MINERALOGY AND CHEMISTRY OF FINE-GRAINED MATRICES, RIMS, AND DARK INCLUSIONS IN THE CR CARBONACEOUS CHONDRITES ACFER/EL DJOUF 001 AND THE UNGROUPED CARBONACEOUS CHONDRITES ACFER 094 AND ADELAIDE. Ansgar Greshake[1], Alexander N. Krot[2], and Klaus Keil[2], [1]Museum für Naturkunde, Institut für Mineralogie, Humboldt-Universität zu Berlin, Invalidenstr. 43, 10115 Berlin, Germany, email: ansgar.greshake@rz.hu-berlin.de, [2]Hawai'i Institute of Geophysics and Planetology, School of Ocean and Earth Science and Technology, University of Hawai'i at Manoa, Honolulu, HI 96822, USA.

Introduction: Apart from the relative coarse-grained high-temperature components – refractory inclusions [Ca,Al-rich inclusions (CAIs) and amoeboid olivine aggregates (AOAs)], chondrules, and Fe,Ni-metal – most carbonaceous chondrites contain abundant, very fine-grained (<1 µm) materials whose origin and genetic relationship to the coarse-grained components remain controversial. These fine-grained materials are observed in several textural occurrences: (*i*) as rims around coarse-grained components, (*ii*) as interstitial matrix, and (*iii*) as lithic clasts (dark inclusions). Due to the small grain size and high porosity, these materials are highly susceptible to aqueous alteration and thermal metamorphism – processes that operated on most chondrite parent asteroids and significantly modified or even erased solar nebular records in fine-grained materials. There are only a few carbonaceous chondrites which appear to have escaped thermal metamorphism and experienced small degree aqueous alteration; these include CR (Renazzo-like) and the ungrouped carbonaceous chondrites Acfer 094 and Adelaide. The primitive nature of Acfer 094 and CR chondrite North West Africa 530 is supported by the discovery of amorphous presolar silicates in these meteorites [1, 2]. In order to decipher the solar nebular records in fine-grained rims, matrix, and dark inclusions of these meteorites, we studied their mineralogy and chemistry using scanning electron microscopy (SEM), electron probe microanalyses (EPMA), and transmission electron microscopy (TEM).

CR chondrites Acfer/El Djouf 001: Fine-grained materials in Acfer/El Djouf 001 include dark inclusions, fine-grained clastic matrix, and rare fine-grained matrix-like rims around chondrules; the latter are texturally similar to those in CM chondrites [3]. Matrix appears to be very heterogeneous and consists of sub-µm sized mostly magnesian olivine and pyroxene, embedded into very fine-grained phyllosilicates interspersed with tiny Fe,Ni-metal and sulfide grains. Olivine is the most abundant anhydrous phase and sometimes occurs as clusters of several anhedral grains; pyroxene is less frequent and many grains are found to be intergrowths of ortho- and clinopyroxene, indicative of quenching at high temperatures (Fig. 1). Phyllosilicates are composed of saponite-serpentine intergrowths, textures commonly observed in CI1 chondrites [4]. Dark inclusions are much finer-grained, display a lower porosity, and contain higher abundances of saponite, serpentine, and magnetite and a lower abundance of anhydrous silicates (olivine and pyroxenes) than the CR matrix [5]. Fine-grained rims are mineralogically heterogeneous and contain regions in which anhydrous phases are more abundant than phyllosilicates. However, such regions are rare and the rims generally resemble the mineralogy of the matrix with abundant serpentine and saponite.

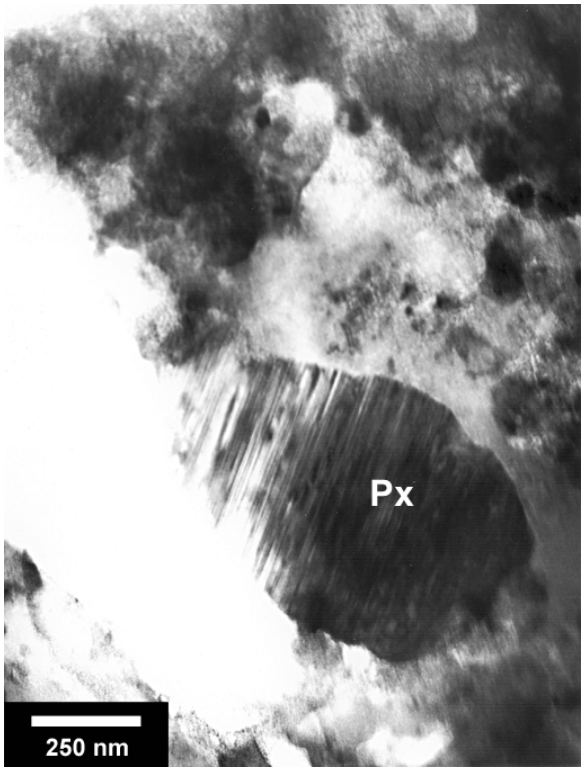

Figure 1. Bright field TEM image showing a Mg-rich pyroxene grain (Px) in the dominantly hydrous matrix of the CR2 chondrite Acfer 097.

