CHARACTERIZATION OF OPAQUE PHASES IN TYPE-II CHONDRULES FROM CR2 CHONDRITES.

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Introduction: The Renazzo-like carbonaceous chondrite (CR) group was first recognized by [1] and then thoroughly defined by [2]. The components of these meteorites have been the focus of numerous investigations, yet type-II chondrules have been largely ignored [3,4]. Metal and sulfides within the type-II chondrules of CR2s were surveyed by [3]. However, the extent and chemical composition of metal and sulfides within type-II chondrules has not been studied in detail. We report the results of our investigation to (1) characterize the metal and sulfide phases within type-II chondrules and (2) compare these finding to other primitive chondrites (OCs).

Table 1. Chondrule characteristics and results.

Sample	Textural Type	Mean Fa [3,4]	Shape [3]	Sulfide (vol%)	#Grains
Renazzo USNM1123-1					
CW2	PO	45.17	CFragt	~10	4
CW7	POP	51.68	Ch	~5	7
CW11	PO/GO	45.52	Ch	~12	11
CWX	PO	69.92	Fragt	~20	2
EET 92011,5					
Ch1	BO[3]	38.8	CFragt	~3	6
Ch2	PO	46.4	Ch	~5	6
Ch4	PO	28.8	Fragt	~5	4
MAC 87320,10					
Ch1	PO	15.6	Fragt	~5	4
Ch2	PO	25.8	Fragt	~10	4

Analytical Procedure: A total of nine type-II chondrules were investigated. We examined one thin section each of the following: Renazzo USNM 1123-1 (Renazzo), MAC 87320,10 (MAC), and EET 92011,5 (EET) (Table 1). Opaque phases were initially characterized using the Hitachi S-4700 FESEM and the Cameca SX-100 EMP at the AMNH. Quantitative analyses were performed on the Cameca SX-50 EMP at LPL using an accelerating voltage of 15 kV and a beam current of 20 nA. The concentrations of Fe, Ni, S, Ca, P, Co, Cr, Al, Na, Si, Mg, Mn, Ti, Zn, Cu, and O were analyzed. For quantitative analyses of oxygen, we followed the technique of [5]. Chondrule silicate compositions are reported in [3,4].

Results: *Renazzo:* The type-II chondrules (Fig. 1) contain pentlandite (average: Fe = 36.3±0.6, Ni = 28.6±0.6, S = 33.4±0.2, Co = 0.98±0.26 wt%) enclosed within tochilinite (best analysis: Fe = 62.4, Ni = 0.57, S = 28.0, O = 9.59 wt%) with a formula of $2[FeS] \cdot 0.66[Fe(OH)_2]$, and an Fe-oxide (best analysis: Fe = 68.0, Ni = 0.47, S = 1.54, Co = 0.09, O = 27.02 wt%). The majority of tochilinite is fine grained and intimately mixed with pentlandite and/or Fe-oxide. The sulfide assemblages are dispersed throughout the chondrules with a greater concentration near the chondrule edges. Most of the assemblages within CW11 are concentrated near the chondrule margin (Fig. 2) and also include minor, euhedral to subhedral Ca-phosphates enclosed within the tochilinite-oxide mixture (Fig 3). The assemblages are rounded or irregular in shape, and range in size from ~ 1 - 150µm on the longest axis.

EET 92011,5: EET's type-II chondrules contain complex fine-grained metal-sulfide assemblages with pentlandite, tochilinite, troilite and Ni-rich metal (average: Fe = 36.5±3.4, Ni = 60.1±4.1, Co = 1.44±0.23
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wt%). To our knowledge, this is the most Ni-rich metal reported from CR2s. The assemblages are either rounded or irregular, with apparent diameter from 15 - 100µm.

