AMORPHOUS CARBON-RICH GRAINS IN THE MATRICES OF THE PRIMITIVE CARBONACEOUS CHONDRITES, ALH77307 AND ACFER 094 Adrian J. Brearley, Dept. of Earth and Planetary Sciences, MSC03-2040, University of New Mexico, Albuquerque, NM 87131, USA (brearley@unm.edu).

Introduction: Chondritic meteorites are known to contain a diverse range of carbon-bearing phases ranging from inorganic materials such as carbides and graphite, to the highly complex organic materials that are present in many of the chondrite groups. The diversity in C-bearing compounds in chondrites is a reflection of the formation of these materials in a wide range of cosmochemical environments that include stellar envelopes, interstellar space, protoplanetary disks and asteroidal parent bodies. Although the origin of some C-bearing phases such as interstellar graphite and silicon carbide is now quite well understood, based on isotopic studies, there are still many outstanding questions regarding the origin of carbon-bearing materials. This is especially true for the complex insoluble organic material (IOM) that is the dominant solid C-bearing material in most chondrites [1].

We have been carrying out a systematic investigation of the distribution of C-rich materials *in situ* using energy filtered transmission electron microscopy (EFTEM) [2, 3]. To date, we have concentrated our efforts on the CM and CR chondrites, because both chondrite groups contain IOM which appears to have a complex origin. Using EFTEM, we have shown that there is significant evidence for the involvement of FTT type catalysis reactions on the surfaces of nanophase metal and sulfide grains. Here we have examined the distribution of C-rich grains in two additional highly primitive chondrites to compare with our data for CM and CR chondrites.

A number of studies have shown that the two carbonaceous chondrites ALH77307 (CO) and Acfer 094 (unique) are among most primitive carbonaceous chondrites in our collections [5,6]. These two meteorites provide key insights into a variety of early solar system processes that are not so well preserved in other type 3 chondrites. One of the most notable characteristics of the matrices of these meteorites is that they contain a significant abundance of amorphous material that acts as a groundmass to crystalline phases such as olivines, pyroxenes, oxides and sulfides [5]. It has been suggested that this amorphous material might represent material that was evaporated during chondrule formation and recondensed under disequilibrium conditions to form amorphous smoke-like materials [5]. The preservation of such amorphous material appears to be a strong indication of the relatively pristine character of both these meteorites.

Both chondrites have received considerable attention recently because they appear to contain among the highest concentrations of interstellar silicate grains [7]. Hence they are key candidates for understanding the characteristics of primitive organic material that was accreted into chondrites. We have therefore studied these chondrites with the objective of learning more about the characteristics and distribution of the carbonaceous material hosted in their matrices. ALH77307 and Acfer 094 contain carbon concentrations of 0.37 wt% and 0.48 wt%, respectively [1], that are similar to the concentrations in the CR chondrites that we have studied previously. [1] found that the IOM in Acfer 094 has been heavily weathered and the hydrogen and nitrogen isotopic compositions may have been extensively modified. On the other hand, IOM in ALH77307 has a composition that is consistent with other CO chondrites, with low H/C and N/C ratios as well as $\delta^{15}N$ and δD values around zero [1]. These data indicate that the IOM in ALH77307 is not as primitive as that in the CM and CR chondrites.

Techniques: We studied several regions of matrix in ALH77307 and Acfer 094 using energy filtered TEM, using both the three window EFTEM technique and spectral imaging techniques (EFTEMSI). For some regions we also used STEM EELS spectral imaging. The bulk of the data presented below were obtained by EFTEM or EFTEM spectral imaging.

Results: ALH77307. In ALH77307, we located several distinct carbon-rich grains embedded within the fine-grained matrix. All these grains are associated with amorphous silicate material. The grains are irregular in shape and are typically ~ 0.1 μm in size (0.08-0.16 μm). An example of a typical grain is shown in Figure 1. The grains are usually subrounded to irregular in shape and appear to have sharp boundaries with the surrounding amorphous material. Electron energy loss spectroscopy and EFTEM imaging show that the grains are essentially pure carbon (Figure 2). No other elements such as N, O or S could be detected. HRTEM imaging shows no evidence of any lattice fringes indicative of partial graphitization suggesting that the carbon is amorphous. This is confirmed by EELS which shows that the near edge structure of the carbon edge is characteristic of amorphous carbon. EFTEM imaging also indicates that carbon is present in low concentrations distributed evenly throughout the amorphous silicate material, but no other distinct occurrences of carbon have been found as yet.

Acfer 094. Our data for Acfer 094 are preliminary, but suggest that distinct C-rich grains are present in the matrix, also embedded within the amorphous silicate material. These grains have similar sizes to those in ALH77307, but appear to be more irregular in shape.

