions for bulk CR2 chondrites and CR2 type I chondrules from [1].

Two of 15, or ~13% of the type II chondrules studied contain relict grains, whereas none are reported for type I chondrules [1,3]. This clearly suggests that type II chondrules experienced multiple melting events whereas such a statement cannot be made with confidence about type I chondrules. The O compositions of type II chondrules seem to be significantly more variable than those of type I chondrules (Figs. 1 and 2). The data could imply that the chondrules exchanged to varying degrees with O reservoirs of different compositions or that they formed from complex precursor materials. In either case, the O data support the idea that type II chondrules had more-complex histories than did type I chondrules.

Finally, FeO-rich chondrules are scarce in CR2s, unlike some other classes. This implies either CR2 chondrules accreted before more chondrules could be subjected to multiple cycles of chondrule formation, and/or type II chondrule precursors were simply not abundant, and/or mixing of type II chondrules into the CR2 accretion zone was limited.

References: [1] Weisberg M. K. et al., (1993) *GCA, 57,* 1567-1586. [2] Krot A. N. et al., (2002) *MAPS, 37,* 1451-1490 (and references therein). [3] Connolly H. C. Jr. et al., (2001) *GCA 65,* 4567-4588. [4] Zanda et al., (2002) *LPS XXXIII*, Abst. #1852. PI M. K. Weisberg NASA NAG5-11546 and PI G. R. Huss NASA NAG5-11543.