Compositionally, matrix, dark inclusions, and rims are very similar; the matrix seems slightly enriched in Ca relative to rims and dark inclusions while the rims might be slightly depleted in Fe. Major deviations

from the CI values are observed for the most volatile elements with K being strongly enriched and Na and S being depleted in all fine-grained lithologies [e.g., 3]. The Ca/Al ratios vary from 1.54 in the matrix to 1.21 in the rims and 1.17 in the dark inclusions (CI=1.07; [6]); Ti/Al-ratios are 0.04 in the matrix and dark inclusions and 0.03 in the fine-grained rims (CI=0.05; [6]).

Adelaide: Our TEM study of the Adelaide matrix is consistent with observations of [7]. It predominantly consists of sub-µm-sized ferrous olivines set into an amorphous to microcrystalline anhydrous groundmass. The olivines commonly form clusters of anhedral grains; euhedral olivines, pyroxenes, and sulfides are less abundant. Some matrix regions are solely composed of tiny ferrous olivines. The bulk composition of the Adelaide matrix normalized to Si & CI shows a Ca depletion: the Ca/Al-ratio (0.16) is much lower relative to bulk Adelaide (0.69; [8]), whereas the Ti/Al-ratio (0.04) is less clearly below bulk Adelaide (0.08; [8]). K, Na, S are depleted, whereas Fe is enriched, possibly due to extensive terrestrial weathering of Adelaide.

Acfer 094: Matrix in Acfer 094 consists of Mg-rich olivine, magnesian low-Ca pyroxene, and Fe,Ni-sulfides all of rounded or elongated morphologies set into an amorphous ferrous silicate matrix (Fig. 2).

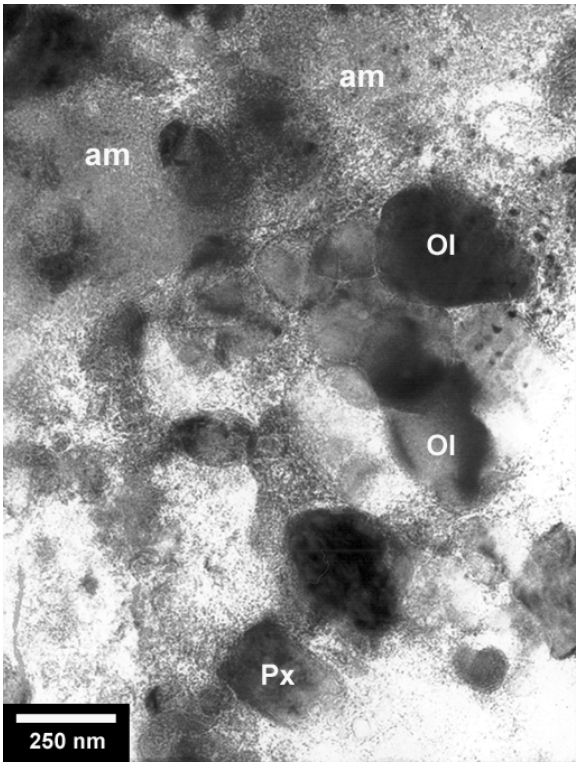

Figure 2. Bright field TEM image of the fine-grained material in Acfer 094 (after [9]). The matrix is dominated by small olivines (Ol) and pyroxenes (Px) embedded in an amorphous groundmass (am).

Phyllosilicates are exceptionally rare; they preferentially replace amorphous material and occasionally form tiny veins cutting through olivines. The bulk composition of the Acfer 094 matrix normalized to Si and CI is chondritic for most refractory and moderately volatile elements; only Ca seems slightly enriched and Ni slightly depleted. The Ca/Al-ratio of 1.6 is clearly superchondritic and the Ti/Al-ratio of 0.04 slightly below the chondritic value of 0.05 [6]. Probably due to terrestrial weathering, K is significantly enriched and Na slightly and S more strongly depleted.

Discussion: Fine-grained matrix, rims, and dark inclusions studied in Acfer/El Djouf 001 experienced aqueous alteration and contain no anhydrous amorphous material; crystalline material is dominated by magnesian olivine and pyroxenes which appear to have been quenched at high temperatures. Fine-grained matrix in Adelaide appears to have experienced thermal metamorphism resulting in formation of abundant crystalline ferrous silicates [7]. Matrix in Acfer 094 appears to be the most pristine; it largely escaped aqueous alteration and thermal metamorphism and contains abundant amorphous ferrous silicates and tiny crystalline magnesian silicates [9]. We infer that the primary components of fine-grained matrices are composed of crystalline magnesian silicates and amorphous ferrous silciates; crystalline ferrous silicates and phyllosilicates are secondary and resulted from aqueous alteration and thermal processing of primitive matrices most likely in an asteroidal setting.

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