

**SUB-MICROMETER COMPOSITION FIELDS OF ACFER 094 AND PARIS MATRICES.** H. Leroux<sup>1</sup>, P. Cuvillier<sup>1</sup>, B. Zanda<sup>2</sup>, R. Hewins<sup>2</sup>, <sup>1</sup>Unité Matériaux et Transformations, Université Lille 1 & CNRS, 59655-Villeneuve d'Ascq, France ([hugues.leroux@univ-lille1.fr](mailto:hugues.leroux@univ-lille1.fr)), <sup>2</sup>Laboratoire de Minéralogie et Cosmochimie, MNHN & CNRS, 61 rue Buffon, 75005 Paris, France.

**Introduction:** Matrices of most primitive chondrites consist of a fine-grained assemblage of components whose origin is likely the accretion of dust in the protoplanetary disk. In most chondrite parent bodies, matrices were strongly modified by thermal metamorphism or water-rock interaction. Only a few of these chondrites, near the type 3.0, were able to preserve pre-accretional signatures. The corresponding matrices exhibit an unequilibrated assemblage of phases including crystalline anhydrous silicates, amorphous silicates, nano-grains of metal and sulfide, and carbonaceous material [1-3]. When unprocessed on the parent bodies, matrices are therefore of interest because they allow us to access materials formed in the protosolar nebula, before the formation of the parent bodies.

Here, we studied matrices of two primitive carbonaceous chondrites (Acfer 094 and Paris) by analytical transmission electron microscopy (ATEM). The objective of the study was to determine the composition fields of the matrices at the sub-micrometer scale in order to quantify the chemical phase heterogeneities. The results are compared to the composition fields of chondritic-porous interplanetary dust particles (CP-IDPs), believed to be the best samples of the building blocks of the solar system [4].

**Methods and samples:** Matrix samples from the carbonaceous chondrites Acfer 094 and Paris were selected for the study. Acfer 094 is an ungrouped carbonaceous chondrite of type 3.0, considered as one of the most primitive chondrite. It contains abundant amorphous silicates, mixed together with anhydrous Mg-silicates (mostly forsterite), nano-grains of sulfide, and carbonaceous matter [2,5]. Paris is a CM2 chondrite recently discovered and described in detail by [6]. This chondrite displays variable degrees of alteration. Most areas display evidence for aqueous alteration but others appear very fresh [6,7]. For this study, only samples from the fresh areas were used. They appear dominated by an amorphous silicate groundmass, as for Acfer 094, or by aggregates of amorphous silicate grains, separated from one another by empty space (porosity) [6]. The amorphous silicates contain abundant nano-sulfides and minor FeNi metal grains.

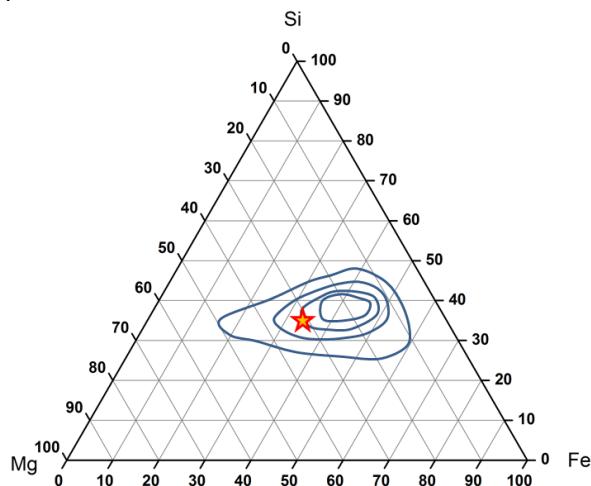
Several FIB electron transparent sections (~100 nm thick) were extracted from the matrix of the two chondrites using an FEI Strata DB 235 at IEMN (Univ. Lille, France). The sections were studied by analytical

TEM at the electron microscopy facility of the University of Lille (France) using an FEI Tecnai G2-20 Twin and a Philips CM30. Microanalyses were performed by X-ray energy dispersive spectroscopy (EDS) using scanning TEM (STEM). The quantitative analytical data were extracted from chemical maps. Chemical heterogeneities and composition fields were determined at different scales by selecting different surface areas on chemical EDS maps. To visualize the composition fields, we used Fe-Mg-Si and Fe-S-Si ternary diagrams (these four elements being the most abundant).