MAC 81321: The assemblages in MAC's type-II chondrules (Fig. 4) contain troilite, tochilinite, phosphate (best analysis: Ca = 3.62, P = 17.4, Fe = 22.3, Ni = 0.12, O = 40.4 wt%), and Ni-rich metal (average: Fe = 71.1±10.6, Ni = 26.7±10.3, Co = 0.87±0.20 wt%). The assemblages contain troilite surrounding phosphate and Fe,Ni metal with apparent diameters ranging from 10 - 200 µm.

Discussion: The opaque assemblages are not homogeneously distributed within type-II chondrules of CR2 chondrites. They typically occur along the outer edge of chondrule boundaries. Rare, isolated assemblages also exist in chondrule interiors. Considerable variability occurs in their abundances and compositions with no apparent correlation between these features and chondrule textural type (e.g., BO, PP, etc.).

The sulfide phases in type-II chondrules are either primary igneous features or products of post-chondrule-formation alteration. Similar troilite-bearing opaque phases within type-II chondrules in OCs are argued to be primary in nature [6]. However, experimental studies of gas-solid reactions have produced metal-sulfide assemblages that are compositionally and morphologically analogous to those observed within type-II chondrules of EET and MAC [7,8]. The experimental results suggest that some of the opaque phases in CR chondrites formed by corrosion at temperatures above the Fe-FeS eutectic in regions of enhanced fS2, compared to canonical values [9].

The presence of tochilinite indicates that other opaque assemblages in CR2s experienced aqueous alteration between 25 - 120 °C [10]. The greater abundance of tochilinite in Renazzo compared to the other CR2s indicates that Renazzo experienced more extensive aqueous alteration than MAC or EET. These variable alteration histories are also reflected in the diverse phyllosilicate abundances within these meteorites.

Our study of opaque assemblages suggests several possibilities. Compared to similar objects in OCs, type-II chondrules in CR2s (1) had considerably different precursors, (2) experienced different environments of formation (e.g., fO2 of fS2), or (3) experienced different post-formation and pre-accretion thermal histories and environments. Furthermore, type-I chondrules of CR2s, unlike those of OCs, lack sulfide phases; suggesting that type-I chondrules in CR2s formed in environments with significantly different fS2, and different from the environment(s) where type-I and type-II chondrules from OCs formed. Differences in environment may indicate different locations in the disk, or different times of formation in the same location.

References: [1] McSween (1979) *GCA,* **43**, 1761-1770. [2] Weisberg *et al.* (1993) *GCA*, **57**, 1567-1586. [3] Connolly *et al*. (2001) *GCA*, **65**, 4567-4588. [4] Connolly *et al*. (2007) *LPSC* **XXXVIII**. [5] Lauretta *et al*. (2001) *GCA*, **65**, 1337-1353. [6] Rubin *et al*. (1999) *GCA*, **63**. [7] Lauretta (2005) *Oxidation of Metals*, **64**, 1-22. [8] Schrader *et al*. (2006) *LPSC* **XXXVII**, #2256. [9] Ebel & Grossman (2000) *GCA* **64**, 339-366. [10] Brearley (2006) in: *Meteorites and the Early Solar System II* (eds. Lauretta and McSween), 587-624. **Acknowledgments:** We thank K. Domanik for assistance with the EMP at LPL and C. Mandeville and J. Mey for assistance with the EMP and FESEM, respectively, at AMNH. This research funded in part by NASA Grant NNG05GF39G (HCCJr, PI), NASA Grant NNG04GF65G (DSL, PI), and NSF-REU # AST-055258.

