HRTEM AND EFTEM STUDIES OF PHYLLOSILICATE-ORGANIC MATTER ASSOCIATIONS IN MATRIX AND DARK INCLUSIONS IN THE EET 92042 CR2 CARBONACEOUS CHONDRITE: Neyda M. Abreu and Adrian J. Brearley, Department of Earth and Planetary Sciences, MSC03-2040, University of New Mexico, Albuquerque, NM87131-1000, USA (abreu@unm.edu, brearley@unm.edu).

Introduction: Based on petrologic and isotopic observations, the CR chondrites represent one of the most primitive carbonaceous chondrite groups. The organic matter in CR chondrite matrices is considered to be among the most ancient carbonaceous matter known, potentially providing a link between organic matter in the interstellar medium and our solar system [1]. However, the organic chemistry of CR chondrites may be complicated by the fact that these meteorites have undergone moderate secondary alteration, which potentially overprints primordial features [2]. Although the general effects of this alteration have been documented [2], the details of the fine-grained mineralogy and alteration styles of CR matrices are not fully understood. Here we present TEM observations of matrix in EET 92042, a CR chondrite that contains particularly primitive insoluble organic matter [1]. Preliminary studies [3] determined that EET 92042 matrix is heterogeneous in terms of mineralogy, texture, and petrographic fabric on the micron scale. EET 92042 contains magnetite-rich regions, foliated matrix and dark inclusions (DIs). Some chondrules show fine-grained rims, similar to those described by [4].

Results: SEM and TEM observations reveal a strikingly heterogeneous matrix mineralogy and degree of alteration from region to region. Some areas of matrix are dominated by phyllosilicates while other areas are rich in porous olivine.

Typical CR Matrix. Phyllosilicate-rich regions appear to be more common than anhydrous areas. These regions are indistinguishable in BSE images and are intermixed with each other at the mm-scale. Texturally, the phyllosilicate-rich regions are similar to other CR matrices [3,5]. They contain numerous, relatively large magnetites (~10-30 µms), finer-grained magnetite framboids and platelets, calcite, and sulfides (<5 µm). TEM studies show that this matrix is dominated by wavy, elongated, poorly-crystalline phyllosilicates (serpentine and saponite) extending for 10s of nms (Fig. 1). These regions appear to contain abundant amorphous or poorly–crystallized Fe-oxide, probably ferrihydrite. Sulfide grains (nms to microns in grain size) with compositions, ranging from pyrrhotite to pentlandite and morphologies varying from sub-rounded to well-faceted, occur embedded in the regions of phyllosilicates. In addition, Fe,Ni-carbide grains surrounded by an Fe-bearing crystalline oxide, possibly magnetite, are also present. Although the sulfides are not associated with carbonaceous material, the carbides are often surrounded by narrow rims of PGC, based on EFTEM and HRTEM imaging. Carbonaceous matter associated with the phyllosilicates is generally found as amorphous hotspots 10s of nms in size. N and S are consistently below the detection limits of EFTEM.

Hydrous Rims. Fine-grained rims tend to be rare, discontinuous, or not particularly well-defined, as they are texturally similar to the interchondrule matrix. Most rims appear to contain a similar mineral assemblage to that of the matrix. We have studied three hydrous rims using TEM. The dominant crystalline phases are serpentine and saponite. However, poorly crystalline ferrihydrite occurs more commonly.

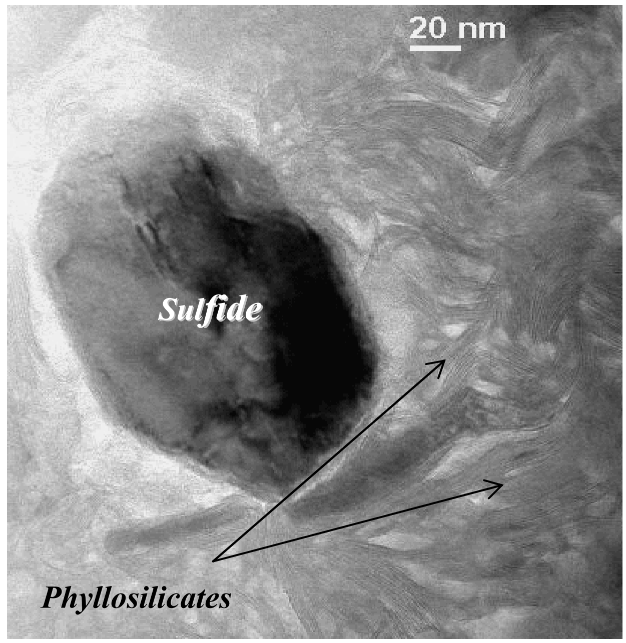

Fig. 1. TEM image of a typical region of hydrous matrix.

Anhydrous Rim. This rim is a highly anomalous region in contact with phyllosilicate-rich regions on the periphery of a type I chondrule. The rim contains highly equilibrated, rounded to elongate olivine crystals with an average composition Fa_{46}. These grains generally range from 0.1 to 10s µms and are porous, often containing inclusions. Pores and inclusions may occur in the same crystals and have a similar size range, (<1 -10s nms). The Fe,Ni-sulfide pentlandite is the most common inclusion type, commonly associated with PGC. Cr-bearing spinels are also present but do not appear to be associated with C-material. Finally, carbonaceous material was found as sub-rounded PGC inclusions and as thin layers of PGC adhering to the edges of pores. EFTEM imaging indicates the presence of S associated with the carbon but no N is detectable.