EFTEM and EELS show that these grains are essentially pure carbon, but unlike the grains in ALH77307

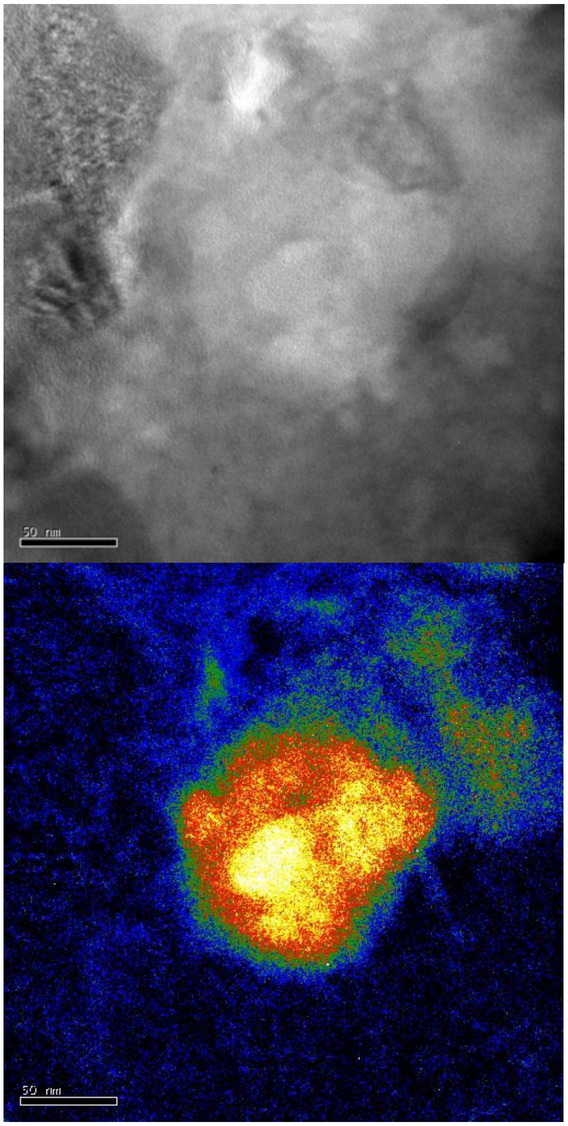

Figure 1 (Top) Bright field TEM image of carbon-rich grain (center of image with lower contrast) embedded in amorphous material in ALH77307 matrix. Figure 2 (Bottom) False color carbon EFTEM map of the same grain, showing the elevated concentrations of carbon. Scale bar = 50 nm.

show some evidence of the initial stages of graphitization. Rare grains of core-rim structured carbon-rich grains have also been found. Based on electron diffraction and HRTEM analysis, these grains have Fe carbide cores with magnetite rims, and are essentially identical to those identified by [2,3] in CM and CR chondrite matrices.

Discussion We cannot, based on our current data, assess exactly what proportion of the carbonaceous material present in ALH77307 and Acfer 094 is present as amorphous carbon. Additional data are required to make a more accurate assessment of the proportion of the bulk carbon that is present in these grains.

The characteristics and distribution of C-rich material in ALH77307 and Acfer 094 are clearly quite different from the CM and CR chondrites that we have studied. The C-bearing grains in ALH77307 and Acfer 094 are much larger and the associations of carbon as rims around sulfide grains and carbide grains, common in CM chondrites, are rare or absent. The amorphous C-rich grains appear to represent a very refractory material which lacks N, S and O and hence appears to have undergone significant processing. These observations are generally consistent with the work of [1] who found that the bulk organic component of ALH77307 had low N, S and O contents. On the basis of limited data for Acfer 094, it appears that some of C-rich grains may have undergone limited graphitization, evidence of thermal processing. Major questions that must be addressed are where and how this material was processed and the nature of the the precursor material. It is possible that the grains were originally primitive macromolecular organic material that has undergone mild thermal metamorphism. If this is the case, then it would indicate that IOM is extremely sensitive to even very low grades of metamorphism, given that Acfer 094 and ALH77307 are two of the most unmetamorphosed meteorites in our collections. Given the evidence that maturation of terrestrial kerogens as a function of temperature is an extremely sluggish process, this seems unlikely. An alternative is that thermal processing of these grains may have happened prior to accretion in the nebula. The matrix dust in both meteorites may be the product of high temperature evaporation and condensation during chondrule formation [5]. Some C-bearing dust may have escaped evaporation but has been processed at high temperatures. This model seems more consistent with the evidence that the CO and CV chondrites accreted with a lower volatile budget than the CM and CR chondrites. Hence the abundance of primitive organic materials that had escaped thermal processing in the nebula was much lower in these meteorites than in the water-rich CM and CR chondrites

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