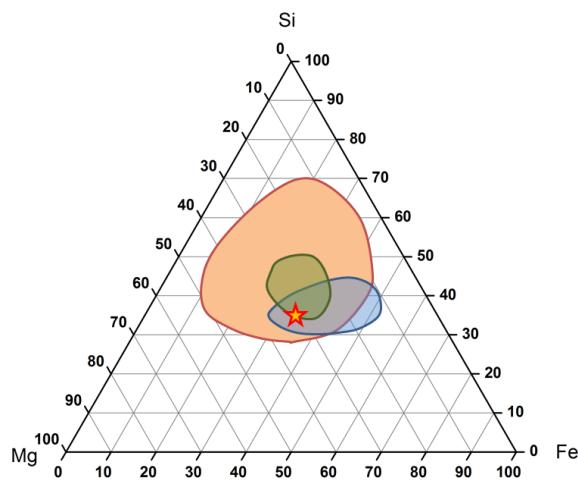
**Results:** In Acfer 094, the amorphous silicate groundmass is the dominant phase. It hosts numerous sulfide nanograins, carbonaceous matter and anhydrous crystalline silicates (mostly forsterite). In order to estimate the composition field of the matrix, chemical maps were recorded on relatively large areas (several  $\mu\text{m}^2$ ). Each chemical map was quantified at different scales, from the full average composition to small sub-areas up to  $100*100 \text{ nm}^2$ . A representative data extraction from a chemical map is shown on a ternary diagram Fe-Mg-Si (Fig. 1). On this figure, several composition fields are drawn as a function of the size of the area selected for quantification (surface ranging from 0.5 to  $0.01 \mu\text{m}^2$ ). This representation shows that the chemical heterogeneities are narrower when the size of the selected domain is increased. The average composition is very close to the value listed in [6], enriched in Fe and Si, depleted in S and Ca when compared to the solar value.

In contrast to the matrix of Acfer 094 which shows a notable chemical homogeneity in the different samples we studied, the matrix of Paris is much more heterogeneous. We focus here our observations on the least altered regions [6,7], ie those that do not contain alteration markers, such as phyllosilicates. As for Acfer 094, several samples are constituted by an amorphous silicate groundmass without porosity and comparable characteristics for the composition fields (average and extent). In particular the matrix is enriched in Fe and Si relative to the solar value. For some other samples, the matrix consists of amorphous silicates blocks well separated by empty space (porosity). Nano-sulfides are present within the blocks and at their edges. Mg-silicates (forsterite and enstatite) are found preferentially in the empty space between the amorphous grains.

The average composition of the amorphous material displays a Si enrichment compared to the solar value. The composition fields are relatively narrow for a large analyzed surface area (typically  $2\text{-}0.5 \mu\text{m}^2$ ) but there is a strong scatter for surface areas of the order of  $0.01 \mu\text{m}^2$  or lower.



**Fig. 1:** Fe-Mg-Si ternary diagram showing the composition field of the matrix of Acfer 094 at the sub- $\mu\text{m}$  scale. The four concentric areas in blue correspond to analyzed surface areas of different size, from  $0.01$  to  $0.5 \mu\text{m}^2$  starting from the outer contour to the inner contour. This representation allows us to assess the magnitude of chemical heterogeneities at the submicron scale. The red star is the solar composition.



**Fig. 2:** Fe-Mg-Si ternary diagram showing representative composition fields of matrix samples of Acfer 094 (blue) and Paris (green), compared with that of GEMS in IDPs (in red; data from [4]). The analyzed surface areas for the three classes of objects are comparable ( $0.04 \mu\text{m}^2$ ).

**Discussion:** The composition fields measured for Acfer 094 and the least altered regions of Paris are compared to the field of composition of the GEMS grains (glass with embedded metal and sulfides) in CP-IDPs given by [4]. To make this comparison possible, we estimated that the average size of the GEMS grains was around 200 nm, which corresponds to an area analyzed of  $0.04 \mu\text{m}^2$ . Composition fields of matrices from Acfer 094 and Paris were extracted at this scale. Data are summarized in Figure 2. Whether for Acfer 094 or Paris, the composition fields are narrower than that of CP-IDPs. This shows that the amorphous silicates of Acfer 094 and Paris interacted with the environment and were chemically homogenized on their parent body. In the case of Acfer 094 and several of our Paris samples, the average composition is enriched in Fe but depleted in S and Ca. This evolution is likely the consequence of aqueous alteration on the parent body, with a preferential leaching of some elements and the incorporation of Fe due to partial alteration and redistribution of Fe coming from metal phases in the matrix. For Acfer 094, an oxidation scenario is indicated by the presence of significant  $\text{Fe}^{+3}$  in the matrix, measured by EELS by [4].

In the case of Paris, the sample with the highest porosity is likely to be less altered than the others. Its texture and average composition are very comparable to those of GEMS material. However, the extent of the composition field is narrower for this Paris sample, suggesting that Fe redistribution occurred at least at the scale of the analysis (diffusion length 200 nm or higher). Despite this local chemical homogenization, this matrix sample from Paris may well be more primitive than our Acfer 094 samples, as suggested by its average composition closer to that of GEMS. Paris is therefore a valuable meteorite for studying the early stages of alteration on the parent bodies of the carbonaceous chondrites.

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