Dark inclusion. One DI was studied in detail. The DI consists dominantly of very fine-grained matrix: chondrules and CAIs are absent. BSE imaging shows that the DI contains abundant, anhedral calcite grains up to 50s µms in size and sub-rounded Fe and Fe,Ni-sulfides. Clumps of phyllosilicates, consisting of poorly-crystalline saponite and serpentine were identified using HRTEM. However, as in the phyllosilicate-rich matrix, amorphous to nanocrystalline ferrihydrite appears to be most abundant. Euhedral to sub-rounded sulfides a few to 10s nms in size occur embedded in the phyllosilicate matrix, ranging in composition from pyrrhotite to pentlandite. Amorphous carbonaceous material in this DI is associated with the phyllosilicates and may occur as hot spots 10s of nms in diameter. N and S are below the detection limits in the C-hotspots examined by EFTEM.

Discussion: Our observations reveal striking variability in texture and degree of alteration of different occurrences of matrix in EET92042. Fluid alteration affected some regions of matrix, containing partially hydrated amorphous material, while rare regions are essentially anhydrous and crystalline. [2,4] observed variable degrees of hydration in different components of Renazzo, which they attributed to aqueous alteration taking place prior to final lithification. This is also probably the case for EET 92042 and the heterogeneity is probably the result of extensive brecciation, resulting in mixing of lithologies that had been altered previously to different extents on different parts of the CR parent body.

Hydrous Regions: Interchondrule matrix and fine-grained rims are often phyllosilicate-rich. The presence of very fine-grained serpentine and saponite, suggests that hydration was pervasive, but occurred at low temperatures. Amorphous material is probably hydrated, but the temperature was too low to drive full recrystallization to form phyllosilicates. Carbonaceous matter shows no obvious association with phyllosilicates, indicating that they probably did not play a role in the formation of complex organics. The only mineralogical relationship observed is limited to the potential carbides and the PGC. If these Fe,Ni crystals are indeed carbides, it may indicate that the carbonaceous material formed by FTT-reactions as in the case of the CM2 chondrite, Murchison [6]. [6] argued that carbides in Murchison formed by FTT-type reactions of Fe,Ni metal grains and C-bearing matter in the solar nebula.

Most of the carbonaceous matter in the phyllosilicate-rich regions is amorphous and occurs as hotspots randomly distributed through the matrix. This suggests that the C-bearing material did not form by any specific reaction that involved other phases as a catalyst, i.e. no surface reactions. The lack of a distinct association between silicates and carbonaceous mateirial suggests that there were distinct nanometer C-rich grains in the nebula that were mixed with Si-rich nebular dust. The presence of very fine-grained phyllosilicates and very primitive inorganic matter are consistent with a low degree of thermal processing for the matrix.

Anhydrous Rim: To our knowledge, these are the first observations of a completely anhydrous region of matrix in a CR2 chondrite, although [7] reported olivine in the matrices of EET87770 and Renazzo. This region is most similar, texturally and mineralogically, to the matrices of oxidized CV3 chondrites. This rim is dominated by strained, porous, inclusion-bearing olivine crystals. These olivines may have formed during thermal metamorphism of the matrix, as suggested by their equilibrated compositions and the degree of graphitization of the PGC they contain. The carbonaceous matter observed in these regions is not associated with N and is probably devoid of lighter elements, also consistent with thermal metamorphism.

Dark Inclusion: The DI mineralogy is very similar to that of the phyllosilicate-rich regions, consistent with studies of other CR chondrites [5]. However, in other CR chondrites [e.g. 4,9], DIs appear to have experienced a higher degree of aqueous alteration than the host matrix, based on mineralogical and isotopic differences. [9] observed that in Acfer 059/El Djouf 001 heavy O-isotopes are enriched in the DIs with respect to the host meteorite and that framboidal magnetite morphologies are limited to the DIs. These differences indicate that the DIs and matrix were altered in different environments. In contrast, our preliminary observations suggest that the host matrix and the DI in EET 92042 are quite similar texturally and mineralogically, suggesting similarities in the alteration styles and conditions of alteration. For example, framboid and platelet magnetites occur in both the matrix and DI, unlike the Acfer 059/El Djouf 001 occurrences. However, comparison between O-isotopes of the hydrous matrix and DIs is necessary to establish a firm genetic link between matrix and DIs in EET 92042.

Despite the mineralogical similarities between the DI and the matrix, the occurrences of carbonaceous material are significantly different. In the DI, the C is more commonly associated with phyllosilicates. Similar observations were reported for the CM chondrites [8]. [8] suggested that FTT reactions between carbonaceous materials and phyllosilicates in the parent body, may have played a role in the compositional evolution of organics. This may also be the case for this DI.

References: [1] Cody *et al.* (2004) *MAPS* 33 (Suppl.): A23. [2] Weisberg *et al.* (1995) *Proc. NIPR Symp. Antarct. Meteorites* 8:11-32 [3] Abreu and Brearley (2004) *MAPS* 33 (Suppl.): A12. [4] Weisberg *et al.* (1993) *GCA* 57:1567-1586. [5] Krot *et al.* (2003) *MAPS* 37:1451-1490. [6] Brearley (2003) *MAPS* 38 (Suppl.):5265. [7] Zolensky *et al.* (1993) *GCA* 57:3123-3148 . [8] Pearson *et al.* (2002) *MAPS* 37:1829-1833. [9] Endreß *et al*. (1994) *Meteoritics* 29, 26-40.

Acknowledgements: This research was supported by NASA Exobiology grant NAG5-13444 (A. J. Brearley, P. I.).