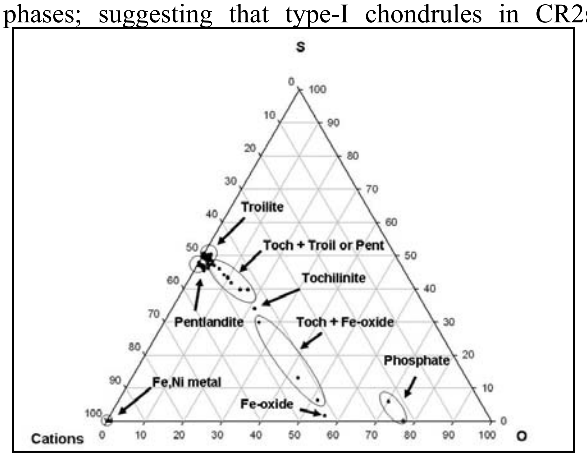

Figure 1. Cations-O-S (at.%) ternary diagram showing the normalized EMP analyses from all samples. (Cations = Fe+Ni+Co+Cu+Cr+Mn+Zn+Ca+Al+Mg)

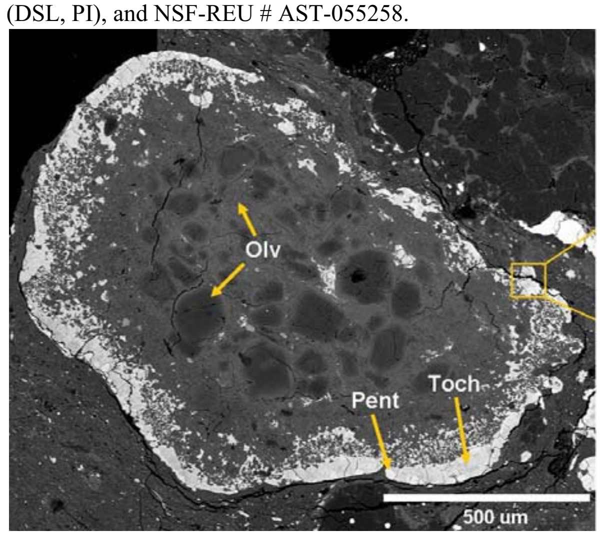

Figure 2. Renazzo, Chondrule CW11.

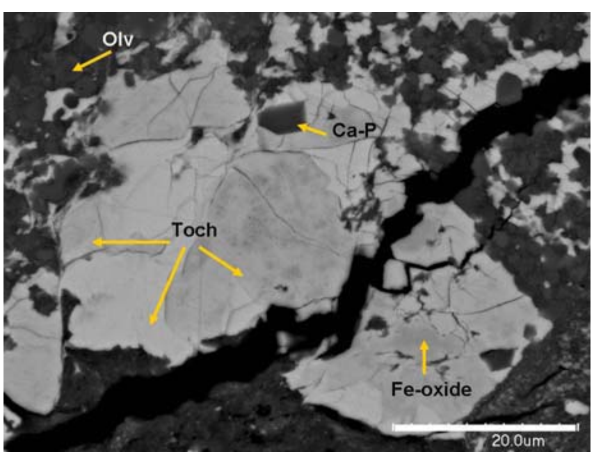

Figure 3. Renazzo, CW11, enlarged area.

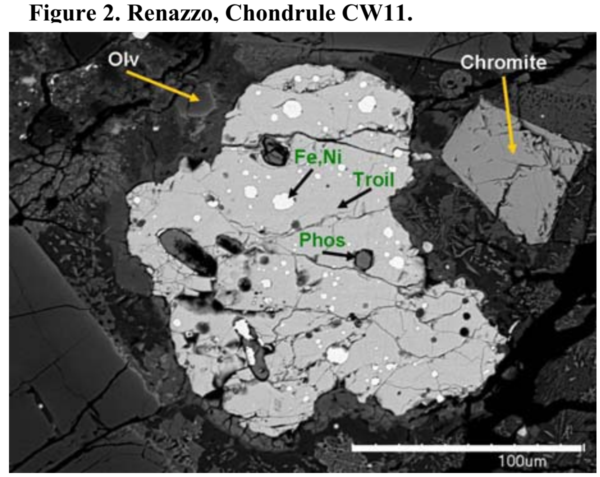

Figure 4. Opaque assemblage in MAC87320 Ch2.